GeoStudio Example File
Material Model: Compound Strength

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Introduction

Many geotechnical systems comprise a soil or rock with an anisotropic strength definition. Consider, for example, a silty soil containing clay stratifications. The shear strength of the silt and clay could be very different. Similarly, the shear strength of jointed or fractured rock can vary significantly from one joint set to the next.

The compound strength model can be used to simulate anisotropic strength (i.e. directionally dependent) in soil or rock by considering the angular proximity of the column base plane to each joint set and the influence of the joint set on the shear strength. Details concerning the definition of Compound Strength can be found in the Slope Stability Modeling reference book. This example demonstrates how to define a compound strength material model for a problem involving two joints and a symmetric geometry.

Compound Strength in 2D

The Compound Strength model is applicable for both 2D and 3D stability analyses. The model is comprised of a base material representing the intact soil or rock and materials assigned to individual anisotropic features, such as a joint set or bedding. The orientation of each joint set is defined using dip direction and dip. Angular ranges A and B specified for the anisotropic feature specify the transition of shear strength from the anisotropic material to the intact strength.

In 2D, the dip direction is effectively ignored as the cross-section is assumed to be aligned with the dip direction. The dip is always entered as a positive value. This rule is applied to differentiate the joint orientation in 2D: a dip direction between 0^{o} and 180^{o} corresponds to a joint dipping to the right; a dip direction from 180^{o} to 360^{o} represents a joint dipping to the left.

A Compound Strength material may consist of multiple joints. During solve time, the angles between column base planes and each of the joint planes are computed. The smallest angle corresponds to the active joint. The angle between the column base and the active joint is then used to calculate the shear strength. If the angle is less than A, the shear strength will be computed using the joint parameters. If the angle is beyond Range B, the shear strength will be computed using the base material parameters. If the angle falls between A and B, the shear strength will be determined based on interpolation of the base and joint shear strengths.

Numerical Simulation

Figure 1 presents the model configuration. The geometry is mirrored at the centreline to demonstrate the influence of model definition on right-to-left and left-to-right analyses. The slopes are 25 m in height and at an angle of about 30^{o}. The geology comprises two joint sets. Set 1 dip 50.5^{o} to the right and Set 2 is 3.75^{o} below horizontal. The block specified method is used to search for the critical slip surface of the side slopes in the analyses.

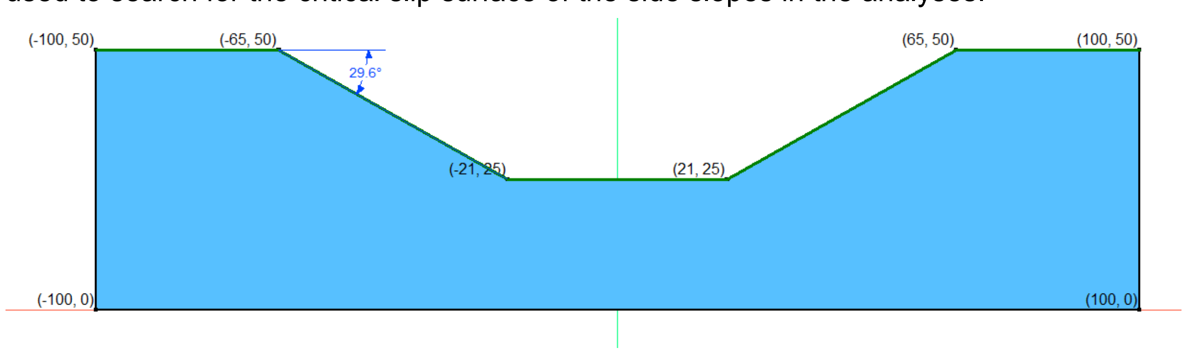

Figure 1. Model geometry.

The definition of the compound strength model is shown in Figure 2. There are three underlying materials in the compound. The intact material is modeled using Hoek-Brown with a UCS, mi, GSI, and D equal to 20 MPa, 10, 35, and 0.9, respectively. The joint sets are modeled using Mohr-Coulomb with $\phi' = 26°$ and cohesion = 5 kPa for Set 1 and $\phi' = 18.5°$ and zero cohesion for Set 2. In this example, both joint sets dip to the right as the specified dip directions are less than 180°. The orientation of a joint can be visualized on the pie chart by clicking the joint in the entry table.

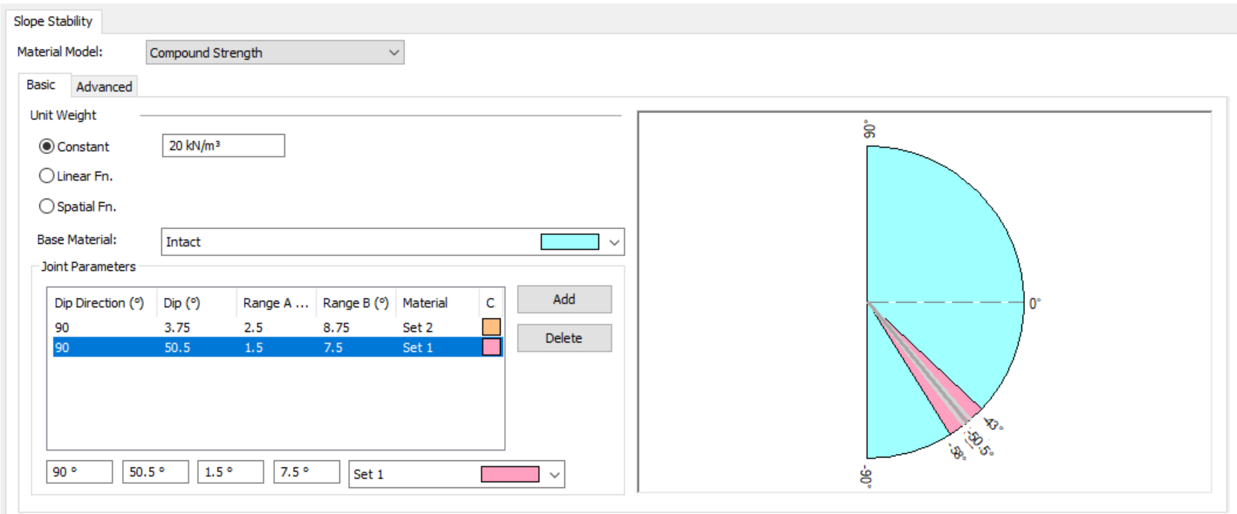

Figure 2. Compound strength definition.

Results and Discussion

Figure 3 and Figure 4 present the calculated FOS values for the left and right slopes respectively. The joint set directions in this example are dipping to the right. As expected, the critical FOS of the left slope is considerably lower than that of the right slope, about 1.47 vs. 2.03 before optimization and 1.12 vs. 1.84 after optimization.

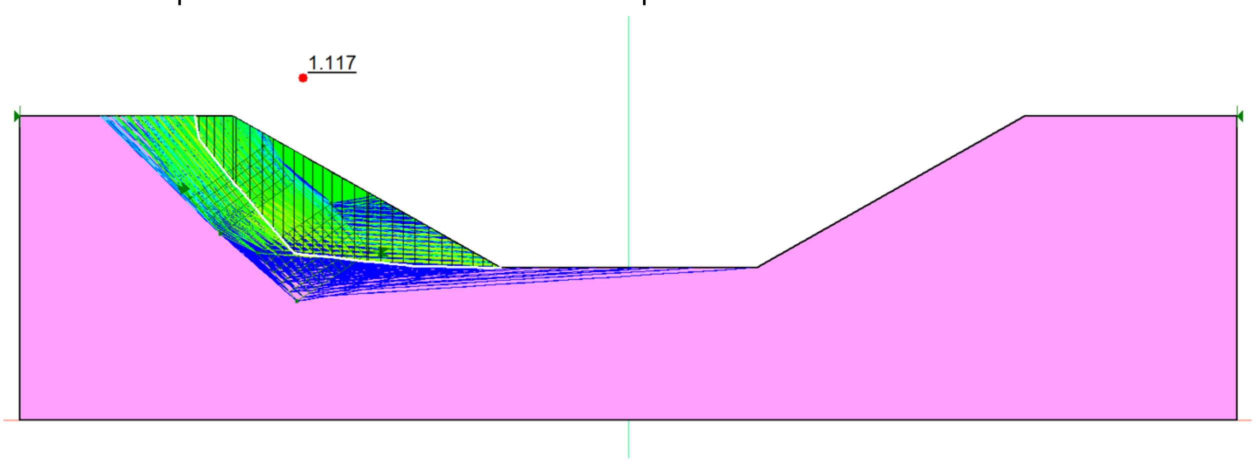

Figure 3. Stability analysis results of the left slope (FOS = 1.47 before optimization).

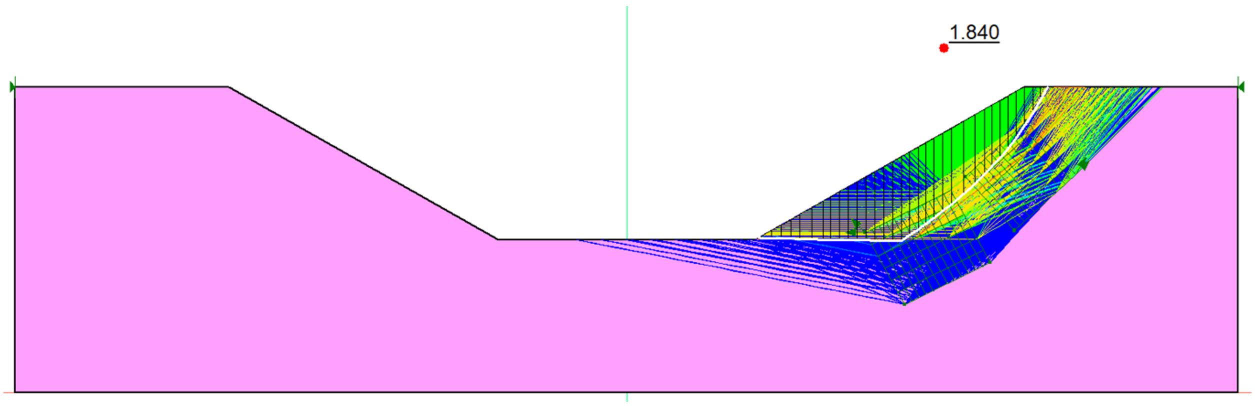

Figure 4. Stability analysis results of the right slope (FOS = 2.03 before optimization).

The trial slip surface created using the block specified method is comprised of three line segments. Each segment corresponds to a column base angle. The underlying material models associated with each of the base angles can be verified by plotting the base angle and the shear strength parameters, as shown in Figure 5 . This slip surface is from the left slope with all the column base angles dipping to the right (negative angle values in the graph). In the entry segment, the difference between the dip of the column base and joint Set 1 is (50.5° - 48.5°) = 2° and Set 2 (48.5° – 3.75°) = 44.75°, respectively. Hence, Set 1 is the active joint for the columns in the entry segment. Since this angle (2°) falls between A (1.5°) and B (7.5°), the shear strengths at the base are computed from interpolation of Mohr-Coulomb (Set 1) and Hoek-Brown (Intact). Following the same logic, Set 1 is the active joint for the middle portion, and the shear strength is computed from Hoek-Brown only based on the angle measured from the column base to Set 1. The Hoek-Brown failure envelope is nonlinear, and the slope of the tangent at effective base normal stress is reported as the friction angle. As can be seen, the friction angle along these two portions of the slip surface varies with normal stress. In the exit zone, Set 2 is the active joint; the shear strength is computed using the Set 2 parameters only. Hence, the friction angle is taken as 18.5°.

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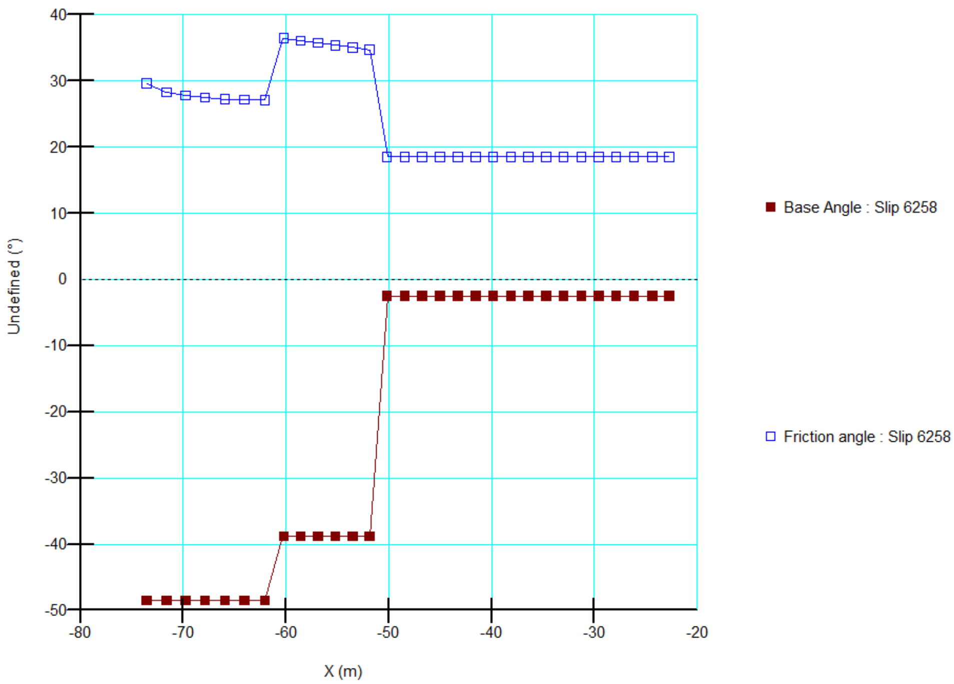

Figure 5. Friction angles and base angles along a trial slip surface for the left slope.

The implementation of the compound strength can also be verified using Column Information (Figure 6). Column #7 is on the entry segment mentioned above. The shear strength is computed from interpolation of Set 1 and the Intact material. The effective base normal stress is 129.79 kPa. The shear strength computed using the Set 1 parameters is 129.79 x tan(26°) + 5 = 68.303 kPa and using the Intact parameters (or from the graph in the material definition) is 148.537 kPa. Based on interpolation, the shear resistance at the column base is (148.537 – 68.303) / (7.5 – 1.5) x (2 – 1.5) + 68.303 = 75 kPa, as shown in the column information.

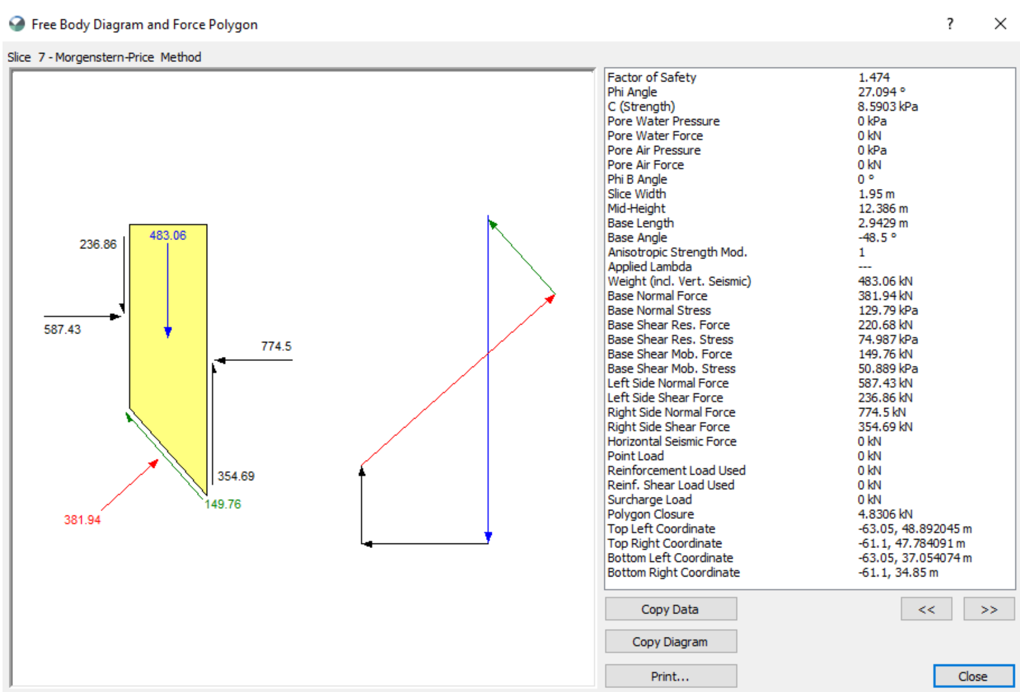

Figure 6. Column information from Slip #6258 on the left slope.

Summary and Conclusions

This example illustrates the definition of compound strength material in a 2D stability analysis. Although half of the pie chart is presented, with the angle range of 180^{o} (i.e. from -90^{o} to 90^{o}), the model defines the strength anisotropy of the material in all directions in a symmetric manner. Draw – Graph and/or View – Column Information should be used to verify that the strength anisotropy is correctly represented by the model. As demonstrated in this example, the left-to-right analysis could produce a very different solution from the right-to-left solution due to the presence of anisotropy.