Shear Strength Characterization of Bauxite Deposits in Kuantan, East Coast Malaysia

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Abstract*: Engineering characterization which are useful for "temperate" zone soils usually fail to predict the field performance of bauxitic soils, because the index tests upon which the characterization are based are not always reproducible for bauxitic soils. Fifteen (15) bauxitic soil of undisturbed and disturbed samples from 3 distinct sites in Kuantan, all derived from basalt parent rock but representing various stages of weathering were subjected to engineering and mineralogic tests. Values for cohesion and friction angles are evaluated. Soils from Semambu has the highest moisture content of 33.27%, the cohesion value is however lower compared to Bukit Goh which has moisture content of 21.74%. Study are further done to discover the relationship with cohesion and friction angles. Thus, by measuring the cohesion and friction angle can evaluate the performance of bauxite shear strength.

***Keywords*: Bauxite deposits; cohesion; friction angle; triaxial test; shear strength**

I. INTRODUCTION

Derived from in situ weathering and decomposition parent rock of Basalt, Bauxite deposit appear as a soil-like rock material. The leaching process of silica from consistent processes of tropical pedogenetic under hot and humid weather, affects the behavior of bauxite deposit. This mainly related with the arrangement (fabric) of particles that makes bauxite has unique character of strength. Bauxite deposits after basaltic in Kuantan, the concretions are concentrated with 32.35% - 52.23% Al_2O_3, 14.96% - 33.99% Fe_2O_3, 3.03% - 6.62% SiO_2 and below detection level (bdl) - 8.07% TiO_2 (Baba M. et al., 2000; Ismail N.I.N. et al, 2019).

Widely distributed group of soil in tropics, basalt residual soil is found including in Malaysia, China, (Tang et al, 1992), Pacific and Caribbean islands (Pushparajah and Amin, 1977; Tuncer and Lohnes, 1977; Lohnes and Demirel, 1983; Moon and Jayawardane, 2004), Africa and South America (Gutierrez et al., 2009). In east coast Malaysia, Kuantan is a city that has areas distributed with bauxite deposit that are originated from basalt.. In recent years, major civil engineering works have been conducted in bauxite deposited areas (De Vallejo et al., 1981; Raharjo et al, 2004), and this require a better understanding on its engineering characteristics.

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Engineering characteristics including shear strength are crucial for design and construction of foundations, slopes and railways.

Most of soil mechanics researchers focused on residual soil derived from granite parent rock for a long time (Agus et al., 2005; Kim and Kim, 2010; Raharjo et al.; 2012) and compacted residual soil (Indrawan et al., 2006; Raharjo et al.; 2011; Yan and Li, 2012; Chiu and Ng, 2014). Even though basaltic residual soil and granite residual soil have similarities in several features, yet they also have distinct features despite of originate from same region. As compared to granite residual soils, basaltic soil is characterized by its smaller grains with significantly higher void ratio and hydrophilic minerals (Huat et al., 2004; Blight and Leong, 2012). Hence, results as regards to granite residual soil studies cannot directly applied to explain the distinctive properties of basaltic residual soil, bauxite deposit for case in Kuantan. The mechanical properties are remained unclear even though several studies have made to explore the mechanical behaviour (Pushparajah and Amin, 1977; Tuncer and Lohness, 1977; Moon and Jayawardane, 2004; Zhang et al., 2016).

Previous research found that, when it is physically high in strength and low compressibility, the plasticity found to be high with small particle size (Zhang et al., 2016). This shows inconsistency between physical and mechanical charateristics of the basaltic soil. In addition, the basaltic soil grains are arranged and oriented well but upon wetting, it become metastable and possible conducive to collapsible settlement and disintegration (Blight and Leong, 2012). Suprisingly, such fundamental geotechnical characteristics have not been satisfactorily explained especially for the case of bauxite deposit in Kuantan. One of phenomena that gives concern to this fundamental was the tragedy of capsized and sank of Bulk Jupiter vessel in year 2015. The pile of bauxite deposits apparently was in concretion formation during transportation but they liquified upon continuous dynamic wave load that induce loss in shear strength. Effect from liquified, it lead to changes metacentric point of the tanker and cause the tanker to loss stability and sank into the Vietnam sea. Investigation conducted by International Maritime Organization (IMO) has concluded that the loss of Bulk Jupiter has uncovered evidence to suggest liquefaction of cargo led to loss stability (IMO, 2015; Muzamir, 2018). This has led to the question among researchers about the true shear strength of bauxite deposit in Kuantan.

Controlled by regional climatic and topographic condition as well as the bedrock nature, the properties of residual soil are varied from region to region (Raharjo el al., 2004). Therefore, this paper discussed the finding obtained from in situ and laboratory investigation on engineering geologicalc characteristics of soil derived from the bauxite in Kuantan area, east coast Malaysia, as to explore the mechanism that underlies its peculiar mechanical behavior. Previously, characterization mostly done on granite residual soil. Hence, this study focuses on characterize the basaltic residual soil (bauxite deposit) shear strength as to evaluate its performance as potential foundation.

II. METHODS

Undisturbed samples were collected for triaxial testing and to evaluate the shear strength. About five (5) undisturbed samples of bauxite soil have been derived using thin wall Shelby tubes at Bukit Goh and Indera Mahkota, and Semambu. There were in total three (3) sites were selected based on previous research mentioned locations that distributed with bauxite soil. At every site, undisturbed samples were collected at each site at every interval 25 meters distance. Sampling and laboratory investigation are discussed further in later sections.

A. Sampling

Each points of interval 25 meters were marked for sampling points. Coordinate at each point was taken and recorded. At first point, is marked at 0 meter and followed with second point at interval 25 meter. Table I shows the coordinate at points marked and label for sampling. Thin wall Shelby tubes were inserted into the ground by using hammer. The tubes were approximately 50 mm in diameter and at least 600 mm length to allow three (3) specimens of having dimension 2:1 (length is twice the diameter) at each point for Triaxial Test. Once the tubes were fully inserted into the ground (with allowance of approximately 100 mm to 150 mm of top soil), shovel been used to take out the samples from the ground. Both ends of the tube were then been covered with wax as to preserve the moisture content. Recovery percentage are calculated before samples are extruded for triaxial testing. This were then repeated at other points. The undisturbed samples taken from three (3) different locations area of Kuantan, which are Bukit Goh (BG), Indera Mahkota (IM), and Semambu (SM). Points were determined and marked to collect the undisturbed soil samples.

B. Laboratory Investigation: Triaxial Testing

Geotechnical properties of soil were investigated through Triaxial Testing as refer to BS 1377, Part 1 – 8 1990 and ASTM D 2850 as guidelines. Triaxial test can be categorized into Consolidated Undrained (CIU) triaxial test, used to determine the shear strength of the soil in cut area (high area) while Unconsolidated Undrained (UU) triaxial test is used in fill area (low area). As per shown in Table I, all samples were tested for CIU, except at BG1, BG2 and BG3. From the triaxial result, Mohr's circle is drawn and used to determine the value of cohesion, c and angle of friction, φ.

III. RESULTS AND DISCUSSION

A. Moisture Content

The average moisture content of the soil sample taken from Bukit Goh, Indera Mahkota, and Semambu was determined using oven-dry method. According to the results obtained, moisture content for Bukit Goh, Indera Mohkota and Semambu was 21.74%, 13.07%, and 33.27% respectively. The result of high moisture content percent influence by the fine particle of the bauxite soil. Large number of fine particle will create large surface area for water absorption, resulting high moisture content.

As compared to previous research, the moisture content for Bukit Goh were in range of 23.51% to 27.69% (Hasan, 2018). Meanwhile for this research is about 21.74% in which still higher compared to allowable moisture content for shipped and exported of maximum 10%, as based on International Maritime Solid Bulk Cargoes Code (IMSBC Code, 2013).

Table- I: Sampling points and types of Triaxial Testing at each point

Point	Distance (m)	Easting	Northing	Elevation (m)	Triaxial Test
BG1	0.0	103°15.116'	03°55.281'	42	UU
BG2	25.0	103°15.122'	03°55.269'	45	UU
BG3	50.0	103°15.123'	03°55.256'	46	UU
BG4	75.0	103°15.124'	03°55.243'	50	CIU
BG5	100.0	103°15.125'	03°55.230'	50	CIU
IM1	0.0	103°15.914'	03°50.502'	28	CIU
IM2	25.0	103°15.927'	03°50.503'	30	CIU
IM3	50.0	103°15.942'	03°50.501'	29	CIU
IM4	75.0	103°15.955'	03°50.502'	31	CIU
IM5	100.0	103°15.967'	03°50.500'	32	CIU
SM1	0.0	103°19.833'	03°52.806'	79	CIU
SM2	25.0	103°19.834'	03°52.820'	82	CIU
BG1	0.0	103°15.116'	03°55.281'	42	UU
BG2	25.0	103°15.122'	03°55.269'	45	UU
BG3	50.0	103°15.123'	03°55.256'	46	UU

As refer to Table II, the moisture content for Indera Mahkota and Semambu are 13.07% and 33.27%, in which both has moisture content higher than 10%. This again proves that bauxite deposits at Bukit Goh, Indera Mahkota and Semambu, all are not suitable for exported as it susceptible to loss of stability due to liquefaction. However, research is required as the deposit distributed within developing area of Kuantan to Kuala Terengganu. Hence, shear strength values at these areas are important to predict the performance of the ground as foundation.

Table- II: Average moisture content (Oven-dry Method)

Sample	Average Moisture Content (%)
Bukit Goh	21.74
Indera Mahkota	13.07
Semambu	33.27

B. Shear Strength Analysis

A 600 mm length of thin wall tube that contained sample, were divided into 3 equivalent specimens dimension of a height: diameter ratio of 2:1. According to Fig. 1, sample at point BG1 is divided into 3 equivalent specimens dimension and then tested for triaxial test at confining stress of at least 50 kPa for first loop, 100 kPa, for second loop and 150 kPa for third loop respectively in order to plot three (3) Mohr's Circle. Following figures show examples of Mohr's circle for BG1, IM4 and SM2.

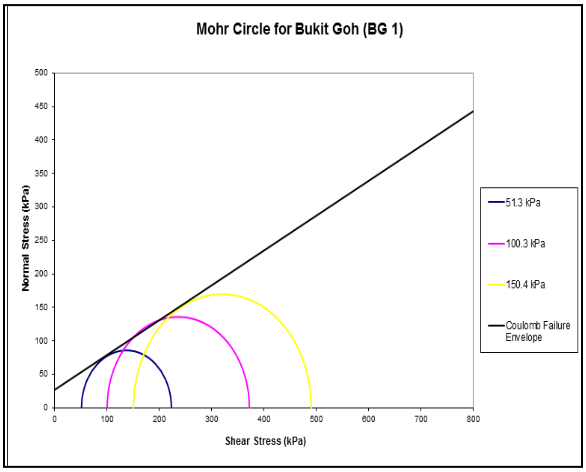

Fig. 1.Mohr's circle for BG1

Fig. 2.Mohr's circle for IM4

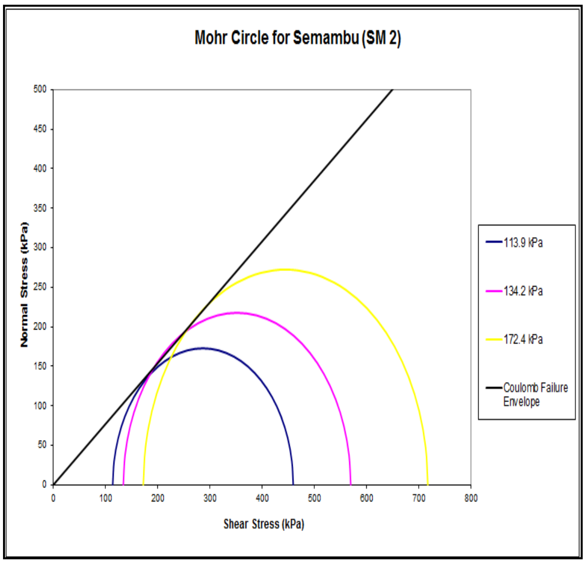

Fig. 3.Mohr's circle for SM2

Based on the Mohr's Circle obtained from the triaxial testing, cohesion is measured based on the intercept of tangent line at y-axis. The friction angle, φ is from the angle of tangent line. Table III shows the value of cohesion and internal friction angle for shear strength. Bukit Goh has the average value of effective consolidated undrained cohesion and friction angle of 48.5 kPa and 18.05° respectively. Meanwhile for unconsolidated undrained condition of 45 kPa and 46.49° respectively.

In contrast, Semambu has friction angle, φ of 37.97° and Indera Mahkota is 38.34°. The cohesion for Semambu and Indera Mahkota is 0. It shows that even though Semambu has the highest moisture content of 33.27%, the cohesion value is however lower compared to Bukit Goh which has moisture content of 21.74%.

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Table- II: Summary result of Mohr's circle analysis for Shear Strength Parameters

Point	C'_{CIU} (kPa)	C_{UU} (kPa)	φ'_{CIU}	φ_{UU}	Ave. C'_{CIU} (kPa)	Ave. C_{UU} (kPa)	Ave. φ'_{CIU}	Ave. φ_{UU}
BG 1	-	27	-	27.47°	-	45	-	46.49°
BG 2	-	43	-	45.00°	-		-	
BG 3	-	65	-	67.00°	-		-	
BG 4	11	-	2.58	-	48.5	-	18.05°	-
BG 5	75	-	15.45	-		-		-
IM 1	0	-	30.96	-	0	-	38.34°	-
IM 2	0	-	41.02	-		-		-
IM 3	0	-	40.03	-		-		-
IM 4	0	-	39.35	-		-		-
IM 5	0	-	40.36	-		-		-
SM1	0	-	34.23	-	0	-	37.97°	-
SM 2	0	-	37.60	-		-		-
SM 3	0	-	37.00	-		-		-
SM 4	0	-	40.00	-		-		-
SM 5	0	-	41.00	-		-		-

IV. CONCLUSION

The finding shows that bauxite can have high value of cohesion even though it has low moisture content as its microstructure contained low silica, in which origin from granitic mineral. This happen during the formation of bauxite deposit where extensive removal of silica occurs within the weathering process. Therefore, further study on geotechnical character of bauxite is required to understand the character of the bauxite as deposited on potential area built for development of infrastructures in Kuantan.

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