Material Model: Shear Normal Function

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Introduction

In a SLOPE/W analysis, the limit equilibrium formulation requires that the friction angle and cohesion are defined at the base of each slice, regardless of the material model selected. The objective of this example is to demonstrate how a shear-normal strength function is used to generate a strength definition along the base of a slip surface.

Background

The primary material property in a SLOPE/W analysis is the shear strength of the soil or rock. The shear strength can be defined by the Mohr-Coulomb equation as:

$$\tau = c^{'} + (\sigma - u_w)\tan\phi^{'}$$ **Equation 1**

where σ is the stress, u_w is the pore-water pressure, and *c'* and ϕ' are the intercept on the shear-stress axis and the slope of the Mohr-Coulomb failure envelope, respectively. Equation 1 is used in the derivation of the factor of safety equations (see SLOPE/W Engineering book) regardless of the material model selected.

The Mohr-Coulomb failure envelope can often be curved. This is particularly true for more coarse-grained soils. SLOPE/W allows you to define a curve failure envelope as a general data-point function (Figure 1). A combination of shear-normal data points are entered to create the curve.

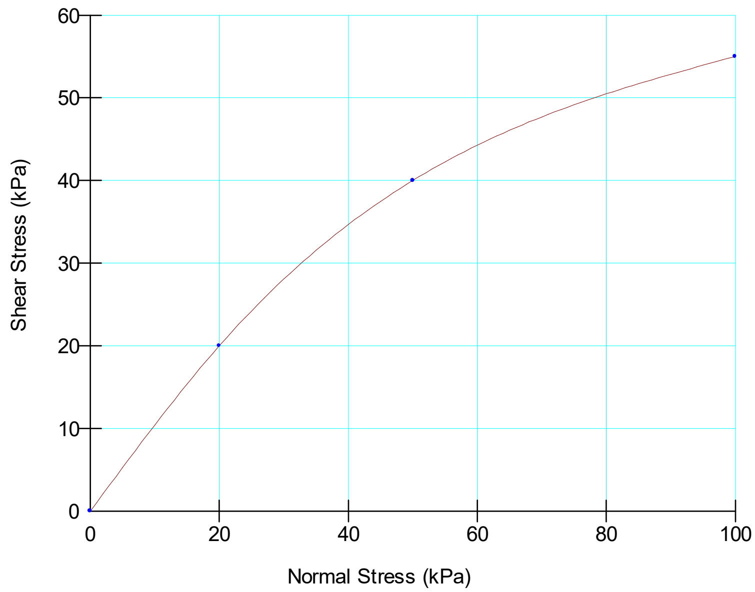

Figure 1. A typical curved failure envelopes.

SLOPE/W uses the basic shear strength equation for a curved failure envelope in the same manner that it does for a linear failure envelope. The c and ϕ, however, vary according to the slice base normal. For each slice, SLOPE/W finds the instantaneous slope of the curve. The slope is equated to ϕ'. The slope-line intersection with the shear-stress axis is equated to c´. This procedure is illustrated in Figure 2.

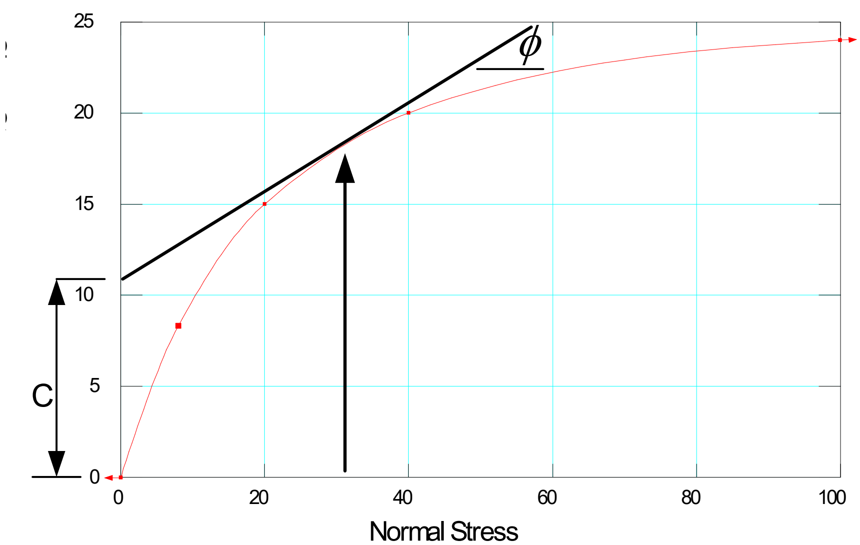

Figure 2. Equivalent c´ and ϕ' for a curved failure envelope.

Numerical Simulation

Figure 3 presents the model domain. The entry-exit technique is used to search for the critical slip surface and the pore-water pressure is defined using a piezometric line. Both regions use a Shear-Normal material model with the failure envelopes presented in Figure 4.

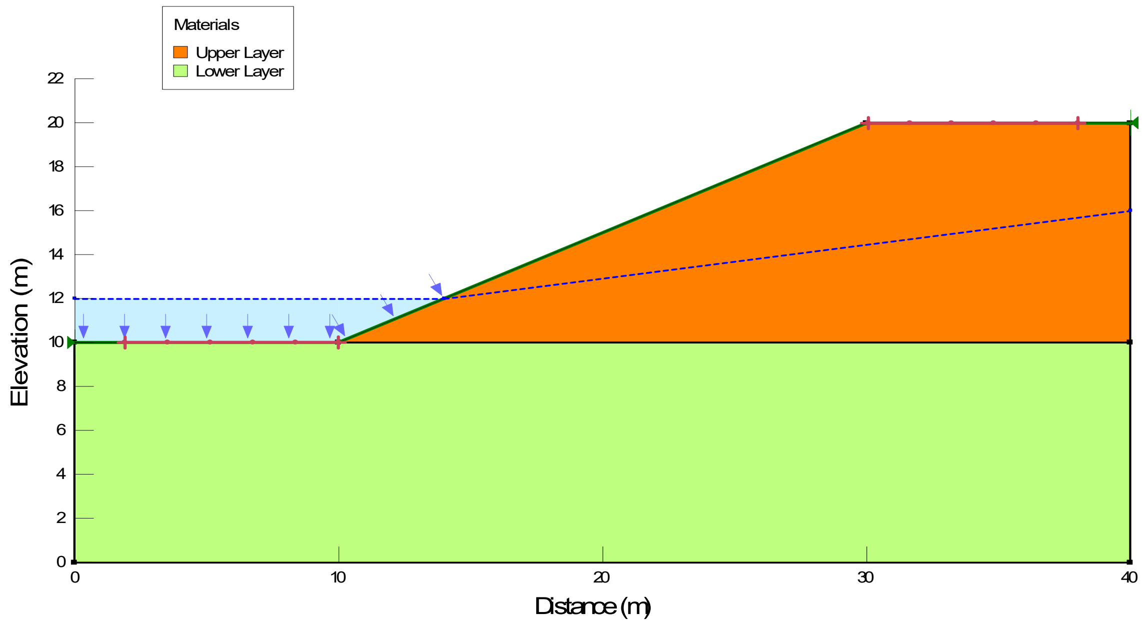

Figure 3. Model domain.

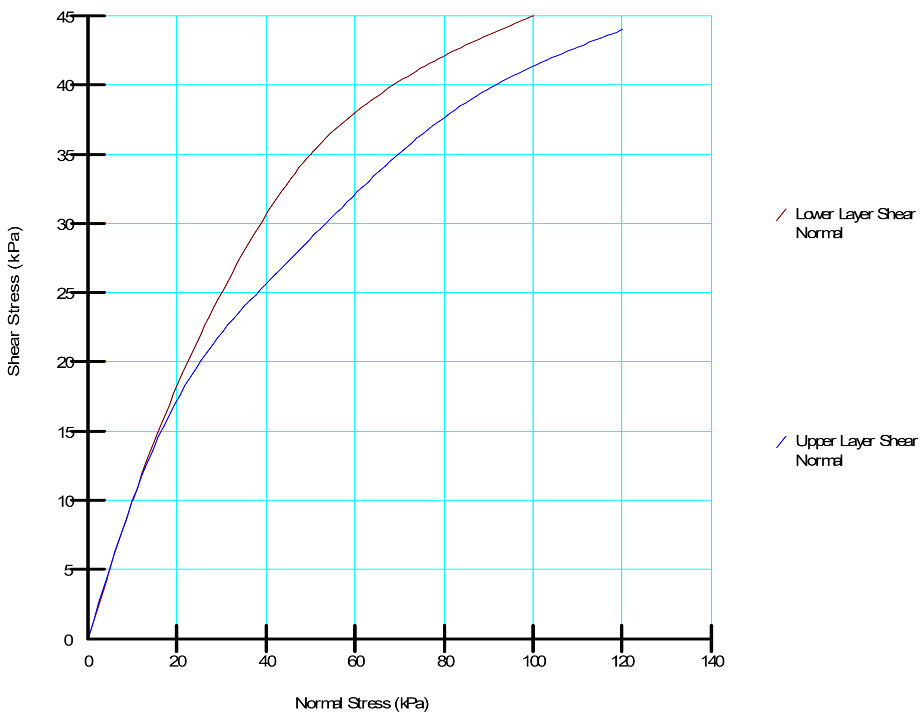

Figure 4. Shear-normal functions for the lower and upper layers.

Results and Discussion

Figure 5 presents the critical slip surface and factor of safety. Figure 6 presents the friction angle and cohesion at the base of each slice. Note that both values are nearly constant for slice 9 to 26. The effective base normal stress for these slices ranges from about 39 kPa to 43 kPa. The slope of the shear-normal function for the upper layer (Figure 4) is fairly constant in this range of stress; so, the tangential slope produces a fairly constant cohesion intercept and friction angle. The frictional strength component for these slices increases as the effective base normal stress increases (Figure 7).

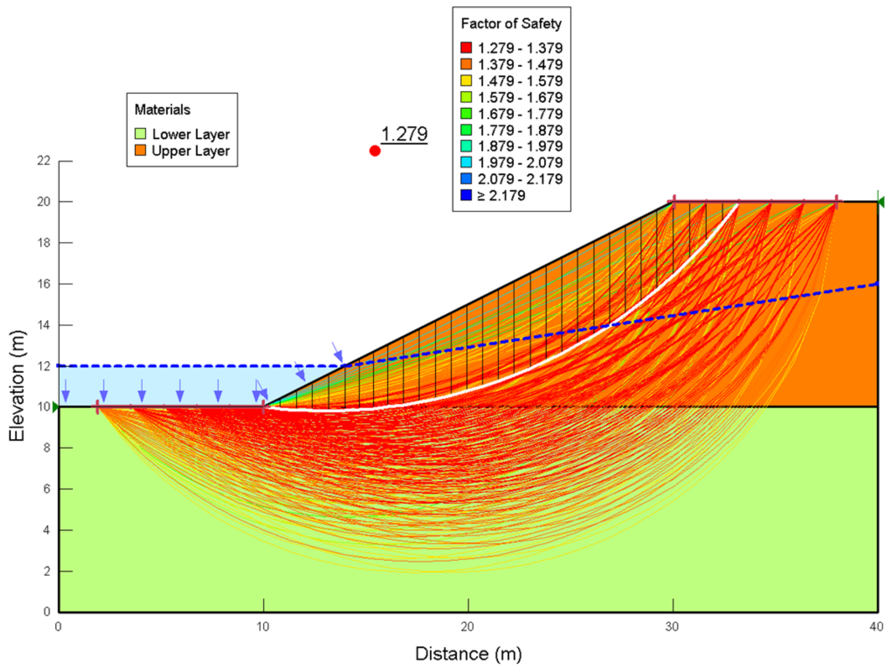

Figure 5. Critical slip surface and factor of safety.

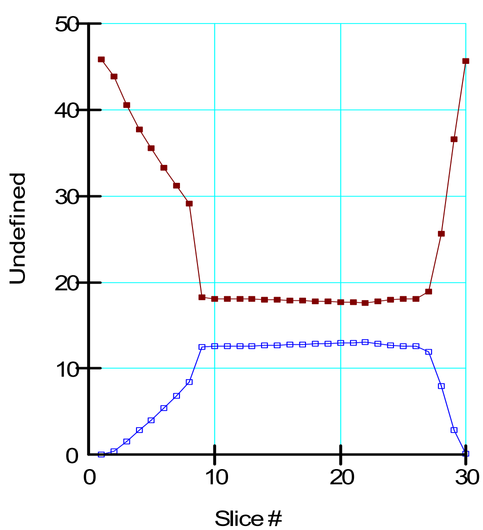

Figure 6. Variation in c′ and ϕ′ along the slip surface from toe to crest.

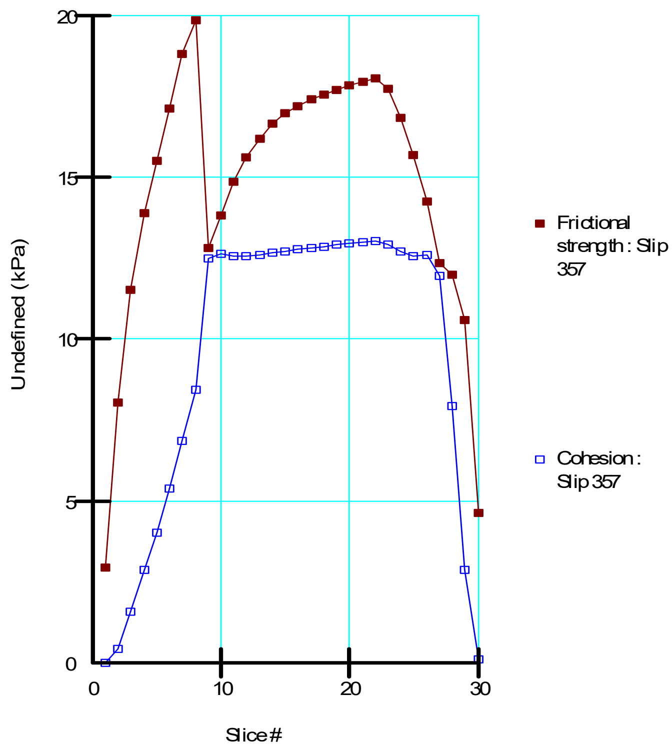

Figure 7. Frictional and cohesive strength components along the slip surface.

Summary and Conclusions

The SLOPE/W formulation is based on the conventional Mohr-Coulomb strength equation. The friction angle and cohesion must be defined at the base of each slice in order to compute the factor of safety. The user can elect to enter a value of zero for either parameter in the Mohr-Coulomb material model. Other material models such as Anisotropic, Strength as a Function of Depth, or Undrained require friction and/or cohesion inputs. However, the Shear-Normal material model uses a functional relationship defined as shear strength verses effective stress. SLOPE/W must therefore use a tangential slope for any given base effective stress to calculate a friction angle and cohesion intercept.