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Development of a geological model for chargeability assessment of borehole using drill monitoring technique

Rajib Ghosh*, Anna Gustafson, Håkan Schunnesson

Division of Mining and Geotechnical Engineering, Luleå University of Technology, 971 87 Luleå, Sweden

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ABSTRACT

In the mining industry, the ability to charge and blast a production borehole is fundamental. However, if rock mass conditions are challenging, with cavities, fracture zones or even unstable boreholes, the charging crew may fail to insert the required amount of explosives, resulting in bad fragmentation and significant production disturbances in the downstream process. Prior detailed knowledge of the chargeability of each production fan or ring will improve both the planning and execution of the charging work in a mine. The paper describes a study using the drill monitoring technique to assess the chargeability of production boreholes. For the study, data were collected on four drill parameters, penetration rate, rotation pressure, feed pressure and percussive pressure, from 23 drill fans with a total of 186 boreholes. A parameter called fracturing was calculated based on penetration rate variability and rotation pressure variability. Sixty-three boreholes were filmed to establish different rock mass conditions: solid rock, cavities, fractured zones and cave-ins. Principal Component Analysis (PCA) was performed to model the relationship between drill monitoring data and the geological features. The developed model shows high potential by identifying charging problems directly from drill monitoring data, and has been verified and validated in a real charging operation in an operating mine.

1. Introduction

The rock mass condition around a borehole normally consists of solid rock (non-fractured) interrupted by zones of fractured rock, water-bearing strata, and cavities. The chargeability, defined as the ability to charge a complete borehole as planned, is significantly influenced by these disturbed zones. For example, a borehole can be sheared into two parts by a fracture or a weak layer, with one part shearing off along a sliding plane.[1] It is almost impossible to charge the sheared part of the borehole. The borehole can collapse because the rock in the sliding plane will break.[2] In another scenario, cave-ins, pieces of rock can collapse from the borehole wall and block the opening.[3] Uncharged and undetonated blast holes will reduce the specific charge and result in poor fragmentation and may even lower ore recover.[4] If there is a cavity, there is also a high possibility that the borehole will be pumped by excessive explosives.[5] Further, if there is a delay between the charging and blasting operation, explosives (emulsion) may flow into the cavity because of gravity, and some part of the borehole may be uncharged. The assessment of the in-situ condition of the rock mass is therefore important to improve the chargeability of a borehole.

Field investigations at Luossavaara-Kiirunavaara AB's (LKAB's) Malmberget underground mine in Sweden have looked at rock mass conditions influencing borehole instability, including shearing, cave-in, cavity, weak rock, fractured rock, crushed zone etc., using a digital camera.[5–7] It is known that borehole instabilities, such as borehole deformation and damage, are likely to be worsened by high-stress states, production blasting, the effect of hanging wall collapse, rock bursts, and mine seismicity.[8]

Measurement While Drilling (MWD) is a well-established technique to characterise the in-situ condition of penetrated rock mass in mining and petroleum industries.[9] In the MWD technique, a number of drill parameters, such as penetration rate, feed force, percussive pressure, rotation pressure etc., are monitored at pre-defined intervals along the borehole and used to calculate the properties of the penetrated rock mass. The drill monitoring technique provides high-resolution data. It is also suitable for different drilling techniques, such as rotary drilling and percussive drilling.[10–17] Brown et al.[18] defined several useful areas of application for the MWD technique. For example, it can provide a measure of mechanical properties of the rocks being drilled based on the relation between measured drilling parameters, compressive strength of the drilled rock and specific energy of the drilled rock. It can also indicate major discontinuities, such as open or clay filled joints and faults. Scoble and Peck[19] showed that the monitoring and interpretation of drill performance data enable the determination of rock mass

* Corresponding author.
E-mail address: rajib04ce@gmail.com (R. Ghosh).

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strength and structure. These authors found a correlation of drill performance parameters with changes in intact rock strength, lithology and frequency of fractures. A relationship between drill performance parameter responses, rock compressive strength and shear strength for rotary blast-hole drilling operation is established in a western Canadian surface coal mine.[11] A portable hydraulic-powered coal mine roof bolt drill was proposed[20,21] to classify roof strata in coal mines, using drill parameters, such as thrust, torque, rotary speed and penetration rate, for the classification. Finfinger[22] conducted a series of experiments to determine the relationship between drilling parameters and geo-mechanical rock properties in tunnel roofs, including the presence of fractures, voids, locations of rock layer boundaries and the strength of rocks. Gu[23,24] attempted to map roof geology in real time by developing a new drilling parameter called drilling hardness to detect the location of interfaces between rock layers and discontinuities and to classify the rock types for underground coal mining. According to Itakura et al.,[25] field experiments using an instrumented roof bolter showed that software could analyse the mechanical data log and display locations of discontinuities using neural network techniques. Kahraman et al.[26] recently provided a comprehensive review of ground characterisation for underground mining and construction using instrumented drills.

The present paper describes a study using MWD data to predict potential chargeability problems in Luossavaara-Kiirunavaara AB's (LKAB's) Malmberget mine, Sweden. It develops a geological model for the assessment of the chargeability of a borehole based on drilling data from water powered In-The-Hole (ITH) drilling.

2. Methodology

The research is based on a literature review, drill-monitoring data, the filming of production boreholes, and the monitoring of the charging operation. It uses statistical methods to analyse drill data. Data were collected from LKAB's Malmberget underground iron ore mine in Sweden.

2.1. Drill monitoring technique

In the Malmberget mine, drilling is done with fully automated Atlas Copco SIMBA W6C drill rigs equipped with hydraulic Wassara In-The-Hole (ITH) hammers. The Atlas Copco drill monitoring system is used to retrieve and store MWD data. The recorded data include penetration rate (m/min), percussive pressure (water pressure measured by bar), feed pressure (bar), rotation pressure (bar), depth (m) and time (YYYY-MM-DDThh:mm:ss). The measurement interval can be set; in this case, it is about 3 cm along the borehole. The data are transferred from the rig to a Rig Remote Access (RRA) server through a wireless network.

Drill monitoring data were collected for a total of 186 boreholes (fans number 21–43) in one of the mine's ore bodies. Of the 186 available boreholes, 63 were filmed using a digital camera; 44 could not be filmed because borehole collapses created obstructions to filming. The diameter of a borehole is about 115 mm with an approximate burden (the distance between two subsequent fans) of 3.5 m. The length of the boreholes in the monitored fans varies between 11 m and 43 m. Most of the fans in the studied drift consist of 8 boreholes but a few, close to the foot wall side, have 9 boreholes.

2.2. Borehole filming

A digital camera was used to capture different rock mass conditions, such as solid rock, rock cavities, crushed zones, fractured zones, cave-ins and changes in rock types, intercepted by the production borehole (blast-holes). Fig. 1a shows the experimental set-up of the borehole filming. The camera was tightly fixed in a funnel shaped steel casing (Fig. 1b). The funnel shape steel casing holding the camera was then fastened to a cylindrical steel casing (Fig. 1c). It was connected to the pipe of the charge truck used to push the camera up into the borehole.

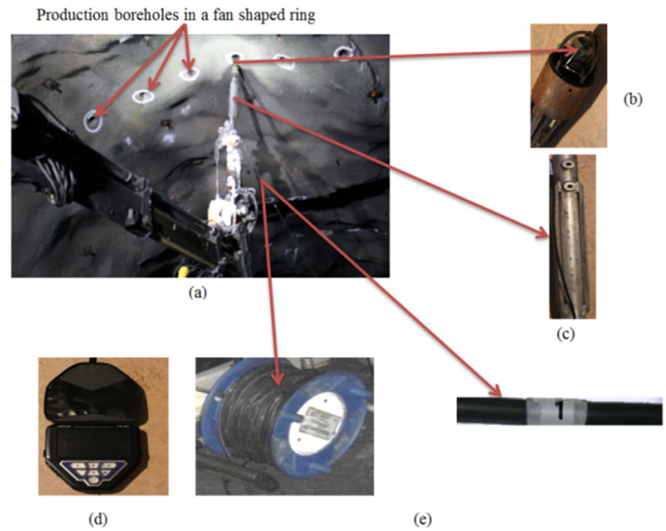

Fig. 1. (a) Steel casing connected to camera and fastened to the pipe of the charge truck, (b) Camera in funnel shaped steel casing, (c) Cylindrical steel casing, (d) Display monitor, (e) Cable wrapped and marked for each metre.

Fig. 1d shows the monitor. The monitor was used to observe different features inside the borehole during filming. Fig. 1e shows a cable of about 60 m in length connecting the camera and the monitor. This cable was marked at every 1 m interval for additional length control.

2.3. Monitoring of charging operation

The analysis of the potential effects of different geological features on borehole chargeability is based on data gathered during the charging operation. To verify the analytical model for chargeability based on MWD data, the underground charging operation at the mine was followed for eight shifts. The goal was to compare predicted chargeability, based on MWD, with the actual problems encountered by the charging personnel. The charging was also monitored to determine the procedures used in the mine. In total, the study followed the charging of 37 fans containing 290 holes. Fig. 2 shows a charging operation carried out for a borehole in one of the studied fans. Different types of charging problems encountered at various depths of boreholes were followed and documented. For example, if the charging hose was obstructed at 5 m depth because of the collapse of rock (cave-in), it was noted as “cave-in at 5 m depth.” If the charging hose was not obstructed, “no charging problem” was noted. Further, staffs responsible for the charging procedure were interviewed to determine their current practices to handle various challenges in the day-to-day charging activities.

Fig. 2. Observation of charging procedure in a borehole.