Utilization of blast movement measurements in grade control

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Metal mining operations, in particular gold mining operations, use intensive ore control procedures in order to manage the extraction of ore zones from benches containing both ore and waste materials. Typical grade control procedures rely on blast hole samples to indicate ore grade. Statistical techniques and geological controls are then used to create two-dimensional polygons, which indicate zones of material designated as ore. These ore-polygons are calculated using pre-blast material locations and are generally not corrected for rock movement caused by blasting. This lack of correction appears to exacerbate the material mischaracterization problem of sending ore to the waste dump and/or waste to the mill. One Nevada gold mining company has estimated that this could be a $10 million per year problem for their operations.

Using a simplified vector field algorithm, a method of taking point movement data and interpolating post-blast positions for all nodes in a polygon has been developed. Currently working in two dimensions (X-Y), this algorithm utilizes the movement vectors calculated from pre- and post-blast positions of targets placed in a blast, to generate a spatial transformation function for any point on the bench. This transformation is then applied to the nodes of the ore-polygons to produce modified dig lines ore polygons reflecting distortion and movement resulting from the blast. The method as implemented uses common mine planning routines and is performed using the Surpac software suite. The method may be adapted to use any pre-and post-blast point movement data available, and most mine planning suites include the simple interpolation algorithms used.

Keywords: Blast movement; Ore control; Open pit blasting; Grade control

Introduction

For open pit mining operations in which ore and waste materials are intimately mixed within the orebody, accurate separation of these materials during loading operations is critical. In many such operations, ore and waste materials cannot be identified solely on the basis of rock type, structure or colour, and ore waste boundaries will be determined on the basis of an economic cut-off grade. An example of this type of orebody is the hydrothermally altered, disseminated gold deposits of Nevada and the orebodies of the western Australian goldfield, as discussed by Shaw1 and Zhang2.

The majority of these mining operations rely on blast hole sampling to identify the ore grade at a point, these data are then used to identify zones of ore and waste within a given bench horizon, termed ore/waste polygons. These polygons are normally calculated using a computer-based interpolation scheme and may be of any shape and size. After the locations of ore and waste polygons in a particular bench have been calculated, the bench is blasted and the ore and waste is marked on the surface of the muckpile using a system of stakes, flags, ribbon, placards and tape. It is important to note that these material polygons are two-dimensional shapes and are marked on the muckpile using X-Y coordinates only, with no reference to elevation.

The location of ore and waste in a given blast is calculated based on the position of the preblast drill samples. The polygon marked on the muckpile is also based on preblast sample locations and as such, any movement of rock in the X-Y plane due to blasting will result in material being misclassified. The classical misclassification occurs when ore material is moved out of the ore polygon and is marked as waste, and conversely, waste material is moved into the ore polygon and is marked as ore. Hence, metal value is lost as ore is loaded to the waste dump, and milling cost per unit metal recovered is increased as waste material is loaded to the mill.

Recently, several mining operations report the use of the ‘mine to mill’ concept in optimizing total cost per unit metal recovered. Part of this methodology is to produce a product in the open pit, which is designed to reduce downstream costs and total unit cost, rather than simply minimizing the cost of the drilling and blasting operation. This method, while resulting in substantial savings in crushing and milling costs according to Bulow3, has in several cases also resulted in increased dilution and poor reconciliation between head grade and polygon grade. This increased dilution is thought to be due to the increased movement experienced by ore polygons during blasting.

As part of an ongoing study of blast movement and its measurement2-7, this paper describes the development of a simple, effective means of using movement data for discrete points in a blast, to account for blast movement and re-calculate ore polygon shapes post blast. The algorithm can be used with any point movement data set and can be adapted to any one of the popular geostatistical interpolation methods.

Background

This section serves as a discussion of common approaches
to minimizing ore movement due to blasting, and methods used to gather point movement data of the kind required for input to the algorithm described later in the paper.

For mining operations which are sensitive to movement of ore polygons due to blasting, methods have been developed which limit movement in an X-Y plane during the blast. The most common approach to this problem is the choke or buffer blast, in which the blast is fired into a buffer of previously broken rock, hence free face movement is hindered. This method is relatively effective, however, field studies indicate that the effect of the buffer may be minimal for blastholes two or three rows back from the free face. When choke blasting in competent rocks, increased powder factor may be required and this generally leads to a large amount of vertical heave. Vertical heave and its effect of ore dilution is difficult to quantify and account for, and should be minimized whenever possible.

Blast sequence can also be used to affect the degree of dynamic relief available to a particular blasthole or row of holes. Short inter-row and inter-hole timing may be used to create reasonable fragmentation while minimizing throw of the muckpile. Again, if the powder factor for the blast is elevated to ensure fragmentation in a more competent rock mass, this method may also result in a large amount of vertical heave. Several mines in the western U.S. report the use of row by row firing with very short inter-row delay.

The role that electronic detonators will play in controlling blast movement for the purpose of grade control is only now being investigated, however, it is likely that the use of this technology will increase rapidly as benefits are proven.

One interesting approach to blasting for grade control is reported by Kunze at the Pegasus gold mine in Montana, U.S.A. Ore and waste polygons to be blasted are tied in such a way that each area of the blast acts as an independent firing pattern, and the timing of the blast is designed such that each area will heave to the centroid of the individual polygon. This method creates troughs in the muckpile along the polygon boundaries, which are then easily identified by the operator during loading. This method as reported used detonating cord as the primary initiation system, however, it appears that electronic detonators would be ideally suited to allowing this type of complex tie-in with minimal extra effort.

Other common aspects of blast designs where dilution due to ore movement is a concern, include the use of short benches to account for variation in ore grade vertically, lower powder factors where possible to reduce the energy available in the blast and square blast patterns allowing easier reconciliation of sample data. Unfortunately, many of these methods are in direct conflict with the principles of open pit blasting which attempt to create a well fragmented, loose, muckpile for a minimum cost per tonne broken.

Several authors report on intensive procedures carried out at Australian mines in which ore dilution is a concern. Mining is carried out using short benches, typically five metres in height. Each blast hole is sampled several times, typically once for the upper and once for the lower bench. Mining is conducted using a backhoe shovel, situated on the top of the muckpile and the bench is mined in flitches, typically three, two-metre flitches will result from a five-metre bench after some swelling during the blast. Ore control polygons are calculated for each flitch based on blast hole samples and as each flitch is mined out, ore control is re-marked for the next flitch. Hence, ore control is marked three times during the loading of the blast.

Methods of measuring blast movement include the use of drill tube, chain, paint, dye, chalk, mill balls, paint cans and polyethylene pipe embedded in un-charged drill holes or in the stemming of a blasthole and paint lines, flags, tape and stakes on the blast surface. The purpose of these methods is to provide a surveyed pre-and post-blast position for a number of points in the blast area. These data can then be used to characterize the movement experienced by the ore contained in the bench. Problems with these simple methods include data loss due to destruction or movement of markers during blasting and loading, failure to find a significant number of markers and issues surrounding the reliability of data for objects which may not have mirrored the movement of the surrounding rock mass.

Zhang, Taylor and Gibilisco report moderate success using blast hole liner bags filled with rock chippings and placed in uncharged drill holes. These bags are marked to indicate the hole number and the depth from the surface of the hole at which they are placed. After the blast, as loading proceeds, bags appearing in the digging face are surveyed and hence a movement vector can be calculated for each bag. The significant disadvantage of the method is that movement data is not available until after the blast is loaded. The research conducted did, however, provide valuable data in regard to characterizing blast movement. Rock is proven to move towards the instantaneous free face available to each blasthole as it fires. Also, rock is found to move more at the mid elevation of a bench than in the toe or in the stemming region.

Harris developed a method of measuring blast movement in which magnetic targets are placed in un-charged blast holes and geophysical techniques are used to determine post-blast target location. This method develops movement data prior to loading and in general, data is gathered for all targets placed in the blast.

At a fundamental level, muckpile surface topography and surface markers such as embedded poly pipe provide reasonably reliable data at minimal cost and for a minor expenditure of effort on the part of the ore control, blast and survey crews. Irrespective of the method used to measure blast movement, assuming point movement data of sufficient number are gathered, these data can then be used to re-calculate the ore polygon position in the post blast muckpile.

Algorithm description

The computation carried out in this analysis is to create, from the movement of targets included in the blast, a vector field transformation that allows the computation of post-blast position of pre-blast points. This displacement vector operator can then be used to map the grade outlines of an ore polygon to re-establish dig lines for the loading operation. Current practice in ore control is for the loader operator to work from ore-waste boundaries marked on the surface of the blasted muckpile. Even though research has shown that the rock in a blast moves differently depending on its elevation in the blast, the algorithm for this analysis is two-dimensional, in keeping with standard loading procedures in use in open pit mines in which ore polygons exist only as two-dimensional figures and ore-waste boundaries are assumed to be vertical.

In order to model the displacement vector field, the movement of targets in the blast is broken into orthogonal horizontal components (ΔN and ΔE). These components are then modelled separately to assign grid values for a trend
surface covering the area of interest. The separate values are then used to compute a resultant displacement vector for each grid point in the area, which is then stored in a cell of a block model. The transformation of an ore-waste boundary is calculated by determining for each vertex in the ore polygon the displacement vector of the cell containing that point and applying that displacement to the point.

The method of modelling the displacement trend can be carried out using any of the standard estimating techniques, such as Triangulation, Polynomial Surface Fit, Inverse Distance or even Kriging. For the purposes of this analysis, a simple Inverse Distance Squared (ID²) model was calculated using the standard Surpac Grid Tools. This method has the advantages of allowing extrapolation beyond the convex polygon of the original targets, honouring the original data points and satisfying the intuitive notion that the influence of a data point diminishes as a function of the distance between it and the point to be estimated. In addition, this model is computationally simple to implement. Further field study is required to determine the 'best' fit method, which is expected to be site specific.

After the vector model has been constructed and the displacement applied to the ore polygon, an estimate can be made as to the cost of ignoring the ore movement. That is, if the ore block is found to move in the blast and the original dig line positions are not amended, two classification errors will occur: Ore will be sent to the waste dump and waste will report to the processing stream. In the former, the cost to the operation is the lost revenue from the misclassified ore and in the latter, the cost is the unnecessary cost of processing the misclassified waste. Surpac allows the rapid calculation of these misclassifications, by creating 'outer-sections' between the original and transformed ore polygons. The area of these sections is easily determined and hence the volume, tonnage and contained metal can be calculated.

Example results
This algorithm was used to analyse a blast at an open pit gold mine that occurred in Fall, 2001. Table I summarizes the blast parameters.

The blast included approximately 300 holes and was fired using shock tube initiation products on surface with detonating cord and Pentolite primers in the hole. The blast was fired to the south into a buffer of broken material, using an approximate V1 effective sequence, Figure 1.

A total of 9 magnetic targets were included in uncharged holes in the blast and located afterward using magnetic geophysics7. The positions of the holes, pre-and post-blast are shown in Figure 2. (Note that the grid coordinates on all

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Table I
Blast parameters for case study

Figure 1. Schematic diagram of blast layout and sequence

Figure 2. Movement of blast targets, showing hole ID#, pre-blast position (+) and post-blast position (Δ)
Figures are in U.S. survey feet, as that is the surveying standard for the mine. The targets show a generalized movement to the south-west, which is consistent with the blast firing sequence. These displacement vectors were then used to compute the displacement vector field for the blast using an ID2 algorithm.

Figure 3 shows the location of the ore polygon for the blast as determined from kriged blast-hole assays. (Ore is inside the polygon.) This ore-waste boundary is flagged on the muckpile surface after the blast, based on the pre-blast location of the polygon, and flags are used to indicate digging limits for the loader operator. No attempt is made to account for movement of the polygon due to blasting. Figure 4 shows the results of applying the computed displacement to the original ore polygon.

Figure 5 shows the results of not adjusting the ore-waste boundary for the blast movement. The lighter shaded area to the NE of the map indicates waste that has moved into the marked ore zone and will be processed unnecessarily. The darker shaded area to the SW represents ore that has moved out of the marked ore zone and so will report to the waste dump and be lost.

**Discussion and conclusions**

Average resultant movement for the case study was approximately 3.0 metres in X-Y space. Table II summarizes the calculated volume and tonnage of material from the ore polygon that would be misclassified if this movement is not accounted for when the ore control polygon is marked on the post-blast muckpile.

Tonnage has been calculated assuming a density of 2.7 tonnes/m$^3$ and a bench height of 6.1 m. Pre-blast or bank volumes and density are used. The average gold grade for
the polygon was 0.1 oz/ton or approximately 3.1 g/tonne. Recoverable gold mass assumes a recovery of 80% and the gold price used is 300.00 U.S. dollars (USD)/oz or approximately 10.58 USD/g.

Gold which is effectively lost as it is loaded to the waste dump, is valued at USD 184,000. The effect of the waste-to-ore miscategorization is to increase the overall processing cost per gram for this blast from 6.61 USD/g to 9.06 USD/g, or a 37% increase in unit processing cost.

It can be argued that for an orebody with dramatic grade gradients at the boundary of ore outlines, it may be necessary to smear sample data such that ore value is not loaded as waste, even if blast movement does occur. An alternative approach would be to account for ore movement and carefully reconcile short-range planning/ore control grades with mill head grades and, where possible, realized metal values.

References


