



## Comparative Study in Method of Compaction by Consolidated Drained and Direct Shear Test

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### ABSTRACT

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Soil compaction has been a common practice in the construction of highways, embankments, earth dams and other related structures where the condition of the soil is high in void ratio and therefore having a very low in bearing capacity. Therefore, the soil needs to be compacted in order to minimize the void ratio and in the same time would result in having a very high bearing capacity to sustain load. Nevertheless, only a few researches have been done to investigate the method of compaction using different energy on the behavior of shear strength by consolidated drained and direct shear test. In this research, the effect of different compaction in energy of 25 number of blows compared to 40 number of blows on the stress-strain behaviour of drained triaxial test has been done and findings of the data are to be compared with direct shear test. Results reveal that there is an increase in soil unit weight by using different energy in compaction with an increase of 5% from 1790 kg/m<sup>3</sup> to 1880 kg/m<sup>3</sup> for 25 and 40 number of blows respectively. However, the stress-strain behaviour of the specimens shows differently when compared between consolidated drained triaxial and direct shear test. The shear strength for direct shear-stress is at higher value compared to drained triaxial test. For drained triaxial test, results reveal that the effective friction angles are increase only about 1% from 37° to 38°. This is due to the soil particles rearranging itself with the different applied pressures thus eliminating the effects of different energy on the shear strength of the specimens. However, for direct shear test, the shear strength increases drastically from 29° to 32°. The increase of the shear strength is more likely influence by the soil particle arrangement due to the impact of the energy of the no of blows to the desired specimen.

#### Keywords:

Compaction; Shear strength;

Consolidated drained; Effective friction

angles

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## 1. Introduction

Ground improvement is one of the solutions when dealing with problematic soil especially when deal with weak ground condition. In order to increase the bearing capacity from weak to very dense ground condition, it is necessary to upgrade its mechanical behavior along with the needs in the

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requirements for construction [10]. Increase the soil bearing capacity can be achieved by modified or stabilized the soil. Soil stabilization is carried out to increase the shear strength and durability of the soil thus help to increase the bearing capacity to blend with construction needs while soil modification is achieved by adding any modifier to modify the soil properties especially with its strength [11]. There are various methods to improve the soil stabilization in the market includes compaction process, piling work, soil stabilization, vertical drain and load reduction method.

This study was done to investigate the behavior of shear strength of a granitic residual soil when used a different energy of compaction and thus to improve the shear strength of the soil. Consolidated drained triaxial and direct shear test was done to evaluate the soil behavior with respect to shear strength. Hypothetically, the shear strength should be increase proportionally when higher energy in compaction is applied. Thus, it would reflect in the outcome of the results where the process of compaction using 40 number of blows should produce higher effective friction angles in the soil specimen compared to the 25 number of blows.

By definition, the process of compaction is a method to densified the soil properties by eliminates the air void in the soil structures without any changes in volume of water by means of mechanical forces [7]. Generally, residual soil was used as a filling material for different geotechnical structures such as road pavements, embankments, retaining structures, land reclamation and landfill. However, the soil is need to be compacted first by means of mechanical plant in order to increase the bearing capacity of the soil [12]. The process of compaction for weak soil was necessary in many engineering works in order to ensure that it can sustain loadings from the infrastructure. Nevertheless, the process of compaction also will minimize the void ratio of the soil and thus will results in decreasing the permeability and in the same this will cause the erosion and surface runoff. Finding from Sabat and Moharana [2] reveal that if the energy of the compaction process increases, the optimum moisture content (OMC) will decrease and in the same time the maximum dry density (MDD) will increase.

Marto and Kassim [9] found that in order to have a good design in structures with elements of safe and robust, there is necessarily to considered various geotechnical parameters lies within the properties of granitic residual soil. The geological formation of granitic residual soils mainly being weathered by chemical reaction and therefore the engineering properties of the soil will depend on climate, parent rock, topography and the time when its being transformed [13]. In addition, Brand [4] and Fookes [6] found that the granitic residual soil is partially saturated consisting of partly entrapped air and water due to the elevation of the ground from sea level causing the shear strength to vary.

Designing of shallow foundations in granitic residual soil need to undergoing for the process of compaction since it is very important procedure in geotechnical design. The process of compaction will eventually increase the bearing capacity of the soil and strengthen the shear strength of the soil to sustain load. According to Brand [4], process of compaction will increase the shear strength of the soil but that's is not the main issues. The expansion and reduction of volume due to drying and wetting effect of the compactness will result in the effectiveness of the compaction outcomes. Compactness of the soil will affect the design of shallow foundations, embankments, dams and many other structures while consolidation is the change in volume due to increase of overburden pressure at a prolonged time causing reduction of soil volume and relates to the clay content that exist within the soil.

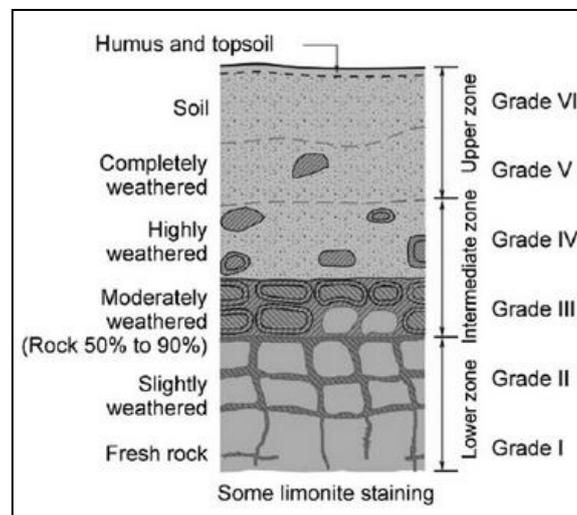
Weathering product of parent rock basically can be categories into two group which are residual and transported soil. The weathering process of this parent rock can be either through mechanical or chemical weathering in situ. Majority of the land in the world especially in Malaysia, about 80% of the land is covered by the residual soil. Location of ground water table located deeper from the

original ground level cause the soil to become partially saturated and hence during rainfall, the water infiltrates through the soil particles and become wetter. These soils generally belong to the residual category that may exhibit collapse settlement upon wetting [3]. Collapsible soil is well-defined as soil that is vulnerable to a large and sudden reduction in volume when wetted. Collapsible soil deposits share two main features, they consist of loose cemented deposits, and are naturally quite dry. Collapsible soil can bear a large applied vertical stress with small amount of compression, but will show large settlement when wet, with no rise in vertical stress [1].

In geological formation and minerals, the common minerals that exhibits in granite minerals are quartz (at least 30%), feldspar (60 to 65%) with biotite and horn blend [14]. This statement is supported by Brand [4], where findings shows that majority of the residual soil in Peninsular Malaysia is red in colour cause of its origin from natural lateritic soil or partly lateritic and the natural laterite might form due to disintegration of fossils under earlier climatic conditions.

Chiu and Ng [5] found that most of the granite residual soil in Malaysia initially be sandy, as sand-sized particles of quartz and partially weathered feldspar are released from the granite. The partially weathered feldspar grains will weather gradually over time completely into fined-grained clay minerals. Quartz does not weather due to its resistant to weathering; therefore, resulting soil will have both sand-sized quartz and clay.

Most residual soils in Malaysia will have a vertical soil section usually known as a soil profile consisting of distinct layers termed as soil horizons forming less parallel to the ground surface. Due to this nature, the soil profile illustrates the weathering aspect which gives rise to a vertical weathered profile that is vital in the engineering perspective. Figure 1 shows a typical vertical soil profile that reflects to the product of chemical weathering in Malaysia for a typical granite weathered residual soil.



**Fig. 1.** Typical profile of the granite weathered residual soil [8]

## 2. Research Methodology

Data collected from the study can be either through full scale test at site or by laboratory study. Hence, in this research, the approach used is experimental study where the objective is to investigate the shear strength behaviour of granitic residual soil compacted at different energy of 25 and 40 number of blows. The experimental procedures of the granitic residual soil can be divided into two categories which known as index properties characteristics and engineering properties. The

index properties characteristics of the soil were determined by conducting wet sieving, sedimentation test, water content and performing the Cone Penetration test and plastic limit tests. On the other hand, the consolidated drained triaxial test (CD) and direct shear test were conducted to determine the effective minimum internal friction angle at failure,  $\phi'_{\min f}$ , transition shear strength,  $\tau_t$  and transition effective stress,  $(\sigma - u_w)_t$  according to the curved-surface envelope shear strength model. For consolidated drained triaxial test, single stage series of four (4) different effective stresses at 50, 100, 200 and 300kPa were applied to obtain a series of Mohr circles. While for direct shear test, the effective shear stress of 50, 100, 200 and 300kPa also were applied to determine the failure envelope when plotting the shear and normal stress envelope.

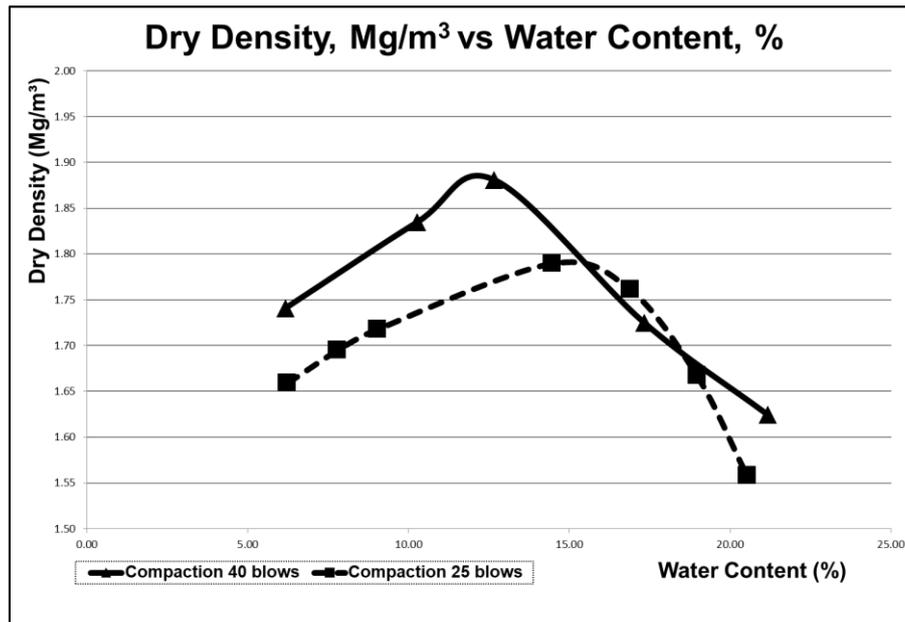
Hutan Lipur Jeram Toi, Kuala Klawang, Negeri Sembilan has been chosen to collect the soil samples since in that particular location consists a lot of granitic residual soil formation. The location of the site is at coordinates of 2°52'09.1"N; 102°00'50.6"E. Disturbed samples were carefully dug out using scope and placed it into the polyethylene bags. In order to minimized the loss of water content from the disturbed soil, the bags containing of the sample were carefully tied up and brought back to the soil laboratory as soon as possible. Laboratory tests were then conducted with the use of appropriate quantities of the soil sample collected.

For consolidated drained triaxial test about eight (8) remoulded specimens were used in the test with the dimensions of 50mm diameter and 100mm in height. In order to make sure that the specimens are in identical, each of the specimens was prepared using the same optimum water content and maximum dry density with 25 number of blows and 40 number of blows consecutively. The objective is to investigate the effect of different energy in number of blows with respect to shear strength of the granitic residual soil. In addition, the specimens also will undergo to assess the shear strength using direct shear test. In this procedure, about eight (8) specimens were prepared with dimension of 60mm x 60mm x 20mm in thickness. The specimens were sheared according to the desired effective stress based on the weight that applied on the top of the specimens.

### 3. Analysis of Results

Data collected from the results shows that the granitic residual soil is classified as silty SAND with 11% of gravel, 60% of sand, 18% of silt and 11% of clay. In addition, results indicate that the optimum water content for 25 number of blows was at 15% with maximum dry density at 1790 kg/m<sup>3</sup> while for 40 number of blows, the optimum water content was 12.5% with maximum dry density at 1880 kg/m<sup>3</sup> when tested in compaction test. Findings reveal that there is a significantly reduction in water content of 17% with an increasing in dry density of 5% when the energy in compaction is increase from 25 number of blows to 40 number of blows. Figure 2 shows the optimum water content and maximum dry density for 25 and 40 number of blows.

During compaction, the higher number of blows will result in higher value of dry density but lower in optimum water content. Basically, when the soil is compacted with higher number of blows, it will re-orientate to denser state of packing and thus will reduce the void ratio. This will reduce the ability of water to seep through the soil body and results in reduction of water content in the soil. This explains why the water content for 40 number of blows is less compared to 25 number of blows.



**Fig. 2.** Optimum water content and maximum dry density for compaction of different energy for 25 and 40 number of blows

In order to determine the effective internal friction angle at failure for the saturated specimens, stress-strain graphs were plotted according to the tabulated data produce from the consolidated drained triaxial and direct shear stress tests. Table 1 tabulated the shear strength parameters for 25 number of blows along with the deviator stress, pore water pressure and cell pressure for consolidated drained triaxial test. Results indicates that the effective friction angle at failure is  $37^\circ$  with transition shear strength,  $\tau_t$  is 66kPa and transition effective stress,  $(\sigma-u_w)_t$  is 62kPa. The value of transition shear strength,  $\tau_t$  with transition effective stress,  $(\sigma-u_w)_t$  were determined using the non-linear shear strength envelope shown in Figure 3(b). To determine the values of these two parameters, the Mohr circle at 50kPa effective stress were selected where the non-linear and linear envelope merge together with these values.

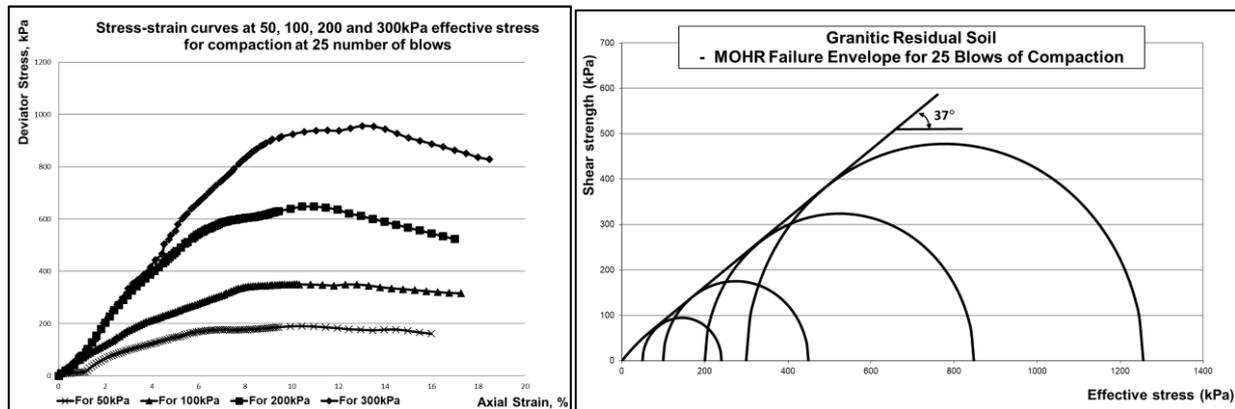
**Table 1**  
 Effective shear stress parameters at failure for 25 number of blows

Effective Stress, kPa	Condition of Failure			Shear Strength Parameters		
	Deviator Stress (kPa)	Pore Water Pressure (kPa)	Cell Pressure (kPa)	$\phi'_f$	$\tau_t$ kPa	$(\sigma-U_w)_t$ kPa
50	190	400	450	$37^\circ$	66	62
100	350	400	500			
200	648	400	600			
300	956	400	700			

Figure 3(a) illustrates the deviator stress for each stress-strain curve of the saturated specimens at 25 number of blows. The maximum deviator stress recorded are 190, 350, 648 and 956kPa for the stress curves at effective stresses of 50, 100, 200 and 300kPa respectively. Four failure Mohr envelopes were drawn using non-linear failure envelope as shown in Figure 3(b).

Table 2 tabulated the data of compaction for 40 number of blows with respect to shear strength parameters. Results reveals that the effective friction angle at failure is  $38^\circ$  with transition shear strength,  $\tau_t$  is 68kPa and transition effective stress,  $(\sigma-u_w)_t$  is 61kPa. Figure 4(a) illustrates the compaction outcome for 40 number of blows with respect to shear strength parameters for each

stress-strain curve of the saturated specimens. The maximum deviator stress recorded are 195, 355, 660 and 995kPa for the stress curves at effective stresses of 50, 100, 200 and 300kPa respectively. Four failure Mohr envelopes were drawn using non-linear failure envelope as shown in Figure 4(b).

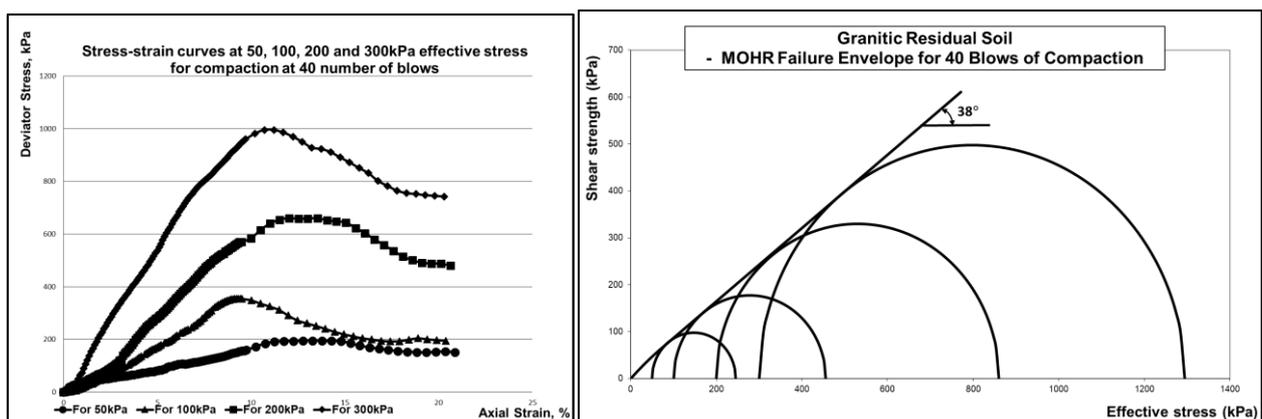


**Fig. 3.** (a) Illustrates the stress-strain curves for 25 number of blows at 50, 100, 200 and 300kPa effective stress while (b) shows the non-linear shear strength envelope at 50, 100, 200 and 300kPa effective stress

**Table 2**

Effective shear stress parameters at failure for 40 number of blows in compaction

Effective Stress, kPa	Condition of Failure			Shear Strength Parameters		
	Deviator Stress (kPa)	Pore Water Pressure (kPa)	Cell Pressure (kPa)	$\phi'_f$	$\tau_t$ kPa	$(\sigma - U_w)_t$ kPa
50	195	400	450	38°	68	61
100	355	400	500			
200	660	400	600			
300	995	400	700			



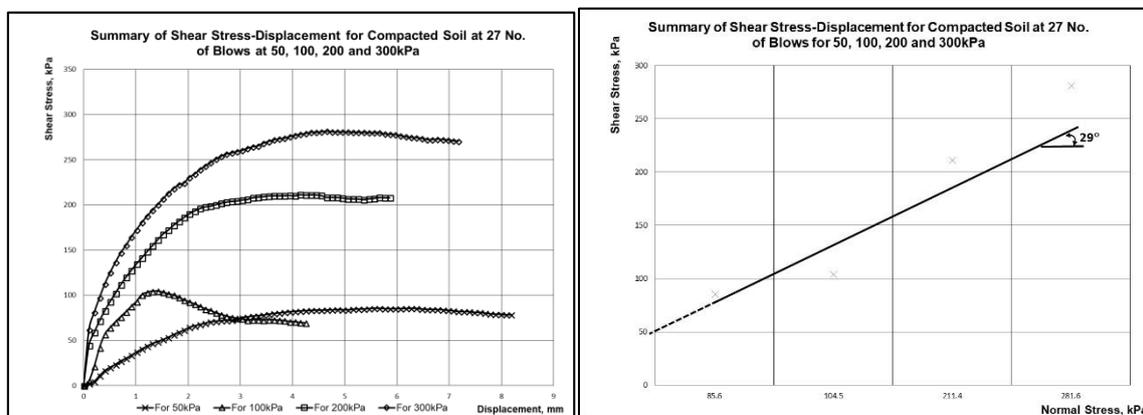
**Fig. 4.** (a) Shows the stress-strain curves for 40 number of blows at 50, 100, 200 and 300kPa effective stress while in (b) shows the non-linear shear strength envelope at 50, 100, 200 and 300kPa effective stress

Meanwhile, Table 3 tabulated the shear strength parameters for 25 number of blows with shear stress and horizontal displacement for direct shear stress test. Results shows that the effective friction angle at failure is 29° with effective cohesion of 50kPa.

**Table 3**  
 Effective shear stress parameters at failure for 25 number of blows

Effective Stress, kPa	Condition of Failure		Shear Strength Parameters	
	Shear Stress (kPa)	Horizontal Displacement mm	$\phi'_f$	Cohesion, $c'$ kPa
50	85.6	6.267	29°	50
100	104.5	1.415		
200	211.4	4.145		
300	281.6	4.650		

Figure 5(a) shows the recorded maximum shear stress for each stress-strain curve of the saturated specimens at 25 number of blows. The maximum shear stress recorded are 86, 104, 211 and 282kPa for the stress curves at effective stresses of 50, 100, 200 and 300kPa respectively. Effective friction angles and effective cohesion can be drawn using shear stress and normal stress envelope as shown in Figure 5(b).



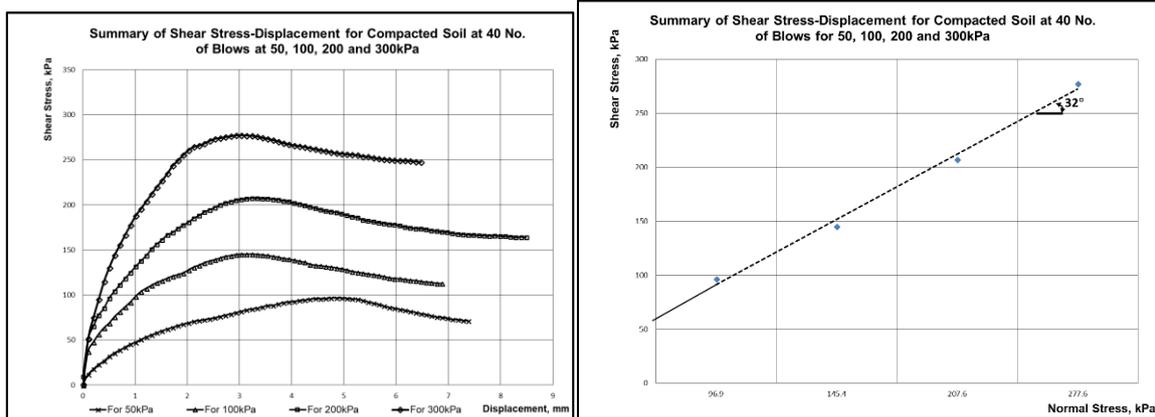
**Fig. 5.** (a) Shows the stress-strain curves for 25 number of blows at 50, 100, 200 and 300kPa effective stress while (b) shows the shear stress and normal stress envelope at 50, 100, 200 and 300kPa effective stress

Table 4 shows the shear strength parameters for 40 number of blows with shear stress and horizontal displacement for direct shear stress test. Results shows that the effective friction angle at failure is 32° with effective cohesion of 60kPa.

**Table 4**  
 Effective shear stress parameters at failure for 40 number of blows

Effective Stress, kPa	Condition of Failure		Shear Strength Parameters	
	Shear Stress (kPa)	Horizontal Displacement mm	$\phi'_f$	Cohesion, $c'$ kPa
50	96.9	4.852	32°	60
100	145.4	3.235		
200	207.6	3.235		
300	277.6	3.033		

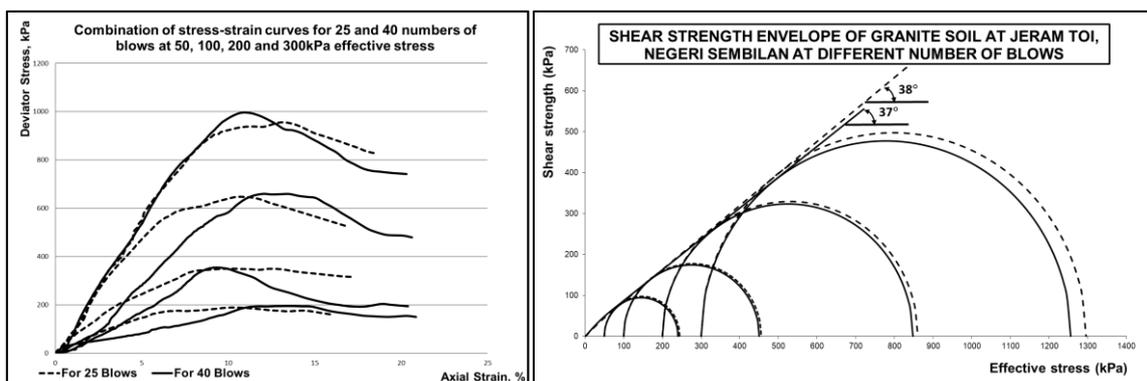
Figure 6(a) shows the recorded maximum shear stress for each stress-strain curve of the saturated specimens at 40 number of blows. The maximum shear stress recorded are 97, 145, 208 and 278kPa for the stress curves at effective stresses of 50, 100, 200 and 300kPa respectively. Effective friction angles and effective cohesion can be drawn using shear stress and normal stress envelope as shown in Figure 6(b).



**Fig. 6.** (a) Shows the stress-strain curves for 40 number of blows at 50, 100, 200 and 300kPa effective stress while (b) shows the shear stress and normal stress envelope at 50, 100, 200 and 300kPa effective stress

There is merely by  $1^\circ$  increase in the shear strength for 25 number of blows and 40 number of blows from consolidated drained triaxial test. The effective friction angles for 25 number of blows and 40 number of blows is  $37^\circ$  to  $38^\circ$  consecutively. The shear strength increases slowly by  $1^\circ$  only. Eventually, the small changes in this shear strength did not contributed significant contribution toward to the shear strength. Although there is significant increase in OMC and MDD for the compaction process of 25 and 40 number of blows, but it did not give any significant contribution to the shear strength of the specimens. This means that an increasing in number of blows for compaction did not increase the shear strength of the soil at all for the consolidated drained triaxial test.

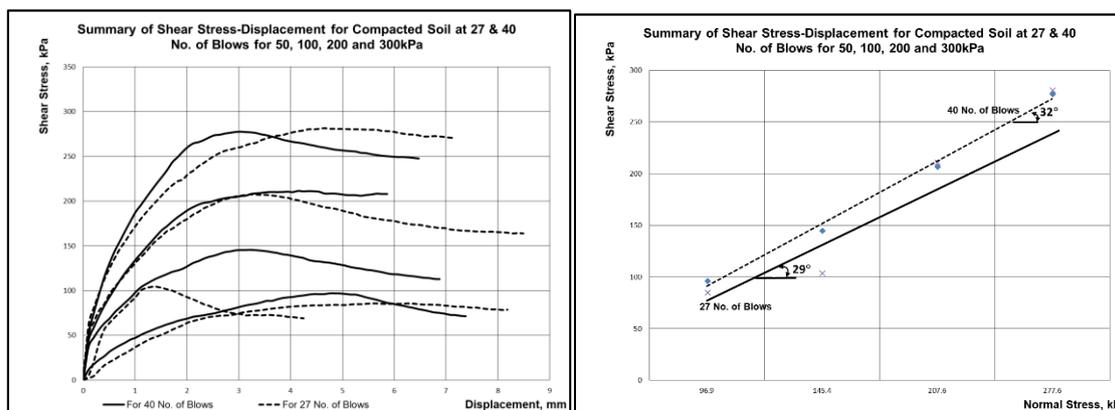
Figure 7(a) illustrated the combination of recorded maximum deviator stress for each stress-strain curve of the saturated specimens at 25 and 40 number of blows. Figure 7(b) on the other hand shows the combination of failure envelope of 25 and 40 number of blows.



**Fig. 7.** (a) Shows the combination of stress-strain curves for 25 and 40 number of blows at 50, 100, 200 and 300kPa effective stress for consolidated drained triaxial test while in (b) shows the non-linear shear strength envelope at 50, 100, 200 and 300kPa effective stress

On the other hand, result from direct shear test shows differently from the consolidated drained triaxial test where the shear strength of the specimens for 25 and 40 number of blows is between  $29^\circ$  to  $32^\circ$  respectively. It means that the shear strength increases significantly for about  $3^\circ$  compared to consolidated drained test where the specimens increases merely by  $1^\circ$  only. The significant changes in effective friction angle have great effect on the shear strength of the soil.

Figure 8(a) shows the combination stress-strain curves for 25 and 40 number of blows at 50, 100, 200 and 300kPa effective stress while Figure 8(b) shows the combination of failure envelope for 25 and 40 number of blows.



**Fig. 8.** (a) Shows the combination of stress-strain curves for 25 and 40 number of blows at 50, 100, 200 and 300kPa effective stress while in (b) shows the failure envelope at 50, 100, 200 and 300kPa effective stress

#### 4. Conclusion and Recommendation

Based on the findings that tabulated in the results section, it can be concluded that even though there is drastically changes in optimum moisture content for compaction process in 20 number of blows compare with 40 number of blows by 17% and maximum dry density by 5%, when compare with the shear strength using consolidated drained triaxial test, the results did not give any significant changes. Results from triaxial test for 20 number of blows compared with 40 number of blows were at 37° and 38° respectively. There different by 1° cannot change anything in the shear strength of the soil. Further conclusion that can be made is by applying different energy in compaction cannot influence the shear strength of the soil if tested in triaxial test due to the stages that involved in triaxial machine especially during the consolidation stages by applying different effective stress. Therefore, even if the specimens were compacted using different energy i.e. different in number of blows, the shear strength will not increase since the specimens will have to consolidated with the desired effective stress in the consolidation stages. However, if the specimens being tested with direct shear test, it produced in higher effective friction angles and thus result in higher shear strength. Compared with 25 and 40 number of blows, the shear strength parameters increase from 29° to 32° respectively. The shear strength increases for about 3° and it can be considered as a significant value in shear strength of the soil.

As for the recommendations for further research, studies can be carried out on the impact of different energy in the form of number of blows on the shear strength using different types of soil and increase the number of blows for the compaction method.

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