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Effect of void ratio to the strength parameters of sedimentary rocks

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Abstract: This paper is to study the influence of void ratio on the compressive and shear strength of sedimentary rocks at different degree of weathering. As void ratio is related to porosity therefore the present of void ratio should influence the mechanical properties of the porous sedimentary rocks such as sandstone and limestone. In order to determine the microstructures including pores and cracks of the samples, sandstone and limestone from different weathering grades were analyzed using photomicrograph analysis method. From the image of photomicrograph, the void ratio of the sample was calculated using image processing technique. The uniaxial compression and triaxial tests were carried out to determine the compressive and shear strength of the same samples by using GCTS Testing System. Results for void ratio, compressive and shear strength of the four different weathering grades of rocks were correlated to see the trend of relationships between the void ratio and the mechanical properties. In relation to weathering grades, the void ratio of the sedimentary rocks increases as the degree of weathering increases. The results also show that the void ratio and mechanical properties of sandstone are closely related. With the increase of void ratio, the compressive strength and shear strength decrease.

Keywords: Void ratio, degree of weathering, finite element, compressive strength, shear strength

INTRODUCTION

Construction of foundation on rock in rural area in state of Pahang, Malaysia is part of major development for infrastructure especially for power cavern of electrical generation. Rock strength is the most important parameter to be determined for engineering design in foundation on rock works. Therefore, many tests related to strength such as shear strength and compressive strength together with physical properties such as density, porosity and void ratio need to be determined and analyzed. The strength of rock as foundation is influenced by many factors such as types of rocks, weathering grades and physical properties. For sedimentary rock type, the strength is strongly influenced by the physical properties such as porosity and void ratio. This is because sedimentary rock like sandstone is formed by deposition of sediment that transported from weathered material of existing parent rock. As the formation is from granular particles arrangement due to compaction and cementation during lithification, the sedimentary rocks are therefore consisting of pores and voids between the grains. For this reason, the present of void in granular sedimentary could affect the strength parameters. Therefore, the study on the effect of the void ratio to the strength parameter is very important to prevent settlement due to the pores between the grains.

In recent years, there are many studies that have been carried out in this area with successful results. Many significant results were obtained from the studies on the effect of physical properties to the strength parameters. A study on evaluating strength and permeability characteristics that included infiltration rate, void ratio and compressive strength showed that when void ratio increases, infiltration rate also increases; compressive strength decreases (Shinde & Valunjka, 2015). However, this study was carried out on concrete where the shape and contents were already known. Studies on relationship between porosity and compressive strength of rocks were carried out by many researchers (Rajabzadeh *et al*., 2017; Li & Aubertin, 2003; Vernik *et al*., 1993), and it shows that it is generally applicable in establishing the relations between compressive strength and porosity. Bell *et al*. (1986) stated it is true when comparing the air-dry with the saturated strength, because, as the porosity decreases the strength increases. As many researches focused on analyzing the relationships between porosity and compressive strength, only few studies were related to shear strength of rock (Vallejo & Mawby, 2000; Xu *et al*., 2016; Yin *et al*., 2016). Recent study by Alshkane & Marshall (2017) on prediction of deformability and failure mode of an interlocked blocky rock mass that showed under high confining stress, the slip and block rotation changed to slip with shear and tensile failure in the rock blocks.

In order to investigate the effect of void ratio to the strength parameters of sedimentary rocks, four different kinds of weathering grade of sandstones were selected for this research. Their compositions were studied using microscopic analysis. By using image processing technique (Md. Hasan *et al*., 2009) the void ratios were determined. As the strength parameters were also part of the investigation purposes, the main objective of this study was outlined as a determination on the effect of void ratio with regard to the compressive and shear strength of sedimentary rock.

MATERIAL AND METHODS

Samples of the sedimentary rocks from 16 boreholes points in cylindrical cored shape were collected from Jerantut site in the state of Pahang. The samples from same borehole were named depend on their depth. As for example samples H10S1 and H10S2, the samples were collected from same borehole but the S1 is taken from upper part of the hole and S2 is from lower part of borehole 10 (H10). Meaning that the location of sample S2 is deeper than S1. Uniaxial Compressive Strength (UCS) was used as an identification of the weathering degree of cored samples. Table 1 shows UCS of collected samples and corresponding weathering grade (WG) based on the classification by Brown (1981).

The samples were subjected to mechanical properties and mineralogy tests. For mechanical properties, the samples were tested for compressive and shear strength.

Table 1: Weathering grade classification of cored samples according to Brown (1981).

UCS (MPa) by Brown	UCS (MPa) this study	Weathering Grade (WG)	Samples Name	No of Samples
100–250	167–211	II	H10S1, H9S2, H6S1, H8S2	4
50–100	79–98	III	H17S2, H6S2, H7S1	3
25–50	22–40	IV	H5S1, H8 S1	2
5–25	5–18	V	H3S1, H3S2, H5S2, H10S2, H17S1, H7S2	6

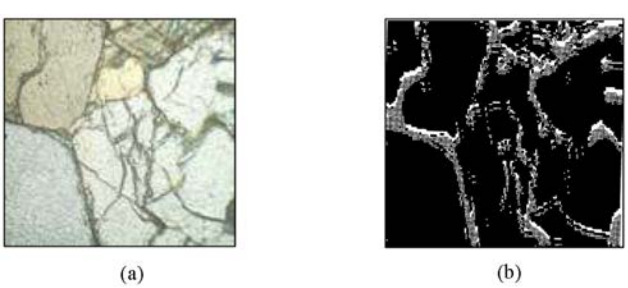

Figure 1: (a) Image of photomicrograph of sandstone under microscope and (b) image of photomicrograph after image processing.

The experimental works were carried out in Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia. Petrographic study was conducted in the Geological Department, University of Malaya. UCS tests and triaxial test of rocks were carried out using GCTS machine with loading capacity of 3000kN.

In normal cases, conducting the petrographic analysis is to determine the mineral composition of the rock samples. By using the electro-microscope, the microscopic properties of the granite such as texture, rock structure, and mineral content can be observed depending on the weathering degree of the samples. However, an analytical image processing technique together with the image processing technique was used in this study as proposed by Md. Hasan *et al*. (2009) to determine the void ratio from the petrographic image.

Example of photomicrograph image processing is presented in Figure 1. The original images taken from petrographic thin sections were digital images that consisted of pixels. Those images can be loaded and grayscale pixel information can be scanned. Threshold function can extract void pixels (crack and boundary of mineral grain) from the gray scaled images. Thus, the total number of extracted pixels multiplied by unit pixel area present represents the void area of unit window. So, the ratio of the void area to the total area of the unit window can be considered as porosity.

The shear strength properties for rock were conducted using triaxial test machine of GCTS model with automatic servo control. The cohesion, c and friction angle, φ of the rock were obtained from the graphical Mohr's circle analysis. Meanwhile direct shear strength test of rock core is purposely to establish the shear strength properties of discontinuities in rock. These core samples were to be tested for their shear strength along selected fracture plane (existing natural joint) and under a specified normal stress. Throughout the shearing process, the normal stress was maintained at constant level. Results obtained from the test were shear behavior (shear stress vs. shear displacement), peak shear strength, and the corresponding horizontal displacement where the peak strength occurs. From here the cohesion of discontinuity or joint surface (φ_{joint}) was determined.

RESULTS

Relationships between void ratio and shear strength parameters (cohesion, c, internal friction angle, φ, and friction angle at joint or discontinuities, φ_{joint})

The shear strength parameters, cohesion, c and internal friction angle, φ, of rock samples were obtained by the triaxial tests of cylindrical cored samples and direct shear test. The correlations and curves between c, φ, φ_{joint} and void ratio, e were obtained by using the least square method to fit the experimental data as shown in Figure 2. The results of actual experimental rock samples present the cohesion, internal friction angle and friction angle at joint decrease with increasing void ratio. When the void ratio of the rock samples increases due to the increasing of weathering grade, the rock becomes deterioration, thus reduce the shear strength. The correlation between void ratio and cohesion; and between void ratio and friction angles are:

$$c = -6.497\ln(e) - 0.273 \quad \text{with } R^2 = 0.6189 \quad (1)$$

$$\varphi = 56.034e^{-1{,}977e} \quad \text{with } R^2 = 0.7281 \quad (2)$$

$$\varphi_{joint} = 41{,}045e^{-0{,}606e} \quad \text{with } R^2 = 0.5411 \quad (3)$$

The correlation curve of e-φ is more significant than e-φ_{joint} as shown by the R^2 value of 0.728 and 0.541 accordingly (Figure 2(d)) because the void ratio is more effective and more responsive to the internal friction between the grain particles in rocks compare to the frictions between the discontinuities or joints surfaces.

Relationships between void ratio and compressive strength parameters, (UCS and Young's Modulus, E)

The compressive strength parameters, UCS and Young's Modulus, E, of rock samples were obtained by the UCS tests and elastic deformation calculation of cylindrical cored samples. The correlation curves between the void ratio and UCS (e-UCS); and between void ratio and Young's Modulus, *E*, (*e-E*) are shown in Figure 3. From the best fit curves, UCS and Young's Modulus decrease with the increase of void ratio. The increase of void ratio causing the increasing of pores that negatively affect the bonding between the grains in the rocks, thus reduce the compressive strength and elastic modulus of the rock. The correlation between void ratio and UCS and between void ratio and Young's Modulus, *E* are:

$$UCS = -48.63\ln(e)+22.746 \quad \text{with } R^2 = 0.6064 \quad (4)$$

$$E = 97.868e^{-1{,}679e} \quad \text{with } R^2 = 0.5275 \quad (5)$$

CONCLUSIONS

From the strength tests and void ratio measurements using photomicrograph and image processing technique on sedimentary rock samples at different weathering grades, a number of conclusions were established. This study proven that image processing on photomicrograph image is new method in determining void ratio of rocks and should be used in future research. Shear strength parameters, *c, φ,* and φ_{joint} effectively reduce when void ratio increase due to the space between the grain particles loosen the bonding with the cement and matrix that tie up the minerals composition. However, the internal friction angle is more affected when compared to friction angle at joint of rock samples. Compressive strength and elastic modulus also decrease with the increasing of void ratio due to the same reason where pore spaces weaken the bonding between the grains that can be easily compressed when load is applied on the sedimentary rocks. All these findings are proven by the correlation curves in Figure 2 and Figure 3.

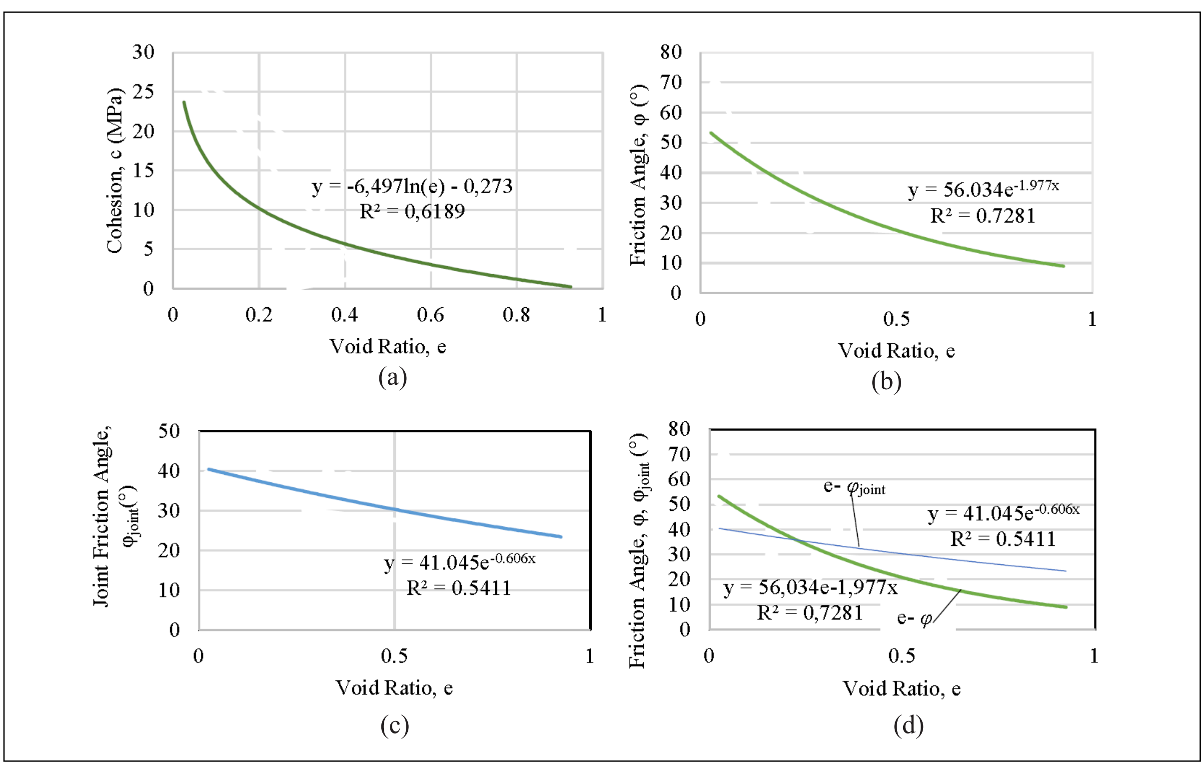

Figure 2: Correlations between void ratio, *e*, and shear strength parameters, *c, φ* and φ_{joint}.

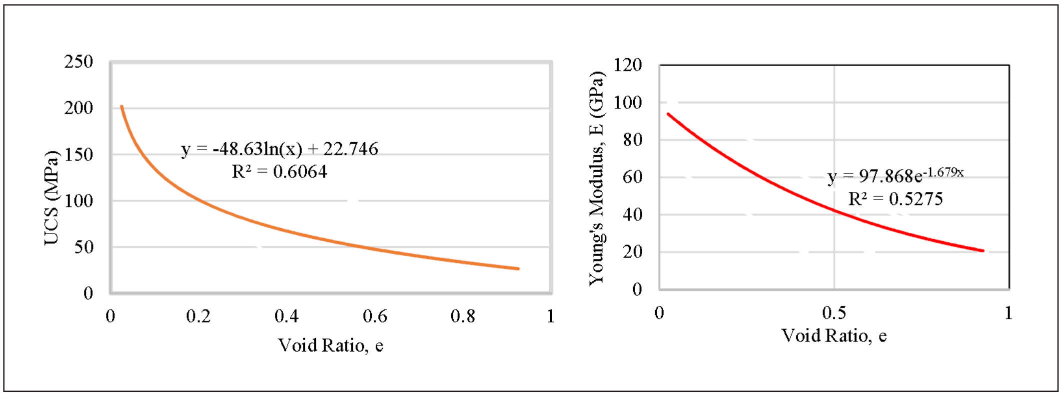

Figure 3: Correlations between void ratio, *e*, and compressive strength parameters, *UCS* and *E*.

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