Reinforcement with Nails

1 Introduction

The purpose of this illustrative example is to show how soil nails 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 sloping soil nails
- 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.

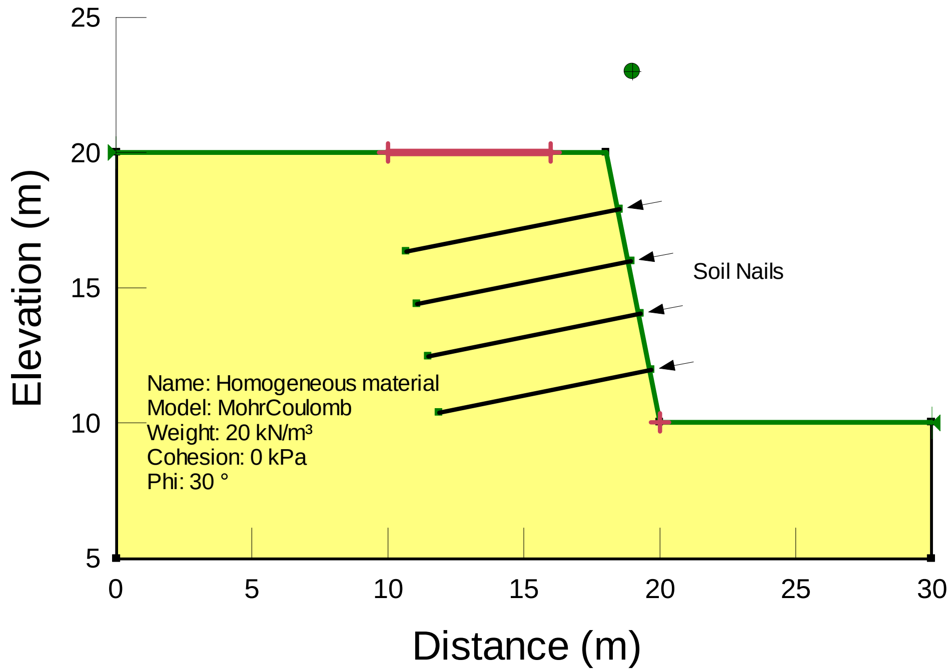

Figure 1 Geometry and material properties

The factor of safety of the slope without the reinforcement is much lower than 1.0. By adding four soil nails to the slope, the factor of safety is much improved. Three cases are modeled in this example to illustrate the various SLOPE/W options in nail reinforcements.

3 Case 1 – FOS Dependent - No

Figure 2 shows the detail specification of the four nails. The nail spacing is 2 m, the specified bond skin friction is 100 kPa with a bond safety factor of 1.5. Therefore, the applied bond resistance is 33.333 kPa (i.e., 100 kPa/1.5/2). Similarly, the specified bar capacity is 300 kPa with a bar safety factor of 1.5. Therefore, the maximum applied load is 100 kN (i.e., 300 kPa/1.5/2). The actual applied load used in the factor of safety calculation is depending on the nail length.

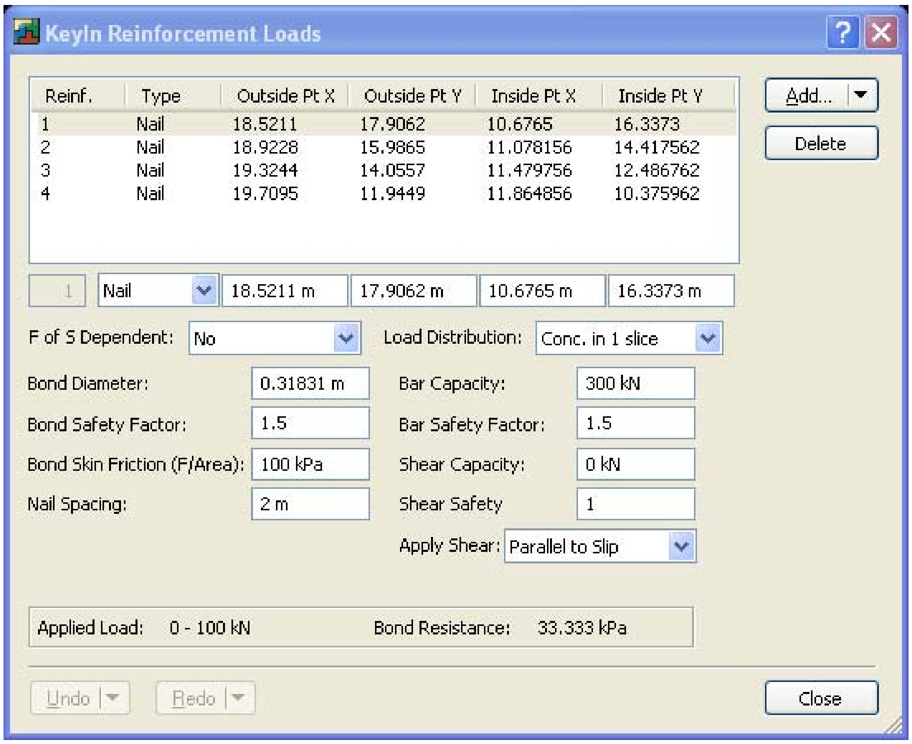

Figure 2 Detail specification of nail reinforcement

Figure 3 shows the critical factor of safety and slip surface of the slope with the soil nail reinforcement. The critical factor of safety is 1.326. For the top two nails, the available bond length behind the slip surface give a bond resistance force lower than the bar capacity. For the bottom two nails, the red box drawn on the nails are painted inside the length of the nails, indicating that the nails are long enough. The maximum loading can be governed by the nail bar capacity or the bond resistance. In general, if the nail is very strong, it is likely that the governing component is the bond, but if the bond resistance is high and the nail is long, then the governing component can be the nail bar. As shown in Figure 3, the bottom two nails are drawn with a dashed line, indicating that the governing component is the nail bar in this case.

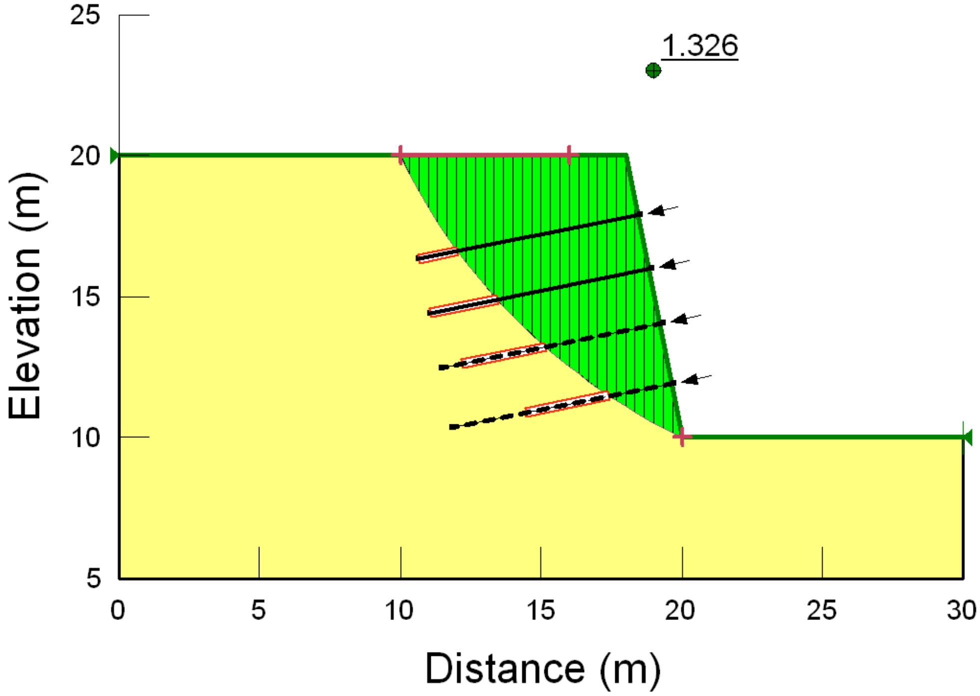

Figure 3 Critical factor of safety and slip surface with constant load

Let’s examine the detail result of the top nail using the view object information in CONTOUR (Figure 4). The applied load option is always “variable” in a nail. This means that the actual fabric load used in the factor of safety computation is depending on the length of the nail. “F of S Dependent – No” means that the actual nail force is not to be dependent on the computed factor of safety. The available bond length (i.e., length of nail behind the slip surface) is 1,3901 m; therefore the maximum allowable nail load is 46.338 kN. However because of the maximum bar load is 100 kN, the bond load governs.

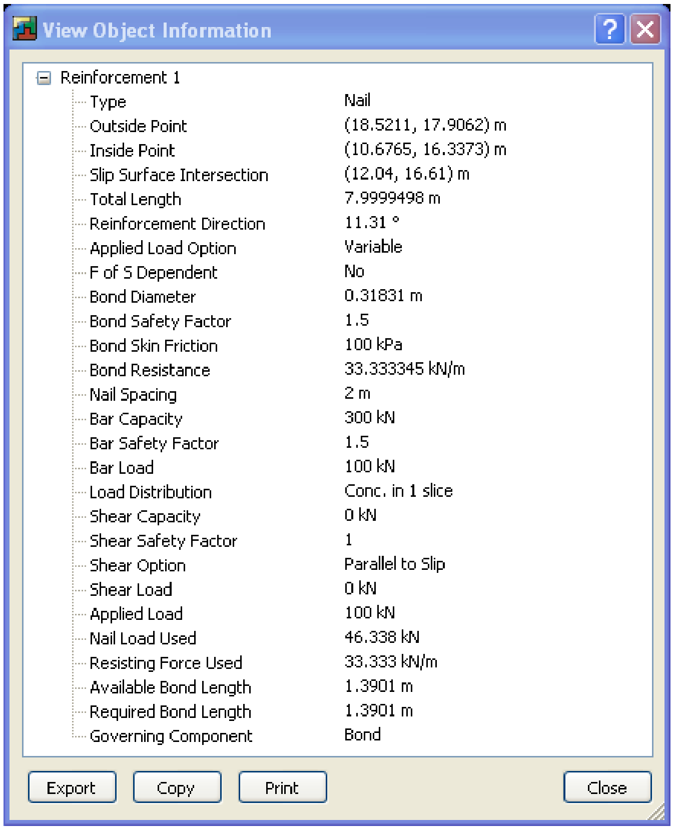

Figure 4 Detail result of the top nail

It is important to check the nail load used in the factor of safety calculation with the View Slice Information feature. The free body diagram and force polygon for Slice 7 is shown in Figure 5. The nail load is shown to be 46.338 kN, which is the same as the load being used (Figure 4).

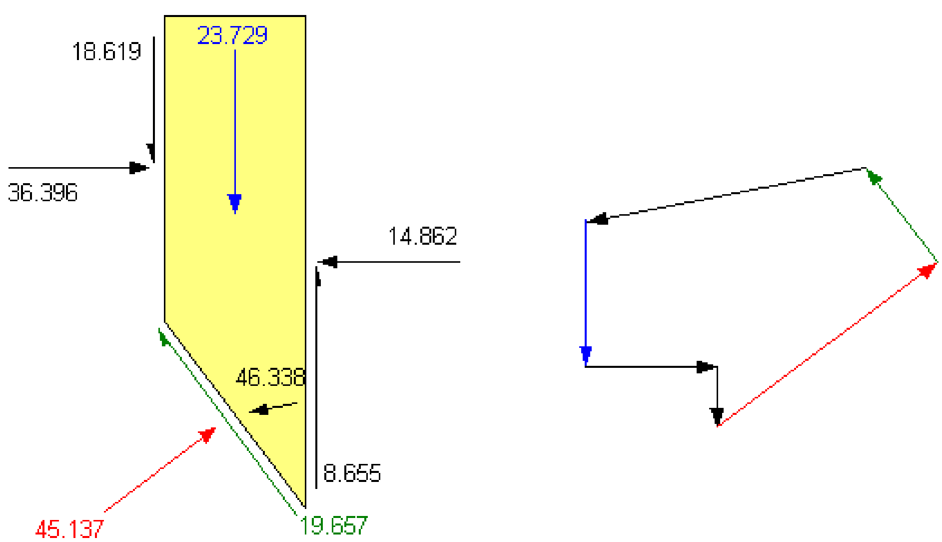

Figure 5 Free body diagram and force polygon of slice 3

4 Case 2 – FOS Dependent - Yes

Since a soil nail 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 nail 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 resistant of the soil. Figure 6 shows the new result when "F of S Dependent" option is "Yes". The factor of safety is now 1.383.

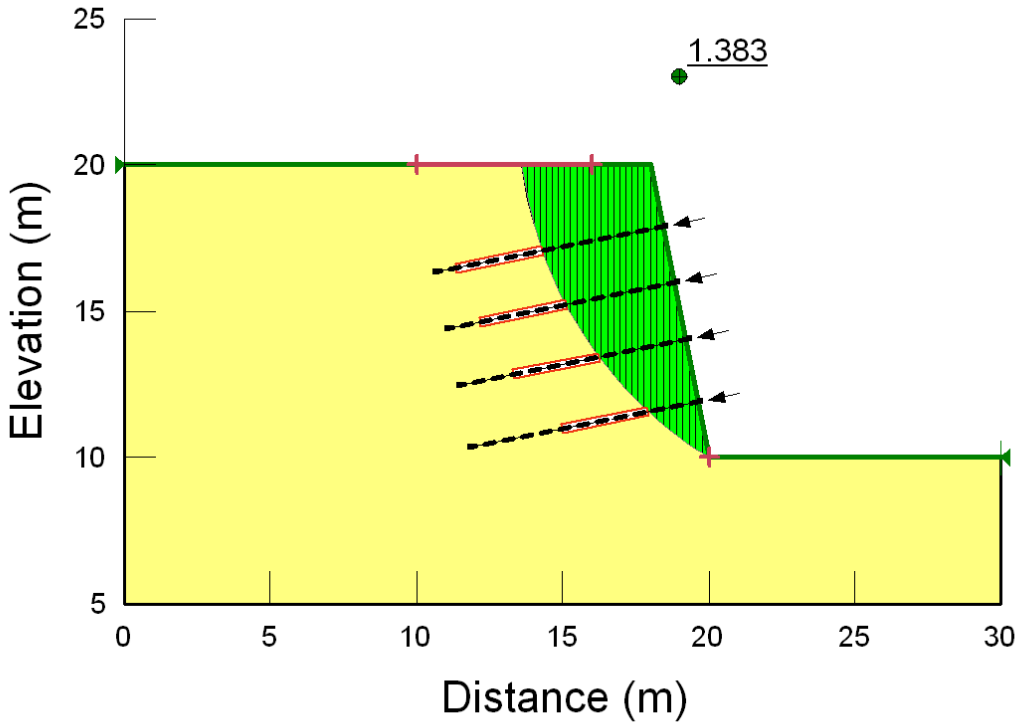

Figure 6 Critical factor of safety and slip surface

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 bar safety factor to 1.0, so that the same factor of safety of the overall slope is also used for the soil nails.

From the free body diagram of Slice 4 (Figure 7), the reinforcement load used in the factor of safety calculation for the top nail is 107.96 kN. This force is the mobilized nail load computed from the nail capability (300 kN/2) divided by the factor of safety (i.e., 300 kN/2/1.383 = 108 kN). The dashed line used in painting the nail indicates that the nail load is governed by the bar capacity.

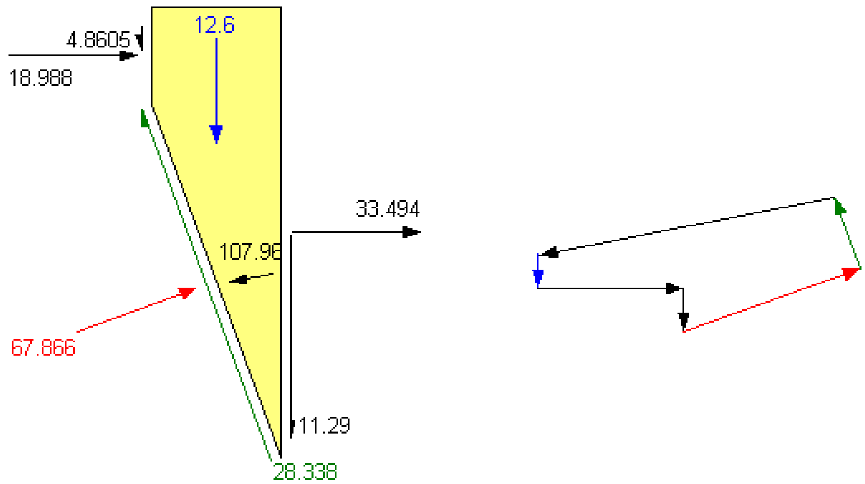

Figure 7 Free body diagram and force polygon of slice 4

5 Case 3 – Distributed nail load

The only difference in between this case and Case 2 is that the applied nail load is assumed to distribute evenly along the soil nails. Figure 8 shows the critical factor of safety and the slip surface. The factor of safety is 1.369.

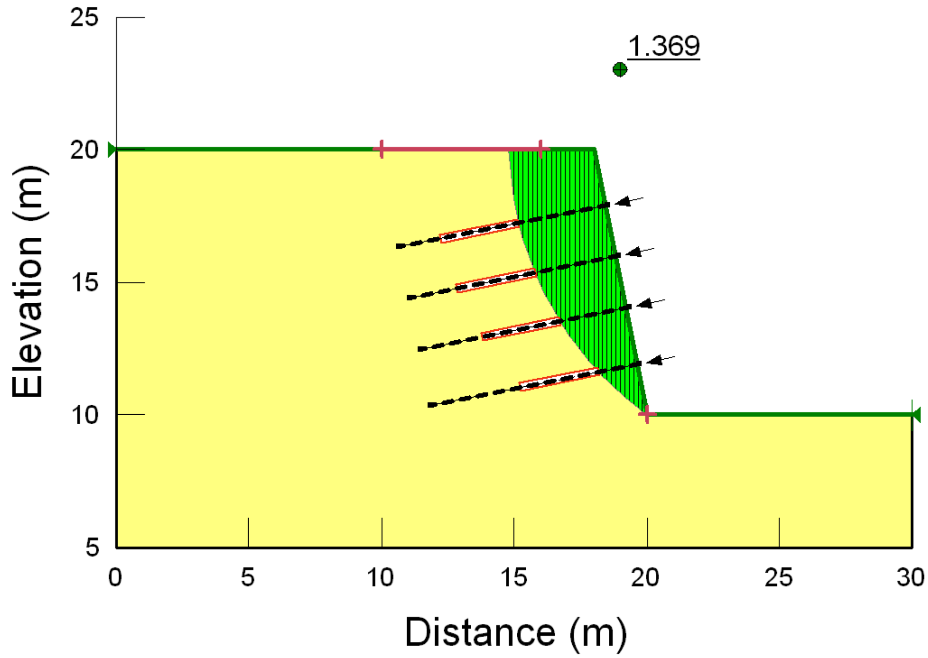

Figure 8 Critical factor of safety and slip surface

From the free body diagram of Slice 3 (Figure 9), the nail load used in the factor of safety calculation for the top nail is 6.0697 kN. Since the nail intersects 18 slices, the total reinforcement load is 109.29 kN (i.e., 6.0697 kN x 18). This force is the mobilized nail load computed from the nail capability (300 kN/2) divided by the factor of safety (i.e., 300 kN/2/1.369 = 109 kN). The dashed line used in painting the nail indicates that the nail load is governed by the bar capacity.

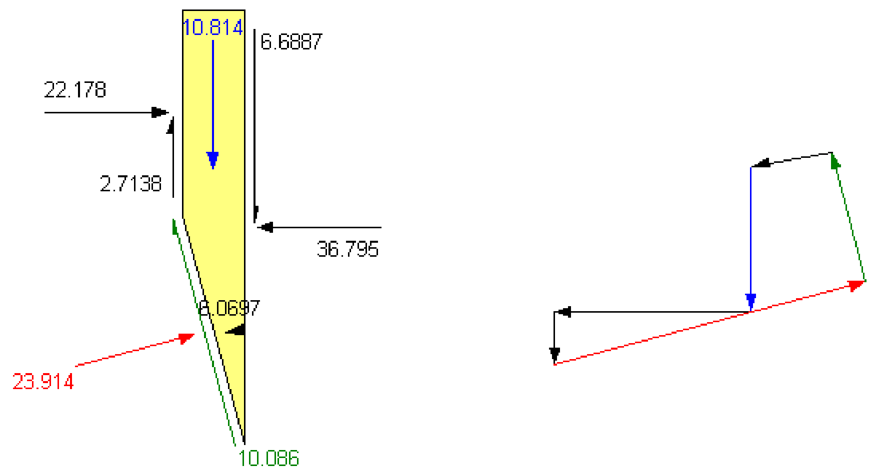

Figure 9 Free body diagram and force polygon of slice 3

Figure 10 shows the free body diagram and the force polygon of Slice 6, which contains the intersecting point of the second soil nail with the slip surface. The nail load is 12.497 kN, as shown on the free body diagram. However, since the Distribute Load Evenly option is used in this case, this nail load includes the top nail load as well. It is important to keep this in mind when checking the reinforcement load used in the factor of safety computation. The actual nail load mobilized from the second nail is 6.427 kN (i.e., 12.497 kN – 6.0697 kN). Since the nail intersects 17 slices, the total reinforcement load is 109 kN (i.e., 6.427 kN x 17). This force is the mobilized nail load computed from the nail capability (300 kN/2) divided by the factor of safety (i.e., 300 kN/2/1.369 = 109 kN). The dashed line used in painting the nail indicates that the nail load is governed by the bar capacity.

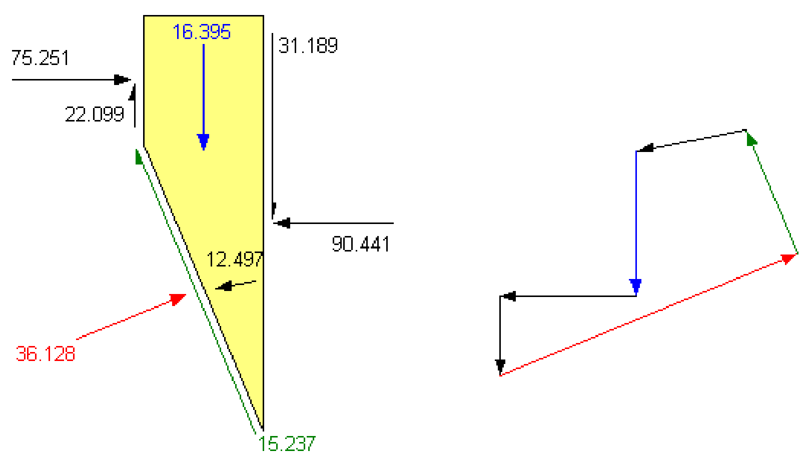

Figure 10 Free body diagram and force polygon of slice 6