Reinforcement with Geosynthetics

1 Introduction

The purpose of this example is to show how geosynthetic reinforcement (e.g. geogrid and geotextile) is accommodated in a stability analysis. The example file makes use of the following SLOPE/W functionality:

Distribution of the pullout forces across many slices;

Factor of safety dependency option for geosynthetic reinforcement;

Calculated pullout resistance based on embedment depth and interface properties (e.g. sheet geotextile);

Load orientation.

2 Configuration and setup

Figure 1 shows the model configuration, soil properties, and entry/exit ranges. All slip surfaces are forced to exit at the toe of the slope. The Draw | Reinforcement command was used to incorporate the geosynthetic reinforcements within the domain. The option to distribute the pullout force over many slices was selected in all but the last analysis which requires that the pullout force be concentrated within one slice. The four cases highlight:

1. Specified pullout resistance (e.g. geogrid);
2. Factor of safety dependency;
3. Calculated pullout resistance (e.g. sheet geotextile);
4. Load orientation.

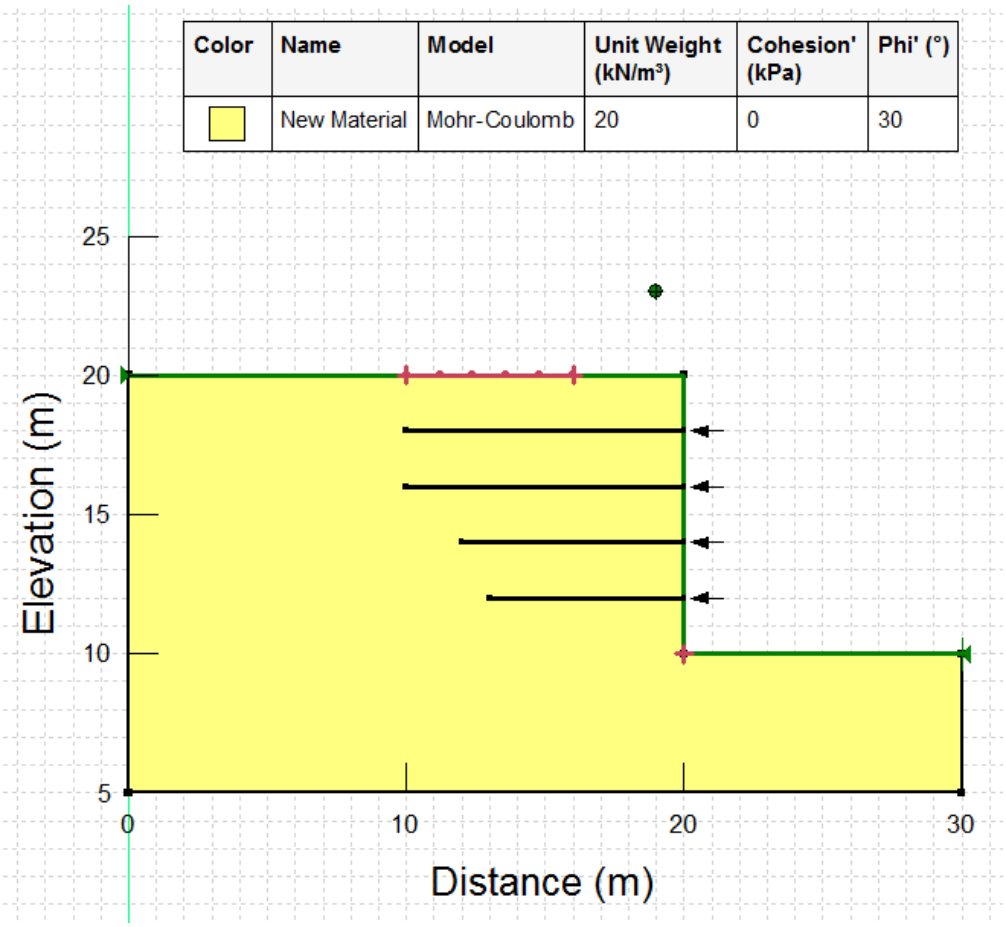

Figure 1 Geometry and soil properties

3 Case 1 – Specified pullout resistance

Figure 2 shows the reinforcement parameters for the first case. The specified pullout resistance is 75 kPa with a reduction factor of 1.5 to account for nonlinear stress reduction over the embedded length. The tensile capacity was specified as 180 kN with a reduction factor of 1.5 to account for installation damage, creep, and durability. The factored pullout resistance FPR per unit length of geosynthetic behind the slip surface is calculated from the pullout resistance PR and resistance reduction factor as:

$$FPR = \frac{PR}{RRF} = \frac{75}{1.5} = 50 \frac{kN}{m}/m$$

where the units indicate the force mobilized per length of geosynthetic behind the slip surface per unit length into the out-of-plane dimension. The maximum pullout force must not exceed the factored tensile capacity FTC:

$$FTC = \frac{TC}{RF} = \frac{180}{1.5} = 120\ kN$$

Figure 3 shows the critical factor of safety and slip surface. The critical factor of safety is 1.415. The pullout force applied to the free body was governed by the factored tensile capacity as indicated by the dotted lines (Figure 3). In general, the governing component is the factored pullout resistance if the

geosynthetic has a high factored (allowable) tensile capacity. In contrast, the factored tensile capacity will generally govern if the factored pullout resistance is high and the geosynthetic is long.

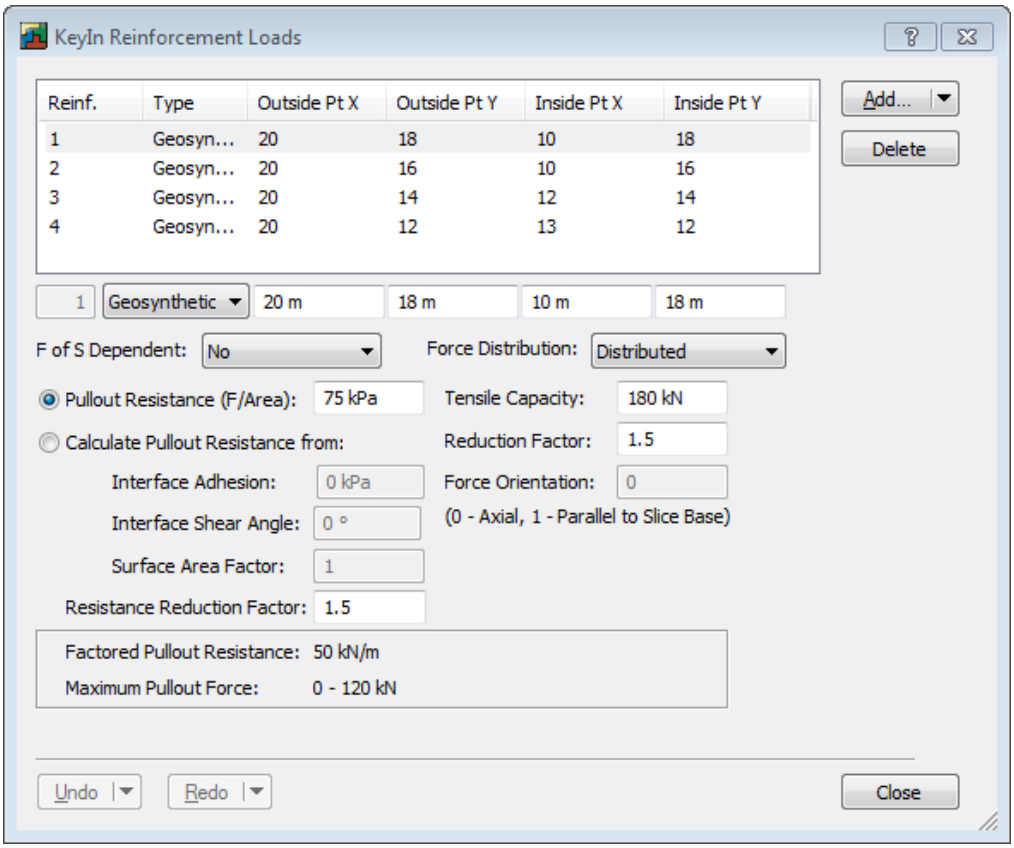

Figure 2 Reinforcement parameters (Case 1)

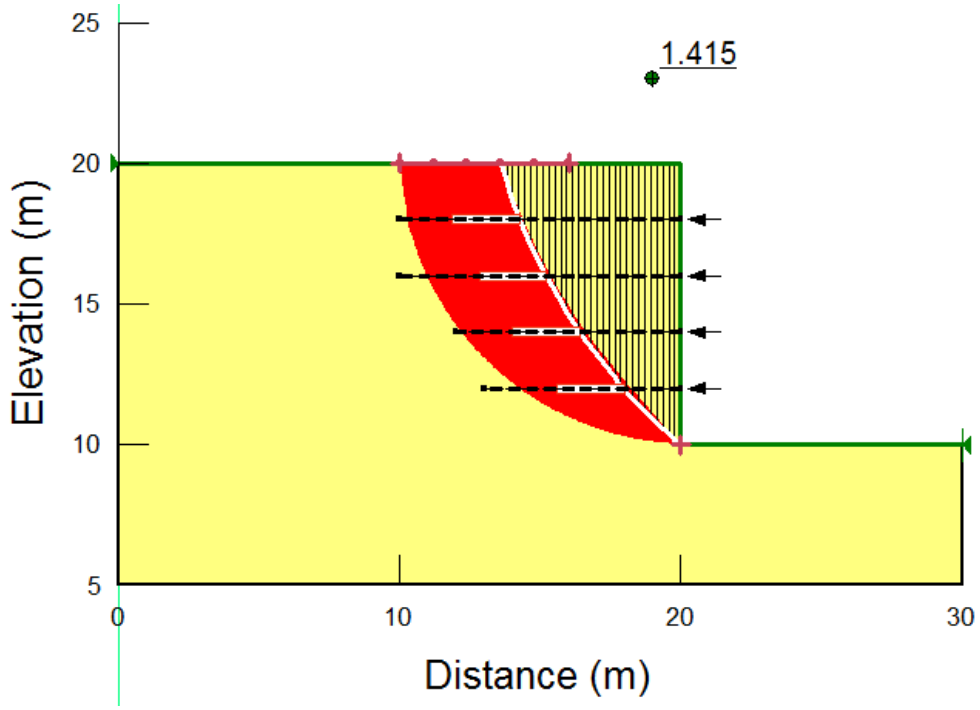

Figure 3 Critical factor of safety and slip surface

Figure 4 shows the result details for the top geosynthetic (View | Object Information). The available length of geosynthetic behind the slip surface is 4.286 m. The length of geosynthetic required to mobilize the pullout force according to the factored pullout resistance is given by:

$120\ kN/((50\ kN/m)\ ) = 2.4\ m$

The red boxes shown on Figure 3 have been dimensioned accordingly.

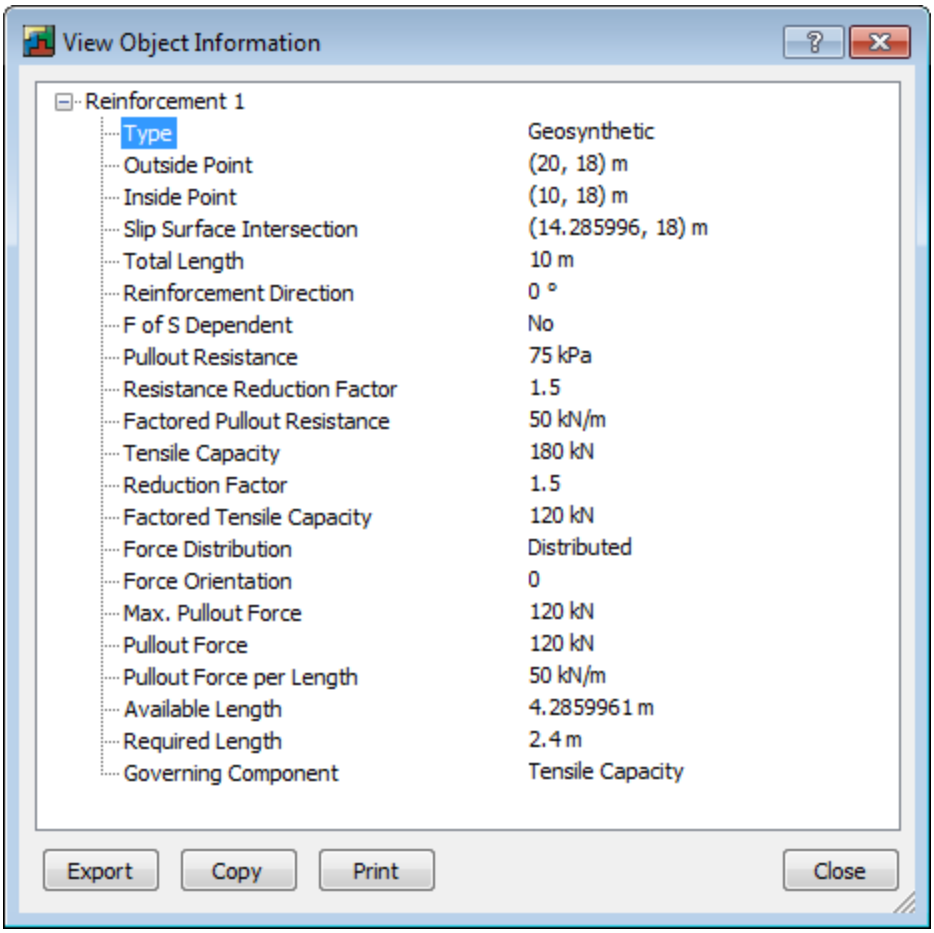

Figure 4 View | Object Information for uppermost geosynthetic

View | Slice Information can be used further interrogate the results. Figure 5 shows the free body diagram and force polygon for Slice 4. The pullout force has been distributed over the 27 slices that are intersected by the geosynthetic. As such, the pullout force on a single slice is equal to:

$$\frac{120\ kN}{27\ slices} = 4.4444\ \frac{kN}{slice}$$

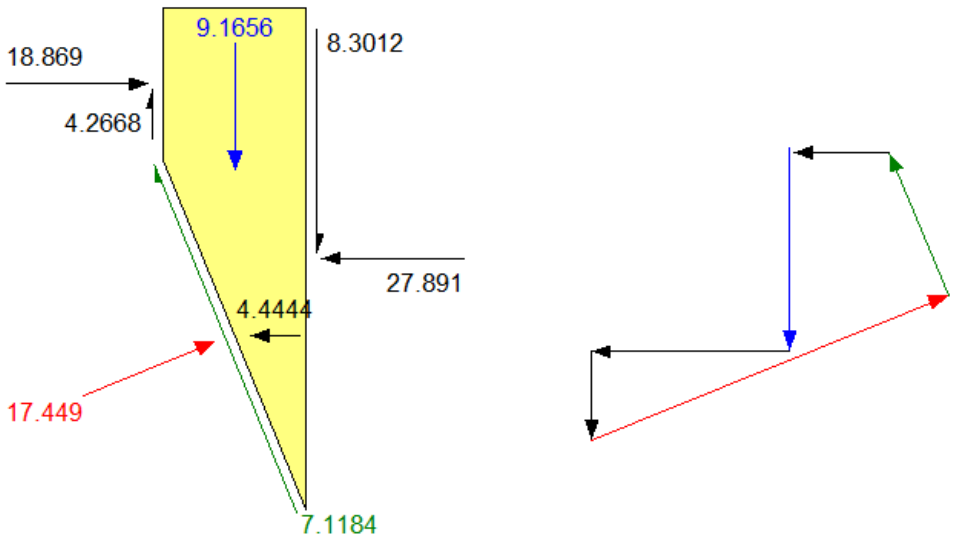

Figure 5 Free body diagram and force polygon for slice 4

4 Case 2 – Factor of safety dependency

Case 2 uses the factor of safety dependency option. The reduction factors for the reinforcement were set to 1.0. Figure 6 shows the critical slip surface and safety map for slip surfaces having a factor of safety varying between 1.420 and 1.520. The location of the critical slip surface has changed because the pullout forces are different. The factored pullout resistance FPR per unit length of geosynthetic behind the slip surface is calculated from the pullout resistance PR, resistance reduction factor, and global factor of safety as:

$$FPR = \frac{PR}{RRF(FS)} = \frac{75}{1.0(1.420)} = 52.82 \frac{kN}{m} \Big/ m$$

The maximum pullout force must not exceed the factored tensile capacity FTC:

$$FTC = \frac{TC}{RF(FS)} = \frac{180}{1.0(1.420)} = 126.76\ kN$$

The maximum pullout force was governed by the factored tensile capacity is therefore calculated (View | Object Information) as:

$$PF = FPC = 126.76\ kN$$

Figure 7 shows the Object information for the uppermost geosynthetic and confirms the preceding calculations. The other three geosynthetics have a maximum pullout force that is also governed by the factored tensile capacity.

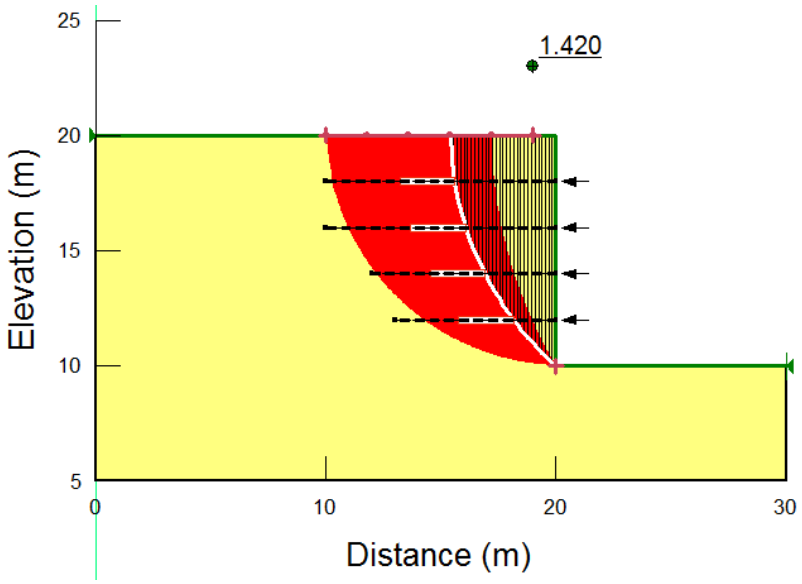

Figure 6 Critical slip surface and safety map.

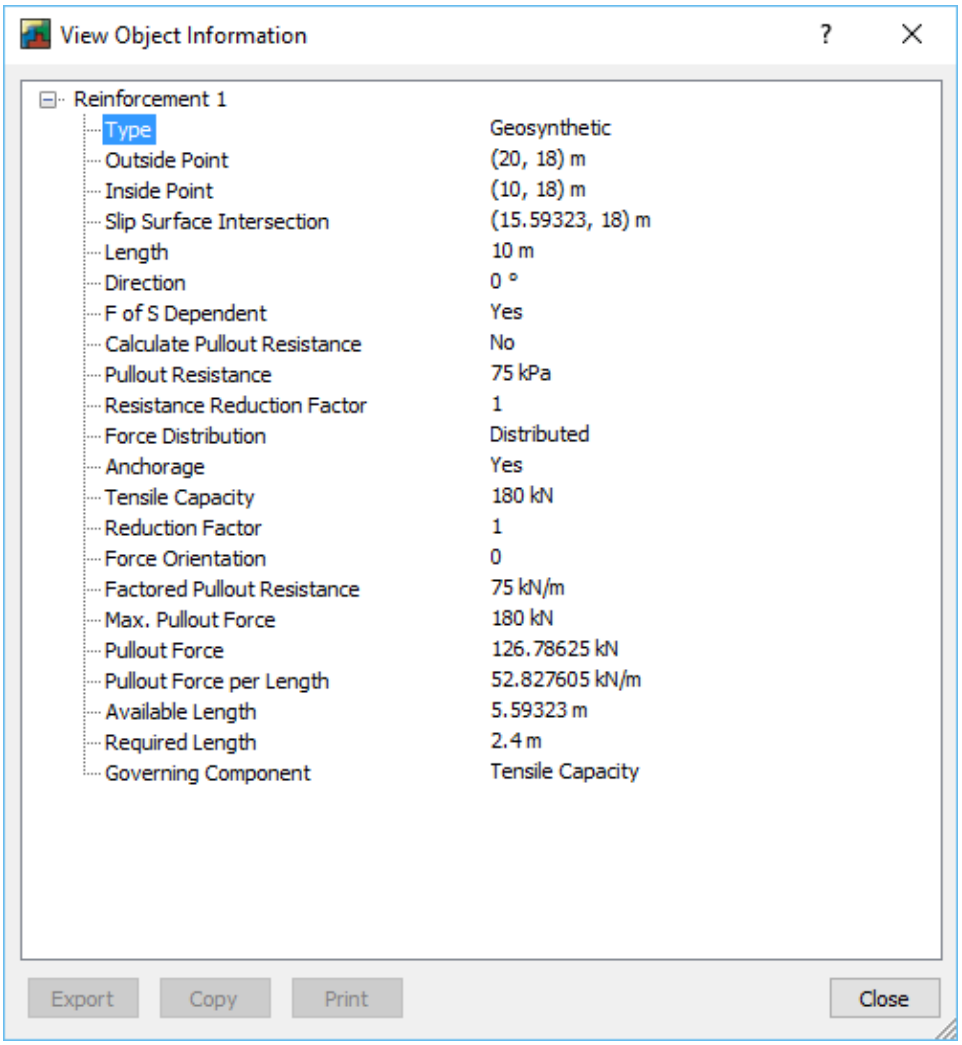

Figure 7 View | Object Information for uppermost geosynthetic

Figure 8 shows the free body diagram and force polygon for Slice 2 that is intersected by the top geosynthetic. The pullout force has been distributed over the 29 slices that are intersected by the reinforcement. The pullout force apportioned to the slices is equal to:

$$\frac{126.76\ kN}{29\ slices} = 4.37\ \frac{kN}{slice}$$

until the next geosytenthic is intersected by Slice 5, at which point the pullout forces become:

$$4.37\ kN + \frac{126.76\ kN}{26\ slices} = 9.25\ \frac{kN}{slice}$$

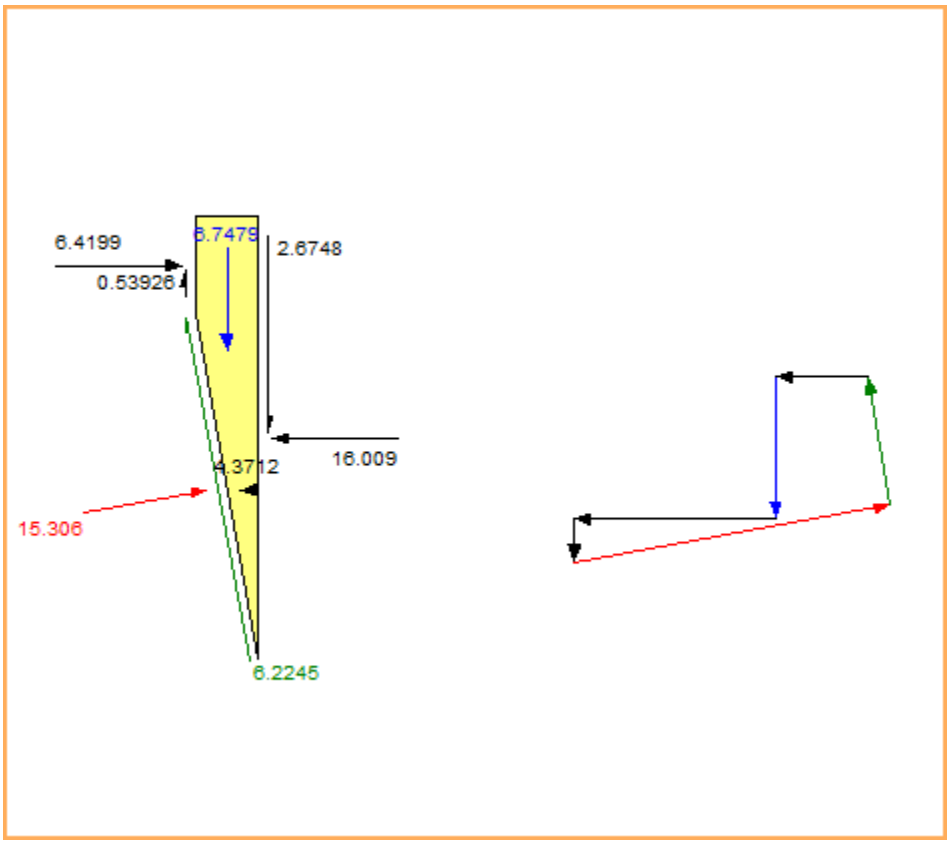

Figure 8 Free body diagram and force polygon for slice 2.

5 Case 3 – Calculated pullout resistance

Figure 9 shows the definition of the reinforcement parameters required to calculate the pullout resistance. The factor of safety dependency option has been selected and the reduction factors have been set to 1.0. The interface adhesion (S_{IA}) was specified as 0 kPa, the interface shear angle (δ) as 25°, and the Surface Area Factor (SAF) as 2.

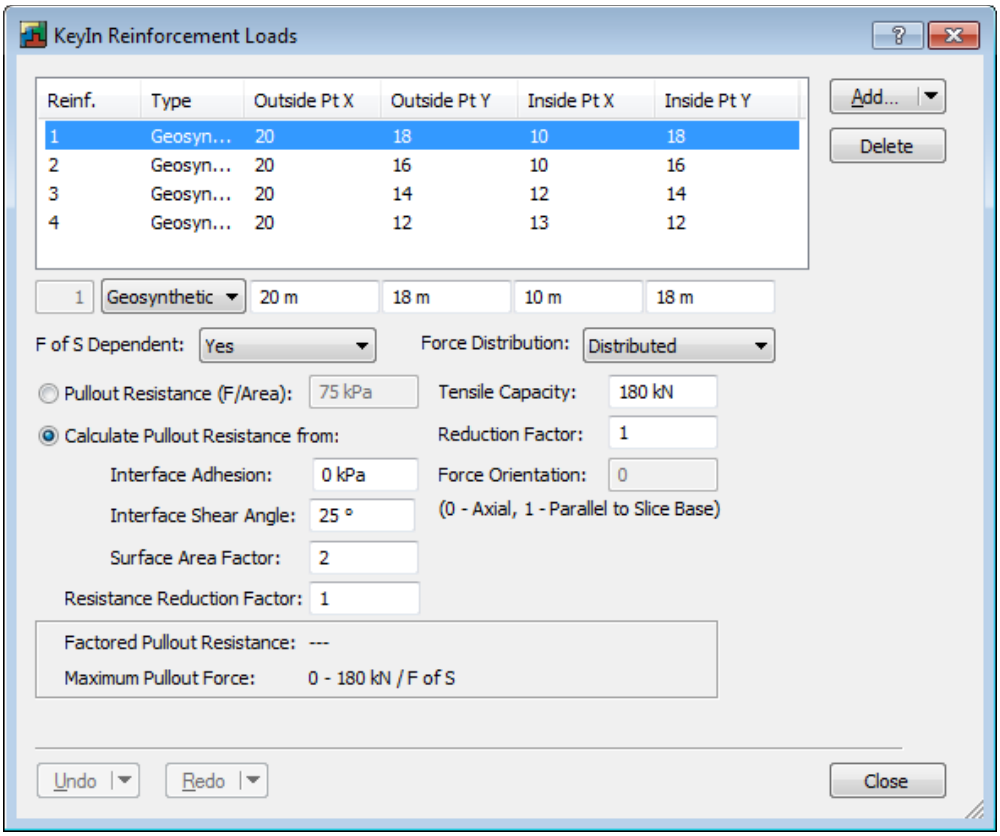

Figure 9 Reinforcement parameters (Case 3)

Figure 10 shows the critical slip surface and factor of safety. The calculated pullout resistance PR is different for each geotextile and is calculated as:

$$PR = \left(S_{IA} + \sigma_v^{'} \tan \delta\right) SAF$$

where $\sigma_v^{'}$ is the effective overburden stress. For example, the pullout resistance for the geosynthetic embedded at elevation 18 m, which corresponds to an embedment depth of 2 m, would be calculated as:

$$PR = (0 + 2(20)\tan 25)2 = 37.3 \frac{kN}{m} \Big/ m$$

The factored pullout resistance FPR for this reinforcement per unit length of geosynthetic behind the slip surface is calculated from the pullout resistance PR, resistance reduction factor, and global factor of safety as:

$$FPR = \frac{PR}{RRF(FS)} = \frac{37.3}{1.0(1.426)} = 26.1 \frac{kN}{m} \Big/ m$$

The maximum pullout force must not exceed the factored tensile capacity FTC:

$$FTC = \frac{TC}{RF(FS)} = \frac{180}{1.0(1.426)} = 126.23\ kN$$

The maximum pullout force for all geosynthetic was governed by the factored tensile capacity of 126.23

kN. View – Slice Information can be used to calculate the pullout force apportioned to each slice as was shown previously.

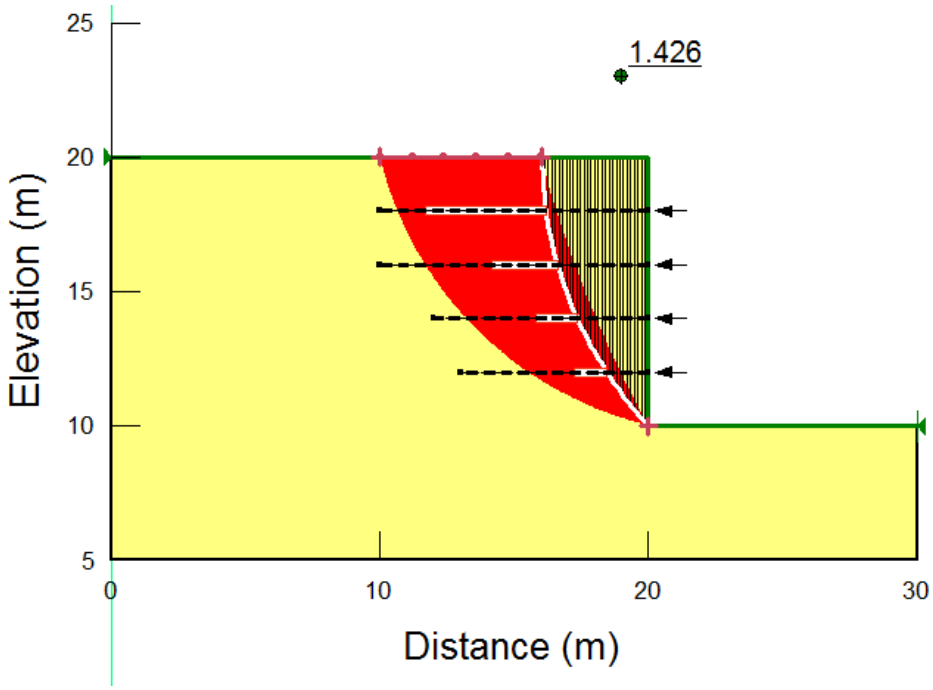

Figure 10 Critical factor of safety and slip surface

6 Case 4 – Load orientation

SLOPE/W has the option to specify the orientation or pullout force. An orientation of 0 applies the pullout force parallel to the orientation of the geosynthetic while an orientation of 1 applies the pullout force parallel to the base of the slice. The Concentrated option must be selected in order to specify the orientation of the pullout force. All other parameters are the same as those for Case 3. The interpretation of the results can be completed following the aforementioned procedure.