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FRACTURE ANLAYSIS OF CRACKED ROCK MASSES UNDER COMPRESSION-SHEAR LOADING

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The rock masses have naturally a large number of cracks and discontinuities that cause to be prone to damage under dynamic loading. The earthquake as a kind of dynamic loading may propagate the inherent cracks in rock masses and leads to failure of the rock structures such as mines, oil and gas wells, tunnels, dams, etc. Therefore, the fracture of rock masses due to cracks under earthquake should be considered by civil, mining and even mechanical engineers and researchers. Fracture mechanics as a branch of mechanical engineering science has been frequently employed for investigating the fracture behaviour of cracked rock structures. According to the orientation of crack relative to applied load, the cracked parts may be subjected to pure or combined mode loading I, II and III. The underground rock masses are often subjected to a compressive loading due to the pressure of upper rock masses. In the first sight, the crack flanks under compression are pressured together and the geometry discontinuity is vanished. However, the crack faces may be subjected to sliding loading and the vulnerability of cracked rock masses is still remained. Therefore, the fracture analysis of cracked rock masses under compression-shear loading should be investigated. Similar to the mixed mode I/II loading, there are several studies in the literature investigated the fracture of cracked specimens under compression-shear loading both experimentally (Al-Shayea, 2005) and theoretically (Li et al., 2009). From the theoretical viewpoint, the compression is considered as a compressive stress in the stress field around the crack tip and then the fracture criteria based on new stress field is utilized for predicting the fracture resistance of cracked specimens.

The aim of this paper is to present a new approach for predicting the fracture load of cracked rock samples under compression-shear loading. The new approach is based on the maximum tangential stress (MTS) criterion that is one of the classical fracture criteria in fracture mechanics. The MTS criterion proposed first by Erdogan and Sih (Erdogan and Sih, 1963) for mixed mode analysis of brittle materials states that the crack propagates from the crack tip perpendicular to the direction of maximum tangential stress. Besides, the fracture occurs when the maximum tangential stress at the critical distance from the crack tip reaches to a critical value $\sigma_{\theta\theta c}$. In the proposed approach, the tangential stress component at critical distance is directly obtained from finite element (FE) analysis. When the compressive loading is applied on the crack flanks, the contact between the crack flanks should be considered. To model the contact between crack faces, the crack was simulated as a thin U-shaped notch. The experimental results carried out by Al-Shayea (Al-Shayea, 2005) on the central-cracked circular disk (CCCD) with different loading angles were employed to evaluate the proposed approach. The CCCD sample is a circular disk of radius R including a center crack of length $2a$ as displayed in Figure 1. The mixed mode loading in this specimen can be achieved easily by varying the direction of crack line relative to the load orientation, i.e. the crack angle α. When the crack angle α reaches to a specific value α_{II}, the CCCD specimen is subjected to pure mode II loading. For higher values of crack angle (higher than α_{II}), the crack flanks are pressured together and a combination of compression-shear loading is attained.

Simulating the BD sample with central U-shaped notch under an arbitrary compressive load (1000 N) in ABAQUS software, the stress field around the notch border were obtained as shown typically in Figure 2. Then, the direction of maximum tangential stress was calculated. After that, the maximum value of tangential stress at the critical distance was measured from FE. Since the linear elastic condition is considered in FE analysis, the stress components are proportional to the applied load. Therefore, the fracture load can be predicted by setting a proportion between tensile strength f_t, measured stress from FE and applied load as follows:

$$P_f = f_t \frac{P_{FEM}}{\sigma_{\theta\theta}(r_c, \theta_0)_{FEM}} \tag{1}$$

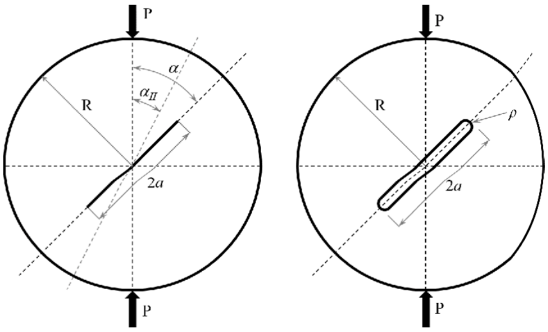

Figure 1. The schematic of CCCD specimen and its model with U-shaped notch.

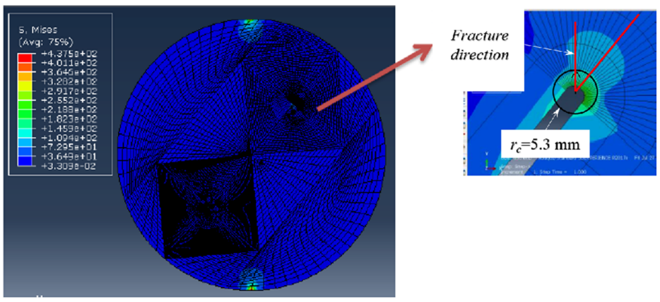

Figure 2. The tangential stress around the crack tip from FE.

Table 1 presents the comparison between the fracture loads predicted by new approach and those reported by Al-Shayea (Al-Shayea, 2005). As seen from this Table, the proposed approach can predict the fracture behavior of rock masses under compression-shear loading.

Table 1. The fracture loads predicted by proposed approach in comparison with those reported by Al-Shayea (Al-Shayea, 2005).

Dimension	Angle (degree)	Fracture load (N)	Fracture load (N) Al-Ahayea
R= 49 mm, a=25 mm	30°	9390	7644
R= 49 mm, a=25 mm	60°	8430	7154
R= 49 mm, a=25 mm	75°	8816	6958

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