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FINITE ELEMENT ANALYSIS OF UNDERGROUND OPENINGS IN HOEK-BROWN ROCK WITH DILATANCY

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ABSTRACT

Underground openings in rock are encountered in a wide variety of engineering projects such as mining, tunnelling, underground storage, hydroelectric power generation and disposal of nuclear wastes. Design of such openings requires the analysis of stresses and displacements in rock mass surrounding the openings. For many types of rock, particularly for jointed rock masses, the conventionally used linear Mohr-Coulomb (M-C) failure criterion is not justified. For such rock masses, the recently developed non-linear Hoek-Brown (H-B) failure criterion [1] is considered to be more suitable. The yield function F and the corresponding plastic potential function Q for this failure criterion are given by

$$F = \sigma_1 - \sigma_3 - \sigma_c \left(m_b \frac{\sigma_3}{\sigma_c} + s \right)^a \quad (1)$$

$$Q = \sigma_1 - \sigma_3 - \sigma_c \left(m_{dil} \frac{\sigma_3}{\sigma_c} + s \right)^a \quad (2)$$

where σ_1 and σ_3 are, respectively, the major and minor principal stresses, σ_c is the uniaxial compressive strength of intact rock, m_b, s and a are the H-B constants depending on the properties of rock mass and m_{dil} is the dilation parameter. The value of a = 0.5 corresponds to the original H-B failure criterion [2]. The value of m_{dil} = 0 corresponds to non-dilating rock and m_{dil} = m corresponds to the associated plasticity.

Due to complexities in geometry and mechanical properties of rock mass, such as brittleness, plasticity and dilatancy, the finite element method is considered to be the most suitable method for the analysis of such problems [3-4]. In the application of this method for H-B rock with dilatancy ($m_{dil} > 0$), a computational difficulty arises because the iterative solutions may not converge. Furthermore, most of the available software for such problems can't handle the non-linear H-B failure criterion.

The objective of this paper is to propose a method of circumventing these computational difficulties by using the equivalent Mohr-Coulomb (EM-C) parameters. Existing

methods of obtaining the EM-C parameters [5] assume the plastic potential function to be linear and corresponding to the M-C failure criterion. The method proposed in this paper considers the plastic potential function to be non-linear and given by Equation (2).

A relationship is established between the dilation parameter m_{dil} and the angle of dilation by using analytical solutions [6-7] for circular openings in rock mass subjected to a hydrostatic in situ stress. The proposed method is implemented by using a commercially available software Phase^2 [8]. Eight-node isoparametric elements are used and for higher accuracy, elastic supports are used to simulate the effects of unbounded rock along the truncation boundary of the finite element model [9].

The effectiveness of the proposed method is demonstrated by conducting elastic-perfectly plastic and elastic-brittle-plastic plane-strain analyses of circular and non-circular openings in rock mass subjected to hydrostatic and non-hydrostatic in situ stresses. Parametric studies are conducted by varying the mechanical properties of rock mass including the dilation parameter. The effect of dilation parameter is found to be very significant on displacements around the openings.

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