

The Field Quality Assessment of Soft Ground Improvement Using Soil Cement Mixing Technology in Ho Chi Minh City, Vietnam

H.H. Tran-Nguyen^{1*}, P.D. Nguyen², and B. Tran³

¹*Faculty of Civil Engineering, Van Lang School of Technology, Van Lang University, Ho Chi Minh City, Vietnam.*

²*Bach Khoa Ho Chi Minh City Science and Technology Joint Stock Company, HCM, Vietnam.*

³*CEO, Chan Tin Civil Engineering Consulting Company, HCM, Vietnam*

**E-mail: hung.tnh@vlu.edu.vn*

ABSTRACT: The Soil Cement Mixing technology (SCM) was employed to create soilcrete columns to improve soft ground and soilcrete retaining walls for excavation to construct reservoirs Ho Chi Minh City, Vietnam. However, several core samples taken in various field soilcrete columns appeared visually non-uniform material and had unexpectedly low strength during the field quality evaluation. The quality of the massive construction was questionable and needs to be further assessment. The available data such as the soil investigation before the construction, design documents, pilot columns, field quality data, and mixing machine data were obtained. The several field, laboratory tests, and additional soil investigation after the construction were conducted. The core sampling in the field soilcrete columns, the river water and groundwater tests, and the strength of the soilcrete specimens made in the laboratory were performed. The results of the robust analyses from the all data indicates that the very high organic content of the in-situ soil, the low pH of the river water, and the low cement content of 220 kg/m³ were the key factors causing low quality of the field soilcrete columns created by the massive construction. The invalidated operation parameters of the mixing machines which were different from those of the machine used for the pilot tests were also convinced by a significant cause of the low field quality soilcrete.

KEYWORDS: Soft Ground Improvement, SCM, Soilcrete, UCS, and Excavation.

1. INTRODUCTION

The Soil Cement Mixing technology (SCM) is widely utilized for soft ground improvement in Vietnam, particularly in Ho Chi Minh City (HCM), Vietnam (Luong & Tran-Nguyen, 2023a, 2023b; Tran-Nguyen et al., 2022, 2014a; Tran-Nguyen, 2020; Tran-Nguyen & Nguyen, 2013). The SCM mixed cement slurry with in-situ soil creates soil cement mixing columns or soilcrete columns having better engineering properties such as higher strength (Tran-Nguyen et al., 2018, 2017, 2016, 2015a, 2015b, 2014b) and lower permeability (Luong & Tran-Nguyen, 2023a, 2023b; Tran-Nguyen et al., 2022; Kitazume & Terashi, 2013). A research site is located near the Dong Nai River and the Saigon River in Thu Duc City, HCM. The SCM was applied for soft ground improvement as temporary retaining walls for excavation to build reservoirs. Much higher soilcrete strength and lower permeability than that of the in-situ soils were expected. The soilcrete retaining walls were also expected to mitigate the seepage of the groundwater during construction. The soilcrete retaining walls were designed to support the excavation rather than conventional sheet-pile walls. Thus, the soilcrete retaining walls were constructed on a massive scale at the research site. However, the quality of field soilcrete columns produced by the massive construction at the research site did not meet the TCVN 9403:2012 [4], the Vietnam standard for soilcrete quality assessment. More than 30% of the field soilcrete samples had lower strength than the designed strength. The near coastline and disadvantageous geotechnical conditions such as a thick soft clay layer and high organic content in HCM may cause much obstruction for the field quality of soilcrete columns. The high organic content and high salinity of the river water and the groundwater in the in-situ soils, especially in the thick top soft clay layer, can hinder the expected quality of soilcrete columns under conventional conditions. Therefore, the quality of the field soilcrete columns constructed massively needed further evaluation. This paper attempted to assess the field quality of soilcrete columns and to provide guidelines to

improve the field soilcrete quality. Several field and laboratory tests, boreholes for soil investigation, and river water and groundwater tests were carried out for quality evaluation.

2. THE IMPLEMENTATION OF THE FIELD QUALITY ASSESSMENT

2.1 The research location

The investigated project is located in the South-East HCM close to the Saigon River and the Dong Nai River (Figure 1). The location is about 30 km away from the coastline and was covered by thick vegetation before the construction. A dredging sand layer with a thickness of 2-3 m was directly filled over the vegetation layer to level the ground surface before construction. Fully undecayed vegetation was found strapped around the mixing blades during the field SCM construction. The soil investigation has indicated that the thick organic soft clay has very low strength and the soft soil layer needs to be improved prior to construct the designed structures (Table 1).

2.2 The SCM construction

The complete constructed SCM area is shown in Figure 2. The SCM was applied for the soft ground improvement and to create the soilcrete retaining walls for the excavation. This paper focuses on the field quality assessment of the soilcrete retaining walls. The 3 pilot soilcrete columns had a diameter of 1-1.2 m and were constructed in Zone #1. The 3 trial soilcrete columns were conducted in Zone #4 prior to the massive construction using machine #4 (Fig. 3). The water: cement ratio (w:c) was 0.8:1, with cement contents of 220, 240, and 260 kg/m³. The length of the tested soilcrete columns was around 14-15 m depending on the ground surface elevation. The 3 core samples were taken from each tested column at 3 different depths for the quality control. The unconfined compressive strength tests (UCS),

q_u , were conducted on the core specimens, and the results showed that all trial columns achieved the design strength of 0.8 MPa (Fig. 4).



Figure 1 The location of the studied project in Ho Chi Minh City, Vietnam (Google Maps)

Table 1 The geological and geotechnical properties of the soil profile at the research site

Properties	Soft clay	Fine sand	Stiff clay
Thickness, m	8-12	5-8	11-16
SPT	0-2	5-15	10-20
Unit weight, kN/m ³	15.3	19.8	20
Void ratio	1.973	0.635	0.7
Cohesion, kN/m ²	5.8	3.5	25
Friction angle, °	3.8	29	12
Organic content, %	14.8-28.5	-	-

The massive construction was executed by three different machines in different zones, based on the good results of the pilot columns, as shown in Fig. 3. However, the random core samples from the field soilcrete columns exhibited lower strength than the design. The zero strengths of the several field specimens were reported to illustrate that the field specimens were taken but the samples cannot be molded due to the high organic contents found (Fig. 5). There was questionable whether the massive soilcrete columns meeting the required quality of the TCVN 9403:2012 standard even though there were number of specimens meeting the designed strength (Fig. 5). The robust field quality assessment was conducted. Several field and laboratory tests, including core sampling, soil investigations and UCS tests on the laboratory specimens, were performed.

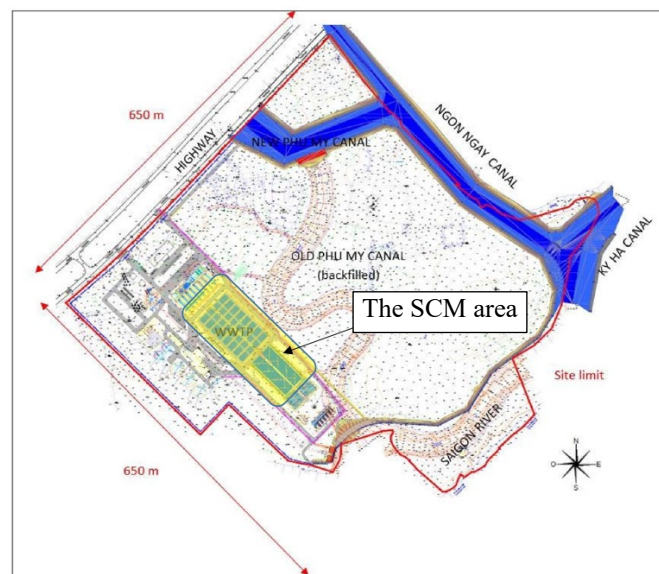


Figure 2 The soft ground improvement area using the SCM in the studied project

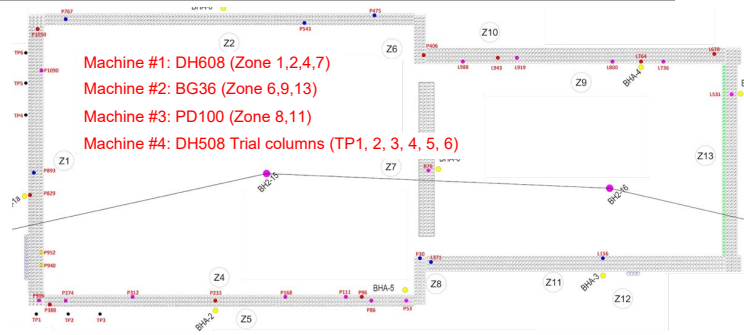


Figure 3 The field layout of the soilcrete columns created by the four different mixing machines

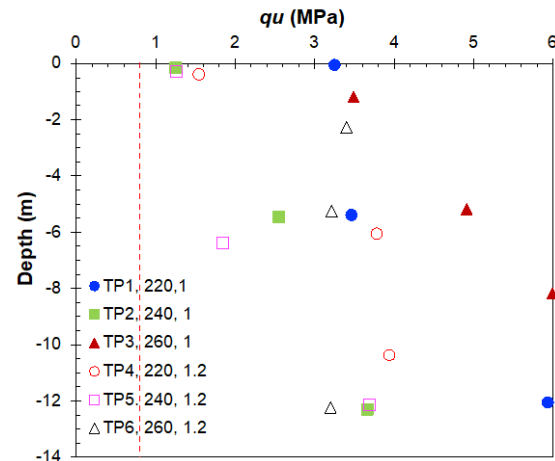


Figure 4 The UCS of the core samples taken in the 6 tested columns at the age of 28 days

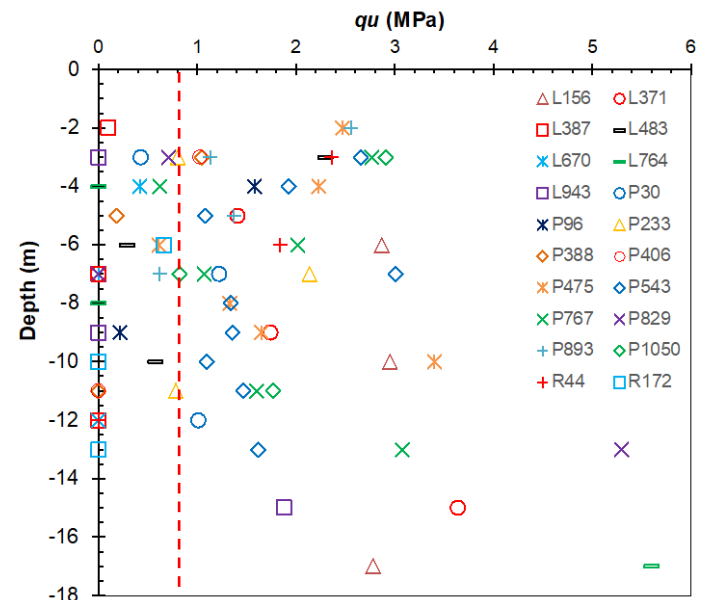


Figure 5 The UCS of the field core samples constructed massively based on the tested columns (by the constructor)

3. RESULT AND DISCUSSION

3.1 The UCS of the field soilcrete columns

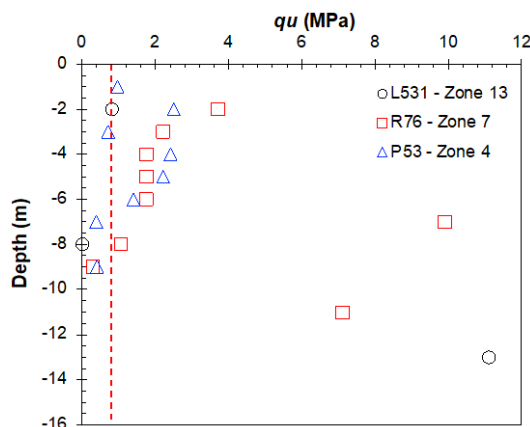
All UCS values of the pilot columns were greater than the design UCS of 0.8 MPa, and the UCS increased with an increase in the cement content (Tran-Nguyen, 2020; Tran-Nguyen et al., 2018, 2017, 2016, 2015, 2014, 2013). However, the increasing trend of the UCS was inconsistent, such as the strength of the TP6 columns (Fig. 4). Fig. 5 shows all strengths of field core soilcrete samples taken at 28 days after construction. The UCS of several field specimens constructed

massively was smaller than the designed UCS of 0.8 MPa. It is noted that the 3 mixing machines used for the massive construction were different from the machine #4 in terms of types and operation parameters.

Fig. 6 exhibits the strength of all 3 additional core samples in the 3 soilcrete columns (L531-zone 13, R76-zone 7, P53-zone 4) taken at the field randomly for a double check. The 3 core samples taken along the 14-m depth of each soilcrete column were visually not uniform (Fig. 6a), and the UCS also fluctuated; especially, several UCS values were lower than the designed UCS of 0.8 MPa (Fig. 6b).



(a) A core sample taken in the L531 column in Zone 13



(b) The UCS of the all core specimens

Figure 6 The UCS of the core specimens taken randomly from the 3 columns constructed massively at the 3 different zones

3.2 Organic content (OC)

Fig. 7 displays the organic content of the soft clay layer from the 4 20-m boreholes conducted for the soil investigation after the massive construction and the collected data before the construction. The organic contents of 15% to 28% (B1-B4) were much higher than the reported organic contents of 4% to 15% from the soil investigations before the construction (H1-H4) (Fig. 7). The higher OC found in the top soil layer may be due to an increase in decaying more vegetation. A high OC in the in-situ soil induces humic acids, causing low pH and delaying chemical reactions in soilcrete. Much of the published research has concluded that organic content of 2% or higher in in-situ soils significantly reduces soilcrete strength (Tran-Nguyen, 2020; Tran-Nguyen et al., 2018, 2016, 2015, 2014; Tran-Nguyen & Quach, 2017a, 2017b; Kitazume & Terashi, 2013).

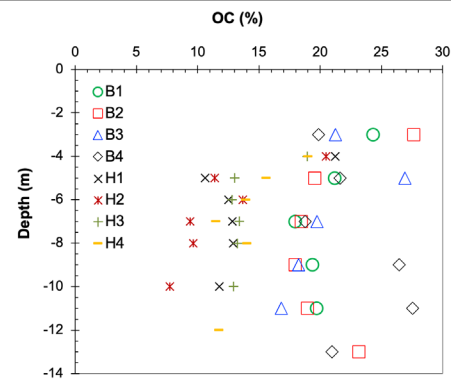


Figure 7 The organic contents along the depth of the soft clay layer

3.3 The river water and groundwater

The pH and salinity of the river water and groundwater were still within acceptable limits according to TCVN 4506:2012 (Table 2). However, the site is about 30 km away from the sea, which is within the circle influenced by seawater. The low pH and high salinity in the water are believed to cause the low strength of soilcrete columns (Kitazume & Terashi, 2013). Fig. 8 demonstrates that the soil strength of the specimens made from the tap water was greater than that of those created from the river water. The result suggests that tap water should be used to mix with cement to create cement slurry.

Table 2. The water properties collected (7 specimens) and tested (5 samples) at the research site (mg/l)

	pH	Cl ⁻	SO ₄ ²⁻	Dissolved solid	Suspended solid	Organic content
River water	6.9-7.78	60-515	30-278	300-1220	10-135	1-3
Ground water	6.7-6.9	120-130	69-75	520-530	NA	NA

3.4 The operation parameters of the mixing machines

The mixing machines (#1, #2, #3) for the massive construction were different from the mixing machine for the pilot soilcrete columns (#4). The operation parameters and the mixing blades of the machine #4 are shown in Fig. 9a and those of the machines #1, #2, and #3 in Fig. 9b, 9c, 9d, respectively. It can be seen that all operation parameters and the mixing blades were changed to speed up the construction progress. Each soilcrete column created massively was faster by 10-30 minutes than those of the pilot soilcrete columns which took time to finish from 50 to 92 minutes per column. However, the operation parameters of the machines #1, #2, and #3 were not validated prior to the massive construction. The field soilcrete quality is strongly influenced by a set of the operation parameters of a mixing machine (Tran-Nguyen, 2020; Tran-Nguyen et al., 2017; Kitazume & Terashi, 2013). The higher speed of the mixing machines, without pilot tests, is believed to cause non-uniform soilcrete in the field.



(a) 0.5 m/min (down), 1.1 m/min (up), rotation 17 rpm

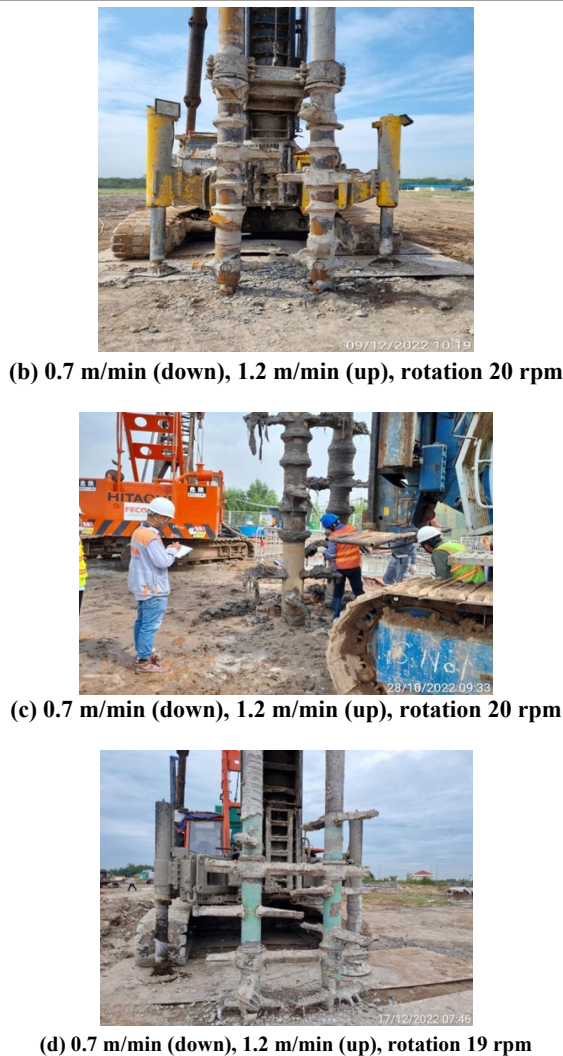


Figure 8 The 4 mixing machines used to create soilcrete columns at the research site

3.5 The UCS of laboratory specimens

To validate the field conditions, 4 sets of soilcrete specimens were molded in the laboratory (50 mm in diameter and 100 mm in height) from in-situ soil samples. The river water and tap water were also used to prepare a cement slurry ($w:c = 0.8:1$) for mixing with the in-situ soil sample at a cement content of 220 kg/m^3 . The 12 specimens were tested for strength at curing times of 21 and 46 days (Fig. 8). The UCS of all specimens was greater than that of the designed strength, but the field strength is only expected to be 0.5 - 0.7 times the strength in the laboratory (Kitazume & Terashi, 2013; TCVN 9403:2012). The strength of specimens created from the river water was lower than that from the tap water. This result suggests that the river water should not be used to mix with cement before mixing with the in-situ soil. The lower field strength of the soilcrete columns created by the massive construction is believed due to the low cement content of 220 kg/m^3 and the river water. Further, the field soilcrete strength is usually lower than the laboratory strength, from 0.5 to 0.7 times (Kitazume & Terashi, 2013; TCVN 9403:2012).

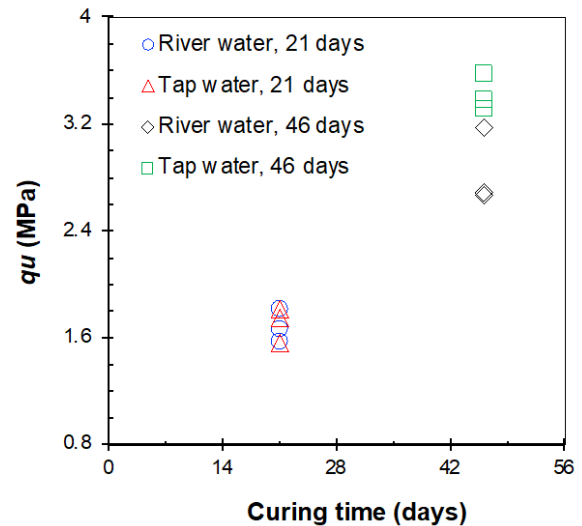


Figure 9 The UCS of the soilcrete specimens in the laboratory at the curing times of 21 and 46 days

4. CONCLUSIONS

To interpret the low field quality of the soilcrete columns constructed massively, 3 core samples were randomly drilled from the 3 soilcrete columns located in the 3 different zones. The 4 20-m boreholes were drilled for the additional soil investigation after construction. The set of 12 soilcrete specimens was prepared in the laboratory for soilcrete strength verification. The pH and salinity of the river water and groundwater were also collected and conducted. All available field data, such as the 6 pilot columns, the strength of the 23 core samples, the soil investigations before the construction, the groundwater (3 samples) and river water tests (9 specimens), and the operation parameters of the 4 mixing machines, were collected and robustly analyzed. The findings are drawn as the followings:

- (1) The cement content of 220 kg/m^3 was not enough to improve the high organic content of 15% or more in the in-situ soil to create the designed quality soilcrete.
- (2) The river water with unstable properties due to being close to the sea was unsafe to use to mix with cement prior to mixing with the in-situ soil.
- (3) The operation parameters of the mixing machines were too fast to mix soil-cement uniformly, especially as the operation parameters were different from those of the pilot tests.

Some possible solutions can be applied to improve field soilcrete quality as the followings:

- (1) A higher cement content of 240 kg/m^3 can be used instead of 220 kg/m^3 to improve the quite high organic content soft clay layer.
- (2) Tap water should be used instead of the river water.
- (3) A new set of the operation parameters of a mixing machine should be used and needs to be validated prior to massive construction.

5. ACKNOWLEDGMENTS

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