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Some Mechanical Properties of Cement Stabilized Malaysian Soft Clay

Meei-Hoan Ho and Chee-Ming Chan

***Abstract*—**Soft clays are defined as cohesive soil whose water content is higher than its liquid limits. Thus, soil-cement mixing is adopted to improve the ground conditions by enhancing the strength and deformation characteristics of the soft clays. For the above mentioned reasons, a series of laboratory tests were carried out to study some fundamental mechanical properties of cement stabilized soft clay. The test specimens were prepared by varying the portion of ordinary Portland cement to the soft clay sample retrieved from the test site of RECESS (Research Centre for Soft Soil). Comparisons were made for both homogeneous and columnar system specimens by relating the effects of cement stabilized clay of for 0, 5 and 10 % cement and curing for 3, 28 and 56 days. The mechanical properties examined included one-dimensional compressibility and undrained shear strength. For the mechanical properties, both homogeneous and columnar system specimens were prepared to examine the effect of different cement contents and curing periods on the stabilized soil. The one-dimensional compressibility test was conducted using an oedometer, while a direct shear box was used for measuring the undrained shear strength. The higher the value of cement content, the greater is the enhancement of the yield stress and the decrease of compression index. The value of cement content in a specimen is a more active parameter than the curing period.

***Keywords*—**Soft soil, Oedometer, Direct shear box, Cement-stabilised column.

I. Introduction

SOFT clays are well known for their low strength and high compressibility. Usually, due to sedimentary process on different environment, both physical and engineering properties of the clays (namely void ratio, water content, grain size distribution, compressibility, permeability and strength) show a significant variation. Furthermore, they exhibit high compressibility (including an important secondary consolidation), reduced strength, low permeability and compactness, and consequently low quality for construction.

Thus, the soil-cement mixing is adopted to improve a soft clay foundation and provides stability during the construction process. It has been used since the 1970's to improve the strength and deformation characteristics of these soft soils [1]. The cement mixing method was developed simultaneously in Sweden and Japan [2]. For the above mentioned reasons, a comprehensive laboratory testing programme was carried out in order to study the effect of inclusion of cement on mechanical and engineering behaviour of soft clay.

In this project, soil is improved or stabilized by mixing in cement. The principle mechanism of ground improvement is done by forming chemical bonds between the soil particles. When the soil particles are bonded, it will be strengthened and become more stable physically and mechanically.

Soft clay, when mixed with cement, will be stabilized because cement and water react to form cementitious calcium silicate and aluminate hydrates, which bind the soil particles together. In addition, the hydration reaction releases calcium hydroxide, $Ca(OH)_2$ or slaked lime, which may in turn react with some components of the soil, in particular clay minerals. Hydration of the cement occurs immediately when it contact with water, but the secondary reactions are slower and may continue for many months [2].

Various methods of soil mixing, mechanical, hydraulic, with and without air, and combinations of both types have been used widely world wide. Deep mixing differs to cement-soil stabilization methods because it is can be done for a deeper depth and larger construction, whereby also require larger cost [3]. Deep mixing is performed in order to change the physical properties of the soil. This is done by introducing binders to the soil.

The design of foundation on soft clay soil has been the concern of engineers since the beginning of soil engineering [4]. The basic requirements for designing foundation on soft clay soils are that the design should be safe against shear failure and the amount of settlement should be tolerable. The shear consideration is theoretically important. To estimate the amount of settlement, it is necessary to study the loaded depth of the footings and the consolidation characteristics of the soft clays.

This study is to determine the correlation of mechanical and chemical properties of UTHM's (Universiti Tun Hussein Onn Malaysia) soft clay and the effect towards the surrounding soft clay when the soft clay is being stabilized homogenously and in a columnar system. For example, for the mechanical properties, the compressibility of stabilized soil is getting lower when more cement is being added to stabilize the soft clay. In the stabilization of soils with cement, the consolidation and settlement of soil will affect the amount of stability of a construction.

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II. Materials

Soft clays were collected at RECESS, UTHM site at 1.5 m to 2 m depth and soil samples were disturbed samples. Some physical properties of typical RECESS clay are shown in Table 1. Based on the index properties of the soil, the soil can be categorized as organic clays or MH (Micaceous or Diatomaceous fine sandy or silty soils or elastic silts) according to Unified Soil Classification System. [5] reported that the clay soil at RECESS, UTHM contained 10.8 % fines, 79.5 % silt and 10.7 % sand.

TABLE I
Physical Properties of Typical RECESS Clay [5]

Parameters	Value
Moisture Content	85.0 %
pH	3.32
Specific Gravity	2.62
Shrinkage Limit	12.9 %
Plastic Limit	31.7 %
Liquid Limit	68.0 %

The material used as stabilizer in this project was Portland cement. Cement is increasingly used as a stabilising material for soil, particularly for the construction of highways and earth dams. It is because cement helps increase of soils and strength with curing time. Cement content requirements vary depending on the desired properties of the soil-cement mixture and the soil type, typically 5 – 15 % of the weight of the soil to be treated [1].

III. Specimen Preparation and Test Setup

A. Specimen Preparation

The soil used was in wet condition. A total of nine homogeneous specimens were prepared for the consolidation test, where three specimens were untreated (0 % cement), three specimens stabilized with 5 % cement and the other three specimens stabilized with 10 % cement. The moisture content determined was 70 %.

Cement treated soil samples were prepared by mixing the soil sample with the required amount of cement in a food mixer. The mixture was stirred in short time (5 minutes) to avoid hardening of the soil-cement mixture. Quantities of the added cement to the soil were 0 %, 5 % and 10 % w/s.w. (weight by soil weight). Then, the stabilized soil was compacted in the oedometer ring in two layers, with each layer tamped by hand with 100 applications in a consistent manner using a hand tamping tool. The ends of the specimen were trimmed flat. The specimen size was 75 mm diameter and 20 mm thick. In order to avoid excessive moisture loss, the specimens were wrapped in a stretch film. They were kept in tightly closed polystyrene box with plastic container raised under some water at a room temperature of 20˚C then left to cure for 3, 28 and 56 days. The box was filled with some bleach solution to prevent fungal growth during the curing period.

This columnar system specimen was done for both consolidation test and direct shear test. The soil used was in wet condition; a small-scale of soil-cement column, 25 mm in diameter was prepared and inserted into the center of 75 mm diameter and 20 mm thick soft clay bed. The soil-cement column was firstly stabilized with 5 % and 10 % cement. The column was made by pressing an aluminium thin-walled tube into the clay bed where a column of clay was extracted, leaving a cylindrical void of 25 mm diameter throughout the height of the clay specimen. Next the stabilized portion was prepared and compacted in the cylindrical void within the specimen, in 2 layers tamped with consistent effort. Finally, with the tube removed, the ends of the composite specimen were trimmed flat. After this, the similar procedures as in preparing for the homogeneous specimens were done.

B. Automated Oedometer Testing Procedures

In this test, a fully automated oedometer is used to run the consolidation test for the cement-stabilized soft clay. The manufactured name of this equipment is LoadTrac-II (by Geocomp Corporation). The soil specimen is placed inside a metal ring with two porous stones, one at the top of the specimen and another at the bottom. The specimens were 75 mm in diameter and 20 mm thick. The load on the specimen was applied and compression was measured by the imbedded control system. The specimen was kept under water during the test. Every load increment will automatically go to the next load when each load has reached its secondary compression. The next load was doubled of the previous load, thus doubling the pressure on the specimen and the compression measurement is continued.

Compressibility properties of nine homogeneous specimens and six columnar system specimen were determined from the incremental loading one-dimensional consolidation test. The vertical stresses applied during the consolidation were 12.5 kPa, 25 kPa, 50 kPa, 100 kPa, 200 kPa, 400 kPa, 800 kPa. During all these tests drainage was permitted from top and bottom of the specimen.

C. Direct Shear Box Testing Procedures

The shear strength measurement for homogeneous and columnar specimens was carried out using the direct shear test. The direct shear machine used was called ShearTrac-II-DSS (by Geocomp). For each test, the specimens were prepared for three similar specimens to test for three different vertical stresses; 50 kPa, 100 kPa and 200 kPa in order to get the Mohr-Coulomb failure plane.

Soil specimens were typically cylindrical and are placed inside a square shear box. The minimum diameter: thickness ratio is 2:1. For this test, the specimen was 55 mm diameter and 20 mm thickness. The shear box consists of an upper and lower half. There were two locking pins that hold the top and bottom of the shear box together while the soil specimen was placed inside but they must be removed during testing. Failure to remove the locking pins during testing will result in damage to the shear box. Another four separating screws pass through

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the top half of the shear box and the tips of the screws rest on the bottom half. The separating screws are used to separate the top and bottom halves of the shear box during testing to minimize the effect of metal-to-metal friction on the shear load.

The shear box was placed in the direct shear machine and the test was conducted so that the plane corresponding to the boundary between the upper and lower halves of the shear box was the failure plane. Horizontal and vertical displacement (ΔH and ΔV) were measured during the test by imbedded control system.

Direct shear testing provides the shear strength properties of soils under conditions of drained loading, which is required for assessing the stability of earth slopes. With respect to shear strength, soil can be viewed as a frictional material. If the normal force, N is increased, a higher value of shear force, F is required to cause the failure plane to slip. By plotting σ versus τ_f over a range of N, a Mohr-Coulomb failure envelope is defined.

IV. Results and Analysis

The homogeneous test result is summarized in Table 2 using instrumented oedometer respectively, where w_o = initial water content, S_{ro} = initial degree of saturation, σ_y' = effective yield stress and ε_{pl} = plastic strain. It can be seen that although the degree of saturation of the specimens was relatively high, in general the specimens were not fully saturated. Hence, for this reason it will somehow affect the test results because when the specimen was not fully saturated, the void in the specimens will influence the test result.

TABLE II
SUMMARY OF TEST CARRIED OUT IN THE OEDOMETER FOR HOMOGENEOUS SPECIMENS

Homogeneous Specimen	w_o (%)	S_{ro}	σ_y' (kPa)	ε_{pl}
H-0c-3d	54.68	0.82	84	0.195
H-5c-3d	64.99	0.97	87	0.198
H-10c-3d	61.55	0.92	193	0.124
H-0c-28d	64.99	0.97	58	0.215
H-5c-28d	60.41	0.90	115	0.160
H-10c-28d	63.85	0.96	230	0.070
H-0c-56d	58.12	0.87	75	0.215
H-5c-56d	63.85	0.96	130	0.139
H-10c-56d	62.70	0.94	235	0.084

Generally, the yield stress for homogeneous specimens increased when the curing periods and cement content increased. The addition of 5 % cement content with the curing periods, increased the yield stress about 55 – 60 kPa as compared to the untreated clay. Addition of 10 % cement content shows a higher yield stress about 100 – 170 kPa compare to the untreated clay. The yield stress increased twice as much as compare to untreated clay when cement content increased from 5 % to 10 % cement. The increased of apparent yield stress was due to the effect of structuration (existing of cementation bond) of treated clay particles. This implies that due to the effect of structuration, the volumetric compressibility of the treated specimens was very small and the stiffness was very high.

According to [6], the σ_y', defines the boundary between stiff and soft deformation response of a soil towards loading. Hence, when the cement stabilized soil is stiffer due to cement content of 5 % and 10 %, it will need a higher yield stress to begin an inter-particles displacement.

While for the plastic strain of homogeneous sample, it became less plastic as more cement was added but for untreated soil, the plastic strain increased with time as seen for H-0c-3d and H-0c-28d with 0.195 and 0.215 respectively. The plastic strains, ε_{pl} for homogeneous specimens were calculated from the compression curve with the rebound line from Figure 1, whereby $\varepsilon_{pl} = \Delta H / H_o$.

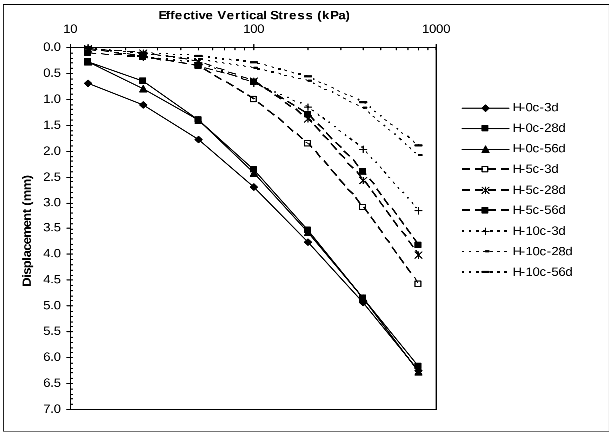

Fig. 1 Compression curve for all homogeneous specimens

The plastic strains of the columnar specimen with 5 % cement increased very minimal as compared to the 10 % cement. If compared with the plastic strain of the homogeneous specimen, homogeneous specimen decreased greater but for the columnar specimen, it increased in its plastic strains. This might have to do with the diameter of the column used to fabricate the columnar system specimen because of the diameter of columnar system is too small, so the stabilized columnar surface area is not sufficient to provide sufficient stiffness when the specimen was consolidated. A summary for oedometer test for columnar system specimens were shown in Table 3.

TABLE III
SUMMARY OF TEST CARRIED OUT IN THE OEDOMETER FOR COLUMNAR SYSTEM SPECIMENS

Columnar Specimen	w_o (%)	S_{ro}	σ_y' (kPa)	ε_{pl}
C-5c-3d	64.99	0.97	78	0.241
C-10c-3d	70.72	1.06	115	0.243
C-5c-28d	66.14	0.99	80	0.226
C-10c-28d	67.28	1.01	140	0.229
C-5c-56d	63.85	0.96	57	0.238
C-10c-56d	59.26	0.89	78	0.248

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D. Test Concerns: Compression Behaviour

From the relationship of curves in Figure 1, the swelling characteristics of treated clay are found to be different from the untreated ones. Test results show that the swelling index reduces significantly due to the effect of cement inclusion in the soft clay and the curing period. For treated clay, the swelling curve is almost parallel to the loading curve at the initial part of the consolidation curve.

For the untreated specimen, curing 3, 28 and 56 days, the displacement was 18 - 19 % of the total height of the specimen. While for soil treated with 5 and 10 % cement with curing 3, 28 and 56 days percentage of displacement is 6 – 10 % and 3 – 6 % of the initial specimen height, which is 20 mm. From these findings, it can be concluded that the percentage of settlement have reduced significantly for all the specimen due to the changes of structure of the soil-cement particles under the similar applied effective vertical stresses. As compare to untreated specimens, the 5 and 10 % cement inclusion into the soil will give only 3 – 10 % of settlement of total Ho of specimen.

Figure 2 shows all the compression curves of columnar system specimens in this study. It shows an obvious decrease of settlement for 10 % columnar system with the curing periods 3 days and 28 days, shown in dotted lines. Overall, it can be observed that the 5 % cement columnar specimen for different curing days collapsed together. However, the settlement increased for 10 % columnar specimen for 3 days as compare to 28 days curing. But, for curing 56 days, the settlement for 10 % cement columnar specimen does not varies much as the 3 days curing specimen.

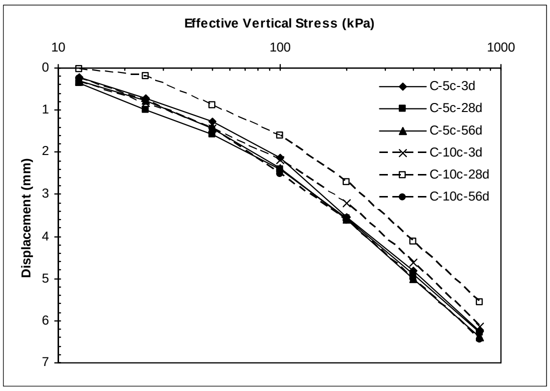


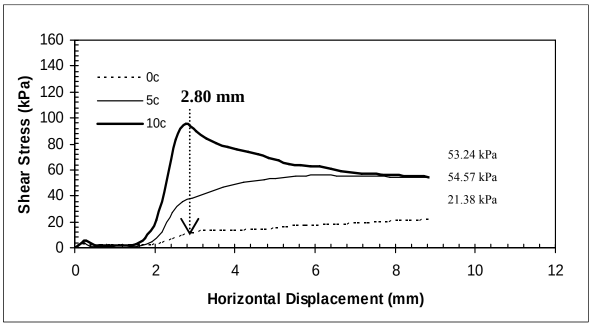
Fig. 2 Compression curve for all columnar system specimens

E. Test Concerns: Shear Strength

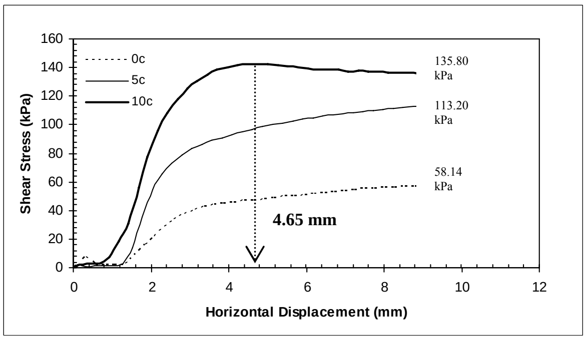
The characteristic shape of the curve for both homogeneous and columnar system specimens are found that the shear stress increases to a peak value and then strain softens to constant ultimate shear strength. With the incremental of the effective stress applied on the specimen, the enhancement shear stress is evident in this figure. In this test, results are obtained from 0 to 10 mm displacement because 10 mm displacement is normally taken for design limit for a structure to fail.

The role of cement content is very clear that the higher the cement content, the greater is the shear stress generation. The higher the effective stress applied on the specimen will give a higher shear stress. Referring to Figures 3(a) and (b), at 50 kPa and 200 kPa the shear stress at 10 mm horizontal displacement is 21.38 kPa and 58.14 kPa respectively for 0 % cement. While for 5 and 10 % cement, the increment of shear strength for 200 kPa was two times more than the amount when applied with 50 kPa.

It can be observed that the shear stress maximum occurs at very low strain for the specimen of low effective stress but at larger strain for the specimen of higher effective stress. It is clearly seen for specimen with 10 % cement, where the specimen with lower effective stress (50 kPa) will reach maximum shear stress at 2.80 mm, where as for specimen with higher effective stress (200 kPa) reaches maximum shear stress at 4.65 mm. Hence, it can be concluded that the treated clay will fail more slowly for higher stress compared to the lower stress because at higher stresses, the stabilized clay is more consolidated when more pore water was diffused and this gives strength to the stabilized clay.



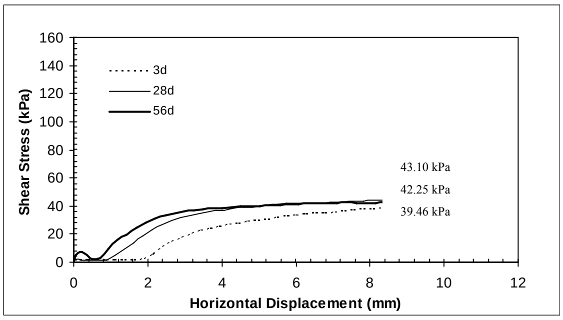
3(a)



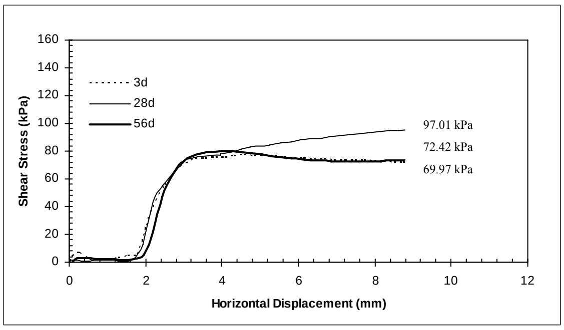
3(b)

Fig. 3 A typical shear stress-strain for homogeneous specimen with (a) 50 kPa and (b) 200 kPa effective vertical stress with different cement content

Figures 4(a) and (b) show shear stress-strain for homogeneous specimen with 0 % and 10 % cement content for different curing periods. The effective stress applied was 100 kPa. For Figure 4(a), a pattern of curve line that collapse into one between all the different curing periods (3, 28 and 56 days) was more obvious for the untreated clay. However, for the treated clay with 10 % cement in Figure 4(b), there was a slight variation of the shear stress obtained in the end of 10 mm horizontal displacement. It can be concluded that, the increase of curing periods is not as significant as the cement content effect on the shear strength of the soil. The shear strength of treated clay with 10 % cement increases as much as double compare to untreated clay. The reason for these curves to collapsed to one might be because the stabilized clay was not sensitive to the effective vertical stress, σ'_v although it was cured. Hence, this behaviour can also be seen for the columnar system specimen.



4(a)



4(b)

Fig. 4 A typical shear stress-strain for homogeneous (a) 0 % cement and (b) 10 % cement comparing with different curing periods

Table 4 shows the shear strength for homogeneous specimen from direct shear test. σ'_v represents the vertical stress, σ'_h as the horizontal stress, ø' as the friction angle, c' as Mohr-Coulomb failure envelope and τ_f as shear stress at failure. The superscript (') over the c, σ and ø terms indicates that the strength properties measured during the test are drained properties, where pore pressure remains near zero throughout the test. τ_f increases with cement content and with curing period, meaning that the shear strength is higher for treated specimen compare to untreated specimen. Table 5 shows only the σ'_v and σ'_h for columnar system specimen as c, ø and τ_f are for homogeneous specimen only.

TABLE IV
SHEAR STRENGTH FOR HOMOGENEOUS SPECIMEN FROM DIRECT SHEAR TEST

Specimen	σ'_v	σ'_h	ø'	c'	τ_f
H-0c-3d	50	20.45	17.3	6.83	22.40
	100	39.46			37.98
	200	68.61			69.12
H-0c-28d	50	17.83	15.1	10.80	24.29
	100	42.25			37.78
	200	59.23			64.76
H-0c-56d	50	21.38	13.1	13.80	25.44
	100	43.10			37.07
	200	58.14			60.34
H-5c-3d	50	44.02	20.1	25.20	43.50
	100	58.47			61.79
	200	98.19			98.39
H-5c-28d	50	38.03	16.0	36.00	50.34
	100	64.81			64.67
	200	92.95			93.35
H-5c-56d	50	54.57	21.5	32.90	52.60
	100	66.59			72.29
	200	113.20			111.68
H-10c-3d	50	66.76	17.0	53.90	69.19
	100	69.97			84.47
	200	117.00			115.05
H-10c-28d	50	45.80	22.4	64.10	84.71
	100	97.01			105.32
	200	143.80			146.53
H-10c-56d	50	53.24	20.0	63.30	81.50
	100	72.42			99.70
	200	135.80			136.09

TABLE V
SHEAR STRENGTH FOR COLUMNAR SYSTEM SPECIMEN FROM DIRECT SHEAR TEST

Specimen	σ'_v	σ'_h		
		3 days	28 days	56 days
C-5c	50	34.65	31.10	32.28
	100	44.02	46.56	48.93
	200	79.26	81.37	85.43
C-10c	50	35.74	37.01	34.39
	100	56.70	49.94	58.22
	200	99.79	65.53	99.54

For the columnar system specimen in Figure 5, it can be observed that the shear stress for 5 % cement gave a very consistent curve that collapse into one for the same effective stress applied and not influenced by the different curing periods. However, it does give a higher stress-strain curve when the effective stress was increased from 50 kPa to 200 kPa. This shows that the stabilized column with 5 % cement content is insensitive to the effective vertical stress, σ'v that was applied. Therefore, it is concluded that the curing period was not a significant effect on the shear strength as compare to the cement content. According to [7], the strength variation in the surrounding clay can be considered resulting from the following factors including soil disturbance, fracturing, and thixotropic hardening; consolidation due to dissipation of excess pore pressures; and cementation due to the diffused cations and/or chemical reactions under high pH conditions. So, it can be observed that the 5 % cement addition to the stabilized column was not sensitive to the cementation effects or the dissipation of excess pore pressure.

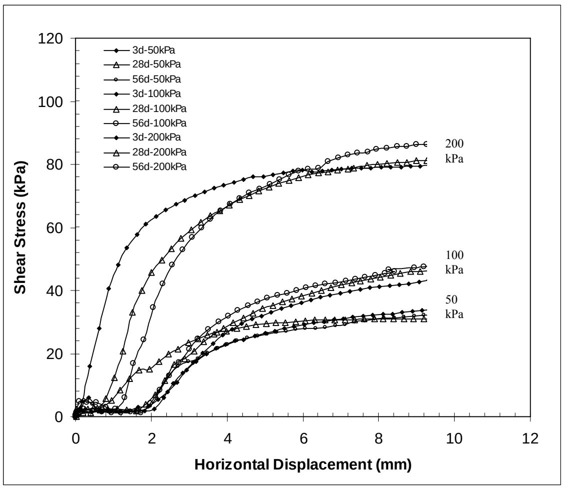


Fig. 5 Shear strength for columnar system specimens (5 % cement)

Whereas for Figure 6, there were some variation in the shear stress for columnar system 10 % cement with effective vertical stress of 100 kPa and 200 kPa. While for σ'_v of 50 kPa there was no variation of the shear strength and this shows that it was not sensitive to the effective vertical stress. The variation of 100 kPa and 200 kPa might be due to the sensitivity of the stabilized column to the effective vertical stress that was applied when the stabilized column became stiffer after cured 3, 28 and 56 days. So, the higher the stress that was applied to the 10 % columnar system, a greater variation of the shear stress curve can be seen. This shows that the stabilized column with higher σ'_v was able to give a higher shear strength because it was more compressed compare to lower σ'_v and this shows the effect of the stabilized column in improving the condition of the soft clay when higher consolidation (100 and 200 kPa) that caused the dissipation of pore water.

V. Interpretation and Discussion of Test Results

F. Index (C_c) and Recompression Index (C_r)

The compression index is an indicative of compressibility of any soil while recompression index is the recompressibility of the soil. C_c was measured from compression curve, e – log σ' as shown in Table 6. This C_c was evaluated by finding coordinates of any two points on the consolidation curve. If the C_c increases, meaning that the compressibility of that soil also increases [8].

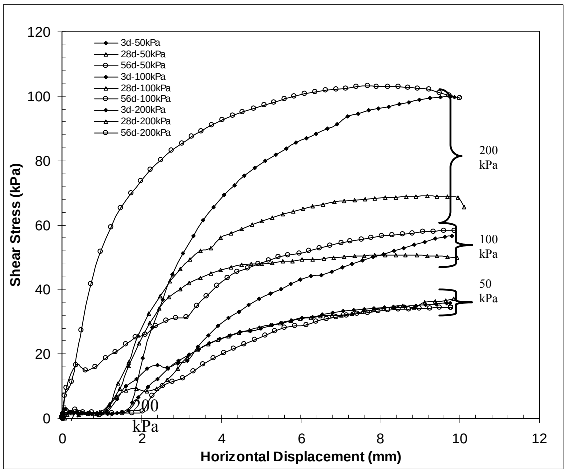


Fig. 6 Shear strength for columnar system specimens (10 % cement)

Table 6 show the variation of compression index, C_c and recompression index, C_r for homogeneous specimens. The C_c values decreases with curing period for homogeneous specimens. For homogeneous specimen 10 % cement curing period 28 and 56 days, C_c values are 0.47 and 0.40 respectively which is lesser than that of Cc for untreated clay which is 0.66. This trend further supports that the compressibility of treated homogeneous specimens is much lesser than that of untreated clay itself. This implies that the treated clay undergoes structuration due to the effect of cementation up to their apparent yield stress and then the destructuration takes place.

As for C_r, the value decreases significantly with the increase of curing period and cement content for homogeneous specimens. The value for C_r was obtained from Figure 1 with the rebound line drawn from the unloading result. Recompression index was taken as the unloading result because both lines fall very near to one another and can be considered the same curve. C_r value was not taken at the beginning of the consolidation curve because in the very early stages of the test, the load applied was taken by specimen's voids and it might not give the exact result of the C_r. This might not give the exact C_r value for the test. Figure 7 gives a more apparent illustration about C_c and C_r for the homogeneous specimen when the curing period and cement content increases.

TABLE VI
C_C AND C_R FOR HOMOGENEOUS SPECIMENS

Specimen	C_c	C_r
H-0c-3d	0.66	0.150
H-5c-3d	0.62	0.061
H-10c-3d	0.60	0.055
H-0c-28d	0.64	0.140
H-5c-28d	0.59	0.075
H-10c-28d	0.47	0.058
H-0c-56d	0.66	0.140
H-5c-56d	0.56	0.090
H-10c-56d	0.40	0.025

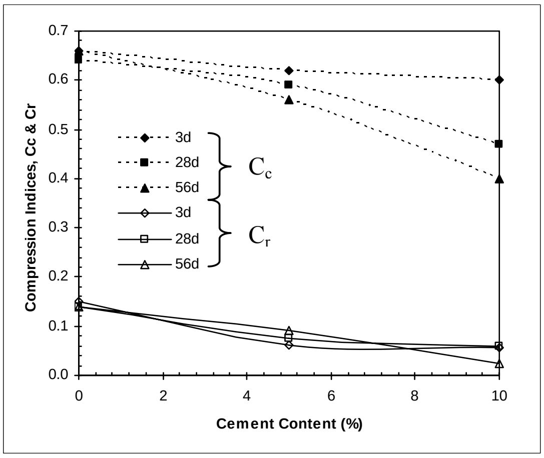


Fig. 7 Effect of cement content and curing time on compression indices homogeneous specimen

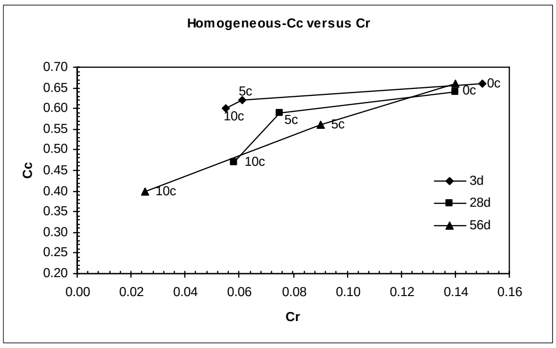


Fig. 8 Comparison of C_c and C_r for homogeneous specimens

Figure 8 shows the relationships between C_c and C_r for homogeneous specimens. This relationship of homogeneous samples give a clear trend of decrease of C_c and C_r as the cement content and curing period increased. It can be observed that for 5 % and 10 % cement in homogeneous specimen, the difference between the two values increases when the curing period increases. This linear relationship of C_c and C_r shows that the higher the C_c is, the C_r will also be higher and vise versa.

The C_c for 3 days curing is much higher than the 56 days curing, while for C_c for 28 days lies between 3 days and 56 days. For example, it is seen clearly that C_c for specimen curing 56 days for 0, 5 and 10 % cement are 0.66, 0.56 and 0.40. However, for C_r value is rather much smaller as compare to C_c value with 0.140, 0.090 and 0.025 respectively. From the pattern of the lines, it can be observed that the effect of cement content affects the structuration of the soil and makes the stabilized soil to become stiffer. The soil skeleton will be more strengthened when more cement content is added because cement function as a good stabilizer for soft clay.

G. Yield Stress Relationship with Undrained Shear Strength

It is common to express the undrained shear strength in terms of the effective vertical stress because for soft clay. This is a constant as the strength is a function of that stress. Figure 9 illustrates the relationship between yield stress from oedometer test and undrained shear strength, τ_f from direct shear test for homogeneous specimens with different curing periods and cement content.

This relationship was obtained by calculating the value for $\tau_f = \sigma_y' \tan ø' + c'$ as shown in Table 7. It is known that the undrained shear strength at yield stress equals to the maximum of undrained shear strength required. This relationship in general relates the maximum undrained shear strength and yield stress of the cement stabilized clay. When the yield stress increases, shear strength of the specimen will also increase. For different curing days, a relationship of linear regression line was obtained which is 0.929. From this figure, it can be proposed the following relationship for RECESS soft clay from this study:

$$\sigma_y' = 1.5871\ \tau \quad (1)$$

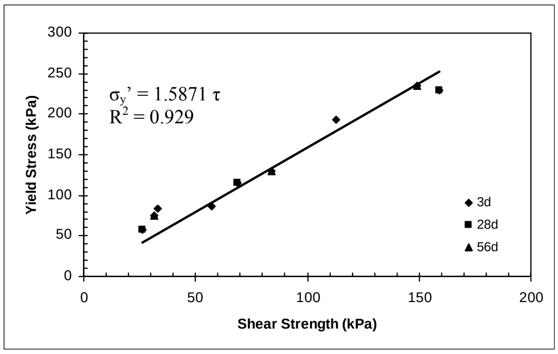


Fig. 9 Relationship between yield stress from consolidation test and shear stress from direct shear test

TABLE VII
UNDRAINED SHEAR STRENGTH USING YIELD STRESS FROM OEDOMETER TEST

Specimen	σ_y' (kPa)	c'	ø	τ_f
H-0c-3d	84	6.83	17.30	32.99
H-5c-3d	87	25.20	20.10	57.04
H-10c-3d	193	53.90	17.00	112.91
H-0c-28d	58	10.80	15.10	26.45
H-5c-28d	115	36.00	16.00	68.98
H-10c-28d	230	64.10	22.40	158.90
H-0c-56d	75	13.80	13.10	31.25
H-5c-56d	130	32.90	21.50	84.11
H-10c-56d	235	63.30	20.00	148.83

VI. CONCLUSIONS

The following are the conclusions drawn from the study:

1) The higher the value of cement content, the greater is the enhancement of the yield stress and the decrease of compression index. Consequently, it was accompanied with gradual reduction of compressibility.
2) With low cement content, the curing time parameter

becomes latent. It can be concluded that the value of cement content in a specimen is a more active parameter than the curing period.

3) The compression index, C_c and C_r value was found to decrease with cement content and curing period. It can be observed that the effect of cement content affects the structuration of the soil and makes the stabilized soil to become stiffer. The soil skeleton will be more strengthened when more cement content is added because cement function as a good stabilizer for soft clay.
4) The compressibility of treated homogeneous specimens is much lesser than that of untreated clay itself. This implies that the treated clay undergoes structuration due to the effect of cementation up to their apparent yield stress and then the destructuration takes place.
5) According to [6], the σ_y', defines the boundary between stiff and soft deformation response of a soil towards loading. Hence, when the cement stabilized soil is stiffer due to cement content of 5 % and 10 %, it will need a higher yield stress to begin an inter-particles displacement.
6) When the yield stress increases, shear strength of the specimen will also increase. For different curing days, a relationship of linear regression line was obtained which is 0.929. R^2 = 0.929 means about 93 % of the data points lie on the best fit line. It can be proposed the following relationship for RECESS soft clay from this study: $\sigma_y' = 1.5871\ \tau$.

Notations

The following symbols are used in this paper:

C_c = Compression index
C_r = Recompression index
σ_y' = Yield stress
ε_{pl} = Plastic strain
ΔH= Differences in height
H_o = Initial height
τ_f = Shear strength at failure
ø' = Friction angle
c' = Cohesion
w_o = Initial water content
S_{ro} = Initial degree of saturation

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