Comparison of hand-mapping with remote data capture systems for effective rock mass characterisation

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ABSTRACT: The use of remote techniques to capture the geometrical characteristics of rock masses has seen increased use and development in recent years. Apart from the obvious improved Health and Safety aspects, remote techniques allow rapid collection of digital data that can be subsequently analysed to provide input parameters for a variety of geomechanical models.

Recent research at the Camborne School of Mines, University of Exeter has focussed on comparison of different remote data capture techniques in order to quantify their benefits and limitations whilst comparing them with conventional hand-mapping. The paper describes the results of a detailed comparison between hand-mapping, terrestrial photogrammetry and high definition surveying (laser scanning) methods of data collection.

Comments are made regarding the need to tailor data collection to end-use requirements. There is also a need to establish a representative scale of measurement, so that key features of the rock mass are captured and incorporated during the characterisation process.

1 INTRODUCTION

Priest (1993) highlighted the need for effective rock mass characterisation prior to any excavation involving rock. This normally involves some form of field mapping that is conventionally undertaken by hand-mapping of representative scanlines or windows for the rock mass under investigation. Recent years have seen increased application and development of remote data acquisition techniques in order to reduce exposure of personnel to potential hazards, where access may be a potential safety issue, to increase the speed of data collection or for automation of data capture and subsequent processing. The adopted techniques make use of either photogrammetry (Donnadieu et al., 2003, Oka, 1998 and Poropat, 2001) or high definition surveying (Kemeny & Donovan, 2005).

After post processing these techniques can produce spatially accurate, densely detailed 3D representations of the rock mass. Measurements of discontinuities from these models allow for collection of large quantities of data in a reasonably short space of time. In addition, where proposed mapping areas are inaccessible or restricted, remote sensing can record whole sections of a particular slope or exposed rock surface. For example, in open pits and quarries the techniques allow data to be collected rapidly (minutes) from bench faces that may be too dangerous for manual data collection. The increased data capture and subsequent analysis can also remove some of the subjectivity involved in interpretation.

As part of ongoing evaluation of the available remote data acquisition techniques several sites have been identified that provide a range of rock types, different set-up problems, different target ranges and different scales of mapping in both natural and man-made environments. The paper describes the results of a detailed comparison of hand-mapping, terrestrial photogrammetry and high definition surveying of a blocky rock mass at one of the project locations.

2 REMOTE DATA ACQUISITION TECHNIQUES

2.1 *Photogrammetry*

Photogrammetry is described as the science of obtaining reliable information from physical objects through processes of recording, measuring, and interpreting photographic images (Slama, 1980). A single orientated photograph can only relay the direction from which an object has originated. Combining two images, a stereopair, containing the same object enables the calculation of the distance and position of that object using triangulation techniques (Crone, 1963).

The photogrammetric system used during the current project was the computer program suite Sirovision (CSIRO, 2005). Photographs were taken using a Nikon D100 digital SLR camera and a 50mm 1:1.4D Nikon lens. Data processing within the software was then undertaken to create a 3D image from two photographs centred on a common control point.

2.2 *High definition surveying*

High definition surveying (HDS) or laser scanning uses infrared lasers to collect spatial data of a scanned area. Two types of HDS equipment were used as part of the project: the HDS3000 time-of-flight (TOF), and the HDS4500 phase shift, both manufactured by Leica Geosystems (Leica, 2005). The basic principle behind TOF is that a point's position in 3D space can be calculated by measuring its distance and orientation from a known point using reflected laser pulses.

A laser scanner emits an infrared laser pulse and as the beam hits surfaces of objects in the surrounding environment, some of the beam's light is reflected back to the scanner. A detector within the scanner is able to make a distance measurement based on the return signal. These distance measurements are combined with internal angle measurements of the scanner's rotating mirrors. A scanner can then establish a relative X, Y, Z position in space for each point on a surface. This process is repeated thousands of times, collecting many points that can be represented as a 3D point cloud (Leica, 2005). Phase shift laser scanners use a continuous laser beam rather than pulses, providing quicker scans, but can only be used at closer distances from the subject.

3 CASE EXAMPLE: TREMOUGH ROAD CUTTING

The road cutting at the entrance to the Tremough Campus, Penryn, Cornwall, UK, shown schematically in Figure 1, was selected as a suitable location for comparison of the techniques over a short target range because of proximity to the University and its relatively blocky structure, shown in Figure 2. The mapped section of the coarse-grained granite rock face is approximately 40m long and ranges from 5 to 8m in height. Few access problems were encountered for either of the two remote sensing techniques, but hand-mapping was restricted to areas of the face that could be safely reached. Hand-mapping was carried out irrespective of weather, whereas the photogrammetry and laser scanning were performed during 'dry' periods.

Photogrammetry was the first technique used to map the road cutting, followed by detailed hand-mapping and finally laser scanning. Individual features were specifically identified so as to perform a feature-by-feature comparison for the different techniques used. The time taken to perform each mapping technique and subsequent analysis was recorded to allow comparison between the methods.

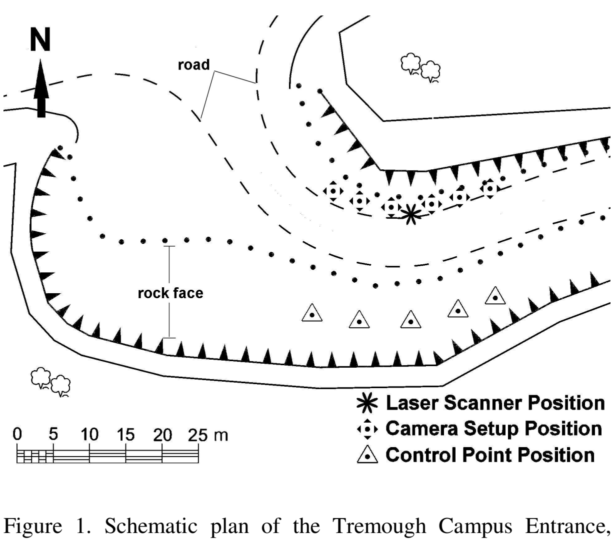

Figure 1. Schematic plan of the Tremough Campus Entrance, showing camera, laser scanner and control locations.

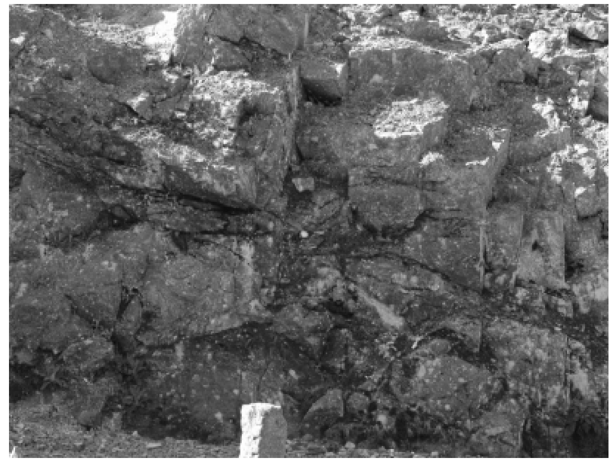

Figure 2. Image showing blocky nature of the granite rock mass at the Tremough Campus road cutting.

3.1 *Photogrammetry*

Five photogrammetrical models were created of the road cutting, moving from West to East. Each model slightly overlapped the former and was approximately 8 m wide. The height encompassed all of the exposed features of the rock face (5 m – 6 m). The camera stations were set up approximately 15 m from the rock face. Using the Sirovision software, and the standard input for the camera and lens type, each model was calculated to contain an average spatial resolution of 2 mm.

The cameras were positioned using a Leica TPS1200 Total Station to a relative or local Eastings, Northings and Elevation coordinate system. The first camera location was assigned an arbitrary position of 1000 m, 1000 m, 100 m. The photogrammetric control point was then surveyed at the centre of the two camera's view of the face. Subsequently, for each new model setup, the respective camera locations and control points were coordinated relative to the origin.

The digital photographs were then uploaded into Sirovision's 3D image creation module, Siro3D (CSIRO, 2005). The images were corrected for lens distortion and orientated using the surveyed positional data. Point matching was run to create the final 3D models. An example 3D model, shown in Figure 3, consists of an interlocking mesh of triangles, giving the model its 3D nature. The orthophoto of the rock face, which is an image corrected for distortion, can also be draped over the mesh to aide feature or discontinuity recognition.

The 3D models were then imported into Sirovision's geotechnical analysis module, SiroJoint (CSIRO, 2005), for further analysis and interpretation. Individual features or discontinuities were delineated from the 3D model of the rock face and selected using the software.

In order to assist identification of common features between the hand-mapped data and the remotely captured data hand-mapping of the rock face was undertaken with the aid of digital photographs. The face was mapped using a standard compass clinometer.

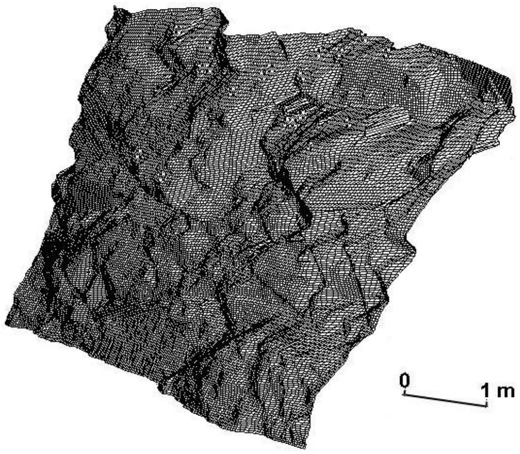

Figure 3. Example 3D mesh of blocky rock face of the Tremough road cutting, created using Sirovision.

3.2 *High definition surveying*

The same section of the rock face was then scanned using the Leica HDS4500. The scanner was set up 15m from the face, approximately in the middle of the mapping region, using a manually set point density of 5mm. Only one setup location was used to assess the effects of potential blinding. The phase shift scanner was used in preference to the time-of-flight scanner to take advantage of its increased speed, and so avoid ghosting created by any passing traffic.

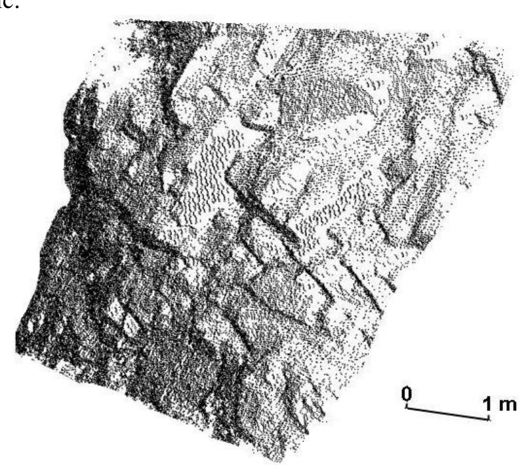

Figure 4. Example 3D point cloud of blocky rock face of the Tremough road cutting, created using laser scanning and subsequently used in Split FX

The captured data points, example shown in Figure 4, were then exported by the Leica software into a point cloud geotechnical analysis program called Split FX (Split Engineering, 2005) for subsequent analysis. Further details concerning point cloud registration and triangulated mesh generation are described by Kemeny & Donovan (2005). The 3D mesh is generated from the point cloud data which is then used to delineate specific discontinuities and an orientation determined from the grouped triangles within the mesh. The software allows automated identification, but hand-picking was undertaken for this project. Identified planes were used for the discontinuity orientation analysis as previous investigation demonstrated that fracture traces were less suitable for orientation analysis.

4 COMPARISON OF RESULTS

A summary of the number of discontinuities identified by the various techniques is given in Table 1 and pole orientation shown in Figure 5. Overall there is reasonable correlation between the measured and extracted orientations. It is not unsurprising that hand mapping identified the least number of features in view of the restricted area of the face that could be safely reached. A clear advantage of the remote systems is their ability to capture data for the whole rock face. Not all the features identified by photogrammetry were identified by laser scanning.

Table 1. Number of planes identified using each mapping technique

Photogrammetry	Hand Mapping	Laser Scanning
280	149	235

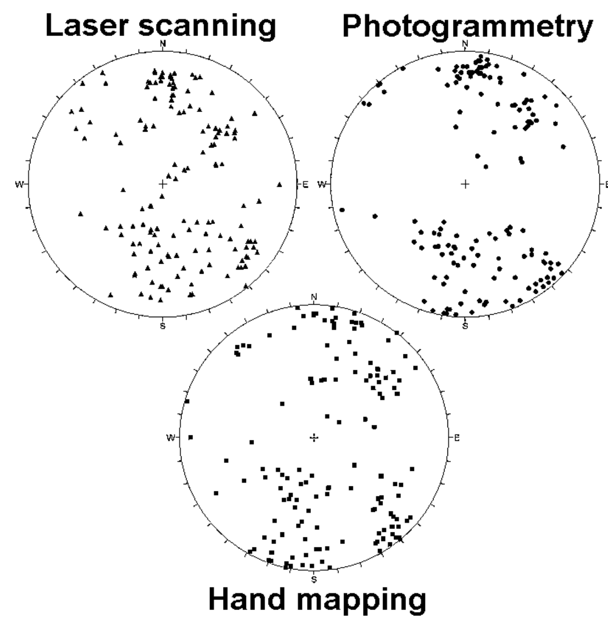

Figure 5. Lower hemisphere representations of poles to identified features from laser scanning, photogrammetry and hand mapping.

The dip and dip direction measured by the three different techniques were compared for individual features that could be commonly identified.

4.1 *Individual feature comparison*

For the purpose of this exercise the dip and dip direction recorded by hand mapping was used as the reference orientation of each identified plane, so that any differences derived by the remote data capture techniques were measured as errors or variations in orientation. Comparison between the dip and dip direction was undertaken by polar representation on a stereonet; the vector of each of the poles was resolved, converting their orientations to a single number. This was performed using a dip/dip direction to pole vector conversion formula embedded within an Excel spreadsheet.

Example visual comparison of selected features is shown in Figure 6. Comparisons were undertaken on 143 features that could be identified from each of the mapping techniques. The data analysis was then split to assess both photogrammetry derived data versus hand-mapped data and laser-scanned derived data versus hand-mapped data.

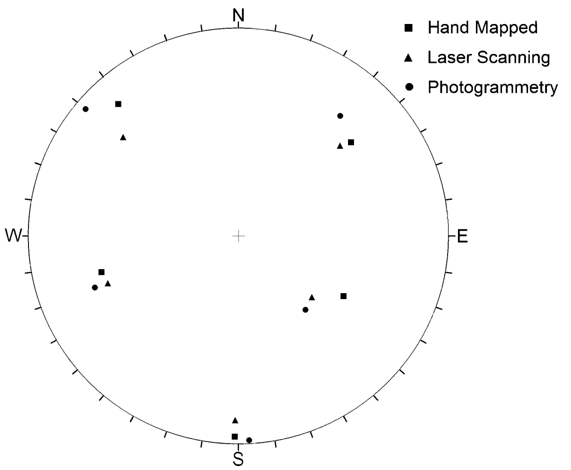

Figure 6. Comparison of derived orientation data for specific planes using hand-mapping, laser scanning and photogrammetry.

The pole vector difference of each plane was then plotted against the area of the identified feature, which is automatically calculated by the remote data capture technique when a feature is delineated. Comparison of these values provided an indication of the relative accuracy of each technique at a range of plane sizes. Figure 7 shows that the smaller planes identified by the remote data capture techniques produced a higher variation or difference in orientation when compared with the hand-mapped result. This is likely to be due to the low point density or spatial resolution of the 3D triangular mesh. Orientation variability of larger surfaces may be the result of real variation over the fracture surface or variations in the mesh topology.

4.2 *Set statistics comparison*

The orientation data from each mapping technique was also analysed separately using the stereographic projection program, DIPS (Rocscience, 2006), to identify potential sets for the respective data. Using both polar and contoured plots four comparable sets were identified for each data group. The pole vector differences between the corresponding sets for each remote technique and the data from hand mapping were calculated and are displayed in Figure 8 and summarized in Table 2.

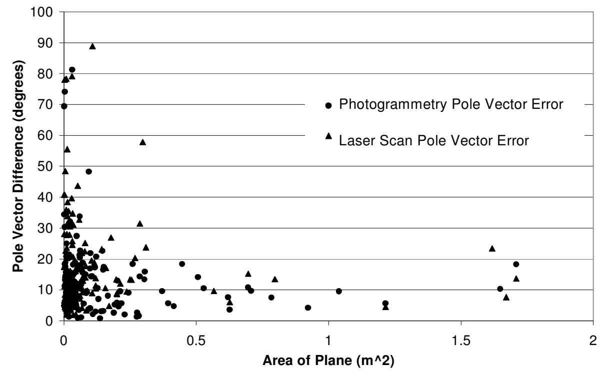

Figure 7. Pole vector difference for remotely captured data compared with hand-mapped orientation as a function of area of the identified fracture plane.

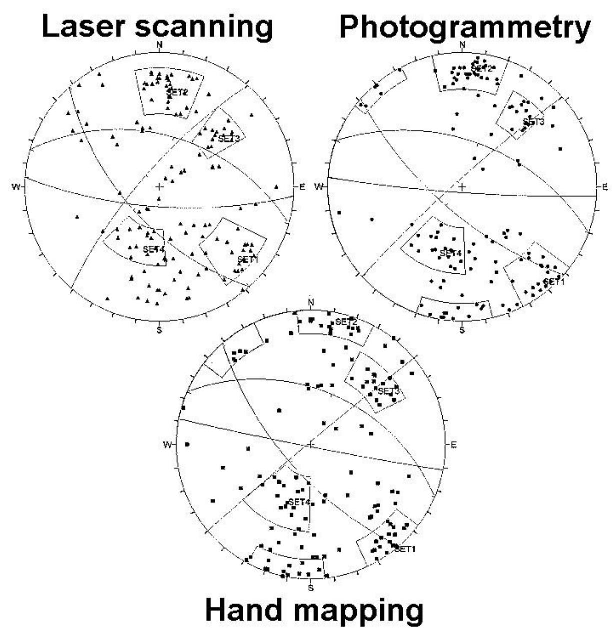

Figure 8. Lower hemisphere representations of poles to identified features from laser scanning, photogrammetry and hand mapping with set delineations

The results show that the photogrammetry-derived set data produced results that more closely match the hand-mapped set data for the near-vertical features. The laser-scanned derived set data has relatively poor agreement with the hand-mapped set data for near-vertical features. This is also depicted in Figure 5 by the lack of poles adjacent to the periphery of the stereonet for the laser scanned data.

This variability may be the result of differing point density, mesh characteristics or blinding as a result of only one set-up location for the laser scanner. As part of further evaluation the laser scanning and subsequent mesh evaluation is to be repeated with multiple set-up locations.

Table 2. Summary of orientation data for each identified set to allow comparison between hand-mapped data and that from both laser scanning and photogrammetry.

Set	Hand mapping Dip degrees	Hand mapping Dip direct. degrees	Laser scanning Dip degrees	Laser scanning Dip direct. degrees	Pole Vector Error degrees
1	88	320	75	311	15.7
2	88	191	73	184	16.5
3	67	229	61	228	6.1
4	46	023	48	016	5.5

Set	Hand mapping Dip degrees	Hand mapping Dip direct. degrees	Photogrammetry Dip degrees	Photogrammetry Dip direct. degrees	Pole Vector Error degrees
1	88	320	84	318	4.5
2	88	191	85	184	7.6
3	67	229	69	221	7.7
4	46	023	52	020	6.4

4.3 *Field work and post-processing time comparison*

One of the most obvious advantages that remote sensing has over hand-mapping is the increased speed and amount of data that can be collected. To confirm this, each mapping technique was split into individual processes, and the approximate time taken to complete them recorded. In order to normalise the comparison, the number of features that were evaluated by each technique was restricted to 100. Figure 9 shows time comparisons for both field mapping and post processing to satisfy the output parameters for one possible end use: that is to produce data in a suitable format for subsequent analysis with the discrete fracture network software FracMan (Dershowitz et al., 1998).

The biggest time saving of remote mapping techniques when compared to hand-mapping is during the field work stages. Surveying and data capture is relatively quick and only takes approximately 2 hours to complete. This will, however, depend on the method of locating the camera or scanner station and the number of subsequent set-up positions. Hand mapping over the restricted height took the most time, approximately 10 hours.

Post processing requirements for each technique depend on the specific end-use of the output data, but this normally takes a similar amount of time for each adopted method. Data processing for the remote techniques is slightly quicker due to the digital nature of the recorded data. By delineating the data using the respective supplied computer programs, parameters such as spacing and tracelength can be determined.

As part of further post processing, and in an attempt to assess the use of photogrammetry-derived data for determination of input data for FracMan, fracture traces were identified from both the 3D photogrammetric model and the digital photographs used during hand mapping. Figure 10 shows a comparison of trace length estimates from both the hand mapping and photogrammetry. Both data sets show a log normal distribution, but the photogrammetric-derived data tends to underestimate the trace length. This is a particular problem with longer fractures, which are often split into segments within post processing, and must be taken into account when using automated analysis.

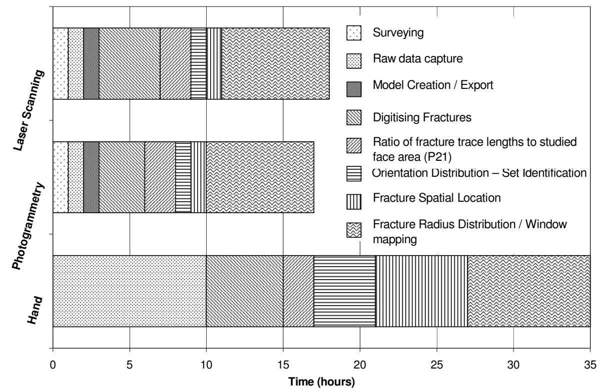

Figure 9. Time comparison chart for data collection and post processing for laser scanning, photogrammetry and hand mapping.

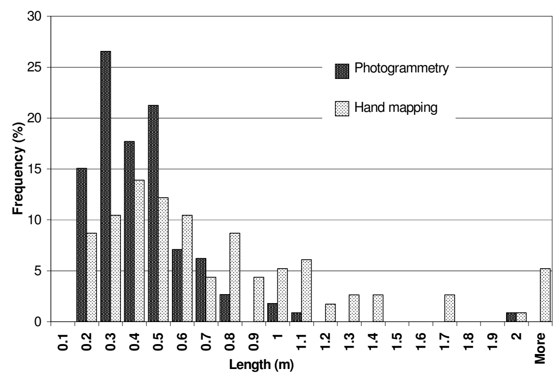

Figure 10. Frequency percentages of mapped trace lengths comparing photogrammetry and hand mapping derived data at a range of identified trace lengths.

5 DISCUSSION

Comparison of remotely mapped data with hand-mapped data raises questions regarding what is the necessary accuracy and appropriate scale of mapping required for effective and representative rock mass characterisation. From the orientation data presented for the Tremough road cutting it would appear that both remote mapping techniques provide a reasonably good representation of the orientation of the fracture network present within the rock mass, although from this exercise the photogrammetry-derived data produced the best comparison with hand-mapped orientation data. The laser-scanned derived data may be improved with an increased point density and multiple set-up locations.

The investigation suggests that, irrespective of the adopted mapping technique, planar analysis is more reliable for determining orientation data, whereas trace analysis is required for evaluation of other parameters such as trace length and spacing. This has implications for the post processing, and suggests that data collection and subsequent analysis needs to be tailored to end-use requirements, taking into consideration specific input requirements that depend on the complexity of the intended analysis. For example, end-use may include kinematic analysis of potential slope failure mechanisms that primarily requires orientation data; two-and three-dimensional discrete analysis of a blocky rock slope that requires simplistic representation of the rock mass fracture network; or more complex stochastic representation of the three-dimensional fracture network using FracMan that requires evaluation of fracture radius and intensity as well as orientation distribution. This means both planar and trace analysis should be part of post processing.

The results of the investigation also suggest that there is a minimum level of detail or area of surface that remote mapping can realistically capture. This will obviously depend on the size of the overall window mapped and should be considered when undertaking the site investigation. This is not unlike hand-mapping where decisions are often made in terms of a minimum fracture length or size of fracture to include in rock mass characterisation. This in turn is often related to the scale of the structure and whether or not fractures have an influence on the engineering behaviour of the rock mass.

The key advantages of the remote techniques are their speed, greater area coverage and ability to map inaccessible areas. It also provides uniformity in the type of data and the method by which it is collected, eliminating many of the biases in data selection and mapping technique adopted by an individual user. This has particular advantages where it may be necessary to map at different scales to provide improved characterisation of the rock mass by using different set-up positions or different lenses. Large scale mapping can be undertaken to provide orientation and trace length data for major structures which can be complemented by more detailed mapping on a smaller scale. Further work is being undertaken to quantify these effects. Clearly there is a need to identify a representative scale of measurement for a particular rock mass.

Automated analysis is not yet recommended and there is still a need for educated users to provide manual intervention, spot checks and associated interpretation. Rigorous mapping methodologies should be developed to incorporate the key advantages of the systems but there is also a need to develop robust guidelines for efficient set-up and operation of the various techniques, including hardware and any associated software. It is important to minimise inaccuracies due to poor set-up and reduce potential effects of blinding. There is also a need to ensure consistency in data format between the various systems.

6 CONCLUSIONS

Remote mapping techniques have the capability to revolutionise rock mass mapping, but there is still a need to establish rigorous mapping methodologies and robust guidelines for efficient set-up and operation of the various techniques.

The results of the investigation show it is also necessary to establish guidelines for effective rock mass characterisation, to ensure that the necessary detail and scale effects are taken into consideration. This will be informed by the increased use of improved methods for geomechanical modelling of the scale effects, fracture persistence and fracture extension under loading, as is now possible with such combinations as FracMan and ELFEN (Dershowitz et al., 1998; Pine et al., 2006; Rockfield Software Ltd, 2007). The time is fast approaching that a new ISRM Suggested Method for Remote Rock Mass Data Capture should be developed.

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