Geotechnical and Geophysical Site Characterisation 5 – Lehane, Acosta-Martínez & Kelly (Eds)

Evaluation of the vulnerability of rock weathering based on monitoring using photogrammetry

D.H. Kim, I. Gratchev, E. Oh & A.S. Balasubramaniam
Griffith School of Engineering, Griffith University, Gold Coast, Australia

ABSTRACT: This article describes a methodology to identify a relationship between spatial topographic changes and the brightness of the 3D images for the assessment of the vulnerability of rock slopes to weathering. In this study, photogrammetry surveys were carried out at a rock slope over a two year interval. The strength properties of the rock material were also investigated under laboratory conditions. The obtained 3D images were employed to the identity of topographic changes and also for image analysis using the intensity of their greyscale images. By comparing the annual photogrammetric 3D images, the data of roughness heights were processed with relative brightness integers obtained from time considered greyscale images using a MATLAB image analysis tool. The results show that the loss of roughness height of the exposed surfaces appeared to be strongly related to the changes of integers of the greyscale images. This study suggests a methodology with regard to the sensitivity of weathering based on annual photogrammetry surveys.

1 INTRODUCTION

As an indication of weathering, surface recession of rocks has been used to investigate the rate of weathering (Meierding 1993, McCarrorll and Nesje 1996, White et al. 1998, Pope et al. 2002, Sancho et al. 2003). In attempting to quantify the recession of rocks, the alteration of rock surface was investigated by simulating the change of the curvatures. McCarrorll and Nesje (1996) used a profile gauge to investigate the roughness profiles and relevant parameters on a boulder of a cliff. In a similar way, Sancho et al. (2003) measured the depth of rock surface using steel pins linked in a specially designed guide frame and compared the surface recession with an original sandstone wall in the Alberuela castle site. However, roughness is solely insufficient to explain the aspect of weathering because the products of weathering appear in different ways due to their geological formation.

In a different way, various surface features were investigated using two dimensional images with image analysis techniques. In order to determine the mineral composition of rocks and to identify individual grain sizes of deposits, 2D images were successfully employed (McEwan et al. 2000, Trauth 2010). Recently, Filin et al. (2013) used an image analysis method to investigate on ground erosion. Similarly, Saito et al. (2010) investigated rock surface roughness by means of local roughness patterns using downscaled topography data. It was suggested from these studies that the image analyses effectively expressed the localized differences on the surface of earth using the information on the adjacent pixels of images.

Digital photogrammetry benefits both the creation of high density spatial data and the obtaining of realistic images of objects. The technique has enabled 3D images to be created at a distance of time as a record of rock surface investigations. Recently, it has been suggested that photogrammetry could provide a satisfactory level of accuracy with high density images in rock surface roughness investigations (Poropat 2008, Kim et al. 2015a). In creating realistic images of surfaces of objects, photogrammetry also enables the pixels of 3D images to be placed in positions for the real surfaces in any orientations. On the basis of the benefits, this study attempts to use the image information of photogrammetric 3D models to investigate roughness characteristics as well as the 3D data.

In this study, photogrammetry surveys were carried out for two years using the same camera positions in order to obtain 3D surface models of a study slope. To investigate the vulnerability of weathering, roughness heights were obtained from sample areas of the 3D models and the differences of roughness were analysed over a two year period. Greyscale images were transformed from the original 3D images and the relevant intensity of the greyscale images to the roughness profiles were analysed combined with the data.

2 METHODOLOGY

2.1 *Assessment of weathering based on alteration of roughness*

Two dimensional roughness of rock surfaces has been used to investigate the degree of rock surface weathering (McCarrorll and Nesje 1996, Sancho et al. 2003). In these previous studies, representative roughness parameters (RMS and maximum height of surface recession) were employed to indicate the recession of a rock surface. In addition, the joint roughness coefficient (JRC) has been employed to study the influence of weathering for jointed rock masses. Based on the weathering process, the change of recession on exposed rock surfaces in jointed rock masses can be observed at the intersections of the exposed joints within the surface areas. In this case, some changes of roughness can be detected along the exposed joints and the recessions can be quantified by using the various roughness parameters.

The aspect of roughness changes may differ according to its geological characteristics. For example, sandstones which are comprised of granular textures may tend to be eroded with rounded edges. On the other hand, laminated structured rocks such as shales and mudstone, exfoliations with a shape of flakes are more dominant than other types of breaks (Merriman et al. 2003). In the previous study using a sandstone and a shale (Kim et al. 2016), it was observed that partial exfoliations with the shapes of shale flakes could cause a significant increase in JRC values of rock surfaces due to the step-like profiles on the altered surfaces near joint intersections. JRC values should be thus carefully interpreted with other complementary investigation.

In this study, heights of surface recession and JRC values are obtained using photogrammetric roughness profiles. The values are compared between the data of 2012 and 2014. As a representative roughness parameter, Z_2, has been employed to estimate JRC values based on digitized roughness data. A regression equation using Z_2 to estimate the JRC values is employed to estimate JRC values as shown in Eq. (1).

$$JRC = 32.2 + 32.47 \log Z_2 \text{ (Tse and Cruden, 1979)} \quad (1)$$

2.2 *Image analysis for the characterization of roughness*

Various geological features have been investigated by two-dimensional images using image analysis techniques. Converting a RGB image to a greyscale image discards colour information and the adjacent colours to the exact same shade of grey. Each pixel of a grey scale image stores a luminance value which can be measured on a scale from black (0 intensity) to white (255 intensity, if the image is 8 bit). Using the differences of brightness, the variation of roughness can be analysed using a MATLAB image analysis tool box (Mathworks 2014). For example, simplified greyscale images successfully analysed roughness variations for the results of direct shear tests (Kim et al. 2014).

As a distinct advantage of 3-D images, extended meshes which cover all the areas of interest in orthogonal directions to the sections, can be obtained as shown in Fig. 1 (b) and (c). This enables an analysis of the integer values of pixels combined with the 3-D roughness data. In this study, the changes of intensity values of greyscale 3D images are interpreted with the changes of asperity heights obtained from photogrammetric profiles. The results are used to estimate the recession areas during the time interval.

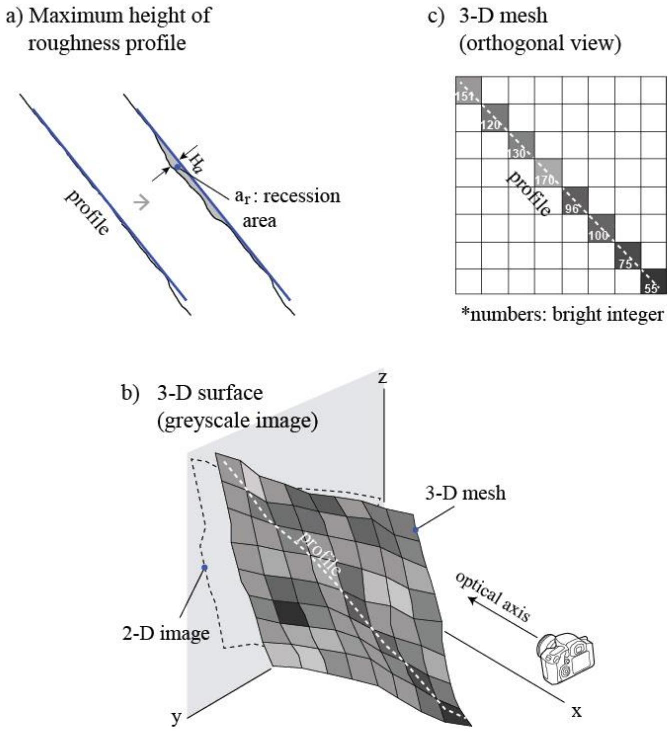

Figure 1. The use of a greyscale 3-D rock surface model to investigate surface recession by weathering

3 SITE INVESTIGATION AND PHOTOGRAMMETRY SURVEYS

3.1 *Geological conditions of the study area*

The study slope is located on the Gold Coast in Australia. The geological condition is composed of the alternate bedding structures of sandstone and shale in the Nerangleigh-Fernvale beds. The texture of the sandstone is medium to coarse grained and joint sets are frequently found from the slope surface. The texture of the shale is fine and has a laminated structure, and the orientations of the beddings are steeply inclined. The textures were observed using digital images taken by an 8 megapixel microscope camera from collected samples, as demonstrated in Fig. 2.

With regard to the strength characteristics, point load tests and slake durability tests were carried out and the results are well reported in the authors' previous publication (Kim et al. 2015b). In this study, the unconfined compressive strengths (UCS) reported in the previous study have been reanalysed using the conversion factor 11 based on the study of Brisbane sandstone (Look & Griffith, 2001). The average values of UCS are 7.4 MPa and 32.4 MPa for the sandstone and the shale respectively. Using the estimated UCS values, the intact rock samples of sandstone and shale can be classified in 'slightly to moderately weathered' and 'fresh to slightly weathered' ranges respectively in accordance with the classification suggested by Bertuzzi & Pells (2002). The slake durability of sandstone samples varied with their strength. Low strength samples, which are classified as medium strength in point strength classification, showed low durability with a loss in weight of 50% (Gratchev & Kim 2016). The sandstone of this area is more vulnerable to physical weathering than the shale as indicated by the damages to the sandstone from the slake process which is more dominant than the loss of weight in the shale.

3.2 *Records of rock surface models using photogrammetry surveys*

Photogrammetry surveys were performed for the study slope within a two year time period (2012 and 2014). A normal digital DSLR camera, which is equipped with a sensor of 16.2 million effective pixels, was employed with a fixed focal length lens (FL = 24 mm). Stereo photographs were taken at two camera positions with 2.5 metres of baseline distances and the camera-to-object distance was around 17 metres. The study regions of the slope was a boundary region between sandstone and shale and the location of the overlapped camera footprint was adjusted to include both rock types together, keeping the same camera positions at a distance of time.

Sirovision (CSIRO, 2012) was used for the post-process of the photogrammetry surveys. Fig. 2 presents geo-referenced 3D models for both shale and sandstone areas of the models created in 2012. Two sections of both shale and sandstone were selected for a detailed investigation of roughness variation over two years. The selected areas were extracted from the both years' 3D models. The dimensions of the selected areas and the density of the 3D image pixels are summarized in Table. 1. The 3D image pixel scale, which indicates the measurement scales and the extent of accuracy of image analysis varied in accordance with the locations of sample sections. However, the range of variation is negligible.

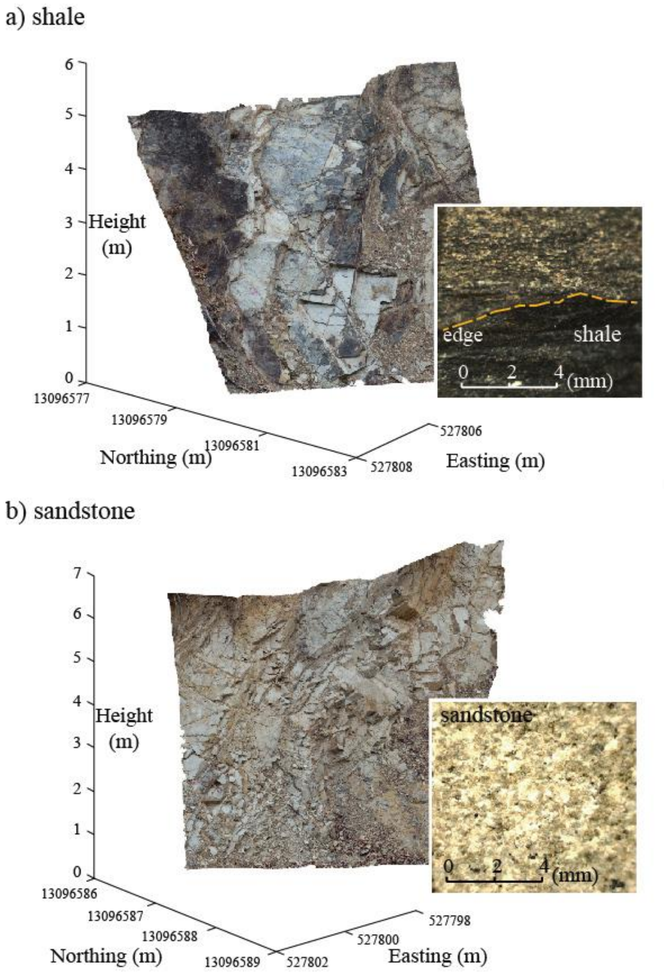

Figure 2. Photogrammetry 3D models of the study area and details of rock surface textures surveyed in 2012; Shale (a), Sandstone (b)

Table 1. Details of 3D images in sampling areas.

Rock types	Shale		Sandstone	
	Section 1	Section 2	Section 1	Section 2
1. Image size (mm)				
Width	331.5	666.6	407.0	523.0
Height	678.3	1123.4	427.2	512.6
2. Image scale (mm/pixel)				
Width	3.9	3.3	3.7	6.8
Height	5.1	4.1	4.8	7.6
3. Profiles (mm)				
Length	430~540	850~1,050	550~680	480~710
Point intervals	2.0	2.0	2.0	2.0

4 RESULTS AND DISCUSSION

4.1 *Variation of roughness profiles and JRC values*

By comparing of the 3D images of 2012 and 2014, the sample areas were selected because they show noticeable changes on the exposed surfaces, especially on the periphery of exposed joints. Using the extracted 3D images of the selected sections, JRC values were then estimated for the sample areas in four radial directions (steepest, 45˚, 90˚, 135˚). The variations of JRC values in the radial directions are presented in Fig. 3. The overall undulations of the extracted profiles approximately simulated the locations of the loss of roughness and the positions of joint sets (see Fig. 4). The shapes of profile variations helped to detect the ranges for the correlation between the loss of height and the intensities of the greyscale images. The JRC values change over time according to the rock types. For example, for the given two year period, the JRC values for shale increased, as indicated in the graphs. Alternatively, in sandstone regions, the JRC values diminished slightly.

The accuracy of photogrammetric JRC values is influenced by various factors. It is generally accepted that high resolution images are required to simulate small scale roughness (Poropat 2008). As presented in Table 1, the point intervals of the extracted profiles are large to simulate small scale roughness in detail. This possibly results in an underestimation of JRC values (Kim et al. 2015a). However, the accuracy of photogrammetric JRC values is beyond the scope of this paper. The use of the estimated JRCs is limited in this study so as to compare the 3D surface models under the same photogrammetry setups.

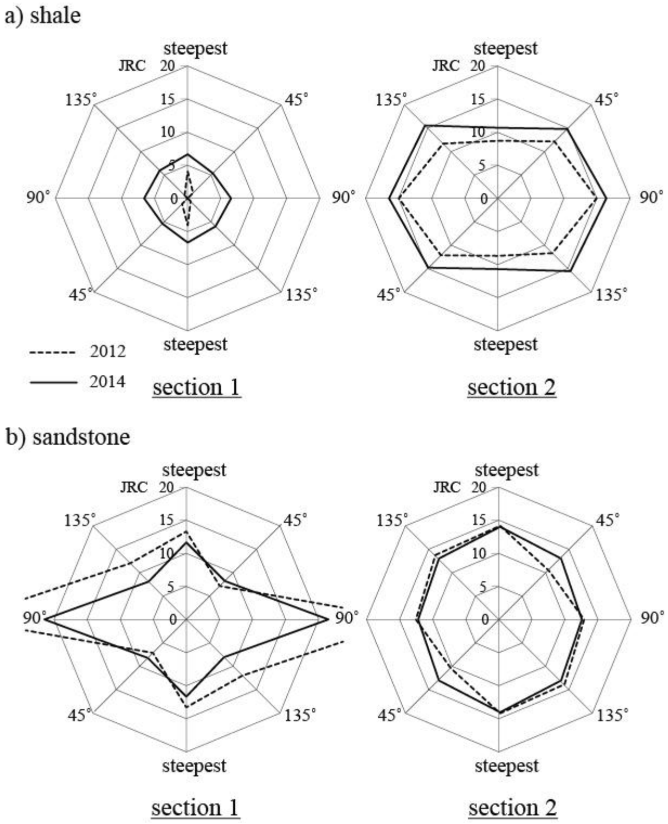

Figure 3. Alteration of photogrammetric JRC values in radial directions (0˚, 45˚, 90˚, 135˚) over the two year interval in the shale area (a) and sandstone area (b)

4.2 *The use of greyscale intensity of 3D images*

The original RGB 3D images were converted to greyscale with 8 bit pixel depth to simplify the image data. Fig. 4 demonstrates the brightness integers and the variation of asperity heights at the same positions along the profiles located in the centre lines extracted from the 3D models of the sandstone section 2. The variations of brightness integers (I) obtained from greyscale 3D images are correlated with the changes of asperity height. In the sandstone area, it is obvious that large variations of (I) values occurred at the same regions where the asperities are lost by weathering. Also, there is an extraneous increment range of (I) values caused by the different luminance between the photographing in 2012 and 2014. It can be also explained by the fact that there is no considerable roughness change in the range. In the shale area, however, it was observed that the ranges of brightness integers considerably varied by a discoloration along the exposed surface as a result of chemical weathering. Due to the various changes in colours, it was difficult to define the correlation between the roughness changes and the integers of greyscale images in the shale area. In addition, the difference of luminous intensity at the moment of photographing also disrupted the image analysis using the brightness integers.

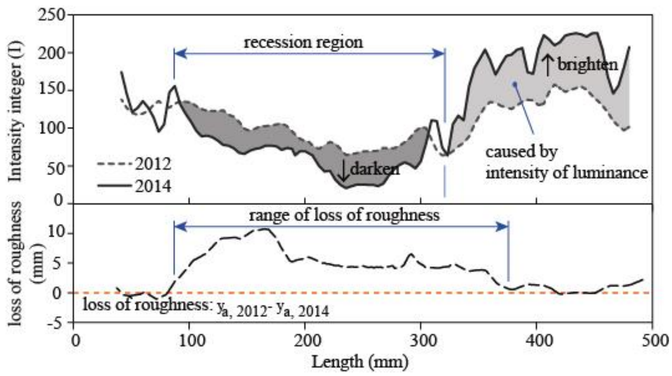

Figure 4. Changes of brightness integers (I) and the loss of roughness of the profile along the centre line of sandstone 2 section

This study also tried to detect the damaged area by weathering over the two year period. Using an image thresholding technique of MATLAB, the pixels of the greyscale images were filtered within the obtained guide ranges of (I) values from the profile analysis as described in Fig. 4. The obtained threshold images are demonstrated in Fig. 5. The percentages of the detected areas to the total areas were also calculated using the corresponding numbers of the pixels. The filtered areas of the sandstone are appeared to be reasonable as an indicator of the products of weathering as the ranges of brightness is relatively simple. As the sandstone in the study area is more vulnerable than the shales as shown by the results of slake durability tests, the recession areas were markedly increased (from 8.1% to 17.6%: section 1, from 8.6 % to 25.4 %: section 2). On the contrary, the recession areas analysed by using the guided integer range are inconsistently distributed on the surfaces of the shale. This result can be explained by the responses of chemical weathering along the laminations of the shale surface.

Through this investigation, it is concluded that the image analysis using the colour information in the pixels of 3D images can be used to investigate the progress of weathering for the rock mass combined with the 3D roughness data. However, the limitations of this technique are related to the differences of luminance and the level of accuracy of photogrammetry models. It is noted that brightness of a rock surface may be inconsistent to be used as the indicator of weathering in accordance with its geological condition.

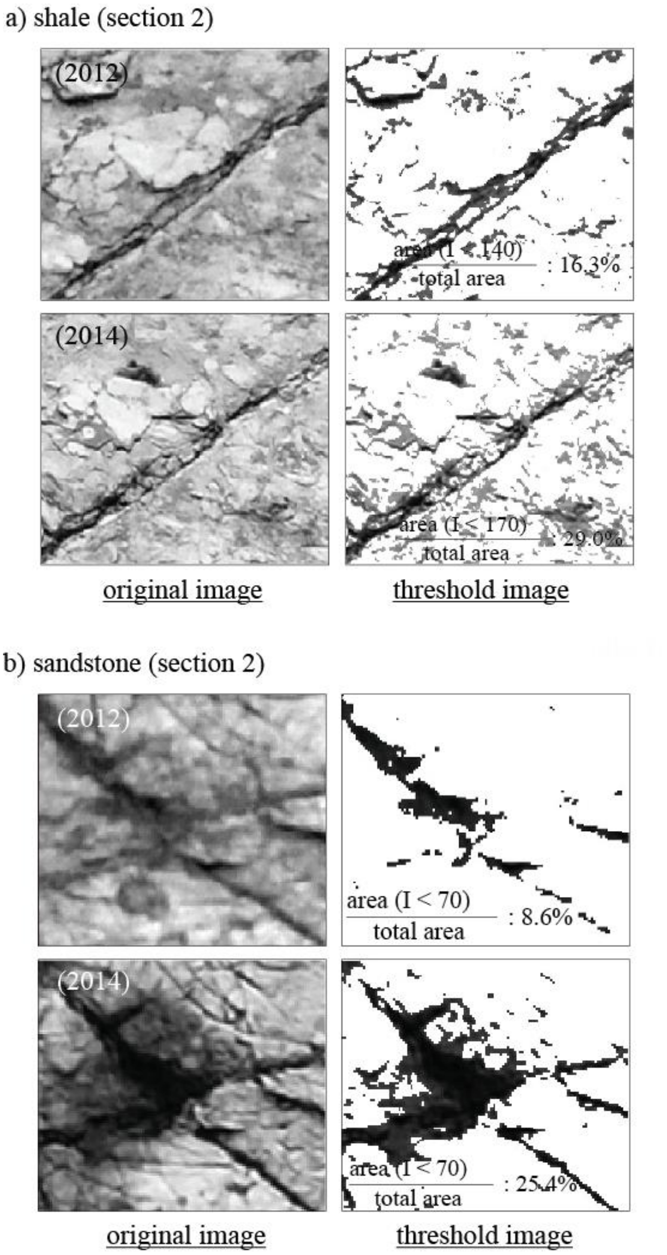

Figure 5. Original images of altered areas by weathering and detected areas by using MATLAB image analysis; for shale section 2 (a) and sandstone section 2 (b)

5 CONCLUSION

This study proposes a methodology to study the progress of weathering using 3D models. By comparing photogrammetric 3D models over a two year period, the recession of weathering for shale and sandstone slopes was investigated. The photogrammetric 3D models provided two dimensional roughness profiles and the 3D RGB image was converted to greyscale images and used as a source of an image analysis. The ranges of the brightness intensity obtained from MATLAB image analysis were compared with the changes of roughness profiles to detect the recession of weathering. The combined image analysis with photogrammetric roughness data could compensate the limitations of both the use of the 2D roughness data and the use of the integer values of 2D images. In the case of sandstone, which showed a simple color variation over the two year period, the recession area can be quantified by using an image threshold technique as changed from 8.6% to 25.4%.

This study suggests that the obtained area can be used to indicate the vulnerability of weathering. However, the intensity of images should be also carefully interpreted by considering both luminance conditions for photographing and the geological characteristics of rock mass.

6 ACKNOWLEDGEMENTS

This research was performed with the financial support of the Griffith University Postgraduate Research Scholarship (GUPRS) program. The authors would like to express their appreciation to CSIRO for providing the program SIROVISION for this study and to thank Mr. George Poropat for valuable helps.

7 REFERENCES

Bertuzzi, R. & Pells, P. J. N. 2002. Geotechnical parameters of Sydney sandstone and shale. *Australian Geomechanics* 37(5): 41-54.

Bureau of Meteorology in Australia Government. 2015. Summary statistics Gold Coast seaway. Website, www.bom.gov.au/climate/average/tables/cw_040764.shtml

CSIRO. 2012. Siro3D-3D imaging system manual version 5.0. CSIRO Exploration & Mining, 198 pp.

Filin, S., Goldshleger, N., Abergel, S., Aray, R. 2013. Robust erosion measurement in agricultural fields by colour image processing and image measurement. *European Journal of Soil Science* 64: 80-91.

Gratchev, I., Kim, D. H. 2016. On the reliability of the strength retention ratio for estimating the strength of weathered rocks. *Engineering Geology* 201: 1-5.

Kim, D. H., Chung, M., Gratchev, I. 2014. Assessment of rock joint roughness using image analysis of damaged area in direct shear tests. In *the 23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23); Proc. Intern. Symp., Byron Bay, 2015.* 745-750.

Kim, D. H., Poropat, G., Gratchev, I., Balasubramaniam, A. S. 2015a. Improvement of photogrammetric JRC data distribution based on parabolic error models. *International Journal of Rock Mechanics & Mining Sciences* 80: 19-30.

Kim, D. H., Gratchev, I., Balasubramaniam, A. S. 2015b. A photogrammetric approach for stability analysis of weathered rock slopes. *Geotechnical and Geological Engineering*, 33: 443-454.

Kim, D. H., Gratchev, I., E. Oh., Balasubramaniam, A. S. 2016. Assessment of rock slope weathering based on the alteration of photogrammetric roughness data. In *the 19th Southeast Asian geotechnical conference & 2nd AGSSEA conference; Proc. Intern. Symp.,Kuala Lumpur, 2016*, 901-906.

Look, B. G., Griffith, S. G. 2001. An engineering assessment of the strength and deformation properties of Brisbane rocks. *Australian Geomechnics* 36(3): 17-30.

McCarroll, D., Nesje, A. 1996. Rock surface roughness as an indicator of degree of rock surface weathering. *Earth Surface Processes and Landforms* 21: 963-977.

McEwan, I. K., Sheen, T. M., Cunningham, G. J., Allen, A. R. 2000. Estimating the size composition of sediment surfaces through image analysis. *ICE-Water and Maritime Engineering* 142 (4): 189-195.

Meierding, T. C. 1993. Inscription legibility method for estimating rock weathering rates. *Geomorphology* 6: 273-286.

Merriman, R. J., Highley, D. E., Cameron, D. G. 2003. Definition and characteristics of very-fine grained sedimentary rocks: clay, mudstone, shale and slate. British Geological Survey Commissioned report, CR/03/281N, 20pp.

Pope, G. A., Meierding, T. C., Paradise, T. R. 2002. Geomorphology's role in the study of weathering of cultural stone. *Geomorphology* 47: 211-225.

Poropat, G. V. 2008. Remote characterisation of surface roughness of rock discontinuities. In *the 1st Southern Hemisphere International rock mechanics symposium; Proc. Intern. Symp., Perth, 2008*, 447-458.

Saito, H., Grasselli, G. 2010. Geostatistical downscaling of fracture surface topography accounting for local roughness. *Acta Geotechnica* 5: 127-138.

Sancho, C., Fort, R., Belmonte, A. 2003. Weathering rates of historic sandstone structures in semiarid environments (Ebro basin, NE Spain). *CATENA* 53: 53-64.

Trauth, M. H. 2010. MATLAB® Recipes for earth sciences. the 3rd edition, Verlag Berlin Heidelberg, Germany: Springer

Tse, R., Cruden, D. M. 1979. Estimating joint roughness coefficients. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts* 16: 303-307.

White, K., Bryant, R., Drake, N. 1998. Techniques for measuring rock weathering: Application to a dated fan segment sequence in Southern Tunisia. *Earth Surface Processes and Landforms* 23: 1031-1043.