Enhancing the Collection of Rock Mass Fabric Data for Open Pit Mines

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ABSTRACT: For slope stability, knowledge of major and minor discontinuity sets that form the rock mass fabric is paramount for pit slope designs. Due to the increased awareness of health and safety in mining projects, efforts have been made to limit structural mapping in order to minimize the risk to personnel associated with approaching potentially unstable areas. Recognizing the importance of such safety precautions, Golder Associates Ltd. is applying a combination of techniques including 3D photogrammetry, conventional mapping and drilling with core orientation to enhance structural data collection. Photogrammetry uses digital photographs to produce a virtual model of a rock mass surface. The application of these techniques will be exemplified through an expansion design of an existing open pit. A comparison of stereonets obtained using these techniques showed some agreements, but also highlighted limitations of each method. The application of photogrammetry was found to be very useful in complementing the other existing techniques.

1 INTRODUCTION

Due to current market trends of decreasing metal prices and also to improve ore extraction, mining companies try to utilize steeper slope angles if geomechanically feasible. The key to most successful slope steepening programs is a rock mechanics based design and implementation approach founded upon detailed geological and geotechnical data collection and analysis (Golder 2002).

The coupling of data collection methodologies consisting of photogrammetric methods, conventional bench mapping methods and geotechnical drilling programs enable data collection on: i) bench and multi-bench scales, ii) on the surface of the excavation walls that have been potentially damaged as a result of excavation (i.e. photogrammetric and conventional mapping) and iii) at depth behind the walls allowing for the collection of more in situ rock mass fabric (i.e. geotechnical drilling with oriented core or televiewer surveys). The coupling of these methodologies allow data to be collected at safer distances, minimizing the risk to personnel and the measurement of a more complete set of geotechnical data (i.e. discontinuity orientations, spacing and persistence). This results in a more complete understanding of the rock mass.

The case study described in this paper is an expansion design (both laterally and with depth) of an existing open pit. The on-going mining activity has exposed discontinuities on bench faces that could assist with the understanding of the rock mass fabric. However, due to blast induced damage, the previously mined pit walls contain unstable blocks which are prone to fall (Fig. 1). These dangers are ubiquitous for bench mapping and prevent the proper collection of joint measurements in some locations and result in the loss of valuable information. In order to safely collect the required data, a coupled data collection methodology is presented through the case study.

Figure 1. Examples of poor and good blasting on pit walls. Left image illustrates the potential risk for rockfalls and thus potentially unsafe working conditions.

2 DATA COLLECTION METHODOLOGIES

As mentioned above, three data collection methods were coupled to assist in characterization of the structural conditions; (1) photogrammetry (Fig. 2a); (2) conventional mapping (Fig. 2b); and (3) geotechnical drilling with core orientation (Fig. 2c). The methods are outlined below with respect to their individual general methodologies, strengths and limitations based on experience in the field.

2.1 *Photogrammetric Methods*

Photogrammetric methods of data collection typically employ software programs that use stereo photogrammetry to produce a virtual model of a rock mass surface. The programs create 3D spatial data sets, which allow the user to determine the orientation of exposed discontinuities at distances away from the pit walls. As a result, detailed pit wall mapping can be completed in the office with limited time spent in the field, which is beneficial in minimizing the risk to personnel related to approaching potentially unstable slopes and working in operational mines around heavy equipment.

In recognition of the benefits associated with 3D photogrammetry, various software packages are available (e.g. ©Sirovision, ©3G – ShapeMetrix & JointMetrix and ©Adams Technology – 3DM Analyst) and commonly used in open pit mines around the world.

Golder Associates Ltd. has incorporated the use of photogrammetric methodologies into pit slope designs and the collection of rock mass characteristics at over 5 mining operations. A case study is presented for the expansion of an existing open pit mine in this paper in conjunction with structural mapping and geotechnical drilling with core orientation to enhance the collection of structural data in difficult access conditions.

Figure 2. Three structural data collection techniques: a) photogrammetry, b) conventional mapping and c) geotechnical drilling with core orientation.

2.1.1 *Field Procedure*

In general, photogrammetric data collection is quick and simple. Only field data in the form of photographs and surveyed control points within the imaging area are required.

The field procedure for the collection of photogrammetric data involves the collection of a pair of 2D images per processing area. The images (taken from two vantage points) are overlapping and only the overlap areas are processed into 3D images. Within the two photographs, control points need to be selected to allow for orientation of the 3D image. Depending on the software package used, a minimum of two control points per overlapping area should be obtained. Examples of control points include distinctive features on the rock face if no access is available (Fig. 3), painted markers or retrievable markers.

While the data collection is straight forward, careful planning is necessary prior to the collection of this data. Planning includes:

- familiarity with the site;
- knowing the approximate distances from which a photograph of the desired rock face can safely be taken;
- knowing the appropriate fixed focal length or zoom camera lenses required depending on the distances to photograph from;
- knowledge of when the rock face is exposed in sunlight. Good light exposure makes it easier for the user and the software program to highlight discontinuity surfaces in the 3D model. Dark photographs and shadows can conceal rock mass details; and
- knowledge of potential obstruction on the excavation surfaces to photographs (i.e. plants, tress, equipment, snow and ice, etc).

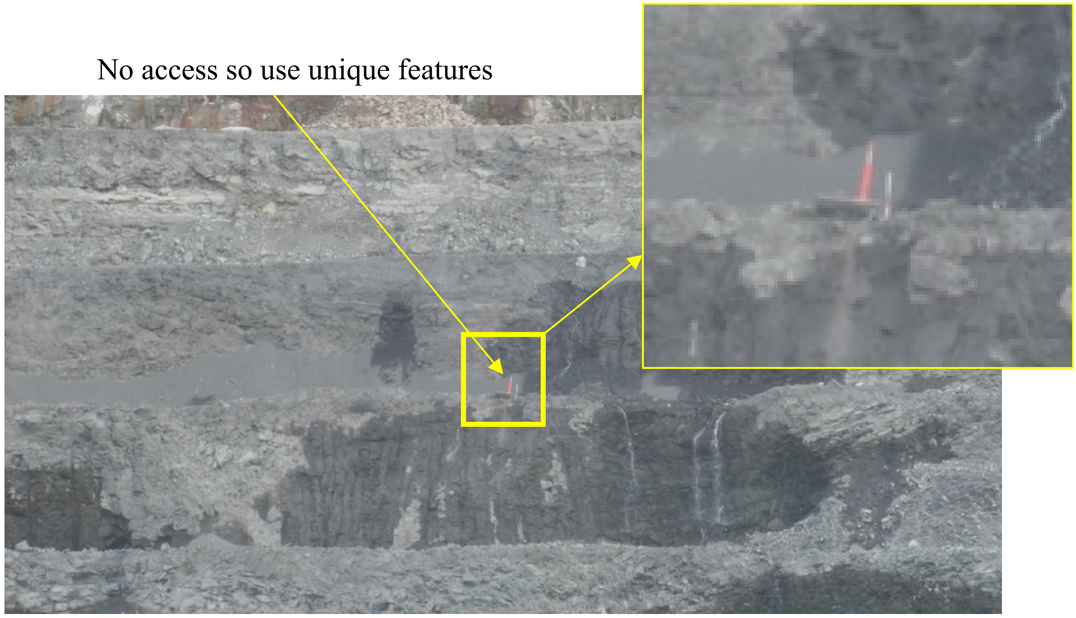


Figure 3. Example of unique feature on a slope that is not accessible to place control points.

2.1.2 *Data Processing and Analysis*

Each software company has their own processing critical path. As such, processing is not discussed. Focus is placed on difficulties arising during the processing phase of the data analysis.

Problems sometimes tend to arise in the 3D image when objects are found in front of the slope face. As seen on Figure 4, foliage distorts the 3D image and often becomes projected onto the rock face. Therefore, it is best to use photogrammetry on clean rock faces, with minimal obstructions such as vegetation, rock debris and snow cover. Snow found on a rock face covers discontinuity features and creates a large color contrast between the rock and snow, which can also distort the processed 3D image if camera settings are not properly adjusted.

3D photogrammetry can be used to determine structural data such as dip, dip direction, spacing, as well as persistence (discontinuity length) of discontinuity sets visible within a rock mass. Figure 5 illustrates various discontinuity planes selected on a bench face. The program determines the orientation of a given discontinuity surface by analyzing the coordinates of at least three points on the surface, which are defined by the user. Depending on what is visible on the rock mass, discontinuity surfaces can be highlighted as either a plane or trace (string of points). Planes are then fitted to traces by the software program for clear visualization of the discontinuity surface. 1170 discontinuity features were measured using the photogrammetric method in this case study.

For analytical purposes, each surface can typically be classified and named individually, which is useful when selecting different discontinuity sets. In general, this classification data, along with all orientation data can be exported and analyzed directly in the photogrammetry software or exported and used in any geotechnical program such as ©Dips, distributed by Rocscience.

One of the limitations of photogrammetric methods is that the collection of shear strength properties of discontinuity features is beyond the current capabilities of the software programs when the photographs are taken at great distances. Consequently, it is important to supplement the structural data collection with other techniques such as conventional mapping and geotechnical drilling with core orientation.

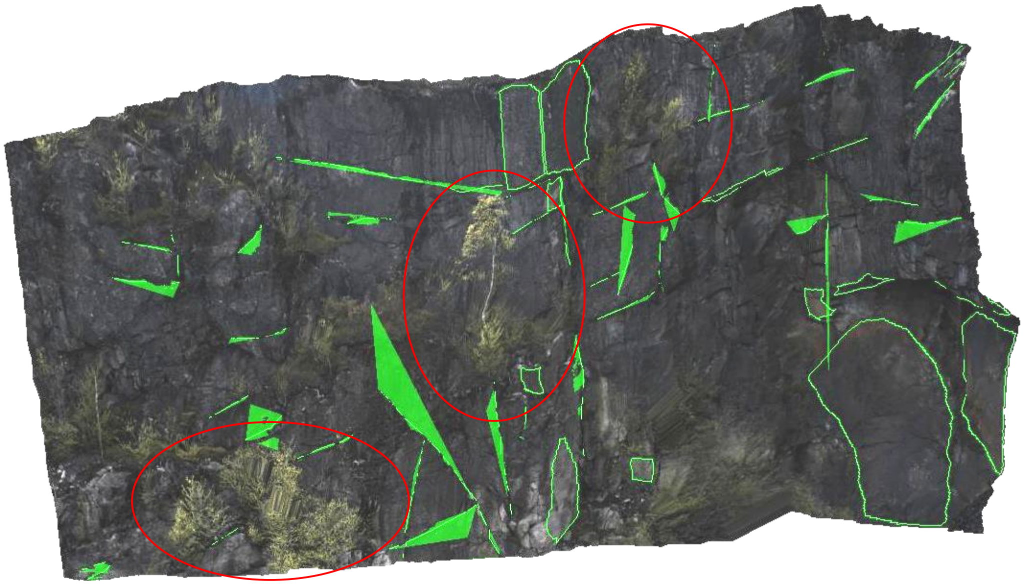


Figure 4. Example of foliage distortion in a processed 3D image.

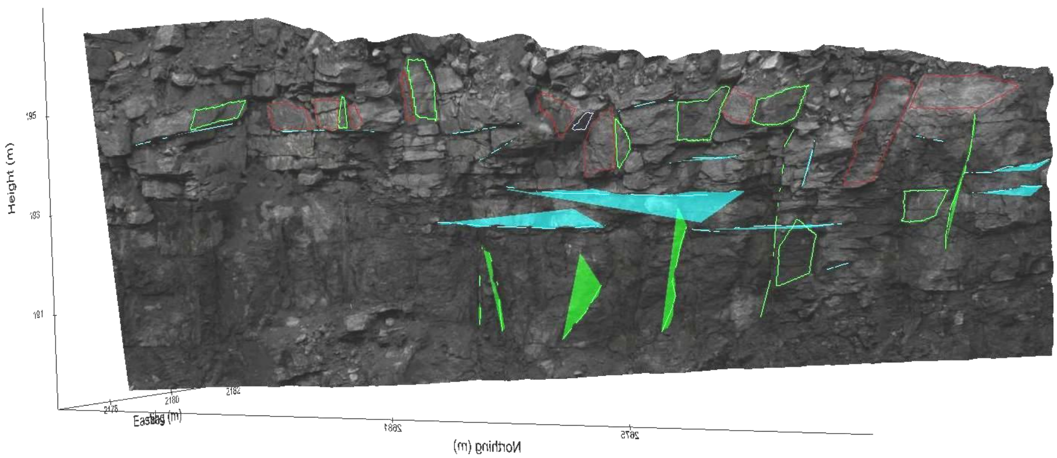


Figure 5. Selected structures on a rock face.

2.2 *Conventional Mapping*

Traditional line mapping was completed in a small portion of the wall at the same time as photogrammetric mapping. Due to limited access to pit walls and reachable height restrictions, a larger area of the rock face was mapped through photogrammetry. Only 189 discontinuity features were measured using conventional mapping compared to 1170 from photogrammetry.

Line mapping is a simple technique that comprises of stretching a tape along the face and mapping every discontinuity that intersects the line (i.e. tape). The ends of each line are surveyed, so that the location of the discontinuities can be determined and orientations corrected for bias. Physical characteristics of each discontinuity intersected are recorded, including persistence, termination, aperture, filling, roughness, shape and spacing, in accordance with the methods proposed by the ISRM (1981).

An issue often encountered during conventional mapping is the disturbance of compass readings due to magnetic properties of a rock mass. When this occurs, manual mapping must rely on non-magnetic structural surveys carried out by measuring orientations relative to points or lines of known locations and orientations. This method is slow relative to conventional compass surveys, and relies on accurate surveys of baselines adjacent to mapping traverses, reducing the accuracy of strike measurements. Through innovations in technology, photogrammetric methods could be applied to these situations to enhance structural data collection.

In terms of personnel required to complete manual structural mapping and photogrammetric mapping, for efficiency and safety reasons, two field staff were appointed for each method. Both of these techniques also required the support of surveyors on site. Generally, mapping through photogrammetry requires less time in the field and more time in the office to process the data, in comparison to line mapping. As a result, it is often favorable to conduct surface structural mapping using photogrammetry to limit the risk of personnel working near unstable rock faces or in regions which are difficult to access, as well as (in this case) limit the disruption to the operational mine activities.

2.3 *Geotechnical Drilling*

Geotechnical drilling has been the traditional method used to collect structural data at depth and in situ rock mass conditions for the design of open pit and underground mines. At this site, the Reflex ACT© core orientation tool was used to obtain structural data, in the form of dip and dip direction. 793 discontinuity features within the rock mass were measured and upon completion, the geotechnical drillhole was accurately surveyed. All discontinuities intercepted in the core of the drillhole were described geotechnically using the Q system (Barton et al. 1974). In addition, the physical characteristics of the rock mass, including weathering, strength and grain size/orientation (fabric), were described in accordance with the methods proposed by the ISRM (1981). Although this logging procedure provides detailed information regarding the rock mass, it only encompasses the rock encountered in the drillhole and introduces data bias

2.4 *Coupled Data Collection*

Each structural data collection technique has unique limitations and benefits. Therefore, when possible, the use of coupled data collection techniques can greatly enhance the depth of knowledge of the rock mass.

One of the main benefits of photogrammetric mapping is that it offers large coverage in a short span of time. Photogrammetry could also be incorporated into monitoring programs at operational mines, to provide detailed records of any changes seen in pit walls. However, 3D photogrammetry is limited to good weather conditions (sunlight and no rain), clean rock faces (little to no vegetation or snow cover) and to areas where a camera can easily capture the rock face. While photogrammetry can obtain persistence and spacing data, this method provides little insight into the geotechnical surface properties (shear strength) of the discontinuities.

Line mapping is limited to accessible and stable rock faces but requires only a compass, survey line and field staff. Rock mass characteristics and geotechnical descriptions, including joint conditions, spacing and persistence are recorded during this surface mapping method.

Geotechnical drilling with core orientation provides structural data at depth and information on the rock mass fabrics, which is the primary method used to design new open pit mines. Core logging records present detailed geotechnical descriptions for each discontinuity intersected (i.e. discontinuity type, roughness and alteration) and the physical characteristics of the rock mass (i.e. strength and weathering) but does not provide information regarding persistence of discontinuities. This data is also subjective towards rock encountered in the drillhole and requires careful interpretation of the results.

3 COMPARISON OF STRUCTURAL DATA

The structural orientation data collected from the east wall of the studied open pit are presented in this section to highlight:

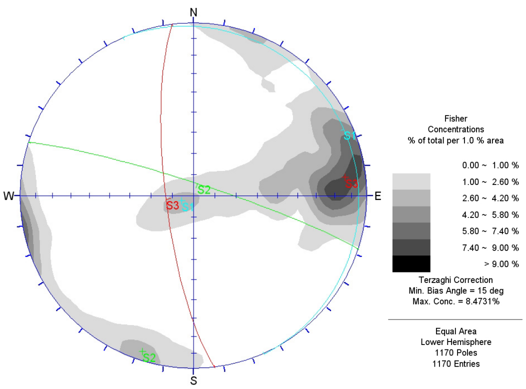
- the coupled data collection process;
- similarities between the data collected by each method; and
- their respective limitations.

The orientation data in all cases was processed using the software program ©Dips (Rocscience, 2003). Other data collected such as joint spacing and persistence are not discussed.

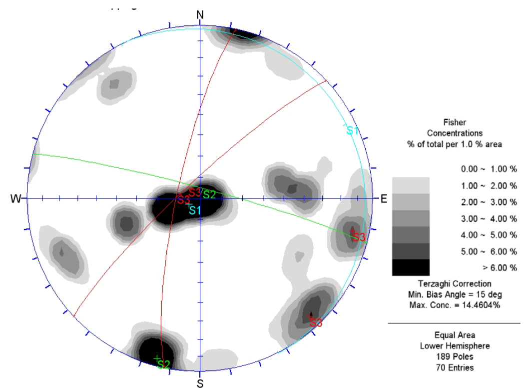
3.1 *Comparison*

Major discontinuity sets presented as stereographic projections from the photogrammetry, conventional mapping and oriented core are presented on Figures 6a, b, c & d respectively and summarized in Table 1.

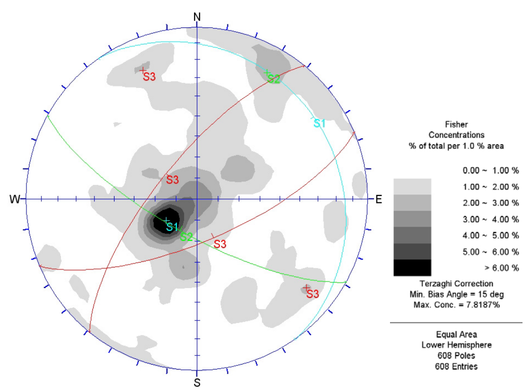
A Terzaghi correction was applied to all orientation data to correct for bias where features that are perpendicular to the direction of surveying are favored over those which are parallel. This bias correction calculates a geometrical weighting factor for each measured discontinuity, with the highest correction applied to the structures that are parallel to the direction of surveying.



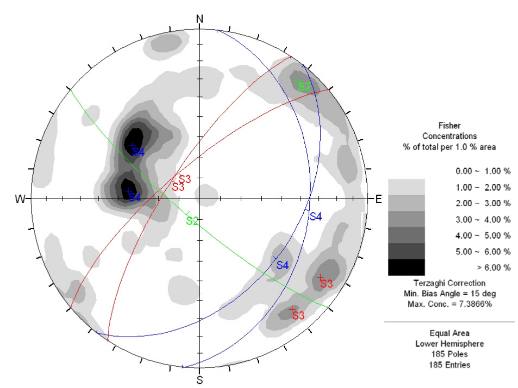
a) photogrammetric mapping



b) line mapping



c) oriented core data (joints only)



d) oriented core data (excluding joints)

Figure 6. Stereographic projection of results from a) photogrammetric mapping, b) line mapping, c) oriented core data from geotechnical drilling (joints only) and d) oriented core data from geotechnical drilling (all discontinuities types excluding joints).

Table 1. Summary of major discontinuity sets from the three structural data collection techniques.

	Label	Dip	Dip Direction	Strike	Set observed on
Set 1	S1	< 20°	NE	NW	Figures 6a, 6b & 6c
Set 2	S2	> 70°	N & S	E-W	Figures 6a, 6b, 6c & 6d
Set 3	S3	> 70°	W to NW & SE	N to NE	Figures 6a, 6b, 6c & 6d
Set 4	S4	30° to 45°	E to SE	N to NE	Figure 6d

3.2 *Photogrammetric Results*

Analysis of the peak orientations found on the stereographic plot highlights three main discontinuity sets found in the rock mass (Fig. 6a):

- Set 1 (S1): Sub-horizontal (dip < 20°) discontinuity set that generally dips to the northeast,
- Set 2 (S2): Sub-vertical (dip > 70°) discontinuity set that generally strikes east-west, and
- Set 3 (S3): Sub-vertical (dip > 70°) discontinuity set that generally strikes north-south.

Discontinuity Sets 2 and 3 are both steeply dipping and are approximately orthogonal to each other. These three major discontinuity sets are also apparent on the rock face, as seen from the color coded planes and traces in Figure 5.

3.3 *Line Mapping*

The results from line mapping are presented on Figure 6b and Table 1. The same major discontinuity sets are evident from line mapping and photogrammetric mapping: Set 1 (sub-horizontal), Set 2 (east-west striking and steeply dipping) and Set 3 (north to northeast striking and steeply dipping). However, several minor discontinuity sets are also apparent on the line mapping stereonet, which are not seen on the photogrammetry stereonet. This apparent scatter in data is most likely attributed to pole frequency. Figure 6b was plotted with a relatively low number of poles (189), when compared to the 1170 poles plotted on the photogrammetry stereoplot (Fig. 6a). The difference in pole frequency is a result of the limited structures that intersect the line during conventional mapping, access restrictions and time limitations in the field.

3.4 *Geotechnical Drilling with Core Orientation*

The discontinuity data collected from geotechnical drilling with core orientation were sorted by structural type (i.e. contact, joint, foliation, fault or vein). Due to the large number of joints recorded, all joint data were plotted separately from the other structural discontinuity types. The stereographic plots of the joint data and all other discontinuity data can be found on Figure 6c and Figure 6d, respectively. A summary of the results are presented in Table 1.

Figure 6c illustrates that the major sub-horizontal Set 1 is a joint set. The steeply dipping Sets 2 and 3 are also evident in the joint data but are less distinguished. In contrast, the orthogonal discontinuity Sets 2 and 3 are apparent on Figure 6d, and are associated with veining. With the agreement in results, rock mass characteristics and shear strength properties obtained from core logging was used to supplement the large number of orientation measurements acquired from photogrammetric mapping.

Unique to the other stereographic projections, the peak pole concentration on Figure 6d is found at Set 4, which dips approximately 30° to 45° to the east and southeast. This is a foliation set and is not obvious in the results from line mapping or photogrammetry. Due to the orientation and the moderate dip of Set 4, this discontinuity set does not act as a kinematic control on the east wall and is not prominent on the bench face. However, this set could contribute to instability on other wall orientations. Since Set 4 dips into the east wall, it appears as a horizontal trace on the bench face surface and could potentially be confused with sub-horizontal Set 1 during surface mapping.

4 DISCUSSION & CONCLUSIONS

3D photogrammetry was used to further improve the understanding of the rock mass interpreted from conventional surface line mapping and geotechnical drilling with core orientation. Structural mapping through photogrammetry involves the use of digital photographs to produce a virtual model of a rock mass surface. Structural orientation data was obtained from the 3D images and analyzed for the major discontinuity sets that would influence slope stability. Results from the east wall of the open pit mine are presented.

Stereographic projections of the line mapping, photogrammetric method and geotechnical drilling emphasize three main discontinuity sets that exist in the east wall rock mass:

- Set 1 (S1): Sub-horizontal (dip < 20°) discontinuity set that generally dips northeast,
- Set 2 (S2): Sub-vertical (dip > 70°) discontinuity set that generally strikes east-west, and
- Set 3 (S3): Sub-vertical (dip > 70°) discontinuity set that generally strikes north to northeast.

Discontinuity Sets 1 to 3 are very pronounced on the photogrammetric stereonet and appear as major sets on the line mapping and oriented core stereonets. However, a fourth major set (S4) is also apparent from the drilling results. Set 4 is a foliation set that dips moderately (30° to 45°)

to the east, into the pit wall. Therefore, this set does not act as a kinematic control on the east wall and is not prominent on the bench face surface.

Directional bias is introduced during data collection in all three techniques, where discontinuities that are perpendicular to the direction of surveying will be more evident than discontinuities that are sub-parallel. This means that structures that are oriented within up to about 20° to the drillhole axis or wall direction cannot be or will be less frequently measured than the structures with other orientations, creating “blind” zones in the stereographic projections. Despite the application of the Terzaghi correction in these projections, it is important to have a good understanding of the influence of these blind zones when interpreting the results. In addition, it highlights the need to carefully map walls with more than one orientation within the existing open pit and to ensure good coverage with directional geotechnical drilling.

Although the analysis of the line mapping and photogrammetry data produced analogous results, approximately six times the number of structural features were recorded with the photogrammetric method, with the same amount of time spent in the field for both techniques. The entire slope face can be mapped with photogrammetry, given that there is sufficient space to capture the rock face with the camera and the availability of the appropriate fixed focal length or zoom camera lenses. Whereas line mapping is limited to areas which are safely accessible and dependent on structural features that intersect the survey line (unless window style mapping is used). As a result, photogrammetric mapping can easily identify the critical discontinuity sets for slope stability, and this information is useful in validating the minor and major sets interpreted from geotechnical drilling.

In summary, there are limitations and benefits associated to each structural data collection technique. Traditional line mapping is simple, requiring little more than a compass, survey line and field staff. However, the risk associated with personnel approaching potentially unstable rock faces can limit coverage. Geotechnical drilling with core orientation offers structural data at depth and knowledge of in situ rock mass fabric conditions. Using this knowledge, shear strength data can be assigned to the major and minor discontinuity sets in the rock mass. The main drawback to geotechnical drilling is that it does not provide a clear insight to discontinuity persistence. 3D photogrammetric mapping can measure persistence and spacing, along with the orientation of discontinuity features but lacks the capability to describe shear strength properties and other joint surface and rock mass characteristics. Photogrammetric mapping also offers large coverage in a short span of time, at distances away from potentially unstable rock faces. However, this method is limited to good weather conditions, clean slopes (few obstructions) and areas where a camera can easily capture the rock face.

Overall, photogrammetric mapping was a very useful tool in determining the major discontinuity sets seen in the existing open pit mine and complementing the other existing structural data collection techniques. In addition, it significantly improved the health and safety working conditions for the geotechnical field team, where access to the pit wall proved to be difficult and risky.

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