GeoStudio Example File
Reinforcement with User Defined

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Introduction

The user defined reinforcement type in SLOPE/W can be used to model a variety of structures including, but not limited to, fixed-end anchors (i.e. a dead-man anchor), anchors and nails affixed to plates, and piles with variable shear resistance. A reinforcement load, regardless of its type, is ultimately treated as a force acting at the base of the slice it intersects. For a user defined reinforcement function, SLOPE/W can determine the magnitude of the force with respect to the distance from the starting point of the reinforcement to the point of intersection with the slip surface. Depending on the specified force orientation, a pullout or a shear force can be simulated. This example illustrates the use of user-defined reinforcement to model four different cases.

Background

A user defined reinforcement force versus distance function can be used to simulate the effect of reinforcement in a stability analysis. The reinforcement force can either be a pullout or a shear force. The distance in the function is the length from the starting point of the reinforcement to the intersecting point with the slip surface. Other input parameters are:

- Spacing
- Reduction factor
- Force orientation - relative to the slice base (0 to 1: 0 is Axial, 1 is parallel to slice base) or perpendicular to the reinforcement

The factored user defined force F' is calculated as:

$$F' = \frac{F}{s \cdot RF \cdot FofS}$$

Equation 1

where F is the reinforcement force based on a user defined F versus distance function, s is the out-of-plane spacing, RF is the reduction factor, and $FofS$ is the factor of safety, which is only applicable if the ‘F of S Dependency’ option is set to ‘yes’. The force orientation can be axial or parallel to the slice base for a pullout condition and is required to be perpendicular to the reinforcement for simulating a pile.

The reinforcement force versus distance function can be developed by considering that

$F = \min(F_1, F_2, F_3)$

where F_1 is the facing connection strength plus the passive pullout resistance mobilized within the sliding mass, F_2 is the end-anchorage capacity plus the pullout resistance mobilized behind the slip surface, and F_3 is the tensile capacity.

Numerical Simulation

Case 1: Fixed End Anchor

Case 1 illustrates a fixed-end anchor. The fixed-end anchors are spaced 2 m in the out-of-plane direction. The capacity of a single anchor is 120 kN. The reduction factor of the anchor capacity is taken as 1.2. A tacit assumption for fixed-end anchors is that the stress/force mobilized in the anchor equals the tensile capacity. In this case, the factored reinforcement load is applied where the slip surface intersects the reinforcement: the user defined reinforcement function is a horizontal line with y-intercept equal to the anchor capacity (Figure 1).

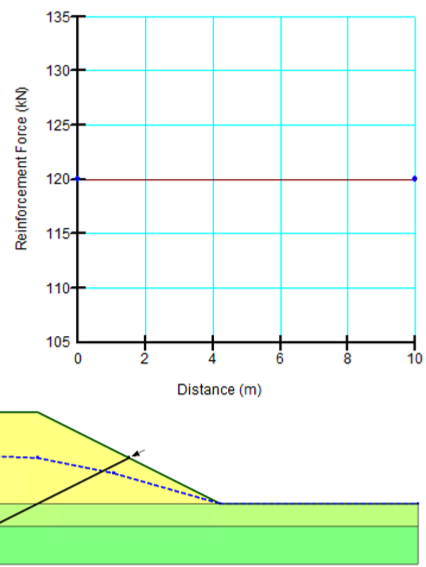

Figure 1. User defined reinforcement function for a dead-man anchor.

Case 2: Embedded Anchor with Plate

Case 2 presents a user defined reinforcement function that takes into account the plate capacity (40 kN), end anchorage (100 kN), reinforcement tensile capacity (200 kN), and soil-reinforcement pullout resistance (20 kN/m). It is assumed that the reinforcement is 23 m long with a spacing of 1 m and a reduction factor of one.

Figure 2 shows the reinforcement function for this case. The maximum reinforcement force at any distance d corresponds to one of three failure modes: stripping (including plate capacity), tensile capacity, or pullout (including end-anchored force). At the connecting point, the pullout force mobilized behind the slip surface (23 m x 20 kN/m) is greater than the tensile capacity, which is greater than the plate capacity (40 kN), so the plate capacity governs. The plate capacity plus the passive resistance mobilized in the sliding mass remains smaller than the tensile capacity until $d = 8\,m$. At a distance of 18 m, the reinforcement force is governed by the length of reinforcement behind the slip surface because this force, including the end-anchored capacity, is less than or equal to the tensile capacity:

$$F = (23m - 18m)\ X\ 20^{kN}/_{m} + 100kN \leq 200kN \qquad \textbf{Equation 1}$$

For a slip surface that passes through the embedded end at a distance of 23 m, only the end anchored force is available (100 kN).

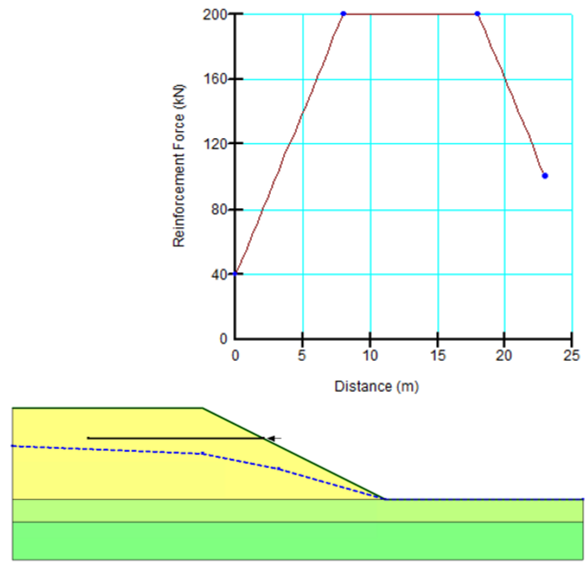

Figure 2. User defined reinforcement function giving consideration to plate capacity, end bearing, tensile capacity and soil-reinforcement interface shear.

Case 3: Anchor Installed in Multiple Layers

User defined reinforcement can be used to consider the mobilization of pullout resistance within different soils. In Case 3, the reinforcement passes through 9 m of sandy soil into 9 m of fine grain soil with pullout resistances of 10 kN/m and 5 kN/m, respectively. For simplicity, no anchorage at the slope face or end-bearing capacity is considered. The reinforcement force orientation in Case 3 is set to be 0.5 (note: 0 indicates oriented along the axis of the reinforcement and 1 indicates parallel to the slice base). As can be seen in Figure 3, the user defined reinforcement function includes four data points. The reinforcement provides zero capacity at both ends. The distance at which there is equality between the mobilized resistance within the sliding mass (stripping) and outside the slip surface is obtained by solving for d from

$$10\frac{kN}{m}(d) = 5\frac{kN}{m}(9\ m) + 10\frac{kN}{m}(9\ m - d)$$

Stripping is therefore the governing failure mode for $d \leq$ 6.75 m. The pullout resistance for $d > 6.75\ m$ is given as:

$if\ 6.75\ m < d < 9\ m$	$F = 5\frac{kN}{m}(9\ m) + 10\frac{kN}{m}(9\ m - d)$
$else\ \ 9 \leq d \leq 18\ m$	$F = 5\frac{kN}{m}(18\ m - d)$

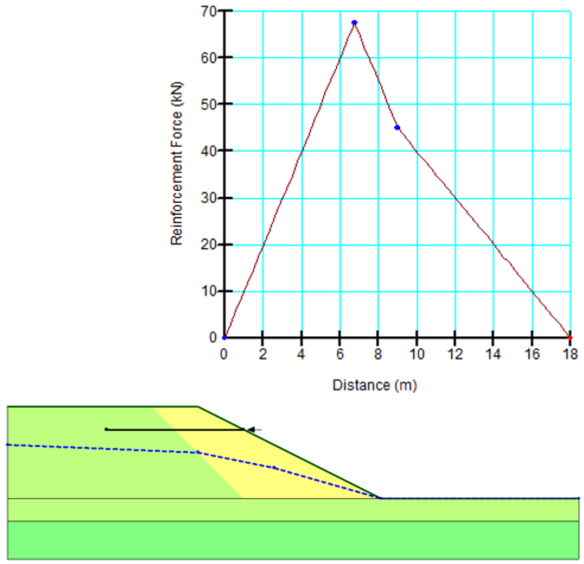

Figure 3. User defined reinforcement installed in two soil zones.

Case 4: Pile

In Case 4, a user defined reinforcement is used to model a pile where the mobilized shear force varies over the length. The stabilizing force provided by a pile is influenced by its embedment relative to the location of the slip surface. In the case where almost the entire pile is contained within the slip surface, the shear force from the pile would be negligible. A similar case would be a slip surface that intersects the pile at very short distance.

Figure 4 presents the reinforcement function defined for a simple case in which the required minimum embedment is assumed to be 2 m in order for the full mobilization of shear resistance. Considering the pile head is about 1.5 m above the ground surface, the function is defined to obtain the shear force of 200 kN at a distance of 3.5 m. Note that the force orientation is set to be perpendicular to the reinforcement.

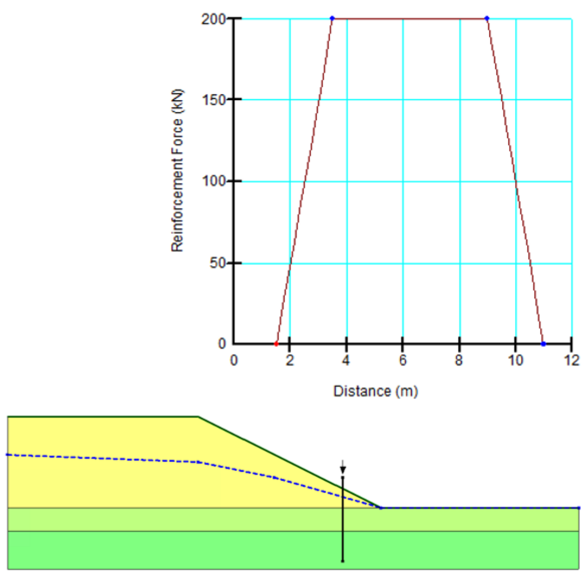

Figure 4. User defined reinforcement for a stabilizing pile.

Results and Discussion

Case 1: Fixed End Anchor

The 'Force Distribution' for the fixed-end anchor in Case 1 is set to 'Distributed'. The Distributed option requires that the Force Orientation be aligned with the reinforcement (i.e. axial). Summation of the reinforcement forces applied at the base of all intersected slices recovers the factored user defined force (Figure 5):

$$F' = \frac{F}{s \cdot RF} = \frac{120}{2 \times 1.2} = 50\ kN$$

Equation 2

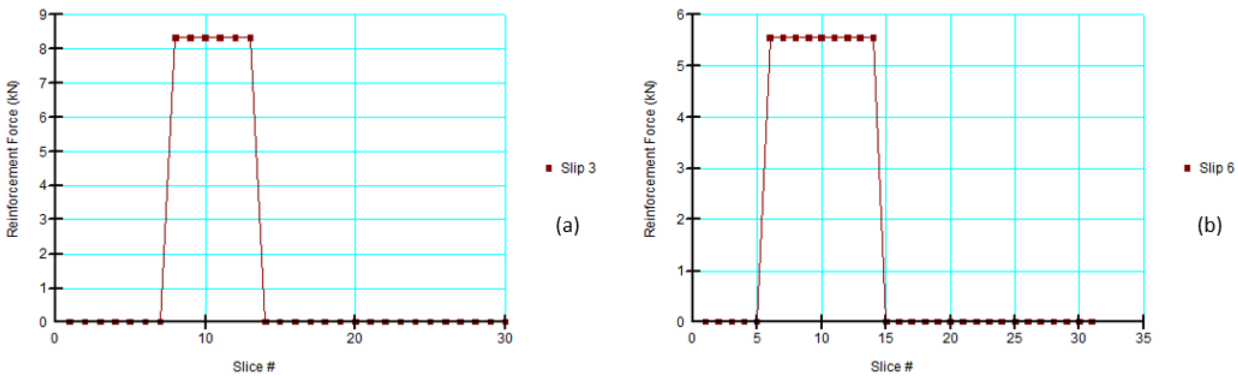

Figure 5. Reinforcement force graphs for Case 1. (a) Slip #3, force distributed in 6 slices and (b) Slip #6, force distributed in 9 slices.

Case 2: Embedded Anchor with Plate

The reinforcement force in Case 2 is considered to be F of S dependent and parallel to the slice base. The force magnitudes used in stability calculations are verified for Slip #2 and Slip #5. The distance from the plate to the slip surface is 6.73 m and 12.54 m, respectively. The reinforcement forces can then be computed from the reinforcement function (Figure 2) as:

For Slip #2,

$$F' = \frac{F}{s \cdot RF \cdot FofS} = \frac{40 + 6.73 \times 20}{1 \times 1 \times 1.412} = 123.7\ kN$$

Equation 3

For Slip #5,

$$F' = \frac{F}{s \cdot RF \cdot FofS} = \frac{200}{1 \times 1 \times 1.725} = 115.9\ kN$$

Equation 4

These numbers are consistent with the Slice Information shown in Figure 6. The orientations of the forces are parallel to the slice base.

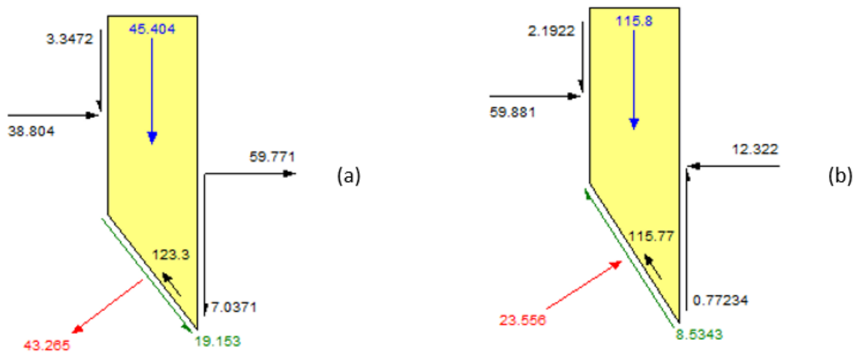

Figure 6. Free body diagrams showing reinforcement forces on (a) Slip #2 and (b) Slip #5 of Case 2.

Case 3: Anchor Installed in Multiple Layers

The slice results for Case 3 are presented in Figure 7 for slip #1 and Slip #4, which correspond to reinforcement lengths of 3.49 m and 9.26 m, respectively. The reinforcement loads are in good agreement with the hand-calculated results given by:

For Slip #1,

$$F' = \frac{F}{s \cdot RF} = \frac{3.49 \times 10}{1 \times 1} = 34.9\ kN \qquad \text{Equation 5}$$

For Slip #4,

$$F' = \frac{F}{s \cdot RF} = \frac{(18 - 9.26) \times 5}{1 \times 1} = 43.7\ kN \qquad \text{Equation 6}$$

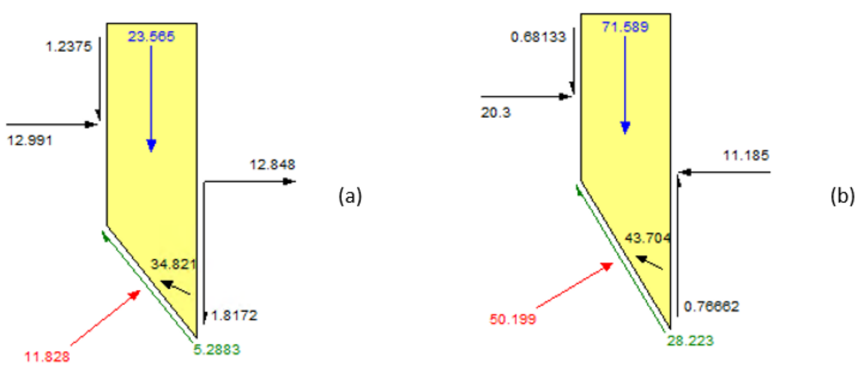

Figure 7. Free body diagrams showing reinforcement forces on (a) Slip #1 and (b) Slip #4 of Case 3.

Case 4: Pile

The user defined reinforcement type is used to model a pile in Case 4. Given the maximum shear force of 200 kN in the function (Figure 4), the fully mobilized shear force would be 100 kN for an out-of-plane spacing of 2 m. As shown in Figure 8, Slip #1 intersects the pile at about 1.5 m below the ground surface (3 m below the pile cap), which mobilizes about 75 kN shear force. Slip #6 almost encompasses the entire pile and the mobilized shear force is negligible. For the slip surfaces where the embedment is sufficient (e.g. Slip #2, #3, and #4), the mobilized shear force is 100 kN.

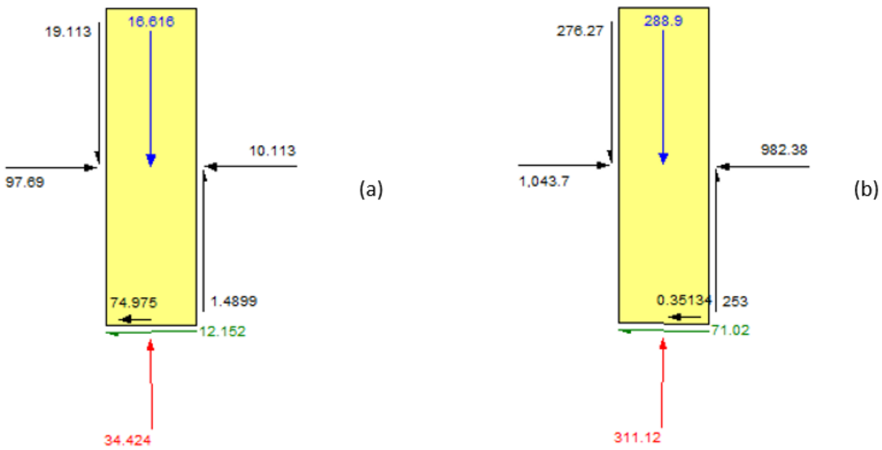

Figure 8. Free body diagrams showing reinforcement forces on (a) Slip #1 and (b) Slip #6 of Case 4.

Summary and Conclusions

The user-defined reinforcement allows for consideration of various modes of failure such as pullout, tensile capacity (of the reinforcement), plate capacity (or connector failure) and so on. The user defined reinforcement can also be used model variations in the mobilized shear force over the length of a pile. Ultimately, user-defined reinforcement provides a generalized approach for modeling reinforcement in SLOPE/W and can therefore be used to enhance the functionality of the other built-in reinforcement types.