*Figure 1: 3-D Mosaic image showing the hanging-wall and footwall*

# Capturing slope data

## DK Llewelyn explains how photogrammetric mapping can be used for pit slope angle optimisation

**T**he requirement to maximise ore extraction and minimise waste stripping is becoming more critical in operating pits as they deepen and economics become tighter. Optimising slope angles has to be based upon reliable rock mass data.

In most circumstances, the access for mapping the required data is restricted due to health and safety concerns accompanied by time constraints. When hand mapping, geotechnical engineers have to make do with the areas that are accessible and within reach (~2m). They are usually limited for time during the mine cycle and little time is available for sufficient geological/geotechnical data collection.

Photogrammetry is a remote data capture system that uses digital pho-

*"Photogrammetry is a remote data capture system that uses digital photogrammetry to produce accurate 3-D structural models of mine features"*

togrammetry to produce accurate 3-D structural models of mine features. Using photogrammetry mapping software such as CAE Mining's Sirovision software, 3-D photogrammetric images of rock faces can be produced rapidly and safely, while remaining cost-effective. The time taken in the field is reduced to the one process of taking orientated photographs of the slope.

The 3-D images created are then mapped using specialist computer software, producing rock mass measurements which can then be subsequently used for a variety of geomechanical applications.

SRK has successfully used photogrammetry mapping to collect rock mass data from numerous operating open-pit mines, which has then been used to optimise pit slope angles with significant cost benefits for its clients. This article discusses how photogrammetry mapping was used to collect geotechnical data for a working gold mine in Ghana and then how the data was used to optimise the pit slope angles.

## DATA COLLECTION

Three scales of mapping were to be undertaken: bench scale (18m high), multi-bench and total slope (~170m).

Photogrammetric mapping requires the cameras to be at a certain distance from the face so that the entire height of the face/bench can be captured in the 3-D image. Photogrammetric mapping was applied to both the hanging-wall and footwall (Figure 1).

The analysis to determine whether there could be an increase in the inter-ramp angle was conducted on the hanging-wall as the footwall slope angle was restricted to the angle of the bedding (~40°). Most of the mapping was done on three ramps along the hanging-wall and the working ramp on the footwall which provided the only good access.

The data gathered was used to create the 3-D images from the photographs and then mapping was carried out on the 3-D images to record the fractures seen in the rock mass. Focus was placed on distinguishing between the bedding planes and joints, as well as identifying discreet structures which may affect slope stability, such as shear zones. ▶



*Excellent excavated wall conditions*

*Figure 2: ▶ Stereonets generated using DIPS software*

Overlapping 3-D images were stitched together to form mosaics, allowing for mapping of larger (full bench and multi-bench scale) features that spanned across numerous models.
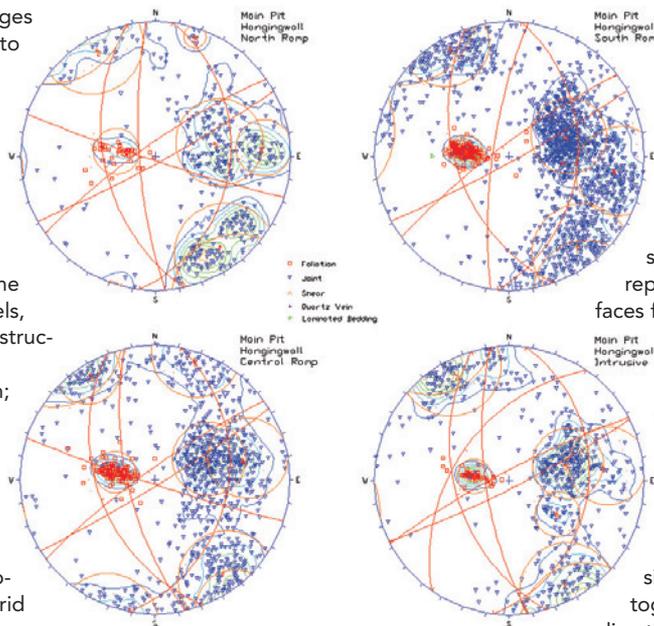
Over 4,000 data points were mapped over eight hours from the photogrammetric models, including the following structural information:

- Dip and dip direction;
- Discontinuity type (joint or bedding);
- Discontinuity length;
- Centroid of each feature – easting, northing, height (geo-referenced to local grid system);
- Discontinuity roughness; and
- Discontinuity set spacing.

*"The photogrammetry mapping data was used as the source of data for the pit slope stability analysis"*

The hanging-wall of the gold mine is a quartzite material and was accessible along each of the three ramps: north, central and south areas. The analysis focused on domaining the hanging-wall to determine any structural changes along the pit strike. Major Joint Sets were chosen using DIPS (a Rocscience stereographic analysis program) according to the concentration of orientation poles on the stereonets and trace length of individual data points (Figure 2).

The evaluation of the different conditions in each domain showed that the sets were comparable with the bedding (foliation in the dacite) and five major structural sets being present in each domain.

A feature of the software enabled the measurement of the joint roughness coefficient (JRC), trace length and spacing values for each structural set (Figure 3). A statistical analysis was carried out upon each discontinuity set to calculate average, minimum, maximum and standard deviation values of spacing, roughness and trace length for each set.

### GEOTECHNICAL MODEL GENERATION AND ANALYSIS

The photogrammetry mapping data was used as the source of data for the pit slope stability analysis, which was carried out in two stages. The first stage of the stability analyses aimed to assess the effect of increasing the slope angle upon bench stability, while the second stage involved stability analysing the entire slope at the increased angle.

### BENCH STABILITY

Bench stability analysis was carried out using GS Esterhuizen's SBlock program, which makes use of the keyblock method to calculate the removability of blocks from a slope face. The program repeatedly selects joint surfaces from the provided joint statistics (collected during mapping) and tests whether a block is formed. The average failure volumes are calculated by the software assuming that every joint truncates against another joint, and it considers the trace length together with joint dip/dip direction.

### OVERALL SLOPE STABILITY

The overall stability analysis used Rocscience's Phase2, a 2-D finite element program which enables the calculation of both probability of failure (POF) and factor of safety (FOS) while incorporating a fracture network into the stability model (Figure 4).

Three inter-ramp configurations were analysed (59°, 62° and 64°) using the planned pits depths of 300m and 400m.

The slope model was split into geological domains: quartzite country rock, crystalline conglomerate orebody and dacite intrusions. Groundwater data was not available for the site and therefore a reasonably high phreatic surface with a steep hydraulic gradient close to the face was assumed based on SRK's

*Figure 3 (below): Part of a single bench showing the mapped discontinuities. Figure 4 (below right): 2-D pit slope section analysed using Phase² software*
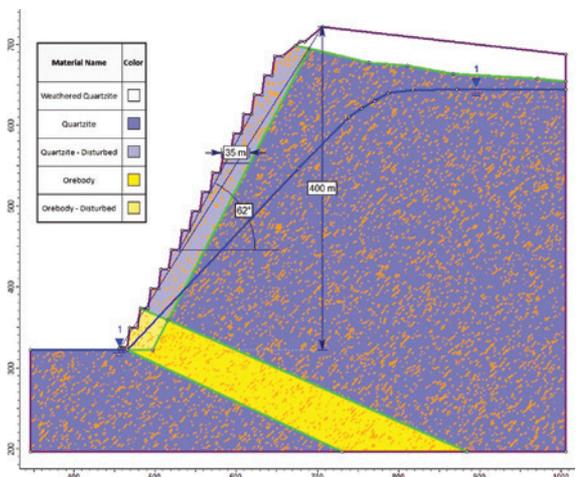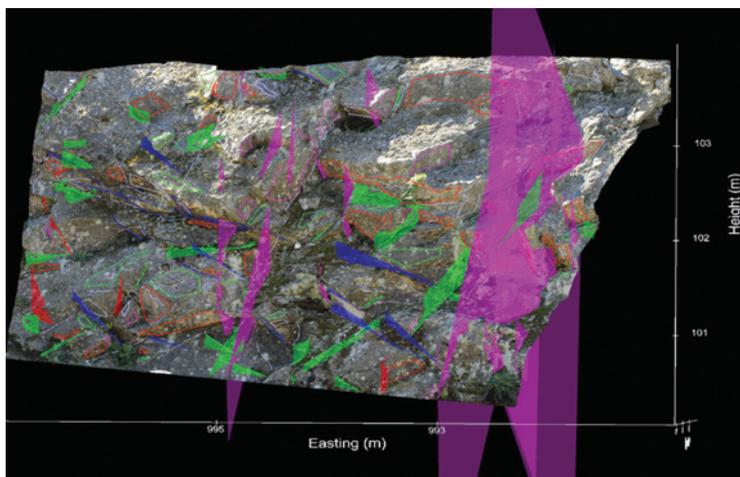
observation of water seepages in the slope during the mapping exercise.

Rock mass strength was calculated using the Hoek-Brown strength criterion and the weathered material using Mohr-Coulomb. Intact rock strength was based on the laboratory testing and the Geological Strength Index (GSI) was based on values estimated from the photogrammetric 3-D models. The disturbance (D) factor varied depending on the proximity to the pit slope face.

SRK recommended to the client that pre-split blasting be used to form the bench faces, which suggests that the thickness of the blast damage zone would be 1.0-1.2 x the height of the bench. The disturbance factor in the 35m-thick blast affected zone was set to 1.0 and to 0.3 for the remaining rock mass. The rock mass modulus was calculated by multiplying the MR (modulus ratio – empirical estimate) and uniaxial compressive strength (UCS) value. The rock mass would behave in a plastic manner and therefore the modelling program was set to invoke residual parameters when failure occurred. A joint set was included in the modelling so that the orientation and strength properties of the most influential structures upon slope stability were considered in the analysis.

## OUTCOMES

SRK was able to recommend an increase in the current pit slope angle configurations; the inter-ramp angle was raised to 62° from 59° and the bench angle to 82° from 72°, allowing for a bench height of 24m and berm width of 9.4m.

The finite element analysis indicated that a total slope failure would be controlled by sliding along the outwardly dipping joint set and the fracture of rock bridges between the discontinuities. A bench height of 24m was used as the client's current drilling practice meant that it was having difficulty conforming to design with an 18m-high bench face. Increasing to 24m-high benches provides the necessary extra berm width, whilst not greatly increasing the burden on the client's drillers.

In order to recommend these increased slope angles, it was highlighted to the client that pre-split blasting would need to be introduced to its mining practices. This would reduce the size of the zone of blast damage into the rock mass and decrease the likelihood of degrada-

tion of the bench faces, which stops the berms from filling with failure material and making them more effective to prevent rock falls.

The increase in inter-ramp angles reduced the amount of waste material that the client would be required to remove before reaching ore. A 3° increase over a 400m-high pit saves around 14 million $m^3$ of material along the 3.5km pit strike when

compared to the original design. An increase in bench face angle from 72° to 82°, even factoring in the reduction in berm width to conform to the increase inter-ramp angle, increased the berm width from 5m to 9.4m.

This increase in berm width will deliver a larger area to stop any falling blocks and provide a safer and clean berm along which to walk. ▾

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*See: www.srk.co.uk/en/our-services/uk-geotechnical-engineering-services*