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INFLUENCE OF MOISTURE CONTENT ON THE STRENGTH OF WEATHERED SANDSTONE

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Abstract: Variation of moisture content of weathered rock is an important issue in the tropical climate as extreme temperature and heavy downpour accelerate the changes in rock properties. This paper presents the results of excavatability study on sandstones of various weathering stages focusing on the effect of moisture content on their strength. Penetration tests were carried out on 127 samples collected from four sites in Bukit Indah, Kempas, Desa Tebrau and Mersing of Johor State. The resistance at 10 mm penetration of Universal Testing Machine is indicative of penetration index of the rock materials, to allow the prediction of rock strength. There is a significant relationship among weathering grades, moisture absorption and strength of rock. This is due to the microstructure changes in the rock in relation to weathering process that controls their physical and mechanical properties. The study revealed that fabric characteristics and pore spaces are very important for assessing the behaviour of weathered rock.

Keywords: *Moisture content, weak sandstone, penetration test, strength*

1.0 Introduction

The physical and mechanical properties of rock materials depend largely on the interaction among the minerals, particles and cementations material of which it is composed. The physical and chemical weathering cause progressive changes in the rock fabric and mineralogy that govern physical attributes of rock especially the strength property (Nicholson, 2001). The rock that has been altered by weathering processes generally shows some anomalous engineering characteristics in comparison with fresh rock or residual soil. Several studies on the effect of weathering on the engineering properties of rock (e.g Lumb, 1983; Tugrul, 2004) revealed that weathering is an important process for the formation of many types of rock. However, very little information was reported on the effect of moisture content rock material of various weathering grades. Among the previous researches is the work by Broch (1974) who explained that the reduction of strength with increase of moisture content is due to the reduction in the internal friction and their surface energy. Furthermore, Moon (1993) reported that the presence of water would soften the bonds or interact with mineral surfaces and alter their surface properties.

Variations in weathering grade usually result in varying engineering properties of rock. Thus, it is important to recognise the role played by the weathering process, including the changes in moisture content, in the performance of rock in engineering application. The purpose of this study is to observe the changes in the strength of sandstone from various weathering grades due to the changes in moisture content. For the purpose of this study, 127 sandstone samples from weathering grade II (slightly weathered) to V (completely weathered) collected from Bukit Indah, Kempas, Desa Tebrau and Mersing (Figure 1) were tested and analyzed.

Figure 1:Location of the study areas

2.0 Methodology

Samples collected from the four sites (Figure 1) were packed in plastic containers to preserve the natural state of moisture content. The weathering state was described at the site using the classification system given in Table 1. Such classification system was chosen as it offers more detailed description of rock and found suitable for the weathered rock masses in tropical areas. This field classification divides wider spectrum of material in zone IV and V into subclasses, i.e. 'a' and 'b', which offers wider divisions as compared to ISRM method for classifying rock masses (ISRM, 1981). Only fine sandstones were selected for testing in order to limit the variation of the results. At least seven samples representing each weathering grade were tested. The determinations of moisture content on rock samples were carried out in accordance with the International Society of Rock Mechanics Standard Procedures (ISRM, 1981).

Petrographic analysis on thin section of rock was used to observe the changes in the rock fabric. In addition, water absorption on the weathered sandstones was assessed before the strength of the rock was measured by penetration test on Universal Testing Machine to determine the strength properties. Physical and mechanical properties of the rock were determined by a variety of laboratory tests. The properties investigated included dry unit weight, water adsorption and penetration load (strength test).

The penetration test was carried out based on the method outlined by Zainab (2004). A non-uniformed cube sample of 30 mm thick, 60 mm wide, and 60 mm long was used. The sample was confined to simulate the actual condition on site. Testing on the absorption of moisture contents were carried out by soaking the samples in water for 15 minutes. The objective of the test is to evaluate the strength required to penetrate the sample with 10 mm diameter of cylindrical shaped probe made of high speed steel (HSS) with flat edge until the sample fails. A uniform static loading rate of 0.06 mm/second was applied. Previous study has shown that this probe is the most suitable size to yield an acceptable and consistent test results (Zainab, 2004). The highest penetration resistance load was recorded by the Universal Test Machine (UTM) is indicative of penetration index of the rock materials, to allow the prediction of rock strength. All samples were tested normal to the foliations (if any).

3.0 Results and Discussion

3.1. General Characteristics of Rock Samples

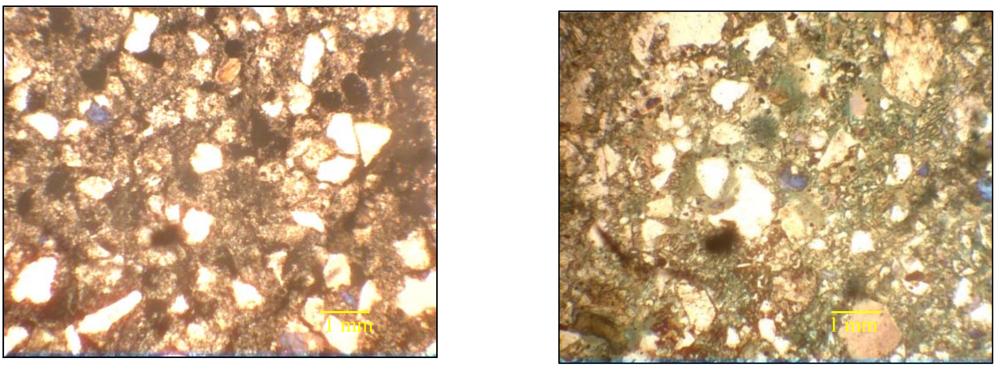
The samples obtained from Bukit Indah and Mersing were classified as weathering grade II to V-b while the samples from Desa Tebrau and Kempas is of weathering grade IV-a and V-a respectively (Table 1). All samples are categorized as fine grained sandstone. The summary of the general characteristics of the samples is given in Table 2.

3.2 Effect of weathering on rock fabric

The results of petrographic analysis showed that the sandstone used in this study was typically greyish in colour and mainly formed by quartz, feldspar, clay, mica and iron minerals. There was a wide range of pore sizes in the weathered sandstone due to grain size variations. Fine sandstone in weathering grade II is dense with tight interlocked structure with a mixture of platy minerals and quartz grains (Figure 2a). The pores are irregular in shape and generally less than 0.5μm in diameter.

As the weathering process continues, it was found that the feldspar minerals decomposed to clay (Figure 2b). The porosity observed in the petrographic study reflects the real change in void spaces due to weathering. It was found that in stronger sandstone (weathering grade II), there is an absence of clayey minerals and the material has good interlocking texture. On the other hand, where there was an increase of clayey minerals, the material has less interlocking texture. The presence of clayey minerals can be an indicator of the role of water absorption and swelling in the rock material (Franklin et al., 1971). It was revealed from petrographic analysis that rock samples have more clayey minerals and pores in higher grade of weathering.

Moderately (Grade III) and highly (Grade IV) weathered sandstones are open textured, weakly bonded, microfractured and iron stained. In completely weathered (Grade V) sandstone, most of feldspar has decomposed to clayey minerals. There is a progressive increase in porosity and microfracture frequency with the increase of weathering. This is due to granular disintegration and loosening in the texture of weathered samples.



(a) Fine sandstone, grade II (b) Fine grained sandstone, grade IVa

Figure 1: Photomicrographs of sandstone showing the feldspar decomposed to clay

Table 1: Weathering classification used to describe the rock mass/material (Edy Tonnizam (2007) modified from Ibrahim Komoo, 1995)

DESCRIPTION	ZONE		MATERIAL				MASS			
			Colour	Texture	Slaking: In water	Slaking: By hand	Structure: Condition	Structure: Changes	Iron-rich layer	Strength (Schmidt hammer)
Residual soil	VI		Completely changed (homogeny)	Destroyed	disintegrate	disintegrate	100% destroyed	Completely changed	None	None
Completely weathered	V	b	Completely changed (homogeny or	Half remains unchanged			<25% remains		Normally exist	
		a								
Highly weathered	IV	b	Completely discoloured	unchanged	Becomes flakes or small pieces	Becomes flakes or small pieces	>50-75% remains	Iron-rich filling in discontinuity	May exist	
		a								
Moderately weathered	III		Slightly discoloured		Remains as Mass	Edges can be broken	100% intact			Less than 25
Slightly weathered	II		No changes			Edges unbroken		Discolorations along discontinuity	none	Exceeds 25
Unweathered	I							No changes		

Table 2: Physical characteristics and weathering grade of rocks used in this study

Rock Type	Location	Colour	Grain size	Weathering Grade	No. of Test
Sandstone	Bukit Indah and Mersing			II	8
				III	8
				IV a	7
					8
			Fine	IV b	7
		Grey			7
				V a	8
					8
				V b	8
					8
					8
					8
	Desa Tebrau		Fine	IV a	8
		Grey			8
	Kempas		Fine	Va	9
		Grey			9

3.3. Effect of moisture content on rock strength

The results of penetration tests are summarized in Table 3. It can be seen that the increase of moisture content reduced the penetration load of all samples. The findings from this study support the work done by Moon (1993) that the presence of water would soften the bonds or interact with mineral surfaces and alter their properties. Subsequently, the increase of pore water pressure will cause instability of weak plane. The moisture within the grains acts as grease and reduces the strength of the material.

The results also shows that the effect of moisture content is more pronounced as the weathering grade increases. As the weathering grade increases, the clayey minerals in the rock material become more dominant due to the decomposition of the original minerals. Subsequently, the porosity of the material increases. The pores within the grains would assist the absorption of moisture within the rock material, thus porous rocks, especially in grade IV and V, showed significant reduction on penetration load. The presence of clayey minerals in the weathered rock will also affect the strength of rock material as it adsorbs water, thus a great reduction of strength was noted.

Soaking process has caused an increase in moisture content of less than 5% of sandstone (weathering grade II and III) collected from Bukit Indah and Mersing. On the other hand, soaking of grade V-b materials has caused an increase up to 35% of moisture content. The results show that the strength measured by the penetration test decreases as weathering increases. As weathering increases, dry unit weight decreases and water adsorption increases. Samples from Desa Tebrau (weathering grade IV a) showed reduction of 38 to 69% of the penetration load while the Kempas samples (weathering grade V a), showed reduction of 77 to 94% of the penetration load. Petrographic analysis shows that changes in microfabric (especially the porosity) seem to be the controlling factor in the reduction of rock strength due to the change in moisture content.

Table 3: Summary of the physical and mechanical properties with weathering grade

Rock Type	**Location**	**Weathering Grade**	**Dry unit weight** (kN/m^3)	**Water adsorption after 15min soaking (%)**	**Total porosity (%)**	**Strength Reduction (%)**
Fine Sandstone	Bukit Indah and Mersing	II	23.6-	<5%	6.2-10.3	6 - 13
		III	23.0-	<5%	6.4-12.2	16 - 20
		IV a	23.3-23.8	<5%	12.3-	22 - 41
				5-10%	12.5-	44 - 49
		IV b	22.3-23.5	5-10%	13.5-	51 - 61
				10-15%	13.7-	62 - 70
		V a	22.0-22.4	10-15%	>15.0	70 - 82
				15-20%		83 - 84
		V b	21.3-22.3	15-20%	>15.0	85 - 92
				20-25%		92 - 94
				25-30%		94 - 97
				30-35%		98 - 100
	Desa Tebrau	IV a	23.5-23.7	5-10%	12.3-	38 - 48
				10-15%	12.5-	46 - 69
	Kempas	Va	22.1-22.5	<5%	>15.0	77 - 90
				5-10%		92 - 94

4.0 Conclusion

Moisture content is an important factor that affects the strength of the weak rock materials. The effect is more obvious on grade IV materials where the dry and wet materials can significantly affect the strength of rock materials. The fresher samples (grade II) show the least absorption of moisture while grade V b shows the most absorption. The percentage of water absorption increases with increasing weathering grade. Thus, it should be carefully taken into account that the same materials that were tested during the initial assessment may have a different strength after heavy rain or during dry condition.

Important changes were observed in pore size distribution and microfracture density of the rocks by progression of weathering. The bigger size of pore and microfracture allow moisture to seep more easily into the rock material, thus increasing the moisture content. Significant correlations were found between porosity and strength. The dry unit weight and penetration load decrease as weathering grade increases. Higher reduction in penetration load before and after soaking was observed in rock material of higher weathering grade. Moisture content is also an important factor that affects the strength of the weak rock materials. The study clearly indicates that textural and fabric characteristics, particularly the pore size are the main features controlling the effect of moisture change on the strength of rock materials. A significant reduction occurs in grade IV materials where the dry and wet materials can significantly affect the strength of rock materials, due to an increasing degree of microfracturing and pores.

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