GeoStudio Example File
Anisotropic Strength

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Introduction

The anisotropy of materials can be simulated using various strength models in SLOPE/W. The objective of this document is to illustrate the use of three material models to simulate the soil strength of material within a slope profile. The three material models are the Anisotropic Strength model, the Anisotropic Function model and the Mohr-Coulomb model with anisotropic function. A tension crack angle is also simulated in this example with a single grid and radius slip surface.

Numerical Simulation

For this analysis, three soil layers make up the profile of a slope (Figure 1). Each of the three soil layers has been assigned a different strength model, which specifies how the soil strength is defined in the analysis.

For this example, soil #1 uses an anisotropic strength material model, which is used to designate anisotropic soil strength. Both vertical and horizontal cohesion (c) and friction angle (ϕ) values are specified. The c and ϕ 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.

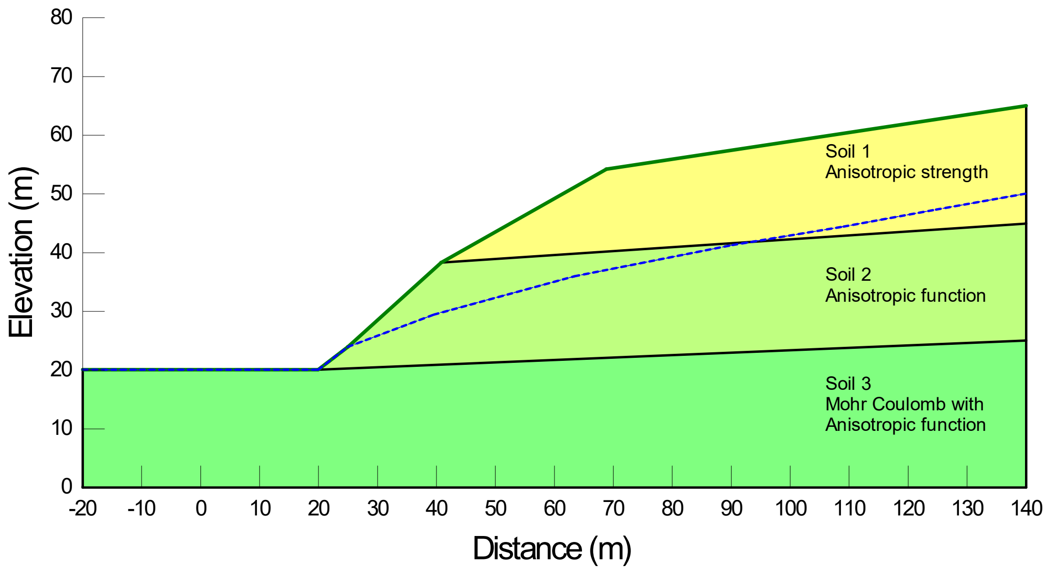

Figure 1. Profile for the anisotropic example showing the soil layers.

Table 1. Input parameters for soil #1.

Parameter	Value
Unit weight, γ	18 kN/m^3
Horizontal cohesion, c_h	20 kN/m^2
Vertical cohesion, c_v	25 kN/m^2
Horizontal friction angle, ϕ_h	30°

Vertical friction angle, ϕ_h	35°

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

The anisotropic modifier function is defined by the user. Figure 2 shows how the modifier factor defined for this particular example varies with respect to base inclination angle for soils #2 and #3. The required input parameters defined for soil #2 are as shown in Table 2.

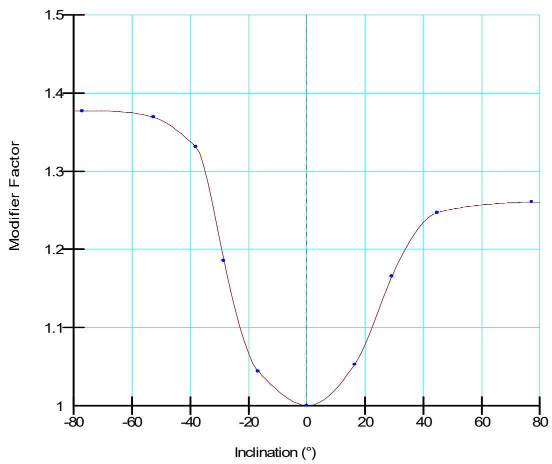

Figure 2. Anisotropic modifier function for soil #2 and #3.

Table 2. Input parameters for Soil #2.

Parameter	Value
Unit weight, γ	18 kN/m^3
Cohesion	20 kN/m^2
Friction angle, ϕ	30°

Soil #3 uses a Mohr-Coulomb strength model and an anisotropic function as shown above 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, γ	18 kN/m^3
Cohesion	10 kN/m^2
Friction angle, ϕ	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.

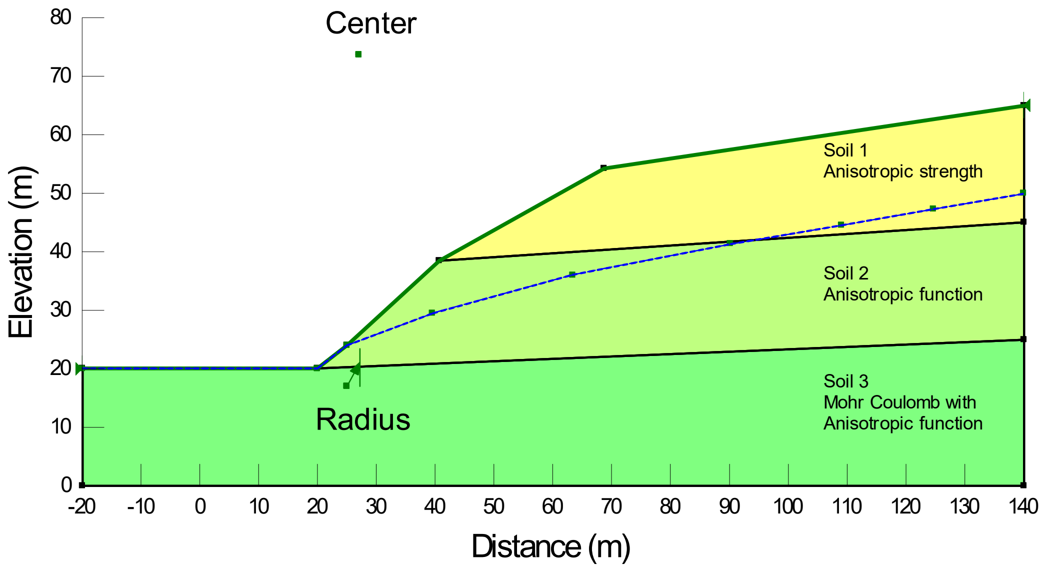

Figure 3. Slip surface and piezometric line definition.

Results and Discussion

The factor of safety computed by SLOPE/W for this analysis was 1.247. The critical slip surface is displayed in the Results View, as presented in Figure 4. To see how the three different strength material models were used in this example, some of the slice information available will be used to verify the strength parameters that were used in the analysis.

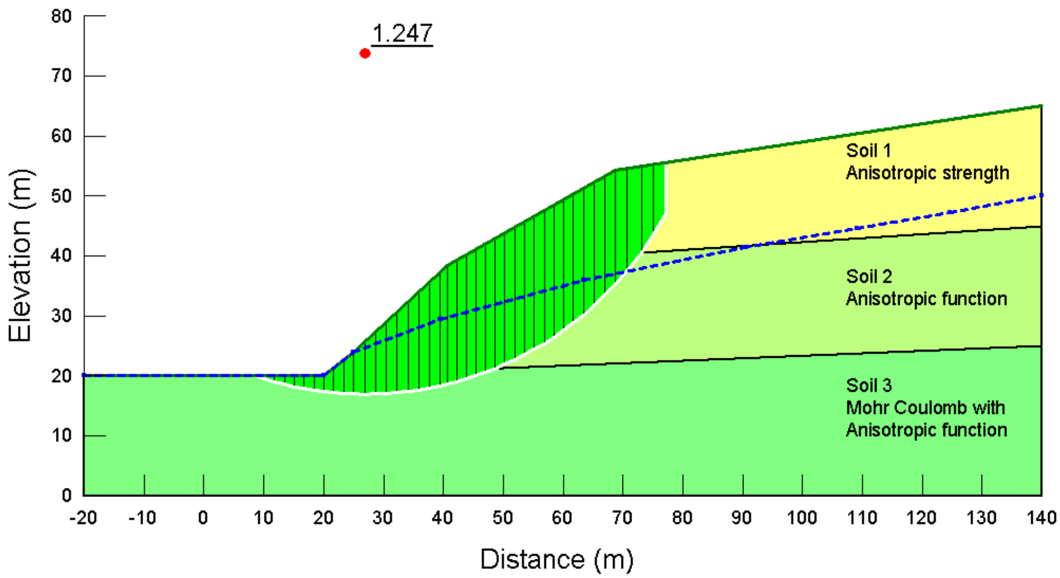

Figure 4. Factor of safety and the location of the critical slip surface.

Soil #1 used an anisotropic strength material model in which the strength parameters, c and ϕ, 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 kN/m^2 in the horizontal direction (c_h) and 25 kN/m^2 in the vertical direction (c_v). The input ϕ value is 30º in the horizontal direction (ϕ_h) and 35º in the vertical direction (ϕ_v). Based on the inclination angle, the c and ϕ values at the base of each slice are adjusted according to:

$$c = c_h \cos^2 \alpha + c_v \sin^2 \alpha = 20\cos^2 59.967 + 25\sin^2 59.967 = 23.748 \quad \text{Equation 1}$$

$$\phi = \phi_h \cos^2 \alpha + \phi_v \sin^2 \alpha = 30\cos^2 59.967 + 35\sin^2 59.967 = 33.748 \quad \text{Equation 2}$$

From the View Slice Information window for slice 40, the base normal stress (σ_n) is given as 64.995 kN/m^2 and the pore-water pressure (u) is negative. Since an 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:

$$\tau = c + (\sigma_n - u)\tan\phi = 23.748 + (64.995 - 0)\tan 33.748 = 67.173 \quad \text{Equation 3}$$

The base length of slice 40 is 4.0239 m and the resisting shear force (S_r) is computed by multiplying the base length by the shear stress:

$$S_r = \tau \times l = 67.173\ kN/m^2 \times 4.0239\ m = 270.30 \quad \text{Equation 4}$$

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

$$S_m = \frac{270.30}{1.2473} = 216.71 \quad \text{Equation 5}$$

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

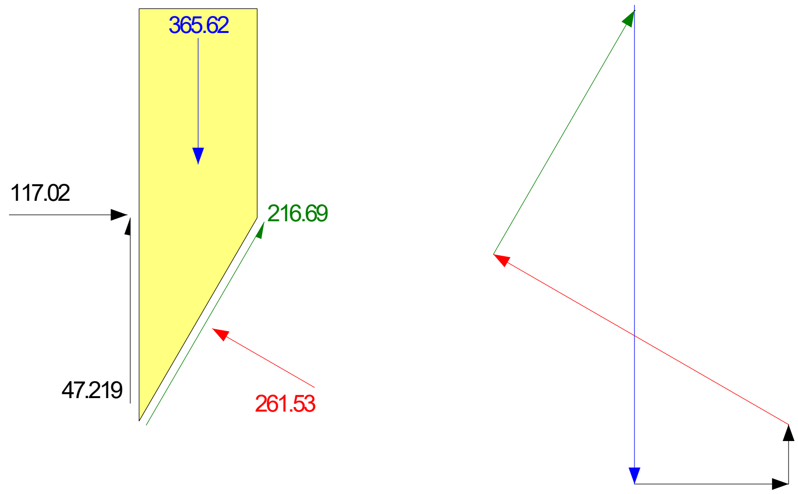

Figure 5. Free body diagram and force polygon of slice 40.

The bottom of slice 30 is in soil #2, which used the anisotropic function. For this particular slice, the base inclination angle is 32.664°. 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 ϕ = 30; therefore, the modified c and ϕ values used in the shear strength calculation become c = 23.842 and ϕ = 35.763. From the view slice information for slice 30, the base normal stress (σ_n) is 289.23 kN/m² and the pore-water pressure (u) is 83.2 kN/m². The Mohr-Coulomb equation for shear stress can then be solved as follows:

$$\tau = c + (\sigma_n - u)\tan\phi = 23.840 + (289.23 - 83.2)\tan 35.763 = 172.23$$

Equation 6

The base length of slice 30 is 1.9481 m and the resisting shear force (S_r) is computed by multiplying the base length by the shear stress:

$$S_r = \tau \times l = 172.23\ kN/m^2 \times 1.9481\ m = 335.52$$

Equation 7

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

$$S_m = \frac{335.52}{1.2473} = 269.0$$

Equation 8

This computed value of the shear force mobilized is the same as the reported shear force mobilized that appears at the base of slice 30 on the free body diagram in Figure 6.

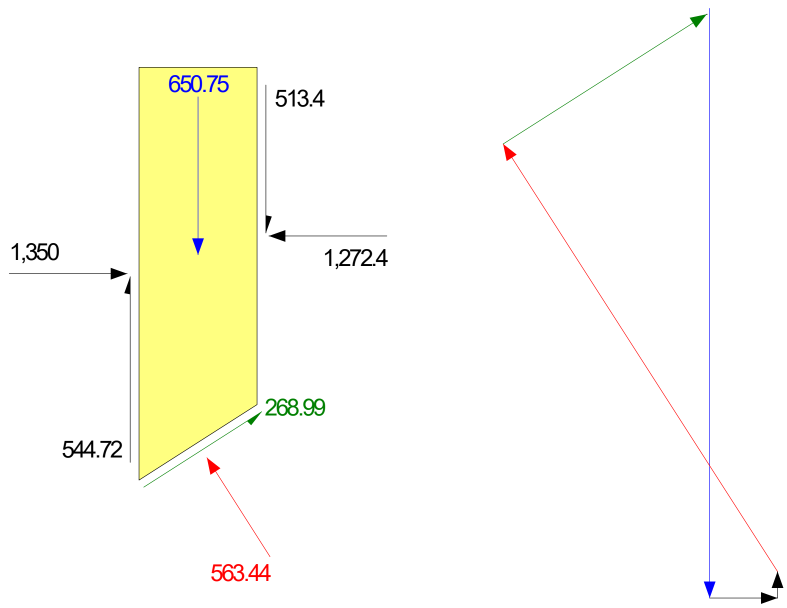

Figure 6. Free body diagram and force polygon of slice 30.

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 ϕ = 30. From the view slice information for slice 20, the base normal stress (σ_n) is 340.52 kN/m^2 and the pore-water pressure (u) is 109.74 kN/m^2. The Mohr-Coulomb equation for shear stress can then be solved as follows:

$$\tau = \left[c + (\sigma_n - u)\tan\phi\right] \times M.Factor = [10.0 + (340.52 - 109.74)\tan 30.0] \times 1.0439 = 149.53$$

Equation 9

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:

$$S_r = \tau \times l = 149.53\ kN/m^2 \times 1.6292\ m = 243.61$$

Equation 10

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

$$S_m = \frac{243.61}{1.2473} = 195.31$$

Equation 11

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.

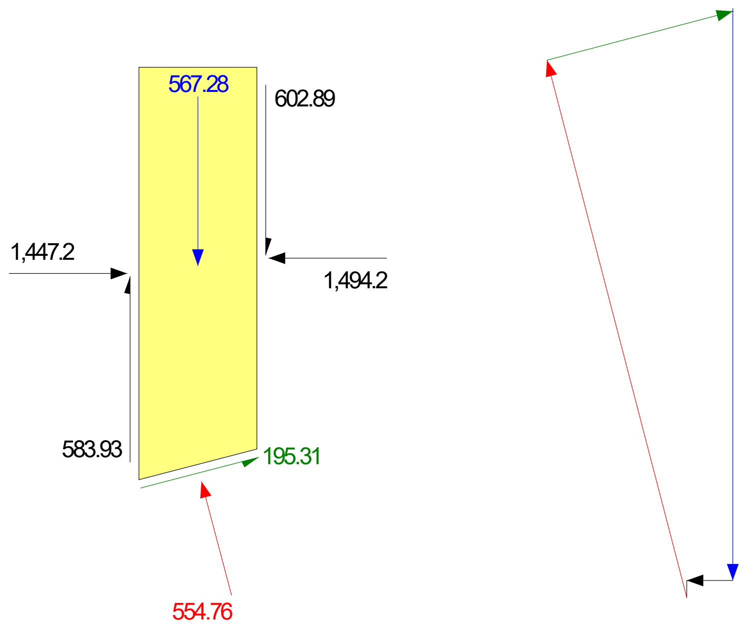

Figure 7. Free body diagram and force polygon of slice 20.

Summary and Conclusions

There are various material models that can be used in SLOPE/W for simulating anisotropy in soil strength. This document illustrated the use of three models: Anisotropic Strength model, Anisotropic Function model, and Mohr-Coulomb model with anisotropic function. Result information for each of the material models was checked by calculating the shear force mobilized for slices within each material layer.