BEHAVIOUR OF CLAYEY SOILS WITH CEMENT ADDITIVE

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ABSTRACT

Soil-cement stabilisation has been used for many years because of the significant improvement in soil properties that may be achieved as a result of cement treatment. The improvement in engineering properties of cement-treated soils is believed to be due mainly to the hardening of cement in the presence of moisture and extension of curing period. Different cement contents and curing period render different reactions for cement-treated soils. This paper presents the results of an investigation aimed at delineating the nature of the mechanism and behaviour between the Ordinary Portland Cement (OPC) and the engineering properties of three natural residual soils at laboratory scale. A series of laboratory tests on engineering properties, such as unconfined compressive strength (UCS), Atterberg limits, moisture-density relationships (compaction) were undertaken to evaluate the effectiveness and performances of cement additive as soil stabilising agent. Cement-stabilised soil subjected to different weathering condition was investigated to evaluate the durability of the material against weather circumstances.

Keywords: Residual soil; Atterberg Limits; Compaction; Unconfined Compressive Strength (UCS); Durability

1. INTRODUCTION

Solid stabilising agents such as cement, fly ash, lime or rice husk ash has long been used to improve the handling and engineering characteristic of soils for civil engineering purposes. The improvement in engineering properties of cement-treated soils is believed to be due mainly to the hardening of cement, which is caused by the hydration of cement and the additional formation of cementitious material between the hydrating cement and the clay components.

There are numerous ways of defining the mechanism of soil-cement interaction. However, it is believed that cement which was added with water into the clay soil, will lead to the reaction of hydration process. Calcium ions from cement will be attracted to the clay surface, replacing other cations such as hydrogen ions in clay lattice according to Lyotropic series. As the concentration of exchanged ions within the clay increases, the capacity of a soil for ion exchange decreases. The combination of high concentration of calcium ions surrounding the clay surface and cement particles will lead to the binding of cement grains and form a hardened skeleton matrix, which encloses unaltered soil particles.

Further to this, the hydration of cement leads to a rise in pH value of the pore water, which is caused by the dissociation of the hydrated cement. The strong bases such as calcium ions will then dissolve the soil silica and alumina from both the clay minerals and amorphous materials on the clay particle surfaces. The hydrous silica and alumina will then gradually react with calcium ions liberated from the hydrolisis of cement to form insoluble compounds. This second reaction is known as pozzolanic reaction.

The effectiveness of cement stabilisation depends on several factors, and two of the important factors are the amount of cement and soil type. Further references can be made through several investigators such as Schaefer et al (1997), Bergado et al (1996), Mitchell et al (1963) and Kedzi (1979) who have described and defined the mechanism and interaction of soil-cement.

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Treatment of soil with cement has been used in highway, rail road and airport construction in order to improve the engineering properties of bearing layers beneath roadways, track beds and runways. In Singapore for instance, cement stabilisation has been widely adopted and studied particularly in land reclamation project.

2. LABORATORY INVESTIGATION

Three fine-grained natural soils with different clay content taken from three different parts of Klang area, namely Kpg Penchala, Sg Buloh and Batu Arang, were utilised in the investigation. The origin and the sampling site of these residual soils are summarised in Table 1.

2.1 Particle Size Distribution

Particle size distribution tests were performed based on a combined sieving-sedimentation analysis with wet sieving and followed with a determination of fine particles by hydrometer procedure as explained by Head (1980) and in accordance with BS 1377 (1990). The results of the natural soils are summarised in Table 1 below:

Table 1 Soil Properties of Research Residual Soils

	Soil 1	*Soil 2*	*Soil 3*
Textural Composition	(%)	(%)	(%)
Gravel	8	1	1
Sand	61	48	14
Silt	14	14	28
Clay	17	37	57
Parent Material	Granite Residual	Granite Residual	Granite Residual
Horizon	Light greyish colour, friable, large pores	Brownish yellow to reddish yellow, soft and small pores	Light greyish to dark greyish colour, stiff and small pores
Sampling depth (m)	0.3 – 0.6	1 – 1.5	1.5 – 2.5

2.2 Mixing Procedure

Dried natural residual soils that passed through 5mm BS sieve were applied to determine the variation of the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the natural and stabilised soils. Standard compaction test in accordance with the BS 1924 (1990) was performed and UCS specimens were prepared by static compaction after the respective MDD and OMC of the stabilised soils had been determined through standard compaction test earlier. The specimens were prepared in a 50mm diameter X 100mm height cylinder mould conforming to the BS 1924 (1990). Investigation was conducted with the incorporation of 3, 6 and 9 percent of cement to dry natural soils. Specimens that were prepared were cured and stored in an incubator for the specified curing periods before the UCS test were performed. Durability specimens for soil 1 and soil 2 were prepared by similar UCS test specimen method and were totally soaked under water with the following testing programme:

a) Normally cured for 7 days and followed by 7 days of totally immersed in water.
b) Normally cured for 14 days and followed by 14 days of totally immersed in water.
c) Normally cured for 21 days and followed by 7 days of totally immersed in water.

3. RESULTS AND DISCUSSIONS

3.1 Atterberg Limits

Cement modification effects on Atterberg limits and shrinkage limit for all the soils cured for 14 days are presented in Figures 1 and 2. It is interesting to note that soil 1 and soil 2 have gained considerable reduction in plasticity indices and linear shrinkage values with increasing cement content. According to

Ingles and Metcalf (1972), lower plasticity indices is generally equated with lower chemical activity, i.e. cation exchange capacity of the clay fraction.

As can be seen, reduction of up to 45 percent and 30 percent in plasticity indices and linear shrinkage respectively are observed throughout the experiment. It may be due to the increased plastic limit and decreased liquid limit of the cement-soil mixture. However, as noticed, any increment of cement contents in soil 3, which has the highest clay content, has shown an increment in both plasticity indices and linear shrinkage. This may be caused by the strong water adsorption characteristic of cement where the cement required higher moisture to achieve its hydration and hydrolisis process, which eventually lead to higher plasticity indices.

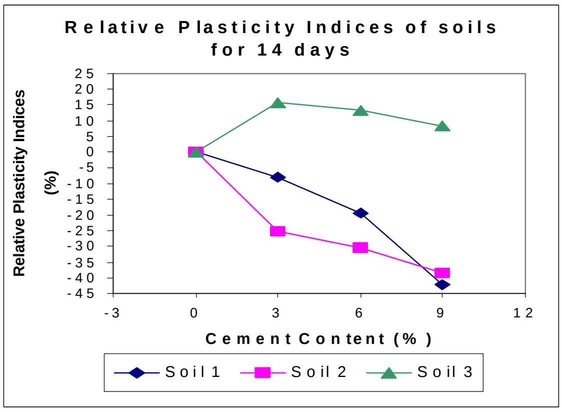


Figure 1 Relative Plasticity Indices with Different Proportions of Cement Content on Soils

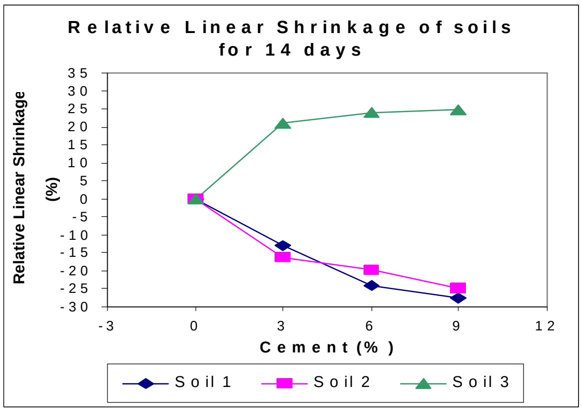


Figure 2 Relative Linear Shrinkage with Different Proportions of Cement Contents on Soils

3.2 Moisture-Density Relationship (Compaction)

As shown in Figures 3 and 4, the incorporation of cement alone in the soils is identical to Kedzi (1979) and Brown (1996) statement that cement would bring an increase in Maximum Dry Density (MDD) and show a reduction effect in Optimum Moisture Content (OMC). Similar trend is observed on cement-treated soil 1, which contains predominantly sand particles. However, both soil 2 and soil 3 which predominantly contain medium and high clay content, have shown slight reduction of MDD and an increment of OMC with the increasing cement additive.

As noticed, soil 3 which contains highest clay content, when adding with increasing cement additive, highest relative increment on OMC is obtained while it achieves the lowest relative reduction on MDD. Although the reason for this does not facilitate for what had been concluded by Kedzi (1979) and Brown (1996), it is suspected that the addition of cement apparently enhanced the affinity of cement for water and aggregation of particles which had resulted the formation of larger macropores within the soil.

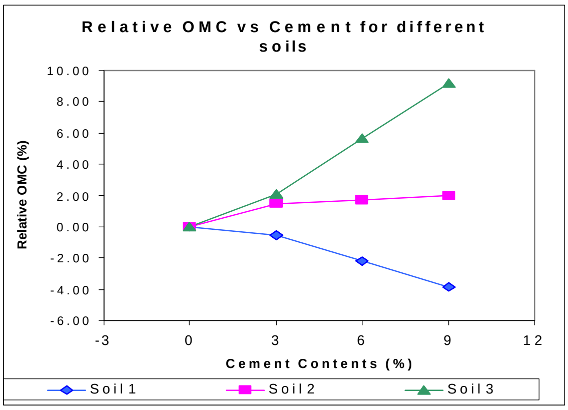


Figure 3 Relative OMC with Different Proportions of Cement Content on Soils

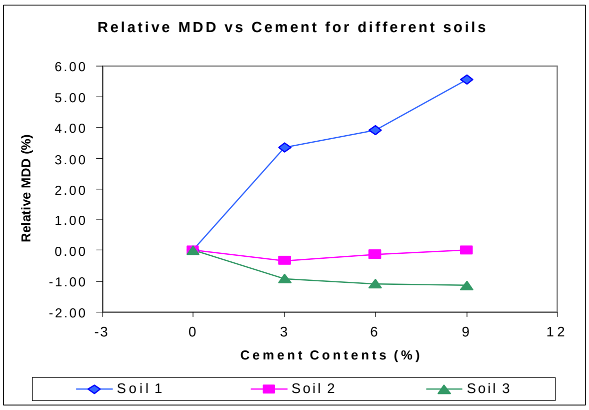


Figure 4 Relative MDD with Different Proportions of Cement Content on Soils

3.3 Unconfined Compressive Strength (UCS)

In terms of compressive strength, cement yields prominent enhancement for the natural soils and this can be shown in Table 2 below. The strength developed by each soil with different proportions of cement is shown in Figures 5, 6 and 7 below.

Table 2 Effect of Cement on UCS of Soils

Soil	Cement (%)	UCS of Curing Period (day/days) (MPa)			
		1	7	14	28
Soil 1	0	0.22	0.22	0.22	0.22
	3	0.39	0.65	0.81	0.98
	6	0.89	1.25	1.58	1.97
	9	1.30	2.40	3.50	4.68
Soil 2	0	0.10	0.10	0.10	0.10
	3	0.15	0.20	0.30	0.38
	6	0.23	0.32	0.49	0.56
	9	0.34	0.55	0.85	1.00
Soil 3	0	0.21	0.21	0.21	0.21
	3	0.27	0.30	0.36	0.39
	6	0.33	0.38	0.48	0.54
	9	0.50	0.63	0.77	0.86

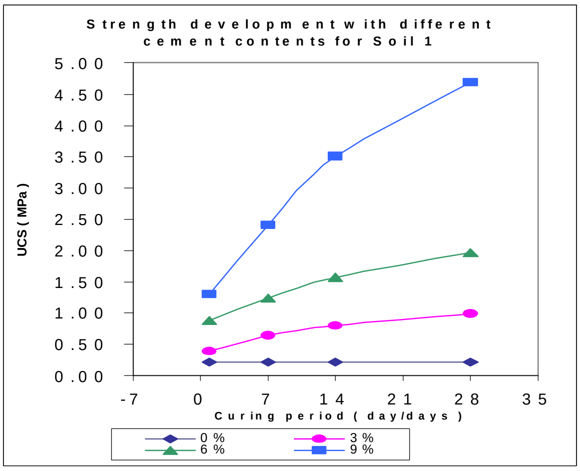


Figure 5 Strength Development of Cement for Soil 1

As illustrated in Figures 5, 6 and 7 respectively, strength increases gradually with age of curing. The results show that increased age of curing has a substantial effect on the UCS particularly soil 1. Compared to soil 2 and soil 3, the strength gain over time exhibits by cement-treated soil 1 is significant greater. This is observed by comparing the gradient/slope of the curves for the four data points plotted beyond the zero percent of cement for each soil. Soil 1 that mixed with 3 percent cement shows moderate increment from 7 days to 28 days and soil 1 with 9 percent cement shows rapid increment with the same curing period. This is in agreement with what had been reported by Bergado et al (1996) that the rate of increase of strength is generally rapid in the early stages and thereafter decreases with time. Both soil 2 and soil 3 on the other hand, show relatively slow increment from 7 days to 28 days even with increment of cement contents. This may be caused by the larger specific surface of both soils and more cement is needed to reach the predetermined strength.

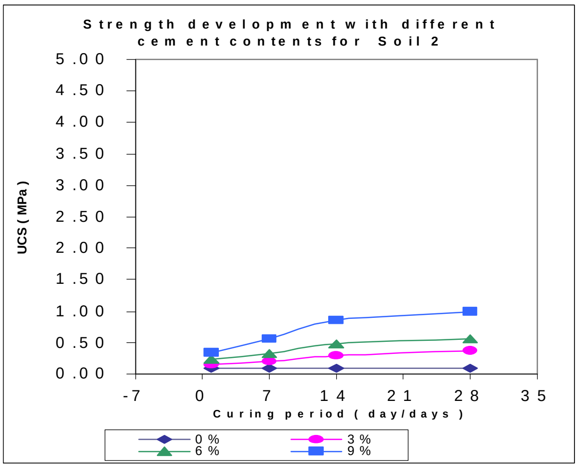


Figure 6 Strength Development of Cement for Soil 2

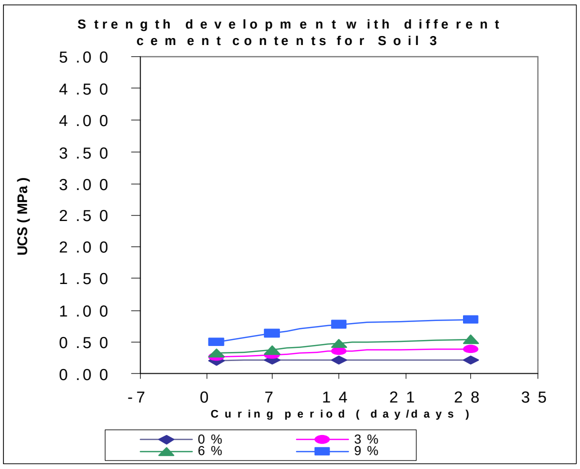
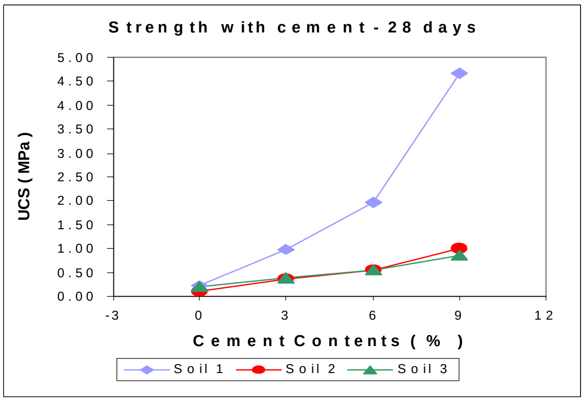


Figure 7 Strength Development of Cement for Soil 3

The UCS values of all the cement-stabilised soils are demonstrated as a function of cement content by Figure 8. As illustrated in Figure 8, with higher cement content, there is a relative increment in the strength, as well as the stiffness of the cement-treated soils. When the cement content is higher, more cement particles would hydrate and create rather strong bonds between the various mineral substances and formed a matrix, which efficiently encloses the non-bonded soil particles, thus generating higher UCS.

This is justifiable to statement by Balasubramaniam et al (1999) that the addition of cement would produce significant increment in strength and modulus of deformation, as well as stiffness of the soil, but simultaneously the clay material would be changed to brittle material.



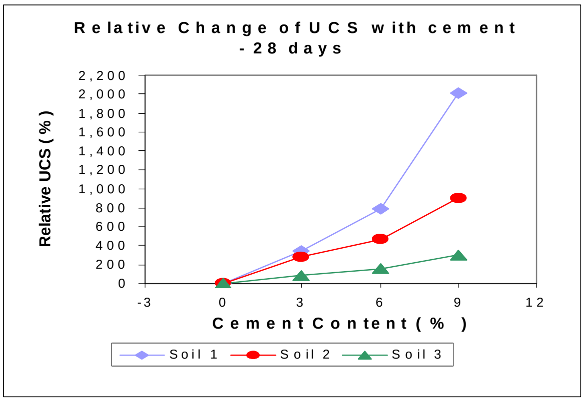


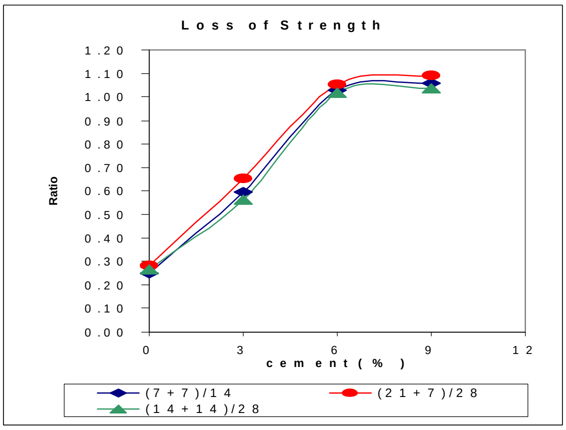
Figure 8 Effect of Cement on Strength Improvement on 28 Days of Curing

Figure 9 Relative Strength Enhancement by Cement on 28 Days of Curing

As seen in Figure 9, soil 1 produces the highest improvement with an increment of up to 2000 percent whereas soil 3 shows the least improvement with an increment of about 300 percent with similar addition of 9 percent of cement after 28 days of curing period. The change in UCS of cement-treated soils as a function of clay content is dramatically different for each soil. Strength improvement for soil 1 is very significant with every increment of 3 percent cement whereas for soil 3, little variation for the same increment is observed. The results have shown that within the similar cement contents, with an increasing quantity of fine particles particularly clay, the strength improvement value would generally decrease. This has recommended that the strength characteristic of the cement-treated soils is governed by the amount and mineral of the clay fractions in the untreated soils.

3.4 Durability

As observed in Figures 10 and 11, when compared with moist cured, in most cases, the UCS for both soil 1 and soil 2 mixed with low cement content, reduces after soaking in the water. This may be considered as a resultant of the deterioration induced during the soaking period. The UCS for these soils immersed in water ranges between 40 to 90 percent of the strength obtained for similar samples that were not immersed. Yet, these values are higher than natural soils which had lost more than 70 percent of UCS when immersed in water. For soil 1 which contains lower clay content, the percent of retained UCS is somewhat higher than soil 2 which contains higher clay content. This can be elucidated that cement react more effectively in lower clay content soil. These results show that cement had provided resistance to adverse effect of saturation.



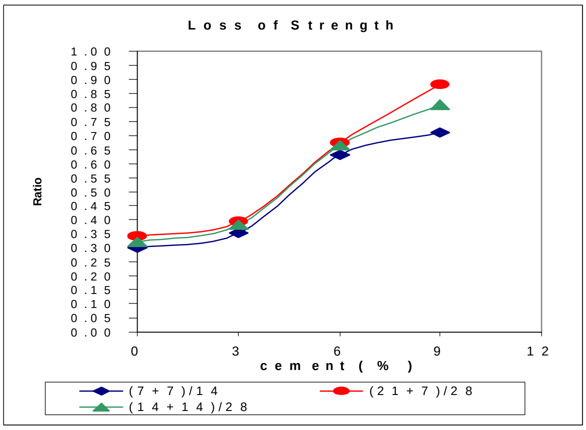


Figure 10 Effect of Immersion on Strength for Soil 1

Figure 11 Effect of Immersion on Strength for Soil 2

However, as observed, the only exception is soil 1 mixtures containing 6 and 9 percent of cement, which shows strength increment in soaked condition. The reason may be attributed to the contribution of water molecules in enhancing the hydration and pozzolanic reactions between cement and soil. It is predicted that for particular type of soil and certain level of cement content, when cured in water for a certain period of time, will achieve higher strength. As expected, prolonging the soaking period from 7 days to 14 days within the same 28 days achieves lesser strength development. This may be caused by the addition of water molecules in influencing the rate of pozzolanic process.

4. CONCLUSIONS

Based on the results presented herein, the following conclusions are drawn from the study.

1) Cement reduces the Plasticity Indices by increasing the plastic limit and reducing the liquid limit.
2) Cement reduces Optimum Moisture Content particularly soil 1 which contains predominately sand particles; both soil 2 and soil 3 which predominantly contain medium and high clay content, have shown slight increment on optimum moisture content with the increasing of cement additive.
3) Cement increases Maximum Dry Density for soil 1 but reduces the maximum dry density for soil 2 and soil 3.
4) Cement increases the UCS by increasing the inter-particle bonding. It is concluded that with an increase of fine particles particularly clay, the strength improvement value would generally decrease.
5) Cement-treated soil tends to retain most of the UCS when soaking in the water compared with untreated soil. However, prolonging the soaking period would cause further strength reduction.

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