Reinforcement with Fabrics

1 Introduction

The purpose of this illustrative example is to show how fabrics can be used to improve the stability of a slope. Features of this simulation include:

- Analysis method: Morgenstern-Price
- Homogenous soil with Mohr Coulomb soil model
- A dry slope with no pore-water pressure
- Four horizontal fabrics
- Entry and Exit slip surface option

2 Configuration and setup

A dry homogeneous material is used in this example. The unit weight of the material is chosen to be 20 kN /m^3. A Mohr Coulomb soil strength model with zero cohesion and a frictional angle of 30^o is assumed. The trial slip surfaces are modeled with the Entry and Exit slip surface option. Since all surfaces are assumed to exit at the toe of the slope, the exit zone is modeled with a single point. The geometry and material properties are shown in Figure 1.

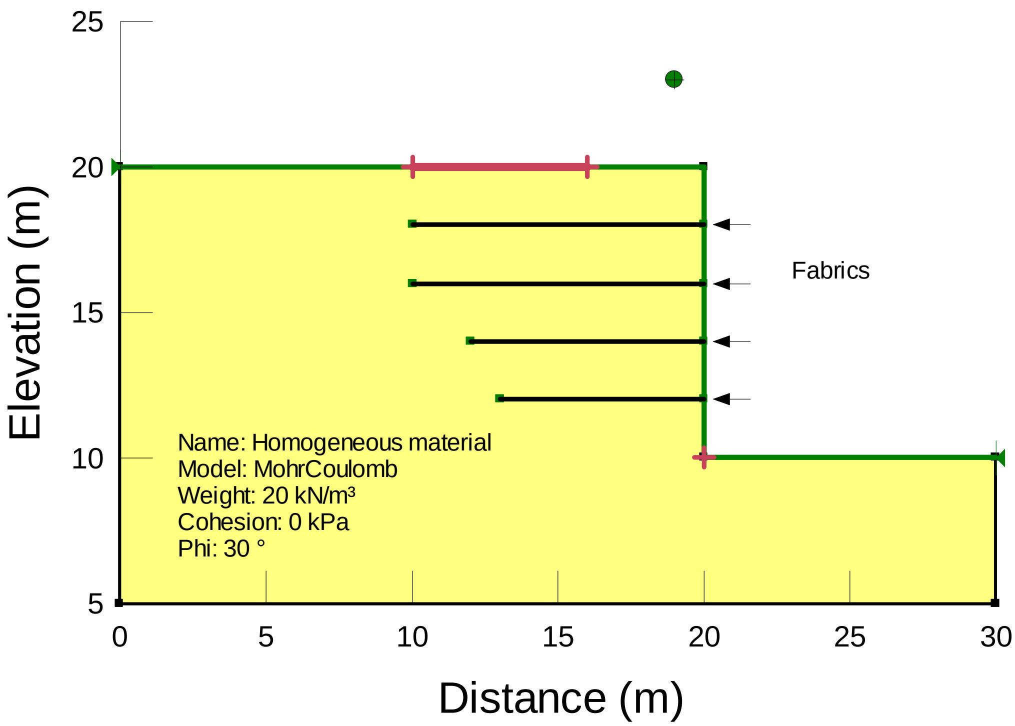

Figure 1 Geometry and material properties

The factor of safety of this vertical slope without the reinforcement is much lower than 1.0. By adding four fabrics to the slope, the factor of safety is much improved. Four cases are modeled in this example to illustrate the various SLOPE/W options in fabric reinforcements. In all four cases, the reinforcement load is assumed to distribute evenly along the fabrics.

3 Case 1 – FOS Dependent - No

Figure 2 shows the detail specification of the four fabrics. The specified bond skin friction is 75 kPa with a bond safety factor of 1.5. Therefore, the applied bond resistance is 50 kPa (i.e., 75kPa/1.5). Similarly, the specified fabric capacity is 180 kPa with a fabric safety factor of 1.5. Therefore, the maximum applied fabric load is 120 kN. The applied fabric load depends on the fabric length.

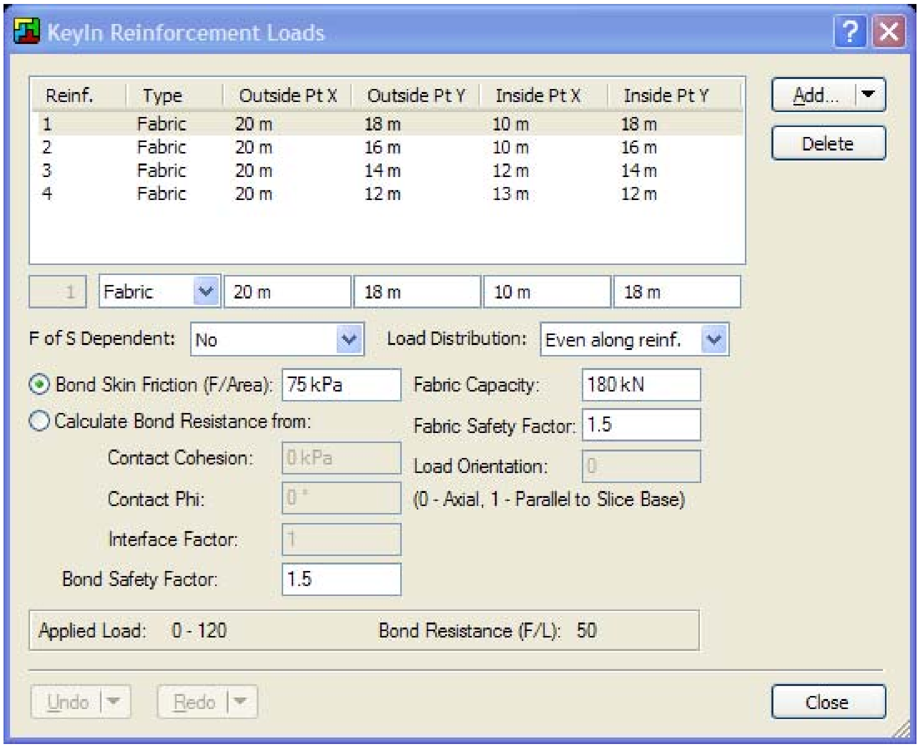

Figure 2 Detail specification of fabric reinforcement

Figure 3 shows the critical factor of safety and slip surface of the slope with the fabric reinforcement. The critical factor of safety is 1.417. The red box drawn on the fabric is inside the length of the fabric, indicating that the fabric is long enough. The maximum loading can be governed by the fabric material capacity or the bond resistance. In general, if the fabric is very strong, it is likely that the governing component is the bond, but if the bond resistance is high and the fabric is long, then the governing component can be the fabric. As shown in Figure 3, the fabric is drawn with a dashed line, indicating that the governing component is the fabric in this case.

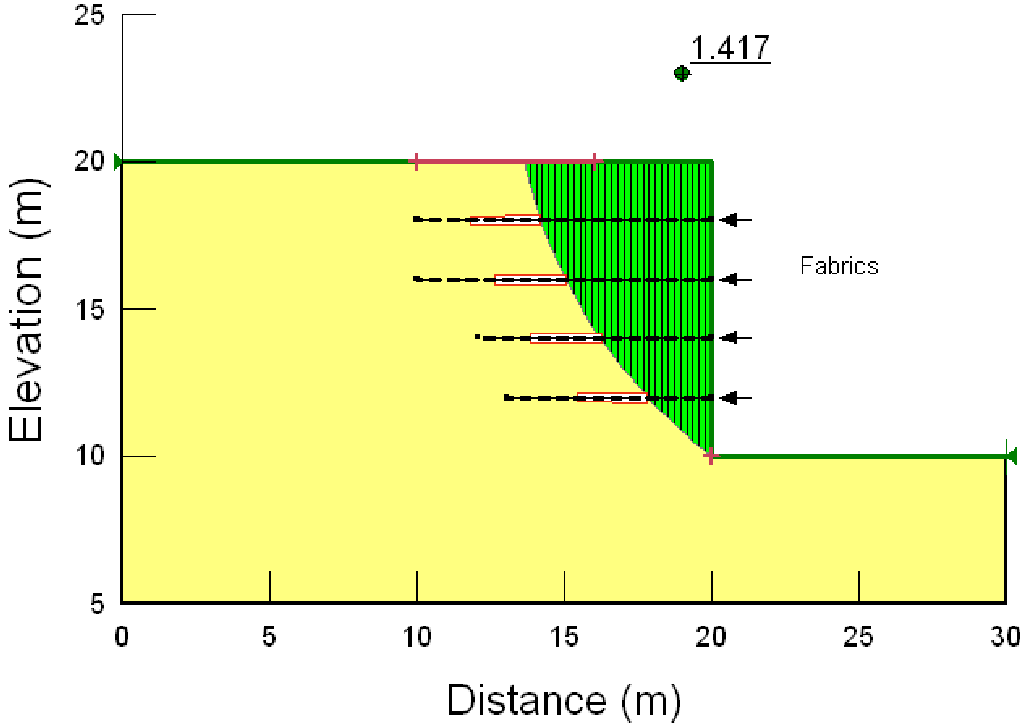

Figure 3 Critical factor of safety and slip surface

Let’s examine the detail result of the top fabric using the view object information in CONTOUR (Figure 4). The applied load option is always “variable” in a fabric. This means that the actual fabric load used in the factor of safety computation depends on the length of the fabric. “F of S Dependent – No” means that the actual fabric force is not be dependent on the computed factor of safety. The available bond length (i.e., length of fabric behind the slip surface) is 4.1911 m; therefore the maximum allowable fabric load is 209.55 kN (50kN/m x 4.1911m). However, because the maximum fabric load is 120 kN, the fabric load governs. The required bond length is 2.4 m, which is equal to 120kN divided by the bond resisting force.

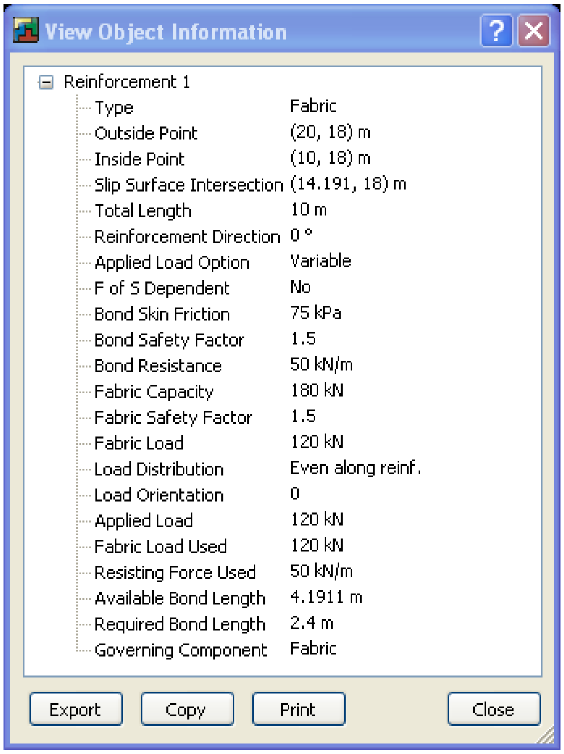

Figure 4 Detail result of the top fabric

It is important to check the fabric load used in the factor of safety calculation with the View Slice Information feature. The free body diagram and force polygon for Slice 3 is shown in **Error! Reference source not found.**. The fabric load is shown to be 4.2857 kN, since the top fabric intersects 28 slices, the total load is 4.2857 x 28 = 120 kN, which is the fabric load used in the factor of safety calculation.

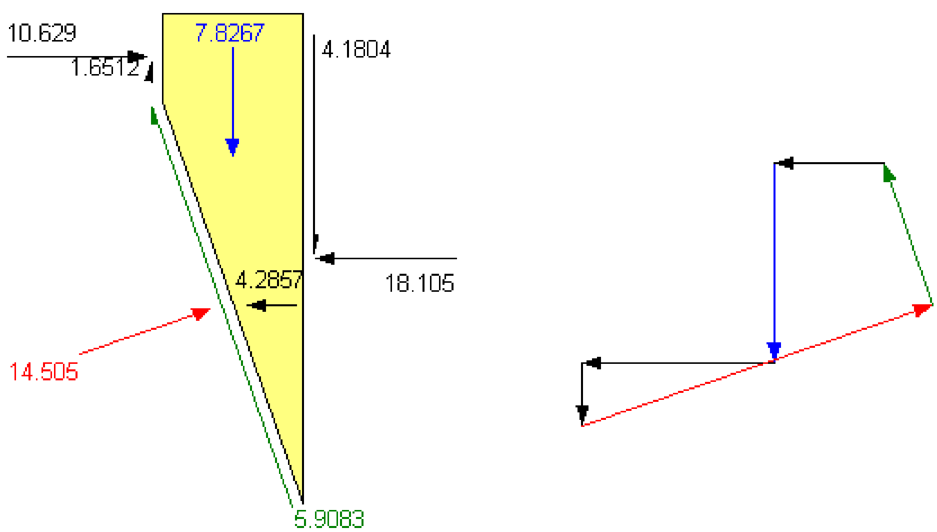

Figure 5 Free body diagram and force polygon of slice 3

4 Case 2 – FOS Dependent - Yes

Since a geofabric is seldom pre-stressed or tensioned, as in the case of an anchor, the applied load may not be there and must be developed with the strain of the slope. As a result, the geofabric loading can be considered as an addition to the resisting force, and it is mobilized in the same manner as the soil strength. In SLOPE/W, this is the “F of S Dependent” option, if you select “Yes” to the option, the applied reinforcement load is actually the mobilized reinforcement load and is depending on the computed factor of safety in the same manner as the mobilized shear resistance of the soil. Figure 6 shows the new result when “F of S Dependent” option is “Yes”. The factor of safety is now 1.419.

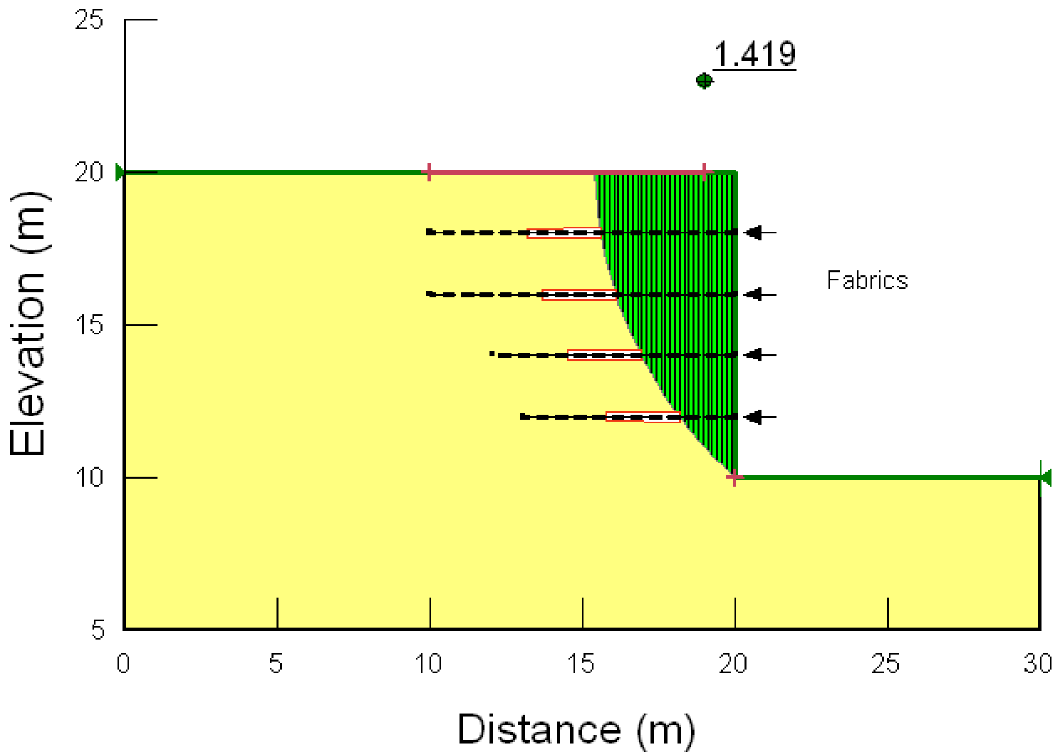

Figure 6 Critical factor of safety and slip surface with a length upper anchor

Figure 7 is a safety map showing the zone of the slip surface that generates a factor of safety between 1.419 and 1.469. Note a large zone of slip surfaces that will generate factor of safety within 0.05 of the critical slip surface. This explains why the factor of safety is very close to the case when the “F of S Dependent” option is No, but the critical slip surface is quite different.

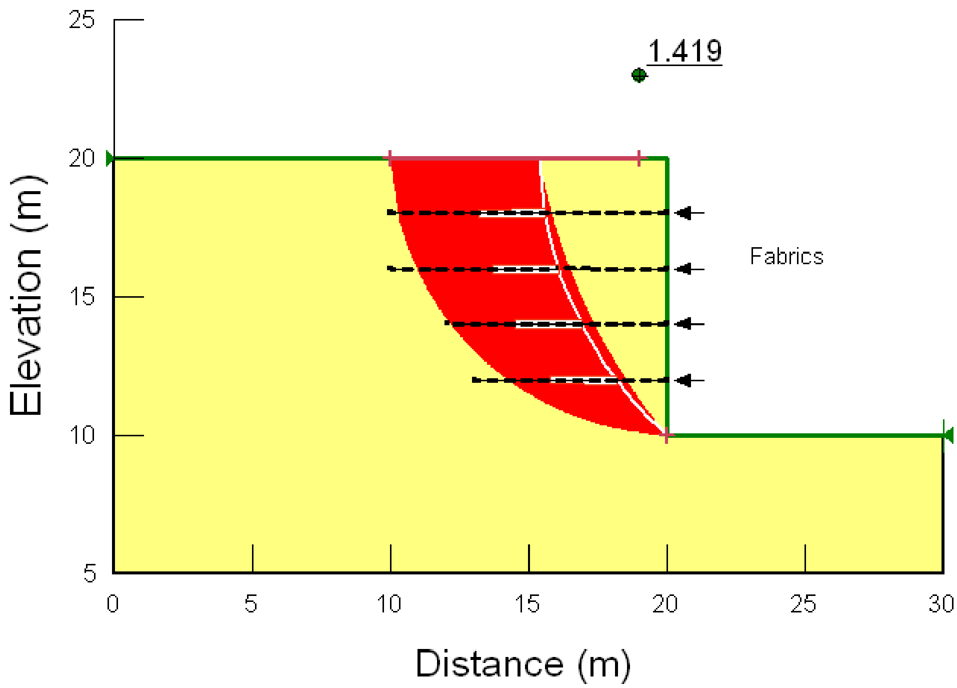

Figure 7 Safety map showing zone of slip surface generating factor of safety from 1.417 to 1.422

One important point to bear in mind is that if the "F of S Dependent" option is Yes, you should specify the bond safety factor and the fabric safety factor as 1.0, so that the same factor of safety of the overall slope is also used for the fabric.

From the free body diagram of Slice 2 (Figure 8), the reinforcement load used in the factor of safety calculation for the top fabric is 4.3701 kN. Since the fabric intersects 29 slices, the total fabric load used is 126.8 kN, which is the mobilized fabric load computed from the fabric load capability divided by the factor of safety (i.e., 180 kN/1.419 = 126.8 kN). The dashed line used in painting the fabric indicates that the fabric load is governed by the fabric capacity.

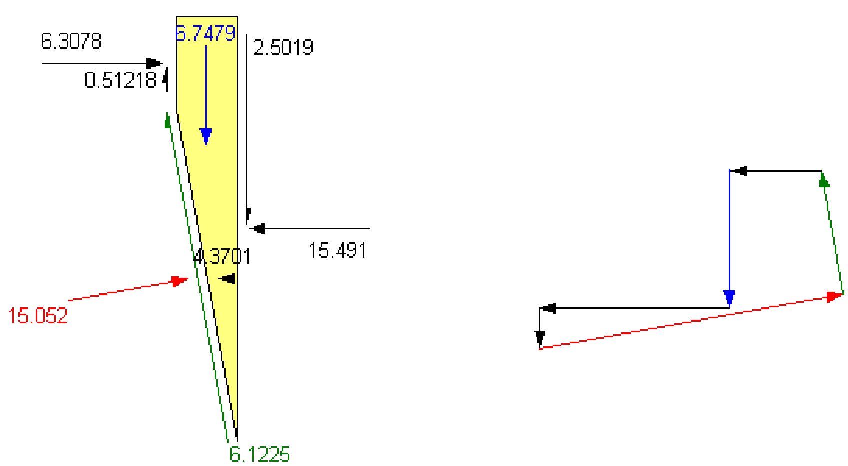

Figure 8 Free body diagram and force polygon of slice 2

5 Case 3 – Bond is Fn (overburden)

Figure 9 shows the detail specification of the four fabrics when the bond resistance is a function of the overburden. Note that the contact cohesion is assumed to be zero, but the contact Phi is assumed to be 30^o. The specified fabric capacity is 180 kPa with a fabric safety factor of 1.0. Therefore, the maximum applied fabric load is 180 kN. The applied fabric load is depending on the fabric length.

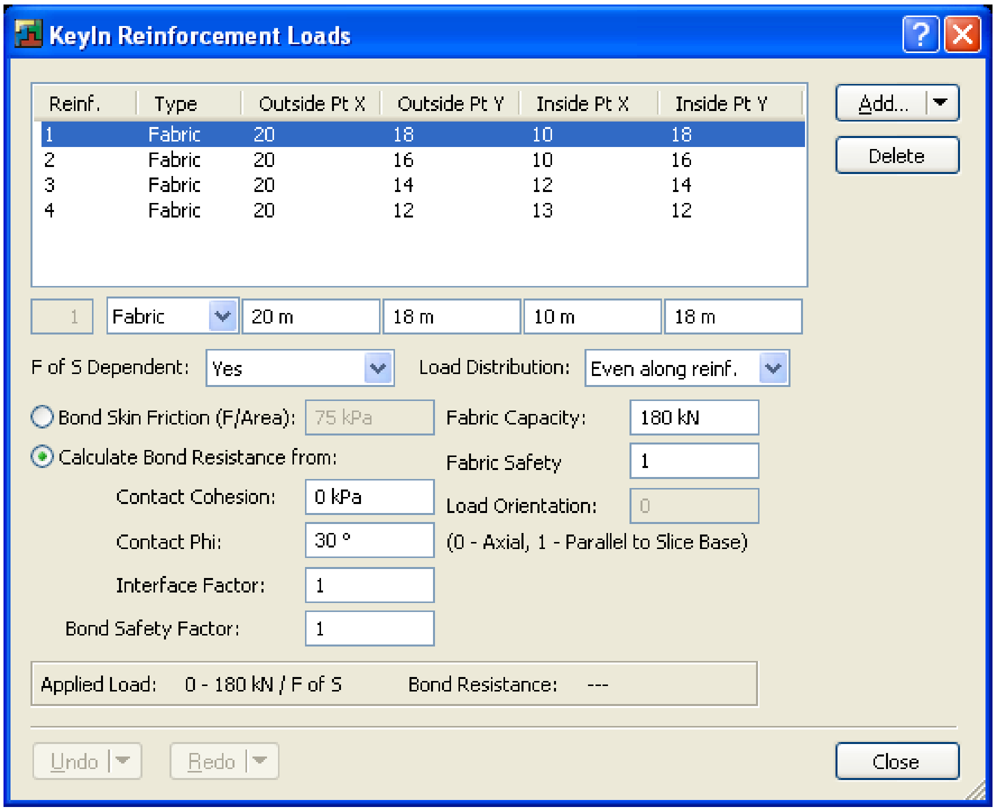

Figure 9 Detail specification of fabric reinforcement

Figure 10 shows the critical slip surface and factor of safety. The critical factor of safety is 1.295. The top fabric is inside the sliding mass and there no fabric load is used for the top fabric. The middle two fabrics have a small available bond length, and therefore, a small applied fabric load. The bottom fabric has higher bond resistance and a longer available bond length. As a result, the fabric load of the bottom fabric is governed by the fabric capacity, while the top three fabrics are governed by the bond resistance.

Figure 11 is the free body diagram and force polygon of Slice 21, which contains the bottom fabric. Note that the fabric force of 16.683 kN includes the contribution from the top three fabrics. The actual force due to the bottom fabric is (16.683 kN – 2.7609 kN) = 13.922 kN. For a total of 10 slices containing the bottom fabric, the applied fabric load of the bottom fabric is about 139.22 kN. Note that if you use the View Object Information of the bottom fabric in CONTOUR, you will see that fabric load used is 139.22 kN.

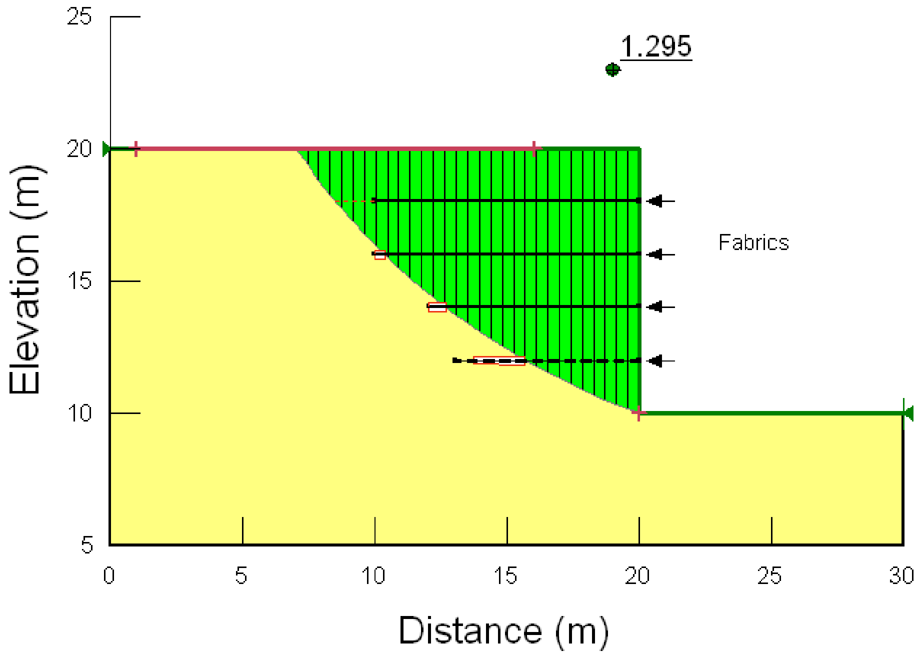

Figure 10 Critical factor of safety and slip surface

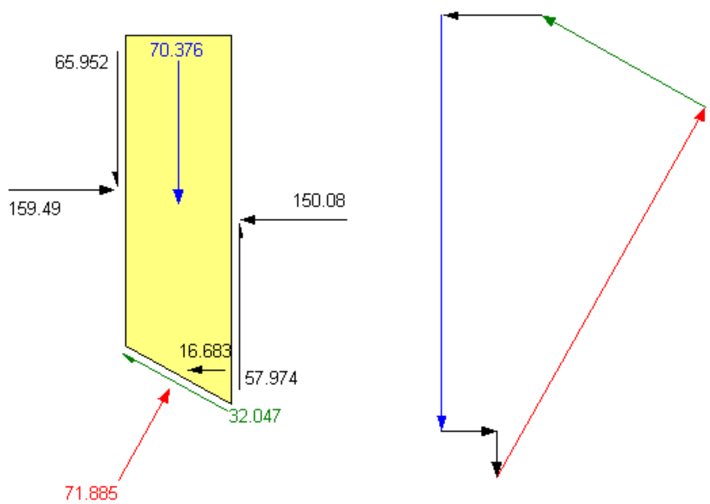

Figure 11 Free body diagram and force polygon of Slice 21

6 Case 4 – Force parallel to base

The location of where the fabric load should be applied has a small effect on the factor of safety. SLOPE/W gives the following two options of where to apply the fabric loads:

1) fabric load concentrates at the base of a slice (the slice that contains the intersecting point between the fabric and the slip surface).

2) fabric load distributes evenly along the length of the fabric.

In this case, the fabric load is assumed to be a concentrated load applied to the base of the slice. Also, SLOPE/W gives you the option to specify the orientation or application direction of the fabric load. A load orientation of 0 controls the fabric load to be applied in the same direction as the fabric and a load orientation of 1 controls the fabric load to be applied parallel to the slice base.

In this case, the orientation of the fabric load is assumed to be parallel to the base. Figure 12 shows the critical slip surface and factor of safety. The factor of safety is 1.270. Figure 13 shows the free body diagram and force polygon of Slice 24. Note that the fabric load of 141.92 kN is acting parallel to the base of the slice. The 141.92 kN is equal to the applied fabric load divided by the factor of safety (i.e., 180 kN/1.270).

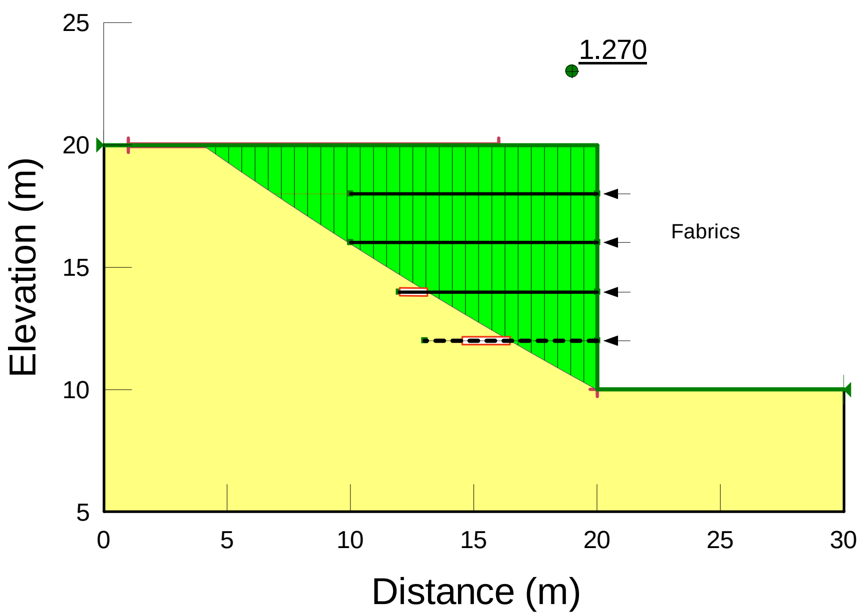

Figure 12 Critical factor of safety and slip surface

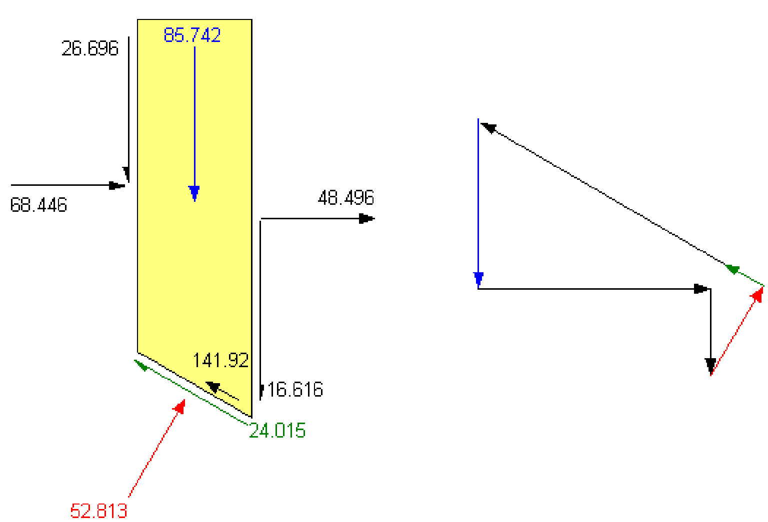

Figure 13 Free body diagram and force polygon of Slice 24