Effect Factors on Unconfined Compressive Strength of Soil-Cement Columns: The Case Study of Ba Ria, Vung Tau, Vietnam

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ABSTRACT

This paper presents the effect of the curing environment on the unconfined compressive strength of soil-cement samples and in finding the optimum output mix ratio and estimating the effect of silica fume in the admixture. This work is based on the data from the Cai Mep-Thi Vai inter-port road project and results from laboratory experiments. The results show that the specimens with the highest strength were cured in soil, lowered in city water with NaCl 2.5% and then NaCl 5%. The optimum silica fume admixture ratio equals to 1% (in comparison with the weight of cement content).

Keywords-soil cement; soil improvement; unconfined compressive strength; mixture ratio; silica fume; soft soil

I. INTRODUCTION

The deep soil mixing method or soil-cement column method is an advanced technology in which the cement is blended with in-situ soft soil. Materials in dry and slurry form could be used in the soil-cement method. The hollows are made by using a rotated mixing machine which combines several types of cutting tools. The cementitious materials are also injected during the execution process. Currently, there are many researched and developed deep mixing terminologies [1, 2]. The three main developing phases include: chemical mixing (lime cement or soil cement), mixed-in-place columns, and soil mixing.

In these terminologies, the Deep Soil Mixing (DSM) has certain advantages such as: rapid stabilization, accelerated construction in site, higher soil strength at lower cost. Authors in [3-5] showed that DSM is suitable for application in some problematic soils, especially expansive soils. Typical DSM has been applied in reclaimed and soft native soils in the transportation sector in Japan [6]. The DSM technique is an advanced technology of improvement. Some projects in Vietnam have used this method, e.g.: the Ba Ngoi harbor project (Khanh Hoa province), Can Tho airport, Bac Lieu airport, etc. More and more projects use this technology for soft soil treatment.

II. INVESTIGATION OF THE REACTION IN SOIL CEMENT COLUMNS

Portland Cement (PC) is created in a controlled chemical process with the combination of aluminum, calcium, iron, silicon, and other compounds. In order to construct Blended Portland Cement (BPC), an amount of gypsum, and several minerals are mixed with PC or clinker in the hydraulic adhesive process [3, 4].

Hydration reaction and hydrated cement (to form primary cementitious product): When using cement to stabilize the ground, minerals on the cement surface react with the hydrated cement from the pore water of the soil quickly to form three compounds: calcium hydroxide, hydrate calcium silicate, and hydrated calcium aluminate. The first cementitious products are the primary cementitious product. Water and cement react as described below:

$$6H + 2C_3S = 3Ca(OH)_2 + C\text{-}S\text{-}H \text{ (hydrated gel)} \quad (1)$$

$$4H + 2C_2S = Ca(OH)_2 + C\text{-}S\text{-}H \quad (2)$$

$$27H + 2C_3A = C_2AH_8 + C_4AH_{19} \quad (3)$$

$$3CSH_2 + 26H + C_3A = C_6AS_3H_{32} \text{ (ettringite)} \quad (4)$$

$$4H + C_6AS_3H_{32} + 3\,C_3A = 3C_4ASH_{12} \text{ (monosulfate)} \quad (5)$$

The structure and strength in the soil matrix are determined by the hydration process which makes agglomeration, and cation exchange, and stabilizes the soil clay and flocculation.

III. EFFECT FACTORS ON UNCONFINED AXIAL COMPRESSION OF SOIL CEMENT SAMPLES

Many soil types such as sandy sand, soft clays, clayey silts, clays, and sands are in turn used to test with the soil-cement column method [7-10]. In these studies, some major soil factors that have the main influence on the compression development of soil-cement columns are I_L (Index liquid), W_n, F_c, and pH.

Authors in [11, 12] showed that some soils have $I_L > 15\%$ and pH < 5, and the unconfined axial compression strength becomes too low, even though they had high other stabilizer properties. The main reason is the reduction of the ion Ca^{2+} for the pozzolanic reactions process. Authors in [8] also showed that with more organic content, the unconfined compress strength decreases. The interference of organic contents in compression gain are not entirely understood, however authors in [13, 14] pointed out that the mechanisms of organic properties are:

- The structural composition and cementing compound can be changed by organic matter via the hydrated process and other extraneous matter.
- The organic matter can hold more than 10 times its dry weight in water, therefore the hydration may be faced with a water limit.

The axial compression could be augmented by some parameters of soil such as soil minerals, sand consistency of fine, plastic index, etc. [5, 8, 9]. Soil cement column quantity depends on the type of clay or sand and the characteristics of each soil, which is especially important given the low pH values (from 5.4 to 5.8) in Mekong Delta, Vietnam [15].

Some of the conditions at the site during the treatment process such as the mixing duration, the rate of installation, the shape of the mixing, etc. affect directly the unconfined compressive strength of soil-cement columns [1, 10, 15-16]. However, not much research has been conducted on the effect of these characteristics of soft soil, as it is difficult to reflect these characteristics in lab conditions.

IV. LABORATORY ASSESSMENT OF THE CASE STUDY RESULTS

The road in port terminal Cai Mep-Thi Vai along the Thi Vai River helps to develop and connect the traffic infrastructure and the industrial areas. Soft soil improvement in the area utilizes soil-cement columns. The road cross-section is illustrated in Figure 1.

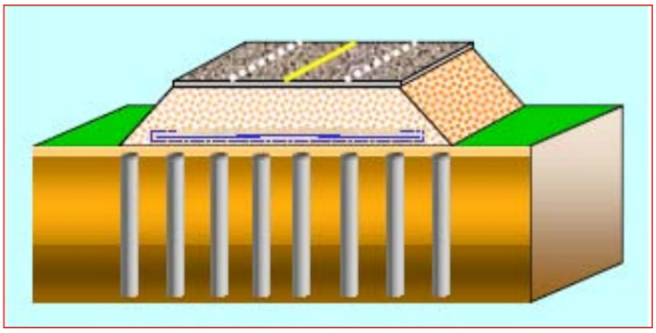

Fig. 1. Embankment supported by deep mixing in a component project.

A. The Effect of Cement Content on the Unconfined Compressive Strength (UCS)

In general, UCS varies from 900.4 to 1320.4kPa at 28 days, and from 1256.2 to 1732.5kPa at 60 days. The optimum cement content is 240kg/m^3 (1175 – 1300kPa). It is lower than that in [17] (300kg/m^3).

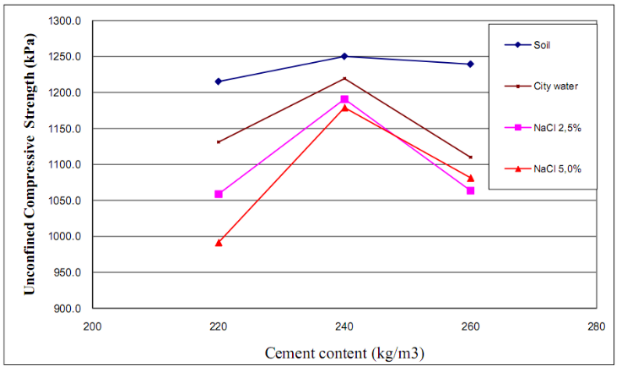

Fig. 2. The effect of cement content on (UCS) at 28 days.

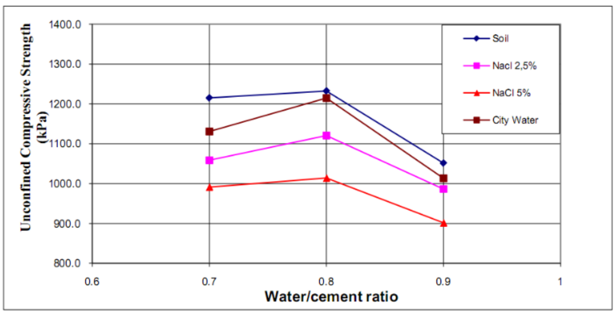

Fig. 3. Variation of UCS with water/cement ratio at 28 days.

B. Variation of UCS with Water/Cement Ratio

The optimum water/cement ratio is 0.8. Increased water/cement ratio means increased water content. Water content is needed to be enough for the hydrate reaction to occur. If the added water content is superfluous, it will make holes full of water in the product, decreasing its strength (Figure 3).

C. Variation of UCS with Silica Fume/Cement Ratio

The highest UCS occurs when silica fume/cement equals to 1%. If silica fume/cement ratio is more than 1%, the UCS will decrease (Figure 4).

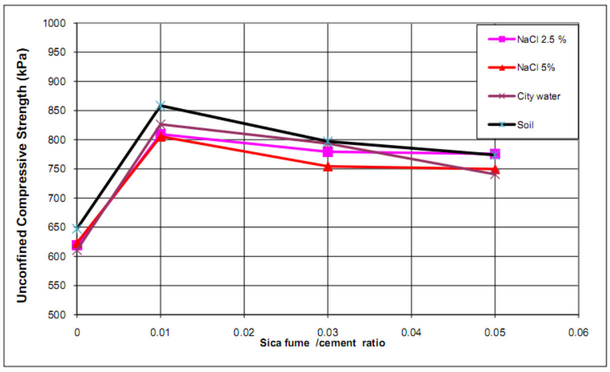

Fig. 4. Variation of UCS with silica fume/cement ratio at 7 days.

In summary, the UCS with silica fume/cement=1%, at 7, 14, 28, and 60 days ranges between 129 and 125%, 112 and 124%, 125 and 138%, and 113 and 135%, respectively. The strength of the soil-cement column increases the stability in the soil environment more than in other environments. Pozzolanic reaction occurs between $Ca(OH)_2$ and silica fume to increase the strength of the specimen when silica fume is added. When the silica fume addition is more than 1% and if the mixed process is not widespread, it will surround the cement gain, preventing the hydrate reaction.

D. Variation of UCS with Curing Time

The longer the curing time the higher the strength of soil cement samples is. The strength develops fastest from 0 to 7 days (equal to around 40% to the strength at 60 days) and then increases in a slower pace (see Figure 5).

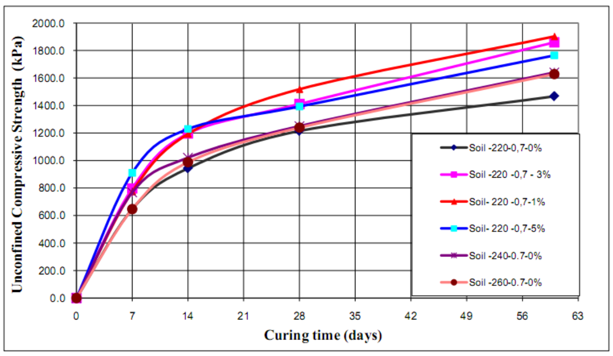

Fig. 5. Variation of UCS with curing time for various soils.

In comparison with its values at 7 days, UCS is around 163 – 192% at 28 days. These values are bigger than the ones obtained in [5] (140 - 150%). Authors in [11] reported strength ratio at 7 to 28 days about (12.0 - 210%). The test result depends on the type of cement, the type of soil treatment, the water/cement ratio, etc. UCS varies from 121 to 131% at 60 days.

V. ANALYSIS AND VARIATION OF CORE SAMPLING AT SITE

A. Effect of Cement Content

The optimum cement content equals to 240kg/m^3. This value is the same with the laboratory research result.

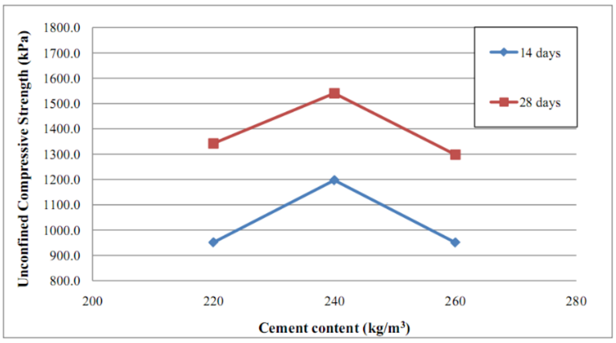

Fig. 6. Variation of USC with cement content.

B. Variation of UCS with Water/Cement Ratio

Maximum strength of soil cement column is reached when the water/cement ratio is 0.7 and lowers a bit when water/cement ratio is 0.8. UCS decreases remarkably when the water/cement ratio is 0.9.

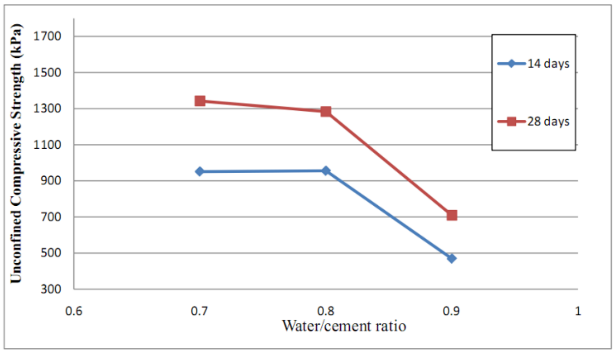

Fig. 7. Variation of UCS with water/cement ratio at 14 and 28 days.

C. Relation between Stress and Strain

The variation of UCS with strain can be seen in Figure 8.

VI. VARIATION RESULT COMPARISON BETWEEN LABORATORY AND FIELD

The strength of laboratory mixed specimens and mixed field samples was compared in order to determine the correlation between them (Figure 9).

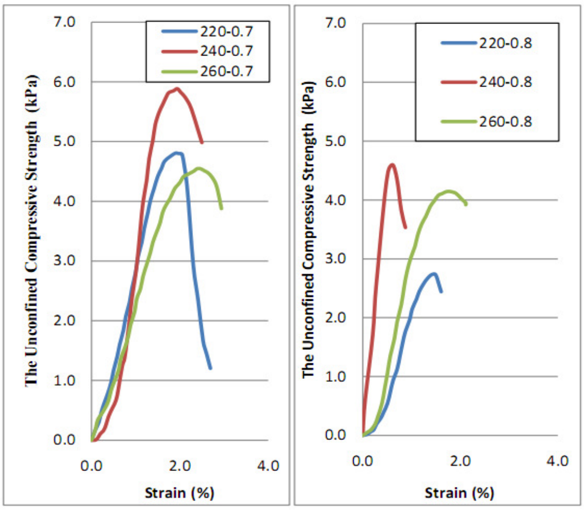

Fig. 8. USC vs strain at 28 days.

(a)

(b)

(c)

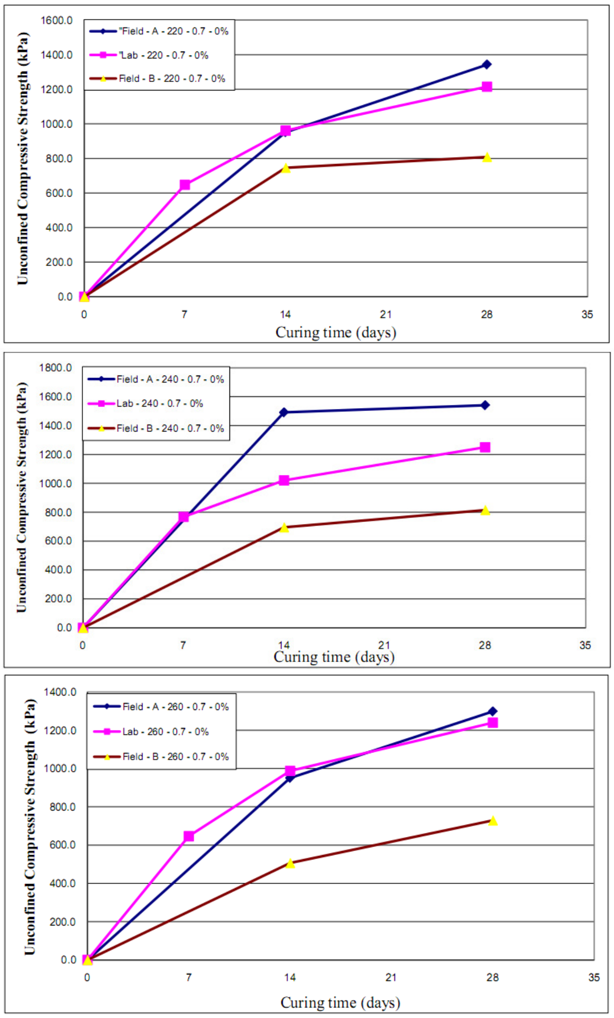

Fig. 9. Laboratory and field UCS result comparison: (a) 220kg/m^3 cement content, 0.7 water/cement ratio, (b) 240kg/m^3 cement content, 0.7 water/cement ratio, and (c) 260kg/m^3 cement content, 0.7 water/cement ratio.

In the same mixture steps, the results in the laboratory are often more worked-out than in the field.

VII. CONCLUSION

The main conclusions derived from the research results of this study are:

1) Optimum Mixture Ratio

The optimum cement content in laboratory and field mixed specimens is equal to 240kg/m^3. The optimum water/cement ratio is 0.8 in laboratory mixed specimens and 0.7 in the field mixes.

2) Effect of the Curing Environment

The curing environment affects negligibly the compression values of soil cement columns. The highest strength of specimens is cured in soil environment, whereas it is lower in city water with NaCl 2.5% and 5%.

3) The Effect of Silica Fume

The optimum silica fume admixture equals to 1% of the weight of cement content for 60 days of curing in the laboratory. More research regarding long term curing is needed in order to evaluate the effect of silica fume. The pozzolanic reaction between $Ca(OH)_2$ and clay material is crucial, especially in the research area, where the type of clay is montmorillonite which is the most active clay.

4) Variation between the Strength of Cement Column in the Site and in the Laboratory

The strength of soil-cement columns depends heavily on contraction. In the current study, the strength of specimens mixed by the contractor A varied from 100 to 115% of the values of laboratory-mixed specimens. The values of the specimens mixed by the contractor B may varied from 42 to 67%.

REFERENCES

[1] D. T. Bergado and G. A. Lorenzo, "Economical Mixing Method for Cement Deep Mixing," in *Geo-Frontiers Congress 2005*, Austin TX, USA, May 2012, https://doi.org/10.1061/40783(162)12.

[2] A. J. Puppala, R. S. Madhyannapu, S. Nazarian, and L. R. Hoyos, "Deep Soil Mixing Technology for Mitigation of Pavement Roughness," The University of Texas at Arlington, Arlington, TX, USA, Technical Report 0-5179–1, Oct. 2007.

[3] G. A. Lorenzo, D. T. Bergado, and S. Soralump, "New and Economical Mixing Method of Cement-Admixed Clay for DMM Application," *Geotechnical Testing Journal*, vol. 29, no. 1, pp. 54–63, Nov. 2005, https://doi.org/10.1520/GTJ12129.

[4] G. A. Lorenzo and D. T. Bergado, "Fundamental Characteristics of Cement-Admixed Clay in Deep Mixing," *Journal of Materials in Civil Engineering*, vol. 18, no. 2, pp. 161–174, Apr. 2006, https://doi.org/10.1061/(ASCE)0899-1561(2006)18:2(161).

[5] T.-O. Ho, D. C. W. Tsang, W.-B. Chen, and J.-H. Yin, "Evaluating the environmental impact of contaminated sediment column stabilized by deep cement mixing," *Chemosphere*, vol. 261, p. 127755, Dec. 2020, https://doi.org/10.1016/j.chemosphere.2020.127755.

[6] W. Frikha, H. Zargayouna, S. Boussetta, and M. Bouassida, "Experimental Study of Tunis Soft Soil Improved by Deep Mixing Column," *Geotechnical and Geological Engineering*, vol. 35, no. 3, pp. 931–947, Jun. 2017, https://doi.org/10.1007/s10706-016-0151-2.

[7] H. Ahnberg, C, Ljungkrantz, and L. Holmqvist, "Deep stabilization of different types of soft soils," in *Proceedings 11th ECSMFE*, Copenhagen, Denmark, 1995, vol. 7, pp. 167-172.

[8] B. B. K. Huat, S. Maail, and T. A. Mohammad, "Effect of Chemical Admixtures on the Engineering Properties of Tropical Peat Soils," *American Journal of Applied Sciences*, vol. 2, no. 7, pp. 1113–1120, Jul. 2005, https://doi.org/10.3844/ajassp.2005.1113.1120.

[9] A. Mosadegh, F. Szymkiewicz, and H. Nikraz, "An experimental investigation of the impact of specimen preparation and curing conditions on cement-treated material strength (deep mixing method)," *Australian Journal of Civil Engineering*, vol. 15, no. 1, pp. 49–60, Jan. 2017, https://doi.org/10.1080/14488353.2017.1372685.

[10] M. Syarif and M. W. Tjaronge, "A Comparison of Organic Cement Made from Recycled Waste Material and Portland Cement," *Engineering, Technology & Applied Science Research*, vol. 11, no. 4, pp. 7442–7445, Aug. 2021, https://doi.org/10.48084/etasr.4323.

[11] R. Babasaki, S. Saito, and Y. Suzuki, ", R., S. Saito, and Y. Suzuki. 'Temperature Characteristics of Cement Improved Soil and Temperature Analysis of Ground Improved using Deep Cement Mixing Method.'JSSMFE. 1984.," in *Symposium on Strength and Deformation of Composite Ground.*, 1984, pp. 33–40.

[12] A. Saand, M. A. Keerio, and D. K. Bangwar, "Effect of Soorh Metakaolin on Concrete Compressive Strength and Durability," *Engineering, Technology & Applied Science Research*, vol. 7, no. 6, pp. 2210–2214, Dec. 2017, https://doi.org/10.48084/etasr.1494.

[13] M. Janz and S.-E. Johansson, "The Function of Different Binding Agents in Deep Stabilization," Swedish Deep Stabilization Research Center, Linkoping, Sweden, Report 9, 2002.

[14] J. F. Hou and M. Y. Li, "Test on Cement Deep Mixing Soil Strength," *Applied Mechanics and Materials*, vol. 401–403, pp. 738–742, 2013, https://doi.org/10.4028/www.scientific.net/AMM.401-403.738.

[15] S. Horpibulsuk, N. Miura, and T. S. Nagaraj, "Assessment of strength development in cement-admixed high water content clays with Abrams' law as a basis," *Géotechnique*, vol. 53, no. 4, pp. 439–444, May 2003, https://doi.org/10.1680/geot.2003.53.4.439.

[16] P. H. V. Nguyen and P. C. Nguyen, "Effects of Shaft Grouting on the Bearing Behavior of Barrette Piles: A Case Study in Ho Chi Minh City," *Engineering, Technology & Applied Science Research*, vol. 11, no. 5, pp. 7653–7657, Oct. 2021, https://doi.org/10.48084/etasr.4389.

[17] S. Horpibulsuk, N. Miura, H. Koga, and T. S. Nagaraj, "Analysis of strength development in deep mixing: a field study," *Proceedings of the Institution of Civil Engineers - Ground Improvement*, vol. 8, no. 2, pp. 59–68, Jan. 2004, https://doi.org/10.1680/grim.2004.8.2.59.