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Technical Note

Blast-induced dynamic rock fracture in the surfaces of tunnels

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1. Introduction

Blasting plays an important and active role in mining and rock engineering. At the same time, however, blasting may cause negative effects on mining safety and environment. For example, blasting usually induces dynamic rock fracture in and near the surface of a drift in underground mines as the surface is close to explosive charge. The most typical example of such a dynamic rock fracture is the back break and brow damage in sublevel caving mining, as shown in Fig. 1 [1] that indicates a church-shape roof formed by the back break and brow damage due to blasting (also due to the orientation of rock mass discontinuities and stress redistribution). Fig. 2 shows a serious dynamic rock fracture consisting of back break and brow damage, mainly because of incorrect detonator placement, where the right part of the figure shows the stress distribution as one portion of explosive charge in the blasthole is detonated. Both back break and brow damage endanger field work such as charging and loading operations. Accordingly, some investigations on the back break and brow damage in sublevel caving mining have been made and corresponding measures for reducing them been studied [1,2]. However, note that the dynamic fracture in back break and brow damage is usually very close to blast sources, meaning that the dynamic loads on rock due to blasting are very strong. Therefore, such a dynamic rock fracture is relatively easy to understand.

In underground mining and tunneling, various types of blasts may be carried out, and the explosive charge may not be close to the surface of a tunnel. In this case, it is necessary to know whether or not the blast will cause any rock fracture in the surface. Furthermore, in case rock fracture happens, we need to know what is the mechanism of fracture and if we can control and reduce such a rock fracture. On this background, this manuscript will report two types of blast tests related to dynamic rock fracture relatively far from the explosive charge. Correspondingly, a simple stress wave analysis will be performed. At the same time, it will be shown that the dynamic fracture in the drift roof by multi-hole blasting can be controlled by changing delay times.

2. Dynamic fracture in drift walls far from explosive charge

2.1. Blast test

This blast was originally for calibrating the seismic system in Malmberget mine. One borehole was drilled in the wall of a drift. The wall was a free surface, as shown in Fig. 3. The borehole was 10 m long and 115 mm in diameter. A total of 4 DynoRex packages each of which was 32 mm in diameter and 1.1 m in length were bound together and stemmed by one plastic plug plus waste clothing. The detonator was placed near the toe of the hole.

2.2. Dynamic fracture caused by the blast

After the blast, the rock in the free surface (i.e., drift wall) surrounding the borehole collar was broken off. The broken region was about 1 m × 1.2 m × 0.2 m, as shown in Figs. 3 and 4. In addition, the borehole length became 5.3 m after this blast, meaning that 4.7 m long borehole was either completely destroyed by the blast or partly broken and partly filled with fragments. We can see from Fig. 4 that the borehole looks good from the collar, i.e., there is no breakage in the borehole wall close to the collar, even though the wall is also a free surface. This is not strange since the borehole wall is curved and its confinement should be much greater than in the drift wall.

The interesting result is the rock fracture in the drift surface shown in Fig. 4, even though the nearest charge position is 8.9 m far from the collar. In addition, the fracture surface in the broken region looks smooth, indicating a typical character of tensile fracture. Note that the broken region was 0.2 m deep from the

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drift wall (as shown in Figs. 3 and 4) and the shotcrete in the drift wall was about 0.1 m thick, so the surface of the broken region was in the rock mass.

3. Dynamic fracture in drift roofs far from explosive charge

3.1. Blast tests

In sublevel caving mining, in order to reduce blast-caused ground vibrations, a blast method called Dividing Ring Blast (DRB) was developed and used in Malmberget mine [3]. The method works successfully in vibration reduction in the mine [4]. Since 2011 this method had been tested to improve rock fragmentation in the mine. In the DRB tests, every production ring is separated into two parts from the middles of the boreholes. For instance, the ring in the right side of Fig. 5 is separated by the dashed line FDG. Each DRB ring consists of two semi-rings, and all the blastholes in both semi-rings are initiated with different delay times. In Fig. 5, one DRB ring includes the lower part of ring 1 (R1) and the upper part of ring 2 (R2). Note that before the blasting of this DRB ring, the upper part of ring 1 has already been blasted. In the blast of this DRB ring, the lower part of R1 and the upper part of R2 are charged, but the lower part of R2 is left to be empty. The empty part is 20 m long in all boreholes in each ring. For example, in borehole 4, the explosive is charged above position D, i.e., the borehole between D and the collar is empty. The longest hole is the middle one, i.e., hole 4 in the figure, and its length is about 40 m, the others are shorter. All boreholes are 115 mm in diameter and they are fully charged.

In order to improve the fragmentation in the upper parts of the DRB rings, electronic detonators with 10 ms delay time between two neighboring holes were employed so that an effective wave superposition was realized from the neighboring holes. Choosing 10 ms delay time was mainly based on the vibration measurements in the mine, showing that the wave length period from each borehole was around 25–27 ms when the vibration monitor was installed at a place 60–90 m from the blast sources. One of the

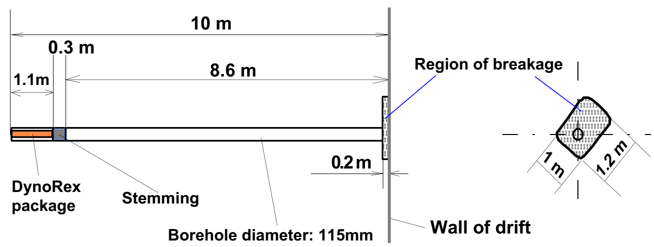

Fig. 3. Parameters of the single shot in the drift wall.

Fig. 1. Church-shape drift roof due to blasting [1].

Fig. 4. Dynamic fracture—spalling—in the free surface (drift wall) due to the single shot. The volume of the broken region is about 1 m × 1.2 m × 0.2 m.

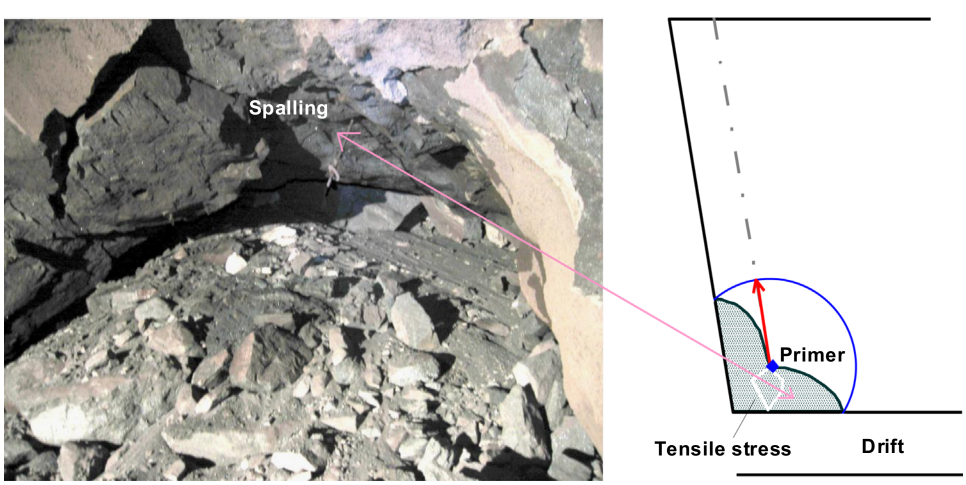

Fig. 2. Dynamic rock fracture—spalling—close to explosive charge when a primer is located near the collar. The shadow area is the region occupied by tensile stress waves when one portion of explosive in the boreholes is detonated.