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Geotechnical Risk Management Concept for Intelligent Deep Mines

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Abstract

Deep mining, driven by the increasing need of the sustainable use of mineral resources, yields a chance to exploit untapped resources. Nevertheless, large depths remain challenging and complex environment, posing geotechnical risks such as stress driven damage. The violent damage mechanisms in deep mines are spalling and strainburst in their most severe forms. Real-time monitoring can not only assist in preventing a failure, but can also assist in post failure mitigations. It can help identify the possible systemic failure of adjacent areas and can therefore help in evacuating people and machinery from these areas. The long-term goal is to develop a real-time risk management concept for intelligent deep mines. The objective of this paper is to summarize the outcomes of I^{2}Mine and DynaMine, formulate a risk concept suitable for real-time analysis and to produce a tangible measure of the risk levels. In this paper the Fault Tree – Event Tree methodology is proposed and an example is worked out using strainburst as an example risk case. The proposed methodology seems to work well and using a scenario with both property damage and ore loss, the risk expressed as financial consequences multiplied with probability drops from € 88,000 to € 11,000 corresponding to a - 80 % reduction in risk. The financial consequences together with the associated risk level can be expressed visually using a modified FN graph with financial loss on x-axis and probability on the y-axis. The developed geotechnical risk management concept suits the need of semi-automated or fully automated risk management. It would fit well in the analysis stage of the raw data and would produce a stress state change, which could be used as input in the risk management chain for intelligent deep mines.

Keywords: Deep underground hard rock mines; risk assessment; rock stress; real-time data; inverse calculation

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1. Introduction

The mineral resources are limited and mines are slowly expanding to tap into deeper deposits. With the increase of depth the transport costs and rock support costs increase. Massive extraction induces stresses and triggers seismic events. Failures in high stress conditions can have violent nature that aggravates mining conditions, threatens

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the mine stability and increases working hazards. The violent damage mechanisms in deep mines are rock spalling and strainburst in their most severe forms [1, 2]. Strainbursts are considered the most common rockburst type in deep underground excavations [3]. Typical indicators for high probability of strainburst are: increased depth of mining, contrasting rock types (e.g. hard and brittle rocks vs. weak and yielding), drill hole behaviour, geological factors (e.g. faults, fractures), the increase of rock noise, large excavations, sudden change in cross-section area, and the increase in microseismicity [4]. The severity of the failure depends on the ratio of far-field maximum stress (σ_1) and the short-term unconfined compressive strength of the rock (σ_c) [1]. Less violent and energetic spalling can start to occur when $\sigma_1/\sigma_c > 0.2$ [1]. In mining conditions, it might be hard to recognize the difference between progressive spalling failure and violent strainburst as both cause a clear notch in a tunnel perimeter and can induce seismic event that can be recorded only if a mine is equipped with a microseismic network. Risk management tools and guidelines are essential to maintain safe and economically feasible extraction in the harsh underground environment, but they still need improvements. One opportunity identified here is the development of the real-time geotechnical risk management systems. The philosophy underlying this concept can be expressed by the Data-Information-Knowledge-Wisdom (DIKW) hierarchy introduced by Ackoff [5]. The author considers data as raw measurements, from which information is derived. Processed and analysed data is used for identification of data relationships that contribute to understanding. Understanding of data patterns and processed information provides knowledge. On the top of the DIKW hierarchy there is wisdom that represents the decision-making based on the knowledge gained. The Innovative Technologies and Concepts for the Intelligent Deep Mine of the Future (I^2Mine) project running under the 7th Framework Program of the European Union produced useful tools that reflect the abovementioned hierarchy. One of them that aim at use of the real-time data is the Dynamic Intelligent Ground Monitoring Internet Network (DIGMINE) capable of stress and seismic near-to-real time measurements and another is the Geotechnical Risk Assessment (GRA) guideline developed to tackle the geotechnical risks in underground mines [6, 7, 8]. In this paper the review of these is given and an expansion of the GRA with the outcome from the Dynamic Control of Underground Mining Operations (DynaMine) project is proposed. The paper discusses the use of financial parameters as means of measuring tolerable and intolerable risk. With the use of Fault – Tree, Event Tree and F – N Diagrams [9, 10], a conversion of geotechnical risk into monetary values and comparing it with pre-set financial targets is proposed. This knowledge can then be used to support a decision-making process for strainburst risk management in underground mines.

2. Geotechnical real-time risk assessment and risk management tools

The risk management methodology in the burst-prone ground has to be suited for challenging geotechnical conditions so that the reduction of high geotechnical risk will receive more attention. Designs best suited for geomechanical characteristics of the site, which will lower the geotechnical risk, should be prioritized, rather than highlighting production and cost constraints [11]. The decision-making in such conditions should be a link between the outcome of the specific strainburst risk assessment and the general mine project risk, and it must be based on a realistic target of the acceptable level of risk specified by mine management [12].

The DIGMINE platform (Dynamic Intelligent Ground Monitoring Internet Network) is a new real-time Global Stress Monitoring concept introduced by INERIS in 2015 [13]. New methodologies of stress and seismic near-to-real time measurements employed in the system are capable of monitoring the stress changes in the vicinity of mining works in deep mines. The innovative equipment can monitor both quasi-static and dynamic stress fields, using global network monitoring arrays and mobile local-scale arrays. Also, the system aims to incorporate mine production data to create an overview of the overall progress of mining works. Continuous measurements of geotechnical and geophysical data would enable early detection of high stress concentrations and unexpected microseismic activity. Determination of initial stress state of a rockmass is performed by back-computation. The stresses are first measured with CSIRO cells and stored in a database with the numerical model according to the range of measured stress states for each location. After the sufficient amount of data is collected, the next step is to fit polynomial functions. Finally, avoiding complex 3D modelling, a fast computation of the corresponding induced or initial stress state is performed from the input stress state, either initial or induced. The system enables to display time-varying curves of measured and calculated stress shifts and enhance detection of caving by analysis