Reinforcement with Anchors

1 Introduction

The purpose of this illustrative example is to show how anchors 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
- Two sloping anchors
- 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 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.

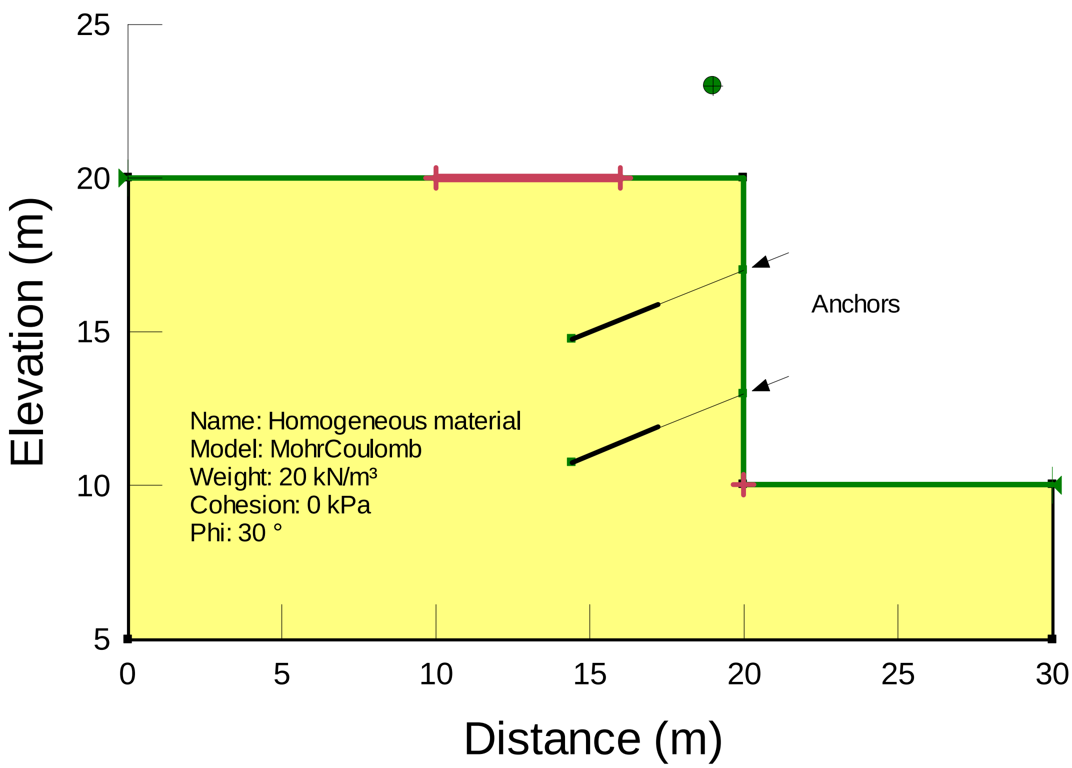

Figure 1 Geometry and material properties

The factor of safety of this vertical slope without the reinforcement is much lower than 1.0. By adding two anchors with a working load of 300 kN each, the factor of safety is much improved. To begin, the anchors are specified with a constant load option; when the critical slip surface is obtained, the anchors are also specified with a variable load option.

3 Case 1 – Constant load

With this constant option, the specified anchor loading is used, regardless of the length of the anchor. This option is useful when trying to determine the critical slip surface of the slope. Figure 2 shows the critical factor of safety and slip surface of the slope when the anchor loading is specified to be constant.

As shown in Figure 2, the critical factor of safety is 1.257. The red box drawn on the lower anchor is inside the length of the anchor indicating that the anchor is long enough. However, for the upper anchor, the red box is drawn outside of the anchor, this indicates that the anchor is too short and needs to be extended beyond the red box.

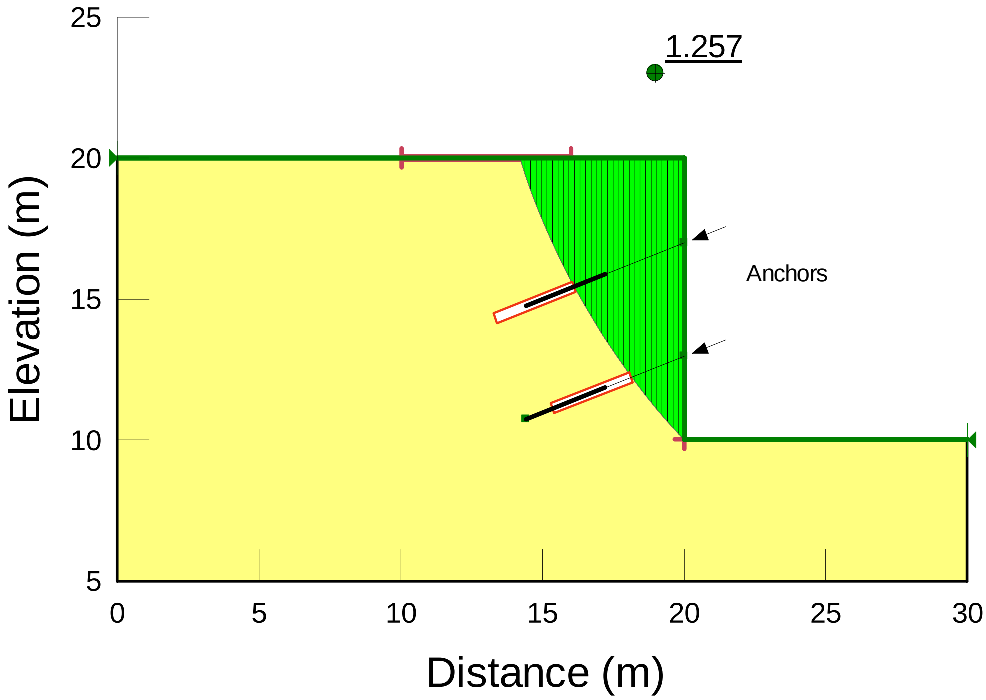

Figure 2 Critical factor of safety and slip surface with constant load

You may check the anchor load used in the factor of safety calculation with the View Slice Information feature. The free body diagram and force polygon for Slice 10 and Slice 21 are shown in Figure 3 and Figure 4.**Error! Reference source not found.** As you can see, the free body diagram correctly shows the specified constant working load of 300 kN for the two anchors.

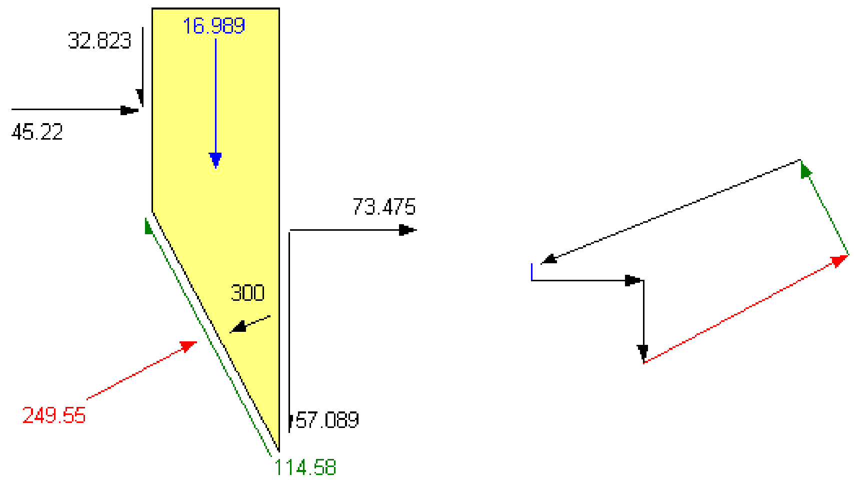

Figure 3 Free body diagram and force polygon of slice 10

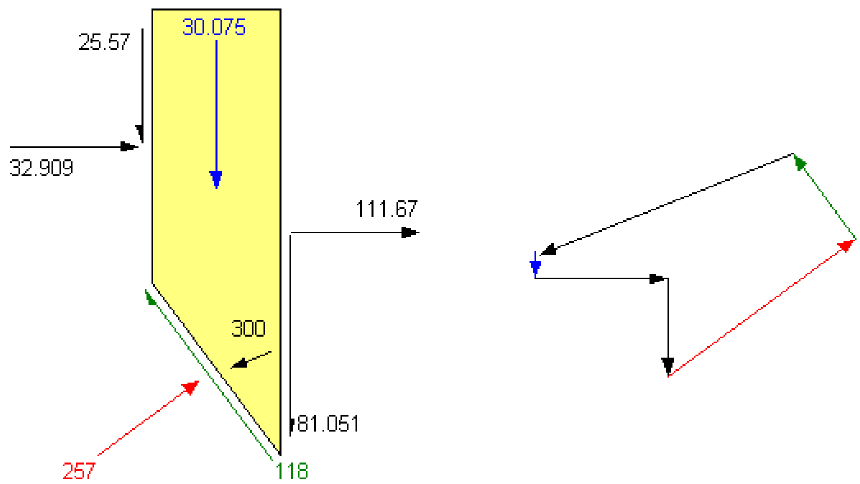

Figure 4 Free body diagram and force polygon of slice 21

Figure 5 shows a graph of the shear resistance along the slip surface. Since the anchors intercept the slip surface at the base of slices 10 and 21, the shear resistance on slices 10 and 21 are much higher due to the anchor loads.

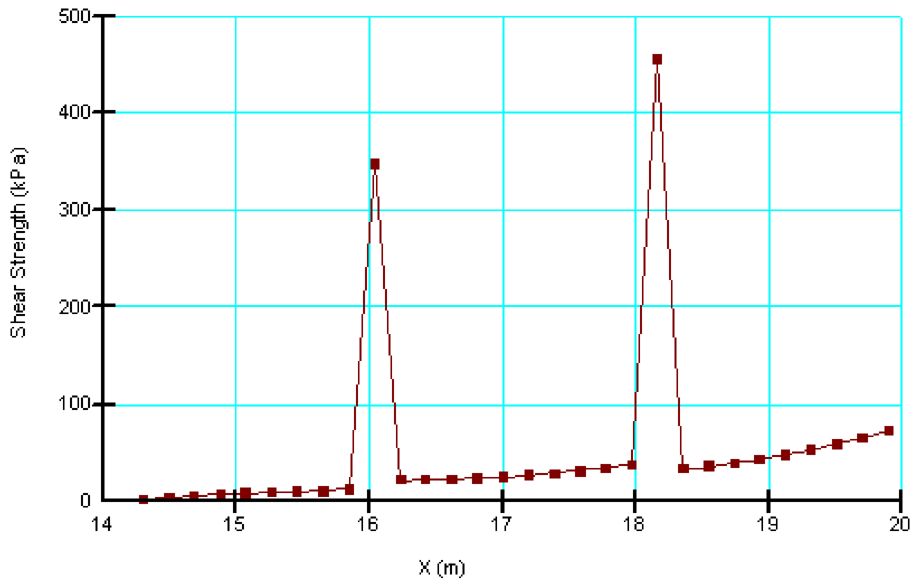

Figure 5 Shear resistance along slip surface

Figure 6 shows the specified parameters of the upper anchor. Note that the specified applied load is 600 kN and the anchor spacing is 2 m. Since SLOPE/W is formulated with a unit width, the working load used in SLOPE/W is 300 kN (i.e., 600 kN divided by the spacing). Also, the bond skin friction is specified to be 300 kPa, and the bond factor of safety is 1,5, therefore, the bond resistance used in SLOPE/W is 100 kN (i.e, 300 kPa divided by bond factor of safety divided by spacing). Furthermore, since the bar capacity is specified as 2000 kN, which is much higher than the applied load, the governing load would be the bond resistance.

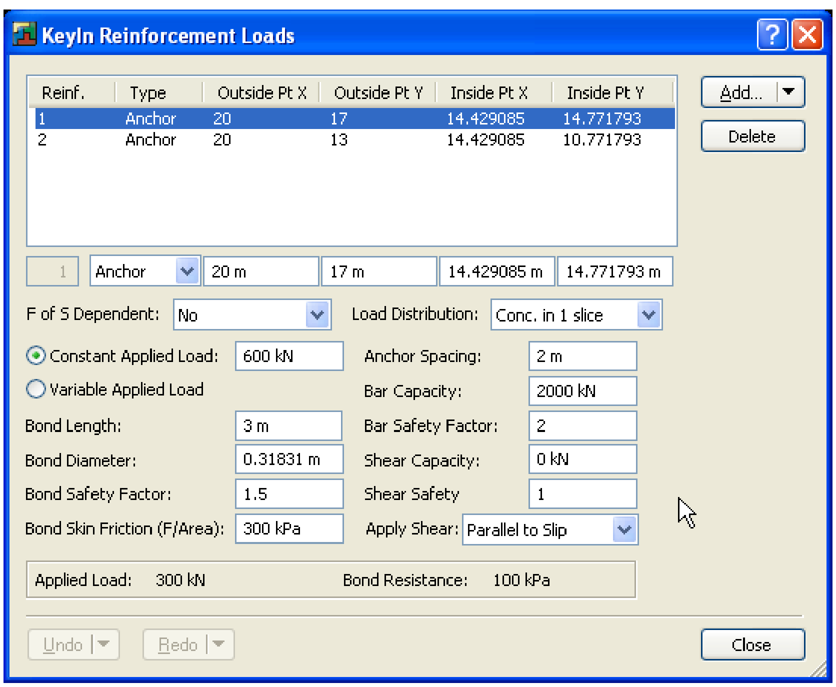

Figure 6 Specified parameters of the upper anchor

You can also examine the detailed result of the anchor design with the View Object Information feature in SLOPE/W CONTOUR. Figure 7 shows the reinforcement details for upper anchor. In this example, a constant applied load option is used, the anchors are assumed to be pre-stressed or tensioned, therefore, the “F of S Dependent” option is set to No. Because of the constant loading condition, the anchor load of 300 kN is used in the factor of safety calculation. The required bond length is 3 m and the governing component is the bond, as anticipated.

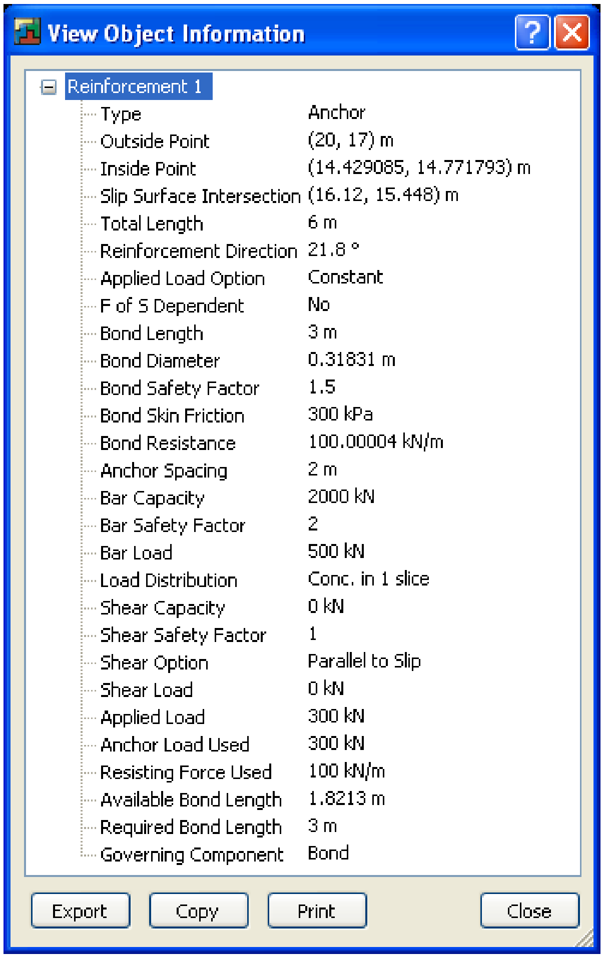

Figure 7 Examine details result of a reinforcement with View Object Information

4 Case 2 – Lengthen the upper anchor

As shown in Figure 2, the upper anchor is too short and needed to be lengthened. In Case 2, the analysis is redone with a longer upper anchor. Figure 8 shows the critical factor of safety and slip surface. Since the working load of the anchor remains constant, there is no change to the solution with factor of safety equals to 1.257. The only difference is that the red box is now drawn inside the anchors, indicating that the anchor is long enough.

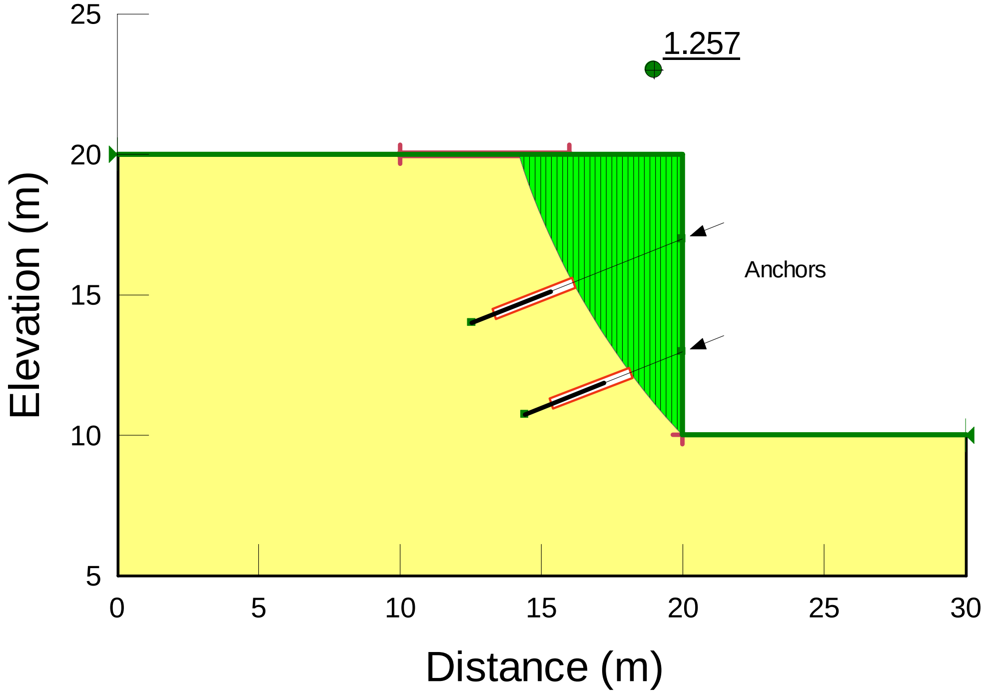

Figure 8 Critical factor of safety and slip surface with a length upper anchor

5 Case 3 – Variable load

Figure 9 shows the critical slip surface and factor of safety of the case when the variable option is used for the working anchor load. With the variable option, the working load used by SLOPE/W can be a function of the length of the anchor. With a variable option, if the anchor is too short, only a portion of the working load may be used by SLOPE/W. But in this example, after the upper anchor has been lengthened, the anchor is long enough and the entire working load is used in the factor of safety computation. As a result, the identical solution is obtained, as shown is Figure 9.

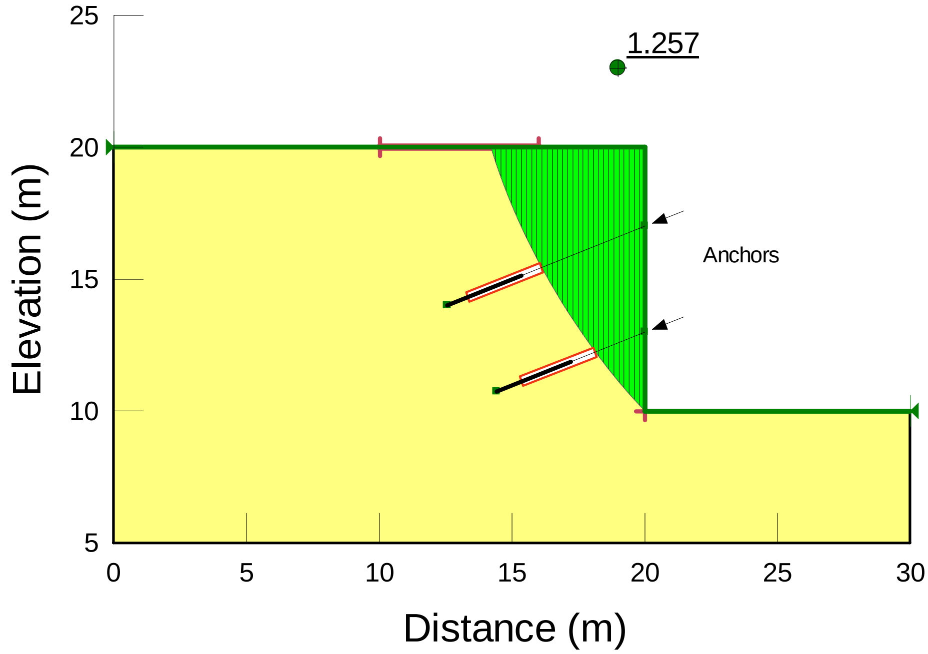

Figure 9 Critical factor of safety and slip surface with variable load

6   Case 4 – Evenly distributed load

The location of where the anchor 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 anchor loads:

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

2) Distribute load evenly along the length of the anchor and apply the anchor load to the center of the slice intersecting the anchor.

In most cases, the option makes an insignificant difference to the final factor of safety. However, in some cases when the anchor load is large relative to the total weight of the sliding mass, a small difference may be observed. Also, in the extreme case when the anchor load is huge and causing convergence difficulty, using the “distribute load evenly” option may resolve the convergence difficulty of the analysis.

Figure 10 shows the critical slip surface and factor of safety of the case when the anchor load is distributed evenly along the anchors. The factor of safety is increased to 1.271. Figure 11 shows a graph of the shear resistance along the slip surface. Note that the shear resistance is more uniform compared with the case with a “concentrate load” option (Figure 5).

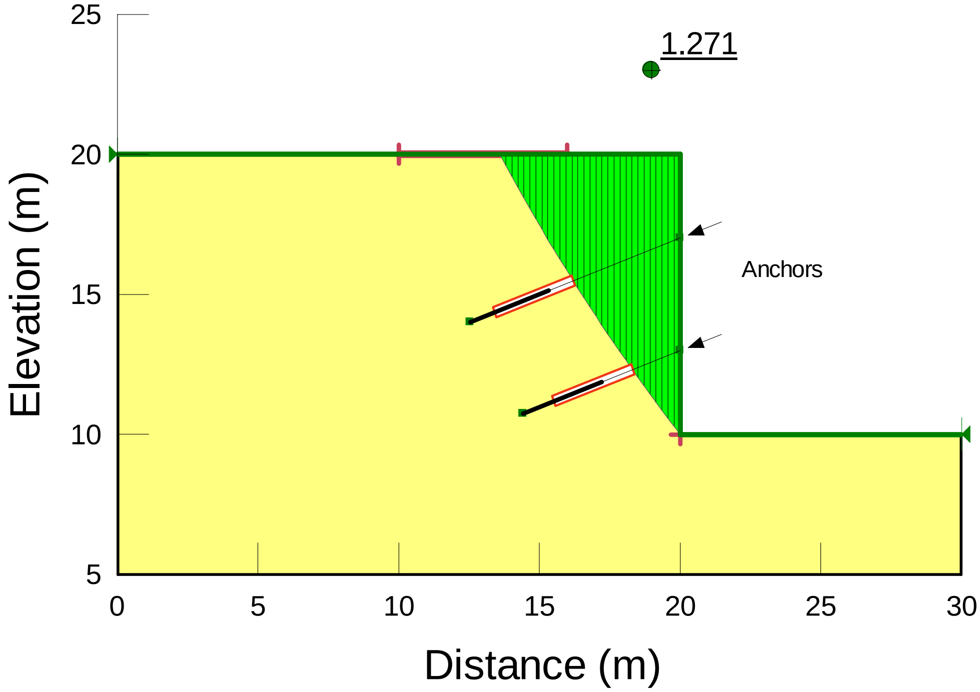

Figure 10 Critical factor of safety and slip surface with uniform distributed anchor load

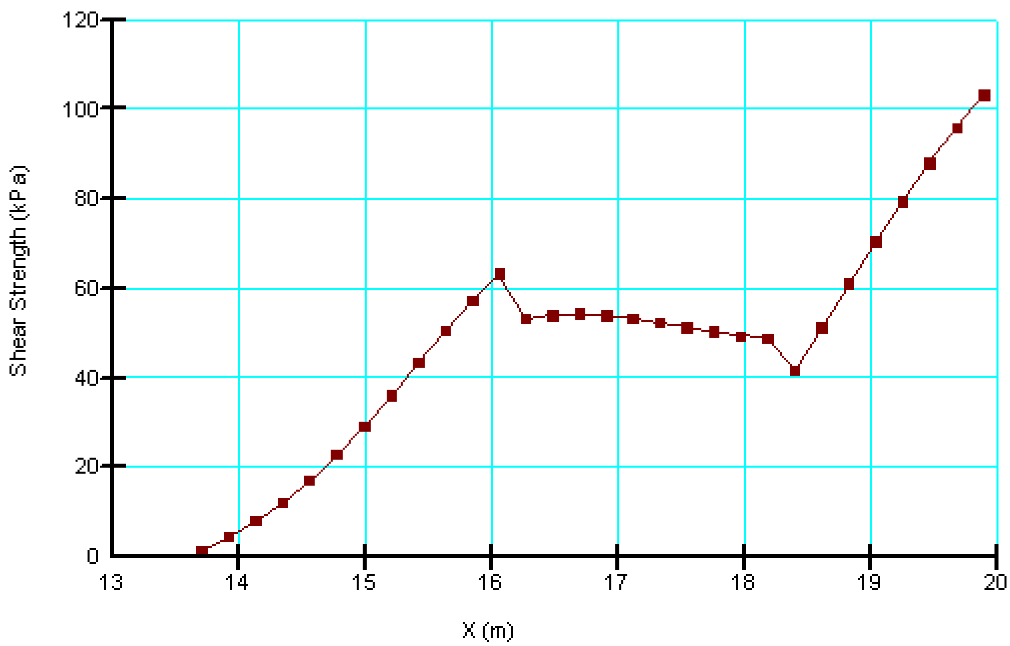

Figure 11 Shear resistance along slip surface

7 Case 5 – With shear load

SLOPE/W allows the simulation of a shear force in the anchor bar. In this case, the bottom anchor is assumed to have a shear force of 50 kN and a shear force factor of safety of 2. In other words, the applied shear force is 25 kN. Using this shear force can increase the final factor of safety. As shown in this case, the factor of safety increases from 1,271 (Figure 10) to 1.362 (Figure 12).

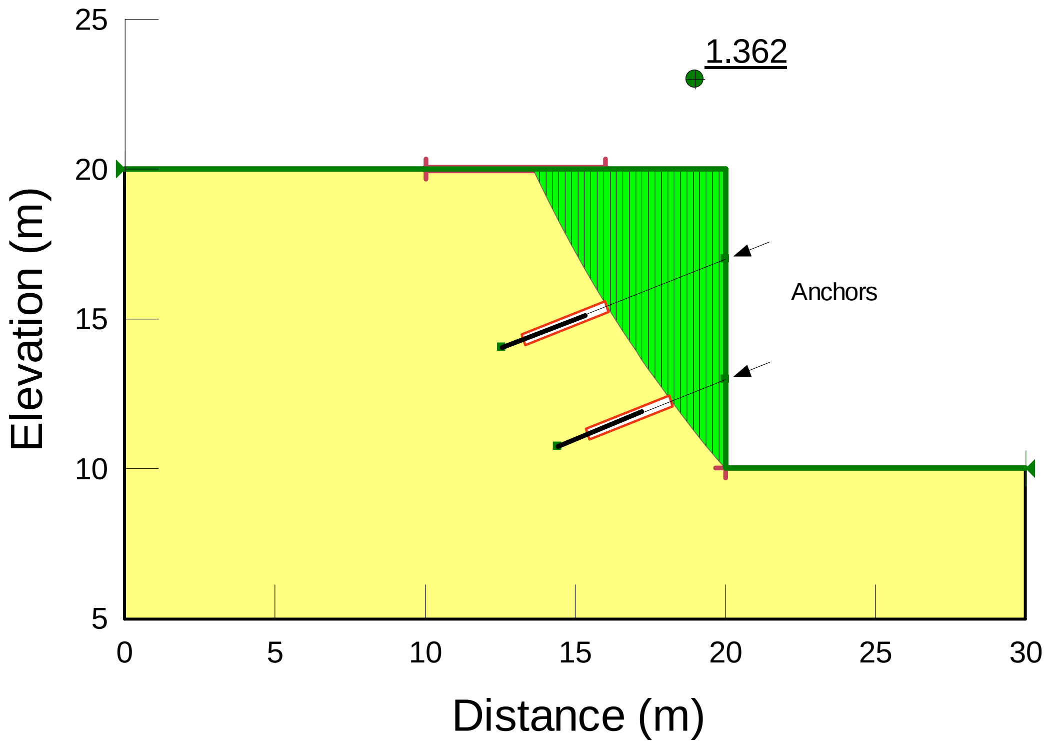

Figure 12 Critical factor of safety and slip surface with anchor shear force

The free body diagram and force polygon for Slice 12 and Slice 22 are shown in Figure 13 and Figure 14. The extra force of 25 kN appearing on the free body diagram of Slice 22 represents the applied shear force. The anchor in Slice 12 is 15.789 kN, which only represents a small portion of the total anchor working force of 300 kN. Since we are using the “distribute evenly” option in this case and the upper anchor intersects 19 slices, you can calculate the total anchor load to be 300 kN (19 x 15.789 kN = 300 kN). Similarly, from the free body diagram of Slice 22, the anchor load is 49.123 kN. Note that this 49.123 kN includes the anchor load from the upper anchor. Since the lower anchor intersect 9 slices, you can calculate the total anchor load to be 300 kN (9 x (49.123 - 15.789) kN = 300 kN). Therefore, you must be careful when examining the anchor load at the base of a slice when the “distribute load evenly” option is used.

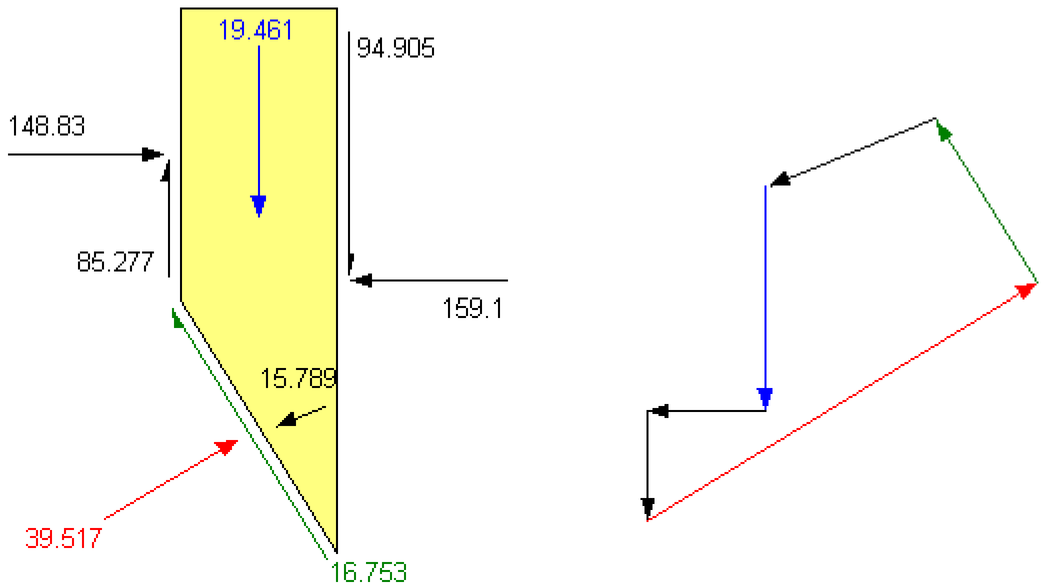

Figure 13 Free body diagram and force polygon of slice 12

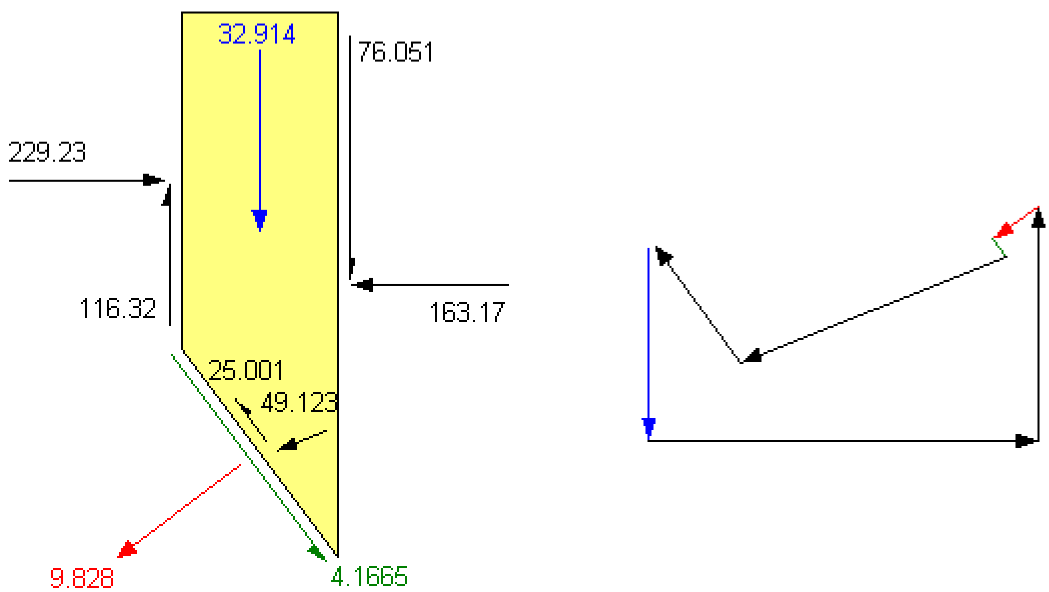

Figure 14 Free body diagram and force polygon of slice 22