Early identification of rock fall hazard regions in surface and underground mines and quarries

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1. Introduction

The occurrence of rock slides and rock falls is frequent in mountainous areas in natural and man-made slopes (e.g. roads, quarries, mines etc.). A rock slide or fall starts from the detachment of a rock block or swarm of blocks from their original place. The initiation is caused due to various possible mechanisms like re-distribution of stresses due to nearby surface or underground excavations, rain-fall, seismic activity, fatigue and damage of rock bridges along critically oriented joints due to temperature fluctuations or freezing thawing etc. After initiation and block detachment a falling rock from high to low grounds will initially slide and roll (violent-fall phase) and finally it will only roll until it stops (tranquil-fall phase) as is shown in Figure 1.

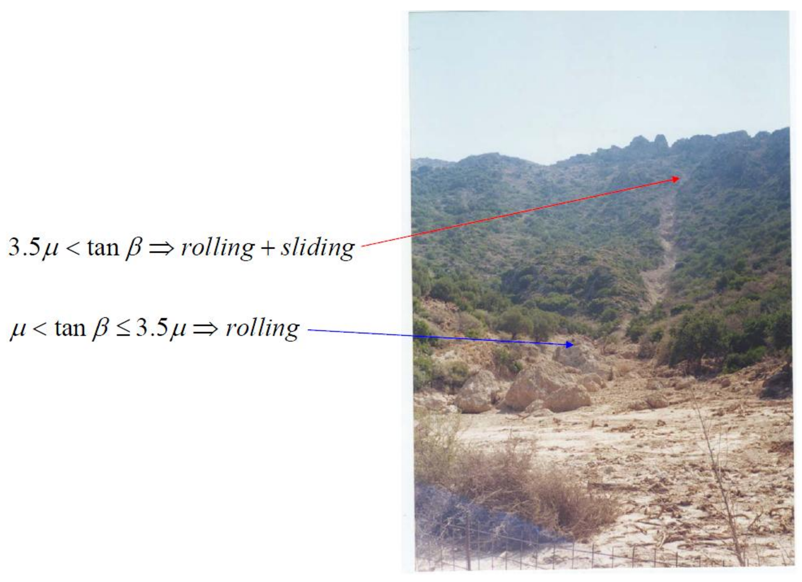

Fig.1

Rock slides and falls from the face, roof and ribs of underground mines are also a hazard of major concern. The scope of this presentation is not to study the dynamics of rock falls, but rather on the early identification of the regions exhibiting critical conditions for the initiation of a rock slide or fall. Provided such hazard zones could be promptly identified, then the proper design and installation of a early warning system based on microseismic measurements could be installed.

2. Construction of the rock mass joint network

Figure 2 presents an example case referring to the topography of a surface quarry and the location of a planned entrance of an underground quarry in the same region. The first step in the procedure of discontinuity geometry modeling in a rock mass should be the identification of statistically homogeneous regions (structural regions). To model discontinuity geometry in 3-D for a statistically homogeneous region, it is necessary to know the number of fracture sets, and for each fracture set, the intensity, spacing, location, orientation, and size distributions. Discontinuity geometry parameters obtained by the field data are subject to errors due to sampling biases and represent only 1- or 2-D properties (boreholes or scanlines and exposed rock surfaces, respectively). Therefore, before inferring statistical distributions for these parameters, sampling biases should be corrected on field data. Principles of stereology need to be used in developing expressions for both corrections for sampling biases and inferring 3-D discontinuity geometry parameter values from either 1- or 2-D parameters.

Figure 3 presents the orientation analysis based on the stereographic projection method of the joints measured at the exposed surfaces of the rock mass. Figure 4 refers to the subsequent discontinuity frequency analysis from a system of exploratory boreholes.

As is shown in Figure 5 the next task is the creation of the DTM and the lateral as well as the bottom boundaries of the model using a CAD software, and joint generation employing a three-dimensional distinct element code (3DEC, Itasca 2009). The subsequent step is the assignment of the intact rock and joint models and the necessary model parameters in the considered ground model (Stavropoulou, 2014).

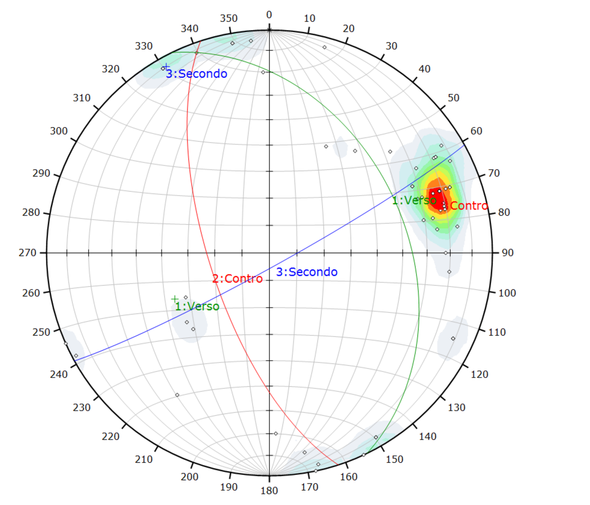

Fig. 3

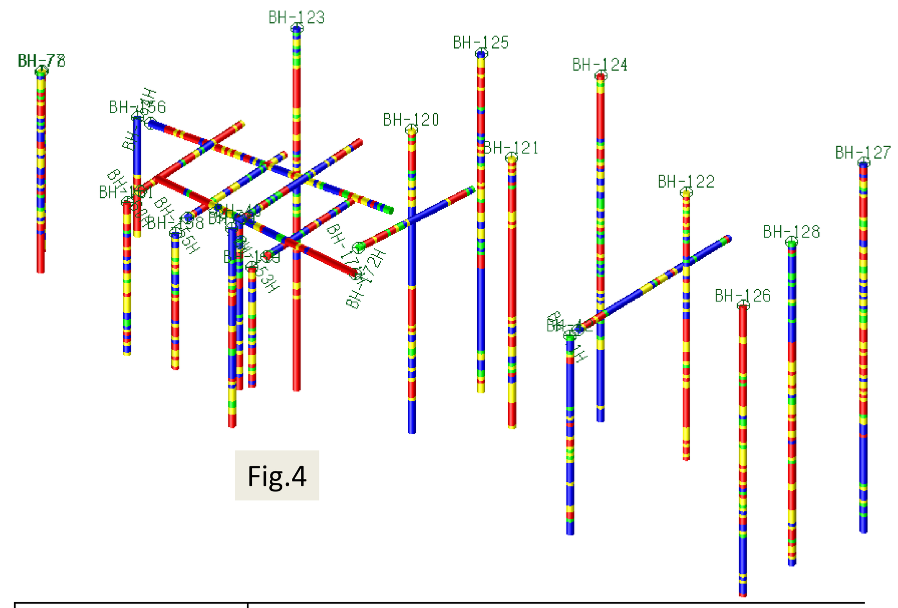

Fig.4

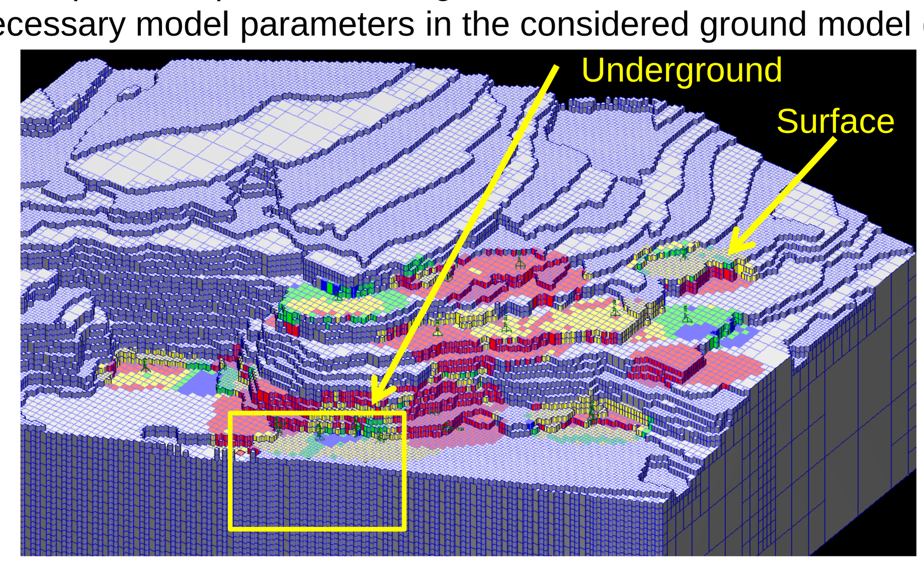

Fig.2

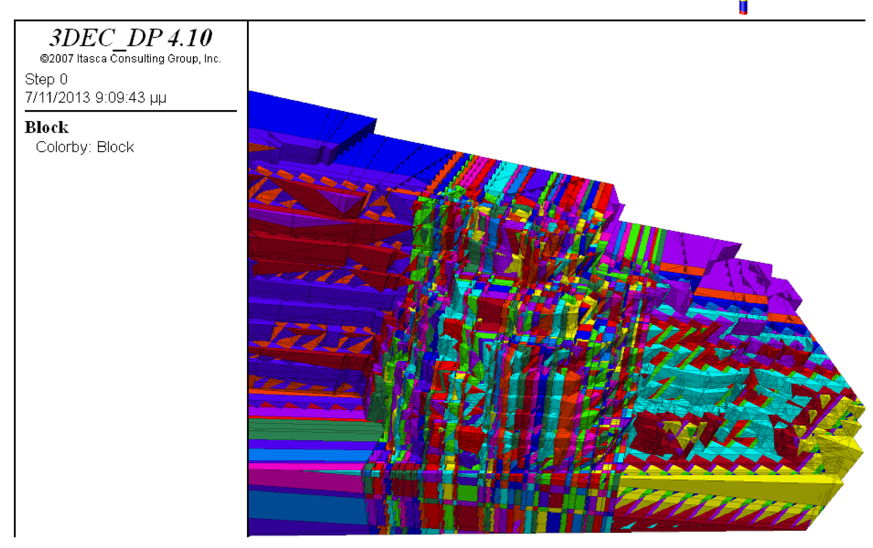

Fig.5

3. Rock joint model

An appropriate rock joint model should be able to reproduce well the main aspects of deformation and damage of cohesive fractures observed experimentally, namely, a non-linear elastic behavior before the stress peak, softening and decrease of the tensile and shear strengths with post-peak deformation, stiffness reduction after stress peak, general trends of irreversible relative displacements and existence of a residual stiffness in ultimate state under compression and shear. The damage process results from gradual breakage of rock bridges in the rock joint, as well as propagation of cracks starting at the end of existing fractures. The coalescence of these cracks forms ultimate failure planes. Damage in rock joints can occur under normal traction as well as shear stresses or in mixed modes. The effect of rock bridges breakage in the failure of rock joints and in the instability of rock slopes has been proven by field observations. Figure 6 presents two modes of failure in rock slopes described by Goodman & Kieffer (2000) namely a) Cracking and breakage of rock bridges under tensile stresses, (b) failure of rock bridges under shear stress. Such a joint model based on a hyperbolic criterion (Liolios and Exadaktylos, 2013) is under development.

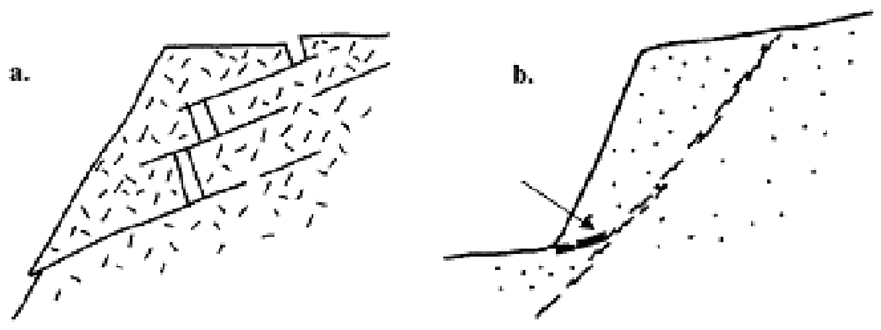

Fig. 6

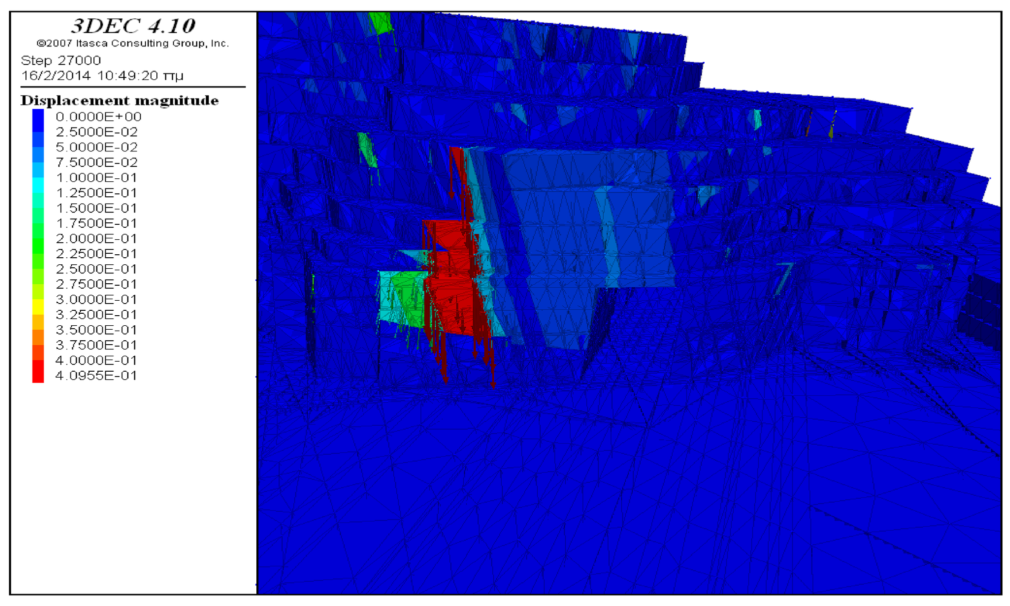

Fig. 7

4. Stability analysis and rock mass behavior monitoring

The stability analysis for the identification of potential rock fall or rock block instability zones could then performed with the following steps:

- After the creation of the 3D ground model the next step is the prescription of the gravity field and water table, the rest of the boundary conditions (displacements or loads), as well as the excavation steps.
- Subsequently, one may proceed with the identification of potential unstable rock block zones in the model as is shown in Figure 7. In this figure there could be observed the potential rock fall zone close to the portal of the underground gallery. The modification of the surface or underground excavation design to minimize potential rock fall zones may then be necessary and subsequently the decision making of the most appropriate active or passive rock support measures (such as bolts, wire-meshes etc).
- A decision on a passive rock mass behavior monitoring system is also important in the design phase. The system could be comprised of extensometers, crack meters and micro-seismicity monitoring stations. For example a seismograph with an array of geophones (e.g. Figure 8) could be used for the long-term monitoring of micro-seismic activity of the rock mass With the long-term monitoring one could investigate the correlation of seismic activity with mining activity, deformations, climatic conditions and direct measurements of a possible sliding process, and get an estimate of the 'normal' seismic activity, which in turn is the basis to detect increased seismicity related to an acceleration of a rock slide.

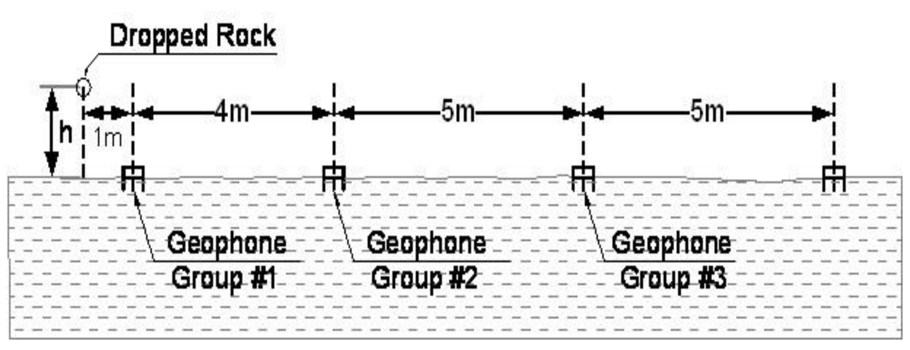

Fig. 8

5. References

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