

# Anisotropic Strength

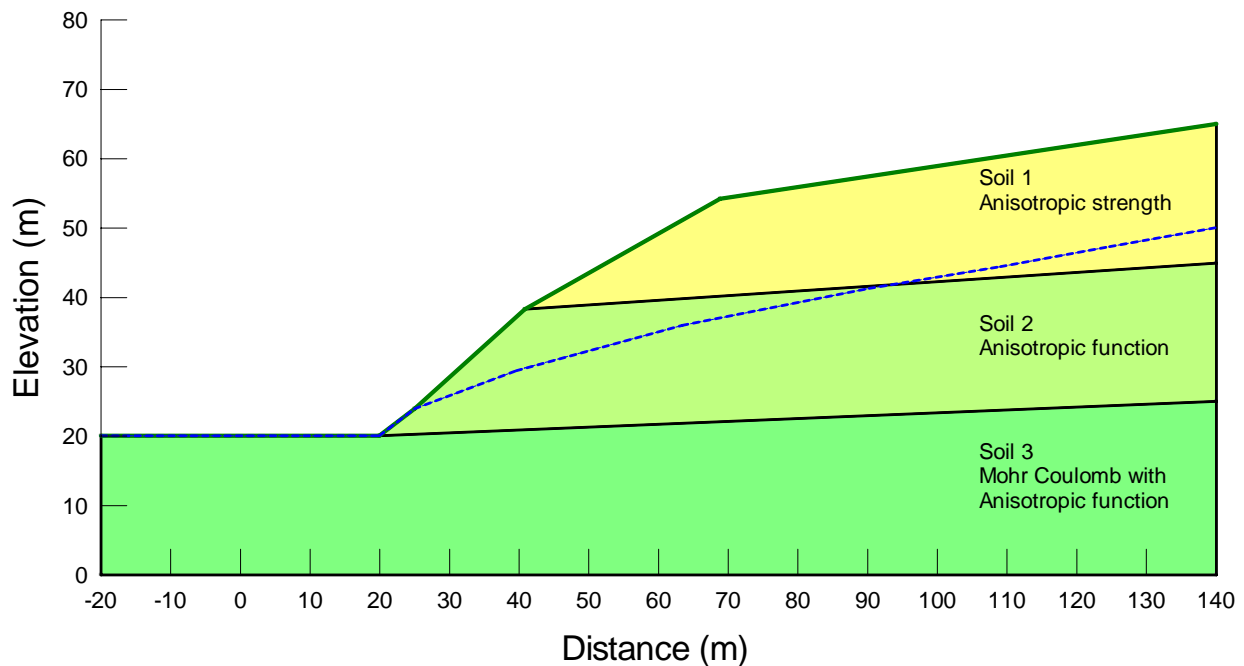
## 1 Introduction

The objective of this example is to highlight the use of various strength models in modeling the anisotropy of the materials. In this example, the features include:

- Use of a single grid and radius slip surface
- Use of anisotropic strength soil model
- Use of anisotropic function
- Use of Mohr Coulomb model with anisotropic function
- Use of tension crack angle

## 2 Configuration and setup

The profile shown in Figure 1 has three different soil layers and each layer has been assigned a different strength model.



**Figure 1 Profile for the anisotropic example showing the soil layers**

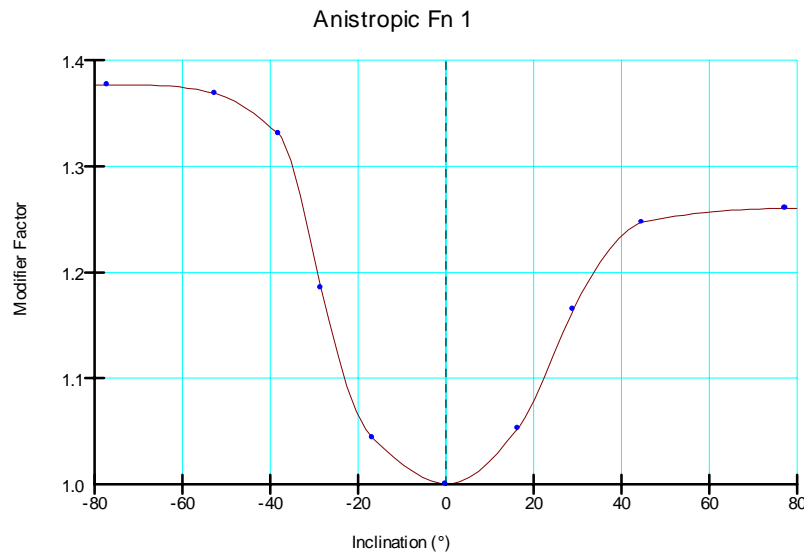
The strength model specifies how the soil strength is defined. For this example, soil #1 uses an anisotropic strength soil model, which is used to designate anisotropic soil strength. Both vertical and horizontal  $c$  and  $\phi$  values are specified. The  $c$  and  $\phi$  values are first adjusted for anisotropy before they are used in the shear strength computation. For more information on this strength model, refer to the chapter in the SLOPE/W engineering book on material strength. The input parameters defined for the anisotropic strength of soil #1 are as shown in Table 1.

**Table 1 Input parameters for soil #1**

Parameter	Value
Unit weight, $\gamma$	18 kN/m <sup>3</sup>
Horizontal cohesion, $c_H$	20 kN/m <sup>2</sup>
Vertical cohesion, $c_V$	25 kN/m <sup>2</sup>
Horizontal friction angle, $\phi_H$	30°
Vertical friction angle, $\phi_V$	35°

Soil #2 uses the anisotropic function model in which, depending on the base inclination angle, both the strength parameters  $c$  and  $\phi$  are multiplied by a modifier factor. The input  $c$  and  $\phi$  values are multiplied with the modifier factor obtained from the function before use in the shear strength computation.

The general function is defined by the user, and Figure 2 shows how the modifier factor defined for this particular example varies with respect to base inclination angle for soils #2 and #3.



**Figure 2 Anisotropic modifier function for soil #2 and #3**

The required input parameters defined for soil #2 are as shown in Table 2.

**Table 2 Input parameters for Soil #2**

Parameter	Value
Unit weight, $\gamma$	18 kN/m <sup>3</sup>
Cohesion	20 kN/m <sup>2</sup>
Friction angle, $\phi$	30°

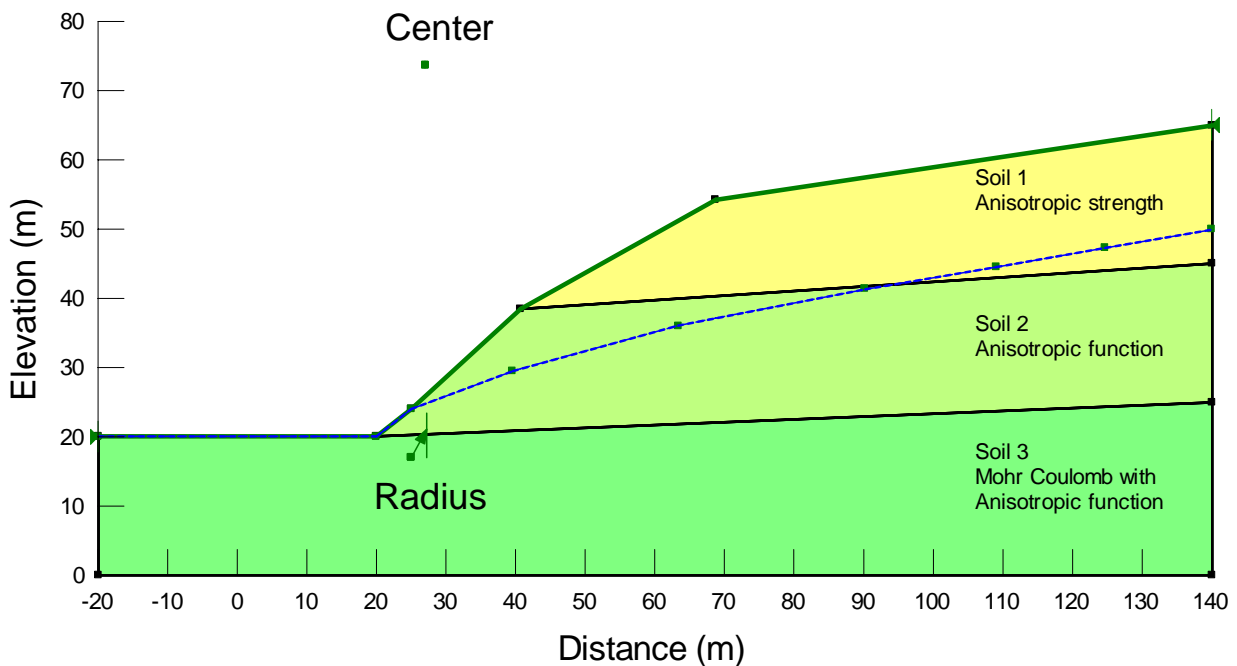
Soil #3 uses a Mohr Coulomb strength model and an anisotropic function as shown in Figure 2. The effective soil strength is first computed with the Mohr Coulomb model and then adjusted based on the modifier factor.

The required input parameters defined for soil #3 are as shown in Table 3.

**Table 3 Input parameters for soil #3**

Parameter	Value
Unit weight, $\gamma$	18 kN/m <sup>3</sup>
Cohesion	10 kN/m <sup>2</sup>
Friction angle, $\phi$	30°

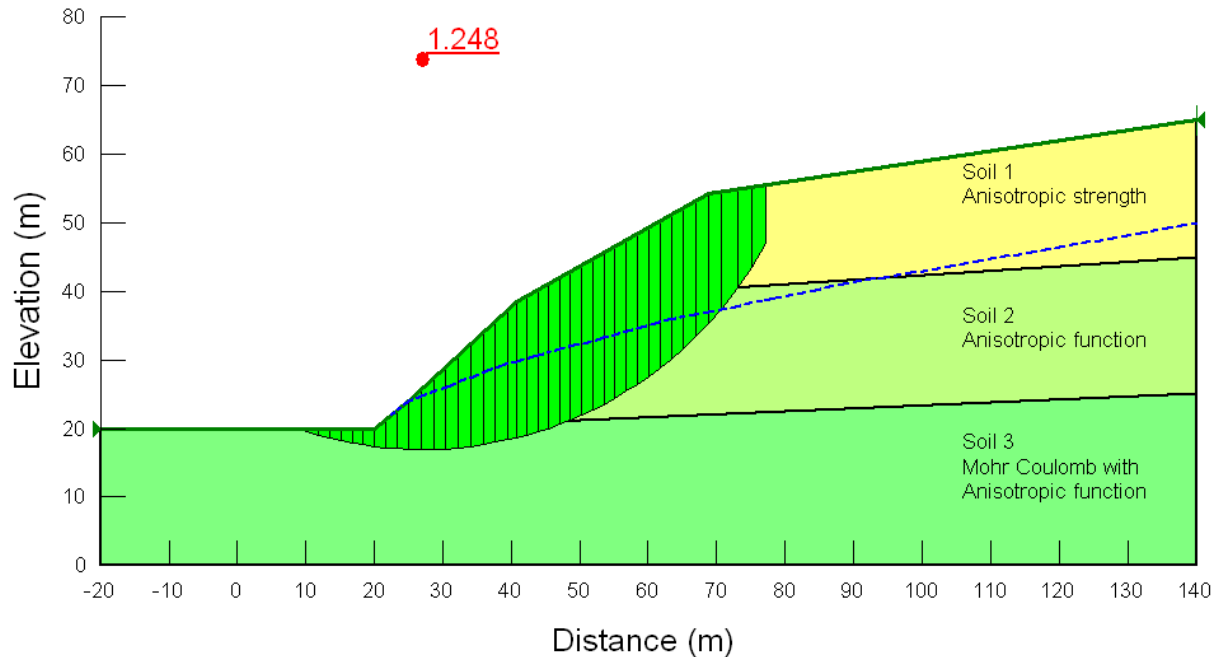
For this example, a single slip surface is analyzed by collapsing both the search grid and radius to single points. In addition, a piezometric line is defined and a tension crack angle of 62° is defined, as shown in Figure 3. A tension crack angle of 62° means that if the angle of the slip surface becomes greater than 62°, the slip surface will be forced vertically to the surface.



**Figure 3 Slip surface definition**

### 3 Critical Factor of Safety

The critical slip surface and the factor of safety of 1.248 are presented in Figure 4.



**Figure 4 Factor of safety and the location of the critical slip surface**

To see how the three different strength models were used in this example, we will use some of the slice information available to verify the strength parameters that were used in the analysis.

**Soil #1 – anisotropic strength model**

Soil #1 uses an anisotropic strength model in which the strength parameters  $c$  and  $\phi$  in both the horizontal and vertical directions are defined. The bottom of slice 40 is within Soil #1, located above the piezometric line and the base inclination angle is 59.967, as reported in the view slice information dialogue box. The input  $c$  value is 20 in the horizontal direction and 25 in the vertical direction. The input  $\phi$  value is 30 in the horizontal direction and 35 in the vertical direction. Based on the inclination angle, the  $c$  and  $f$  values at the base of each slice are adjusted according to:

$$c = c_h \cos^2 \alpha + c_v \sin^2 \alpha = 20 \cos^2 59.967 + 25 \sin^2 59.967 = 23.748$$

$$\phi = \phi_h \cos^2 \alpha + \phi_v \sin^2 \alpha = 30 \cos^2 59.967 + 35 \sin^2 59.967 = 33.748$$

From the view slice information for slice 40, the base normal stress ( $\sigma_n$ ) is given as 64.867 kN/m<sup>2</sup> and the pore-water pressure ( $u$ ) is negative. Since unsaturated strength parameter is not specified in this example, the negative pore water pressure is not used and the pore water pressure is taken as zero in the strength calculation. The Mohr-Coulomb equation for shear stress can then be solved as follows:

$$\tau = c + (\sigma_n - u) \tan \phi = 23.748 + (64.867 - 0) \tan 33.748 = 67.087$$

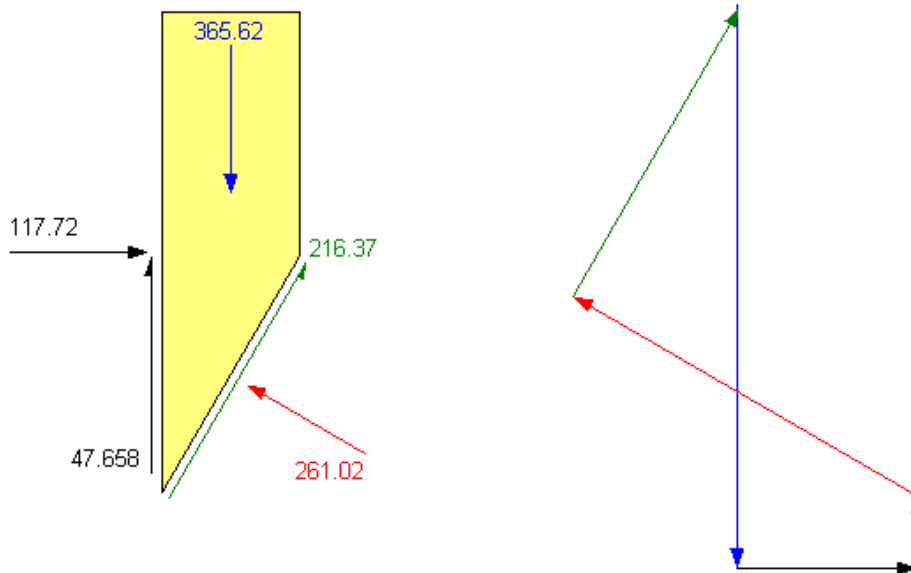
The base length of slice 40 is 4.0248 m and the resisting shear force ( $S_r$ ) is computed by multiplying the base length by the shear stress:

$$S_r = \tau \times \ell = 67.087 \text{ kN/m}^2 \times 4.0248 \text{ m} = 270.01$$

The shear force mobilized is then determined by dividing the resisting shear by the factor of safety (i.e., 1.2473), therefore:

$$S_m = \frac{270.01}{1.248} = 216.40$$

This computed value of the shear force mobilized is exactly the same as the reported shear mobilized force that appears at the base of slice 40 on the free body diagram in Figure 5.



**Figure 5 Free body diagram and force polygon of slice 40**

**Soil #2 – anisotropic function**

The bottom of slice 30 is in soil #2, which used the anisotropic function. For this particular slice, the base inclination angle is 32.66. Using the anisotropic function shown in Figure 2, the modifier factor for this slice is approximately 1.192. The input parameters were  $c=20$  and  $\phi = 30$ , therefore, the modified  $c$  and  $\phi$  values used in the shear strength calculation become  $c = 23.842$  and  $\phi = 35.763$ . From the view slice information for slice 30, the base normal stress ( $\sigma_n$ ) is 289.16 kN/m<sup>2</sup> and the pore-water pressure ( $u$ ) is 83.2 kN/m<sup>2</sup>. The Mohr-Coulomb equation for shear stress can then be solved as follows:

$$\tau = c + (\sigma_n - u) \tan \phi = 23.840 + (289.16 - 83.2) \tan 35.763 = 172.18$$

The base length of slice 30 is 1.9482 m and the resisting shear force ( $S_r$ ) is computed by multiplying the base length by the shear stress:

$$S_r = \tau \times \ell = 172.18 \text{ kN/m}^2 \times 1.9482 \text{ m} = 335.44$$

The shear force mobilized is then determined by dividing the resisting shear by the factor of safety (i.e., 1.248), therefore:

$$S_m = \frac{335.44}{1.248} = 268.82$$

This computed value of the shear force mobilized is exactly the same as the reported shear mobilized force that appears at the base of slice 30 on the free body diagram in Figure 3.

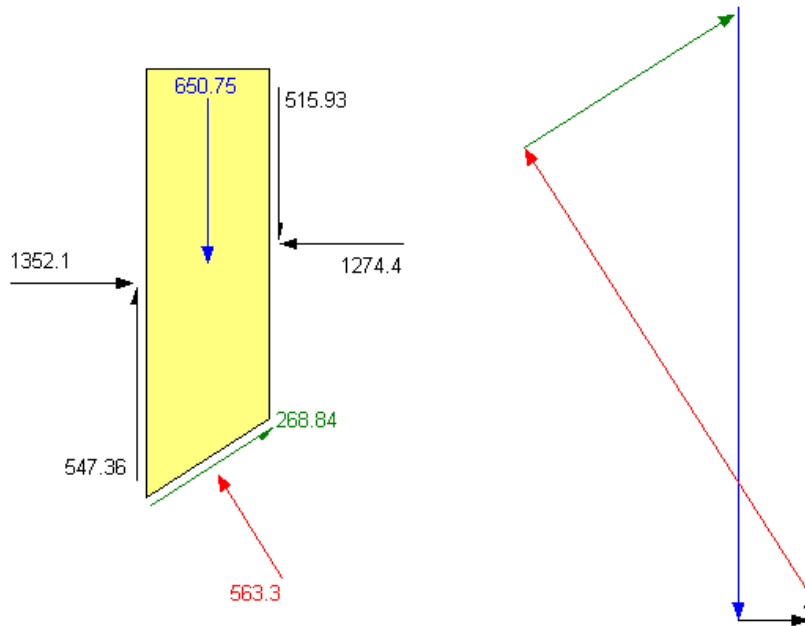


Figure 6 Free body diagram and force polygon of slice 30

### Soil #3 – Mohr Coulomb with anisotropic function

The bottom of slice 20 is in soil #3, which used the Mohr Coulomb with an anisotropic function. For this particular slice, the base inclination angle is 14.815. Using the anisotropic function shown in Figure 2, the modifier factor for this slice is 1.0439. The input parameters were  $c=10$  and  $\phi = 30$ . From the view slice information for slice 30, the base normal stress ( $\sigma_n$ ) is  $340.54 \text{ kN/m}^2$  and the pore-water pressure ( $u$ ) is  $109.74 \text{ kN/m}^2$ . The Mohr-Coulomb equation for shear stress can then be solved as follows:

$$\tau = [c + (\sigma_n - u) \tan \phi] \times \text{M.Factor} = [10.0 + (340.54 - 109.74) \tan 30.0] \times 1.0439 = 149.54$$

The base length of slice 20 is 1.6292 m and the resisting shear force ( $S_r$ ) is computed by multiplying the base length by the shear stress:

$$S_r = \tau \times \ell = 149.54 \text{ kN/m}^2 \times 1.6292 \text{ m} = 243.63$$

The shear force mobilized is then determined by dividing the resisting shear by the factor of safety (i.e., 1.140), therefore:

$$S_m = \frac{243.63}{1.248} = 195.21$$

This computed value of the shear force mobilized is exactly the same as the reported shear mobilized force that appears at the base of slice 20 on the free body diagram in Figure 7..

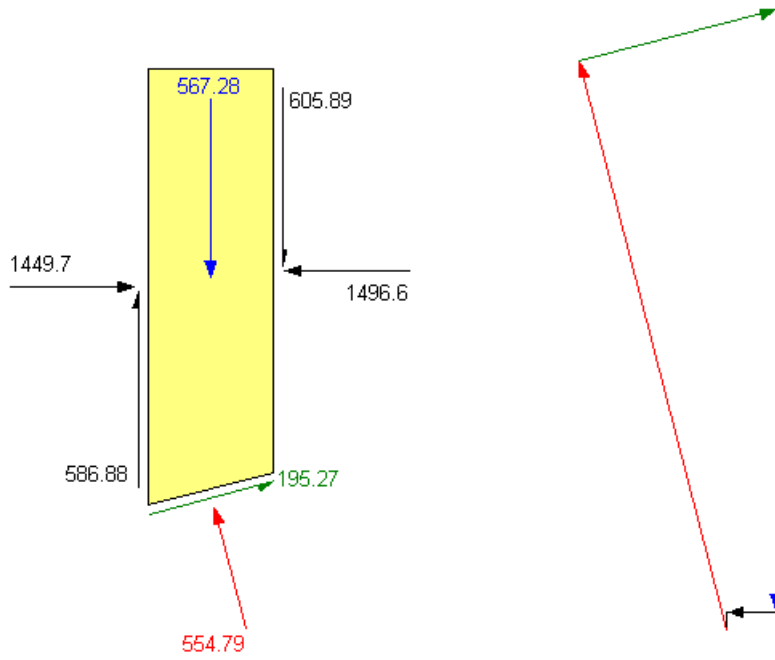


Figure 7 Free body diagram and force polygon of slice 20