

13. ChSoil Material Model – FLAC

This model is the ChSoil model that is presented in FLAC. The model is developed using the user-defined material model option in RS² and RS³.

This model is a simplified version of the CySoil model. The model is designed to capture the deviatoric hardening behavior that is observed in soils associated with exhibition of increase in the stiffness and irreversible deformations. Such behavior was simulated by hyperbolic stress-strain in Duncan-Chang model. The short fallings of the Duncan-Chang model are that, 1) constitutive behavior is applicable prior to the failure and might produce unrealistic behavior afterward, 2) the volumetric behavior such as dilation cannot be simulated, and 3) the behavior was independent of the Lode's angle; for example the stress ratio at failure would be the same in triaxial compression and extension tests. The ChSoil model is a good alternative to Duncan-Chang model and does not have its aforementioned limitations.

The model is built upon the Mohr-Coulomb model and has a built-in deviatoric hardening rule and two options for plastic potential function. The elastic behavior is also nonlinear as the elastic modulus is dependent on the level of confinement. The yield surfaces and hardening characteristics of this model are illustrated in Figure 13.1.

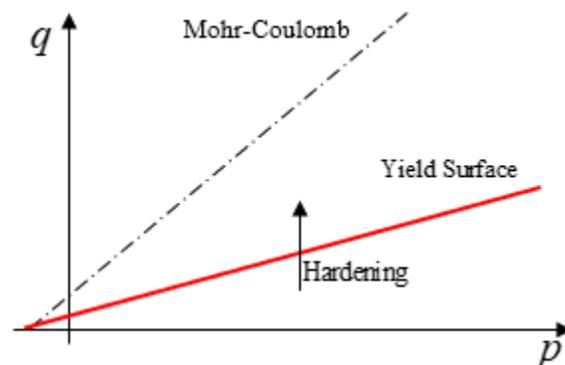


Figure 13.1- The yield surfaces of the CySoil Material Model

The stress dependency of shear and bulk modulus in ChSoil model are formulated separately but are similar as shown by

$$G_e = G_{ref} \left(\frac{p}{p_{ref}} \right)^n, \quad K_e = K_{ref} \left(\frac{p}{p_{ref}} \right)^m \quad (13.1)$$

where G_{ref} and K_{ref} are the shear and bulk modulus numbers, respectively, p_{ref} is the reference pressure, and m and n , are the modulus exponents which control the stress dependency of the elastic modulus and they are within the range of $0.5 < m, n < 1.0$. The combination of the two equations in 13.1 should be such that the Poisson's ratio is in its admissible range.

The yield surface of ChSoil model is very similar to the yield surface of the Mohr-Coulomb model.

The equation for the deviatoric yield surface using the principal stresses (p, q, θ) invariants is given by

$$F_s = q - Mp - Nc = 0 \quad (13.2)$$

where

$$M = \frac{3 \sin \varphi_m}{\sqrt{3} \cos \theta - \sin \theta \sin \varphi_m}, \quad N = \frac{3 \cos \varphi_m}{\sqrt{3} \cos \theta - \sin \theta \sin \varphi_m} \quad (13.3)$$

In above φ_m is the mobilized friction angle and c is the cohesion. The hardening for this yield surface is considered for the mobilized friction angle and it is attributed to plastic distortion, ε_q^p

$$\frac{d(\sin \varphi_m)}{d(\varepsilon_q^p)} = \frac{\sqrt{3} G_e}{2 p} \left(1 - \frac{\sin \varphi_m}{\sin \varphi_f} R_f \right)^2 \quad (13.4)$$

where φ_f is the ultimate/failure friction angle, and R_f is the failure ratio, one of the material parameters (less than 1.0 with a default value 0.9).

To establish an initial value for the mobilized friction the model takes advantage of another parameter, φ_{nc} , normally consolidated friction angle. The initial state of stress is also checked against this initial friction angle, if the initial state is not on or inside the yield surface the value of initial friction angle will be calculated such that the initial state is on the yield surface.

There are two options for the flow rule for the deviatoric mechanism of this model. The flow rule is defined in terms of the relationship between the plastic volumetric strain and plastic deviatoric strain in a way that

$$\dot{\varepsilon}_v^p = \sin \psi_m \dot{\varepsilon}_q^p \quad (13.5)$$

where ψ_m is the mobilized dilation angle.

The first option is based on the stress-dilatancy theory by Rowe (1962). In this theory the mobilized dilation angle is calculated based on the mobilized friction angle φ_m and critical state friction angle φ_{cv} . The essential concept behind the critical state friction angle is that while under shear the material will undergo dilation if $\varphi_m > \varphi_{cv}$ and will contract otherwise.

$$\sin \psi_m = \frac{\sin \varphi_m - \sin \varphi_{cv}}{1 - \sin \varphi_m \sin \varphi_{cv}} \quad (13.6)$$

$$\sin \varphi_{cv} = \frac{\sin \varphi - \sin \psi}{1 - \sin \varphi - \sin \psi} \quad (13.7)$$

In above ψ is the ultimate dilation angle.

The second option for the plastic potential uses a constant dilation angle, similar to that of the Mohr-Coulomb model where a dilation angle (ψ) is defined and controls the dilation tendency of the material, with a difference that it accepts an input value for critical friction angle, φ_{cv} , and dilation only happens when the mobilized friction angle is larger than the critical friction angle.

$$\begin{aligned} \psi_m &= 0 & \text{if } \varphi_m < \varphi_{cv} \\ \psi_m &= \psi & \text{if } \varphi_m \geq \varphi_{cv} \end{aligned} \quad (13.8)$$

The model takes advantage of a tension cutoff as well. This mechanism is to incorporate the tensile strength of the material to this model. In this mechanism the minor principal stress is limited to the tensile strength of the material. The flow rule is associated and the mechanism has no hardening.

$$F_T = \sigma_3 - T = 0 \quad (13.9)$$

In above T is the tensile strength of the material.

References

FLAC, "User's manual" (2011).