20– Slide-Isotropic Models

Slide and Slide3, two of the slope stability analysis tools developed by Rocscience, take advantage of the Limit Equilibrium approach in calculations of the Factor of Safety. The library of material failure criteria in this two software is very extensive. The Finite Element method with association with the Shear Strength Reduction (SSR) method provides a very powerful method for analysis of slope stability problems and evaluation of factor of safety as well. RS2 and RS3 the two Rocscience's finite element packages offer the SSR method. To extend the compatibility between our slope stability tools equivalents of all the failure criteria in Slide are developed as elastoplastic material models.

The Slide failure criteria, their formulations and special considerations for equivalent elastoplastic constitutive models are presented below. These models can take advantage of various elastic (stiffness) options in RS2 and RS3 that are included linear and nonlinear isotropic, transversely isotropic and orthotropic elasticity. The notation and conventions in representations of Slide models follow the conventions used in Slide.

20.1- Barton-Bandis

The Barton-Bandis strength model is originally formulated to model the shear strength of a joint. The Barton-Bandis strength model establishes the shear strength of a failure plane as:

$$\tau = \sigma_n \tan\left[\varphi_r + JRC \log_{10}\left(\frac{JCS}{\sigma_n}\right)\right] \tag{20.1}$$

where τ is the shear strength, σ_n is the normal stress (compression positive, as in Slide), φ_r is the residual friction angle of the failure surface (Barton and Choubey, 1977), JRC is the joint roughness coefficient, and JCS is the joint wall compressive strength.

The yield function of the equivalent elastoplastic model uses a Mohr-Coulomb criterion with instantaneous friction angle and cohesion calculated based on the current stress state. The residual strength for the elastoplastic equivalent model is a cohesionless frictional material with the residual friction angle φ_r. A dilation angle, ψ , is defined for the plastic potential function. The peak and residual tensile strengths are zero for this model.

For further information on Barton Bandis criterion see the Material Properties section in Slide help documentation.

In slope stability analysis using the Finite Element Method with Shear Strength Reduction, the factored shear strength can be calculated by applying the Strength Reduction Factor directly to the shear strength defined in equation (20.1). The instantaneous Mohr Coulomb properties are calculated based on the tangent to the factored shear strength envelope.

The SRF is applied to the dilation angle in the same way that is applied to the friction angle or Dilation angle in Mohr Coulomb criterion.

$$\psi_{SRF} = \operatorname{atan}\left(\frac{\tan\varphi\psi}{SRF}\right) \tag{20.2}$$

20.2- Power Curve

The Power Curve criterion for shear-strength can be expressed as:

$$\tau = a(\sigma_n + d)^b + c + \sigma_n \tan(\theta_W) \tag{20.3}$$

where a, b and c are parameters typically obtained from a least-squares regression fit of data obtained from small-scale shear tests. The d parameter represents the tensile strength. If included, it must be entered as a positive value. The parameter θ_W is the "waviness angle" defined for joints (Miller 1988).

The yield function of the equivalent elastoplastic model uses a Mohr-Coulomb criterion with instantaneous friction angle and cohesion calculated based on the current stress state. The residual strength for the elastoplastic equivalent model uses the same formulation as the peak strength. To define the plastic flow a constant dilation ratio is considered to find the equivalent dilation angle based on the instantaneous friction angle. The peak and residual tensile strengths are zero for this model.

For further information on Power Curve criterion see the Material Properties section in Slide help documentation.

In slope stability analysis using the Finite Element Method with Shear Strength Reduction, the factored shear strength can be calculated by applying the Strength Reduction Factor directly to the shear strength defined in equation (20.3). The instantaneous Mohr Coulomb properties are calculated based on the tangent to the factored shear strength envelope. The flow rule will use the same dilation ratio that is applied to the factored instantaneous friction angle.

20.3- Hyperbolic

A Hyperbolic shear strength criterion is defined by the following equation:

$$\tau = \frac{c_\infty \sigma_n \tan\varphi_0}{c_\infty + \sigma_n \tan\varphi_0} \tag{20.4}$$

Figure 20.1 shows this criterion in the shear-normal plane.

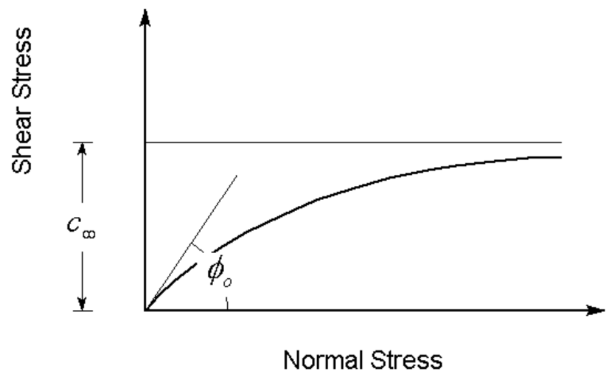

Figure 20.1. Hyperbolic shear strength criterion

Cohesion c_∞ is defined as the shear strength at $\sigma_n = \infty$, and friction angle φ_0 is defined as the friction angle at $\sigma_n = 0$. The Cohesion for a Hyperbolic shear strength envelope is the limiting, maximum shear strength, for high normal stress.

The Hyperbolic shear strength model has been found to characterize the shear strength of soil/geo-synthetic interfaces, and other types of interfaces (Esterhuizen, Filz & Duncan, 2001)

The yield function of the equivalent elastoplastic model uses a Mohr-Coulomb criterion with instantaneous friction angle and cohesion calculated based on the current stress state. The residual strength for the elastoplastic equivalent model uses the same formulation as the peak strength. To define the plastic flow a constant dilation ratio is considered to find the equivalent dilation angle based on the instantaneous friction angle. The peak and residual tensile strengths are zero for this model.

For further information on Hyperbolic criterion see the Material Properties section in Slide help documentation.

In slope stability analysis using the Finite Element Method with Shear Strength Reduction, the factored shear strength can be calculated by applying the Strength Reduction Factor directly to the shear strength defined in equation (20.4). The instantaneous Mohr Coulomb properties are calculated based on the tangent to the factored shear strength envelope. The flow rule will use the same dilation ratio that is applied to the factored instantaneous friction angle.

20.4- Shear/Normal Function

The Shear/Normal Function model allows you to define an arbitrary Shear /Normal function and construct a non-linear Mohr-Coulomb strength envelope for a material from piecewise-linear tabular entries.

The yield function of the equivalent elastoplastic model uses a Mohr-Coulomb criterion with instantaneous friction angle and cohesion calculated based on the current stress state. The residual strength is also defined in the same tabular format as the peak strength. Note that the yield surfaces are to be convex for both peak and residual states. To define the plastic flow a constant dilation ratio is considered to find the equivalent dilation angle based on the instantaneous friction angle. The peak and residual tensile strengths can also be defined for this model.

In slope stability analysis using the Finite Element Method with Shear Strength Reduction, the factored shear strength can be calculated by applying the Strength Reduction Factor directly to the values of shear strength in defined Shear /Normal function. The instantaneous factored Mohr Coulomb properties are calculated based on the stress level and factored Shear/Normal function. The flow rule will use the same dilation ratio and the Dilation angle is calculated based on the dilation ratio and the factored instantaneous friction angle.

20.5- Vertical Stress Ratio

The Vertical Stress Ratio criterion for shear-strength can be expressed as:

$$\tau = K\sigma_v' \tag{20.5}$$

where σ_v' is the in-situ effective vertical (overburden) stress by and K is a constant factor.

The yield function of the equivalent elastoplastic model uses a Mohr-Coulomb criterion with instantaneous cohesion calculated based on the current stress state. The residual strength for the elastoplastic equivalent model uses the same formulation as the peak strength. Friction angel and dilation angle are zero for this model. The peak and residual tensile strengths are optional and can be assigned for this model.

For further information on Vertical Stress Ratio criterion see the Material Properties section in Slide help documentation.

In slope stability analysis using the Finite Element Method with Shear Strength Reduction, the factored shear strength can be calculated by applying the Strength Reduction Factor directly to the shear strength defined in equation (20.5). The instantaneous Cohesion is calculated based on the factored shear strength envelope.

20.6- SHANSEP Strength Model

The SHANSEP model (Stress History and Normalized Soil Engineering Properties) is used for modeling undrained shear strength of certain clay soils (Ladd and Foote, 1974). For a soil subjected to a given stress path, the following equation describes the undrained shear strength:

$$\tau = A + \sigma_v' S(OCR)^m \tag{20.6}$$

where *A* is the minimum undrained shear strength, σ_v' is the in-situ effective vertical stress, *S* is the normally consolidated ratio of $\left(\frac{\tau}{\sigma_v}\right)_{nc}$, *OCR* is the overconsolidation ratio and the exponent *m* is a constant typically between 0.75 and 1.

The Stress History Type can be based on Overconsolidation Ratio or Preconsolidation Pressure. The following options are available for defining the stress history.

1- Constant - a constant value of OCR or Pc is defined for the material
2- By depth from upper material boundary - enter values of Depth and OCR or Pc. Depth is measured from the top of the material layer.
3- By elevation (y-coordinate) - enter values of Elevation and OCR or Pc. Elevation is the actual y-coordinate.

The in-situ vertical stress could be material dependent. By default, the weight of all materials above a given point, will contribute to the vertical effective stress at that point. However, options are available to fully or partially exclude some materials from contributing to the vertical effective stress. For this purpose, in the dialog, select Add Material to define the material(s) you wish to exclude from contributing to the vertical stress calculation, and then define a Vertical Stress Factor for each of these materials (0 to 1).

This is useful for excluding the weight of an added embankment material (for example) from the vertical effective stress calculation, or for simulating the staged addition of layered embankments.

The yield function of the equivalent elastoplastic model uses a Mohr-Coulomb criterion with instantaneous cohesion calculated based on the current stress state. The residual strength for the elastoplastic equivalent model uses the same formulation as the peak strength. Friction angel and dilation angle are zero for this model. The peak and residual tensile strengths are optional and can be assigned for this model.

For further information on SHANSEP criterion see the Material Properties section in Slide help documentation.

In slope stability analysis using the Finite Element Method with Shear Strength Reduction, the factored shear strength can be calculated by applying the Strength Reduction Factor directly to the shear strength defined in equation (20.6). The instantaneous Cohesion is calculated based on the factored shear strength envelope.

References

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