Ground Improvement using Soil-Cement Method: A Case Study with Laboratory Testing and In-situ Verification for A Highway Project in Southern Vietnam

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ABSTRACT: This article presents the experimental unconfined compressive strength results of soil-cement columns to improve the soft soil gained by Tan Son Nhat–Binh Loi Outer Ring Road Project, located in Ho Chi Minh City, Vietnam. Initially, in the laboratory, two cement materials were chosen to stabilize the soil with different depths, including Stable Soil cement and tower (60%) slag cement. The specimens were prepared by mixing method. Three trial ratios of cement content (i.e. 160 kg/m^3, 200 kg/m^3, and 240 kg/m^3) mixed into soil which obtained from 3m, 6m, 9m, 12m and 15m depths from in-situ. All specimens were cured at the age of 7-, 14-, 28-day with the temperature of 20±3°C. The laboratory test results revealed that the Stable Soil cement has a greater unconfined compressive strength than tower (60%) slag cement and it was suitable with soil condition in this area, irrespective of the curing time and depth. Based on obtained results from three trial cement ratios, the target cement content of 240 kg/m^3 was satisfied not only a required compressive strength (≥ 24 kgf/cm^2) but also a low-cost. In site, the deep mixing method was applied to produce soil–cement columns. The unconfined compressive strength of core specimens was tested at various depths of 3m, 6m, 9m, 12m, and 15m for test piles and official piles. The obtained results are expected to provide an experience for further design and construction in Ho Chi Minh city and its vicinity.

Keywords: Soil-cement method, Sable Soil cement, Tower slag cement, UCS.

1. INTRODUCTION

In recent years, Ho Chi Minh City significantly developed the infrastructure such as road, bridge, dam, and industrial zones. In among them, Tan Son Nhat–Binh Loi Outer Ring Road Project is a typical project, which runs from the Nguyen Thai Son intersection not far from Tan Son Nhat International Airport to National Highway 13, as shown in Figure 1. It has 12 lanes and a total of 13.6 km in length.

This Road is an important part of the ring road, serving to connect Tan Son Nhat International Airport with industrial parks in Binh Duong Province through National Highway 13. It is expected to help reduce traffic, accidents, and pollution on severely congested roads like Xo Viet Nghe Tinh, Dinh Bo Linh, Bach Dang, Phan Dang Luu, and Phan Van Tri streets. In addition, the geological condition in this area belongs to the soft soil. The geological condition in this area and Mekong Delta has been studied by some certain scholars (Ta et al. 2002; Giao et al. 2008).

Generally, any structure laid on soil is generally sustained to settlement and inclined settlement. But for soft soil, the settlement is more significant and greater. Excessive settlement is tipped to cause big problems as it often exceeds the permissible limits. In fact, some constructions were unsafe as building on such soil condition such as settlement, inclined settlement, and disruption. Therefore, it is essential to find out a solution for treating the soft soil condition to ensure a good foundation design against failure as well as differential settlements, especially for Ho Chi Minh City in where the soft soil was distributed in a large area.

Over the past five decades, many soil improvement techniques have been considered and employed in practice, including mechanical stabilization, stabilization using soft aggregates, bituminous stabilization, lime stabilization, cement stabilization, thermal stabilization, chemical stabilization, and electric stabilization. Various admixtures such as cement, fly ash, lime, blast-furnace slag cement, calcium chloride were used in different area in the world (Bardet 1997). Particularly, in among them, cement-soil stabilization (CSS) was known as a well-known method, and was most widely used. Compared to pure soils, CSS has more advantages such as low compressibility, high compressive strength, and its cost efficiency. Due to these significant advantages, CSS has been applied and become popular for improving soil condition (Arulrajah et al. 2009; Consoli et al. 2011; Lopez et al. 2009; Maher et al. 2007; Rollins et al. 2010; Xing et al. 2009; Yilmaz and Ozaydin 2013). Also, the available studies on CSS for soft soil were shortage (Chew et al. 2004; Horpibulsuk et al. 2005; Horpibulsuk et al. 2004; Liu and Starcher 2012; Lorenzo and Bergado 2006; Moses and Rao 2009; Xiao and Lee 2009). It is very essential to fully find the mechanical behavior of CSS to satisfy various requirements in the field. In fact, effects of curing stress on the mechanical behavior (i.e., compressive strength, axial strain) were found to be significant. Regarding curing stress, a few studies have conducted to find the effect of curing stress on strength as well as strain (Consoli et al. 2013; Consoli et al. 2006, 2000; Kuwano and Boon 2007; Liu and Starcher 2012; Taiyab et al. 2012; Yamamoto et al. 2002). In general, based on the previous results, some conclusions were drawn such as when cement content increased, liquid limit decreased, shear strength parameters increased with cement content; unconfined compressive strength (UCS) and isotropic compression strength remarkably increased with the increase in curing time, UCS significantly increases as vertical stress increases.

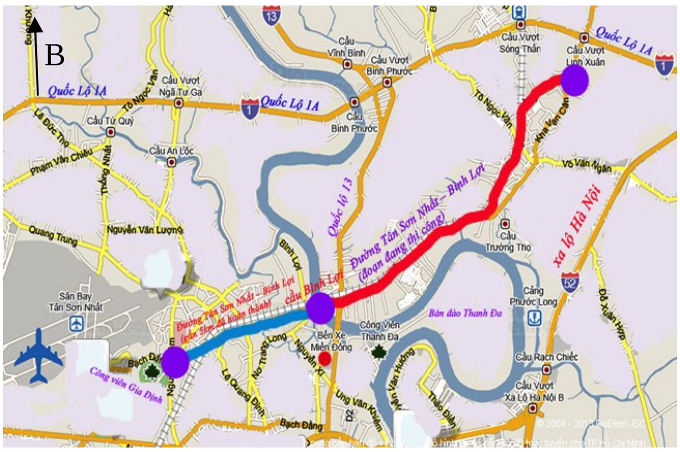


Figure 1 Tan Son Nhat - Binh Loi Outer Ring Road location

In Vietnam, although additives have popularly been used in practice, there were no obvious reports on the strength of using these additives in laboratory as well as in the field. This paper presents a case study on Tan Son Nhat - Binh Loi Outer Ring Road Project. The works consisted of (a) to collect the geotechnical condition to have more understanding the soft soil deposit of this area; (b) to present the laboratory test to determine which type of cement was satisfied with the target compressive strength of design and what is the cement dosage for a 1 m^3 soft soil; (c) to test UCS of the specimens obtained from test piles; (d) to test UCS of specimens obtained from official piles. The experimental data provide a quantitative basis and lesson for further designs, recommendations and practice of infrastructure located both in Ho Chi Minh City and its vicinity.

2. BACKGROUND OF CHEMICAL STABILIZATION

Once the additives such as cement, slag, and lime are mixed with soil with the presence of of water, a series of reactions occurs that produces the dissociation of calcium oxide (CaO) in the binders and the cementitious and pozzolanic gels, such as calcium silicate hydrate gel, CSH, and calcium aluminate silicate hydrate gel (CASH).

$$CaO + H_2O \Rightarrow Ca(OH)_2 \quad (1)$$

$$Ca(OH)_2 \Rightarrow Ca^{2+} + 2[OH]^- \quad (2)$$

$$Ca^{2+} + 2[OH] + SiO_2 \Rightarrow CSH \quad (3)$$

$$Ca^{2+} + 2[OH] + Al_2O_3 \Rightarrow CASH \quad (4)$$

It is noted that the strength is closely related to the type and quality of possible reaction product, such as cement reaction product, CSH for short-term strength and pozzolanic reaction product, CASH for long-term strength gain.

These reactions result in stabilization of soft soil in two ways. Firstly, the above mentioned reactions reduce the plasticity of soft soil by the exchange of calcium ions in the pore water with monovalent cations on clay surfaces and by compression of the adsorbed layer because of the elevated ionic strength of the pore water (Tastan et al. 2011). Secondly, the CSH or CASH gels formed by cementitious and pozzolanic reactions connect and bind the solid particles together, and this process makes a stronger soil matrix (Tastan et al. 2011). For organic soils, mechanism of organic matter interference with strength gain in chemical stabilization can be summarizes as manners (Hamp and Edil 1998; Tastan et al. 2011): (a) organic matter can alter the composition and structure of CSH gel, a cementing compound that forms bonds between particles and also the type and amount of other hydration products; (b) organic materials often contain materials such as humus or humic acid, which retard strengthening reactions; (c) organic matter holds 10 or more times its dry weight in water and may limit water available for hydration; and (d) organic matter forms complexes with alumino silicates and with metal ions, and such complexes interfere with hydration.

3. EXPERIMENTAL PROGRAM

3.1. Engineering properties of soil and soil classification

Due to the inconsistent geological condition of this project, this study thus focuses on the geological condition for the section 2 (from Km 3+ 400 to Km 10 + 600). According to the results of geological survey, the strata can be divided into layers, as indicated in Table 1. According to 22 TCN 262-2000, the subground must be improved before constructing the embankment and pavement structure.

Table 1 Basic physical properties of soil

No.	Layer	Thickness (m)	W (%)	γ (g/cm^3)	e_0	SPT
1	CH/MH	1.1÷27.9	88.1	1.48	2.39	0÷3
	CH	4.6÷10.9	64.3	1.58	1.81	2÷9
2	CH/MH	0.9÷4.8	31.2	1.78	1.005	5÷49
3	Clayey Sand	Unidentified	13.3	2.09	0.466	9÷>50

Based on the results presented in Table 1, the subground is a soft soil layer and it should be treated by an artificial method before constructing the pavement structure and thus soil-cement was chosen to improve the soil improvement in this area.

3.2. Stable soil cement and tower (60%) slag cement

3.2.1. Stable soil cement

Cement stable soil is a special cement of which only designed to stabilize soils with a low bearing capacity. It is well suited for cement deep mixing applications, jet-grouting, and any other type of soil mixing. The properties of cement stable soil result in a high strength for stabilizing of soft soil, in particular for plastic and clayey soils. Test results of basic properties and chemical analysis are shown in Tables 2–3, respectively.

Table 2 Properties of Stable soil cement

Properties	Test results
Compressive strength, MPa	
3 days	21.5
28 days	50.4
Setting time, min.	
Initial	200
Final	415
Fineness, cm^2/g	4420
Specific gravity	3.15

Table 3 Chemical properties of cement stable soil

Composition	L.O.I	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Content (%)	0.8	29.9	11.4	1.6	48.2	4.6
Composition	SO_3	K_2O	Na_2O	TiO_2	MnO	P_2O_5
Content (%)	2.2	0.4	0.2	0.2	0.2	0.0

3.2.2. Tower (60%) slag cement

Tower slag cement is specially blended cement. Soil stabilizations using tower slag cement have chloride and sulphate resisting properties with improved durability. Chemically, granulated blast furnace slag consists of calcium, aluminum, silica, and iron; its components were found to be similar to cement, but different proportions were found. The ground granulated slag is dry-blended together with OPC as per requirements. The hydrated property is accelerated by the presence of calcium hydroxide releasing from mixing Portland cement and water. Test results of basic properties and chemical analysis are shown in Tables 4-5, respectively.

Table 4 Properties of tower (60%) slag cement

Properties	Test results
Compressive strength, MPa	
3 days	19.3
28 days	49.5
Setting time, min.	
Initial	155
Final	225
Fineness, cm^2/g	4570
Specific gravity	3.05

Table 5 Chemical properties of tower (60%) slag cement

Composition	L.O.I	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Content (%)	1.3	27.1	11.5	2.0	48.9	3.7
Composition	SO_3	K_2O	Na_2O	TiO_2	MnO	P_2O_5
Content (%)	2.6	0.8	0.5	0.8	0.6	0.0

3.3. Mix proportions and specimen preparation

In the laboratory, the soil specimen was dried to get a constant weight. Air-dry soil was uniformly mixed with the predetermined percent of the additive. For each additive, three ratios by weight were used, such as 160 kg/m^3, 200 kg/m^3, and 240 kg/m^3. The water-to-cement ratio is 0.8. The specimens were tested at 7-, 14-, and 28-day curing. The aim of the first series of tests was to determine the appropriate ratio of each binder. The cylindrical cement soil specimens of size 5 cm x 10 cm were prepared. The mixtures were poured into the moulds and carefully compacted to avoid the honeycombs. All cylinders were covered with wet burlap for 2 - 3 days and then carefully remould from the moulds. The specimens were thereafter moved into humidity room which had the temperature of 25 ± 20°C and at 100% relative humidity and allowed to cure for 7-, 14-, 28-day, respectively. All samples must be no damages or scratches during demoulding and moving process. Unconfined compression strength was tested by (ASTM D2166-2000), the strain rate was 1%/ min during compression test, each strength result was tested on three specimens and mean value strength was obtained.

In field, the cement was mixed with soil by the deep mixing method up to the depth of 12 to 15 m which depended on the geological condition. The cement-soil specimens were drilled and taken at different depths. Specimens were carefully moved to the laboratory and tested at 28 days curing. During the testing process, all of the specimens were cured by the same condition with a laboratory test.

4. RESULTS AND DISCUSSION

4.1. Laboratory results

As indicated in the introduction, this study just presented the results of UCS in section 2 due to the soft soil condition. To get this process, the method of soil investigation and indoor mixing test to determine the soil profile and the appropriate cement content for the deep mixing column prior to the construction. Soil samples were collected from depths of 3 m, 6 m, 9 m, 12 m, 15 m, and 18 m, as indicated in Table 6:

Table 6 Location and sample depth

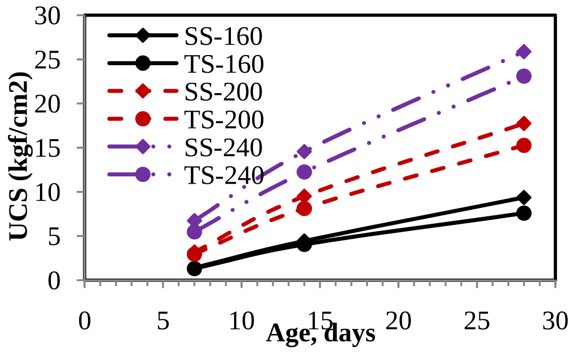
Stage	Location	Sample depth (m)
Preliminary	Km4+400	1 ÷ 3.
Main	Km4+400	3, 6, 9, 12.
	Km8+000	3, 6, 9, 12, 15, 18.

After collecting the soil specimens, the specimens were mixed with cement content of 160, 200, and 240 kg/m^3 and tests were conducted to determine the unconfined compressive strength of soil.

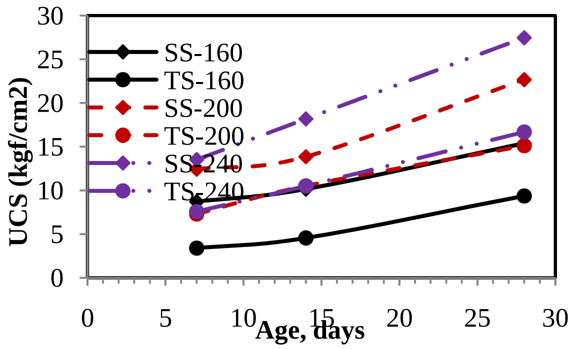
Figure 2 presents the relationship between unconfined compressive strength (UCS) and day curing at different depths of 3 m, 6 m, 12 m, 15 m, and 18 m. It is very clear that strength improves with day curing and higher cement yields greater UCS. In addition, cement stable soil has a stronger strength at the same cement content.The increasing strength with time is inconsistent at day curing less than 28-day. However, when time curing is longer than 28-day, the increasing of UCS is consistent with the increasing of cement content. However, it is noted that there are no specific functions obtained, such as between the cement content and UCS as well as curing day and UCS. Finally, cement stable soil was thus used to mix with soil in the field.

Subsequently, to get the target strength in the field of 8 kgf/cm^2, the strength in laboratory must be chosen as three times as that of in the field. Based on the result of Figure 3, the cement content was chosen as 240 kg/m^3 which yielded the strength equal to or greater than 24 (kgf/cm^2). Thus, it was the target cement content for deep-mixing in the field.

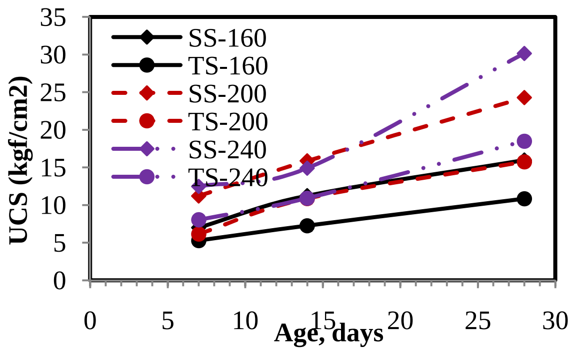
In addition, the strength of soil stabilization is very different with the change in depth. Generally, a deeper depth gives a greater UCS due to better geological condition.



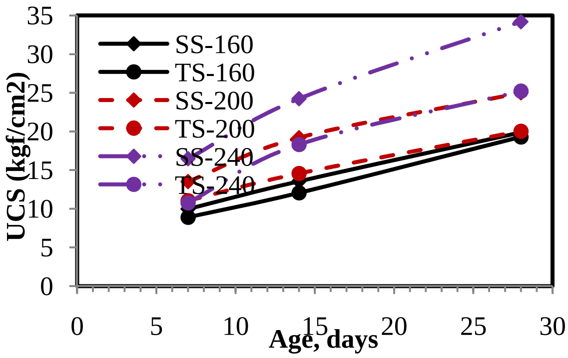
(a) At 3 m depth



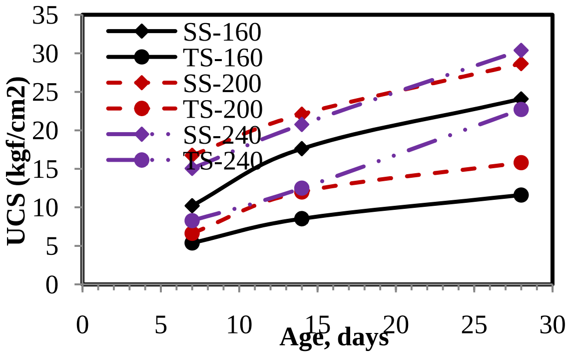
(b) At 6 m depth



(c) At 9 m depth



(d) At 12 m depth



(e) At 15m depth

Figure 2 Various compressive strengths with age (Note: SS-Stable Soil cement; TS-Tower slag cement)

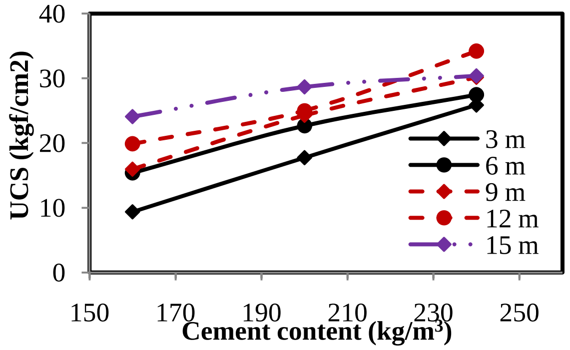


Figure 3 Various compressive strengths with cement content

4.2. Field test results

In the field, cement stable soil was used to inject into soft soil in the field. To get this step, there were two stages to decide how much cement content was used in site, such as test piles and official piles. For the test piles, cement content was in a range from 200 to 250 kg/m^3 with the increment of 10 kg/m^3. The specimen was tested with the dimension of 5 cm x 10 cm at the curing age of 28-day. The results of UCS for 18 test piles are shown in Figure 4. According to the results of UCS from in site, to get the target UCS of 8 kgf/cm^2, the cement content must be chosen as 220 kg/m^3. Thus, this cement content is used for official piles, the results of UCS for 49 official piles are presented in Figure 5.

Based on the results obtained from the site, all data were satisfied the strength of design requirement. However, it is very difficult to determine the relationship between depth and UCS due to the inconsistent geological condition for different areas in this project.

According to the results obtained from the test piles and official piles, it can be concluded that the cement content of 220 kg/m^3 which yields the UCS larger than 8 kgf/cm^2.

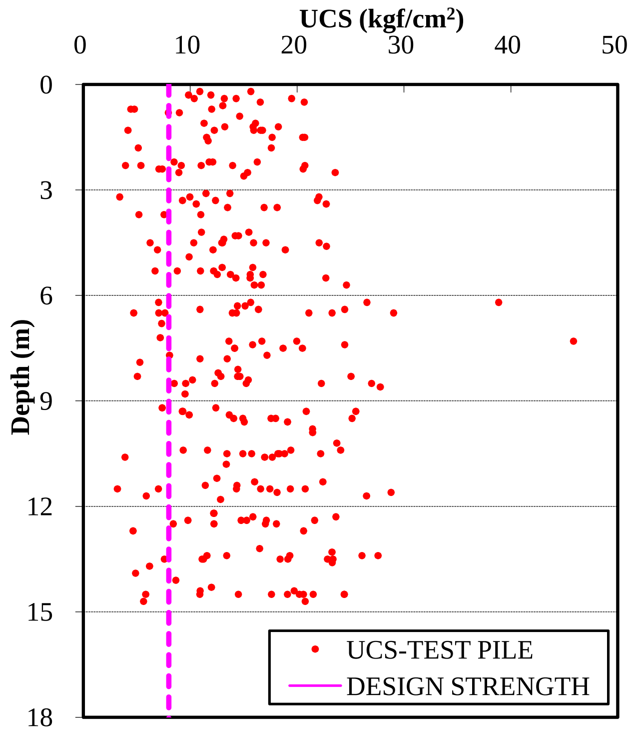


Figure 4 Profile of interpreted compressive strengths with depths of test piles

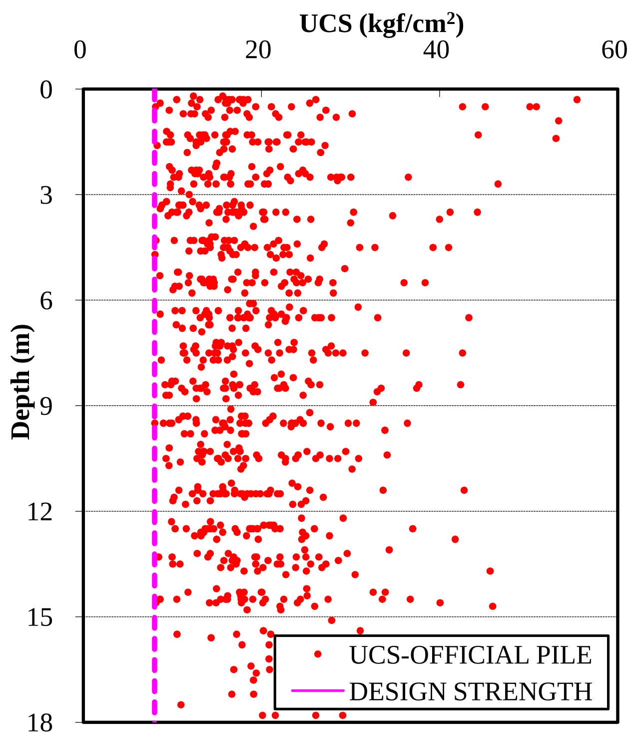


Figure 5 Profile of interpreted compressive strengths with depths of official piles

5. CONCLUSION

Based on the obtained results of soil-cement columns, the following conclusions were drawn:

- The subground in this study was a soft soil layer and it should be treated by an artificial method before constructing the pavement structure and other structure according to Vietnamese current specifications.
- The Cement stable soil was suitable with the improvement of soft soil in this area when comparing with other cements.
- To get the target strength at least of 8 kgf/cm^2, in the field, the cement content should be used with the cement content of 220 kg/m^3.
- The deep mixing method seemed to be a suitable method to improve the soft soil which has a homogeneous strength in Ho Chi Minh City and its vicinity.

6. ACKNOWLEDGEMENT

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