Brittle failure criteria of entry roof and its support system optimization in underground mines

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Abstract: Since the early 1970s, U.S. coal mine entries have been supported by hundreds of millions of roof bolts. Many lives have been saved and hundreds of millions of tons of coal have been produced safely and economically. However, roof falls are a major threat to the safety of coal miners. The main reason is the inappropriate roof support system which could not be able to control/mitigate roof failures under low confinements (also named the roof brittle failure). Currently, the roof brittle failure mechanism is not fully understood due to inaccurate modeling of weak planes (joints, fractures, bedding planes or laminations), which are syn-genetic and exist everywhere in mines. In this research, there are two objectives: 1) develop the brittle failure criteria of entry roofs taking weak planes into account, 2) optimize the roof support system based on the proposed failure criteria.

Numerical simulations with UDEC/FLAC3D will be conducted to help understand the roof brittle failure mechanism. Rock brittle failure criteria will be developed at three scales, i.e., lab rock specimen (small-scale), synthetic rock mass (middle-scale), and entry roof (large-scale). At each scale, the bedding planes and flaws will be identified and coordinated with digital image processing techniques to build numerical models as similar as the lab rock specimen, synthetic rock mass and entry roof.

Firstly, brittle failure criteria of lab rock specimens with various confinements and anisotropy factors will be developed. The micro-parameters of zones and contacts will be calibrated directly to match the macro-parameters obtained in the lab, including geometrical parameters, elastic parameters, inelastic parameters, strength parameters and even crack propagation modes. However, the calibrated micro-parameters won't be used directly to the entry roof modeling due to the scale effect until the transmission by the middle-scale modeling (synthetic rock mass) is conducted. Therefore, we will propose a new method to transfer micro-parameters from small-scale to large-scale considering the micro-parameters reduction and the geometrical parameters of contacts (orientation, density, length, etc.). Besides these considered factors, the calibrated small-scale modeling, as a small unit, was spliced into the middle-, large-scale modeling. Brittle failure characteristics of each small unit will be calibrated based on the small-scale modeling results under various stress states. The macro-properties of middle, large-scale modeling will be verified based on the previous empirical equations and underground measurements. Brittle failure criteria at large-scale modeling will be developed after the above calibrations. Based on this criteria, the brittle zone in the modeled entry roof will be identified during different mining stages. Meanwhile, the ground reaction curves will be generated for further validating various roof support systems combined by bolts, cables, cribs. Finally, the most optimal roof support system will be determined based on the brittle failure criteria of entry roofs.

Therefore, for optimizing the entry roof support system, three scales analysis will be conducted on rock brittle failure criteria from small to large through numerical modeling. The results from modeling will be applied into the roof support system design for optimizing roof stress state to minimize roof issues. This research will be categorized as a fundamental study and serves as the basis for applied researches in utilizing numerical modeling to the mining industry.

Keywords: brittle failure criteria; entry roof support; weak planes; image processing