NGHIÊN CỨU THÍ NGHIỆM CƯỜNG ĐỘ CỦA ĐẤT SÉT TRỘN VỚI XI MĂNG
EXPERIMENTAL STUDY ON STRENGTH OF CEMENT SATBILIZED CLAY

Nguyễn Minh Tâm, Hui-Joon Kim, Du-Hwoe Jung

Lab. of Advanced Soil Testing, Civil Engineering, Pukyong National University, Korea

BẢN TÓM TẮT

Bài báo này mô tả kết quả thí nghiệm của mẫu đất sét trộn với xi măng được chuẩn bị từ những điều kiện thí nghiệm khác nhau như phương pháp trộn, hàm lượng xi măng, độ ẩm, tỉ lệ nước và xi măng, và thời gian. Kết quả từ nghiên cứu này chỉ ra rằng cường độ nén một trục của mẩu đất sét trộn với xi măng được làm từ phương pháp trộn khô thì cao hơn phương pháp trộn ướt. Thêm nữa, những mối quan hệ chắc chắn giữa cường độ nén một trục, module đàn hồi, biến dạng của mẫu bị phá họai và những hệ số ảnh hưởng cũng được chỉ ra trong nghiên cứu này.

ABSTRACT

This paper describes the results of laboratory test on the cement admixed clay specimens, which are prepared from different conditions such as mixing method, cement content, water content, ratio of water and cement, and curing time. The results from this study indicate that the unconfined compressive strength of soil-cement samples prepared by dry mixing method is higher than that prepared by wet mixing method. Additionally, the definite relations between the unconfined compressive strength, secant Young's modulus, E_{50}, axial failure strain and the influenced parameters are also given through this investigation.

1. INTRODUCTION

The behavior of soft clay can be improved with soil-cement columns created by a deep mixing method (DMM). Soil-cement columns are used primarily to reduce settlement and improve stability. The deep mixing method encompasses a group of technologies that provide in situ soil treatment. The method in which dry powdered cement is used as a stabilizing agent is generally known as the dry method of deep mixing, whereas the use of stabilizing agent in a slurry form is referred to as the wet method of deep mixing. The dry mixing method is usually used to improve soft clay that has high natural water content because of sufficient groundwater to hydrate the cement (Esrig and MacKenna, 2001). The wet mixing method is generally recommended for dry or arid environments or sites with deep groundwater tables. Although the dry mixing technology is predominant in Scandinavian countries and the wet mixing method has been frequently used in Japan, there is a very limited conclusive research available on the choices of one of these two methods, which one can result in a better improvement.

A comparative study, carried out by Shiells et al. (2003), on the strength of soil cement admixture of these two mixing methods, stated that the wet mix method generally used a dosage rate higher than the dry mixing method. The dosage rate ranged from 180 to 400 kg/m^3 for the wet mixing method and it ranged from 90 to 180 kg/m^3 for the dry mixing method. However, Lin and Wong (1999) inversely reported that the unconfined compressive strength of improved soil using cement slurry was lower than that using cement powder. This may be attributed to the difference in water cement ratio of stabilized soils prepared from two mixing methods. Specimens prepared from the wet mixing method had higher water content and further increased the water-cement ratio, and thereby resulting in lower strength. These results from Shiells et al. (2003) and Lin and Wong (1999) should not be compared each other because sample preparation methods are different in these two investigations.

The main purpose of this study is to investigate the strength characteristics of cement stabilized clay samples prepared with different mixing methods and mixing conditions. Additionally, the effects of other important factors including curing time, dry weight ratio of cement to clay (A_w), water-clay to cement (wc/c) ratio, on the strength charcateristics of cement treated clay were also evaluated to provide a better understanding of the behavior of cement stabilized clay.

2. PROPERTIES OF NATURAL SOFT CLAY

Two different types of clays were obtained from Nak-dong river basin. Their physical and mechanical properties were determined and compared in Table 1.

Table 1 Properties of natural clays

Properties	Clay 1	Clay 2
Unit weight (kN/m^3)	17.75	18.24
Liquid Limit LL(%)	48	42.4
Plastic Limit PL (%)	24.7	27.64
Water Content w(%)	52.71	45.22
Specific Gravity	2.61	2.67
Grain size distribution		
Sand	5%	8%
Sieve (% < #200)	95%	92%
q_u (kPa)	41	65
ε_f (%)	9.5	6.5
E_{50} (Kpa)	779	1239

3. SAMPLE PREPARATION AND TEST CONDITIONS

Normal Portland cement was used for sample preparation in both dry and wet mixing methods. Although some differences exist in Scandinavian and Japanese methods, a sample preparation method proposed by Japanese Coastal Development Institute of Technology (CDIT, 2002) was employed in the study.

In order to investigate several factors affecting strength characteristics of cement stabilized clay, samples were prepared with different conditions as indicated in Table 2.

4. TEST RESULTS AND DISCUSSION

4.1 Stress-Strain Curves

Stress-strain curves obtained from unconfined compression tests on soil-cement samples cured for 28 days are presented in Figure 1 for various dry weight ratio of cement to clay (A_w). Samples with higher cement content showed more brittle failures. Samples with A_w of 15% and 20% showed brittle failures, where the peak strengths achieved at lower strains and their residual strengths were much lower than their peak strengths. On the other hand, samples with lower A_w showed decreased peak strengths and larger failure strains. It is also interesting to realize from Figure 1 that the failure strain tends to decrease with increasing unconfined compressive strength.

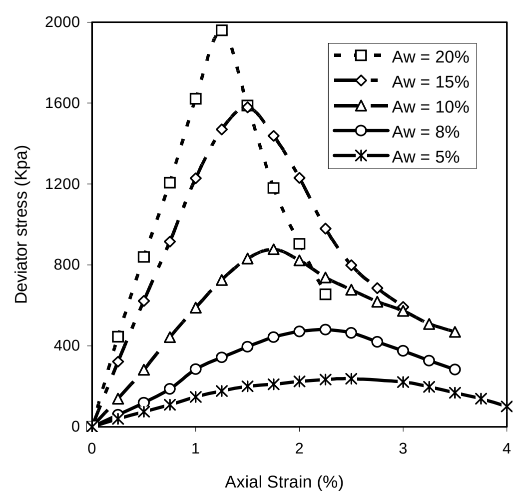


Figure 1 Stress-strain curves of unconfined compression test on soil-cement samples tested after 28 days of curing

4.2 Effect of Mixing Method and Curing Time

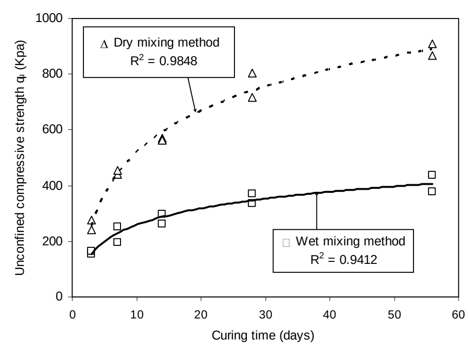
Table 2 Sample preparation methods and test conditions employed in the study

Test number	Soil group	Mixing Method	Number of samples	Initial water content of natural clay	Additional water to cement ratio of cement slurry	Modified initial water content of natural soil after mixing	Cement mixed clay paste		
							Dry weight ratio of cement toclay	water-clay to cement content ratio	Initial Water content
				(%)	(%)	(%)	(%)	-	(%)
1	Clay 1	Wet	10	45.22	100	55.22	10	5.52	50.20
		Dry	10	45.22	100	55.22	10	5.52	50.20
2	Clay 2	Wet method	6	52.71	100	57.71	5	11.54	54.96
			6	52.71	100	60.71	8	7.59	56.21
			6	52.71	100	62.71	10	6.27	57.01
			6	52.71	100	67.71	15	4.51	58.88
			6	52.71	100	72.71	20	3.64	60.59
3	Clay 2	Wet method	6	52.71	50	57.71	10	5.77	52.46
			6	52.71	100	62.71	10	6.27	57.01
			6	52.71	150	67.71	10	6.77	61.55
			6	52.71	200	72.71	10	7.27	66.10
			6	52.71	300	82.71	10	8.27	75.19

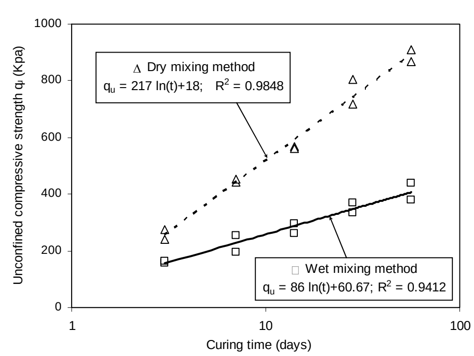
To investigate the effect of mixing methods on strength characteristics of soil-cement samples, 10 soil-cement samples were prepared with clay 1 by each mixing method as indicated in Table 2. As shown in Figure 2, the unconfined compressive strength of soil-cement samples mixed by dry mixing method was much higher than that by wet mixing method. Furthermore, the rate of strength gain was appeared to be much faster for dry mixed samples compared to wet mixed samples.

Unconfined compressive strength of both soil-cement samples tended to develop rapidly in an early curing stage and the development of strength tended to slow down afterwards. Strength gaining of cement stabilized soil is mainly caused by a combination of cement hydration and pozzolanic reaction that are time dependent. Especially, it can be found from Figure 2b that the unconfined compressive strength of soil-cement sample increases almost linearly with a logarithmic curing time, which is consistent with data published in literatures (Kitazume et al. 2003, and Hayashi et al. 2003). Based on the predicted strength gains in the soil cement specimens, designers may estimate a time schedule for construction.

In addition, the unconfined compressive strengths of soil-cement samples after 3 days of curing for both dry and wet mixing methods were about 160 and 259 kPa, respectively, which were much higher than the strength of natural clay employed in the test. This implies that the strength gain of cement mixed clay after mixing is progressed very fast. This result was also consistent with results presented by Shen et al. (2003).



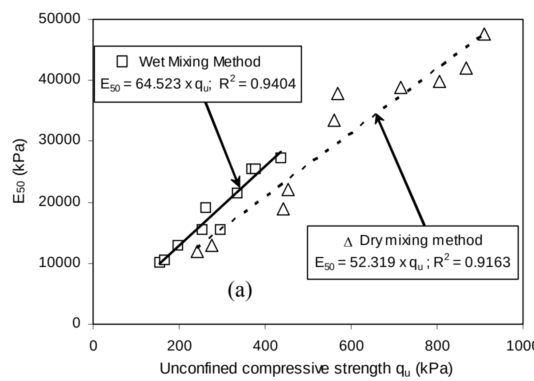
(a) In arithmetic scale



(b) In logarithmic scale

Figure 2 Relationship between q_u of soil-cement samples and curing time for dry and wet mixing methods

Figure 3a shows a relationship between the modulus of elasticity and the unconfined compressive strength of soil-cement samples and Figure 3b shows a relationship between the axial failure strain and the unconfined compressive strength of soil-cement samples. The modulus of elasticity tended to increase with increasing unconfined compressive strength, whereas the failure strain tended to decrease with increasing unconfined compressive strength. This implies that soil-cement samples with higher strength tend to show more brittle failures. In addition, soil-cement samples mixed with wet method provided slightly higher modulus of elasticity whereas soil-cement samples mixed with dry method provided greater failure strain. This implies that soil-cement samples mixed with wet method tend to show more brittle failures compared to those mixed with dry method.



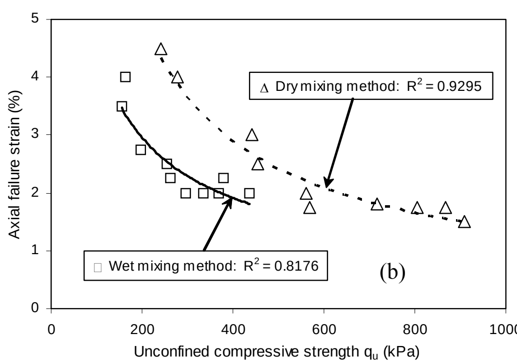
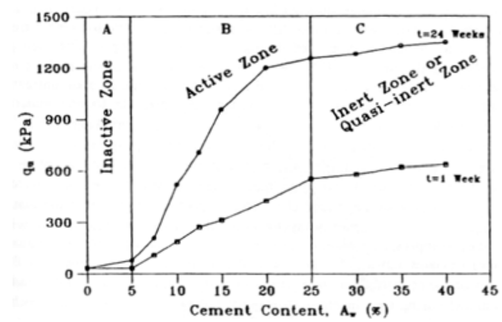


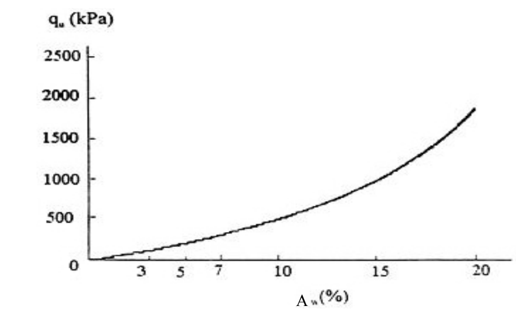
Figure 3 Comparison of test results between wet and dry mixing methods

4.3 Effect of dry weight ratio of cement to clay, Aw (Cement content)

Bergado et al. (1996) proposed that the relationship between unconfined compressive strength and cement content can be divided into 3 zones: Inactive Zone, Active Zone, and Inert Zone as shown in Figure 4a. The shapes of the relationship curve between q_u and A_w presented by Tatsuoka and Kobayashi (1983), and Bouazza et al. (2004) were similar to the curve shown in Figure 4a. However, Lin (2000) proposed a different relationship between unconfined compressive strength and cement content of soil-cement as shown in Figure 4b. This aspect was also investigated in the study to validate these two conflicting investigation results.



a) After Bergado et al. (1996)



(b) After Lin (2000)

Figure 4 Comparison of the relationship between q_u and A_w of cement stabilized clay

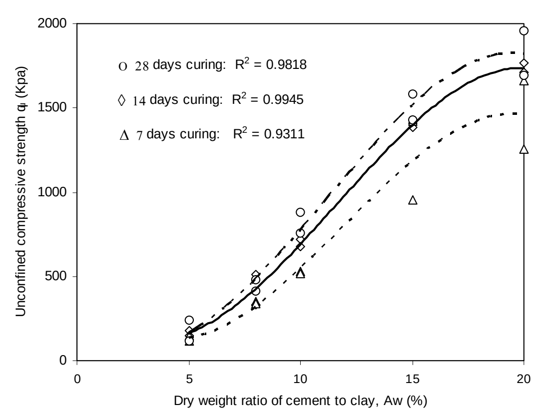


Figure 5 Variation of q_u with A_w

The influence of cement content on unconfined compressive strength was investigated by performing unconfined compression tests on soil-cement samples prepared with clay 2. The ratio of additional water to cement was fixed at 100%. Soil-cement samples were mixed with A_w of 5%, 8%, 10%, 15%, and 20% by wet method. All these samples were tested after 7, 14 and 28 days of curing and test result was plotted in Figure 5. As expected, unconfined compressive strength showed a tendency to increase with increasing cement content. The unconfined compressive strength increased rapidly increased up to the cement content of 20% and then tended to slow down. The shape of the relationship was appeared to be similar to that proposed by Bergado et al. (1996).

4.4 Effect of clay water/cement ratio (wc/c)

Miura et al. (2001) suggested that a prime factor governing the engineering parameters of cement-stabilized soil is the clay-water/cement ratio, *wc/c*. This is defined as the ratio of initial water content of the soil (%) to the cement content. The wc/c is a paramount parameter combining the effects of water content and cement content, which is more advantageous than the parameter water content. The importance of this ratio is emphasized by Najaraj (2002) that the natural clays, which have different mineralogy, exhibit different strength characteristics after mixing with cement. However, the strength development of a particular clay-cement mixture after a certain curing time is only dependent upon the wc/c, which is structural parameter reflecting both the effects of microfabric and their cementation. The denominator A_w would reflect the level of bonding that could be induced.

Figure 6 depicts the role of wc/c ratio on unconfined compressive strength development of soil cement samples tested after 28 days of curing. The relationship of wc/c ratio and q_u appears to be nonlinear over the range of wc/c ratio investigated. Unconfined compressive strength of soil-cement samples tended to decrease with increasing wc/c ratio.

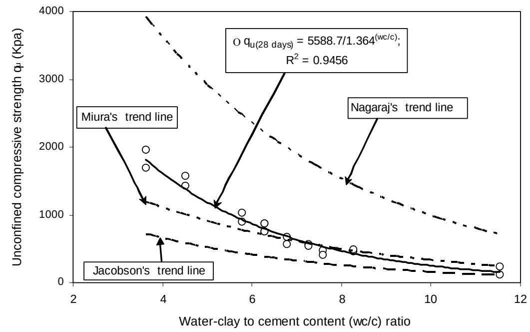


Figure 6 Comparison of test data and published data

A comparison of test results obtained from the study with data published in literatures is presented in Figure 6. The trend line obtained from unconfined compressive tests on soil-cement samples cured for 28 days is fairly consistent with the results reported by Miura et al. (2001) and Jacobson (2002). However, the trend line proposed by Nagaraj (2002) was appeared to be far off from others. This can be attributed to differences in the characteristics of natural clay such as water content, mineralogy, Atterberg limits, organic content, pH value etc., and cement type.

4.5 Axial Failure Strain of Soil Cement Samples

Dertemining the axial train of soil cement mixture at failure state is significant part to evaluate the interaction between deep mixing cement columns and unstabilized soil around the columns and thus the stability analysis of structures founded on soft soil improved by soil cement columns system is performed. Failure strain has also a large influence on the reduction of the bearing capacity and on the increase of lateral displacement of the columns. In this section, the axial failure strain is, therefore, investigated.

The relationship between unconfined compressive strength and failure strain of soil cement samples obtained from test results on unconfined compression tests in laboratory is shown in Figure 7. It can seen from the figure that the failure strain decreases in general with increasing unconfined compression strengt and that failure occurs at relatively small axial strains, at 1% to 3.5% with a unconfined compressive strength largely varies about from 100 to 2000 kPa.

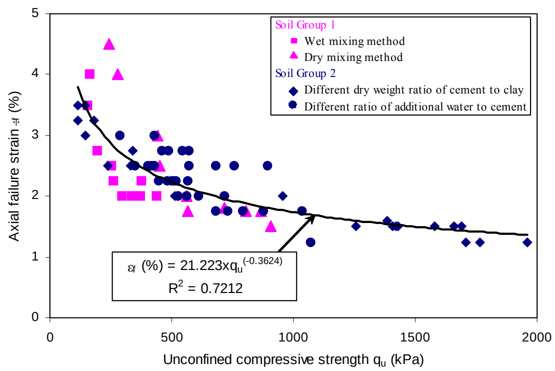


Figure 7 Relationship between q_u and failure strain of soil cement samples.

Compared to the failure strain of natural clay, It can be seen that the axial strain at the peak shear strength of soil cement samples performed on unconfined compression test was small, about 1% to 3.5%, while this value of natural clays ware 9.5 for clay 1 and 6.5 for clay 2. Therefore, it is important to consider the small failure strain of the cement columns which will reduce the interaction of the cement columns with the unstabilized soil between the columns. This inverse with the assumption, used in design, that the peak shear strength of cement column is mobilised at the same strain as peak shear strength of the unstabilized soil.

5. CONCLUSIONS

Based on the results obtained from unconfined compression tests carried out on soil-cement samples prepared with different conditions, the following can be appropriate;

1. Soil-cement samples with higher cement content showed more brittle failures.
2. The unconfined compressive strength of soil-cement samples prepared from dry mixing method was greater than those prepared from wet mixing method. However, soil-cement samples prepared from dry mixing method tended to show more brittle failures compared to those prepared from wet mixing method.
3. The modulus of elasticity tended to increase with increasing unconfined compressive strength, whereas the failure strain tended to decrease with increasing unconfined compressive strength. However, soil-cement samples mixed with wet method provided slightly higher modulus of elasticity whereas soil-cement samples mixed with dry method provided greater failure strain.
4. Unconfined compressive strength showed a tendency to increase with increasing cement content. The unconfined compressive strength increased rapidly increased up to the cement content of 20% and then tended to slow down. The shape of the relationship was appeared to be similar to that proposed by Bergado et al. (1996).
5. Unconfined compressive strength of both soil-cement samples prepared with dry and wet mixing methods tended to develop rapidly in an early curing stage and the development of strength tended to slow down afterwards.
6. The trend line showing an effect of water-clay to cement content ratio obtained from unconfined compressive tests on soil-cement samples cured for 28 days was fairly consistent with the results reported by Miura et al. (2001) and Jacobson (2002).

REFERENCES

1. Bergado, D. T., Anderson, L. R, Miura, N. and Balasubramaniam, A. S. (1996). *Soft Ground Improvement in Lowland and Other Environments*, ASCE press, 1-9., 234-304.
2. Bouazza, A., Kwan, P. S., and Chapman, G. (2004) "Strength Properties of Cement Treated Coode Island Silt by the Soil Mixing Method", Proc. Geotechnical Engineering for Transportation Projects, ASCE press, 1421-1428.
3. CDIT (Coastal Development Institute of Technology). (2002). *The Deep Mixing Method: Principle, Design and Construction.* A.A. Balkema, The Netherlands
4. Esrig, M. I. and MacKenna, P. E. (2001). "Lime Cement Column Ground Stabilization for I-15 in Salt Lake City." *Practice Periodical on Structural Design and Construction*, ASCE, Vol. 4, No. 3, 104-115.
5. Hayashi, H., Nishikawa, J., Ohishi, K., and Terashi, M. (2003). "Field Observation of Long-Term Strength of Cement Treated Soil." *Grouting and Ground Treatment, Proc. of the 3rd Int. Conf.*, ASCE GSP, No. 120, 598-609.

6. Jacobson, J. R. (2002). "Factors Affecting Strength Gain in Lime-Cement Columns and Development of a Laboratory Testing Procedure." Master Thesis, Virginia Tech. Institute
7. Kitazume, M., Takeshi, N., Terashi, M., and Ohishi, K. (2003) "Laboratory Tests on Long-Term strength of Cement Treated Soil." *Grouting and Ground Treatment; Proc. of the 3rd Int. Conf.*, ASCE GSP, No. 120, 586-597.
8. Lin, K. Q. and Wong, I. H. (1999). "Use of deep cement mixing to reduce settlements at bridge abutments." *ASCE 125,* No. 4, 309-320.
9. Lin, K. Q. (2000). "Behaviour of DCM Columns under Highway Embankment at Bridge Approaches." *Thesis for the Degree of Doctor of Philosophy, Nanyang Technical University*.
10. Miura, N., Horpibulsuk, S., and Nagaraj, T. S. (2001). "Engineering Behavior of Cement Stabilized Clay at High Water Content." *Soils and Found.. Japanese Geotechnical Society*. Vol. 41, No. 5, 33 – 46.
11. Nagaraj, T. S (2002). One Day Lecture on Ground Improvement Techniques, Technical committee of Thick Deposit (ATC-7), Dong A University, Busan, Korea, 59-95.
12. Shen, S. L., Miura, N., Han, J., and Koga, H. (2003). "Elevation of Property Changes in Surrounding Clays due to Installation of Deep Mixing Columns." *Grouting and Ground Treatment; Proc. of the 3rd Int. Conf.*, ASCE GSP, No. 120, 634-645.
13. Shiells, D. P., Pelnik III, T. W., and Filz, G. M. (2003). "Deep Mixing: An Owner's Perspective." *Grouting and Ground Treatment, Proc. of the 3rd Int. Conf.*, ASCE GSP, No. 120, 489-500.
14. Tatsuoka, F. and Kobayashi, A. (1983). "Triaxial strength characteristics of cement-treated soft clay." *Proc. of the 8th European Con. of SMFE,* 421-26.