Reinforcement with Soil Nails

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Introduction

Soil nailing is a construction technique used for earth reinforcement. Nails can be used as a remedial measure for natural slopes or to allow for over-steepening of new or existing slopes. Soil nails are usually installed in a top-down procedure much like anchors and are typically grouted into place. Unlike anchors, however, soil nails are usually not pre-stressed. This example illustrates the use of soil nail reinforcement in SLOPE/W to stabilize a steep excavation.

Background

The behaviour of reinforced systems depends on the complex interaction between the soil and the structure. In most cases, the soil provides both the activating and resisting stresses, while the structural members provide a load transfer mechanism. Consider an earth retaining wall reinforced by a geosynthetic. The earth pressure acting on the wall will increase as the soil behind the wall deforms towards the excavation. Assuming the geosynthetic is affixed to the wall, this load will be transferred deeper into the soil profile. The load transfer occurs as the geosynthetic undergoes elongation (i.e., axial strain), which in turn mobilizes shear stress at the interface between the soil and the geosynthetic.

The design of reinforced earth structures has traditionally been conducted using the limit equilibrium method. Although the complex soil-structure interaction is not modelled using this approach, the method ensures static equilibrium of the system, thereby providing a global factor of safety for the ultimate limit state.

Soil nails are included in SLOPE/W by defining the pull-out resistance, which represents the amount of stress mobilized per unit area at the interface between the nail and soil. An implicit assumption is that enough strain has occurred to mobilize some portion of the pull-out resistance. This resistance is converted into a force by SLOPE/W based on the geometry of the nail and slip surface, along with other inputs discussed below.

Numerical Simulation

Figure 1 presents the configuration of the example problem and Table 1 gives the details of the nail specifications. The domain comprises a 10-m excavation reinforced with four levels of nails. The nails are spaced 2 m in the out-of-plane direction. Each nail is approximately 8 m in length with a bond diameter of 0.3183 m.

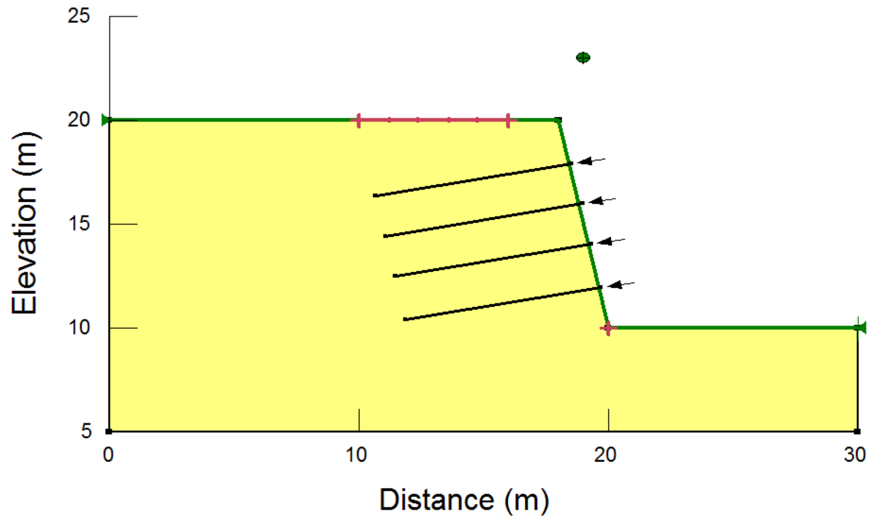

Figure 1 Model Configuration

Table 1 Nail Specifications

Input	Value
Length	8 m
Inclination	14 Degrees
Pullout Resistance	100 kPa
Bond Diameter	0.31831 m
Resistance Reduction Factor	1.5
Nail Spacing	2 m
Tensile Capacity	400 kN
Shear Force	0 kN
Shear Reduction Factor	1

There are three cases included in the GeoStudio Project. The soil nails in Case 1 have the factor of safety option set to ‘No’ with the distributed force option selected and the anchorage option set to ‘Yes’. Case

2 introduces the factor of safety dependency option, while Case 3 removes the effect of anchorage at the face.

Results and Discussion

Case 1 – Distributed Nail Load

Figure 2 presents the results for Case 1. The Safety Map (red band) represents a zone of several slip surfaces that have very similar factors of safety. In this case, eight slip surfaces with a factor of safety between 1.253 and 1.303 sit within this band.

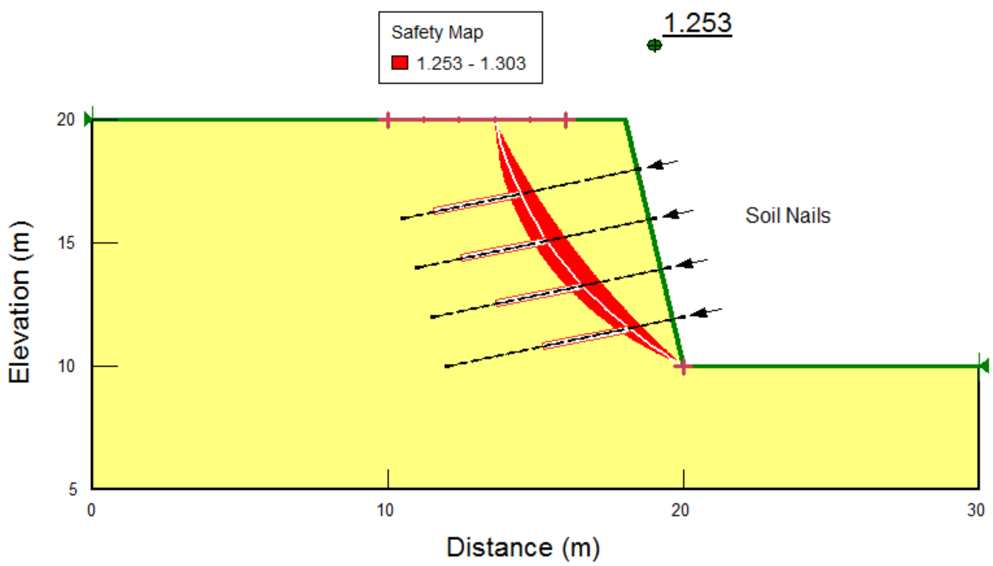

Figure 2 Critical Slip Surface for Case 1

The nail forces used in the factor of safety calculations can be inspected with the View Object Information command in the Results View (Figure 3). The factored pullout resistance (FPR) represents the amount of force that can be mobilized in the nail per length of nail and is calculated as:

$$FPR = PR * {}^{area}/_{(RRF\ \times spacing)} = 100\ kN/m^2 \times 1\ m^2/\ (1.5 \times 2m) = 33.3\ kN/m \qquad \text{Equation 1}$$

where PR and RRF are the pullout resistance and resistance reduction factor, respectively. The RRF is used to account for any process, such as corrosion or installation damage, that may reduce the capability of the nail. Note that the FPR is normalized for spacing to account for the two-dimensionality of a SLOPE/W analysis.

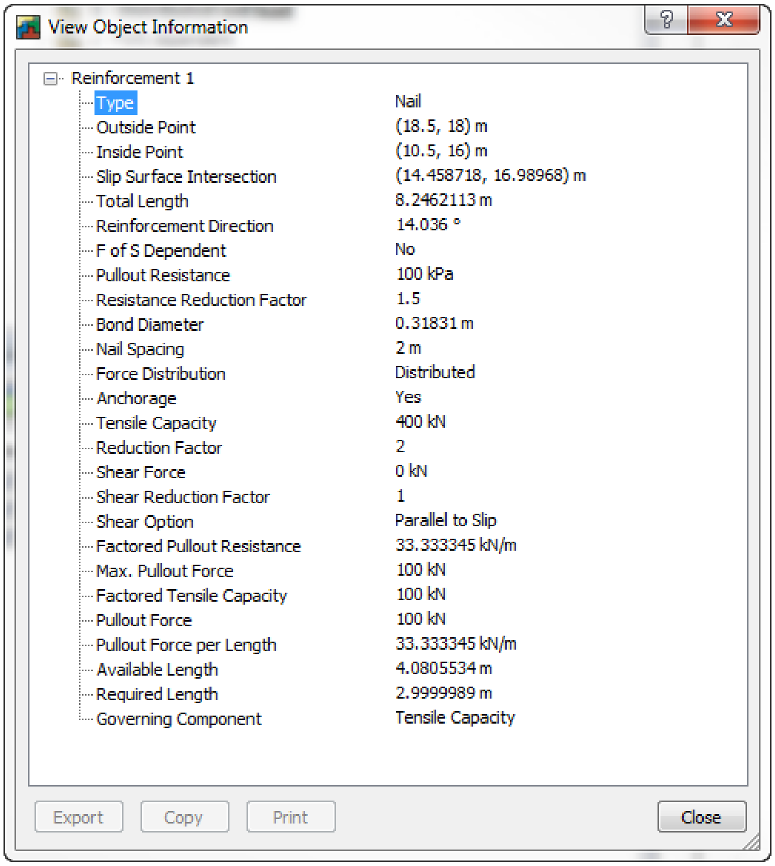

Figure 3 Detailed information available on the nail forces used in the stability calculations

The factored tensile capacity (FTC) is also normalized for spacing and is calculated as:

$$FTC = {}^{TC}\!/_{(RF\ \times spacing)} = {}^{400kN}\!/_{2\times 2m} = 100kN \qquad \text{Equation 2}$$

where TC is the tensile capacity and RF the reduction factor. As shown in Figure 3, the length of bar behind the slip surface is 4.1 m. The factored tensile capacity of the bar is 100 kN, so a length of only 3 m is required to mobilize enough pullout resistance to equal the tensile capacity. The pullout force applied to the free-body diagram is therefore 100 kN.

The nails are drawn with a dashed line in Figure 1, indicating that the tensile capacity is the governing component. Stated another way, the length of nail behind the slip surface is long enough to mobilize the full tensile capacity. The red boxes provide another visual indicator that the maximum amount of force has been mobilized. The boxes are drawn to a length at which the pullout force equals the tensile capacity.

Case 1 uses the option to distribute the reinforcement load, which means that the total nail force of 100 kN is distributed amongst all of the slices intersected by the lines of action of the nails. This option is recommended for analyzing reinforcement because it improves numerical convergence. The F of S verses lambda plot for the critical slip surface shows a clear cross-over between the force and moment F of S lines, indicating acceptable convergence (Figure 4 Convergence Plot for Case 1Figure 4). Choosing the option to concentrate the nail force in a single slice usually results in more convergence difficulties because it creates high strength contrasts between adjacent slices.

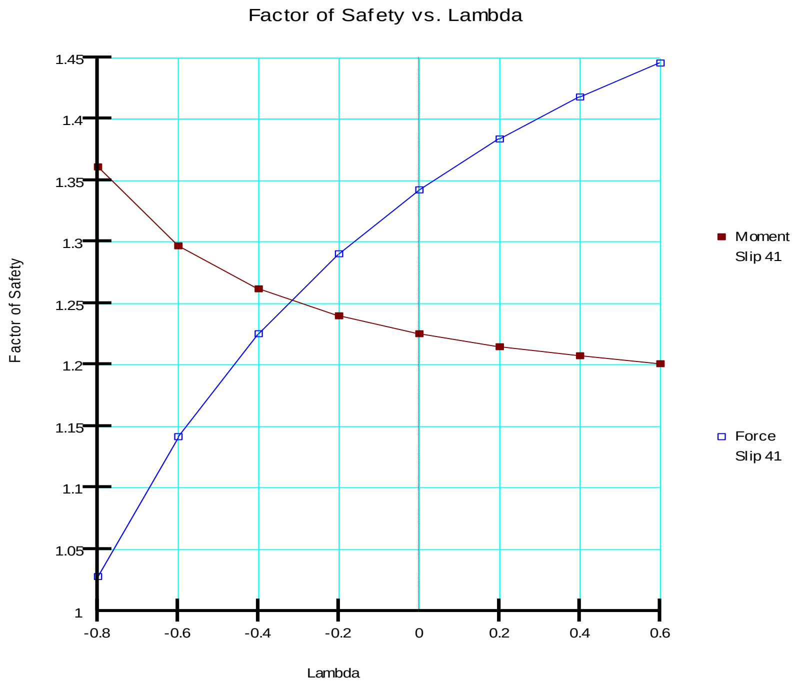

Figure 4 Convergence Plot for Case 1

Figure 5 presents the result for Slip Surface 17. The uppermost soil nail is drawn as a solid line because the pullout resistance governs. The length of nail behind the slip surface is 2.43 m, yielding a pullout force of 81.1 kN, which is less than the 100 kN factored tensile capacity.

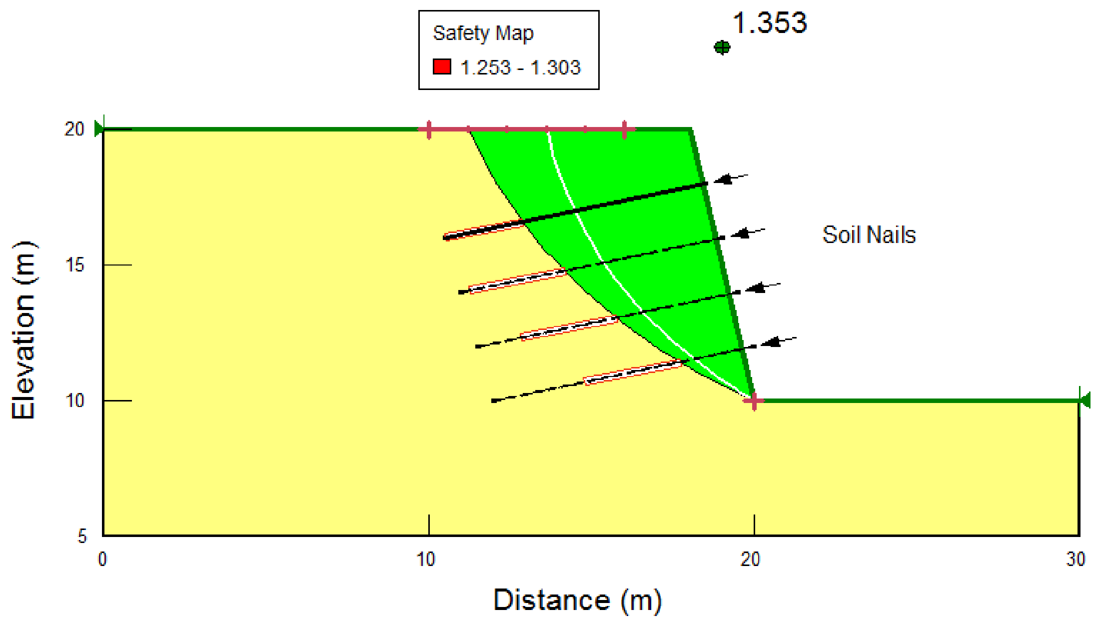

Figure 5 Result for Slip Surface 17

Case 2 – F of S Dependent

Figure 6 present the results for Case 2 in which the factor of safety dependent option has been selected for all four soil nails. The pullout resistance is therefore factored down by the computed factor of safety. As such, the specified resistance reduction factors are to 1.0, so that it is possible to better ascertain the impact of relating the reduction factors to the computed factor of safety.

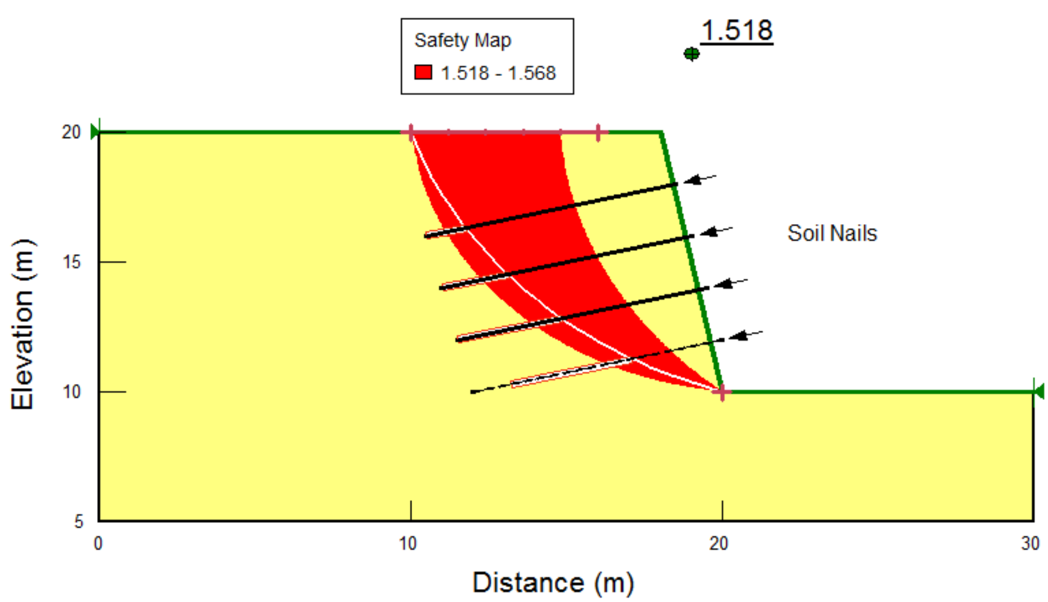

Figure 6 Critical Slip Surface for Case 2

The force in the lowest nail is governed by the tensile capacity of the bar. The factored tensile capacity of the bar was calculated as:

$$FTC = {}^{TC}\!/_{(RF\ \times spacing)} = {}^{400kN}\!/_{1.518 \times 2m} = 131.76kN$$ **Equation 3**

The result means that the factor of safety against sliding of the active wedge is 1.518, and the reduction factors for both the pullout and tensile capacity are also 1.518.

The Safety Map in Figure 6 is relatively wide. Generally this infers that there is more than one mode of failure with a very similar safety factor. In this example, a shallow slip (near the wall) and a deeper slip have a similar safety factor that is greater than 1.5. Consequently, the design is acceptable for both potential modes of failure.

Case 3 – No Anchorage

Excavation faces or slopes that are reinforced with nails usually have some form of structural facing material, such as a wire reinforcing mesh and shotcrete. The prime purpose of the facing material is to prevent surface sloughing and to anchor the nails to the face.

SLOPE/W assumes by default that the nails are connected to a facing, even though the facing material is actually not included in the cross-section. It is possible in SLOPE/W to over-ride the default by setting the anchorage option to 'No' under the KeyIn Reinforcement dialogue box.

Figure 7 shows the result for Case 3 when the nails are not anchored to the facing material. It is noted that the red box is in front of the slip surface for the bottom two nails. This means that the resistance to sliding offered by the lower two nails arises from the portion of the nail in-front of the critical slip surface. The low factor of safety (0.963) for indicates that the design would not perform satisfactorily without some form of structural facing.

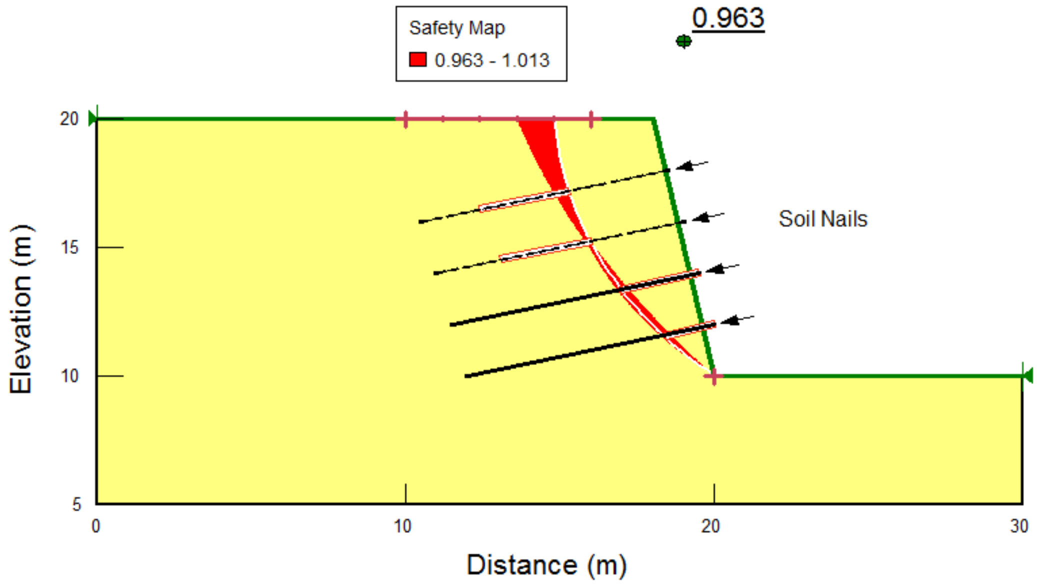

Figure 7 Critical Slip Surface for Case 3

Summary and Conclusions

Soil nails are a type of reinforcement that can be modelled in SLOPE/W. This example demonstrates that it is best to distribute the nail forces amongst all of the slices intersected by the line of action, which yields better convergence. The pull-out resistance of the nails can be factored down by a user-defined resistance reduction factor or the computed F of S. An anchorage option can also be selected to study the effect of not including wall facing.