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# Tunnel stability assessment by 3D DDA-key block analysis

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ABSTRACT

The key block theory is often the first analysis carried out in assessing potential instability caused by tunneling through jointed rock masses. This study suggests that it is beneficial to include it as the first step for a detailed design analysis by discrete numerical modeling, such as 3D DDA. The procedure is illustrated with an example which is simplified but is general and contains both primary and secondary key blocks. The agreement of the identified key blocks from 3D DDA and the key block theory provides credence for the DDA study, while the DDA, in turn, gives insights on how the failure of the unstable blocks evolves and complements the key block analysis.

## 1. Introduction

Before a detailed mechanical analysis is carried out, the key block theory (Goodman and Shi, 1985; Goodman, 1995) is often used first in identifying potentially unstable regions of a tunnel going through a jointed rock mass. All it needs is the spatial distribution of rock joints and the layout of the tunnel. With roots in topology, the key block theory finds the blocks formed by joints that can be removed from the face of a tunnel. It is from these removal blocks, or key blocks, instability may initiate. The process of locating key blocks is rational, fast, well defined and field verified (Hatzor and Goodman, 1992). As a result, the key block theory has become an indispensable tool for initial stability assessment of construction involves jointed rock masses (Greif and Vlčko, 2013; Sun et al., 2015; Fu et al., 2016). We propose herein that the key block theory could also play a vital role at the initial phase of a numerical investigation. To deal with the mechanical interaction across the discontinuous joint planes, a discrete numerical method, such as 3D DDA, is often employed for design. Such discrete numerical model is constructed using the same joint information employed by the key block theory, and that facilitates the proposed procedure. Specifically, we suggest that, for a given project, a global key block analysis for the whole tunnel be first carried out as it is generally done to locate the regions of potential instability. But before a detailed DDA study is conducted, an equivalent key block study is carried out in DDA.

The essence of the key block theory is that instability of a jointed rock mass can only be initiated on daylight blocks that are removable without obstruction. Once identified, the stability of the key blocks are determined by considering the local kinematics from its interaction with immediate neighbors. The key block theory utilizes the spatial distribution of joints for its topological construct, and the surface mechanical properties of the removable block for the stability calculation.

The key blocks first identified for a given problem have been referred to as the primary key blocks (Wibowo, 1997). By removing the primary key blocks, some neighboring blocks may be exposed to daylight and become removable. These newly removable blocks are denoted as secondary blocks. Progressive failure could take place through a cascade of such a removal sequence. To capture this, the key block theory is applied repeatedly by removing the newly formed secondary key blocks (Fu and Ma, 2014).

The key block theory does not deal with mechanical analysis and thus does not provide block displacement or stress information. The mechanical analysis of a jointed rock mass requires discrete numerical methods such as DDA (Shi and Goodman, 1989; He et al., 2013; Zhang et al., 2016; Zheng et al., 2016) to model the blocky system delimitated by joints. Its computational cost is high as DDA requires not only a continuous update of the location of each block, the contact states among blocks, but also the incorporation of the block mechanics. In a 3D setting, except for problems with simple geometry, the block interaction often is complex, and the veracity of a DDA solution difficult to verify. A key block analysis carried out within DDA could provide credence to a DDA model, and at the same time DDA also gives a clear picture of how key blocks become unstable, or how the progressive failure could evolve and be prevented. We therefore propose that the first step of a discrete mechanical analysis should be the computation of

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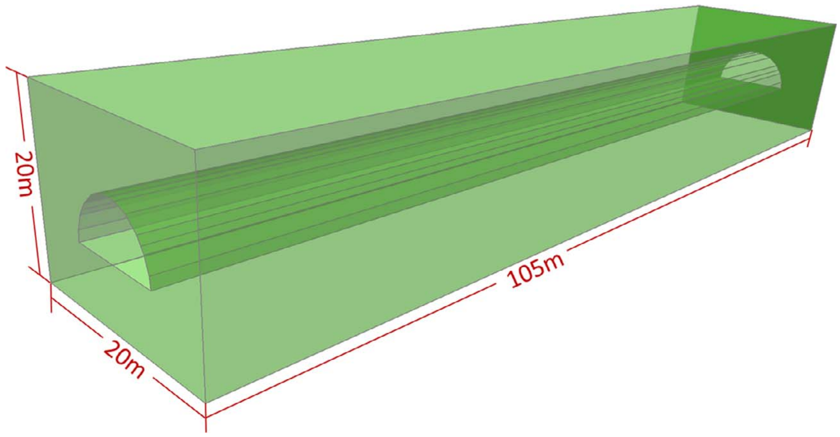


**Fig. 1.** 3D geometrical model of the tunnel.

**Table 1**
Joint set at the study site.

| No. | Dip angle | Dip direction | Quantity | Average Spacing spacing |
|---|---|---|---|---|
| 1 | 84.3° | 53.7° | 30 | 3.47 m |
| 2 | 81.7° | 326.9° | 8 | 4.26 m |
| 3 | 79.4° | 192.7° | 2 | 14.43 m |
| 4 | 65.1° | 208.2° | 1 | – |
| 5 | 86.4° | 88.4° | 1 | – |

key blocks.

The propose procedure includes the following steps. Firstly, the traditional key block theory is conducted as usual using the available joint information and the tunnel alignment. Based on the locations of key blocks identified, either a full 3D DDA model or sub-models, by taking only segments out of the full tunnel model, are built. Then, the key block analysis is conducted within the DDA on each of the segment extracted. In the following, we present an illustrative problem. It is first solved by a key block analysis and followed by a DDA study using a

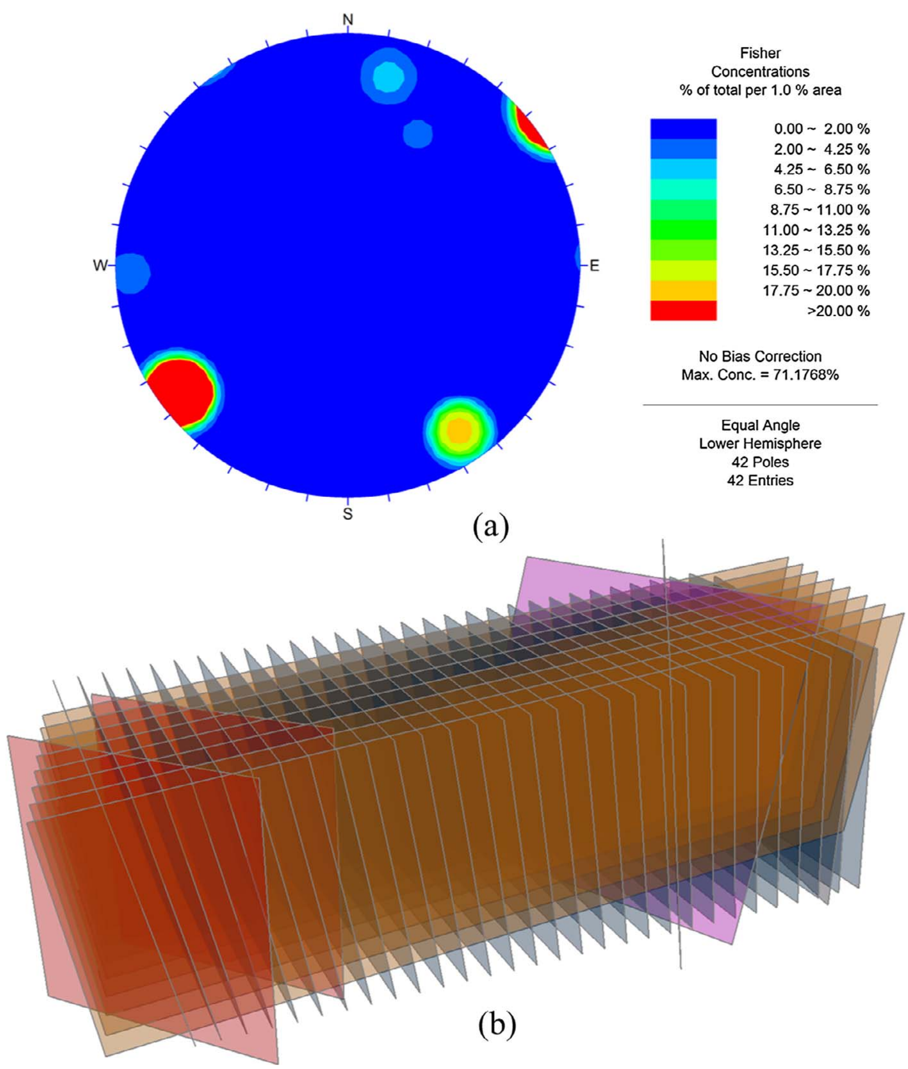


**Fig. 2.** Joint information (a) stereographic projection of joint orientation (b) a realization of the joint sets for analysis.