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A STUDY ON THE CALCULATION OF DEFORMATION OF CEMENT DEEP MIXING COLUMNS THAT STABILIZE SOIL EROSION AND LANDSLIDES ON RIVER ROADS

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ABSTRACT: The erosion of riverbanks in the Mekong delta has become a serious issue. For instance, in Tien Giang province, riverbank erosion has led to landslides which have destroyed many buildings and roads on both sides of the river, causing devastating consequences to the people who live along the sides of the river. One method that may potentially minimize the damage caused by landslides is the method of cement deep mixing (CDM) columns, which aims to stabilize the slope of the canal bank. In this study, a series of finite element problems were analyzed using Plaxis V8.2 software under different conditions regarding the water level in the canal and the shape of the CDM columns for stable improvement of the slope of the canal bank. In addition, the effects of cement content on the formation of CDM column’s strength are considered in this study. The results show that the following characteristics can allow CDM columns to effectively stabilize the slope of the canal bank and prevent landslides along Cho Gao canal: 1) Composition: 20% of cement content; 2) Dimension and configuration: 0.6m in diameter, 10.3m in length, arranged in 5 rows with the spacing of 1m.

Keywords: Soft soil, Cement deep mixing, Unconfined compressive strength, Lateral moment, Deformation.

1. INTRODUCTION

According to the standard 22TCN 262:2000 and TCXD 245:2000, soils are considered to be soft when they are in their natural state. Their water content is approximately equal to or higher than the yield limit. Soft soils have large void ratio and cohesion (c) according to the results of rapid shearing without drainage from 15 kPa or less. They have friction angle (φ) between 0o and 10o, adhesive force from field cutting results of smaller than 35 kPa, static nose penetration resistance of smaller than 100 kPa, and standard penetration index SPT of smaller than 5 [1, 2] . In general, soft clay is a soil with low load capacity and high compressibility. Most countries around the world agree on the definition of soft ground according to the undrained shear resistance (Su) and the standard penetration value (N). The definition is as follows: very soft soil with S_u 12.5 kPa or N≤2; soft soil with $S_u \leq 25$ kPa or N ≤ 4. Le Ba Luong et al. (2005) concluded in his study of soft soil in the Mekong Delta that most of the soil is soft soil and has a thickness of range from 10 m to 40 m [3].

There are many methods to improve and stabilize soft grounds. Han-Georg Kempfert and Berhane Gebreselassie (2006) have classified the methods of improving and stabilizing soft soils into three main groups: 1) consolidation, 2) soil replacement, and 3) column type elements [4]. The method of stabilizing soft soil using CDM columns is one of column type element methods in this classification.

The mechanical method of applying improvement to the soil using mixing equipment is called the Deep Mixing Method (DMM). DMM has become a general term to describe soft soil reclamation techniques. Bruce, D. A. (2000) suggested that these techniques could be classified according to the following characteristics: 1) method of introducing binder into soil, 2) method of mixing, and 3) location of mixing blades [5].

Deep mixing technology has many acronyms. Filz et al. (2005) pointed out some acronyms used in construction and research [6]. Other phrases, which are occasionally used, include Mixed - in - Place piles, in situ soil mixing and soil cement columns. In this study, the words “deep mixing” will be used and the product of the deep mixing construction process is CDM columns.

Although there are many different deep mixing techniques, the most common method is to create stabilizing posts with a drill with one or multiple mixing rods in order to bring the binder into the soil where the improvement is located (Holm, G., 2003). The commonly used binder is a mixture of cement, lime, water and sometimes additives. The resulting mixture of binder and soil produces a material which has greater strength and stiffness than natural soil but less than concrete. The main purposes of the DMM are: 1) Reduce deformation, 2) Increase the strength of the soil, 3) Increase the dynamic stiffness of the soil, and 3) Overcome the consequences of contaminated ground [7].

The mechanical properties of stabilized soil by DMM are affected by a number of factors such as the amount of water, clay, the content of organic matter in the soil, the type and proportion of binder; and the effect of stabilizing the soil with CDM columns. Some prominent research on soil from literature are as follows. Toshihide Shibi and Yuki Ohtsuka (2021) studied the effects of compressive stress during curing on the unconfined compressive strength of soil cement specimens [8]. Thanakorn Chompoorat et al. (2022) studied to improve the mechanical properties and shrinkage cracking of soil cement mixtures [9]. Pitthaya Jamsawang et al. (2017) investigated the swelling behavior of soil cement specimens to design structures for shallow and deep foundations [10]. Hua Yu et al. (2022) attempted to use CDM columns to stabilize soft ground with cement for liquefied gas storage foundation [11].

Terashi, M. (1997) considered all factors that may the compressive strength of soil cement specimens such as the characteristics of the improving agent, the characteristics and conditions of the soil, and the mixing and maintenance conditions [12]. Among these factors, the important factors that strongly affect the unconfined compressive strength of soil cement specimens include the characteristics of the soil environment that is to be stabilized.

Thiam-Soon Tan et al. (2002) conducted an experiment to determine the unconfined compressive strength of soil cement specimens on three types of clay in three different sea areas: Eunos sea clay, City Hall and SAC with 20% cement content and 90% moisture content [13]. After 7 days of curing, the unconfined compressive strength of soil cement specimens varied greatly. Thus, each type of clay has a different mineral composition that can affect the strength improvement of the soil cement specimens.

Nozu, M. and Nakai, N. (2010) carried out experiments on three different types of clay mineral soils, including Southern Vietnam clay, American clay, and Japanese clay [14]. Soil cement specimens made with Vietnamese and American clay are shown to not perform well due to the absorbent properties of Montmorillonite (MMT) minerals that are present in the soil. At the same time, the results of the unconfined compression test show that both Vietnamese and American clays have low strength. From these results, the scope and method of constructing CDM columns that can stabilize diaphragm wall and avoid lateral pressure caused by swelling soil are also proposed.

According to the standard TCVN 9403:2012, the physical characteristics and mineral composition of the soil are required to be determined in the geotechnical investigation stage. This stage takes place before the design stage where the soft ground is stabilizeded using CDM technology [15]. In the standard, Annexes D and E show the methods for determining the unconfined compressive strength of soil cement specimens.

Nguyen Ngoc Thang and Nguyen Anh Tuan (2018) use the FEM method to analyze the embankment when the characteristics of the CDM columns such as diameter, distance, and length, are varied [16]. The results show that the settlement of the soft ground stabilized with CDM columns is reduced by 93% compared to the unstabilized foundation. The stress distribution and settlement of CDM columns and soft soil layers are used to determine a reasonable length for the CDM columns. The length of CDM columns, which have been treated to be used for soft soil roadbeds, gradually decreases from the center of the road to the two sides of the talus.

E. N. Kurbatskiy et al. (2018) determine the load capacity of stabilized soft ground with CDM columns using a 1-g model in the laboratory to evaluate the influence of mineral content of MMT [17]. The soft soil layer in the model is re-engineered to contain MMT whose content varies from 6% to 15%. This soft soil layer is used to evaluate the change in strength of the stabilized soil with CDM columns. The results show that the bearing capacity of the soil decreases with the increase in MMT content.

Tuan Anh Nguyen and Thang Ngoc Nguyen (2020) have adopted FEM method to study the behaviors of CDM columns combined with geotextiles [18]. These CDM columns are used to stabilize soft soils under embankment work. The results show that the behaviors of the CDM columns are indicated by the stress distribution and settlement of the stabilized foundation system. This calculation method is suitable for estimating the concentrated load on the top of the columns and the load distributed on the soft ground, which is located in the middle of the CDM columns in the soft soil.

Kitazume at al., (1996, 1999, 2000), Kivelo (1998), and Broms (1999) show that CDM columns can be damaged by cutting, puncture, compression, swelling, and bending [19-23]. From conducting a centrifugal experiment combined numerical analysis, Kitazume et al. (2000), Kartstanev et al. (1997), and Miyake et al. (1991) have shown that failure due to bending and toppling often occur on the sliding surface in the stability assessment [21, 24, 25]. From the above studies, the solution of CDM columns arranged in grid form is found to be the most useful and economical solution to stabilizing the slope of the roadbed. However, the studies have not analyzed the capacity to withstand vertical and horizontal displacement of CDM columns when they are used to stabilize the slope. In this study, CDM columns will be applied to river routes in the Mekong Delta for the purpose of stablizing slopes against slippage/sliding.

2. RESEARCH SIGNIFICANCE

This preliminary application of the cement deep mixing-CDM method in situ soil treatment and improvement technology in Tien Giang province has revealed a great potential for the application of new technology to the construction of structures that prevent landslides along rivers. In order to implement this new technology on a large scale, it is necessary to continue to learn from experience and select appropriate characteristics of the columns to suit the requirements of the contractors.

3. MATERIALS AND METHOD

In the design of improvement for soft ground with CDM columns, the study of factors that affect the strength of CDM columns is very important. This study can suggest the optimal technical characteristics for CDM columns. The mechanical properties of CDM columns depend on various factors such as the characteristics of the stabilizing agent, the characteristics and conditions of the soil, the mixing conditions, and the curing conditions.

3.1 Making and curing of soil cement specimens

The collected soil sample was dried, crushed and passed through a 5 mm sieve so that the impurities can be removed. Soil samples mixed with cement were created in different conditions on:

1) Cement content, a_w= 10%, 15%, 20% and 25%;
2) Ratio of total water and cement, w_T/c= 3, 4 and 5;
3) Curing time, t= 7, 14 and 28 days;
4) Domestic sample curing environment.

A total of 12 test cases with 108 soil cement specimens were fabricated. The basic physical properties of the soil are as shown in Table 1.

In the experiment, the cement sample is Ha Tien Portland cement PCB40 which is widely used in the market. The physical and chemical properties of cement PCB40 provided by the manufacturer are shown in Table 2.

Table 1 Physical properties of soft soil used in the experiment

ID	Parameters		Value
1	Water content, W (%)		45.14
2	Wet unit weight, γ_w (g/cm^3)		1.743
3	Dry unit weight, γ_d (g/cm^3)		1.201
4	Void ratio, e_o		1.290
5	Liquid limit, LL (%)		47.59
6	Plastic limit, PL (%)		25.2
7	Liquidity index, I_L (%)		0.90
8	Modulus of total elasticity (kPa)		1820
9	Cohesion, c (kg/cm^2)		0.067
10	Friction angle φ (°)		$3^0$53’
11	Grain size distribution	Gravel (%)	0
		Sand (%)	18.1
		Silt (%)	43.5
		Clay (%)	38.4

Table 2 Properties of Ha Tien Portland cement PCB40

ID	Parameters	Value
1	Compressive strength	
	3 days	≥ 18 (N/mm^2)
	28 days	≥ 40 (N/mm^2)
2	Level of smoothness	
	Parts remained on sieve 0.08 mm	≥ 12 %
	Surface area	≥ 2700 cm^2/g
3	Time of setting	
	Initial set	≥ 45 minutes
	Final set	≥ 600 minutes
4	Volume stabilization	≤ 10 mm
5	Anhydrous sulfuric content (SO_3)	≤ 3.5 %

Soil samples mixed with cement were made according to the standard A.S.T.M. D1632-96. Composition and weight of materials: Soil W_s(g), cement W_c(g) and the total amount of water w_T(g) for one mixing are calculated before mixing. After mixing the soil and cement mixture, water is added and the mixing is continued. The mixing time is about 10 minutes at 48 rpm. The mixture is poured into a round plastic mold of 50mm inner diameter, and 100mm high. The bottom of the plastic mold is sealed with 3 layers. After each layer, the sample is placed on the vibrating table so that air bubbles inside the sample can be removed. Excess mixture is removed from the mold surface, which is then flatten and covered with a layer of waterproof nylon cloth. The sample is kept in the mold for 24 hours. Finally, the sample is removed from the mold and put in fresh water for curing [26].

3.2 Unconfined compression test on soil cement specimens

The unconfined compression tests according to the standard A.S.T.M. D5102-96 were conducted for the specimens, which were collected after 28 days of curing in fresh water [27]. The unconfined compressive strength is the maximum axial load achieved per unit area, or the load per unit area at 5% axial strain, whichever occurs first. During the test, the axial compressive force was gradually increased until the specimen failed or the deformation along the axis reached 5%. The rate of increase in compression pressure was controlled so that the rate of axial strain was about 0.5% - 2%/min. The strain level was determined so that the test duration did not exceed 15 minutes.

Results of relationship between the unconfined compressive strength and curing time with w_T/c= 3, w_T/c= 4, w_T/c= 5 are shown in Fig. 1, Fig. 2, Fig. 3 respectively.

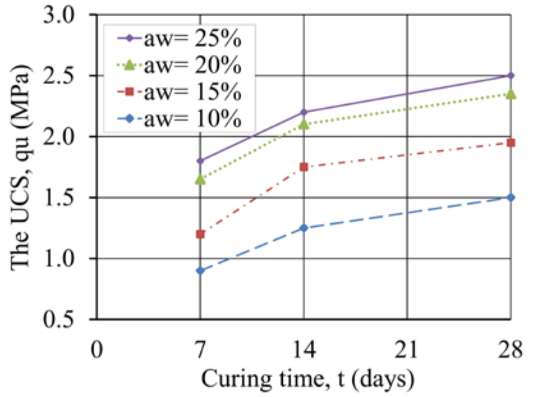


Fig. 1 Relationship between the unconfined compressive strength and curing time with w_T/c= 3.

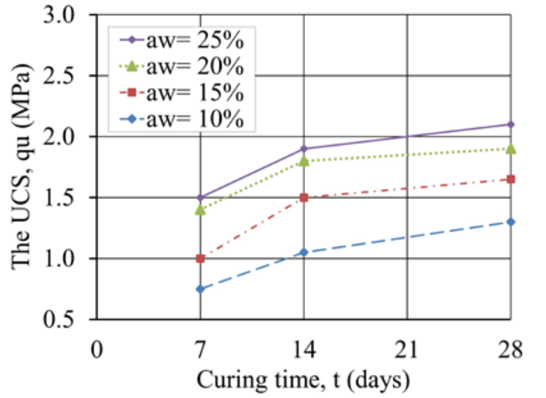


Fig. 2 Relationship between the unconfined compressive strength and curing time with w_T/c= 4.

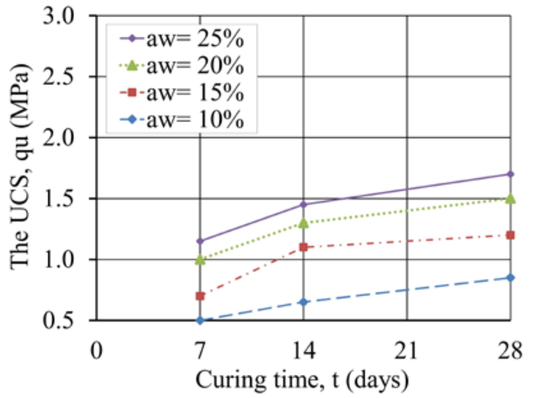


Fig. 3 Relationship between the unconfined compressive strength and curing time with w_T/c= 5.

Results of Relationship between the unconfined compressive strength and total water /cement ratio with the curing time of 7 days, 14 days and 28 days are shown in Fig. 4, Fig. 5, Fig. 6 respectively.

The unconfined compressive strength of the soil cement specimen changes when the w_T/c ratio changes (Figs. 7 - 9). As w_T/c increases, the compressive strength decreases. The unconfined compressive strength does not decrease up to the point where the moisture content of the mixture when mixed is close to the yield strength of the untreated soil, and then the strength tends to decrease more strongly with increasing w_T/c. Therefore, when choosing a wet mixing solution for soil cement mixture, the total water content of the mixture should be selected such that water content is close to the flow limit of untreated soil. The compressive strength increases rapidly at a_w=20% and increases slowly at higher cement contents.

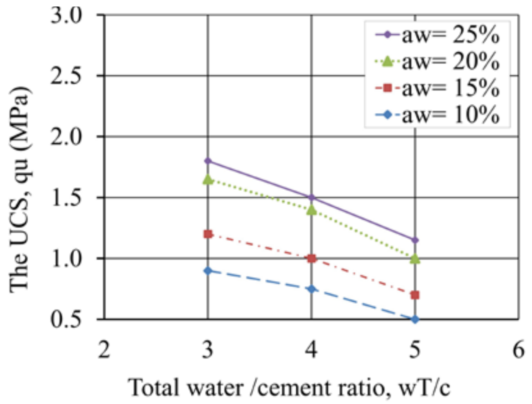


Fig. 4 Relationship between the unconfined compressive strength and total water /cement ratio with the curing time of 7 days.

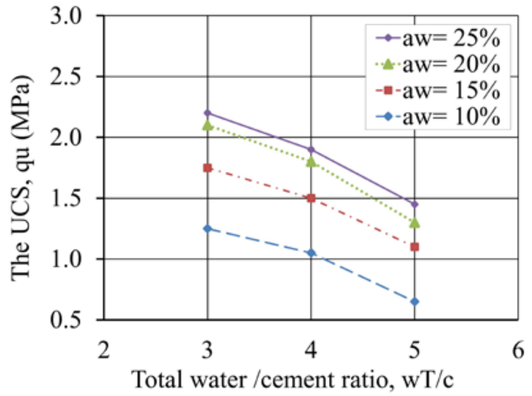


Fig. 5 Relationship between the unconfined compressive strength and total water /cement ratio with the curing time of 14 days.

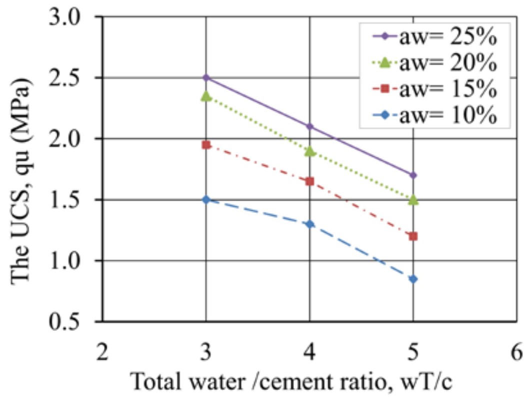


Fig. 6 Relationship between the unconfined compressive strength and total water /cement ratio with the curing time of 28 days.

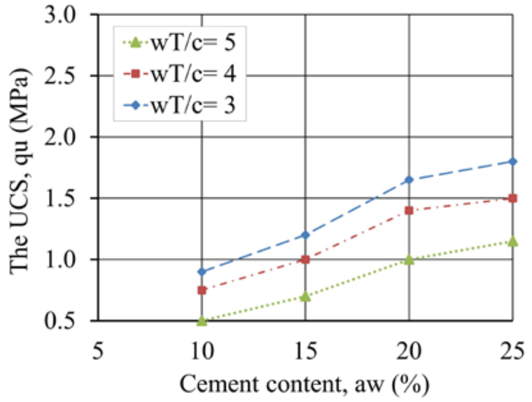


Fig. 7 Relationship between the unconfined compressive strength and cement content with the curing time of 7 days.

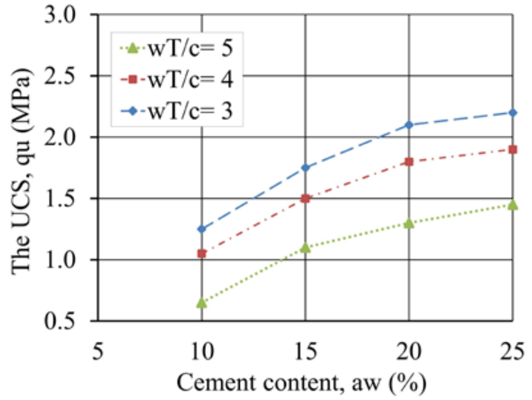


Fig. 8 Relationship between the unconfined compressive strength and cement content with the curing time of 14 days.

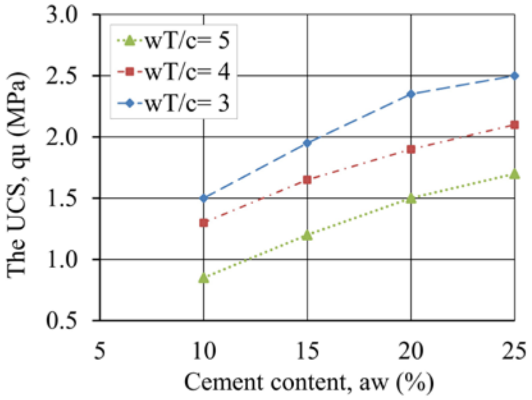


Fig. 9 Relationship between the unconfined compressive strength and cement content with the curing time of 28 days.

The samples obtained from pozzolanic reaction are analyzed using their SEM images with 20% cement content after 28 days of curing (Figs. 10-12). This analysis can show the difference in strength based on the water/cement content. The cement-mixed soil sample with a large w_T/c ratio showed many voids whose diameters vary from 3.5 µm to 10 µm. The presence of rods and flakes appears to increase the degree of homogeneity and decrease the pore diameter of soil samples. Soil with small w_T/c ratio has higher degree of heterogeneity and larger pore diameter than soil with rods and flakes.

The strength of CDM columns at the site can be affected by many factors such as soil properties, mixing conditions, equipment and mixing process, and nursing conditions. Therefore, it is difficult to accurately determine the field strength in the design phase. It is necessary to establish and verify the field strength through steps by testing mixed specimens in the room.

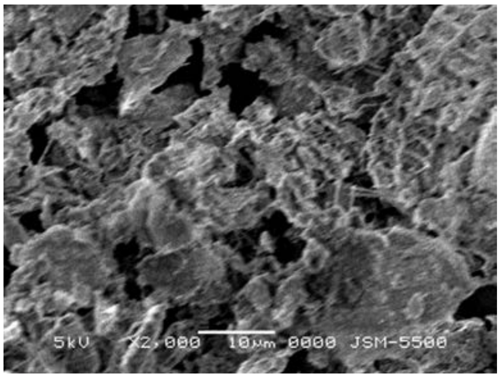


Fig. 10 SEM image for w_T/c=3.

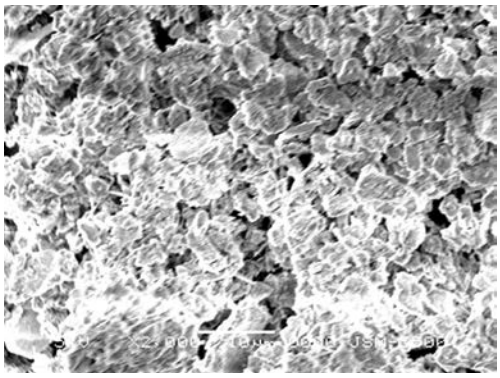


Fig.11 SEM image for w_T/c=4.

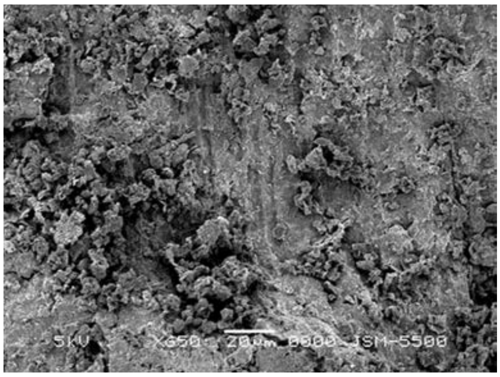


Fig. 12 SEM image for w_T/c=5.

4. FEM ANALYSIS

4.1. Calculation procedure

Cho Gao canal is a 28.5km-long waterway, including the Rach La section which starts from

Vam Co River and has a length of about 10km. At the end of the canal is the Ky Hon canal of 7km long which connects to Tien river in My Tho area. There is a straigh canal that connects between Rach La and Ky Hon canal. This canal also connects Tien river to Vam Co river and flows through various districts, such as Cho Gao district, Tien Giang province and Chau Thanh district, Long An province. This canal can be considered as the arterial waterway connecting Ho Chi Minh City with the southwestern provinces. According to the assessment of the government, the general landslide speed is about 2-3m/year. In the area of Long Thanh hamlet (Quon Long commune) the landslide speed can go up to 4m/year. The model for analyzed of riverbank and soft soil is shown in Fig. 13.

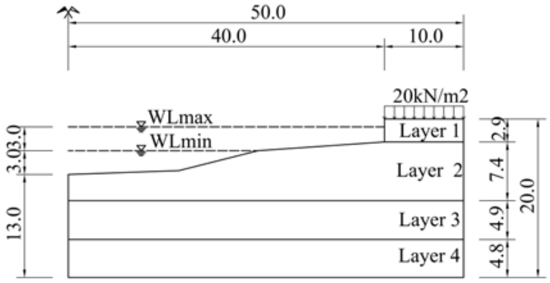


Fig. 13 Cross-section of Cho Gao canal.

To obtain data on natural soil properties, a 20m-borehole was drilled at the bank of Cho Gao canal - Quan Long commune, Cho Gao, Tien Giang. Based on the drilling results, which include the physico-mechanical and statistical parameters, the stratigraphy at the drilling site is classified into the following classes:

Layer 1: Clay, brown, and soft juiciness; 2.9 m thick.

Layer 2: Clay mud, dark gray, flowing state; 7.4 m thick.

Layer 3: Clay, brown with white spots, hard plastic state; 4.9 m thick.

Layer 4: Clay, white gray with brown spots, semi-hard state; 4.8 m thick.

4.2 Finite Element Method

The finite element model has the same 2D dimension as the dimension of the cross-section of the eroded Cho Gao canal (Fig. 14). The plane strain model is used in the analysis, meaning that the displacement perpendicular to the horizontal plane is assumed to be 0.

The process of analyzing the condition of CDM columns using FEM is as follows:

1) Change the CDM columns length, L= 2.9 m, 6.6 m, and 10.3 m.

2) Change CDM columns diameter, d= 0.6 m, 0.8 m and 1.0 m

3) Change the distance of the CDM columns, s= 0.6 m, 0.8 m, 1.0 m, 1.2 m and 1.4 m.

A total of 27 models were analyzed.

To model the soil layers, it is possible to use a 6-node or 15-node triangular element to consider the problem as a flat problem for simplicity. The 6-node triangle element is the default element for a 2-D analysis. It provides an interpolation of two for displacements. The element stiffness matrix is estimated using numerical integration and the sum of three Gaussian stress points. To calculate the stability of the channel slope, a 15-node triangular element may be used to model the ground to increase accuracy.

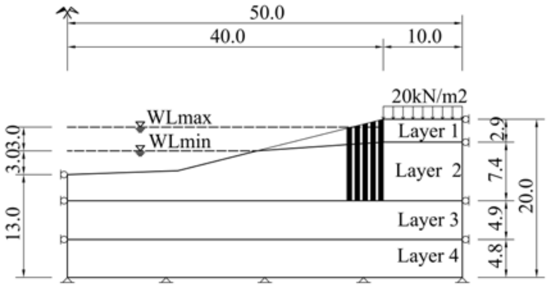


Fig. 14 Model of slope stabilized with CDM columns.

In Plaxis, acceptable soil models are linear elastic model (LE), Mohr-Coulomb model (MC), hardening soil model (HS), soil model Soft Soil model - SS), creep model for soft soil (Soft Soil Creep model - SSC) and user-defined model (UD).

From all the models mentioned above, the Mohr - Coulomb model was chosen to describe the real properties of the soil and the computational applicability of Version 8.2. This is an ideal plastic-elastic model consisting of five basic parameters of the soil, namely Young’s modulus (E), poisson’s ratio (ν), cohesion (c), Friction angle (φ) and Dilatancy angle (ψ). Normally, all parameters indicate the effective stress state of the soil. An important property of soil is the existence of pore water pressure. The influence of pore water pressure is divided into three types of behaviours in the software: 1) drained behavior, 2) undrained behavior and 3) porous behavior.

The model parameters, properties of the ground layers, and properties of CDM columns are shown in Tables 3.

The properties of CDM columns are tested from the unconfined compression tests (q_u). From literature, the properties of CDM columns are collected and shown in Table 4.

Each model is examined in 6 stages:

1) Earthening to regenerate the canal roof;

2) Constructing CDM columns;

3) Applying load of 20kN/m^2;

4) Examining FS4 stability level;

5) Lowering canal water level;

6) Examine FS5 stability level.

Plastic Calculate: Plasticity calculation is the calculation of elastic-plastic deformation. It is used to analyze the damage and stability of an object. Plasticity calculation does not take into account the time dependence of pore water pressure, and therefore is not suitable for settlement analysis in weakly permeable soils. On the other hand, this type of calculation can be used to calculate settlement in highly permeable soils, or final settlement of a structure.

Consolidation Analysis: Soil saturated with water must be drained as settlement increases (because water cannot withstand compression). In weakly permeable soils, such as clay, this process takes a long time. It is important to include this time factor in settlement analysis. This is the main phenomenon in consolidation computation. Therefore, this calculation is suitable for the analysis of settlement over time for saturated soils and soils with weak permeability.

Safety Analysis (Reduce φ): For the safety analysis (e.g., calculation of factor of safety), Plaxis included a calculation called the reduction of PHI-C. This is a plasticity calculation in which the strength parameters of the soil and the interface are gradually reduced until failure. The factor of safety for an object is calculated by dividing the instantaneous strength value by the strength at the time of failure.

Table 3 Parameters of soil layers the Plaxis model

ID	Parameters	Symbol	Layer			
			1	2	3	4
1	Material Model	Model	Mohr - Coulomb	Mohr - Coulomb	Mohr - Coulomb	Mohr - Coulomb
2	Material behavior type	Type	Drained	Drained	Drained	Drained
3	Soil unit weight above phreatic level, (kN/m^3)	γ_{unsat}	13.2	10.0	14.0	16.3
4	Soil unit weight below phreatic level, (kN/m^3)	γ_{sat}	18.3	16.0	18.5	19.9
5	Young's modulus, E (kN/m^2)	E	3.708	1.822	6.654	7.460
6	Poisson's ratio (-)	ν	0.464	0.483	0.444	0.429
7	Cohesion, (kN/m^2)	c_{ref}	17.1	6.7	27.1	38.9
8	Friction angle, (degree)	φ	7.77°	3.88°	11.6°	14.38°
9	Dilatancy angle, (degree)	ψ	0°	0°	0°	0°

Table 4 Parameters of CDM columns in Plaxis model

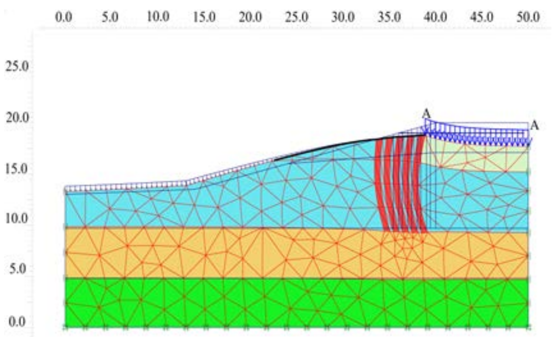
Parameters	Symbol	CDM columns
Material Model	Model	MC
Material behavior type	Type	Drained
Soil unit weight above phreatic level, (kN/m^3)	γ_{unsat}	11.15
Soil unit weight below phreatic level, (kN/m^3)	γ_{sat}	18.4
Young's modulus, (kN/m^2)	E	100
Poisson's ratio, (-)	ν	0.333
Cohesion, (kN/m^2)	c_{ref}	150
Friction angle, (degree)	φ	30°
Dilatancy angle, (degree)	ψ	0°

4.3. FEM Results

As it is expected, the CDM column may reduce the large settlement of the soft soil layer subjected to a horizontal load as shown in Figs. (15-20). The results indicate the capability of the nonlinear FEM to simulate the stabilization of the soft soil using CDM columns. An insignificant changing in these responses indicating that the model may be decided as an optimum configuration for the case of stabilization of the soft soil layer in the Mekong delta area.

Under the influence of the soil layer's weight and road loads, there is a natural tendency to lose lateral shear instability when dynamic loads due to waves and riverbank currents are ignored. The displacement of the CDM columns is the greatest when the water level in the channel is the lowest. As the water level increases, the horizontal displacement of the CDM columns decreases. Smaller displacement is caused by the increase in pore pressure from the water level difference and the formation of underground flow from the land to the canal.

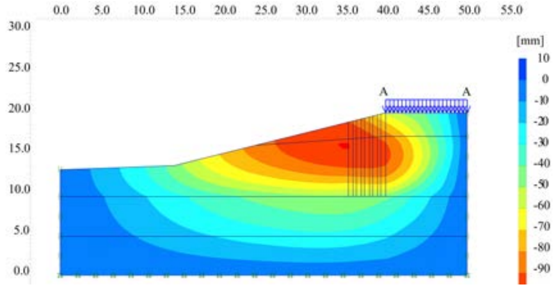
Along with this horizontal displacement, the safety of the slope also changes when the water level in the canal changes. The factor of safety is the lowest when the water level in the canal is the lowest, and increases when the water level is at maximum. As the diameter of the CDM columns increases, the displacement of the column decreases gradually. The small diameter CDM column is bent in the center of the column. As the diameter increases, the CDM column tends to tip over and the largest displacement is found at the column head.



Deformed Mesh

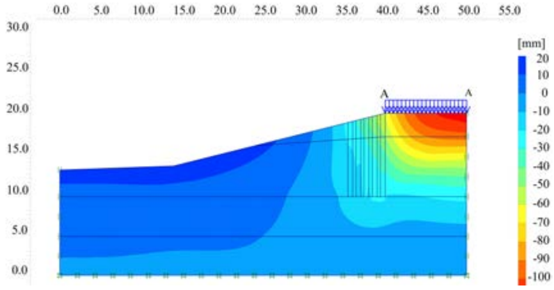
Extreme total displacement 111.51*10^{-3} m

Fig. 15 Displacement of the canal slope with WL_{max}.



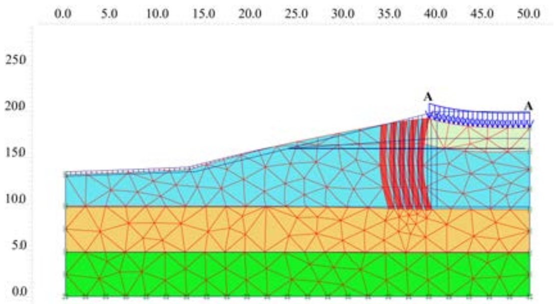
Horizontal displacements (Ux)
Extreme Ux -101.00*10^{-3} m

Fig. 16 Horizontal dispalcement of the canal slope with WL_{max}.



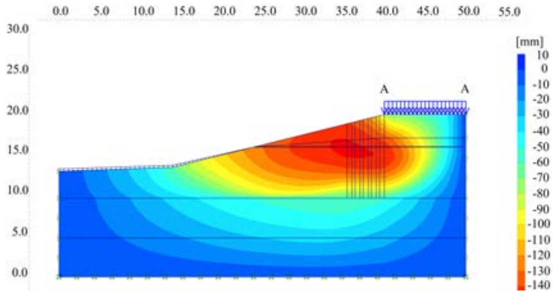
Vertical displacements (Uy)
Extreme Uy -109.57*10^{-3} m

Fig. 17 Vertical dispalcement of the canal slope with WL_{max}.



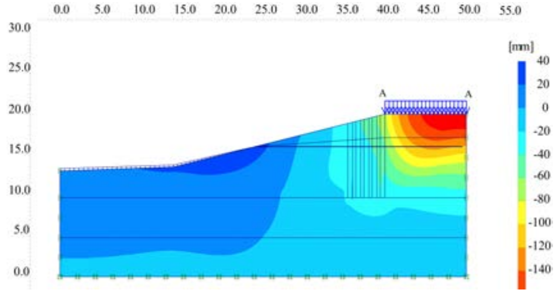
Deformed Mesh
Extreme total displacement 180.95*10^{-3} m

Fig. 18 Displacement of the canal slope with WL_{min}.



Horizontal displacements (Ux)
Extreme Ux -152.40*10^{-3} m

Fig. 19 Horizontal dispalcement of the canal slope with WL_{min}.



Vertical displacements (Uy)

Extreme Uy -176.86*10^{-3} m

Fig. 20 Vertical dispalcement of the canal slope with WL_{min}.

From the calculation results obtained for the above 27 cases, it can be seen that after five years of construction, the road along the Cho Gao canal is stabilized with five rows of CDM columns with a diameter of 0.6m, a distance of 1.0m, and a length of 10.3m. The CDM columns have a horizontal displacement of 0.152m and a vertical displacement of 0.177m with a stability factor of 1.567.

4.4 Discussion

The determination of the deformation of the ground stabilized with CDM column is built on the following condition. The soil stabilized with CDM columns is considered as an ideal elastic compressive material, which fails under the conditions of Mohr - Coulomb yield. According to this study, stabilized CDM columns, which prevent landslides in riverside works, are calculated based on the viewpoint in which the columns and the ground are working as an equivalent foundation block. The foundation system will have equivalent load capacity and shear resistance. From this viewpoint, the two possible cases of failure are the failure of the equivalent foundation block and the failure of the circular arc at the edge of the block.

When the embankment load is applied to the normal ground, that is, when there is no CDM column system underneath, the applied stress on the load region is completely supported by the ground soil bearing the load. When the ground has a CDM column system installed, the load distribution on the column and the surrounding soil will obviously be different from the original case. Therefore, it is important to explore the law of stress distribution at the column head cross section and the distribution of loads on the column.

For the first problem where the stress is distributed on the column head: The purpose of the analysis is to find the stress concentration coefficient of the column. As stress concentration on the column will be accompanied by a stress reduction in the soil around the column. It is important to determine an appropriate amount of embankment load that the CDM column can withstand so that the deformation between the column and the surrounding soil can be considered as relative deformation. It is necessary to solve the two cases, one with geotextile arrangement on the top of the column and the other without geotextile arrangement on the top of the column, to see the effects of the stabilizing geotextile.

For the second problem where the stress is distributed along the depth: The analysis aims to determine the stress distribution along the depth of each column, which is located in the horizontal row of column. From the stress distribution along the depth and the allowable load capacity of the ground, we can determine the minimum length for the foundation. Note that along the length of foundation will be the column.

5. CONCLUSIONS

Based on the compression test on cement-mixed soil samples and the analysis conducted using the FEM, the conclusions are as follows:

The soil cement specimens can harden and increase in strength over a period of time. The basic principle of stabilizing soft soil with CDM column is that cement, after mixing with the soil, will produce a series of chemical reactions and then gradually harden. Their main reactions are: hydrolysis and hydration reactions of cement, reaction of soil particles with hydrates of cement, carbonation reaction.

Each type of soil has a different MMT content so that when stabilized with CDM columns, different soil types will have different improvement effects. For the same requirement for strength of the stabilized soil, it is necessary to determine the amount of cement used to create CDM coulumns. This amount of cement is considered as the appropriate cement content. The cement content, which is suitable for stabilized soft soil in Cho Gao district - Tien Giang province, is proposed to be 20%.

The slope of the canal is stabilized with 5 rows of CDM coulumns, each of which has a diameter of 0.6m, a distance of 1.0m, and a length of 10.3m. These characteristics are considered to be optimal for anti-slip improvement structure found along the Cho Gao canal - Tien Giang province.

6. REFERENCES

[1] 22TCN262-2000. The specification of surveying and designing the motorway sub-grade on soft ground, Ministry of Transpot, Vietnam, 2000.

[2] TCXD 245:2000, "Ground improvement by pretabricated vertical drain (PVD)," Ministry of Construction, 2000.

[3] Le Ba Luong, Le Ba Khanh and Le Ba Vinh, "Study on the vertical and horizontal deformation of soft ground under riverbank buildings in the Mekong delta". Faculty of Civil Engineering – Ho Chi Minh city University of Technology, 2005, pp.753-757.

[4] Han-Georg Kempfert and Berhane Gebreselassie, Excavations and Foundation in Soft Soil, Krips bv, Meppel, 2006.

[5] Bruce, D. A., An Introduction to the Deep Soil Mixing Methods as used in Geotechnical Applications, FDWA-RD-99-138, Federal Highway Admisnistration, McClean, VA, 2000.

[6] Filz, G. M., Hodges, D. K., Weatherby, D. E. and Marr, W. A., "Standardized Definitions and Laboratory Procedures for Soil-Cement Specimens Applicable to the Wet Method of Deep Mixing," in Proc. of the Int. Conf. on Deep Mixing, Stockholm, 2005, pp. 1-13.

[7] Holm, G. "State of Practice in Dy Mixing Methods." Grouting and Ground Treatment, Proceedings of the 3rd International Conference, ASCE Special Publication No. 120, New Orleans, 2003, 145-163.

[8] Toshihide Shibi, Yuki Ohtsuka, "In fluence of applying overburden stress during curing on the unconfined compressive strength of cement-stabilized clay," Soils and Foundations vol. 61, 2021, pp. 1123-1131. DOI: 10.1016/j.sandf.2021.03.007.

[9] Thanakorn Chompoorat, Thanakit Thepumong, Anupong Khamplod, Suched Likitlersuang, "Improving mechanical properties and shrinkage cracking characteristics of soft clay in deep soil mixing," Construction and Building Materials, vol. 316, 2022. DOI: 10.1016/j.conbuildmat.2021.125858.

[10] Pitthaya Jamsawang, Nuttapong Nuansrithong, Panich Voottipruex, Smith Songpiriyakij, Pornkasem Jongpradist, "Laboratory investigations on the swelling behavior of composite expansive clays stabilized with shallow and deep clay-cement mixing methods," Applied Clay Science, vol. 148, 2017, pp. 83-94. DOI: 10.1016/j.clay.2017.08.013.

[11] Hua Yu, Yaolin Yi, Alessandro Romagnoli, Wooi Leong Tan, "Cement soil stabilization for underground liquid natural gas storage," Cold Regions Science and Technology, vol. 194, 2022. DOI: 10.1016/j.coldregions.2021.103438.

[12] Terashi, M., "Deep Mixing Methods – Brief state of the art," in 14th International Conference on Soil Mechanics and Foundation Engineering, Germany, 1997, pp. 2475-2478.

[13] Thiam-Soon Tan, Teik-Lim Goh and Kwet-Yew Yong, "Properties of Singapore Marine Clays Improved by Cement Mixing," Geotechnical Testing Journal, Vol. 25, No. 4,

2002, pp. 422-433.

[14] Nozu, M. and Nakai, N., "A comparative study on influence of soft clay properties for deep soil cement mixing in the Mekong and Mississippi Deltas," 2010, pp. 59-64.

[15] TCVN 9403:2012, "Stabilization of soft soil - The soil cement column method". Vietnamese Standard, 2012.

[16] Nguyen Ngoc Thang, Nguyen Anh Tuan, "Nonlinear FEM analysis of cement column configuration in the foundation improved by deep mixing method," Strength of Materials and Theory of Structures, No. 100, 2018, pp. 18-26.

[17] E. N. Kurbatskiy, N. A. Telyatnikova, N. N. Thang and N. Anh Tuan, "Study on Using Laboratory Model to Research for Bearing Capacity of Soft Ground Improved by Deep Cement Mixing Columns due to Embankment Load with Different Montmorillonite Contents," 2018 IEEE Inter. Conf. "Quality Management, Transport and Information Security, Information Technologies" (IT&QM&IS), 2018, pp. 121-127. DOI: 10.1109/ITMQIS.2018.8525125.

[18] Tuan Anh Nguyen, Thang Ngoc Nguyen. Study on Stress Distribution in Soft Ground Consolidated with Deep Cement Mixing Columns under Road Embankment. Civil Engineering and Architecture, 8(6), 2020, 1251 – 1265. DOI: 10.13189/cea.2020.080609.

[19] Kitazume, M., Miyake, M., Omine, K. and Fujisawa, H. "JGS TC report: Japanesse Design procedures and recent activities of DMM." Proc. of the 2nd Int. Conf. on Ground Improvement Geosystems, Vol. 2, 1996, 925-937.

[20] Kitazume, M., Yamamoto, M. and Udaka, Y. "Vertical bearing capacity of column type DMM ground with low improvement ratio." Proc. of the Int. Conf. on the Dry Mix Methods for Deep Soil Stabilization, 1999, 245-250.

[21] Kitazume, M., Okano, K., and Miyajima, S. "Centrifuge model tests on failure envelope of column type deep mixing method improved ground." Soils and Foundations, 40(4), 2000, 43-55.

[22] Kivelo, M. "Stabilization of embankments on soft soil with lime/cement columns." Doctoral Thesis, Royal Institute of Technology, 1998.

[23] Broms, B. B. "Keynote Lecture: Design of lime, lime/cement and cement columns." International Conference on Dry Mix Methods: Dry Mix Methods for Deep Soil Stabilization, Rotterdam Balkema, 1999, 125-153.

[24] Karastanev, D, Kitazume, M., Miyajima, S. and Ikeda, T. "Bearing capacity of shallow foundation on column type DMM improved ground." Proc. of the 14th Int. Conf. on SMFE, Vol. 3, 1997, 1621-1624.

[25] Miyake, M, Wanda, M, and Satoh, T. "Deformation and Strength of Ground Improved by Cement Treated Soil Column." Geo-Coast 91, Yokohama, 1991, 369 -372.

[26] A.S.T.M. D1632-96, "Standard Practice for Making and Curing Soil-Cement Compression and Flexure Tests Specimens in the Laboratory."

[27] A.S.T.M. D5102-96, "Standard Test Method for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures."