Photogrammetric Mapping and Survey Assessment of Complex Structural Geology in the Design Analysis of Pit Walls: Superpit, Kalgoorlie

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Abstract

Kalgoorlie Consolidated Gold Mines (KCGM), operator of the Superpit, has recently completed a comprehensive optimisation project on the eastern pit wall that delivered approximately AUD$950M value to the life of mine (LOM) reserve. A key component to project success was the establishment of a detailed photogrammetric face mapping system that enabled large sections of inaccessible pit wall to be accurately mapped for both i.) geotechnical defects and ii.) face performance parameters. A key feature of the face mapping and survey system was the incorporation of an on-site database linked with the graphic design software to enable data sourced from the photogrammetry system to be compared graphically against other sources and assigned a weighting in subsequent design analyses.

The photogrammetry system was also used to survey (measure) the amount of crest loss incurred within the design project area. The results of these surveys allowed accurate calibration of the bench stability analyses enabling them to be used in risk modelling. The development of the photogrammetry system was a pivotal point in advancing the slope optimisation project principally through increasing the amount of data able to be collected; this in turn raised the confidence of the final design.

1 Introduction

The Superpit is currently one of the world’s largest producing open cut gold mines and is situated adjacent to the Australian regional outback city of Kalgoorlie-Boulder. The pit is famous for amalgamating the results of more than 100 years of mining of the Golden Mile deposit into a large modern open pit operation that currently produces >750,000 ounces of gold per annum. As part of the ongoing business improvement initiatives the owners of the Superpit have sponsored the completion of a comprehensive pit wall optimisation project. This required full updating of the structural geology and geotechnical models.

The Golden Mile deposit is hosted within Archean greenstones of the Eastern Goldfields province. The greenstones comprise meta-dolerite and meta-basalts and within the Superpit are represented as moderately structured (faults, fractures) hard green rocks. Rock mass strength is good, with typical Rock Mass Rating (RMR) values of 70+ and the prevailing wall failure mechanisms are controlled by faults and extended fractures. Within this context pit face mapping data becomes an important input to the structural geology modelling process.

One of the legacies of the protracted mining history in the Superpit is more than 3500km’s of relict underground workings (voids). As these repeatedly intersect the pit wall they ensure that access across and along mining berms is typically restricted. As a consequence photogrammetric methods needed to be considered in order to provide sufficient coverage of the pit wall that included areas inaccessible on foot due to the voids.
2 Development of the KCGM photogrammetry system

Initial assessment of the available photogrammetric software packages was undertaken and a package (ADAMTech™) was selected for initial trial followed by subsequent purchase. Key features that were relevant to the decision to purchase the ADAMTech™ software included:

1.) Reduced survey control requirements and the ability to utilise a variety of different control point configurations within the system.

2.) Ability to use an off-the-shelf DSLR camera and calibrate the lens for site-specific conditions using the software.

3.) Relatively quick collection of photographs in-field and ability to stitch these together using the new software to produce a full 3D textured photographic image and associated DTM surface.

4.) Ability to import the resultant image easily and quickly into the mine planning software so that it could be geo-referenced against other data sources such as diamond drilling and field mapping.

5.) A comprehensive mapping tool, included in the software, which made the collection of defect data from the images a relatively quick and simple process.

Other packages had been used previously at KCGM however the ADAMTech™ package provided advantages in terms of the effort required to gain appropriate survey control and higher level features that enabled the data to be transitioned more readily from collection to analysis. An added benefit was that the ADAMTech™ software was headquartered in Perth, the capital city for Western Australia, thus improving the response time for help-desk queries.

2.1 Photogrammetric method

The photogrammetry was undertaken in the field with consideration to the following points:

- Survey reference boards were positioned on the pit wall at regular locations to provide control points on which the resultant photogrammetric images could be geo-referenced (Figure 1). Once established the survey boards provided a convenient control network for the whole pit that has been utilised for other systems requiring geo-referencing. For many control points a prism was also installed in the centre of the board for use by the ATS system.

- Photography of the pit wall was undertaken using a Canon EOS5D DSLR camera and 100mm lens. This combination allowed images of sufficient resolution to be captured from the other side of the pit at a distance of up to 1.8kms, although the typical distance from the wall was around 500m.

- An image fan technique was utilised, with each fan containing a minimum of 3 camera stations and consisting of images with 10% overlap. Camera stations need to be positioned approximately perpendicular to the wall being imaged and each station is generally required to be on a similar level.

- The images were processed to a full 3DTM surface using the dedicated software and imported for use within the mine planning (Vulcan™) software.

- Image files were archived using the camera stations and the date on which the photographs were taken; this allows an advanced feature of the software to be utilised through being able to process additional image fans from different camera stations at a later date into the original mosaic effectively updating and/or expanding the resultant image.

2.2 Structural mapping method

The resultant photogrammetric image was then used to undertake structural geological and geotechnical defect mapping of pit faces, many of which were inaccessible. This was undertaken with consideration to the following points:
Structural mapping was undertaken on the digital terrain models. Defect planes were modelled by the user digitising points on the defect plane or trace to which a circular plane was automatically fitted by the photo-mapping software (Fig. 2). The radius of the circular plane was adjusted to accurately represent the observed persistence of the structural trace.

A site mapping template was used to ensure that mapped structures/defects were assigned to a consistent ‘Structure Type’ by all personnel.

The photogrammetric method allowed major structures to be readily traced across multiple batters and the undulating nature of some major structures could be represented by the digitisation of multiple planes along the trace. Each modelled ellipse representing a major structure was assigned an identification code unique to the structure being mapped.

Minor structures were digitised to obtain rock mass defect data for the primary structural sets and structural types.

The ability of the user to zoom and pan to readily view the structural traces and sets from different vantage points facilitated an accurate assessment of structural persistence and joint set spacing.

A site photogrammetric mapping file was used to contain all structural mapping data. This helped to ensure complete mapping coverage of the pit wall and prevented duplication of mapping within adjacent photogrammetric projects.

Figure 1. Survey control point network (blue crosses) positioned around the pit and a registered photogrammetric project photographed from camera stations (red circles) on the east wall of the pit.
The photogrammetric structural mapping provided an almost complete sampling of daylighting structures with persistence greater than approximately 25m, which was the targeted data set. There was a high correlation between photogrammetry and traditional face mapping for parameters such as: i.) defect orientation, ii.) persistence and iii.) spacing. There was also good correlation with some sets common to both the photogrammetry and diamond drilling (logging) data. The photogrammetric mapping did not provide data on defect surface conditions, apart from large scale waviness. However, this data can be obtained for each defect set and major structure from equivalent face mapping and drill core logging in the subsequent validation process.

3 Data manipulation and validation

The photogrammetric data that was collected was subsequently data-based and then compared to that obtained from other sources. Important aspects of the data collection and mapping process were the ability to subsequently store and manipulate the collected data. Principally, this occurred through the use of mine planning software that also contained its own on-board database system.
3.1 Database structure
Data from the various sources, including that of the photogrammetry, was input into an MS Excel spreadsheet in csv format and then uploaded into the onboard database. The database included the following key sets of fields:

1.) Source and Type of Data.
2.) Data point location, Identification and Priority Weighting fields, the latter so that progressive user-defined filtering of the data could be enacted.
3.) Lithology and other general geological characteristics.
4.) Geotechnical Characters.
5.) Hydrogeological Characters.
6.) Structural class and significance, and structural name (if applied).

Once established, all face mapping, core logging and photogrammetry data was maintained in the database. Routine update of the spreadsheets provided a first pass validation of the data integrity as well as the ability to flag duplicate data.

3.2 Graphical representation
Once databased, the data from all sources was able to be uploaded into the mine planning software and graphic visualisation using layers was then undertaken. As well, reduced photogrammetric digital terrain models were available for loading into a geotechnical directory. The ability of the mine planning software (Vulcan™) to produce a 3D visual representation of the entire geotechnical data streams was critical for validation of the data and for downstream processing. Geotechnical data points were graphically represented by 3D ellipses. The important capabilities of the database graphic interface included:

- Visualisation of all the geotechnical data together in 3D with pit shells, structural and domain DTMs.
- Representation of individual defects using 3D ellipses whereby the centre represents the geographic location and the ellipse diameter is proportional to the defect length.
- The ability to select features graphically and edit individual data records.
- Capability to filter the data presented graphically to a particular area, data collection type, structure ID or domain solid.
- Ability to digitise new records such as from registered underground level plans containing mapping data.
- The opportunity to enact updates to the structural geology and geotechnical models using the newly derived data.

3.3 Data validation
Visually reviewing mapping and logging data greatly facilitated the detection of errors or mis-referenced data that would be less obvious and significantly more difficult to detect in other ‘non visual’ formats. In addition to standard character validation checks other errors could be detected readily by the operator especially when displayed visually. Specifically the following types of data collection errors were easily validated:

- Positional errors of the plotted mapped points.
- Orientation errors in mapping data or drill hole section line orientation.
- Structural types with inconsistent persistence.
It is also important that structural mapping data generated through two different means (e.g. face mapping and photogrammetry) can be validated through direct comparison of the outcomes from each method. This comparison can include:

- Specific Validation – where the geotechnical characteristics for a structural feature derived through different methods are directly compared.
- General Validation – where the distribution of structural sets obtained by both methods is compared such as when comparing different stereonet distributions.

3.4 Data weighting

Various methods were applied to the collected data to enable efficient extraction and filtering of the data-set. In this manner the system aims to keep as much of the data as possible, even if duplicated, but to enact subsequent filtering to ensure that duplicity does not affect the outcomes derived from the data.

3.4.1 Duplicate mapping data

One of the significant issues faced when using both face mapping and photogrammetry methods is the potential for duplication of data points. This will occur where the same structural feature is mapped multiple times by different people within the geotechnical group, or by the same person but using different methods. In effect the database then contains two or more data points effectively representing the same feature (statistic). Such duplication is undesirable in the rock mass data set, as it will lead to adverse over-representation of particular defects if not managed and their requisite geotechnical traits.

To address the issue of duplicate data a ‘Priority Weighting’ was applied in order to mark the record selected to represent the structural feature. This process was undertaken as follows:

1.) Data was graphically loaded (as discussed above) and previous mapped areas systematically checked for duplicate data points,

2.) For each duplicate data point the individual source data was reviewed and a decision made on the run for which ‘Priority Weighting’ would be applied. This point was then marked (assigned the code within the database field).

By applying the weighting procedure described above, all records were able to be maintained within the dataset, thus preserving the integrity of the data collection from different sources. By doing this, albeit with some initial effort, subsequent data analyses can review the selection of the specific duplicate point and, if necessary, reapply the weighting to another point. If this data were culled from the database (so as to remove the duplicates) then this subsequent re-interpretation phase would not be possible.

3.4.2 Capturing the advantages of photogrammetry and field mapping

In determining which of the duplicate data to maintain as priority, an assessment of the reliability and overall representativeness of the record was undertaken. In some cases it was advantageous to combine the data from the photogrammetric and field mapping to form a single record. For example structural orientation data determined from photogrammetric mapping was considered more representative of the overall structural orientation than face mapping data collected at the smaller scale. Similarly persistence and spacing data could also be measured more accurately using the photogrammetric method however joint surface properties needed to be assessed by traditional field mapping. In these situations a single data record was compiled capturing the most representative traits derived from each method. Once the combined record was generated it was also assigned a ‘Priority Weighting’ so that it would be preferentially selected during data queries.
3.4.3 Assigning identification and weighting to major structures

Another issue faced when mapping laterally extensive and high pit walls is the ability to track significant structures as the mining front progresses. Face mapping collects data typically at the bench scale however the inevitable structural modelling requires that pit-scale structures are accurately mapped and modelled. As the mapping progresses over multiple benches numerous mapping/data records are obtained that relate to each specific individual structure.

Once again this issue was addressed by assigning a specific identification code to the multiple mapping or data records collected on the same structure. This identification code, which is unique to each structure (ie. structure name), was assigned to all mapping points collected that related to the structure. This could either occur at the time of mapping or upon subsequent data manipulation using the graphic visualisation. The edits were placed directly into the database and facilitated the building of the structural model by enabling filtering of data to specific major structures. Data points relating to major structures were also assigned a ‘Priority Weighting’ to differentiate this data from that used for the general rock mass dataset.

4 Measurement of actual batter and berm performance

Photogrammetry methods were also utilised to measure the achieved batter angles and berm widths in order to undertake reconciliation between the pit design and the as-built for the optimisation project. This process involved measurement of the amount of crest loss being achieved through implementation of the existing design. The amount of crest loss can then be directly related to the achieved catch capacity of the mine berms. This measurement process became especially important when assessing the field performance of batter face trials, which were undertaken in the pit wall optimisation project to test steeper wall configurations.

The key product derived from creation of the photo-mosaic is a detailed digital terrain model (DTM). This DTM is typically more accurate than traditional surveys due to:

- A significantly higher point density being incorporated in the DTM. and
- The photogrammetric DTM reaches areas not accessible to surveyors.

4.1 Method of measurement

The following method was utilised to measure the actual (as-built) face performance:

1.) The relevant DTM was prepared and imported into the mine planning software (e.g. graphical representation). The applicable pit design shell was also loaded into the mine planning software at this time.

2.) Both the photogrammetric (asbuilt) and pit design DTM’s were sectioned by establishing closely-spaced (5m) section lines perpendicular to the slope orientation (design crest line).

3.) Each section was displayed, working across the DTM, and the following measures were digitised as single segment lines to represent the achieved batter berm slope relative to the pit design (Fig. 3):
   a. Crest Loss (blue segment in Figure 3).
   b. Batter Flare (red segment in Figure 3).
   c. Achieved batter face angle (measured from achieved toe to achieved crest).

4.) Once digitised the segments, comprising a start and end point, were exported via csv file format to MS Excel where the length of each segment was calculated using trigonometry. This enabled a clear geo-referenced record of the areas that were measured and made subsequent numerical analysis easier.

5.) The measurements were undertaken for specific sections of pit wall corresponding to relevant geotechnical domains and wall orientation sectors.
4.2 Identification of key mechanisms

One important advantage of using the photogrammetric DTM to undertake measurements of the as-built is that identification of the mechanisms that cause compromised batter berm performance is sometimes possible whilst the measurement process is in progress. Once the primary mechanism has been identified appropriate steps may be taken to reduce the influence of the mechanism. Mechanisms that are relevant to this include:

- Blast damage – identified from highly irregular surfaces bounding the lost portion.
- Kinematic structural failure – evident from the defects present in the section and photogrammetric mosaic (and previous structural mapping).
- Aggressive scaling – can arise from attempts to mitigate the two above mechanisms and is observed through ‘teeth marks’ evident on the batter face from the photo.

4.3 Analysis and data presentation

Once the as-built performance was measured the data was then available for analysis of a variety of performance indicators. The measurement data obtained for each geotechnical domain and wall orientation sector can be presented in a graphical format as shown in Figure 4, which shows as an example a cumulative frequency curve summarising the amount of crest loss on a measured berm. Specific issues that may be addressed through use of the measurement technique include:

1.) An assessment of the berm reliability for different slope sectors and geotechnical domains.
2.) The probability of achieving required berm width for loading capacity and the subsequent effect on rock fall catch requirements.
5 Utilisation of photogrammetric DTM for rock fall modelling

The photogrammetric DTMs also provide realistic pit face surfaces for use in Rocfall™ improving the accuracy of these models. Such models have become important tools in managing the rockfall risk at KCGM (Hewson & Corskie, 2009). In addition to providing an accurate section of the actual pit face and berm geometry (Fig. 5) the photogrammetric DTM also enables an assessment of the ‘roughness’ factor of the batter face, a parameter that is required for the modelling and which can be quite sensitive on the outcomes. The surface profile of the batter face also has a significant influence on the rock fall trajectories, and this is able to be much better defined for the rockfall modelling by using sections derived from the photogrammetric DTM.

6 Conclusions

The establishment of the pit wall optimisation project generated a need for a means by which numerous pit face exposures needed to be mapped quickly and accurately. The use of photogrammetry enabled this to occur and provided additional tools by which the data could be validated and subsequently manipulated for use in geotechnical design programs. Although sometimes difficult to fully establish, the photogrammetric system developed for the Superpit was a key component in the success of the east wall optimisation project.
Figure 5. Rock fall model using a pit wall surface generated using photogrammetry.

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8 References