Blast-induced rock movement measurement for grade control

by Ananta L. Yennamani, Salvador Aguirre and Pierre Mousset-Jones

Blast movement measurement (BMM) transmitters are a practical method to measure three-dimensional (3D) rock movement because of blasting. The BMM transmitters are activated, programmed and installed in specially designed drill holes prior to the blast and the BMM detector locates the transmitters after the blast. The BMM software then calculates and summarizes the 3D movement of each BMM transmitter ball. This information helps to redefine the ore and waste boundaries and enables improved ore and waste selection, resulting in a genuine step change in grade control.

The BMM program was carried out at Newmont Mining Corp.’s Phoenix Mine, in northern Nevada near the town of Battle Mountain. The mine is in a historic mining district that contains gold, silver and copper. The geology of the pit consists of different formations made up of sandstone, siltstone, limestone, chert-pebble conglomerate, shale, skarn and quartzite, to name a few. Some of the rock is extremely hard and a powder factor of up to 0.5 kg/t (1 lb/st) is required to get adequate fragmentation to ensure sufficient throughput through the crusher and the mill. The result of using such a high powder factor translates into considerable blast movement and heave.

This movement means that the ore/waste digging polygons estimated by the ore control engineer from sampling the initial blast holes will no longer be located in their original positions. The purpose of this project was to test the measurement method and to see if locating the digging polygons in the broken muck pile and excavating to those polygons will improve grade control through the mill. Case studies (Zhang, 1994), (Taylor, 1995), (Gilbride, 1995), (Harris, 1997), (Taylor, 2003), Barrick Goldstrike (Goldstrike Mine, 2008), Ruby Hill Mine (Hilkewich, 2009), (Porcupine Mine, 2005) and (Aguirre, 2010) have shown that, by accounting for the blast movement, there is a potential to increase mineral recovery by as much as 25 percent for individual blasts for only a modest cost increase.

Blasting practices

The production benches at the Phoenix Mine are 12.2-m- (40-ft-) high with a sub-drill of 1.5 m (5 ft). The diameter of the drillholes is 17 cm (6.75 in.), with spacing and burden varying from 4 m (13 ft) to 5.18 m (17 ft). The burden and spacing for a pattern are normally decided depending on the rock hardness, rock quality...
and explosive load. The Phoenix Mine schedules four production blasts per week, Monday through Thursday, with an average of 200 to 500 holes per pattern, yielding approximately 272 kt (300,000 st) of blasted material. The initiation direction of the blast is designed in such a way that it is perpendicular to the faults and coincides with the strike of existing mineralized structures. The initiation of the pattern depends on the free face and may be a V, echelon or center lift. Figure 1 illustrates the blastholes and movement of the BMM’s.

The production holes are drilled vertically with an explosive column of 9.75 m (32 ft) and 3.96 m (13 ft) of stemming (crushed rock – 10-mm- (0.4-in.-) diameter) and are spaced either on a staggered or a square pattern. The design of a square or staggered pattern depends mostly on the hardness of the rock. The square pattern is used in soft rock, while in hard rock, a staggered pattern is used. An emulsion/ANFO, at an average ratio of 25 percent emulsion to 75 percent ANFO is used as the primary blasting agent. The powder factor ranges from 0.26 kg/t to 0.5 kg/t (0.52 lb/st to 1 lb/st), according to the hardness of the rock. The types of explosives used for blasting are 458 HANFO, 462 HANFO, 458 ANFO, 462 ANFO and 290C. 458 HANFO stands for Heavy ANFO, which is a blend of emulsion and ANFO, 458 has 26 percent emulsion and 74 percent ANFO and 462 has 32 percent emulsion and 68 percent ANFO. Pattern timing and layout are designed to promote the vertical movement of the rock and also to minimize the horizontal rock movement in order to reduce ore dilution.

Blastholes are loaded with ANFO mechanically and are initiated with a 0.45-kg (1-lb) cast booster using Ikon down-hole delays and harness wire to tie the shot circuit. Detonating cord down to each hole, and a booster, are used in patterns with soft rock and no faults, and also when there is no change of rock type. This helps reduce the possibility of cutoffs due to the ground shifting. Electronic detonators are used with hard rock and when a change of rock type is present in the shot. As a rule of thumb, electronic detonators are used when there is a fault present.

It should be noted that 12.2 m (40 ft) benches are blasted, but they are excavated in two separate 6.1 m (20 ft) benches.

**Blast movement measurement**

Blast movement measurement has been done in the past using poly pipes, sand bags, magnetic targets, etc. Blast movement technologies (BMT) developed a new method to measure the rock movement. BMT developed target balls that can be placed in drillholes, which transmits a radio signal that can be picked up by the BMM receiver on the surface.

The measurement and analysis of the rock movement using the BMM method, requires the following equipment:

- BMM ball (transmitter).
- BMM activator (which triggers the BMM transmitter).
- GP4 100 BMM detector.
- Surveying equipment (GPS, compass, etc.).

It is necessary to determine the location, number and depth of the extra holes that need to be drilled to insert the BMMs within the production blasthole pattern. This depends on the blast size, number of blastholes, blast parameters, geology, estimated ore/waste polygon shapes, etc. Typically, the balls are placed at dif-
ferent depths in the drillholes. This is done to have a better understanding of the movement at different locations of the blast. The drill-and-blast foreman is provided with all of the maps and data concerning the blast design no later than 24 hours before drilling. The blasting and ore control engineers decide where to drill the BMM holes. The estimated waste polygons are generally not considered to be an important target. Sometimes, irrespective of the ore and waste areas, the balls are placed just to study the movement, depending on the rock type and the faults in the blast pattern.

**Procedure**

After the pattern is drilled and before the blast, the BMMs are activated and dropped into the blast movement study holes and their depth is recorded in the detector as well as the signal strength. The depth and the signal strength will be used by the BMM software in order to calculate the movement in the Z-direction, as shown in Fig. 2. The surveyor records the x and y coordinates of these pre-blast locations. These holes are then backfilled with stemming.

After the blast, the blasting engineer and the surveyor walk over the blasted muck pile using the BMM detector to locate the BMM balls. The blast can result in balls moving up to 10 m (33 ft) horizontally and 3 m (10 ft) vertically. In addition, there is considerable heave of the blasted muck pile with steep slopes, which can affect the location process. Using GPS, the surveyor locates the pre-blast location of the BMM and the blasting engineer moves from that location along the general movement direction of the shot (predicted from the blasting software) until the BMM ball is found. Once the blasting engineer finds the post-blast location by the peak signal from the BMM ball, the surveyor records the coordinates of that position on the muck pile and saves the information with an appropriate BMM identification value. This process continues until the blasting engineer finds all the BMM transmitters. Sometimes it is difficult to find the post-blast location of the ball due to reasons such as BMM transmitter damage and wrong time delays for a ball. All the data from the BMM detector is transferred into a PC and the surveyor provides the coordinate data for the BMM locations.

The BMT software is used to obtain the 3D movement vectors of the BMMs. The mine uses AutoCAD or “Orecon” (Newmont’s ore control planning) software to create digitized shapes that show the location of the post-blast ore polygons within the blasted muck pile. If this process is correct, it will result in

**Table 1**

<table>
<thead>
<tr>
<th>BMM #</th>
<th>Initial depth (m)</th>
<th>Direction (deg)</th>
<th>Horizontal distance moved (m)</th>
<th>Vertical distance moved (m)</th>
<th>3D distance (m)</th>
<th>Inclination (deg)</th>
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the shovel correctly digging the ore/waste polygons in their new positions. The after blast digging polygons are marked on the muck pile by the surveyors and on CAES display files available for the shovel operators to follow. Figure 3 shows the pre- and post-blast location of digging polygons. The blue polygons are pre-blast and the red polygons are post-blast, which were moved using Surpac. It is important to note that different software will give different shapes and locations of the post-blast polygons based on the vertical and horizontal movement vectors.

Results and discussion

The results obtained in the blast tests at the Phoenix Mine using the BMM equipment and software are discussed below with an example.

**Blast PX014306.** This shot was blasted on the 6160 bench. The following data was required as input for the BMM assistant.

- **Blast ID** – PX014306.
- **Date of blast** – 07/23/09.
- **Bench height** – 13.7 m (45 ft).
- **Sub-drill** – 1.5 m (5 ft).
- **Stemming** – 3.9 m (13 ft).
- **Hole diameter** – 17 cm (6.7 in.).
- **Burden and spacing** – 4.5 m × 4.5 m (15 ft x 15 ft).
- **Powder factor** – 0.3 kg/t.
- **Initiation** – Echelon.
- **Explosive** – 458.
- **Rock type** – Virgin fault (soft).

The pattern had two free faces and the initiation was Echelon. A total of 272 holes were drilled along with the BMM holes. A total of six BMMs, four on the top bench and another two on the bottom, were placed in the pattern. All of the BMMs were recovered and the average horizontal and vertical distances moved by the BMMs were 4.94 m (16.2 ft) and 2.26 m (7.44 ft), respectively. This movement is specific to this rock type and low powder factor. The results of the movement from the BMM assistant are shown in Fig. 4 and the results are shown in Table 1.

In Fig. 4, the green-colored holes were the pre-blast BMM positions and the red colored holes were the post-blast BMM positions. Six BMMs (1, 2, 3, 4, 5 and 6 in Fig. 4) were placed in the pattern and all of the BMMs were recovered after blasting. The three dimensional movement of the blast is shown in Fig. 5.

**Cost analysis of BMM balls**

The cost of measuring the blast-induced rock movement was determined to see the economic benefits this system can provide. The Phoenix Mine has leased the BMM hardware and software and has been using it for more than a year. The rental details of the equipment and the drilling costs (US$) are the following:

To measure the BMM ball movement, a blasting engineer and a surveyor are required.

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**Table 2**

<table>
<thead>
<tr>
<th>BMM #</th>
<th>Initial depth (m)</th>
<th>Direction (deg)</th>
<th>Horizontal distance moved (m)</th>
<th>Vertical distance moved (m)</th>
<th>3D distance (m)</th>
<th>Inclination (deg)</th>
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**Table 3**

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<th>Batch</th>
<th>Estimated polygon grade (gm/tonne)</th>
<th>Grab sample grade (gm/tonne)</th>
<th>Mill grade (gm/tonne)</th>
<th>% change mill/estimated</th>
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<td>8.70</td>
</tr>
<tr>
<td>3</td>
<td>6.22</td>
<td>309</td>
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<td>2.50</td>
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<tr>
<td>4</td>
<td>6.28</td>
<td>290</td>
<td>6.83</td>
<td>2.59</td>
</tr>
</tbody>
</table>

**Figure 3**

Examples of pre- and post-blast locations of digging polygons.
Blasting

For example, consider a blast pattern, PX014306 in which six BMM balls were dropped and all six were recovered.

- Cost of BMM equipment and software per day* = $50.
- Cost of six balls used in the pattern = $2,070.
- Cost of drilling the six extra holes = $325.
- Cost of personnel = $59.
- Total direct cost for blast movement for blast PX014306 = $2,504.

When considering the 38 blasts where movement was measured at the mine up to March 2010, the direct cost of all the blasts was $67,048 and the average direct cost per blast was $1,948.

A batch test was carried out in which four ore polygons were relocated after blasting according to the blast movement results and the estimated polygon grade was compared with the mill grade. The moved ore zones were separated for sampling and processing. The batch test results for gold, silver and copper grades are illustrated in Tables 3, 4 and 5, respectively. The results show that the mill grade was significantly higher than the estimated grade. More batch tests are planned at the mine.

- Mine site and/or user specific BMM equipment cost information is available from Blast Movement Technologies Inc.

Conclusions

- The direction of blast-induced rock movement was parallel within ± 5 degrees from the predicted vector of movement given by the blast design software.
  - The secondary free face tended to provide sufficient relief to bias blast movement towards the initiation direction.
  - The blasting of an area of ore into a waste zone results in an overlay of the top portions of the ore zone on the waste zone, which makes separation of zones difficult and causes dilution.
  - Blast movement correction to reduce ore loss and dilution should be considered, particularly when high powder factors are required to obtain adequate fragmentation.
  - In many cases where geology is
similar, the blast movement measurement with BMM balls may not be necessary for every bench.
- Not all the balls were found, due to electronic failure due to blast damage.
- The batch test was inconclusive, since it was not known whether the estimated ore/waste boundaries actually existed where they were located.

**Recommendations**
- BMM balls with unique IDs in order to identify them individually in the muck pile. (These are being developed by the manufacturer.)
- A detector with an integrated GPS would reduce the cost of the surveyor.
- Careful consideration should be given to modeling the location and shape in 3D of the post-blast polygons based on the measured vectors from the blast. It is a complex process, and the modeling software available produces different shapes and locations for the same input data.
- A well-thought-out batch testing program to verify that adjusting digging polygon location for blast movement is economic and helps reduce dilution and ore loss.
- In order to verify the estimated polygon boundaries actually exist in a bench, the following methods could be considered:
  a) Sampling across the polygon boundaries: For example, select a pattern with an ore polygon surrounded by waste polygons. Collect the samples along the red colored line as shown in Fig. 6. After the blast and after relocating the polygons collect the samples along the same line and at same positions.
  b) Using Spectral Imaging or X-ray fluorescence analyzer.

Both methods might be applicable to locate the mineral boundaries, and verify the location of the adjusted digging polygons. Spectral imaging has the advantage that it can scan the whole surface of a bench or the digging face of the bench, which makes it quicker and easier to use (references are available from the authors).

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