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Rock mass structural characterization via short-range digital hotogrammetry

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ABSTRACT

Because of the important role of rock mass structural properties on its mechanical behavior, determining the qualitative and quantitative properties of has been a subject of intense research. In this regard, numerous techniques such as scanline surveying, cell mapping, and geologic structure mapping have been proposed. However, applying such field surveying techniques for rock mass properties involves spending substantial costs and times and high risks. Besides, due to the errors induced by operations, measurements, systematic errors, etc., the results of these techniques are not accurate and precise enough. Short-range digital photogrammetry is an state-of-art technique applied for surveying rock mass characteristics. Through this novel approach, rock mass surface is imaged, the obtained images are analyzed, and rock mass characteristics are determined, and finally, the technique is validated by comparing the obtained results with field surveys. In the present work, two digital photogrammetry based methods including digital image processing and laser-based imaging are implemented in rock mass characterization. The results show that short-range digital photogrammetry can be effectively employed in rock mass structure characterization. Moreover, this approach, unlike the existing traditional ones, involves low costs, high speed, and sufficiently accurate and precise results.

1- Introduction

Rock mass generally is defined as the assembly of rock material and rock structure, which involves discontinuities and fractures. While intact rock represents rock material, which is considered as a solid body in a laboratory scale, civil and mining engineering activities in rock engineering field are involved with rock mass. The results of field studies and tests show that bearing capacity and strength of rock mass are controlled by quantitative and qualitative characteristics of its discontinuities (Hosseini and Gholinejad, 2014). Hence, having a proper understanding of rock mass discontinuities (structures) conditions may considerably affect the design and operation process associated with rock engineering activities.

Rock mass characterization is typically performed through the field survey based techniques such as scanline surveying, borehole logging and structural characterization, surface profile evaluation, and engineering geology mapping. Among the most important parameters in discontinuity, studies are orientation, length, spacing, roughness, persistence, aperture, filling, and termination (Hu et al., 2011; Pires et al., 2016).

Although the efficiency of these methods in rock mass structural characterization is well established, its implementation is accompanied by high errors such as numerous human and instrumentation errors from data recording and to data interpretation and analysis (Samieinejad et al., 2017). Moreover, sampling and accessibility problems and required operational costs and times are the inborn shortcomings of these techniques.

By the recent technological advances, use of novel scientific techniques for rock mass characterization have been highly noticed. The present research investigates the efficiency of short-range digital photogrammetry in rock mass characterization. In the recent years, application of digital imaging and digital image processing (Yang and Chen, 2017; Tan et al., 2016) and laser-based imaging (Fekete et al., 2010; Ferrero et al., 2009) in rock mass characterization have been investigated. Applying these technologies have facilitated achieving a comprehensive automatic or semi-automatic model for collecting rock mass discontinuity information. For example, through digital image processing, it is now possible to determine various parameters such as spacing, length, and orientation of discontinues (Samieinejad et al., 2017). Moreover, laser-based imaging is employed through high-resolution laser scanning devices for rock surface scanning. The main advantage of this technology is its high scanning accuracy and speed and possibility of quick data processing using super-computers (Krosley et al., 2006).

The digital images only represent the trace of fractures. Image processing, however, illustrates the three-dimensional characteristics of discontinuities and fractures through some specific mathematic algorithms. It has to be noted that fracture trace is a two-dimensional feature achieved by scanning a three-dimensional fracture. For instance, Fig. 1 presents the digital image of a rock face from benches of Chadormalu iron ore in Yazd, Iran.

Fig. 1- Digital image of a fractured rock face.

As shown in Fig. 1, this rock face has numerous fractures that care difficult to be characterized due to the time, cost, and accessibility constraints. On the other hand, with the aid of image processing technique and mathematical algorithm, these fracture traces can be determined within an acceptable accuracy range. Fig. 2 presents the fracture trace demarcation.

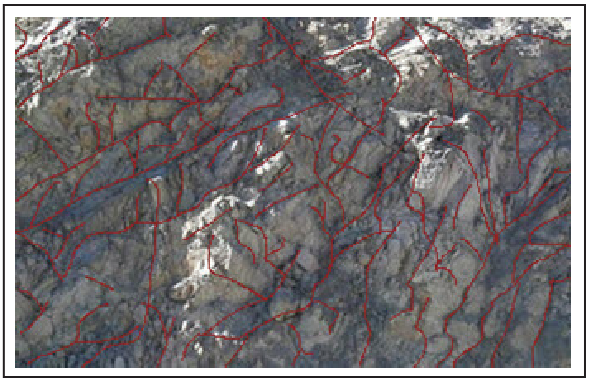

Fig. 2- Fracture trace demarcation in the image.

Information extracted by assessing fracture traces through image processing software are trace orientation, length, spacing, and large-scale roughness. Moreover, the three-dimensional information extracted from two-dimensional images consist of the orientation (dip and dip direction), true fracture spacing, and fracture shape and size, among which orientation is the most important factor. Orientation includes the mean orientation of each joint set and some information about the mean orientation scattering. Since the previous studies show that Fisher distribution fits well with fracture orientation data, we applied it as probability density function (PDF) in the present work. Fisher distribution (Fisher, 1925), which is expressed by the Fisher constant (K), is a symmetric distribution around mean orientation.

To characterize rock mass features in order to process rock face images, first fracture traces are determined (Fig. 2). The algorithm designed for this purpose is based on the Hough Transform (Ballard, 1981), which can detect fracture traces automatically and with high precision. Hough Transform is among the common methods for feature extraction in image processing, computer vision, and digital image processing that is capable of effectively detecting straight lines in a digital image. In other words, Hough Transform can convert a point in image space to a curve in parametric space as follows:

$$\rho = x\cos\theta + y\sin\theta$$

where ρ and θ are normal vectors across the main image.

By determining fracture traces in the image, it is possible to extract information such as trace angle, length, spatial location, and roughness for each fracture. The trace angle information can be used for fracture trace categorization in different classes and further analyses of each joint set.

The main function of digital image processing is to extract three-dimensional information of fractures from their fracture traces. To do so, these techniques employ some raw mathematical equations to relate normal vector of joint plane and the orientation of the vector created by the intersection of discontinuity plane and rock surface with trace angel of the joint on the rock surface. In this connection, some straightforward mathematical equations have been proposed by Post (2001) and Post et al. (2001) on the basis of vector differential calculus.

In addition to these mathematical equations, also some simplifying assumptions are needed. Among these assumptions is the resemblance of joint orientation distribution in each joint set with Fisher distribution, which was also proved in the previous works (Priest, 1993; Priest and Hudson, 1981). According to Fisher distribution function, the probability of finding an angular area unit in a given angular area   in the center of angle   from the true mean is expressed as:

$$f(\theta) = \frac{K e^{K \cos\theta}}{2\pi(e^{K} - e^{-K})}$$

where K is Fisher constant.

Fisher distribution is a symmetric distribution around the orientation mean that is expected to be the maximum in the real mean ($\theta = 0$). The large K values imply a severely concentrated distribution around the true mean. Based on the previous experiments, K value for a jointed rock mass lies within the range of 20 to 300 (Priest and Hudson, 1981).

2- Chadormalu Iron Ore Mine

Chadormalu iron ore mine is located in central Iran and in northern slope of Chah-Mohammad grey mountains in southern margin of Saghand salt marsh about 180 km from north-east of Yazd and 300 km from south of Tabas desert (Fig. 3). The first pit of the mine is in form of a heart, which has respectively 960 m and 225 m width and depth. It has been designed for thirty years. In order to excavate Chadormalu mine using open pit method and its reconstruction as a pit, respectively, slope angle of pit, slope angle of wall face, width of safe bench, bench height, distance between safe benches, width of road, and ramp slope are considered 50-55°, 69.5°, 10 m, 15 m, 30 m, 25 m, and 8% (Nekouei and Ahangari, 2013).

Fig. 3- Geographical location of the Chadormalu iron ore mine (Esmaeili and Salimi, 2015).

According to the geology studies performed in this region, it was cleared that Chadormalu fault between the plain and high lands is the major factor of ore creation and mineralization in the region formed in two forms of northern and southern anomaly. In addition, petrography studies on the mine rocks shows that major rocks in Chadormalu mine area are Metasomatite, Albitite, Diorite, Magnetite and Hematite (Azimi et al., 2010; Kulatilake et al., 2012).

Structural geology and tectonic in Chadormalu mine is impressed by local major faults of Chadormalu, Kabki, Dochahi and Sepidan, which among them the active Chadormalu fault is located in the forehead of the southern heights of current mine pit. The fault sets and their caused joints are the main factor of the instabilities, failures, seepage and blasting problems. Intersection of the mentioned faults in the south east of the mine caused forming a very loos, fractured and crushed zone, which is now the main water seepage path in the mine pit.

It should be mentioned that, performance of different faults in this area makes the mine rocks to be severely tectonized and provide suitable conditions for different ruptures of the wall.

3- Digital image processing of a rock surface

As mentioned earlier, there are numerous faults in Chadormalu iron ore as well as blasting operations that severely affect the structural quality of rock masses in the pit walls. Therefore, these fractures can threaten stability condition of the mine at local scales. For this purpose, some parts (composed of diorite) from the southern and eastern walls of the pit were selected. Clearly, imaging method and image resolution can highly affect image processing and the obtained results. Hence, it is required to select the images optimally. The effective resolution, camera distance from the rock face, camera lens adjustment, and other parameters obtained from field experiences and trial and error approach were considered for choosing optimum images. Because sunlight radiation level on pit walls varies depending on sun location at the sky at different hours of a day, to ensure the quality of the images it is recommended to perform imaging within a short time period (Samieinejad et al., 2017). Moreover, the climatic conditions varying alternatively between sunny and cloudy days are not suitable for imaging.

In the present work, pit wall imaging was done using a Canon EOS-5DS Body digital camera equipped with lenses with f = 50 mm (Fig. 4). The parameter f, herein, represents focal length of lens zoom. The smaller f is accompanied by the wider the diaphragm, more light absorption, and a deeper field control. For instance, when f is 50 mm, the lens has a focal distance of 50 mm.

Fig. 4- The digital camera Canon EOS-5DS Body used in this study.

Fig. 5 presents some samples taken from pit wall images. To prepare these images, camera resolution was set to 960 × 1280. In all images, the camera was aimed along the strike of the rock outcrop.

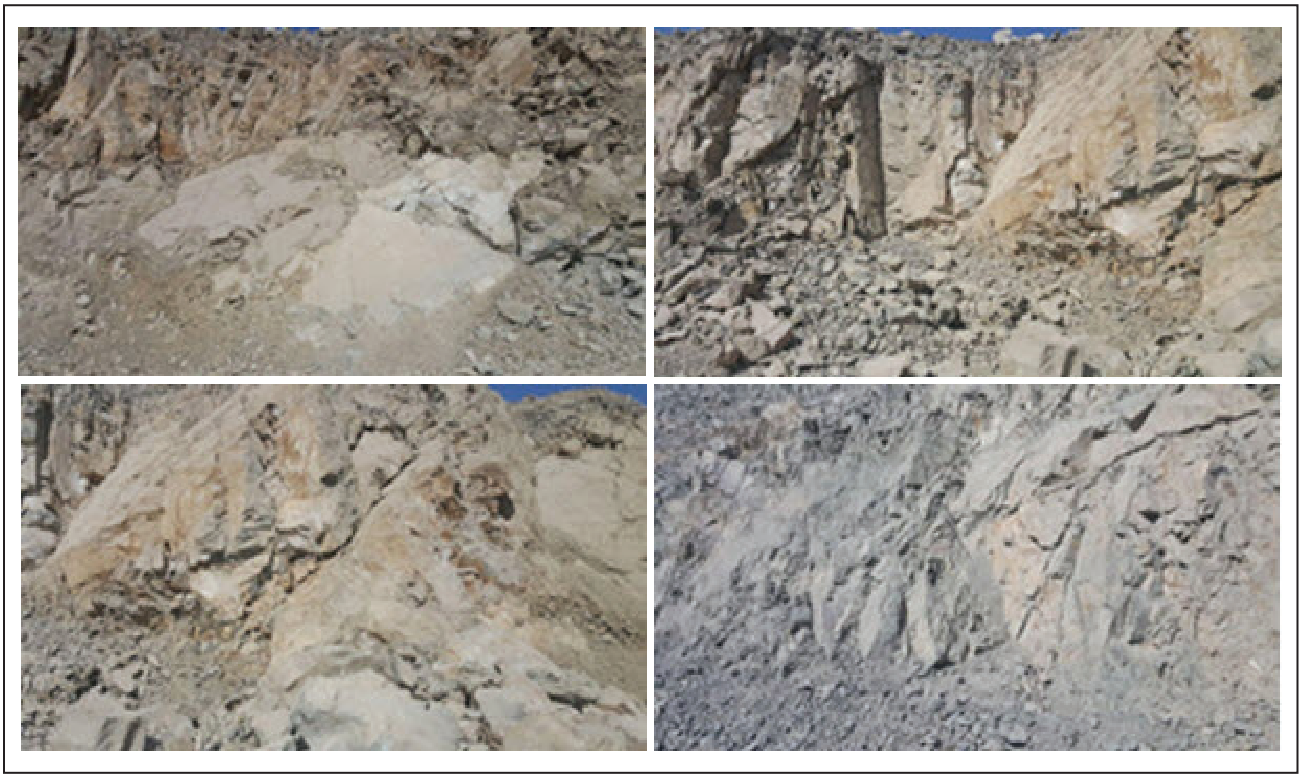

Fig. 5- Rock profile images of diorites in the eastern and southern walls of Chadormalu Mine.

4- Image processing and discontinuity characterization

To characterize the discontinuities and apply image processing, the genetic algorithm (GA), which is the differential evolution, was employed (Peralta et al., 2010). In this algorithm, the characteristics of angular distribution (e.g., mean, standard deviation, skewness, etc.) for a joint set in the rock face are used to predict joint set parameters (e.g., mean dip, mean dip-direction, and Fisher constant (K)). The differential evolution is applied mainly to find the optimum mean dip values, mean dip direction, and Fisher constant (K) such that they fit with the angular distribution of fracture traces. In this GA structure, each input chromosome consists of three genes, which are indeed the joint set parameters. After each iteration, the error of each chromosome is estimated and the chromosome with the least error is passed to the next iteration. Moreover, to create secondary vectors, chromosomes also perform mutation and recombination tasks. A complete description of GA implementation and performance is supplied by Post (2001). After each iteration, the mean error value is estimated for the new primary vector population. If the population error is less than the threshold defined by the user or if the number of reproduction reaches its maximum value, the differential evaluation algorithm is terminated. Next, the chromosome with the least error is selected from the primary vector and three-dimensional parameters of the joint set are defined for the traces of each image.

In the present work, fracture traces of the images were determined using the hand-editing tool in NIH software (Rasband, 1998). Once fracture traces were determined, the corresponding angle of each trace was measured using the functions of this measuring software and then the traces are classified into different sets such that each class represents one joint set. In this regard, three main joint sets were detected and investigated. The fracture trace angles were directly imported to differential evolution algorithm and the three-dimensional parameters of each set including mean dip, mean dip-direction, and K were estimated.

To assess the performance of applied photogrammetry system, the joints in rock face were recorded through scanline surveying in the field. The actual and predicted results of mean dip, mean dip-direction, and Fisher constant (K) are presented in Table 1.

The results show that fracture trace processing using the taken photos predicts dip and dip direction with 1-3° and 2-8° respectively, which are accurate enough. However, for Fisher constant, a significant difference exists between the predicted and actual values. To explain Fisher constant (K), we present two joint sets in Fig. 6 with dip and dip-direction of 55 and 130°, respectively, which K estimated to be 20 and 160°.

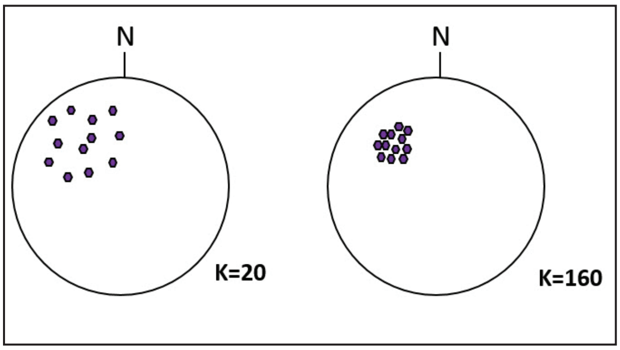

Fig. 6- An illustration of Fisher constant concept (Kemeny et al., 2002).

Clearly, an increase in the number of joints is accompanied by high errors. For example, the low number of measurements and some assumptions such as assuming the rock mass surface as flat may arise some errors. The measurement number error may be attributed to the rock surface orientation with respect to the camera. For instance, Fig. 7 presents a situation that is hidden from camera sight (shadow zone) due to the occlusion phenomenon.

As shown in Fig. 7, the potential orientation bias, which is needed to be modified, is typically expected considering the wall geometry.

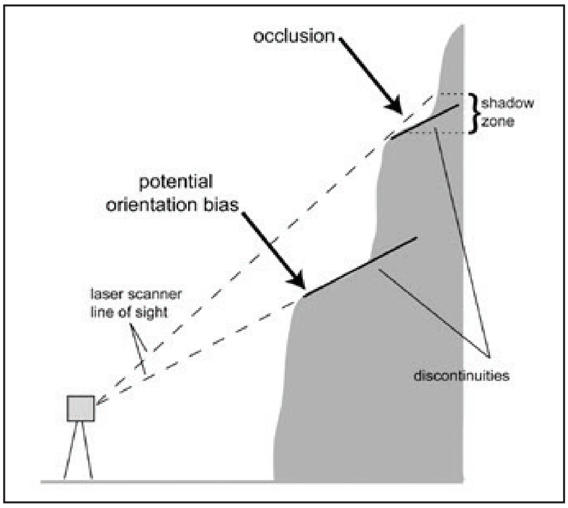

Fig. 7- Hiding of a part of rock wall from camera view (Sturzenegger and Stead, 2009).

Furthermore, the computer programs assume that rock surface is flat and perpendicular to the camera, which is not a true assumption, particularly at small scales. Thus, surface irregularities can affect distance length values in the image and thus, result in fracture angles and traces difference from the reality. Another error source affecting the image processing is the surface covered by the photo compared to the area covered by the scanline zone. Digital images, depending on their lens type and camera location with respect to the rock face, cover a wide range. In comparison, scanline surveying faces with access limitation and is performed only in the lower accessible parts of the wall. Above all these limitations, the most shortcoming of this work is applying the Fisher assumption for joints orientation.

5- Conclusion

In this study, the short-range digital photogrammetry technique was applied for rock mass characterization using the digital processing of the images prepared using rock surface. For this purpose, in the present work, an artificial intelligence-based method (i.e., digital photogrammetry) with relatively high accuracy and precision was proposed for image processing. In the digital photogrammetry technique, which is based on applying taken photos, the quality of images particularly their brightness and shadow, perpendicularity of camera lens on the rock surface, and image resolution plays a key role in results interpretation. In the present study, focusing on three joint sets in Chadormalu Iron Ore, the image processing results were highly consistent with the field survey results of the discontinuities. Among the major advantages of this new approach are its high accuracy and precision as well as its required low time and cost. Although the error of this method in detecting small discontinuities is very high, it provides almost unacceptable results for images with low quality. Nevertheless, the major discontinuities are detected accurately; thus, this method, if improved in technical aspects, can be widely applied in stability analysis of open pit walls.

Table 1- Image processing results for image samples taken from Chadormalu Iron Ore.

	Joint set 1		Joint set 2		Joint set 3	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
Dip	55	52	71	70	9	11
Dip-direction	345	350	270	262	211	209
Fisher constant, K	82	222	67	144	71	150

References

Hosseini, N. and Gholinejad, M., 2014- Investigating the Slope Stability Based on Uncertainty by Using Fuzzy Possibility Theory, Archives of Mining Sciences Journal, Volume 59, Number 1, pp. 179 – 188.

Hu, X., Wu, F. and Sun, Q., 2011- Elastic modulus of a rock mass based on the two parameter negative-exponential (TPNE) distribution of discontinuity spacing and trace length, Bulletin of Engineering Geology and the Environment, Volume 70, Issue 2, pp 255–263.

Pires, A., Chaminé, H. I., Piqueiro, F., Pérez-Alberti, A. and Rocha, F., 2016- Combining coastal geoscience mapping and photogrammetric surveying in maritime environments (Northwestern Iberian Peninsula): focus on methodology, Environmental Earth Sciences, 75:196, doi:10.1007/s12665-015-4936-z.

Samieinejad, M. M., Hosseini, N. and Ahangari, K., 2017- A field investigation of application of digital terrestrial photogrammetry to characterize geometric properties of discontinuities in open-pit slopes, Journal of Mining and Environment, DOI: 10.22044/jme.930.

Yang, J. and Chen, S., 2017- An online detection system for aggregate sizes and shapes based on digital image processing, Mineralogy and Petrology, Volume 111, Issue 1, pp 135–144, doi:10.1007/s00710-016-0458-y.

Tan, X., Konietzky, H. and Chen, W., 2016- Numerical Simulation of Heterogeneous Rock Using Discrete Element Model Based on Digital Image Processing, Rock Mechanics and Rock Engineering, Volume 49, Issue 12, pp 4957–4964, doi:10.1007/s00603-016-1030-0.

Fekete, S., Diederichs, M. and Lato, M., 2010- Geotechnical and operational applications for 3-dimensional laser scanning in drill and blast tunnels, Tunnelling and Underground Space Technology, Volume 25, pp. 614–628.

Ferrero, A. M., Forlani, G., Roncella, R. and Voyat, I., 2009- Advanced Geostructural Survey Methods Applied to Rock Mass Characterization, Rock Mechanics and Rock Engineering, Volume 42, Issue 4, pp 631–665, doi:10.1007/s00603-008-0010-4.

Krosley, L. K., Shaffner, P. T., Oerter, E. and Ortiz, T., 2006- Digital ground-based photogrammetry for measuring discontinuity orientations in steep rock exposures. In Proc. 41st U.S. Symp. on Rock Mechanics (USRNS), Golden, Colorado, 17-21 June 2006.

Fisher, R. A., 1925- Statistical Methods for Research Workers. Oliver & Boyd, Edinburgh.

Ballard, D. H., 1981- Generalizing the Hough transform to detect arbitrary shapes. Pattern Recognit 13:111–122.

Post, R., 2001- Characterization of joints and fractures in a rock mass using digital image processing, M.S. Thesis, University of Arizona, Tucson.

Post, R., Kemeny, J., and Murphy, R., 2001- Image processing for automatic extraction of rock joint orientation data from digital images, Proceedings 38th US Rock Mech. Symp., Washington, D.C., A.A. Balkema, Rotterdam.

Priest, S. D., 1993- Discontinuity Analysis for Rock Engineering, London, Chapman & Hall.

Priest, S. D. and Hudson, J. A., 1981- Estimation of discontinuity spacing and trace length using scanline surveys, International Journal of Rock Mechanics, Mining Science & Geomechanics Abstracts, 18, 183-197.

Nekouei, A. M., Ahangari, K., 2013- Modified stability charts for rock slopes based on the Hoek–Brown failure criterion, Archives of Mining Sciences, Volume 58, Issue 3, 2013, pp. 747-766, DOI 10.2478/amsc-0052.

Esmaeili, M. and Salimi, A. R., 2015- Carsten Drebenstedt, Maliheh Abbaszadeh, Abbas Aghajani Bazzazi, Application of PCA, SVR, and ANFIS for modeling of rock fragmentation, Arabian Journal of Geosciences, September, Volume 8, Issue 9, pp 6881–6893.

Azimi, Y., Osanloo, M., Aakbarpour-Shirazi, M. and Aghajani, B. A., 2010- Prediction of the blastability designation of rock masses using fuzzy sets. Int J Rock Mech Min Sci;47(7): 1126–40.

Kulatilake, P. H. S. W., Hudaverdi, T. and Qiong, W., 2012- New prediction models for mean particle size in rock blast fragmentation. Geotech Geol Eng; 30:665–84.

Peralta, J., Gutierrez, G., Sanchis, A., 2010- Time series forecasting by evolving artificial neural networks using genetic algorithms and estimation of distribution algorithms. In Proceedings of the 2010 WCCI conference, IJCNN-WCCI'10, Barcelona, Spain

Rasband, W., 1998- NIH Image, an image processing program.

Kemeny, J., Mofya, E., Holman, J. and Ahlgren, S., 2002- Digital Imaging for Rock Mass Characterization, In Proceedings of the 2nd Annual Conference on the Application of Geophysical and NDT Methodologies to Transportation Facilities and Infrastructure, Los Angeles, April.

Sturzenegger, M. and Stead, D., 2009- Close-range terrestrial digital photogrammetry and terrestrial laser scanning for discontinuity characterization on rock cuts. Engineering Geology 106, 163-182.