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Enhancing riverbank stability: A case study on soil improvement through Jet grouting along Can Tho riverbank

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ABSTRACT

Soil cement mixing (SCM) using a high-pressure grouting method (Jet grouting), considered an improvement solution for soft soil has been popular in countries, especially in Japan and other countries in Northern Europe. However, the implementation of Jet grouting is still quite modest in the Mekong Delta. In this study, the depth effect on the compressive strength of soil-cement mixing is conducted at the Can Tho River embankment project. The results show that the uniformity of SCM depends on the cement content. The higher cement content gives a better distribution of compressive strength from the bottom to the top of SCM. In this study, the cement content of 400 kg/m^3, considered the suitable content for the Jet-grouting method in Can Tho, is much higher than in (TCVN 9906:2014).

1. INTRODUCTION

The soil improvement method with soil-cement mixing (SCM) was first proposed and deployed in Japan in the late 1960s and, after 10 years, was applied to other countries around the world (Kitazume & Terashi, 2013). The advantages of SCM compared to other ground reinforcement methods such as applying to many types of soil at different depths without breaking the superstructure, constructing fast in tight conditions (Guler & Gumus Secilen, 2021) and is highly effective, increasing load-bearing capacity and reducing ground settlement (Wang et al., 2019). The operating principle of soil cement mixing is to create chemical bonds (C-S-H) between soil particles due to the cement hydration reaction, by injecting cement mortar directly into the soil, the cement hydration process and the pozzolanic reaction creates cement binders, which fill the pores in soft soil, thereby improving soil strength (Kim et al., 2018).

Currently, soil-cement piles are commonly applied to projects with thick, soft soil layers such as traffic construction, irrigation, airports, ports, etc. The strength of soil-cement core is directly affected by the clay-water/cement ratio, these decreases lead to an increase in cement bond strength (Miura et al., 2001; Horpibulsuk et al., 2005; Thanh & Long, 2016). In addition, physical properties such as specific gravity, cohesion, moisture content, friction angle, plasticity index, minerals, soil pH, different construction methods and conditions give the difference in soil cement strength between the laboratory and the field. The strength of reinforced soil with cement content of 300 kg/m^3 from 9.8 to 11.8 daN/cm^2 in Hau Giang area and increasing to

15.4 and 19.5 respectively with cement content of 300 kg/m^3 and 350 kg/m^3 in Ca Mau area (TCVN 9906:2014), and the strength of soil reinforced with cement content of 300 kg/ m^3 can increase up to 7.83 daN/cm^2 in Dong Thap area (Giang et al., 2022). These values are suggested for ground improvement method using SCM.

Jet grouting is a popular method of constructing deep cement mixing (DCM) due to quality optimization construction, fast execution, cost saving, less impact on the environment, and is a potential technique of treating a variety of soils from gravel to clay. The cement-water mixture is pumped at a high speed and pressure of at least 300 bar into drilled holes (Guler & Gumus Secilen, 2021). This technique is very flexible and convenient for construction because it can be applied not only vertically but also obliquely or even horizontally (Atangana Njock et al., 2018). The main purposes of Jet grouting are to decrease foundation settlement and enhance the mechanical properties of subsoil, resulting in an increase in the bearing capacity of soil foundation. Jet grouting requires grouts that can be pumped at very high pressures with a depth up to 100 meters. The amount of cement of treated soil varies between 350 to 700 kg/m^3, and 450 kg/m^3 is usually the mean value employed (Covil & Skinner, 1994; Guler & Gumus Secilen, 2021). Although Jet grouting is one of the main ground improvement techniques, there is little empirical data on this method. Guler and Gumus Secilen (2021) investigated the strength properties of jet grout columns based on five cases in various ground conditions in Turkey. They confirmed that it was not easy to predict jet grout column strength in the field and the design values had to be verified by using unconfined compression tests on the core samples. They also concluded that groundwater chemistry, seepage velocities, and non-homogeneous soil with depth also effect the soilcrete strength. Besides, Pan, et al., (2021) collected and analyzed statistically 8627 field test results of dry soil mixing (DSM) columns with the maximum depth of 20m. Their results showed that the proportions of great quality and unqualified were 64.84% and 1.4%, respectively. The results also indicated that the mean strengths of DSM columns decreased with increasing depth and distributed in the range of 3 to 10 daN/cm2. They concluded that it was difficult to manage the quality of DSM columns and that there were more unqualified DSM columns the deeper the DSM column.

TCVN 9906:2014 does not mention the highest content applying to the Jet-grouting method. The data in the standard is also very limited and generally lists a number of projects with cement content from 250 to 350 kg/m^3 resulting in piles reaching 400 ÷ 1000KN/m^2. In addition, TCVN 9403:2012 and TCVN 9906:2014 also list some geological data, cement contents, and reference compressive strengths applied for some areas such as Vung Tau, Hai Phong, Ca Mau, Hau Giang, and Hue.

In general, there is very little research data on this ground improvement method for soft soils in the Mekong Delta area. The study aims to evaluate the quality of soil cement piles constructed for the Can Tho River embankment project.

2. MATERIALS AND METHOD

2.1. Studied location

The studied location is on the left riverbank of Can Tho between Hung Loi Bridge and Quang Trung Bridge (Figure 1). The average shoreline elevation in the area ranges from +0.5 m to +2.5 m. The Can Tho river bed is relatively complex and changes suddenly with different elevations, in which the river bed is only 11m deep and some locations where the level of topographic change is very large due to deep river erosion down to -24m. Therefore, erosion and landslides often occur, especially in the studied area.

Figure 1. The studied location

2.2. Geology in the studied area

The soil includes 05 soil layers distributed from the elevation +2.0 to -35.0 (Table 1).

– Class K: Backfill soil: sand, rock, gravel.

– Layer 1: Clay mud with sand, dark gray, blue gray, flow state.

– Layer 1b: Mixed sand, sand, gray-brown, yellow-brown, dark gray, blue-gray, flow state, loose.

– Layer 2: Clay, mixed with sand, yellow brown, red brown, gray brown, yellow gray, semi-hard state.

– Layer 2a: Clay, mixed with sand, yellow brown, red brown, gray brown, purple gray, blue gray, hard plastic state.

The thickness of the soft soil layer is especially thick (layer 1 and layer 1b) at the elevation +0.0 to -24.0.

Table 1. Physical and mechanical properties of soil

Soil type	Dept (m)	Unit weight (kN/m^3)	Angle of friction (^{0})	Cohesion (C, kN/m^2)
Layer K	+2.0 ÷ +0.0	-	-	-
Layer 1	+0.0 ÷ -15.0	16.2	4°43'	6.8
Layer 1b	-15.0 ÷ -24.0	17.6	4°39'	9.1
Layer 2	-24.0 ÷ -30.0	19.4	14°31'	30.1
Layer 2a	-30.0 ÷ -35.0	19.2	14°23'	27.5

2.3. Equipment

The automatic mortar mixer is in Figure 2. The mixer originates from China; the machine is equipped with automatic mortar injection and loading control system HNBS-Y350L. High-speed mixing system with a speed of 1400 rpm and a capacity of 7.5 KW. The mixing time for one batch ranges from 3 to 5 minutes. The mixer has a capacity of 250 to 450 kg of mortar per batch combined with a 1200-liter tank with a low-speed mixing system of 400 rpm, a capacity of 2.2 KW.

Figure 2. Mortar mixer

Figure 3 shows a high-pressure grouting pump system (YBM Jet Grouting Pump SG-75SV). The system originated in Japan. The machine has injection pressure from 30 to 40 MPa with a maximum flow of 75 liters/minute (maximum pressure 40 Mpa) and 100 liters/minute (pressure 30 MPa), multi-level rotation adjustable by variable and variable from 148 v/min to 320 v/min. Spray content ranges from 150 to 500 cement/m^3 soil piles. N/X ratio from 0.7 to 0.8 is very suitable for cement types PCB30 or PCB40.

Figure 3. Jet grouting pump

Figure 4. Drilling system used in the study

The drilling machine combined with a hydraulic pump system for rotary drilling and lifting requires a capacity of 15KW (Figure 4.). The rotary drilling system has a rotation speed of 10 to 30 rpm and a maximum drilling depth of 60m. Pumping capabilities are as follows: 1 phase medium injection pump with pressure from 15 to 30 Mpa to create medium piles with diameters from D = 0.6 m to D = 12 m; 2 phase pumping: 1 mortar phase (injection pressure 20 to 35 MPa) + 1 gas phase (pressure 0.7 MPa) to create mortar piles with diameters from D = 1 m to D = 1.5 m; 3 phase pump: 1 water phase (pressure 20 to 35 MPa) + 1 gas phase (pressure 0.7 MPa); and 1 medium phase (injection pressure 2.5 to 5.0 MPa) to create grout piles with lines Glasses from D = 1.5 m to D = 3 m.

2.4. Jet-grouting implementation

A total of 4 SCM are performed with a cement content mixed with soil of 350 kg/m^3 (A1, A2) and 400 kg/m^3 (B1, B2) (Figure 6). After 14 days of curing in the laboratory, the uniaxial compression tests are performed to determine the core strength (Figure 9).

In this study, the testing standards comply with ASTM D-2166, which is the Standard Test Method for Unconfined Compressive Strength, and TCVN 9403:2012, which is the Stabilization of Soft Soil-The Soil Cement Column Method. According to TCVN 9403:2012, at least laboratory sample test results must be available after 28 days of curing for the wet mixing method and 90 days for the dry mixing method.

2.5. Evaluation of SCM quality

The consistency of SCM is confirmed by visual inspection on the core sample obtained from drilling the SCD sample, based on sample length L_0 = 1 m (Figure 5).

Figure 5. Drilling SCM cores and determining quality

2.6. Implementation steps

The implementation steps include (i) constructing SCM (Figure 6), (ii) Drilling core after 14 days (Figure 8)., (iii) Sample curing for 14 days in conditions of 25^{o}C and humidity > 90% in the laboratory (Figure 8) and (iv) Compression testing (Figure 9).

Figure 6. SCM by Jet-grouting method

Figure 7. Drilling to take experimental samples

Figure 8. Field core drilling samples

Figure 9. Sample curing and compression test

3. RESULTS AND DISCUSSION

3.1. The intact of SCM

The SCM intact is presented in Table 2. The results show that the soil improvement by the Jet grouting method can conduct uniform and intact samples.

Table 2. Results of SCM intact

Sign	Sampling depth (m)	Sample length (m)	Observation result
A1-1; A2-1 B1-1; B2-1	-0.3 ÷ -1.3	1.0	Intact Uniformity
A1-2; A2-2 B1-2; B2-2	-2.3 ÷ -3.3	1.0	Intact Uniformity
A1-3; A2-3 B1-3; B2-3	-4.3 ÷ -5.3	1.0	Intact Uniformity
A1-4; A2-4 B1-4; B2-4	-6.3 ÷ -7.3	1.0	Intact Uniformity
A1-5; A2-5 B1-5; B2-5	-8.3 ÷ -9.3	1.0	Intact Uniformity
A1-6; A2-6 B1-6; B2-6	-10.3 ÷ -11.3	1.0	Intact Uniformity
A1-7; A2-7 B1-7; B2-7	-12.3 ÷ -14.3	1.0	Intact Uniformity
A1-8; A2-8 B1-8; B2-8	-14.3 ÷ -15.3	1.0	Intact Uniformity
A1-9; A2-9 B1-9; B2-9	-16.3 ÷ -17.3	1.0	Intact Uniformity
A1-10; A2-10 B1-10; B2-10	-18.3 ÷ -19.3	1.0	Intact Uniformity
A1-11; A2-11 B1-11; B2-11	-20.3 ÷ -21.3	1.0	Intact Uniformity

3.2. Results of compression tests

The results of the uniaxial compressive strength of SCM are presented in Figure 10. The results compared with the results of the compression test at the same curing of 28 days performed in Dong Thap province in the study of Giang et al. (2022).

Figure 10 shows that the compressive strength of the SCM varies with depth. For SCM with low cement content (A1 and A2), the difference in compression strength with depth is very clear. The compressive strength has the lowest values at depths from -13.0 to -19.0m for A1 and A2. A1 reaches its largest value at -1.0m elevation with 15.3 daN/cm^3 and the difference in compressive strength value compared to the lowest value is about 144%. The compressive strength increases with depth more in SCM with greater cement content (B1 and B2) than in A1 and A2. The compressive strength reaches the lowest values of 8.6 and 8.9 with depths of -19.0 and -17.0 and the highest values of 12.3 and 11.3 with depths of -5.0 and -3.0 for B1 and B2, respectively. The compressive strength has a difference of 32 to 38% for piles B1 and B2, respectively. The compressive strength with depth reaches a larger average value for the SCM with higher cement content. This indicates that the greater the depth of SCM, the more difficult to control the homogeneous strength of SCM with depth. This result is consistent with the results of Pan et al. (2021) for the DSM method.

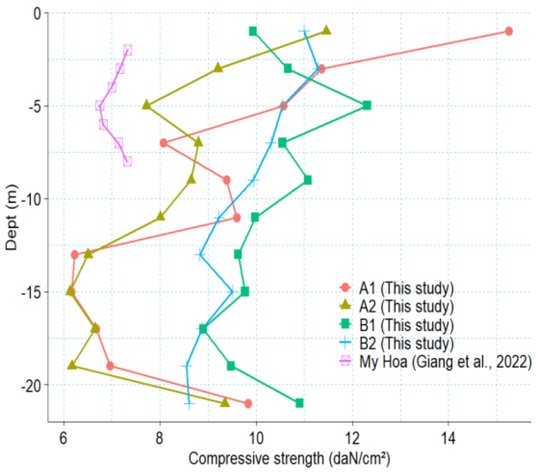

Figure 10. Relationship between compressive strength and pile depth

In addition, the compressive strength of the piles increases again at the tip of piles (-21.3m), which can be attributed to good construction technique at the tip of the piles, since the pile is filled with cement from tip to top. The mean compressive strengths in the study are greater than those of the previous studies (Pan et al., 2021; Giang et al., 2022). Clearly, higher cement content contributes to the increased compressive strengths of the samples. Therefore, the cement content of 400 kg/m^3 is a reasonable ratio for ground reinforcement construction in this study, while the previous study (Giang et al., 2022) showed the cement content of 300 kg/m^3, which was proposed for the short piles (8m) with the compressive strength relatively stable with depth. This can be concluded that the determination of cement content depends on the uniformity of SCM with depth. In other words, the compressive strength of SCM is greatly influenced by geology and the thickness of the soft soil layer. The cement content of 400 kg/m^3 is higher than the values suggested in TCVN 9906:2014 and Giang et al. (2022).

4. CONCLUSIONS

This study has been proposed for soil improvement after the landslides of riverbank occurred in 2022. Based on the research results, some conclusions are drawn as follows:

(i) For Jet grouting, the influence of depth on the compressive strength is confirmed. For this study, the cement content of 400 kg/m^3 is relatively suitable for the geology in the studied area and is higher than in TCVN 9906:2014 and the previous study.

(ii) The limitation of the project is using the compressive strength of SCM at day 28 for predicting at 90-day. Therefore, it is necessary to synthesize many other data with the influence of depth, soil type and pore water pressure in areas with similar soft soil to serve as a database for applying soil cement mixing in the Mekong Delta region.

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