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Analysis of blasting damage in adjacent mining excavations

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A R T I C L E   I N F O

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A B S T R A C T

Following a small-scale wedge failure at Yukon Zinc's Wolverine Mine in Yukon, Canada, a vibration monitoring program was added to the existing rockbolt pull testing regime. The failure in the 1150 drift occurred after numerous successive blasts in an adjacent tunnel had loosened friction bolts passing through an unmapped fault. Analysis of blasting vibration revealed that support integrity is not compromised unless there is a geological structure to act as a failure plane. The peak particle velocity (PPV) rarely exceeded 250 mm/s with a frequency larger than 50 Hz. As expected, blasting more competent rock resulted in higher PPVs. In such cases, reducing the round length from 3.5 m to 2.0 m was an effective means of limiting potential rock mass and support damage.

1. Introduction

Yukon Zinc is a wholly-owned subsidiary of Jinduicheng Molybdenum and operates the Wolverine mine located approximately 280 km northeast of Whitehorse, Yukon, Canada, as shown in Fig. 1. The mine recovers ore from a polymetallic volcanogenic massive sulfide (VMS) deposit consisting of two ore zones on either side of a largely barren saddle zone. The Wolverine and Lynx ore zones each consist of multiple lenses with numerous cross-cutting faults. Current mining faces are accessed by a ramp extending over 200 m vertically at a grade of −15%.

The ore is relatively competent massive sulfide rock with an average geological strength index (GSI) of ~40. The ore, however, is highly fractured and faulted in some zones reducing its competence. The hanging wall is of very poor competency, consisting of argillite, which is graphitic in many regions. The hanging wall has a GSI < 20 and ~10 when encountered in graphitic form. The hanging wall has a tendency to exhibit "chimney" failure where a drift back may unravel in excess of 100% of its drilled height, especially when not blasted carefully. In contrast, the footwall is a somewhat more stable rhyolite with typical GSI ratings between 20 and 30. Nevertheless, due to the presence of clay minerals, it is very susceptible to swelling and washing out in the presence of water.

The relatively shallow dip of the ore, around 35°, precludes the use of conventional horizontal mining such as room and pillar as well as conventional vertical methods such as long hole stoping. Rather, overhand and, more recently, underhand, cut-and-fill mining is employed. Production headings are generally driven 4.5 m × 4.6 m (width × height) at a grade of 2%. When the end of the ore body is reached, paste pipes are installed and one wall is retreat-slashed. After slashing, a cemented tailings backfill (CTB) is pumped from the mill into the stope behind a shotcrete arch barricade. After filling, mining is carried out beside, over or under the paste.

The relatively heavy ground support requirements are dictated by the aforementioned poor ground conditions. Primary support consists of 8 ft regular (2.4 m) and 12 ft super (3.7 m) inflatable rockbolts with respective capacities of 12 t and 24 t. In addition, steel fiber reinforced shotcrete is used prior to bolting in some headings, while regular shotcrete is sometimes applied after bolting. Shotcrete is generally used for intersections, the main ramp, hanging wall exposure and wet footwall exposure. In cases where excavation widths exceed 10 m or ground movement is observed, 18 ft connectible inflatable bolts and/or steel sets may be installed (Shin, 2014a).

Prior to the start of vibration monitoring, instrumentation in use or previously used on site includes multipoint extensometers to measure movement at critical pillars, tilt meters to measure movement of steel arches at the main ramp and load cells to record loading at the shotcrete barricades. A recent addition to the instrumentation program is vibration monitoring carried out with a Blastmate III with a triaxial geophone. Vibration monitoring was introduced following a small-scale wedge failure at the 1150 level, which will be discussed in the next section.

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The aim of the study was to find an effective way of measuring and mitigating the impact of blasting-induced seismic waves on adjacent mining excavations. Once this process is understood, mine planning can be performed with greater confidence in the minimum required pillar distance. In the case of Wolverine, the primary goal was to verify that current blasting practices are not inducing damage in neighboring tunnels. The approach focuses on underground measurements that verify theoretical approaches derived from blasting theory and dynamic wave propagation.

The results are immediately applicable since blasting can be adjusted underground by the engineering and operations department immediately after each blast if required. In addition, precautions can be taken ahead of time if vibration monitoring indicates high or potentially damaging stress wave propagation prior to blasting safety-critical rounds.

A novel aspect of the study is that findings and results are immediately implemented at the discretion of the engineering staff in collaboration with the mining production staff. Moreover, the setup of instrumentation is performed by engineers around the production schedule and does not result in any lost production or downtime. This results in an immediate, direct benefit to operations and further encourages such research at operating mines.

2. Investigation of the 1150 level wedge block failure

Supported ground failed at the 1150 level, 10 m downdrift of a pillar to the 1160WV level on 31 January 2014. A wedge of rock slid in from the right wall which had been previously supported with 8 ft regular inflatable friction bolts rated for 12 t each. A cross-section of the failure is shown in Fig. 2.

A photograph of the wedge failure is presented as Fig. 3. The failure occurred as a result of a combination of three factors: loss of rockbolt friction resistance, separation or slip along a hidden fault plane, and blasting damage from 1160WV level. During excavation, geological mapping revealed a shallow 12° joint set which was assessed by a geotechnical engineer as having a low risk of sliding failure. The hidden fault behind the right wall was not observed

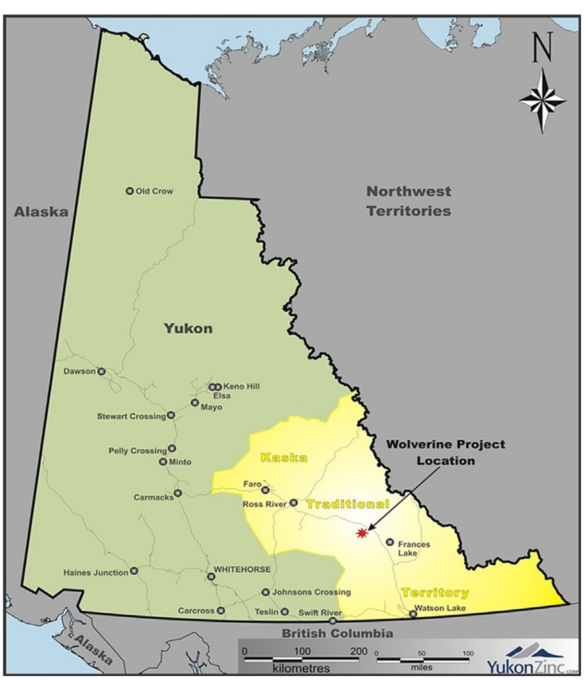

Fig. 1. Wolverine Mine in Canada (YZC, 2014).

during mining of the 1150 level as it was not seen in either the wall or face.

After repeated blasting from the 1160WV level 7–10 m away, the frictional resistance of the installed rockbolts was weakened and the separation was induced at the hidden fault. A wedge was formed by the intersection of the joint set and the fault that exceeded the capacity of the installed rockbolts. The wedge then slid into the 1150 tunnel during nightshift. No one was injured.

A rehab plan was issued calling for the region to be shotcreted, re-bolted with 12 ft 24-t friction bolts and re-shotcreted. Another 50 m of the drift were bolted with two rows of the higher capacity 12 ft bolts 1 m apart along the right wall (Shin, 2014b).

The four recommendations from the wedge failure investigation were as follows:

(1) Rehab the region with shotcrete and 12 ft rockbolts;
(2) Modification of the Ground Control Management Plan to include mandatory 12 ft bolting when the slope distance between sublevels is below 10 m;
(3) Pull testing of sublevel regions to verify integrity of rockbolts following vibration damage;
(4) Vibration monitoring to determine the impact of blasting on adjacent drifts.

3. Vibration monitoring

3.1. Wolverine Mine blasting procedure

Underground blasting is carried out at the end of dayshift and/or nightshift in accordance with Part 14 of the Yukon Occupational Health and Safety Regulations. Rounds are loaded primarily with 32 mm × 400 mm Geldyne cartridges while 19 mm × 600 mm Xactex is used for perimeter control. An inert collaring agent, Envirostem, is used in production rounds with greater than 50% massive sulfide ore in the face to minimize the risk of sulfur blasts. The typical powder factor is just under 0.5 kg/t, with loading and drilling performed according to Figs. 4–6.

Note that there are 13 perimeter holes that are not loaded. The remainders of the perimeter holes, shaded in Fig. 4, are loaded with Xactex as shown in Fig. 5. Finally, production holes are loaded as depicted in Fig. 6.

Initiation is achieved with Exel down hole non-electric detonators. The down hole detonators are connected by shocktube to det cord at the face, which is initiated by two independent electric caps connected to the central blasting system. Eighteen detonator periods are available with delay periods as shown in Table 1. Other relevant blasting parameters are included in Table 2.

3.2. Vibration monitoring system

Starting in February 2014, a BlastMate III with a triaxial geophone, calibrated in December 2013, was used to collect vibration data in underground headings. While monitoring is currently ongoing on an as-needed basis, April 2014 was the cutoff for data included in this analysis. Sampling is performed at 2048 Hz over three channels corresponding to the standard orthogonal axes. A sensor check is performed prior to each data collection and the event trigger threshold is set at 8 mm/s, which was found to be about one order of magnitude below most blast peak particle velocity (PPV) while not being sensitive enough to trigger by nearby non-blasting mining activity.

Displacement, particle velocity, acceleration and frequency data are available along the transverse, longitudinal and vertical directions. The peak vector sum (PVS) is also reported for each blast