Reinforcement with Geosynthetics

GEO-SLOPE International Ltd. | www.geo-slope.com

1200, 700 - 6th Ave SW, Calgary, AB, Canada T2P 0T8
Main: +1 403 269 2002 | Fax: +1 888 463 2239

Introduction

Reinforced earth walls or Mechanically Stabilized Earth (MSE) walls are gravity retaining structures built with earth and some form of reinforcement. Their construction involves placing alternating layers of soil and reinforcement, connected to front facing panels. The reinforcement can be metal strips, steel grids, or geosynthetic materials, like geogrid or geofabric. The soil within the wall itself is usually engineered granular material.

This example demonstrates the use of SLOPE/W to check the internal stability of reinforced earth walls. From a stability analysis perspective, the concepts are very similar to analyzing the stability of anchored tie-back walls or soil nail walls, where the reinforcement simply becomes a concentrated line load. However, for these structures, the bond or shear resistance between the soil and the reinforcement is a function of the overburden stress because the soil is a granular material.

Background

The magnitude of the geosynthetic load is governed by either: (1) the pull-out resistance of the geosynthetic; or (2) its tensile capacity. There are two methods available for defining the geosynthetic pull-out resistance (green box, Figure 1), depending on the stress transfer mechanism of the reinforcement. If the dominant stress transfer mechanism is passive resistance, than the pull-out resistance can be specified as a force per unit length of geosynthetic, per unit width in the out-of-plane direction. Passive resistance is generally associated with the development of bearing stresses acting on relatively stiff reinforcement members, situated normal to the pull-out direction. Conversely, if frictional resistance is the dominant stress transfer mechanism, the pull-out resistance, PR, can be calculated from the overburden stress by:

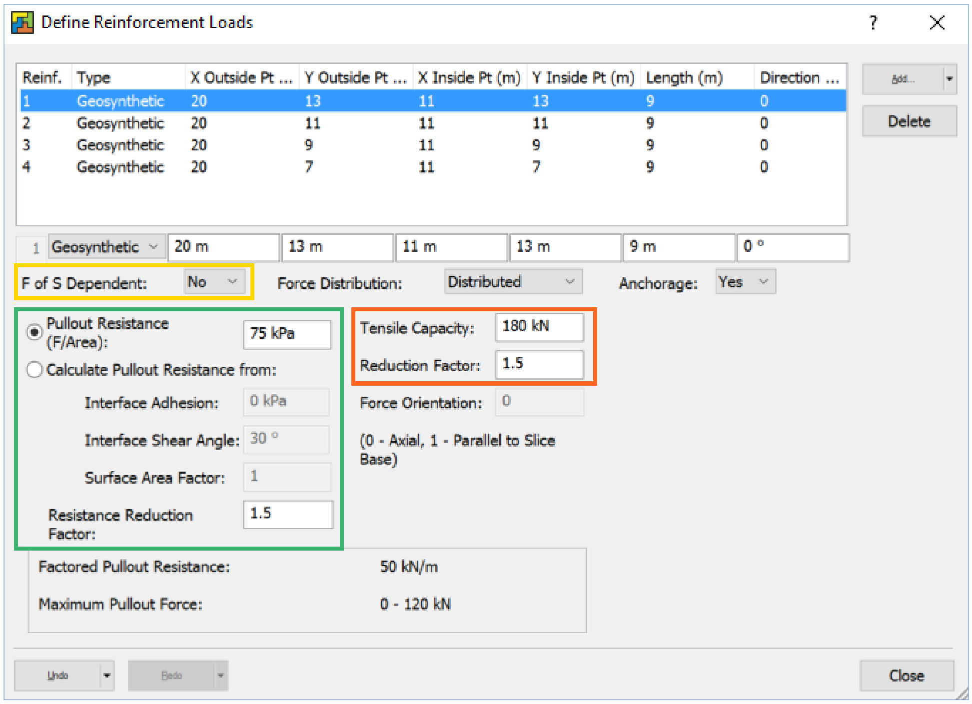
$$PR = \left(S_{IA} + \sigma_v^{'} \cdot tan\delta\right) \cdot SAF \qquad \text{Equation 1}$$

where σ'_v is the effective overburden stress and S_{IA} is the interface adhesion, which is the apparent cohesion under effective drained soil conditions, or the undrained strength at the geosynthetic-soil interface. The interface shear angle, δ, represents the angle of interface shearing resistance and SAF is a surface area factor, which accounts for the mobilized pull-out resistance on the geosynthetic top and bottom. A resistance reduction factor, RF_R, may be specified such that the factored pull-out resistance, FPR, is:

$$FPR = \frac{PR}{RF_R}$$

Equation 2

where the resistance reduction factor can be used to account for a variety of issues such non-linear stress reduction over the embedded length or installation damage and deterioration. There is no spacing term included in this equation, as with anchors or nails, since geosynthetic reinforcement is continuous in the out-of-page direction. Thus, the reinforcement properties are considered to be per unit distance.



Reinf.	Type	X Outside Pt ...	Y Outside Pt ...	X Inside Pt (m)	Y Inside Pt (m)	Length (m)	Direction ...
1	Geosynthetic	20	13	11	13	9	0
2	Geosynthetic	20	11	11	11	9	0
3	Geosynthetic	20	9	11	9	9	0
4	Geosynthetic	20	7	11	7	9	0

1 Geosynthetic 20 m 13 m 11 m 13 m 9 m 0 °

F of S Dependent: No

Force Distribution: Distributed

Anchorage: Yes

● Pullout Resistance (F/Area): 75 kPa

○ Calculate Pullout Resistance from:

Interface Adhesion: 0 kPa

Interface Shear Angle: 30 °

Surface Area Factor: 1

Resistance Reduction Factor: 1.5

Tensile Capacity: 180 kN

Reduction Factor: 1.5

Force Orientation: 0

(0 - Axial, 1 - Parallel to Slice Base)

Factored Pullout Resistance: 50 kN/m

Maximum Pullout Force: 0 - 120 kN

Figure 1. Geosynthetic reinforcement specifications for the base case (Analysis 1), including factor of safety dependence (yellow box), pull-out resistance definition (green box), and tensile capacity definition (orange box).

A reduction factor may also be applied to the tensile capacity, such that the factored tensile capacity, FTC, is calculated as:

$$FTC = \frac{TC}{RF_T}$$

Equation 3

where TC and RF_T are the specified tensile capacity and tensile reduction factor, respectively, in the reinforcement dialogue box (orange box Figure 1). When the ‘factor of safety dependent’ option is selected (yellow box in Figure 1), then the factor of safety is added to the denominator in both Equation 2 and Equation 3.

Numerical Simulation

This example considers a 10-m high MSE wall with four layers of geosynthetic reinforcement (Figure 2). The general slope material and engineered fill have a unit weight of 20 kN/m^3, a cohesion of 0 kPa, and a friction angle of 30⍰. The slip surfaces are defined by the axis point at coordinate (19,18) and the Entry and Exit method such that all trial slip surfaces exit the domain at the bottom of the wall (Figure 2). The Spencer limit equilibrium method is used to determine the factor of safety for each slip surface. Pore water pressures are not defined in this project.

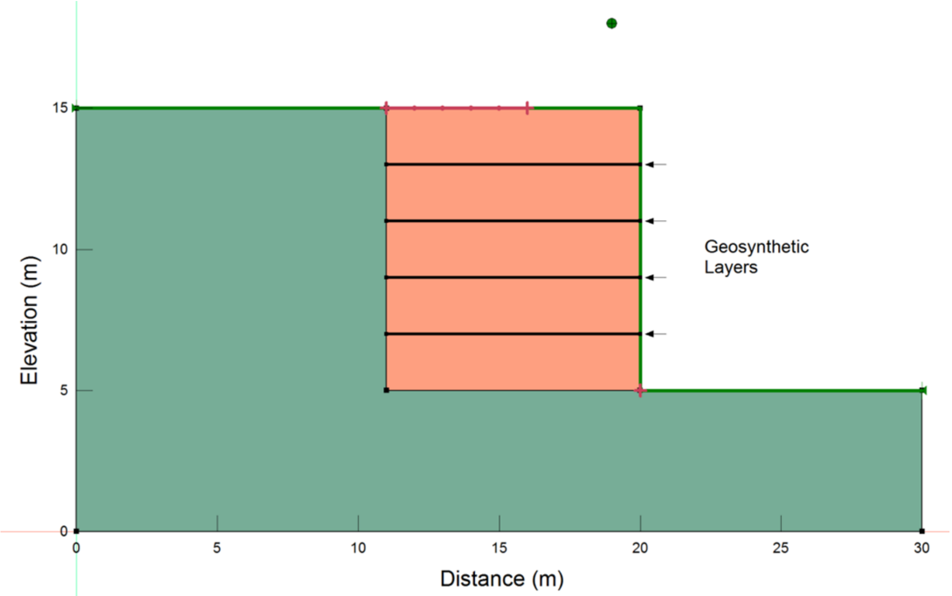
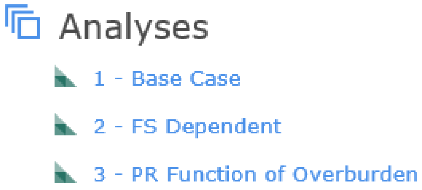


Figure 2. Example configuration with the slip surface definition and geosynthetic reinforcement for all three analyses.

The example includes three analyses (Figure 3). The first represents the base case where the reinforcement is not dependent on the factor of safety and the pull-out resistance is a constant, specified as a force per area. The second analysis considers the stability when the reinforcement load depends on the factor of safety, and the third calculates the pull-out resistance given the overburden pressure, given an interface shear angle of 30°. The specified properties for the geosynthetic reinforcement are given in Table 1.



Analyses

1 - Base Case

2 - FS Dependent

3 - PR Function of Overburden

Figure 3. Project analysis tree.

Table 1. Geosynthetic reinforcement specifications for all three analyses.

Property	Analysis 1	Analysis 2	Analysis 3
Length	9 m	9 m	9 m
Inclination	0°	0°	0°
Factor of Safety Dependent	No	***Yes***	No
Force Distribution	Distributed	Distributed	Distributed
Pull-out Resistance	75 kPa	75 kPa	***Calculated***
Resistance Reduction Factor	1.5	1.5	1.5
Tensile Capacity	180 kN	180 kN	180 kN
Tensile Reduction Factor	1.5	1.5	1.5

The factored pullout resistance for Analysis 1 is 50 kN (75 kN / 1.5) per metre of embedment behind the slip surface, while the maximum tensile capacity is 120 kN (180 kN /1.5). Therefore, as the embedment length behind the slip surface increases, the geosynthetic force will increase from 0 kN until the maximum tensile capacity is reached (120 kN). The embedment length associated with a pull-out resistance of 120 kN is 2.4 m. Thus, when the embedment length is greater than 2.4 m, the tensile capacity will govern the geosynthetic force used in the stability analysis.

Results and Discussion

The critical slip surface for the base case (Analysis 1) has a factor of safety of 1.401 (Figure 4). The slip surface colour map indicates that many of the slip surfaces have a factor of safety between 1.4 and 1.44 (light green area in Figure 4). The results also show that sufficient embedment is available, as indicated by the length of the red boxes around the reinforcement. This means that the pull-out resistance is greater than the tensile capacity of the reinforcement and, consequently, the tensile capacity governs. This information can be found in the View Object Information list, and is depicted by the dashed reinforcement lines (Figure 4). Thus, each reinforcement layer provides 120 kN towards the stability, which is distributed amongst the slices intersecting the reinforcement line of action.

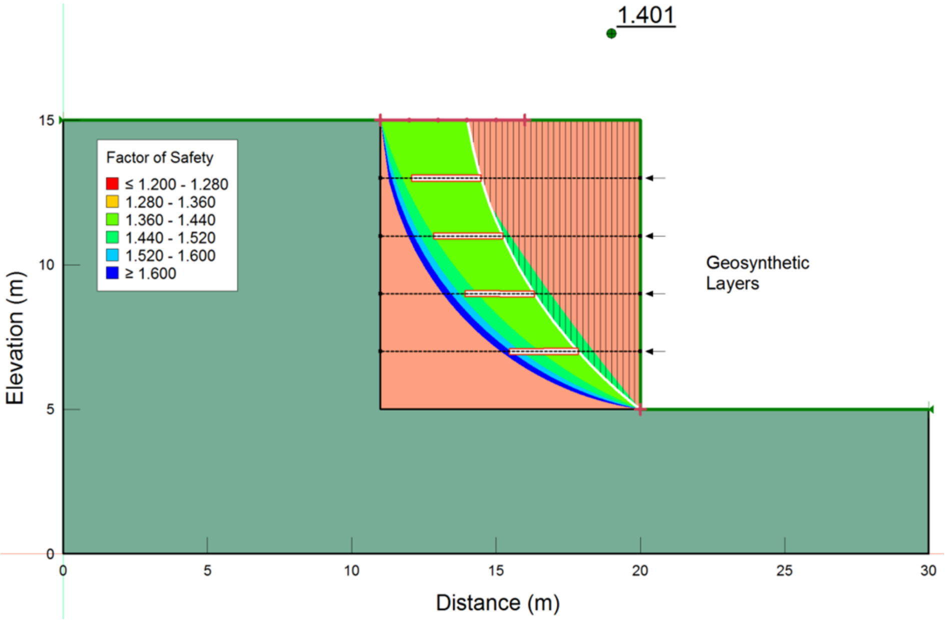


Figure 4. Stability results for the base case (Analysis 1) when the pullout resistance is a constant and the reinforcement is not factor of safety dependent.

When the reinforcement load depends on the factor of safety (Analysis 2), the critical factor of safety is 1.434 (Figure 5). Overall, the results are similar to the base case as the reduction factor for both pull-out resistance and tensile capacity specified in Analysis 1 was 1.5, which is relatively similar to the computed factor of safety. The factor of safety contours indicate that most of the slip surfaces have a factor of safety between 1.434 and 1.52. These results suggest that there is a wide shear band governing stability, as opposed to one specific slip surface.

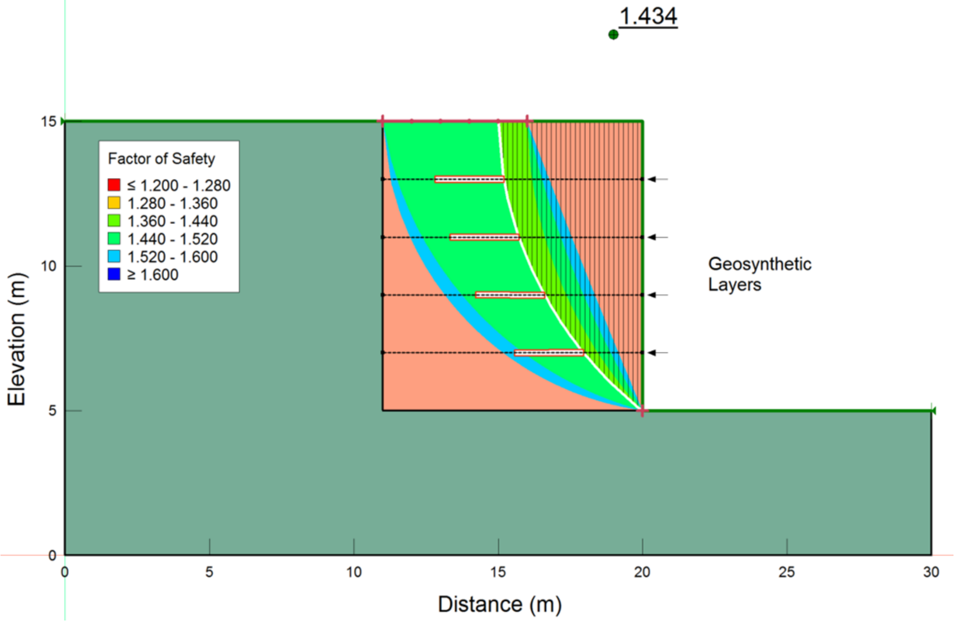


Figure 5. Stability results when the reinforcement load depends on the computed factor of safety (Analysis 2).

The critical factor of safety computed in Analysis 3, when the pull-out resistance is a function of overburden pressure, is 1.199 (Figure 6). The overburden pressure increases with depth so the top two reinforcement layers have a lower pull-out resistance due to lower overburden pressure. Thus, the pull-out resistance governs the force available from the top two reinforcement layers (indicated by the solid line in Figure 6). The greater overburden pressure at the depths of the lower two reinforcement layers, corresponds to higher pull-out resistance and so the geosynthetic tensile capacity governs (dashed lines in Figure 6). The forces contributed by the lower two reinforcement layers are the same as in the previous analyses (120 kN each) but the forces provided by the upper layers are less (20.8 and 87.8 kN), resulting in a lower factor of safety than the previous two analyses.

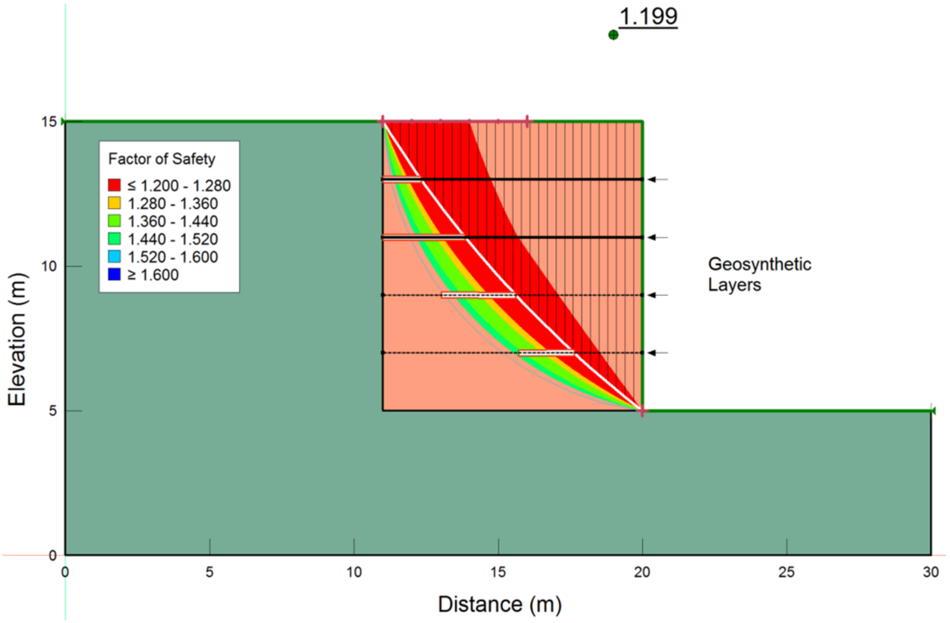


Figure 6. Stability results when pull-out resistance is a function of the overburden pressure (Analysis 3).

SLOPE/W includes an option to specify the direction of the reinforcement force; for example, parallel to the slip surface. Unfortunately, this means that the entire reinforcement force is concentrated at the point where the line of action crosses the slip surface, which generally causes convergence issues. Therefore, this option should be used sparingly and only for investigating its effect on specific slip surfaces.

Summary and Conclusions

This example demonstrates the various inputs and options available when simulating the stability of MSE walls. The base case indicated that tensile capacity governed the reinforcement loads contributing to stability. When the reinforcement load was dependent on factor of safety, the results did not change significantly. However, if the pull-out resistance and tensile capacity reduction factors were specified differently in Analysis 1, the results would be less similar to those computed in Analysis 2. When the pull-out resistance was calculated as a function of overburden pressure, the factor of safety decreased due to the decline in pull-out resistance of the top two reinforcement layers.

One of the most challenging parts of simulating MSE walls is applying the appropriate pull-out characteristics and tensile capacities for the reinforcement, as this information is often considered proprietary. For this reason, it is usually necessary to work with the reinforcement supplier when analyzing these systems. Finally, the guidelines provided by Holtz et al. (1997) are also helpful for analyzing and designing MSE walls.

References

Holtz, R.D., Christopher, B.R. and Berg, R.R. 1997. *Geosynthetic Engineering*, BiTech Publishers Ltd., Richmond, British Columbia, Canada.