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Technical Note

# Improvement of methodology for block identification using mesh gridding technique

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ABSTRACT

This paper revisits a methodology for block identification in rock masses using a mesh gridding technique recently published by the authors (Zhang et al., 2010. A new methodology for block identification and its application in a large scale underground cavern complex. Tunnelling and Underground Space Technology 25, 168–180). An extension to the originally proposed methodology is introduced in this paper. The improvement involves consideration of the finite nature of the geological fractures when defined in a mesh grid. In accordance with this consideration, modifications to the block identification algorithm are made, and as a result, the number of nodes in the reconstructed model can be decreased considerably. This, in turn, allows the inclusion of a significant larger number of geological fractures into the model and the implementation of probabilistic block analyses schemes for a large number of stochastic fractures in a model. The improved methodology is applied to the block identification in other projects, including an underground powerhouse at Three Gorges Project in China and a hydropower plant in Zambia. Results with the proposed extended methodology are compared with those obtained with other techniques, for example, a computer code (GeneralBlock) and also with field observations of unstable blocks at the site. Results (location, geometry and degree of stability of blocks) with the different methods are seen to agree, suggesting that the extended proposed methodology can be applied to get valuable results in the process of identifying unstable blocks in rock masses around engineering structures.



## 1. Introduction

During the design and construction of excavation projects in blocky rock masses, the prediction and corresponding reinforcement measures of instable blocks are always major concerns for both researchers and engineers (Boyle et al., 1986). Rock masses always contain numerous fractures, such as faults, fissures and joints. It is also the fracture existence that makes rock masses different from intact rock entity. After rock excavation, the intersection between fractures and excavation surfaces inevitably generates rock blocks. Many of these blocks are exposed around excavation surfaces. If not properly reinforced, the exposed blocks will be probably a potential threat to project stability. As a result, the issue of block stability is placed with great attention in many engineering practices, such as the excavation of slopes, dam foundations and underground spaces in blocky rock masses (Gonzalez-Palacio et al., 2005; Turanboy, 2010). It is common knowledge for rock mechanics scope that an individual block is a complete rock entity enclosed by a combination of fractures, excavation surfaces and natural surfaces. As the geological discontinuities distribute arbitrarily in rock masses, the excavation of rock masses also leads to the arbitrary intersection of excavation surfaces and geological discontinuities. Therefore, rock blocks around excavation surfaces constitute a complex block system. Based on the above understanding, to make a successful and reasonable prediction of instable blocks under such circumstances, the following two necessities should be satisfied simultaneously:

- The excavation of rock masses should be precisely considered. For hydraulic, railway and highway tunnels, their profile is simple either on cross-section direction or along longitudinal direction. For instances, their cross-section shape can be describe by common forms such as circle, ellipse and horseshoe. As a result, the excavation of these tunnels can be easily considered and precisely described in block analysis. Many scholars have put forward block identification algorithms based on these simple-shaped tunnels (Liu et al., 2004; Song et al., 2001). Unlike the above conventional tunnels, the underground spaces of hydropower plants are characterized by their spatial complexity (Fig. 1). The underground spaces of hydropower plants typically

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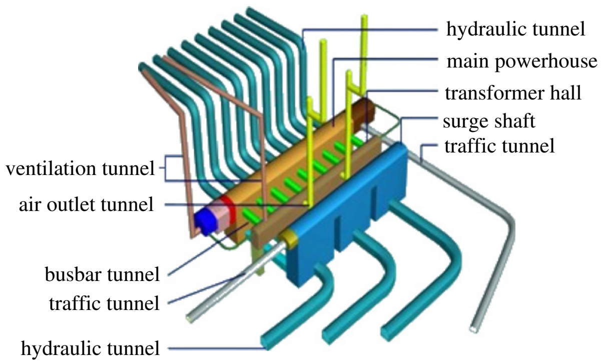


**Fig. 1.** Typical layout of hydropower underground cavern complex.

consist of a large number of caverns, including many intersected tunnels and large chambers. There are hydraulic, testing, traffic, air outlet and ventilation tunnels, etc. Also, the main powerhouse, transformer hall and surge shaft are generally named as the three primary chambers of underground hydropower plants. The above tunnels and chambers can be together collectively called as underground cavern complex. When an underground cavern complex is excavated in blocky rock masses, complex excavation surfaces are formed. Due to the complexity of excavation surfaces, their intersection with even a single fracture may generate instable blocks in both two and three dimensional cases (Zhang et al., 2010). Therefore, an accurate simulation of rock excavation is thus attached with great importance. To ensure an accurate simulation of rock excavation in underground cavern complex, it is required that both spatial shape of all caverns and detailed excavation steps of rock masses should be considered.

- Every detail of the geological fractures, including faults, fissures and joints, should be taken into consideration comprehensively. The fractures can be typically classified into deterministic fractures derived from field geological survey and random fractures used in stochastic analysis. For deterministic fractures, their location, occurrence and extent can be fixed and the information is clear. For random fractures, they do actually have arbitrary shapes and spatial extension in rock masses from three dimensional point of view. However, to obtain the real shape and extent of fractures is so far almost impossible. To facilitate the analysis of block identification, numerical simplification is introduced by many researchers when studying this issue (Kulatilake et al., 1993; Priest, 2004). A common and widely adopted assumption is to deem fractures to be planar and of a certain shape (Pan and Xu, 1989). For instance, fractures can be assumed to be disk shaped (Zhang and Wu, 2007). Therefore, although currently random fractures considered in block identification are likely not accurate enough compared to real situation, they are probably the most appropriate description to the best of people's knowledge.

The key block method proposed by Warburton (1983), Shi and Goodman (1989) and developed by many researchers (Lin et al., 1987; Ikegawa and Hudson, 1992; Lu, 2002) is recognized as a powerful tool in coping with block stability issues. Among these approaches and applications, the focuses are primarily placed on either the description of fractures or the identification process of blocks. The engineering objects which are to be excavated are often generalized as simple layout and concise profile, such as horseshoe-typed tunnels. As the research focus placed on the complexity of rock excavations is not sufficient enough, block identification applications in large and complex rock excavations, such as underground cavern complexes in hydropower plants, are rarely reported so far. Although current block identification algorithms may also handle these issues in which complex rock excavations are considered, their efficiency and applicability is restricted to a certain extent.

Mesh gridding technique refers to the technique commonly used in mesh discretization of analyzed objects. It is a fundamental procedure for finite element method and finite difference method. The block identification methodology using mesh gridding technique provides a new approach for block analysis. It is totally different from the traditional topology-based block identification algorithms. We introduced the basis of this methodology (Zhang et al., 2010, hereinafter referred to as previous study) and concluded that the employment of mesh gridding technique is able to precisely simulate the complex profiles of intersected tunnels and chambers. By applying the new methodology to block identification of a large scale underground cavern complex at a hydropower plant in southwestern China, its significant advantage to simulate complex rock excavations was verified. However, we also admitted that the proposed algorithm can only include limited numbers of geological fractures and lack capacity to cope with stochastic block analysis in which a great number of random fractures were considered. In this paper, this issue is further studied and the block identification algorithm is improved. The improvement is made with its focus on how to include as many fractures as possible. By introducing several modifications, the improved algorithm is able to include a large number of fractures in block identification. Thus, every detail of the geological fractures, including deterministic type and random type, can be reflected. Therefore, the two requirements for a successful prediction of complex block system can be fulfilled. To verify the correctness and rationality of the presented method, it is firstly applied to the underground powerhouse of Three Gorges Project to identify blocks. Afterwards, the proposed method is illustrated with its application to a hydropower underground cavern complex. The block identification results validate the effectiveness and reliability of the improved methodology.

## 2. General steps of the improved methodology

### 2.1. A review of previous study

The basic ideas of the methodology proposed by our previous study can be illustrated by a simple three dimensional example. A cubic region is supposed to be intersected by two fractures, entitled I and II (Fig. 2a). It is obvious that four blocks, entitled A, B, C and D (Fig. 2b), are formed within the considered region. The block identification algorithm using mesh gridding technique is carried out by three steps.

*Step 1:* the cubic region is discretized using mesh gridding technique (Fig. 3a). Fractures at this step are not yet considered. After mesh discretization, the analyzed region can be represented by mesh lines and mesh elements. It can be also deemed as the mesh grid which is commonly adopted in finite element analyses.

*Step 2:* fractures are inserted one by one into the mesh grid using element reconstruction technique (Fig. 3b). The element reconstruction technique solves the problem of how to represent fractures by mesh lines. As can seen, by applying the element reconstruction algorithms, totally 126 elements are generated in the cubic region. There are two dimensional algorithms and three dimensional algorithms for the element reconstruction algorithms, respectively. For two dimensional cases, the reconstruction algorithms are simple. There are two intersection patterns between a quadrilateral and an infinite fracture (Fig. 4). In pattern I (Fig. 4a), fracture I–I directly split the initial