

BEHAVIORS OF FIELD SOILCRETE CREATED BY A LIGHT WEIGHT EQUIPMENT SYSTEM TO REINFORCE AN EARTH LEVEE IN VIETNAM

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Abstract: The current techniques reinforcing earth levees in the Mekong Delta have been less effective. The soil cement deep mixing technology (SCDM) using a small light weight equipment system has high potential to reinforce earth levees effectively and sustainably due to utilization of the in-situ soils. This paper investigated characteristics of field soilcrete created by a small light weight equipment system known as the NSV system in Dong Thap province which is one of thirteen provinces in the Mekong Delta. A 30-m soilcrete wall was completely constructed using the NSV in Dong Thap province. A 0.5-m thick wall of single row soilcrete columns and a 1-m thick wall of double row soilcrete columns with a depth of 8 m were built in 15 m long. Unconfined compressive strength test (UCS) was employed to determine the strength and stiffness of soilcrete specimens. About 60 soilcrete specimens were successfully made and tested using a UCS instrument in laboratory. Unconfined compressive strength, q_u , inside a soilcrete column was higher than those of the designed strength about 4 to 5 times. The q_u of 2-column overlapped locations was higher than those of inside columns about 1.6 to 2.5 times. The q_u of 3-column overlapped locations was lower than those of inside columns about 1.4 to 1.6 times. Ratio of secant modulus of elasticity to UCS is about 28 to 140 times.

Keywords: *Deep mixing method, unconfined compressive strength, secant modulus of elasticity, earth levee, soilcrete.*

1.0 Introduction

Dong Thap province has about 6.000 km long earth levees to protect paddy fields against annual floods and to utilize as rural roads for ground transportation (Dong Thap People's Committee, 2012, 2014). Dong Thap province locates in the upstream of the Mekong River when the river reaches the Vietnam land and has been influenced by annual floods from the Mekong River. Earth levees in Dong Thap province have often collapsed in flood seasons due to internal erosions or piping under flood water pressure. Sliding is another type of earth levee failures in Dong Thap province. The Dong Thap government has spent effort to treat earth levee failures to mitigate losses every year.

However, the local government has prevented earth levee failures ineffectively and they have spent millions of US dollars annually to repair earth levees. Earth levees in Dong Thap province have been constructed using dredging materials in a river along an earth levee. The dredging materials were often piled up and were compacted by self-weight. As a result, high void spacing remains in an earth levee body. Annual flood water seeps through void spacing and washes out soil particles to create piping. Some section of an earth levee can be broken when the piping is critically developed. In addition, sliding of earth levees can occur because of local sliding that triggers larger sliding of some sections of an earth levee under flood-dry cycles. The current solutions are usually temporary or high budget required or additional materials transporting from other places. Therefore, new technologies that can be applied to reinforce earth levees with least additional materials are crucial for the Dong Thap government. This study investigates characteristics of soil-cement mixing or soilcrete created at the field using a system of small light weight machines (or NSV technology) to protect an earth levee against annual floods in Dong Thap province.

This paper evaluated quality of soilcrete created by the NSV technology in the research site to form soilcrete walls. The characteristics of field soilcrete were assessed by UCS tests and excavation to expose soilcrete columns for shallow parts (≤ 3 m) of soilcrete columns. The results help to compare with the design targets and to generate guidelines how to apply the NSV massively to reinforce earth levees in Dong Thap province and the Mekong Delta.

2.0 Research Location

A field experiment for the NSV technology was chosen at a 30-m section of 2/9 Canal at An Hoa ward, Tam Nong district, Dong Thap province (Figure 1). The 2/9 Canal is typical earth levees employed as rural roads in Dong Thap province. In general, earth levees in Dong Thap province protect paddy fields and serve local ground transportation. This earth levee was constructed using dredging materials taken along the 2/9 Canal, piled, and self-compacted, that is, a typical construction technique to build earth levees in Dong Thap province. The embankment width is 3-5 m at an elevation of 5 m above the sea level. A 25-m borehole was drilled to investigate soil properties along the soil profile. Key soil properties along the soil profile are given in Table 1.

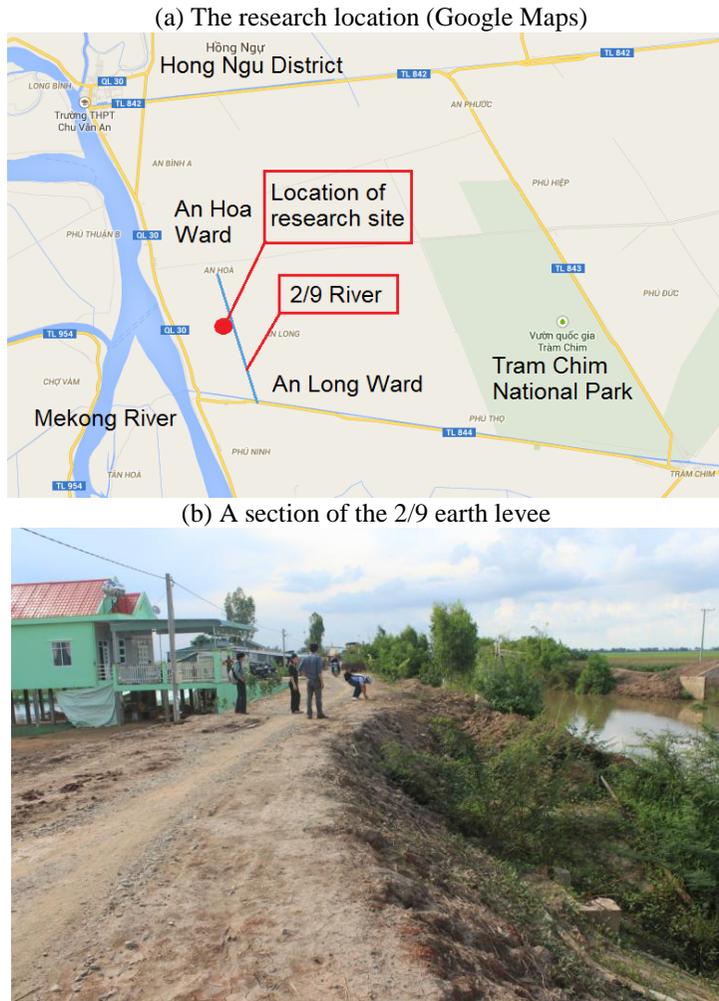


Figure 1: A research site at An Hoa ward, Tam Nong district, Dong Thap province, Vietnam

3.0 Field Trial Construction

3.1 Cement Slurry

Cement slurry was made by a ratio of water to cement (w:c) of 0.7:1, a w:c used in the laboratory (Le Khac Bao *et al.*, 2014). Water in the 2/9 canal that water quality was tested and ordinary Portland cement PCB40 meeting the TCVN 6260:2009 code (Ministry of Construction, 2009) were used for the field experiment.

Table 1: Key soil properties along the 25-m soil profile (LAS XD475, 2013)

Properties	Medium clay	Soft clay	Stiff clay
Thickness (m)	4.6	2.9	7.0
Liquid limit, $LL(\%)$	35.9	53.8	30.2
Plasticity Index, $PI(\%)$	14.7	27.5	13.0
Moisture content, $w(\%)$	27.6	61.5	22.0
Natural unit weight, γ_w (kN/m ³)	19.4	16.0	20.3
Secant modulus of elasticity, E_{50} (MN/m ²)	2.9	0.7	4.9
Unconfined compressive strength, q_u (kN/m ²)	151.3	33.9	77.5
Standard penetration test, N	8	1	14
pH (%)	7.8	7.4	7.6
Organic content (%)	5.3	4.7	2.6

3.2 Trial Construction

The construction was carried out according to the design conducted by Le Khac Bao *et al.* (2014). A 30-m earth levee was divided into the 2 15-m sections as the follows (Figure 2, 3):

- (1) Section 1: 15-m double row soilcrete columns of 600 mm in diameter with a depth of 8 m. A cement content of 250 kg/m³ was employed.
- (2) Section 2: 15-m single row soilcrete columns of 600 mm in diameter with a depth of 8 m. A cement content of 300 kg/m³ was employed. Two trial soilcrete columns with cement content of 150 and 200 kg/m³, respectively, were also conducted to investigate field soilcrete varying with cement contents.

A small and lightweight equipment system called the NSV (Figure 4) was utilized to form 0.6-m diameter soilcrete columns at the field. The equipment can create a maximum depth of a soilcrete column of 12 m which is enough for this field experiment.

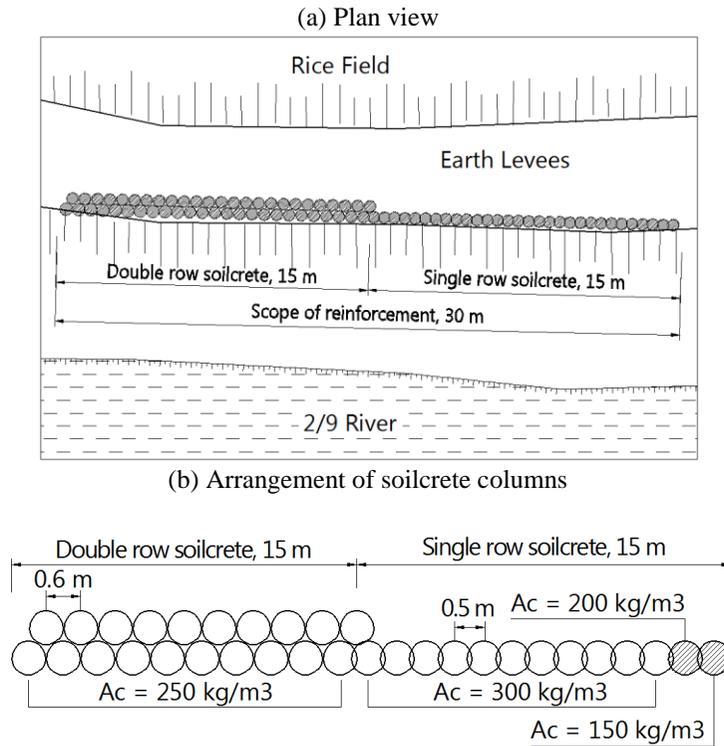


Figure 2: A 30-m trial reinforcement using the NSV system in Dong Thap province, Vietnam

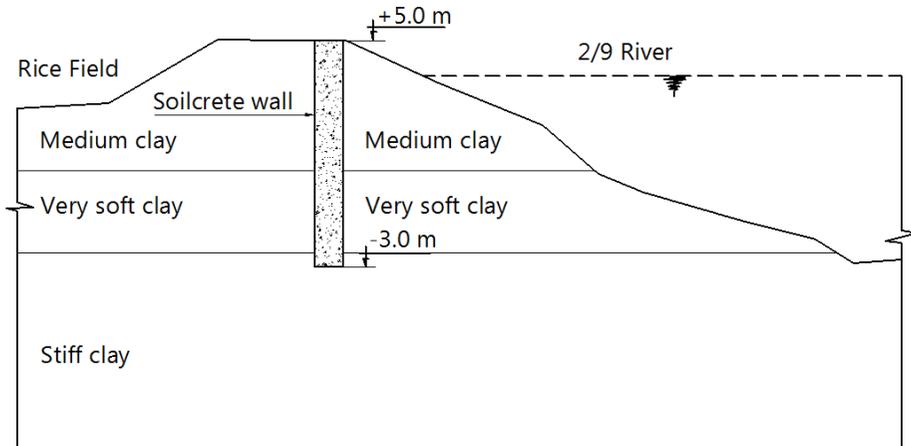


Figure 3: A typical cross-section of the reinforced earth levee in Dong Thap province, Vietnam

(a) The mixing blade of the NSV technology



(b) The NSV equipment



Figure 4: The NSV equipment used for the field construction in Dong Thap province, Vietnam

Key steps of the field construction:

- (1) Determine position of soilcrete columns at the site.
- (2) Perform calibration for the NSV equipment, and conduct the two pilot tests.
- (3) Construct soilcrete columns to form soilcrete walls according to the design.

4.0 Quality Assessment

Excavation to expose soilcrete columns for shallow parts (≤ 3 m) and full-length core borehole sampling are two typical techniques to assess field quality of soilcrete columns (Tran-Nguyen *et al.*, 2013a, 2014a). Figure 5 shows how to excavate soilcrete columns to examine visually soilcrete dimensions at the field. Figure 5(b) displays how to mark positions for drilling core boreholes.

Drilling to take core samples for full depth of soilcrete columns is another technique to verify field soilcrete quality such as soilcrete strength, stiffness, and uniformity. Six locations were chosen for drilling core samples as shown in Figure 7. A XY-100 drill machine was used to take core samples at the field (Figure 6). Procedure to take core samples follows Vietnam code of 22 TCN 259-2000.

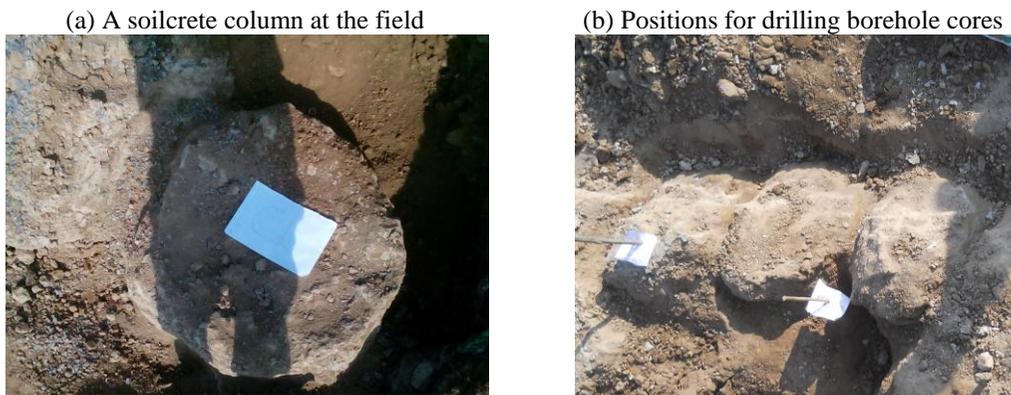


Figure 5: Demonstration of excavation to expose soilcrete columns at the field

(a) A XY-100 drill machine

(b) A double Shelby tube



Figure 6: A XY-100 drill machine and a double Shelby tube used to take core samples at the field

Unconfined compressive strength tests (UCS) on field core specimens were utilized to determine unconfined compressive strength q_u and secant modulus of elasticity E_{50} for examining field soilcrete behaviors. The UCS test follows the ASTM D-2166 (ASTM, 2013), ASTM D-1633 (ASTM, 2007), and TCVN 9403:2012 (Ministry of Construction, 2012). Soilcrete specimens were modified from the core sampling with a diameter of 68 mm and a height of 140 mm so that a ratio between the specimen heights to its diameter is not less than 2.0. The load rate applied on a soilcrete specimen during a test to create vertical displacement was less than 1 mm per minutes. Figure 8 demonstrates how a UCS test was setup in the laboratory. The target of the UCS tests was to conduct UCS tests for each meter in deep along a soilcrete column and at least 1 specimen per each soil layer. The UCS tests were performed on cement contents of 150, 200, 250, and 300 kg/m^3 , respectively.



Figure 7: A core sample taken at the VT3 and VT4 locations



Figure 8: A soilcrete specimen made and a UCS test setup on the TSZ30-2.0 triaxial instrument in the laboratory according to ASTM D-2166, ASTM D-1633, and TCVN 9403:2012.

5.0 Results and Discussion

Based on unconfined compressive strength test (UCS) results, field measurements, and visual investigation on 6 full-depth core samples of soilcrete columns (Figure 5, 6, 7, 8), quality of field soilcrete was assessed. All soilcrete specimens were conducted using the

UCS tests. Quality and behaviors of field soilcrete were investigated via continuity and uniformity, strength to compare with the design, strain at failure, and E_{50} versus q_u .

5.1 Uniformity of Field Soilcrete versus Depth

Visual observation on field core samples indicates that the field soilcrete formed quite uniformly along depth of the soilcrete columns drilled (Figure 5, 6, 7, 8). The soilcrete specimens taken from medium and stiff clay layers appeared more uniform than those of the soft clay layer. However, some insignificant parts of VT1 and VT5 boreholes exposed soil-cement scattered (Figure 9).

Overlapped locations between two (VT2) or three (VT3) soilcrete columns (Figure 9) were uniform along the depth and looked stiffer than soilcrete samples taken at the center of a soilcrete column. For the VT2 location, soilcrete samples were believed to be higher cement content than those of inside soilcrete columns due to additional cement content and mixing energy. For the VT3 locations, soilcrete appeared homogenously even though the locations remain some parts unmixed according to the design (Figure 9). Cement content existing in the VT3 locations is thought as vibration of the mixing blade around its center during the construction making soilcrete diameter bigger with depth. Thus, soilcrete walls are believed to be formed uniformly with depth even though soilcrete at some locations remains less uniform.

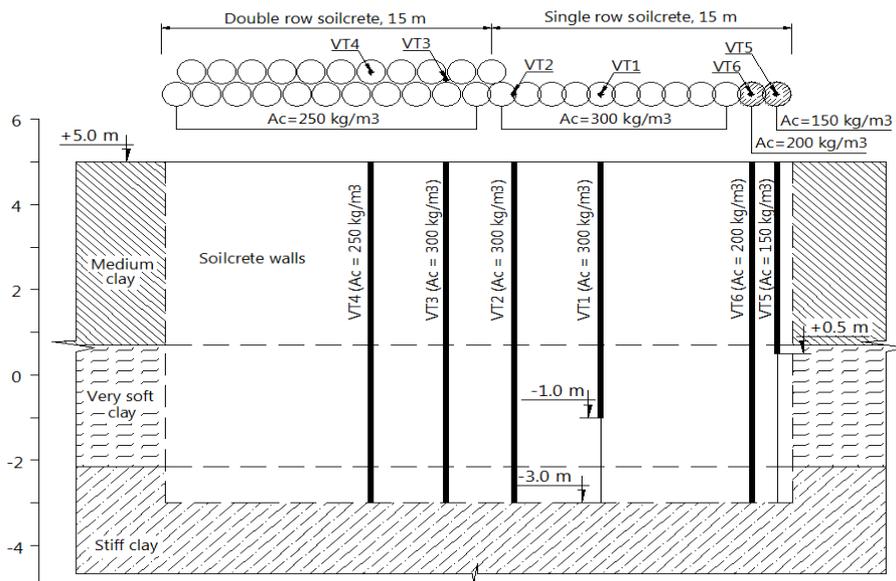


Figure 9: Locations of the drilling core boreholes to take field soilcrete samples and appearance of soilcrete along the soilcrete columns

5.2 Soilcrete Strength versus Depth

Soilcrete strength of specimens taken at the center of a soilcrete column (VT1) was smaller than those at the overlapped locations (VT2) (Figure 10a). These locations were on the single row soilcrete columns with a cement content of 300 kg/m^3 . It can be seen that q_u along the VT2 borehole was greater than those of the VT1 about 1.6 to 2.5 times and higher the designed q_u of 0.35 MPa about 5 times (Figure 10a). The result indicates that cement content and mixing frequency in the overlapped locations were higher than those of inside soilcrete columns.

On the contrary, soilcrete strength of specimens taken at the center of a soilcrete column (VT4) was higher than those at the overlapped locations (VT3). These locations were on the double row soilcrete columns with a cement content of 250 kg/m^3 . It can be seen that q_u along the VT4 borehole were greater than those of the VT3 about 1.5 times and higher the designed q_u about 4 times (Figure 10b). The above result indicates that a cement content and mixing frequency in the overlapped locations were lower than those of inside soilcrete columns, and vibration of the mixing rod and mixing blade generated soil-cement mixing in the VT3 locations even though the VT3 locations have no soilcrete based on the design. In the VT3 locations, soilcrete was only formed by vibration of the mixing blade during construction. Thus, soilcrete may be less cement and mixing energy than inside 0.6-m diameter of a soilcrete column.

5.3 Soilcrete strength versus soil types

q_u in the soft clay layer was the lowest among those in the medium and stiff clay layers (Figure 11). q_u of soilcrete created in the laboratory provided similar soilcrete behaviors (Le Khac Bao *et al.*, 2014; Mai Anh Phuong *et al.*, 2014; Tran-Nguyen *et al.*, 2014b). About 5% organic content in the soft clay layer is believed to be the main factor causing low soilcrete strength to compare with other clay layers (Kitazume and Terashi, 2013; Kamruzzaman, 2002). High water content of 61.8% which is higher the Liquid Limit of the soft clay layer (53.8%) (Table 1) also caused low soilcrete strength (Kamruzzaman, 2002). For the medium and stiff clay layers, q_u was high even at a low cement content of 150 kg/m^3 (Le Khac Bao *et al.*, 2014). The trial construction was carried out in the dry season which is in February 2014, and the water content on medium stiff clay layer was quite lower than its *LL*. The construction was performed into two steps: (1) inject water, cut, and mix with the in-situ soils before (2) inject cement slurry and mix to form soil cement mixing. The construction technique provided high mixing energy and suitable moisture content for the medium clay layer (Tran-Nguyen *et al.*, 2013b). As a result, q_u was higher than that of other layers.

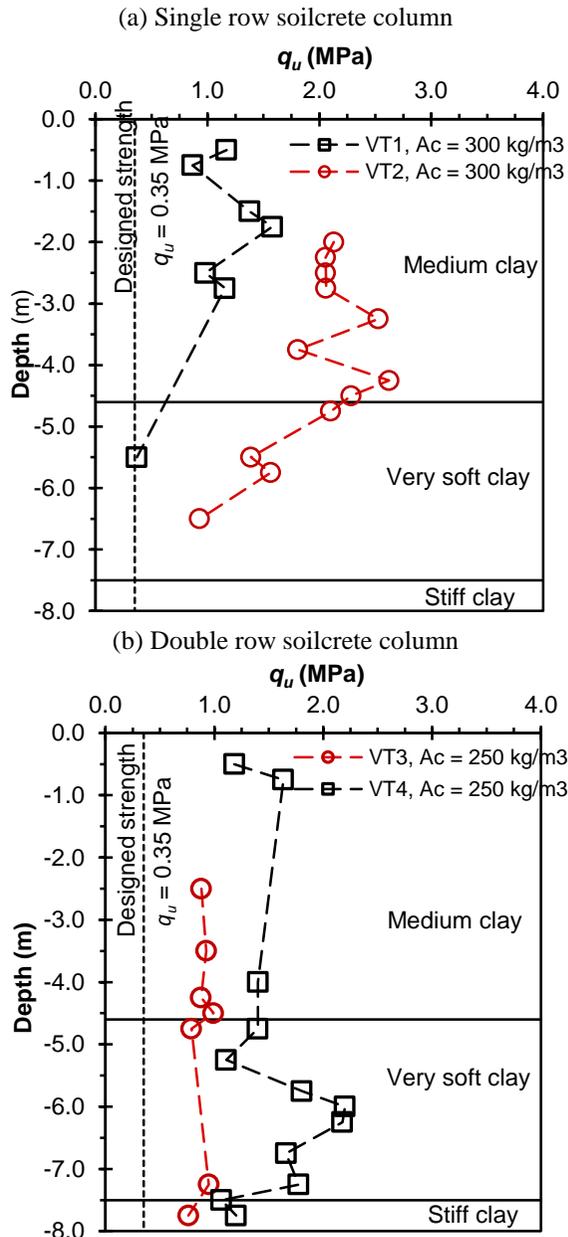


Figure 10: Unconfined compressive strength versus soilcrete depth

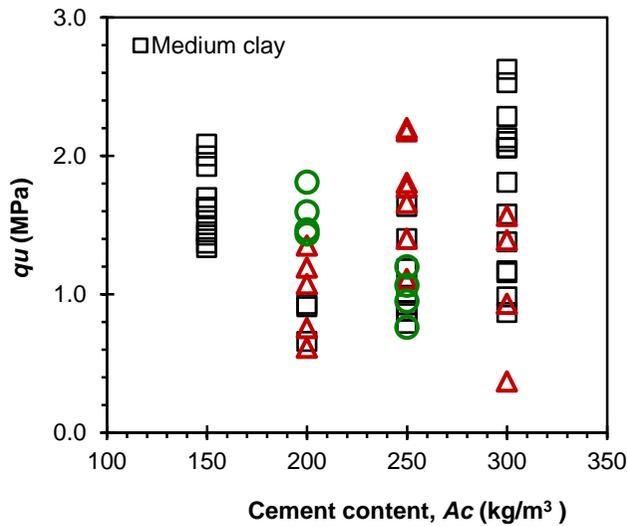


Figure 11: Soilcrete strength, q_u versus soil types

5.4 Soilcrete Strength Varying with Cement Contents

In this field experiment, the 4 nominal cement contents of 150, 200, 250, and 300 kg/m³ were applied and the first two cement contents were only used for pilot tests (VT5 and VT6). q_u increases slightly with increasing in cement contents (Figure 12). However, the field cement contents were quite different from the nominal contents as shown in Table 2. The nominal cement contents of 150 and 200 kg/m³ were 300 and 250 kg/m³, respectively, after the construction. These results explain why q_u was not significantly various with the cement contents. The field q_u was also much higher than the designed q_u of 0.35 MPa.

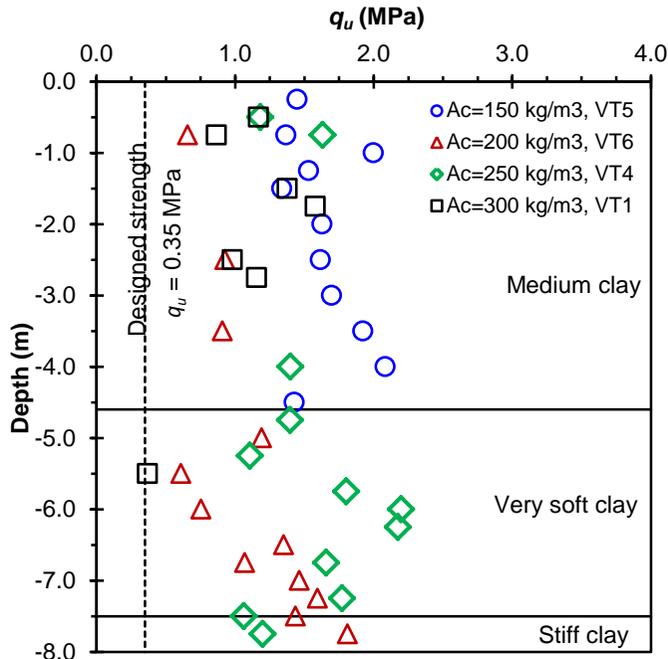


Figure 12: Soilcrete strength, q_u varying with cement contents and depth

Table 2: Cement contents at the field and the design

Nominal cement content, A_c-tk (kg/m^3)	150	200	250	300
Field cement content, A_c-tc (kg/m^3)	308	279	254	311
A_c-tc/A_c-tk	2.07	1.40	1.01	1.04

5.5 Effect of Mixing Frequency on Soilcrete Strength

Table 3 shows variation of mixing frequency of the mixing blade per meter depth of a soilcrete column (T – rounds per meter). With T varying from 164 to 202 rpm, soilcrete appeared uniformly based on the field observation on soilcrete core samples. In general, the higher T , the greater q_u is, but the more energy is consumed (Larsson, 2005).

Table 3: Average mixing frequency of the mixing blade per meter depth of soilcrete column

	Nominal cement content (kg/m^3) – core drilling location			
	150–VT5	200–VT6	250–VT4	300–VT1
T (rpm)	164	192	181	202

5.6 Strain at Failure under Unconfined Compression

Figure 13 displays strain at failure (ϵ_f) of all soilcrete specimens under unconfined compression. Typically, ϵ_f varied from 1% to 3% and was much lower than the in-situ soils which are around 10%. A range of failure strains of field soilcrete specimens is close to those of laboratory soilcrete specimens which is around 1% to 2% (Le Khac Bao *et al.*, 2014; Mai Anh Phuong, 2014; Tran-Nguyen *et al.*, 2014b, 2013a). The results indicate that small amount cement of 10% to 20% can change significantly behaviors of the in-situ soils. In other word, soilcrete behaves like brittle materials. An average q_u of 1.5 MPa was at a failure strain of 1.8%, whereas the q_u of the in-situ soils were less than 0.1 MPa at a failure strain of 10% or more (Table 1).

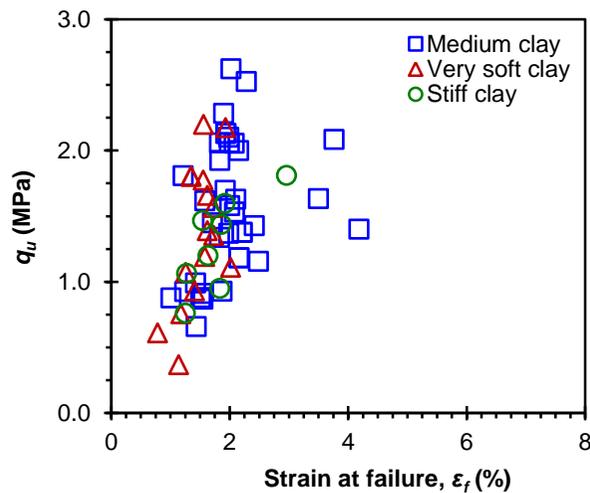


Figure 13: Strain at failure of soilcrete specimens, ϵ_f

5.7 Variation of Secant Modulus of Elasticity with Soilcrete Strength

A ratio E_{50}/q_u varies from 28 to 140 (Figure 14) and this result is quite lower than those reported in literature such as Le Khac Bao *et al.* (2014) (50 to 350), Niina *et al.* (1981) (350 to 1000) (from Kitazume and Terashi, 2013), and Tran-Nguyen *et al.* (2013a, 2013b) (100 to 250). The results indicate that the surfaces of some soilcrete specimens may be not perfectly parallel during the UCS tests and may cause local failures at the surfaces before a specimen reaches the full failure state.

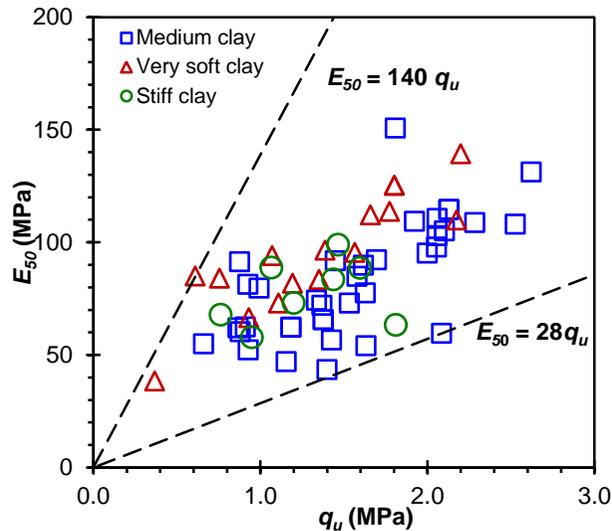


Figure 14: Secant modulus of elasticity, E_{50} versus q_u

6.0 Conclusions

A 30-m section of an earth levee along the 2/9 Canal was completely constructed in An Hoa ward, Tam Nong district, Dong Thap province. About 60 soilcrete specimens with 68 mm in diameter and 140 mm in high were successfully made from 6 core boreholes taken at the field for field quality assessment according to ASTM (2012). Excavation to expose soilcrete columns was applied for visual observation and measurement. All soilcrete specimens were conducted by unconfined compressive strength tests at a curing time of 240 days.

- (1) Soilcrete walls were uniformly created by the NSV technology.
- (2) Field soilcrete strength was higher 4-5 times than the designed strength.
- (3) At overlap locations, soilcrete was formed and soilcrete strength was higher than that of the design.
- (4) Soilcrete strength in the soft clay layer was the lowest among the soil layers.
- (5) Strain at failure from 1% to 2.5%, or soilcrete is a brittle material.
- (6) A ratio of the secant modulus of elasticity to unconfined compressive strength varying from 28 to 140.

7.0 Acknowledgements

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