Shear Strength Behaviour for Older Alluvium Under Different Moisture Content

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ABSTRACT

Moisture content is one of the most crucial factors influencing soil and rock strength. This paper deals with the effect of moisture content on the strength of older alluvium under dry, wet and saturated conditions. Older alluvium is semi cemented sediment, which was eroded, deposited and reshaped by water to become a non-marine setting. The wide distribution of older alluvium in Malaysia creates problems in many field of construction such as excavation, slope stability and foundation in understanding their engineering characteristics especially the behavioral changes in dry and wet condition. In this study, samples were collected from a slope construction site in Desa Tebrau, Johor, Malaysia. The material shows equilibrium between distribution of the clay/silt and gravel with percent finer approximately 38% and 38.5% respectively, while sand content of 23.4%. The natural moisture content tested on the samples is within the range of 17.98% to 19.65%. The results revealed that moisture content have great influence in the reduction of the shear strength τ, friction angle Ø and cohesion c. Specimens were tested for shear strength and hardness. Normally in the design of engineering projects, the shear strength, friction angle and cohesion parameters of the older alluvium are assessed at dry condition. However, the test results revealed that the strength was extremely reduced with the increased of moisture content especially at saturated condition. When the moisture content of older alluvium increased, the shear strength reduced to 22.3% and 75.3% at wet and saturated condition respectively (the shear strength equal to 57.4kPa and 18.3kPa for wet and saturated condition respectively) in comparison to the magnitude of shear strength at dry condition (shear strength at dry condition equal to 74.1kPa). Similarly, the friction angle reduced to 18.6% and 66.9% at wet condition and saturated condition respectively (friction angle equal to 55.19^o and 22.45^o for wet and saturated condition respectively) in comparison to the magnitude at dry condition (at dry condition friction angle equal to 67.83^o). In addition, the results show that the magnitude of cohesion at dry condition was equal to 21.044 kPa. At wet condition the cohesion increased to 12.7% (cohesion equal to 23.71kPa) in comparison to the magnitude at dry condition. At saturated condition the cohesion value decreased to 54.6% (cohesion equal to 9.54 kPa) in comparison to the magnitude at dry condition.

KEYWORDS: Older Alluvium; Moisture Content; Friction Angle; Cohesion.

INTRODUCTION

A geotechnical engineer must take precautions when the materials at hand cannot be classified as rock or as soils in terms of their behaviour in slopes or in civil engineering works in general. In their in situ form, the geologic formations may have appearances that imply rocklike behaviour but behave very much different when it is subjected to saturated condition. Older alluvium or semi-cemented sediment which was eroded, deposited and reshaped by water in a non-marine setting has these characteristics. Once disturbed, this formation may degrade to soil-size particles in a time frame and their engineering properties will deteriorate drastically, that is relevant to the long term performance of slopes built in or in other civil engineering work. The wide distribution for older alluvium in Malaysia creates problems in many field of construction such as excavation, slope stability and foundation. The water content is known as one of the most important factors lowering the strength of rocks. A small increase in the moisture content may lead to a marked reduction in strength and deformability (Erguler and Ulusay, 2008a; 2008b).

Study in basic engineering properties such as the grain size distributions, hardness, strength, durability and shear strength parameters (cohesion c and friction angle ϕ) is important to understand the behaviour for older alluvium and avoid the inherence problems (David, 2007). Many previous researchers Abdul Shakoor and Barefild, 2009; Engin et al., 1998; Vásárhelyi and Ván, 2006; Romana and Vásárhelyi, 2007; Edward and Abdul Shakoor, 2006; Namdar, 2010; Joseph et. al., 2009 studied the changes of engineering properties for igneous and sedimentary rocks but very minimal works has been carried out for older alluvium.

Edy Tonnizam et al. (2008) noted the increase of water absorption with weathering grade. Neyde Fabiola et al. (2003) found that micro-morphological features in kaolinitic soils were related to compaction, increased tensile strength, penetrometer resistance, bulk density and hard setting behaviour. Fine particles of silt and clay form structural connections between sand particles and as the material dried out the strength of these connections increased (Mathieu Lamotte et al., 1997). Namdar (2010) compared between several types of mixed soil in mineralogy, optimum moisture content OMC, cohesion, friction angle and bearing capacity of soil, and he found that the soil cohesion decreases continuously with reduction of clay minerals in the soil.

The older alluvium have become notorious as a result of the numerous foundation, slope stability, excavation and embankment failure problems with which they are often associated. Most of these problems resulted from the change of moisture content. By increasing the water content, the older alluvium exhibit significant reductions in strength and deformability. Thus, by understanding the behaviour of this material will certainly help in the designing stage with the actual performance of this material.

This case study is representing of one of this statement. An older alluvium at Desa Tebrau, south of Johor, Malaysia shows very different engineering properties within dry, wet and saturated condition. The older alluvium behaves as rock at dry condition, but it becomes very weak at saturated condition. In rock and soil engineering projects, the effect of moisture content is important for the safety and stability of slopes and underground openings. In addition, for conservation and reclamation of ancient buildings and monuments, determination of the effect of the moisture content on rock and soil strength has a prime importance. Thus, this research is carried out to study the effect of moisture content to the shear strength and strength parameters (c and ϕ) of the older alluvium. Determining the characteristics of this material is essential for effective evaluation of the behaviour of subsurface as a whole for many civil engineering applications (Torok and Vasarhelyi, 2010).

METHODOLOGY

The standards and tools and equipments such as Schmidt hammer, geological hammer, geological compass and digital camera were used during the field visit. During the field and laboratory tests, the steps were reordered and documented by a digital camera to improve the effectiveness of explanation. Some of the initial standard procedures for sampling were amended to correspond with the site situation and ability to retrieve the samples. For example, the point-load and slake durability tests at wet condition were not able to be performed because the samples became very friable. In addition, the samples for direct shear tests were prepared on site, i.e. after rainfall because of the difficulties in preparing it at dry condition.The standards which used were, ASTM5873 for Schmidt hammer test, ASTM D5731 for point-load test, ASTM D 4644 for slake durability test, BS1377: Part 2, 1990 for sieve analysis (wet sieving), ASTM D4959 for natural moisture content, ASTM D3080 for direct shear test.

Study Area And Material Sampled

The study has been carried out at Desa Tebrau, south of Johor, Malaysia. The differences between older alluvium and alluvium at Johor State are described by Burton (1973) as shown in Table 1.

Table 1: Comparison between the older alluvium and alluvium at Johor State (Sources Burton, 1973).

	Older alluvium	Alluvium
Age	Pleistocene	Recent to Sub-Recent
Description	Semi-consolidated sand and clay- Boulder beds	Unconsolidated
Components	Type (a1): Boulder beds Type (a2): Gravel, Sand and Clay	Gravel , Sand and Clay
Origin	Fluviatile and Shallow-marine	Fluviatile and Shallow-marine

The older alluvium covers about $300m^2$ of the site. The older alluvium was surrounded by granite deposits, and colour of older alluvium is yellowish with some dark brown-red lines. Moreover, some of relict structures with about 1 to 10 m long with main dip direction about 35 south west 145^o, and approximately vertical dip and between 13^o to 80^o angle dip directions. The relict structures contain iron deposits which leaching through this structure to form iron deposits occurrence between the joint of older alluvium and marked as dark brown-red lines. However, no occurrence for fossils or trace for remain old organic. In another side, the apparent grain size of particles of older deposits does not exceed more than 7.5 mm. The angular shape of granular soil particles give evidence to close the location of deposits of older alluvium from the source of soils which was represented by quartz veins (ASTM D2488, 2009; David, 2007. The mean maximum daily temperature at the site is 38°C and the mean minimum is 30°C. Annual rainfall is approximately 1260 mm.

The material was sampled from an exposed outcrop after levelling of earthwork. A total of 35 samples were collected on the surface of the outcrop. The profiles were described using ISRM (1981) suggested method. Intact samples of measuring approximately 30 cm in length, 30 cm in height and 20 cm in width, were collected from site and then sealed in plastic and hessian bags for transport to the laboratory.

During collection of samples for direct shear test several difficulties were encountered such as: First, after collected the irregular samples the processes of reshaped was very difficult and impractical even by using several methods and equipments, so the only way to reshaped by extracted directly with regular shape insitu. Second, extract the regular samples in situ required to fabricated tools get the perfect shape for sample. Third, the weathering had effect at the potential of extracted samples as well as the quality of samples so the good samples were collected after rainfall.

RESULTS AND DISCUSSION

Wet Sieve

The older alluvium (O.A.) shows equilibrium between distribution of clay/silt and gravel with lowers presence of sand and it is classified as Clayey-Gravel (CL or CH) or Silty-Gravel (ML or MH) according to ASTM D2487 (2010).

From Table 2 it can be concluded that the percentage of finer of fine material (clay and silt <63 μm) are ≈ 395 g from the total mass of 1035g, in another words, it represented ≈ 38% of the component of older alluvium. The coarse material recorded 640.12g from total mass 1035g with percent finer ≈ 61.9%. Moreover, the sand (from > 63 μm to < 2 mm) recorded 241.98g from total mass 1035g with percent finer ≈ 23.4%. However, the gravel was recorded 398.14g from total mass 1035g with percent finer ≈ 38.5%. The high percentage of gravel (about 38.5% of whole O.A.) gives a good explanation for the high portion of friction angle. However the presence the fine material (about 38% of whole O.A.) give ability for soil to stick together and provide strong bond between the particles (cohesion, c). The fine material (i. e. clay) considering as good source of cohesion, but its weakest binding material in rock (Mathieu Lamotte et al., 1997; Engin et. al., 1998).

Table 2. Results of wet sieve analysis.

Opening sieve size (mm)	Mass retained on each sieve (g)	Cumulative mass (g)	Percent finer* (%)
10	0	0	100
6.3	18.36	18.36	98.23
5	66.61	84.97	91.79
3.35	203.67	288.64	72.11
2	109.5	398.14	61.53
1.18	61.42	459.56	55.60
0.600	69.09	528.65	48.92
0.425	28.07	556.72	46.21
0.300	25.67	582.39	43.73
0.212	20.02	602.41	41.80
0.150	16.79	619.2	40.17
0.063	20.92	640.12	38.15
Pan	394.88	1035	0.00
	ΣM =1035		

$$\text{* Percent finer} = \frac{\Sigma M - \text{column 3}}{\Sigma M} \times 100 = \frac{1035 - \text{column 3}}{1035} \times 100$$

Moisture Content Test

In general, the natural moisture content was within range of 17.98% to 19.65% with average of 18.75%. It should notice that the samples was token after one day rain (low to medium rain density), and the same moisture content was approved as moisture content for wet condition, see Table 3.

Table 3. Results of moisture content tests.

	Units	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Depth of sample	m	1	1	1	1	1	1
Sample number	N/A	1	2	3	4	5	6
Container Number	N/A	MG 22	MG 36	MG 44	MG 58	MG 59	MG 62
Mass of water (M_w)	g	29.732	29.527	29.375	29.249	29.382	29.514
Mass of container + wet sample (M_1)	g	219.107	181.571	192.196	199.962	187.158	196.210
Mass of container + dry soil (M_2)	g	189.706	157.374	165.462	172.777	163.116	170.085
Mass of water (M_w)	g	29.401	24.197	26.734	27.185	24.042	26.125
Mass of dry soil (M_s)	g	159.974	127.847	136.087	143.528	133.734	140.571
Moisture content(w%)	%	18.38	18.93	19.65	18.94	17.98	18.59
The Average of Natural Moisture Content = 18.75 %							

Direct Shear Test

A total of 21 tests were performed on the samples. However only 10 tests were succeeded and the other 11 tests were give unsatisfactory results. Table 4 shows the results of 10 samples (4 dry, 3 wet and 3 saturated samples). The total number of samples that collected and prepared were 30 samples, and it collected after rainfall in order to reduce the potential of extracted the samples because reduce the strength of older alluvium after rainfall (Joseph et. al., 2009; Romana and Vásárhelyi, 2007). Table 4 shows the applied load which used, i.e. 11.3kPa, 21.1kPa and 30.9kPa for dry, wet and saturated condition, while the load of 50.5 kPa was used only for dry condition. The moisture content measured was 0% for dry condition, between 18.1% to 21.7% for wet condition and between 25.3% to 26.8% for saturated conditions.

Table 4. Comparison of peak stress, applied normal stress, W.C., condition and type of soil of older alluvium samples.

Sample No.	condition	W.C.* (%)	Degree of saturation (%)	Type of soil**	Normal stress (kPa)	Peak stress (kPa)
1	Dry	0	0	Dense	11.3	49.6
2	Dry	0	0	Dense	21.1	74.1
3	Dry	0	0	Dense	30.9	92.9
4	Dry	0	0	Dense	50.5	146.6
5	Wet	18.1	80.26	Dense	11.3	38.2
6	Wet	20	78.13	Dense	21.1	57.6
7	Wet	20.7	90.83	Dense	30.9	66.4
8	Saturated	25.3	86.14	Dense	11.3	14.2
9	Saturated	26.8	92.61	Dense	21.1	18.3
10	Saturated	26.5	91.87	Dense	30.9	22.3

* W.C. = Moisture content (Water content)

** Type of soil refer to the type of curve between horizontal and vertical displacement

The results show that, the shear strength τ decrease with the increase of moisture content and degree of saturation. The shear strength was represented by the peak stress was within range 49.6kPa to 92.9kPa, which indicate that the older alluvium can be classified as stiff soil (considering the applied normal stress σ = 21.1kPa which represented 1 m beneath of older alluvium deposits surface (Budhu, 2007). At wet condition, the shear strength range was from 38.2kPa to 66.4kPa, which can also be classified as stiff soil. However, at saturated condition, the results range from 14.2kPa to 22.3kPa which it can be classified as soft soil (Das, 2006; 2008).

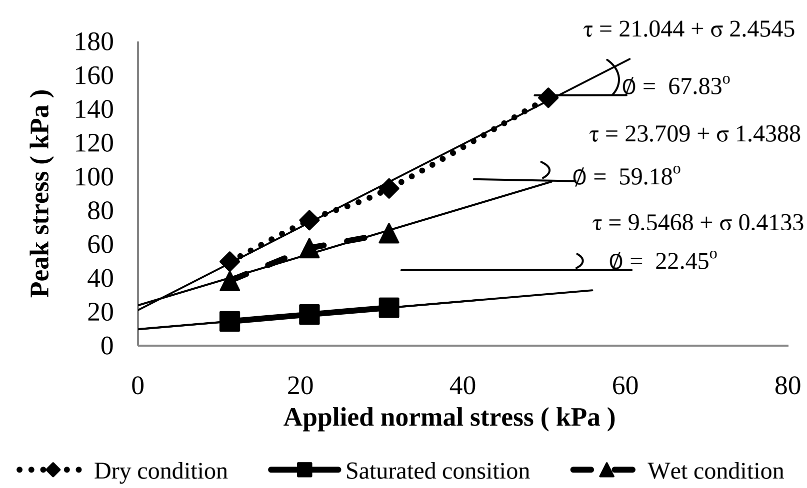
Table 5 and Figure 1 show the friction angle ∅ at dry, wet and saturated condition were

Table 5: Conclusion of the results of direct shear test for different condition (dry, wet and saturated).

Sample condition	Shear stress equation	Cohesion c (kPa)	Friction Angle $\emptyset^o$
Dry	$\tau = 21.044 + \sigma\ 2.4545$	21.044	67.83
Wet	$\tau = 23.709 + \sigma\ 1.4388$	23.709	55.19
Saturated	$\tau = 9.5468 + \sigma\ 0.4133$	9.5468	22.45

67.83o, 55.19o and 22.45o respectively. In addition, the results show the cohesion c value at dry, wet and saturated condition were 21.044kPa, 23.709kPa and 9.5468kPa respectively. The explanation for relative high value of friction angle and cohesion at dry and wet conditions on older alluvium can be related to the mixture of particles especially the percent finer for gravel and clay (Namdar, 2010).

Table 6 shows the reduction of shear strength. At wet condition (moisture content w= 20%), the reduction on shear strength noted as 22.3% in comparison to value at dry condition. However, a



slight increase of moisture content at saturated condition (moisture content w =26.8%) produced a reduction of shear strength up to 75.3%. On the other hand, the value of friction angle gave reduction up to 18.6% at wet condition, and 66.9% at saturated condition in comparison to value at dry condition. However the effect of change moisture content at cohesion was variable, the cohesion increased progressive with increase the moisture content to be greater by +12.7%, until reach to specific value of increasing the moisture content w= 25.3%, then the magnitude of cohesion start to decrease, so the reduction became 54.6% in comparison to the dry condition.

The explanation for that behaviour is related to the percentage of water content between the soil particles. At dry condition the friction angle was 67.83^o which represented the friction resistance forces between gravel and coarse sand. Otherwise the fine material (clay and silt <

0.63μm) which have percent finer about 38% (this percent is high) created high portion of cohesion. Otherwise, at wet condition, appearance of water increased the force of cohesion and decrease friction force, in another word the exit water between the medium and big particles act as lubrication so the sliding movement between the particles will be easier because decrease the friction resistance between it. Furthermore, the existence of water increase the cohesion between the fine particles which represented around 38% of particles percent size and give the soil higher consistency, so the bond between the fine particles add extra cohesion force to the soil. However, the extra increase of water (such as at saturated condition) will make friction resistance force between the gravel and coarse sand tend to reduce to 66.9%,. In addition, the bond between the fine particles reduced as the high portion of water tend to extend the distance between the fine material, cause decreased the attraction force between fine materials, so the cohesion reduced, consequently the shear strength will reduced rapidly to 75.3% in comparison to dry condition.

Table 6: Comparison on reduction of shear strength, friction angle and cohesion at dry, wet and saturated condition of older alluvium samples (considering the applied normal equal 1m beneath the surface).

Sample Condition	Moisture Content (%)	Degree of saturation (%)	Normal stress σ (kPa)	Shear Strength τ (kPa)	Reduction at τ (%)	Friction Angle ∅°	Reduction at ∅ (%)	Cohesion c (kPa)	Reduction at c (%)
D.	0	0	21.1	74.1		67.83		21.044	
W.	20	78.13	21.1	57.6	22.3%	55.19	18.6%	23.709	+12.7%
S.	26.8	92.61	21.1	18.3	75.3%	22.45	66.9%	9.5468	54.6%

D. = Dry Condition W. = Wet Condition S. = Saturated Condition
\+ means no reduction but there was increase in the value

Figure 2 shows the shear strength at normal stress (σ = 11.3kPa, 21.1kPa and 30.9kPa) reduced gently with increased of moisture content, until the moisture content cross over the natural moisture content then the value of shear strength will reduce rapidly to reach the lowest value. This can give signature to zone of moisture content which have high harmful effect on the older alluvium. This harmful zone of moisture content could be starting when the value moisture content becomes higher than 22%.

Figure 3 shows the effect of change of moisture content on shear strength parameters (friction angle ∅ and cohesion c), for friction angle the same as shear strength it reduced gently with increase the moisture content until the moisture content cross over the zone of natural moisture content w > 21%, then the value of friction angle reduce rapidly. On the another side, the cohesion increase slowly with increase of moisture content then when the moisture content value cross over > 21% the cohesion start to go down and reduced with increase the moisture content.

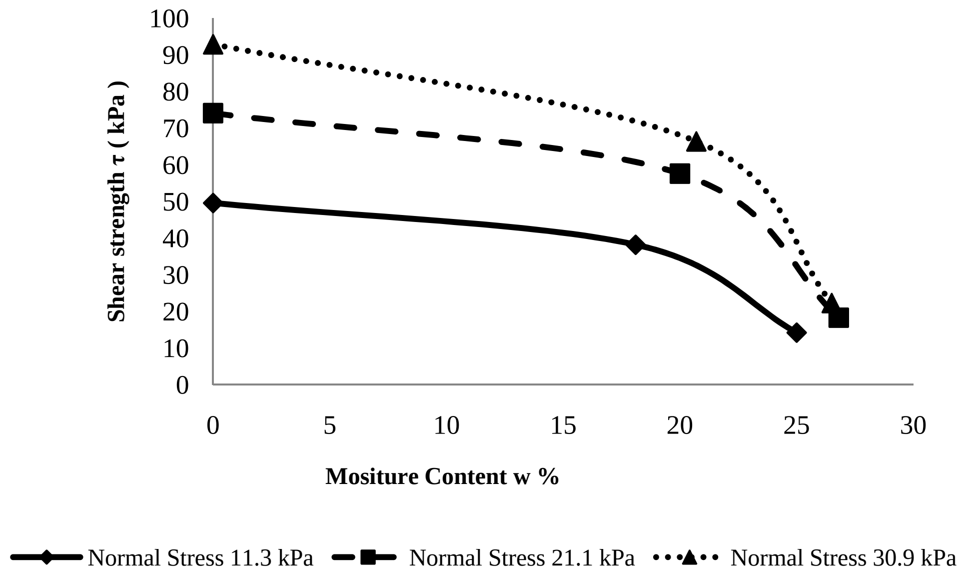


Figure 2: Comparison reduction of shear strength with moisture content at different applied normal stress(11.3–21.1–30.9kPa).

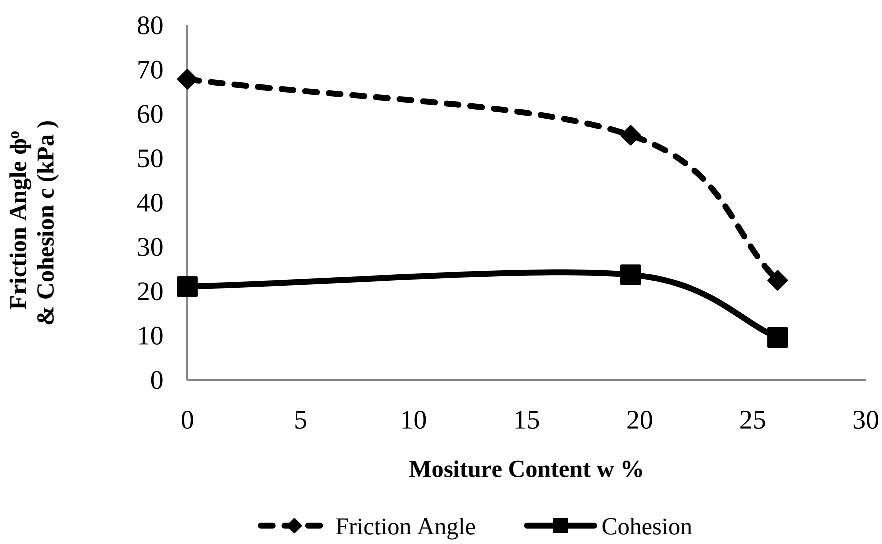


Figure 3: Comparison change of shear strength parameters (friction angle ∅ and cohesion c with moisture content**.**

CONCLUSION AND RECOMMENDATIONS

Conclusion

In general the older alluvium has different behaviour at different level of moisture content.

The results from the grain size analysis show high percentage of fine material i.e. clay and silt which was around 38%, but generally it less than coarse material i.e. gravel 38.5% and sand 23.4%. Moreover the natural moisture content was within range of 17.98% to 19.65% and with average of 18.75%.

However, during the experiments, it was found that it was difficult to perform the direct shear test on samples without used specific steps and fabricated tools to prepare samples in situ, because it required exist confined pressure during preparation the undisturbed samples. Otherwise, using disturb samples usually are not represented the actual situation at field.

The results from direct shear test show various values of shear parameter at different condition and the highest shear strength τ value recorded at dry condition, while the lowest value was at saturated condition. The same as for friction angle $\emptyset$ which give highest portion at dry condition, while the lowest portion at saturated. Otherwise, the cohesion c recorded the highest value at wet condition and lowest value at saturated condition.

Recommendations and Suggestions

From this research, a few lessons are learnt to avoid the difficulties faced during implementation of the project. The following recommendations are worth to be observed:

- Undisturbed samples should be used for direct shear test to represented the actual field condition.

- Fabricated especial tools to extract the regular samples at field.

- More tests should be performed on older alluvium at deeper depth to study engineering properties, such as at levels where the pile foundation is normally driven, so the results will give actual strength parameter. Otherwise, should not depend on results from only standard penetration test SPT, which could not provide actual behaviour of older alluvium when the moisture content is changed. Also, care should be given during design stage for not deliberately adapt the shear test result as the result may not within the safety range for portion of shear strength at saturated condition.

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