Consolidation Characteristics of Lime Stabilised Soil

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ABSTRACT

Soft clay is always associated with settlement and consolidation. Stabilisation of soft clay with lime as bearing stratum is an alternative to replacement of that material. The compression and consolidation characteristics of the stabilised material need to be fully understood for design purposes. This paper presents the results of study on the consolidation characteristics in terms of compressibility, rate of consolidation and the permeability characteristics of both unstabilised and lime stabilised soil samples using Oedometer test. Oedometer specimens of 50 mm diameter and 20 mm height were tested with respect to age at 0, 7, 14 and 28 days and effective stress at 0, 200, 400, 800 and 1600 kPa. Three soil types were selected and studied in this project; they are Tapah Kaolin, Sungai Buloh clay and UTM clay. From the test results, it is discovered that lime stabilisation improved the consolidation characteristics and reduced the settlement of unstabilised clay with age especially after stabilisation phase is achieved, i.e., after the age of 14 days.

INTRODUCTION

Lime stabilisation is a method where lime acts as a stabilising agent that alters the properties of an existing soil chemically to meet the specified engineering requirements based on its application, in this case, to improve the consolidation characteristics of a soil. It is generally known that lime treatment decreases the plasticity, swell and shrinkage potential and improves the strength characteristics of soils [1]. Relatively, less is known about the effect of lime on consolidation characteristics, though it is well known that the volume change behaviour is considerably improved [1].

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This project therefore aims to reveal more information about the effect of lime stabilisation on the consolidation characteristics of the soil and the relationship between consolidation characteristics of lime stabilised samples with progression of time and increment of loading.

SCOPE OF WORK

Only hydrated lime is used as a stabilising agent since quick lime is very sensitive to high humidity. Using hydrated lime as a stabilising agent will generate two processes, ie., modification and stabilisation. Dry mixing method is used in preparation of lime stabilised samples to achieve maximum mixing efficiency. Consolidation study is based on Terzaghi theory of consolidation and using oedometer test (BS1377: Part 5: 1990) to obtain consolidation characteristics of soil samples. All samples are prepared from recompacted specimens with an hour of mellowing period.

TEST PROGRAMME

All observations and findings of this project is based on the results of laboratory works that consists of the following major stages (Figure 1).

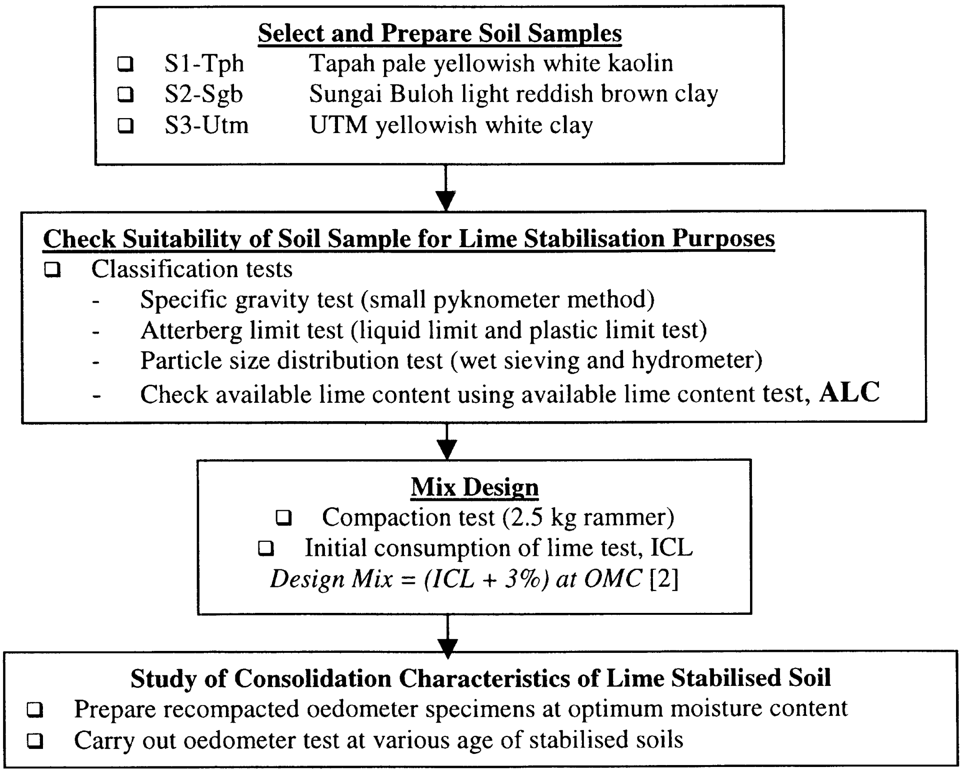


Figure 1 Flowchart for the test programme.

RESULTS AND OBSERVATIONS

Suitability of Soil Sample for Lime Stabilisation

Based on British specification for lime stabilised capping layers [3], all soil samples are found suitable for lime stabilisation purposes as they are well within the range of cohesive material (7E) properties as shown in Table 1.

Table 1 Suitability of Soil Samples for Lime Stabilisation Purposes (before addition of lime) (British Specification, Department of Transport 1991).

Soil Properties	Requirements	Classification Tests Results		
		S1-Tph	S2-Sgb	S3-Utm
Materials permitted	Any cohesive material (7E) other than unburnt colliery spoil.	ME Silt with extremely high plasticity	MH Silt with high plasticity	MV Silt with very high plasticity
Grading				
- Passing 75 mm sieve (%)	100	100	100	100
- Passing 28 mm sieve (%)	95 – 100	100	100	100
- Passing 63 μm sieve (%)	15 – 100	93.94	83.2	98.94
Plasticity Index (%)	> 10	50.5	27.8	32.8
Sulphate content (%)	< 1	not tested	not tested	not tested

Based on British Soil Classification System (BSCS), Tapah kaolin can be classified as silt with extremely high plasticity (ME); Sungai Buloh soil as silt with high plasticity (MH) and UTM soil as silt with very high plasticity (MV) from the result of Atterberg limit test.

Design Mix

Design mix is needed to determine the most suitable lime content to enable the lime modification and stabilisation process. The minimum lime content needed to enable lime modification or the initial consumption of lime, ICL can be obtained from the result of initial consumption of lime test. For stabilisation however more lime is required in order to produce pozzolanic reaction. Pozzolanic reaction is a long term reaction that produce calcium silicate hydrate and calcium aluminate hydrate gel which crystallised with age. Design mix for stabilisation is taken as ICL + 3% taking into consideration the long term leaching effect of lime [4].

Table 2 Design Mix used for the test programme.

Soil Sample No.	Design Mix = ICL + 3% at stabilisation phase [4]	Standardise Design Mix	Optimum Moisture Content, OMC	
			Unstabilised	6 % Lime Stabilised
S1-Tph	2.0 + 3.0 = 5.0%	6.0 %	38.0 %	39.0 %
S2-Sgb	2.5 + 3.0 = 5.5%		25.0 %	28.0 %
S3-Utm	3.5 + 3.0 = 6.5%		30.5 %	32.0 %

A standardise design mix of 6 % lime is established based on the average value of all lime stabilised samples in order to enable the comparison of consolidation and permeability characteristics between samples. As recompacted sample is used in this project, the oedometer specimens are prepared based on each optimum moisture content, OMC, with an hour of mellowing period.

Consolidation Characteristics of Lime Stabilised Soil

The consolidation characteristics of lime stabilised samples were studied based on the progress of time and effective stress (loading). A comparison between unstabilised and lime stabilised sample's consolidation characteristics was also carried out to observe the effect of lime stabilisation on untreated samples.

i) Compressibility Characteristics of Lime Stabilised Soils

Modified compression curve (e/e_o vs. log σ') is used in this project for the analysis of compressibility characteristics of lime stabilised soil. As recompacted specimens are used in this project, it is necessary to use modified compression curve instead of the conventional compression curve (log e vs. σ') in order to eliminate the variation in initial void ratio, e_o arises from different compactive effort [5].

The use of the normalised common parameter, e_o (initial void ratio) will enable the comparison of results between recompacted samples. Since e/e_o is a function of change in void ratio (e/e_o = 1- $\Delta e/e$), it would not change the shape of the graph, but rearranging the curve in such a way that the relationship between the stiffness of sample and age can be clearly seen.

Modified compression index, C_{cm} and yield effective stress, σ_y' can be obtained from the modified compression curve instead of the actual compression index, C_m and the pre-consolidation pressure that can be obtained from the conventional compression curve. The term yield effective stress, σ_y' is used to define the point where the recompacted specimen starts to yield and can be determined using the Cassagrande construction.

In order to enable the comparison of the compressibility between the three soil types, the actual compression index, C_c has to be determined. The actual compression index, C_c can be obtained using Equation 1:-

$$C_{cm} = C_c / e_o$$

or

$$C_c = C_{cm} \times e_o \qquad (1)$$

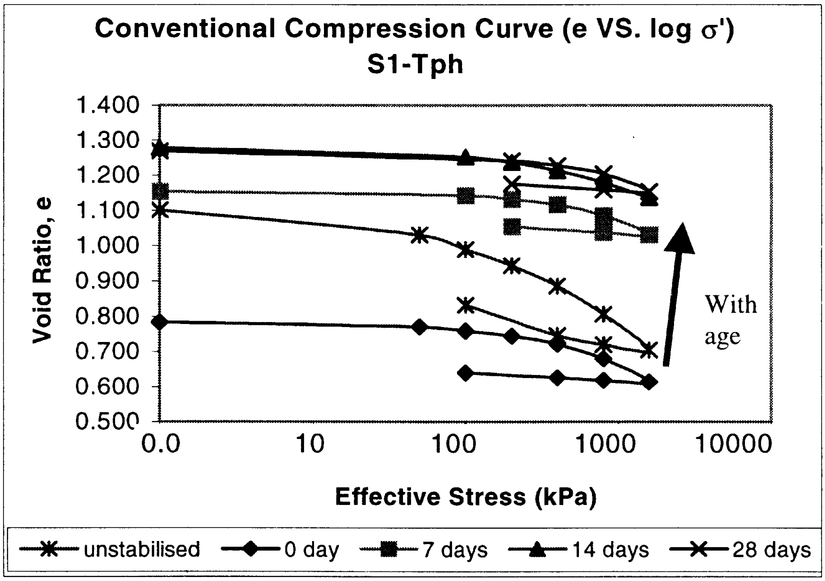
Based on the modified compression curve, the compressibility characteristics of lime stabilised soil is observed as in Table 3.

Table 3: Observation of compressibility characteristics of lime stabilised soil.

Compressibility Parameters	**Compared to Unstabilised Sample**	**With Progress of Time**	**With Increment of Effective Stress**
Stiffness	Higher	Higher	N.A
Initial Void Ratio, e_0	(0 - 12) % higher	Lower	N.A
Effective Yield Stress, σ_y'	1.2 – 4.5 times higher	Higher	N.A
Modified Compression Index, C_{cm}	Lower	Lower	N.A
Settlement, Δh	60 % lower at 28 days	Lower	Higher
Coefficient of Compressibility, M_v	2 – 3 times lower	Lower	Lower

Figure 2 shows the modified compression curve does not change the shape of the curve but shows a clearer relationship between stiffness and age. As observed from the arrangement of the modified compression curve, the stiffness of lime stabilised samples increase with age. The same observation is obtained for the effective yield stress of lime stabilised samples. Both observations clearly indicate that the strength of soil samples has improved with age.

Modified compression index, settlement and coefficient of compressibility of stabilised soil reduce with age which gives the indication that the stabilised soil will have a lower compressibility with age. This is due to the facts that as the permanent bonding developed the resistance to settlement increases.



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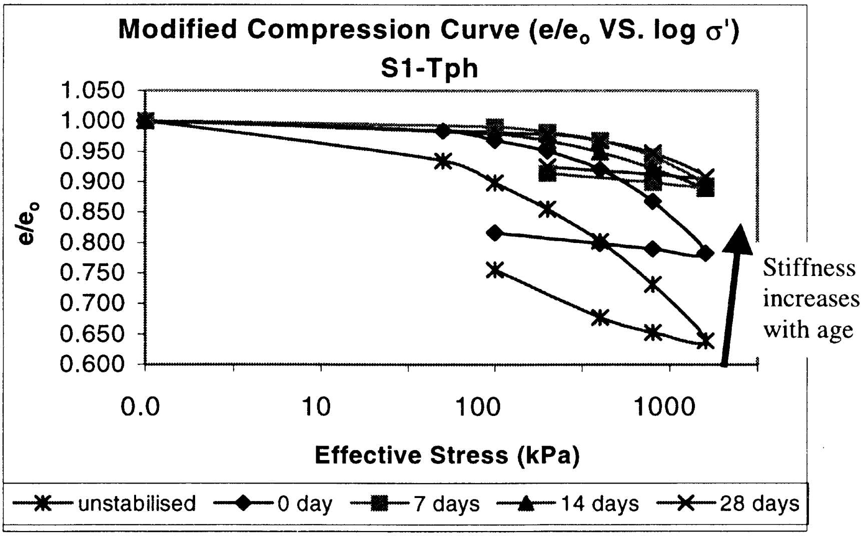
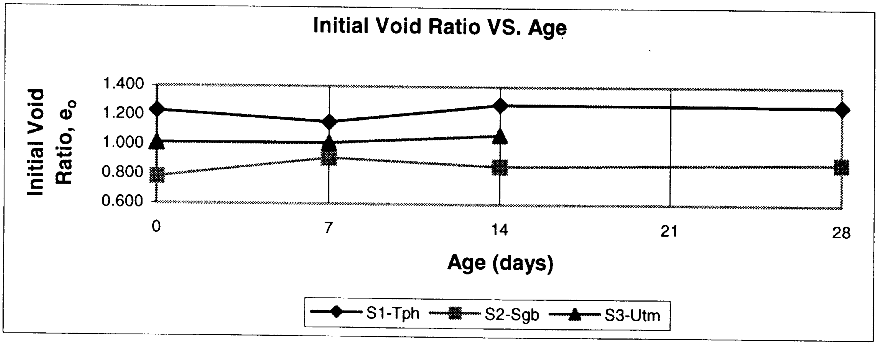


(b)

Figure 2 (a) The conventional compression curve (e vs. log σ'),
(b) The modified compression curve (e/e_o vs. log σ').

The initial void ratio, e_o of lime stabilised samples is greater compared to unstabilised samples due to the flocculation process (modification phase). A new material that is produced in this process will cause more voids in the soil. This new material has a needle-like interlocking molecular structure compared to the plate-like structure of natural clays [6]. But as time progress, it is observed that e_o gradually decreases. This is caused by the formation of the tough and watersoluble gel, which crystallised with age forming calcium silicate hydrates and calcium aluminate hydrates in the soil during the stabilisation phase.



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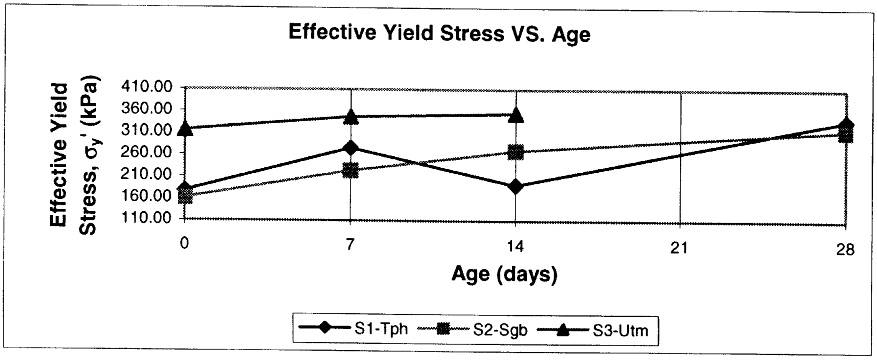

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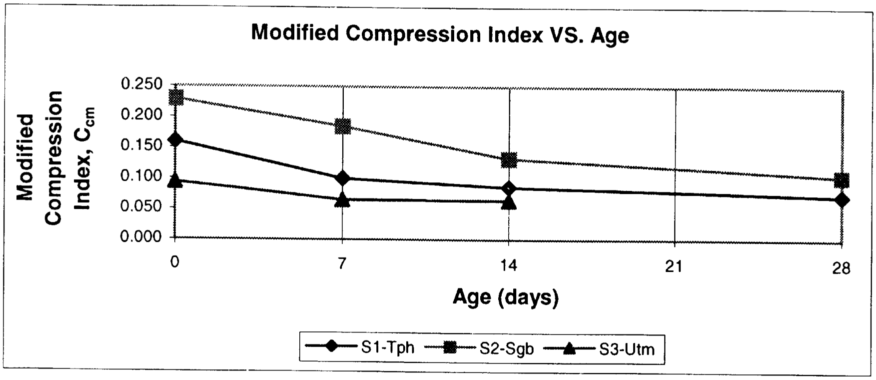


(c)

Figure 3 Compressibility characteristics of lime stabilised samples with age in terms of (a) Initial void ratio, e_o, (b) Effective yield stress, σ_y', (c) Modified compression index, C_{cm}.

A comparison of compressibility characteristics between the three soil samples was done based on the result of actual compression index, C_c and settlement, Δh. It is observed that the sequence of compressibility of soil samples from high to low: S2-Sgb (PI=27.8), S1-Tph (PI=50.5), S3-Utm (PI=32.8).

From Figures 4a, 4b and 5, it is observed that the sequence of compressibility characteristics between soil samples from high to low as the age increases. As the permanent bonding between the soil particles developed the resistance to compression increases.

ii) Rate of Consolidation Characteristics of Lime Stabilised Soils

Coefficient of consolidation, C_v is the parameter used to study the rate of consolidation characteristics of soil samples. No significant trend is discovered for the relationship of rate of consolidation with age as variations exists in the results. In general, a higher rate of consolidation is observed when compared to the unstabilised samples as shown in Fig. 6a.

The main cause for the variation in C_v is the unique relationship between the permeability k, M_v and C_v. From Equation (2), C_v can also be expressed in a function of k / M_v. It is known that M_v will decrease with age, thus C_v will increase with age. On the other hand, k will also decrease with age due to the development of cementitious gel filling up the pores that causes C_v to decrease with age.

Therefore, C_v will varies in order to strike a balance between these two relationships. The correlation between the C_v values with effective stress also exhibits the same phenomena. They have to strike balance between reduction in void ratio and the increase in the effective stress.

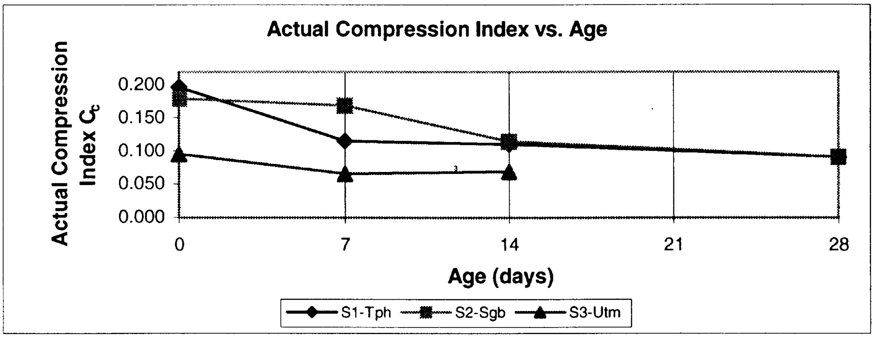
iii) Permeability Characteristics of Lime Stabilised Soils

The coefficient of permeability, k is used to study the permeability characteristics of soil samples. The coefficient of permeability, k is found based on the analytical result of the coefficient of consolidation, C_v and the coefficient of compressibility, M_v as shown in equation (2).

$$k = C_v \, M_v \, \gamma_w \qquad (2)$$

where γ_w is the unit weight of water and k is the permeability.

Generally, it is discovered that a lower permeability of lime stabilised samples is achieved with age (stabilisation phase i.e after 14 days) and with the increment of loading (Figure 7). This observation indicates that lime stabilised soil will be less permeable with age, which is due to the cementious gel that formed in the soil structure at stabilisation stage.



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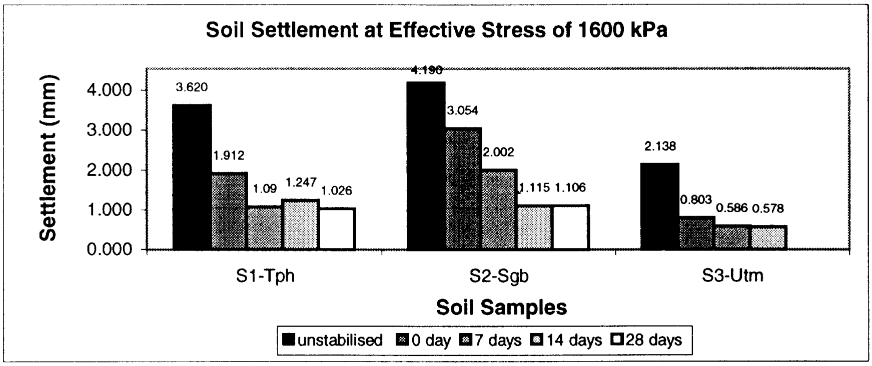


(b)

Figure 4 (a) Actual compression index of soil samples obtained using Eq. (1), (b) Soil settlement at 1600kPa.

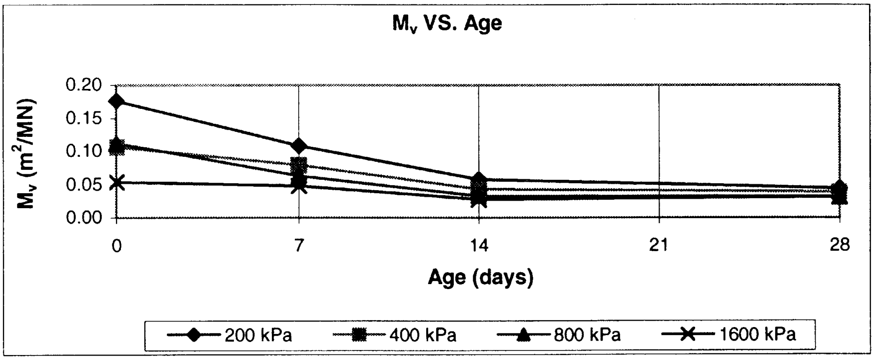
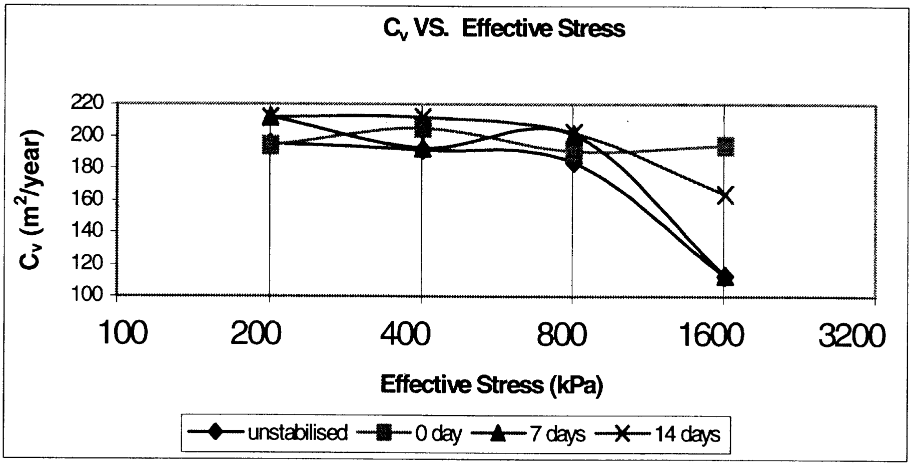


Figure 5 Compressibility characteristics of lime stabilised samples with age in term of coefficient of compressibility, Mv for Sungai Buluh soil (S2-Sgb).



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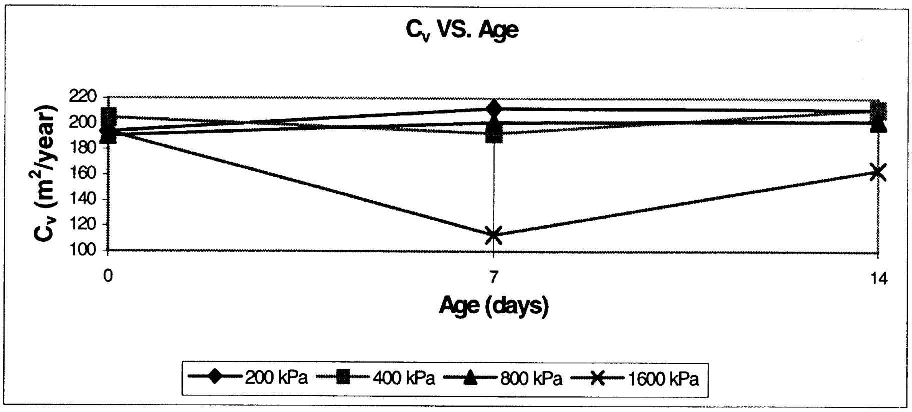
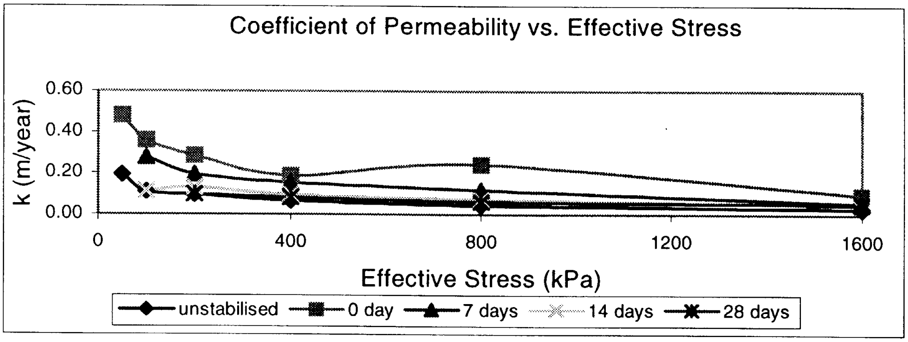


(b)

Figure 6 Rate of consolidation characteristics of lime stabilised UTM soils (S3-Utm): (a) with increment of effective stress, (b) with age.



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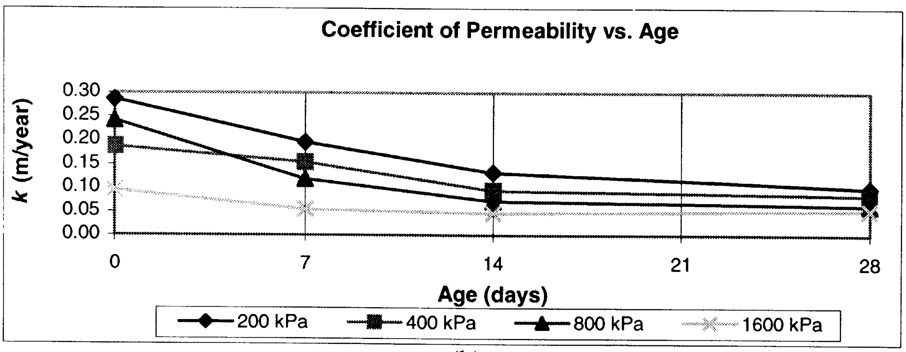

(b)

Figure 7 Permeability characteristics of lime stabilised Sungai Buluh soil samples(S2-Sgb): (a) with increment of effective stress, (b) with age.

DISCUSSIONS AND CONCLUSIONS

It is observed that most soil parameters behave inconsistently at the age below 14 days. This indicates that the clay-lime mechanism is still undergoing modification phase below 14 days, where the bonding developed in the soil structure is still weak. The significant improvement in consolidation characteristics after 14 days is a result of the long-term reaction (stabilisation phase), where a strong and permanent bonding has been developed.

In general, lime stabilisation improved the consolidation characteristics, i.e., the stiffness of untreated clay, significantly. Reduction in settlement of about 60 % was achieved with lime stabilised soils at the age of 28 days. Permeability of stabilised soil reduces with age due to the development of gel during pozzolanic reaction. At the early age, the permeability of the stabilised soil was however higher compared to that of the unstabilised soil. A combination of surcharge and lime stabilised column could lead to practical application, taking the advantage of higher permeability at the early age and stiffer soil condition due to pozzolanic reaction in the long term.

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