

# Reinforcement with Piles

## 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
- One to two vertical piles
- 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<sup>3</sup>. A Mohr Coulomb soil model with a cohesion of 10 kPa and a frictional angle of 30° is used. 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.

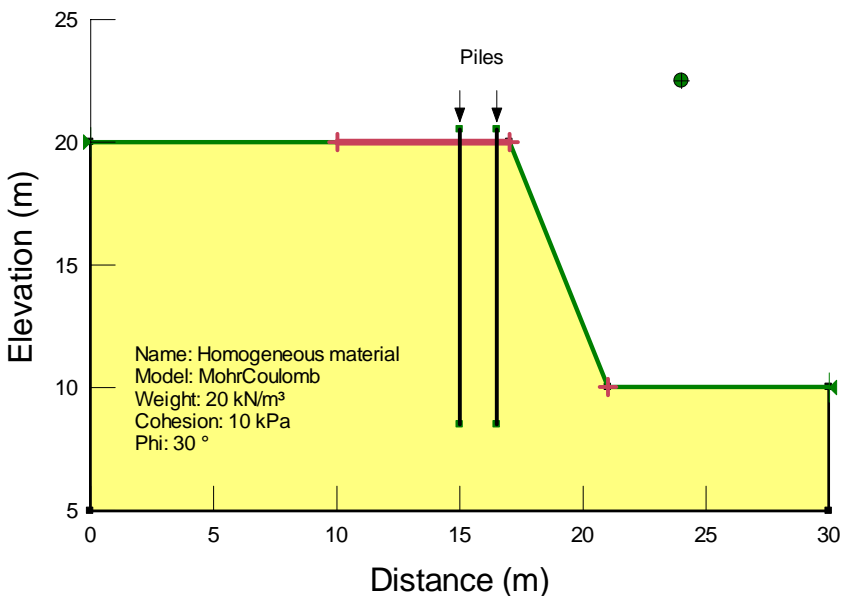


Figure 1 Geometry and material properties

### 3 Case 1 – No Pile

The factor of safety of the slope without any reinforcement is 0.784, as shown in Figure 2. The slope is unstable and therefore needs to be reinforced.

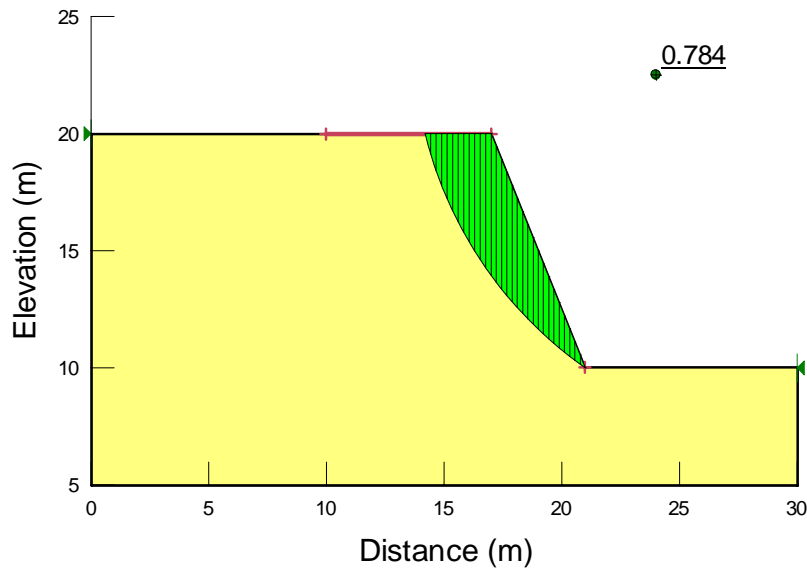


Figure 2 Critical factor of safety and slip surface with no reinforcement

### 4 Case 2 – Single Pile with Shear Parallel to Slip Surface

Figure 3 shows the detail specification of the pile. The pile spacing is 2 m, the specified shear force is 300 kN with a bond safety factor of 1.5. Therefore, the applied shear force from the pile is 100 kN (i.e.,  $300/2/1.5$ ).

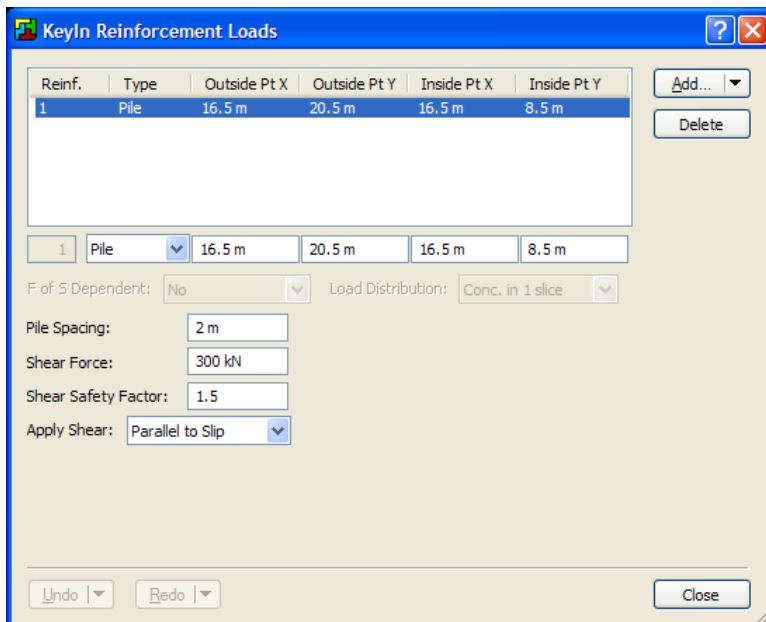
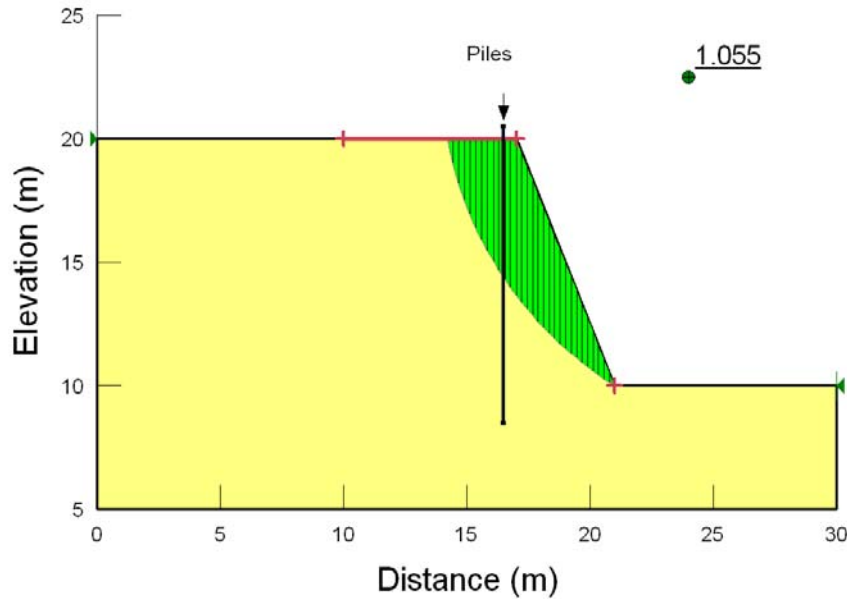


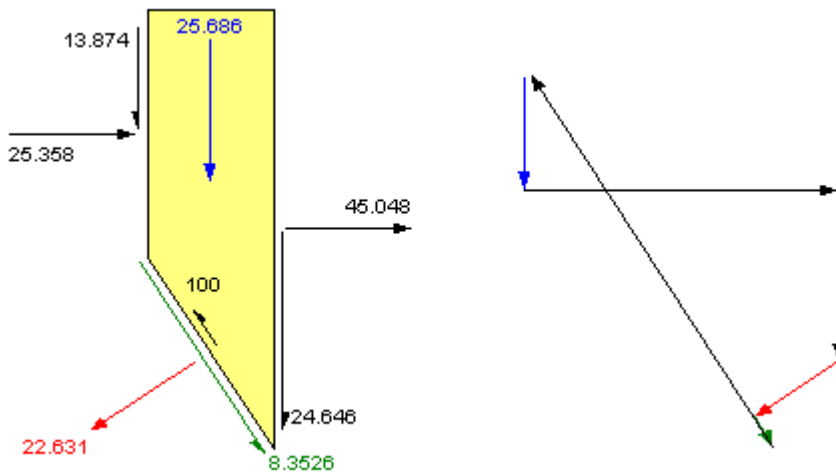
Figure 3 Detail specification of pile reinforcement

Figure 4 shows the critical factor of safety and slip surface of the slope with single pile reinforcement. The critical factor of safety is 1.055.



**Figure 4 Critical factor of safety and slip surface with single pile**

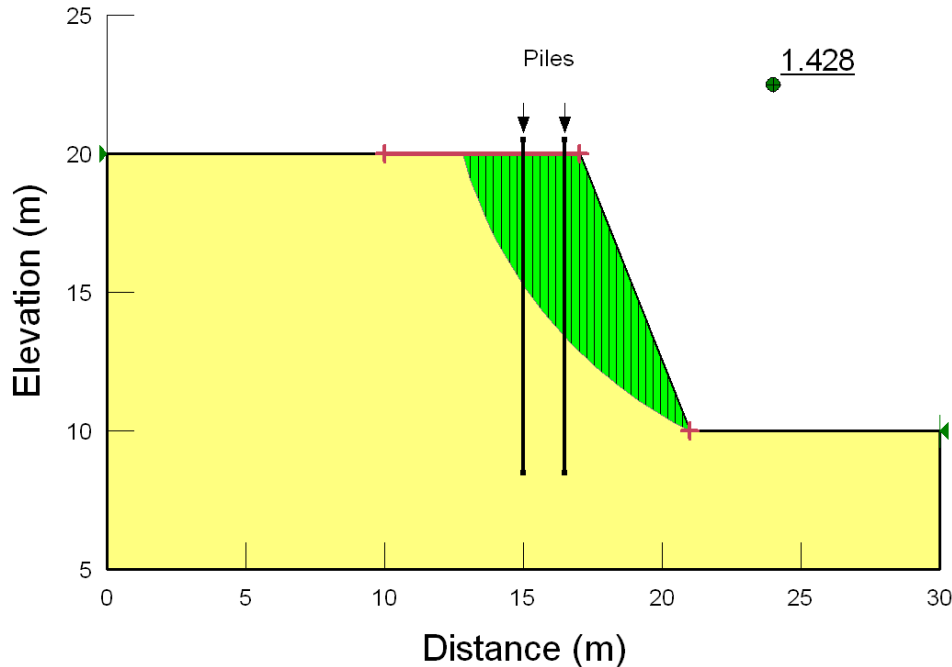
Figure 5 shows the free body diagram and force polygon for Slice 10. The pile shear force is shown to be 100 kN acting parallel to the slice base, which is the same as the specified loading condition (Figure 4).



**Figure 5 Free body diagram and force polygon of slice 10**

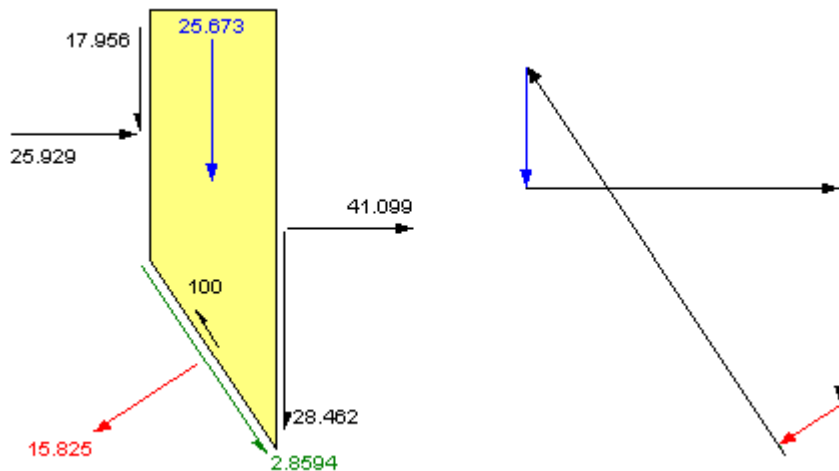
## 5 Case 3 – Two Piles with Shear Parallel to Slip Surface

Figure 6 shows the critical factor of safety and slip surface of the slope with two piles. The critical factor of safety is now improved to 1.428.



**Figure 6 Critical factor of safety and slip surface with two piles**

From the free body diagram of Slice 8 (Figure 8Figure 7), the pile shear force used in the factor of safety calculation is 100 kN. Note that the direction of the applied shear force is parallel to the base of the slip surface as specified.



**Figure 7 Free body diagram and force polygon of slice 8**

## 6 Case 4 – Two Piles with Shear Perpendicular to the Reinforcement

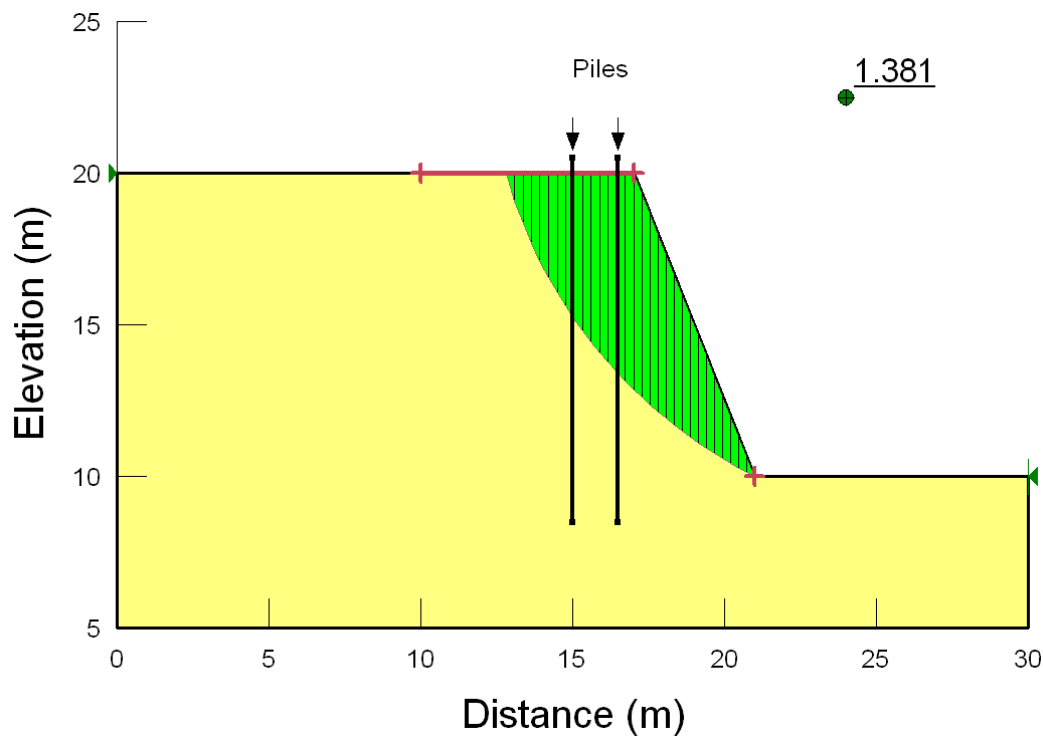
Note that the normal force acting on Slice 8 (Figure 7) is pointing away from the slice base. This indicates that the slice normal is in tension. This tension force is due to the relatively large shear force acting in the upward direction (parallel to the slice base). The negative normal causes the shear mobilized (2.8594 kN) to be acting in the opposite direction as the sliding mass. This is physically inadmissible when the

direction of the movement of the sliding mass is from left to right. To resolve this difficulty, either more piles should be used, so that the pile shear force can be reduced, or the direction of the applied shear force should be changed.

SLOPE/W provides two options for the direction of the applied shear force from the pile:

- Parallel to Slip – with this option, the shear force will be applied parallel to the slip surface.
- Perpendicular to Reinforcement – with this option, the shear force will be applied perpendicular to the pile.

It is up to you which shear force direction you want to select. The factor of safety is slightly higher when “Parallel to Slip” is chosen. Figure 8 shows the critical factor of safety and slip surface of the slope with two piles when the shear force is assumed to be applied perpendicular to the piles. The critical factor of safety is 1.381, which is slightly lower than Case 3 when the “Parallel to Slip” option is used.



**Figure 8 Critical factor of safety and slip surface with two piles**

Figure 9 shows the free body diagram and the force polygon of slice 8. From the free body diagram, the pile shear force used in the factor of safety calculation is 100 kN. Note that the direction of the applied shear force is perpendicular to the pile reinforcement. Also note that the normal force is not in tension and the mobilized shear force is in the correct direction as expected.

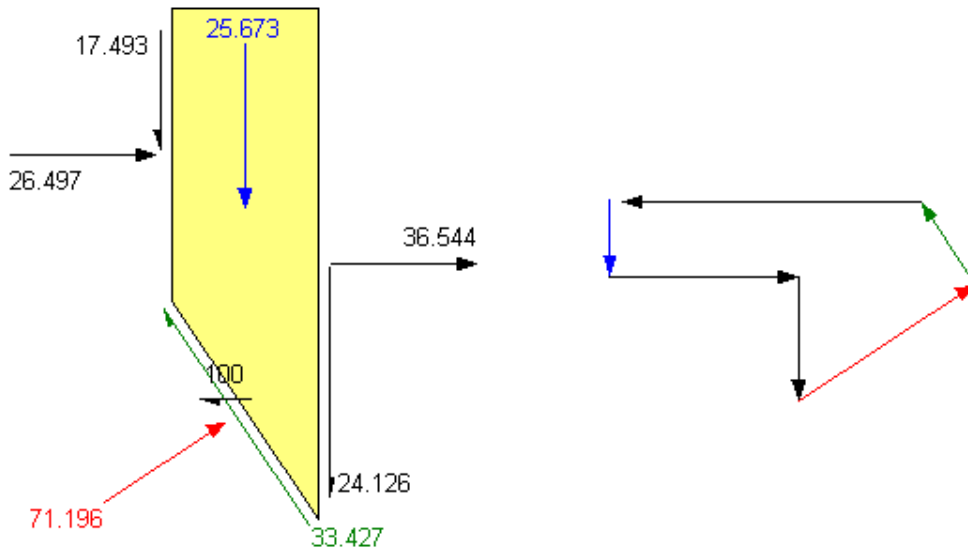


Figure 9 Free body diagram and force polygon of slice 8