Geotechnical Block Modelling for the 3-Dimensional Visualisation of Rock Mass Quality in the Mining Environment

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Abstract

The collection and analysis of geotechnical data forms the basis for understanding the geotechnical characteristics and the overall quality of the rock mass in a mining environment. This data in turn makes available a number of empirical methods for the evaluation of stability, the design of support and the selection of mining methods in underground and open pit operations, which allow safe mining to take place.

As rock mass quality is often presented as averages over large domains it can be difficult to form a visual impression of the quality of the rock mass. This paper therefore focuses on the creation of geotechnical block models that provide a 3-dimensional visual representation of rock mass data which estimates rock mass conditions (with varying levels of confidence) across the planned mining area. This concept is illustrated using case studies where geostatistics is adopted to estimate the rock mass quality between boreholes by applying the appropriate geostatistical methodologies.

From this study it can be concluded that while geotechnical block models can provide insight in the variability of the rock mass conditions in the mining area, these models should not be used in a prescriptive manner to design rock support on a local scale. Instead, a geotechnical block model should provide insight on areas where potential instabilities can occur, allowing for the opportunity to address these instabilities. Overall, once a geotechnical block model is created, it should also be updated on a continuous basis as more data is gathered as mining takes place.

Keywords: geotechnical block modelling, geostatistics, rock mass quality, geotechnical data
1 Introduction

A detailed understanding of rock mass conditions is essential for safe, productive mining to take place. To gain insight on the quality of a rock mass, boreholes are usually drilled, geotechnically logged and analysed prior to and during mining operations. During this process, data is often assessed using rock mass classification systems. While the results from the use of these systems provide an impression of the rock mass conditions, it can be difficult to form a 3D visual impression of the quality of the rock mass across the mining area. To account for this, spatial variability in rock mass data can be estimated and assessed using 3-dimensional geotechnical block models. This paper presents case studies where geotechnical block models have been created to allow for a 3-dimensional visual representative of the rock mass conditions, where the identification of data deficient areas and potentially poor ground conditions are outlined. Similar work has also been carried out by Jenkin and Seymour (2009), Bye (2006)\(^a\), b, Luke and Edwards (2004) as well as by other authors, which may also be used as a reference point when conducting 3-dimensional geotechnical block modelling.

2 Kipushi Geotechnical Block Model

Kipushi Mine (Kipushi) is a high-grade underground copper-zinc mine located adjacent to the town of Kipushi in the southern Haut-Katanga Province in the Democratic Republic of Congo. Kipushi is currently investigating the potential to mine a high grade zinc orebody known as the big zinc (MSA, 2016). Major lithologies in the mining area are sphalerite (orebody), the kakontwe dolomite formation (comprising of the upper, middle and lower Kakontwe dolomite) and the shales, siltstones and sandstones of the Grand Lambeau Formation, all of which fall within the Central African Copper Belt. For the Pre-feasibility stage of the project, a geotechnical block model was created for Kipushi, with the aim to determine the variability in rock mass quality across the project area and to identify gaps in the data set.

2.1 Rock Mass Quality

Data input into the Kipushi geotechnical block model is based on rock mass quality information which was determined with the use of Barton et al’s (1974) Norwegian Geotechnical Institute’s Q-System (Barton et al, 1974). This system was applied to a total of 90 geotechnical borehole logs which were identified across the project area. A Q value was determined for each geotechnical interval for every available borehole.

As Q values are expressed on a log scale, all Q values were converted to rock mass rating (RMR) values using Barton’s equation ($\text{RMR} = 15\log Q + 50$). RMR values range between zero and 100, whereby the higher the RMR the better the quality of the rock (Table 1). The converted RMR values were used to populate the block model. A histogram illustrating the rock mass classification results (uncomposited) is presented in Figure 1 (left).

<table>
<thead>
<tr>
<th>RMR</th>
<th>Rock Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 20</td>
<td>Very Poor</td>
</tr>
<tr>
<td>21 – 40</td>
<td>Poor</td>
</tr>
<tr>
<td>41 – 60</td>
<td>Fair</td>
</tr>
<tr>
<td>61 – 80</td>
<td>Good</td>
</tr>
<tr>
<td>81 - 100</td>
<td>Very Good</td>
</tr>
</tbody>
</table>
Following the rock mass classification, a weighted averaging method known as compositing was applied to the data to produce geotechnical intervals of equal lengths, allowing for statistical analysis. This operation was performed using the software package, LEAPFROG. A compositing length of 3 m was chosen for the data as this was the typical core run length. Rock mass classification results based on the compositied data are presented in Figure 1 (right) and Figure 2.

**Figure 1**: Histogram of RMR from Q - not composited (left) and composited (right)

**Figure 2**: Rock Mass Classification Results

### 2.2 Geotechnical Domains

On analysis of the rock quality across the project area, it was observed that overall the rock mass quality is lower to the north of the project area compared to the south (Figure 2). It was therefore decided to separate the data into two domains, domain A and domain B. As the poorer quality rock in the north may be due to the more fractured nature of the rock in the north (upper Kakontwe dolomite), the boundary between the middle and upper Kakontwe was used to separate the domains (Figure 3).
The distribution of RMR values for Domain A and Domain B are presented in Figure 4. Both domains share the bimodal negatively skewed distribution of the total dataset however; the first peak in domain A has a higher kurtosis than the first peak in Domain B. Furthermore, whilst the mean RMR values for Domain A and Domain B are similar (80 and 77), the distribution of RMR results illustrate that there is very little data with an RMR of less than 60 (RMR >60 = good rock) for Domain A (43 samples) compared with Domain B (872 samples). Domain A and Domain B were thus modelled separately to highlight areas with the poorer quality rock (Domain B) without distorting the good quality rock (found in Domain A) and to honour the observed differences across the middle to upper Kakontwe stratigraphy.

2.3 Geotechnical Model Creation
For the creation of the Kipushi geotechnical block model, use was made of the Datamine Studio RM and Isatis software packages. The process followed in creating the model is described briefly below.

2.3.1 Variograms
The anisotropy of the RMR values was assessed through a semi-variogram map, which showed moderate anisotropy. It was observed that the data has the longest range of continuity
in the vertical direction, and the shortest along the north-south axis. For the creation of the model, variograms were required and thus created in 3 orthogonal directions to gain an impression of the spatial continuity of the data across the project area (Figure 5). Based on these results, a variogram model was created for Kipushi (Table 2).

![Figure 5: Modelled semi-variograms](image)
Table 2: Variogram model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Domain</th>
<th>Range</th>
<th>Nugget</th>
<th>Sill</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>Domain A</td>
<td>68</td>
<td>53</td>
<td>69</td>
<td>35</td>
</tr>
<tr>
<td>Domain B</td>
<td>68</td>
<td>53</td>
<td>69</td>
<td>31</td>
</tr>
<tr>
<td>Domain A</td>
<td>200</td>
<td>120</td>
<td>230</td>
<td>35</td>
</tr>
<tr>
<td>Domain B</td>
<td>200</td>
<td>120</td>
<td>243</td>
<td>31</td>
</tr>
</tbody>
</table>

2.3.2 Prototype
To create a block model, a model prototype is required. The prototype defines the location and dimensions of the block model prior to the adding data to the model. The block size is 5 x 5 x 5 m, which was chosen to match the grade estimation block model.

2.3.3 Statistical Approach
Two methods were employed for the creation of the block model:
- Nearest Neighbour
- Ordinary Kriging

To honour the data within the boreholes, the nearest neighbour method was applied to a 5 m radius from each sample. This method does not involve weighting sample values. Instead, each cell is assigned the value of the 'nearest' sample, where 'nearest' is defined as a transformed or anisotropic distance which takes account of any anisotropy in the spatial distribution of the RMR values.

Kriging is the geostatistical method for estimating the value of a volume and involves the assignment of weights to the surrounding data. The calculation of the kriged weights is based on the modelled semi-variogram, which describes the correlation between two samples as a function of the distance between them. One of the major advantages of kriging is that the weights are calculated in order to minimize the error variance. When minimizing the error variance, kriging takes into account the spatial location of the samples relative to each another. Hence, if several samples are clustered together, this will be taken into account when the weights are calculated and the weights reduced accordingly.

There are two variations of kriging i.e. ordinary kriging and simple kriging. For ordinary kriging, a weight is calculated for each sample, and the sum of these weights is 1. For simple kriging a weight is calculated for each sample and a weight of $(1 - \Sigma W)$ is assigned to the mean, therefore the sum of the sample weights, plus the weight assigned to the mean equals 1. Simple kriging is not as responsive as ordinary kriging to local trends in the data, since it depends partially on the mean, which is assumed to be known, and constant throughout the area. Ordinary kriging is therefore the most commonly used method of kriging and was thus applied to the Kipushi data.

Ordinary kriging was applied to the Kipushi data using a three search pass strategy, where the distance from the data was incrementally increased for each search pass (Table 3). This was done to increase the smoothing of the block model as the distance from the data increased, while locally honouring the nearby data. The ranges chosen for each search pass was based on the variogram results (Table 2). For each search pass, a minimum and maximum number of samples to be utilised was defined. Note that where more than the maximum number of samples within search volume exist, the nearest samples are selected.
Table 3: Search pass parameters

<table>
<thead>
<tr>
<th>Search Pass</th>
<th>Range (m)</th>
<th>Minimum no. of samples</th>
<th>Maximum no. of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>6</td>
<td>20</td>
</tr>
</tbody>
</table>

2.4 Results

Figure 6 illustrates the confidence in the block model, which decreases as the distance from the boreholes increase. As there is no data available in the far east of the project area, this was not modelled. A horizontal section through the Kipushi block model, showing the estimated RMR values, is presented in Figure 7.

Based on the block modelling it was established that the rock mass conditions are generally good to very good, especially in the south of the mining area. The block model also highlights that there is little to no information to the east of the mining area. As footwall development is planned in the east, further drilling is recommended here to confirm the rock mass conditions in this area (Figure 2).
3 Platreef Geotechnical Block Model

Ivanplats (Pty) Ltd, has undertaken an investigation to assess the feasibility of developing a 4Mtpa vertical-shaft accessed underground platinum mine known as the Platreef project. The project is located on the Northern Limb of the Bushveld Complex in South Africa, near the town of Mokopane, approximately 280 kilometers northeast of Johannesburg. Geologically the Platreef is a complex PGE deposit subject to various processes over the course of its genesis. Major lithologies across the project are from the Upper Critical Zone stratigraphy which has been locally divided into the uppermost Norite Cyclic Unit (NC1), the Turfspruit Cyclic Unit (TCU), a footwall Norite Cyclic Unit (NC2), the UG2 (hangingwall chromitite and hazburgitic footwall) and the lowermost mafic and ultramafic magmatic units of the Lower Zone. The TCU hosts the two dominant ortho-magmatic mineralised zones (orebody). A major fault known as the Tshuduku fault also traverses the project area from the north to the south. For the feasibility stage of the project, a geotechnical block model was created for Ivanplats, with the aim to determine the variability of the rock mass quality across the planned mining area and to highlight the poor ground caused by the presence of the Tshukudu fault.

3.1 Rock Mass Characterisation

As discussed in Section 2.1, the Norwegian Geotechnical Institute’s Q-System was utilised to facilitate the derivation of Q values for the rock mass per geotechnical interval per stratigraphic unit. A total of 83 borehole geotechnical logs were assessed using this system and thereafter the Q values were converted to rock mass rating values (RMR) using the equation described in Section 2.1. The compositing process was accomplished using the software package Datamine Studio RM. A 10 m interval (compositing) length was applied to the data, as this was the block size chosen for the z-axis.

3.2 Geotechnical Block Model Creation

The following processes describe a summary of the development of the Platreef block model:

- Conversion of the Barton Q values into Rock Mass Rating values (RMR).
- Importing of the geotechnical borehole collar, survey and RMR data into the software package (Datamine Studio RM).
- Compositing (regularising) the RMR data within the borehole to 10 m lengths.
- Importing the Tshukudu fault wireframe to creates a zone of influence (poor ground).
- Defining the model extents based on the lithological wireframes.
- Assigning a RMR value of 20 (very poor ground conditions) to a 5 m zone around the Tshukudu fault wireframe and a RMR value of 40 (poor ground conditions) to a 30 m buffer zone around the fault wireframe.
- Estimating the RMR data within the model extents based in the inverse distance squared algorithm with a 3 pass estimation neighbourhood.
- Creation of the geotechnical block model based on the resultant data from the above processes.

3.2.1 Statistical Approach

The method employed for the creation of the Platreef block model was the inverse distance squared algorithm as outlined in the summary. Inverse Distance Squared Weighting is a type deterministic method for multivariate interpolation with a known scattered set of points. The values that are assigned to unknown points are calculated with a distance weighted average of the values available at the known points.

Anisotropic search ranges were chosen based on the orientation of the major structures in the area, as the expected maximum continuity of weak zones is anticipated to align with these. A block size of 20 x 20 x 10 m was chosen, and the blocks were informed in a three pass search strategy. The first pass was very restrictive, in order to ensure the estimates honoured the
local data, using only 1 sample and a very short range (the nearest neighbour type estimate used in section 2.2.3). The second pass utilised a longer range and a maximum of five samples in the estimate. All remaining blocks, not estimated in the first two passes were assigned a RMR value of 62 (the average RMR from our dataset). The confidence in the third pass is naturally low, as there is insufficient data to inform the estimates. Search pass parameters are presented in Table 4.

Table 4: Search pass parameters - Platreef

<table>
<thead>
<tr>
<th>Search Pass</th>
<th>Range (m)</th>
<th>Minimum no. of samples</th>
<th>Maximum no. of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Assigned Average RMR = 62</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.3 Results
A summary of the values determined using the statistical function imbedded into the Studio RM programme for RMR are presented as Table 5 for search pass 1 (highest confidence) and search pass 2 (medium confidence).

Table 5: Summary Geotechnical Block Model RMR Results

<table>
<thead>
<tr>
<th></th>
<th>RMR Search Pass 1</th>
<th>RMR Search Pass 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td><strong>Min</strong></td>
<td>31</td>
<td>38</td>
</tr>
<tr>
<td><strong>Max</strong></td>
<td>82</td>
<td>82</td>
</tr>
<tr>
<td><strong>Mean + Std Deviation</strong></td>
<td>73</td>
<td>71</td>
</tr>
<tr>
<td><strong>Mean – Std Deviation</strong></td>
<td>37</td>
<td>39</td>
</tr>
<tr>
<td><strong>Number of Samples</strong></td>
<td>42 980</td>
<td>353 759</td>
</tr>
</tbody>
</table>

These search passes are also illustrated in Figure 8, and can be considered as a proxy for the confidence in the estimates. In contrast to the Kipushi model, the geotechnical data on the Platreef project are less densely clustered, and so the search passes appear more like the classic spotted dog. The diagram illustrate that the first and second passes represent reasonable confidence in the estimates, while the third search pass highlights areas that are poorly informed, and require additional data to model.

Based on the block modelling exercise, it is recommended that further drilling is conducted in areas where there is insufficient data. For the planning process, the geotechnical block model should be used to identify areas of “poor” ground to ensure that placement of permanent structures are avoided in these areas (eg. in the vicinity of the Tshukudu fault).
4 Conclusions

Geotechnical block models were successfully created for Kipushi Mine and the Platreef project to provide a 3-dimensional visual impression of the rock mass conditions in the planned mining areas. While these models provide insight on areas where potential instabilities may occur, such models should not be used in a prescriptive manner to design rock support on a local scale. Instead, they should be used to create awareness and provide the opportunity to address potential rock mass instabilities that each mine may be faced with during the excavation process. As the proposed mining at Kipushi and Platreef has not commenced, it should be noted that the block models serve only as a platform that should be continually built and improved upon as more data is gathered as mining takes place.

Based on this study it was determined that geotechnical block models may be utilised successfully for various mining applications that require a detailed understanding of the variability in rock mass conditions. Creating such models not only allow for the assessment of the spatial variability in the rock mass information, but in addition allows for the identification of data-deficient and high risk areas. The use of geostatistics with geotechnical datasets has also highlighted the specific challenges which come with geotechnical data such as a combination of background values (undisturbed rock mass) and planar features (such as faults and lithological boundaries) which require specific consideration and domaining.

References

Bye, A. 2006b. The strategic and tactical value of a 3D geotechnical model for mining optimization, Anglo Platinum, Sandsloot open pit.