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Large scale dynamic testing of rock support at Kiirunavaara – Improved test design

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ABSTRACT

Based on the test results and preliminary numerical analysis of four large scale dynamic testing of rock support (Tests 1, 2, 4, and 5), a modified test (Test 6) was designed at LKAB Kiirunavaara underground mine. The aim of the modified design was to avoid the unexpected damage of burden as was observed in earlier tests, and to modify the dynamic loading leading to increase the depth of fractured zone and if possible pushing the support system beyond its limit. In this test, ground motion measurements were conducted using accelerometers, fracture investigations were made using an inspection borehole camera, and ground motion imaging and laser scanning were performed before and after blast. In Test 6, the columns of explosive were located in the middle of a pillar between two cross-cuts one supported by a rock support for seismic conditions, and the other supported by only plain shotcrete. Results indicated that a larger fractured zone compare to earlier tests was developed behind the support system while the installed support system was still functional. In cross-cut without support system, the ejection of blocks of rock from the test wall was observed. Evidence from two cross-cuts indicated a reduction of radial cracks that provide access for the gas expansion. Furthermore, the performance of the rock support was investigated by comparing with the results from the unsupported cross-cut. The results indicated that the installed support system, designed for dynamic conditions, performed well under the loading conditions which can cause ejection.

1. Introduction

Increasing mining depth causes an escalation of ground control problems due to over-stressed rock as well as an increase in occurrence of damage caused by seismic events with increasing magnitude. Safe and stable underground constructions are crucial to achieve a safe working environment, optimal utilization of mineral resources and efficient mining at great depths. One of the most important measures to maintain stable and safe openings is ground support systems which are capable of withstanding strong dynamic loads.

Under dynamic loading conditions, the dynamic capacity of systems and the demand that will be imposed by the rockburst are unknown. This introduces a case of design indeterminacy (Potvin and Wesseloo, 2013; Stacey, 2011). However, according to Stacey (2011), the physical testing of the capacity of support elements provides positive information regarding the design of rock support for rockbursting conditions. In order to quantify the performance of the rock support systems under dynamic loading conditions, four main types of dynamic tests are considered including simulated large scale experiments by means of blasting, drop test facilities that apply an impact load on the reinforcement, laboratory tests applying dynamic loads on core samples, and passive monitoring and back analysis of case studies (Hadjigeorgiou and Potvin, 2007).

This paper focuses on to develop an in-situ testing method for rock support, i.e., to determine the dynamic load that causes failure to the test wall and/or support system, and to evaluate the performance of rock support systems under strong dynamic load. Large scale seismic event simulations have been performed in different parts of the world in order to assess the capacity of ground support systems since 1969 (Andrieux et al., 2005; Ansell, 1999, 2004; Archibald et al., 2003; Espley et al., 2002; Hagan et al., 2001; Heal et al., 2005; Heal and Potvin, 2007; Heal, 2010; Ortlepp, 1969, 1992; Tannant et al., 1994, 1995). Different blast layouts (e.g. blasthole angle and burden) were used by the different researchers based on the objective of their tests. Different levels of success in obtaining the desired amount of damage to the rock support/rock mass were observed. Despite the difficulties and uncertainties with simulated seismic event tests, the method still

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Nomenclature

List of symbols

A	accelerometer (–)
B_{ave}	average burden (m)
BH	blasthole (–)
d_C	charge diameter (mm)
E	energy (kJ/m^2)
g	gravitational acceleration (m/s^2)
I	observation borehole (–)
L_{BH}	length of blasthole (m)
L_C	charge length (m)
v	peak particle velocity (m/s)
t	depth of failure (m)
ρ	rock mass density (kg/m^3)

provides the greatest validity as a significant test of rockburst support capabilities, even though it does not simulate a rockburst (Stacey, 2012).

In previously conducted large scale dynamic testing of rock support, the crucial issue for success was the design of the blast in order to generate waves which in some way imitate the characteristics of the waves from a real seismic event. Another issue was to reduce the destructive effects of expanding gases generated by the blast. A series of large scale tests (Tests 1, 2, 4, 5 and 6) were carried out in pillars/cross-cuts in the northernmost part of the Kiirunavaara mine. The results from Tests 1, 2, 4 and 5 (Shirzadegan et al., 2016) raised questions related to the above mentioned issues. Therefore, in order to improve the blast design, the failure mechanisms were investigated by studying the results from earlier tests (Shirzadegan et al., 2016) and numerical simulation of the tests using a two-stage numerical modelling approach (Zhang et al., 2013). The findings were then used to design Test 6 which is described in detail in this paper. Evidences from the damage investigations after the blast in Test 6 indicated that the new design was quite successful in generating a more planar wave and reducing the gas expansion. Furthermore, attempts were made to estimate the performance of the surface support by linking the deformation of the rock support system from this series of the tests to the results from previously conducted laboratory tests (e.g. Thyni (2014)). The performance of the installed support system was investigated based on the damage mapping after the blast, the PPV and the kinetic energy calculations.

2. Kiirunavaara mine and the geology of the test site

The Kiirunavaara mine, in the northern part of Sweden, is an iron ore mine with an orebody that strikes nearly North-South and dips 60° to the East. It is about 4 km long of which 3.8 km is currently being mined (Malmgren, 2005) and has an average thickness of 80 m. The mining method used at the Kiirunavaara mine is large scale sublevel caving. The tests were carried out in the northernmost part of the Kiirunavaara mine (Sjömalmen) at the block 9 mining level 741 m. The cross-cut 100 (right/southern wall) and cross-cut 103 (left/northern wall) were used for the Test 6. The location of the test site and the overall geology in the test area is illustrated in Fig. 1. According to Andersson (2010), the rock types in the test area have traditionally been referred to as syenite porphyries, including a nodular variety (Geijer, 1910), mainly consisting of trachyte to trachyandesite (Ekström and Ekström, 1997) of variable character and degree of alteration. The rock mass in the area was very blocky and the geological strength index (GSI) values

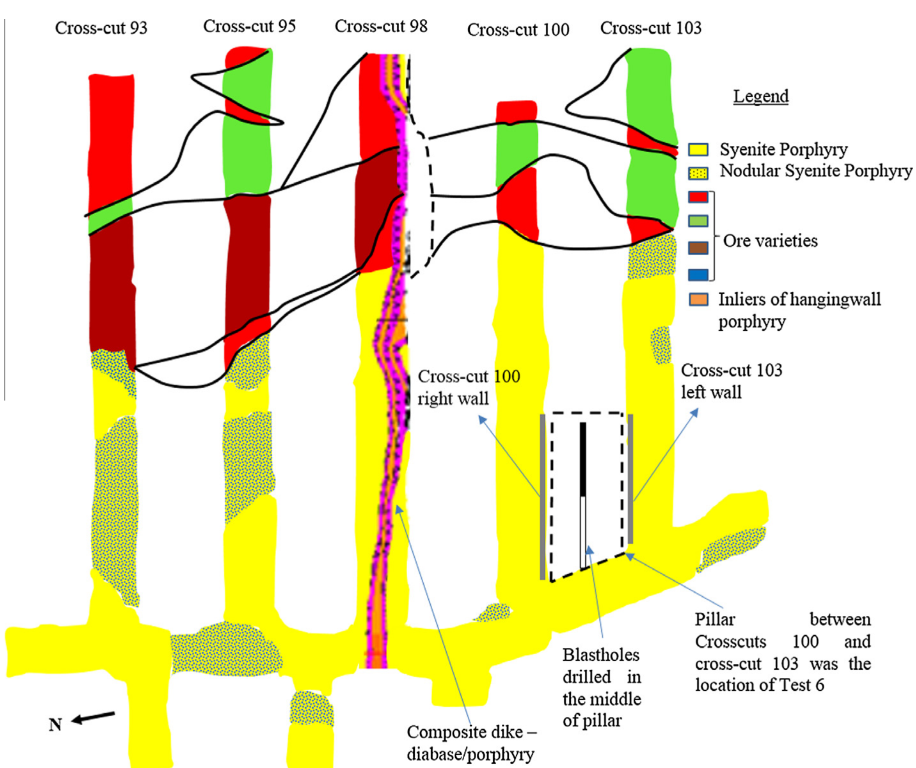

Fig. 1. Geology of the test site. Extracted from the database of underground mapping at LKAB (Andersson, 2010).