International Journal of GEOMATE, Feb., 2024 Vol.26, Issue 114, pp.1-8
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2024.114.4200
Geotechnique, Construction Materials and Environment

AN INVESTIGATION OF CEMENT DEEP MIXING COLUMNS STABILIZATION IN THE ROAD FOUNDATION ALONG THE CHO GAO CANAL

*Thang Ngoc Nguyen

Faculty of Engineering Technology, Tien Giang University, Vietnam

*Corresponding Author, Received: 26 Oct. 2023, Revised: 19 Dec. 2023, Accepted: 25 Dec. 2023

ABSTRACT: Cho Gao Canal is one of the most important water transportation routes in the Mekong River system in Tien Giang province, Vietnam. Recently, traffic jams on the canal have become a frequent occurrence, accompanied by the problem of river erosion, which has damaged many buildings and roads on both sides, resulting in losses to both people and property. To reduce the damage caused by landslides and collapse, the Cement Deep Mixing (CDM) column method is being studied to stabilize the road foundation along the canal. A series of finite element method (FEM) simulations in PLAXIS 2D are being conducted under various conditions, including different water levels and configurations of CDM columns, to assess the stability of the canal's slope. Additionally, this study considers the influence of factors such as cement content and the surrounding environment, including air, soil, freshwater, and saltwater, on the formation of CDM column strength. To improve the slope stability of the Cho Gao canal, the recommended configuration involves utilizing CDM columns with a diameter of 0.5 meters. According to the research results, these columns are strategically arranged in three rows with a spacing of 0.5 meters, and each column is designed to have a length of 10 meters.

Keywords: Cho Gao canal, Landslides and Collapse, DCM, FEM, Road foundation

1. INTRODUCTION

Many of Vietnam's cities and provinces are located within the Mekong Delta and the Red Delta regions, where soft ground is frequently encountered. The thickness of the soft ground layer in these areas can range from 4 to 40 meters. This geographical characteristic has significant implications for construction and infrastructure development in these regions, as it necessitates special engineering considerations and techniques to ensure the stability and safety of buildings and structures.

Over the next few years, Tien Giang province is facing the imperative of embarking on a multitude of infrastructure projects. These encompass critical areas such as power supply, telecommunications, portable water supply, sewage systems, wastewater treatment facilities, transportation infrastructure, public amenities, housing developments, and high-rise buildings, in addition to the expansion and improvement of road networks. The undertaking of these projects signifies a concerted effort to enhance the province's overall infrastructure, meeting the growing demands of its residents and promoting economic growth and development in the region. However, Tien Giang province must pursue development in a sustainable and environmentally friendly manner. Engineers, particularly specialized geotechnical engineers, must take on these new responsibilities and tackle the associated challenges. In any project, geotechnical and geoengineering considerations must take precedence.

The Cho Gao canal stands as one of the most vital water transportation routes within the Tien Giang river systems. Its strategic location and connectivity play a pivotal role in facilitating the movement of goods and people, promoting trade, and fostering economic development in the region. This canal not only serves as a key component of Tien Giang's transportation infrastructure but also reflects its historical and contemporary significance in supporting the province's growth and prosperity. Currently, many large ships carry goods, sand, and concrete through the Cho Gao canal, as illustrated in Fig.1. Due to the high density of this transportation system, numerous unsafe collapse and slip surfaces have emerged on both sides of the Cho Gao canal, as shown in Fig.2.

Fig.1 Many large ships in the Cho Gao canal

Some residents living along the Cho Gao canal have taken the initiative to address the stability of the riverside slopes. They have implemented solutions such as concrete soldiers, overlapping sandbags, and the planting of vegetation along the riverbank, as depicted in Fig.3. However, these solutions have proven to be unstable in both the short and long term. As a result, the safety and well-being of the local people residing along the riversides are in a perilous state.

Fig.2 Landslide on both sides of Cho Gao Canal

Fig.3 Traditional solution for the stability of Cho Gao canal

In today's context, technical solutions rooted in slope stability theories and computer programs for slope analysis have become crucial. The determination of slip surfaces, safety factors, and overall slope stability, hinging on ultimate shear resistance and shear resistance stress of the soil, plays a vital role. The stability of slopes, riverbanks, and landslide prevention are significant challenges for achieving sustainable development. These issues are intricate and contingent upon numerous soil behaviors and various factors. A variety of protective measures, including different types of retaining walls, piles, anchors, revetments, and methods for improving soft soil, have been employed to maintain slope stability thus far. Consequently, there is an imperative need to conduct studies and develop optimal protective solutions that ensure the safe stabilization of riverbanks and cost-effectiveness in Tien Giang province.

Nguyen, N. T. and Nguyen, A. T. (2018) employed the FEM to analyze embankments with varying characteristics of CDM columns, such as diameter, distance, and length [1]. Their findings indicate a remarkable 93% reduction in settlement for the soft ground stabilized with CDM columns compared to the unstabilized foundation. Analyzing stress distribution and settlement patterns of both CDM columns and soft soil layers helps establish an optimal length for the CDM columns. In the context of soft soil roadbeds, the treated CDM columns exhibit a gradual reduction in length from the center of the road toward the two sides of the talus.

Tuan, A. N. and Thang, N. N. (2020) utilized the FEM to investigate the performance of CDM columns in conjunction with geotextiles [2]. These CDM columns were employed to stabilize soft soils beneath embankment constructions. The study's findings, as indicated by stress distribution and settlement patterns within the stabilized foundation system, demonstrate the effectiveness of the CDM columns. The calculation method employed is well-suited for estimating both the concentrated load on the top of the columns and the load distributed across the soft ground, located between the CDM columns in the soft soil.

2. RESEARCH SIGNIFICANCE

This study conducts a comprehensive examination of various factors, encompassing cement content and environmental conditions such as air, soil, freshwater, and saltwater, to assess their influence on the strength development of CDM columns. To improve the slope stability of the Cho Gao canal, the configuration advocates for the implementation of CDM columns with a diameter of 0.5 meters. According to the research findings, these columns are strategically arranged in three rows with a spacing of 0.5 meters, and each column is designed to have a length of 10 meters. Leveraging the characteristics of CDM materials, the research explores the potential use of CDM as a method to achieve both secure stabilization of riverbanks and economic efficiency in Tien Giang province.

3. MATERIALS AND METHOD

3.1 Proposed approaches

The CDM method is an in-situ soil treatment and improvement technology that involves blending the ground with cementitious and other materials to create vertical, rigid inclusions within the soil. These materials, often referred to as 'binders' can be introduced in either a slurry or dry form and are injected into the ground using hollow, rotating mixing shafts equipped with cutting tools. This technique enables physical and chemical reactions to occur deep beneath the ground's surface, involving components such as cement, clay minerals, and water. These reactions encompass processes like hydration, pozzolanic reactions, ion exchange, flocculation, precipitation, oxidation, and carbonation, resulting in the rapid formation of high-strength material. As time progresses, this material continues to gain strength, ultimately exhibiting lower permeability and compressibility compared to the native ground [3]. The deep mixing methods (DMM) have found application across various purposes, as highlighted by Holm (2003) [4].:

(a) To enhance the soil's deformation properties, the following objectives are pursued: minimizing settlement and differential settlement, mitigating horizontal deformations, expediting settlement processes, and consequently, shortening the construction period. Additionally, these measures aim to alleviate excess pore water pressure in soft clay;

(b) To enhance the strength of the soil, the following objectives are pursued: improving the stability of riverbanks and road embankments, increasing its bearing capacity, reducing the active load on retaining walls, and safeguarding against liquefaction;

(c) To remediate contaminated land, the following methods are employed: solidification, stabilization, and hydraulic cut-off walls.

When addressing concerns regarding slope stability along riverbanks and incorporating the use of CDM columns, CDIT (2002) recommends a combined approach involving numerical analyses alongside slope stability assessments to thoroughly examine settlement and structural stability [5]. The FEM has proven its reliability as an analytical tool for predicting the real-world behavior of clay treated with CDM columns beneath various structures [1]. Moreover, FEM has been employed to replicate model tests conducted under diverse conditions, consistently yielding results that closely match the measured outcomes. These numerical simulations provide valuable insights into the mechanical performance of these structures. The FEM offers a robust mathematical model for comprehending the interactions among the columns, the untreated soil, and the embankment when subjected to operational loads, even as the critical point of failure is approached [6, 7, 8]. This approach enhances the ability to assess and predict the effectiveness of CDM columns in enhancing slope stability along riverbanks and ensures the structural integrity of the embankment.

The use of numerical analysis to study riverbank stabilization in the Cho Gao canal through the CDM column method is a topic that has not been extensively and comprehensively explored in Vietnam. This analysis takes into account multiple factors that influence riverbank stabilization, including tide and water level in the Cho Gao canal, the river's water environment, the water-to-clay ratio of the cement slurry, the mixing method, the geometry and length of CDM columns, the lateral loads from ship-induced waves, and confining pressure [2, 9, 10]. As of now, there is a dearth of comprehensive research in Vietnam regarding these aspects, making it an area ripe for further investigation.

3.2 Expected outcomes

Given the reasons mentioned in the previous section, the research focuses on employing FEM analysis to investigate the primary factors that influence riverbank stabilization when using the CDM column method to enhance the soft soil foundation of riverbanks. These factors encompass the tide and water level of the Cho Gao canal, the river's water environment, the water-to-clay ratio in the cement slurry, the mixing technique, the configuration and length of CDM columns, the lateral loads resulting from ship-induced waves, and confining pressure. Addressing these aspects represents a significant objective in this research.

To achieve the objectives of this research, a series of FEM parametrics will conduct using a 2D model. The parameters mentioned above assess their impact on riverbank stabilization while enhancing the soft soil foundation with CDM columns.

To input the parameters of CDM material into the FEM model analysis, a comprehensive series of unconfined compression tests and bedding tests were conducted in the laboratory for this research. These tests were carried out on samples prepared under various conditions to determine suitable CDM material parameters and the factor of safety for riverbank stabilization. The research also explored the effects of other vital factors, including curing time, the dry weight ratio of cement to clay (a_w), the water-clay to cement (w_T/c) ratio, the curing environment, and confining pressure.

3.3 Test on soil cement specimens

Soil samples were collected from the riverbank of the Cho Gao canal in Tien Giang province, specifically in the area where significant collapses have occurred, affecting Cho Gao town. Samples were extracted to depths of 1-2 meters (layer 1^{st}) and 4-6 meters (layer 2^{nd}) through a careful excavation process. For this purpose, PVC tubes with a diameter of 100 mm were used. These tubes were modified to have thin edges to minimize disturbance to the soil. Each tube had a height of 200 mm and was gently inserted to extract the soil sample. Once collected, the samples were preserved inside the PVC pipes, carefully surrounded by plastic sheets to facilitate subsequent testing within a controlled environment [11]. In this research, the tests involved samples prepared under various conditions, aimed at determining suitable CDM parameters and the factor of safety for riverbank stabilization. The research also considered the influence of several factors, including curing time, the dry weight ratio of cement to clay (a_w), the water-clay to cement (w_T/c) ratio, the curing environment, and confining pressure.

3.3.1 Unconfined compressive test - ASTM D5102-96 [12]

In this testing method, unconfined compressive strength is defined as the maximum axial load per unit area, or the load per unit area at a 5% axial strain, whichever occurs first during the test. In a laboratory compression test, a cylindrical mixture of cement and soil with a diameter of 50 mm and a height of 100 mm is subjected to vertical compression, with force increasing until deformation or failure occurs along the axis, reaching a 5% strain. The samples are compressed according to the cylindrical sample's height. The compression pressure rate is controlled to ensure a deformation speed along the axis of approximately 0.5% to 2.0% per minute. The deformation rate is chosen such that the total test duration does not exceed 15 minutes.

3.3.2 Bending strength of the soil-cement mixture-ASTM D1635-00 [13]

The sample size measures 40 mm x 40 mm x 160 mm. These samples are stored under various conditions based on their intended use. The samples are positioned with the distance between the two supports set to three times the width of the beams. A continuous load is applied, and the load at the point of collapse is recorded. Measurements are taken with an accuracy of 0.25 mm to determine the average width and depth of the specimens at the section where failure occurs.

3.4. FEM analysis

To accomplish the objectives of this research, a series of FEM parametric studies were conducted using a two-dimensional model. These studies involved varying the values of the parameters mentioned above to assess their impact on riverbank stabilization when improving the soft soil foundation using CDM columns. The model used for the analysis of the riverbank and soft soil is depicted in Fig.4. The numerical analysis was performed using the PLAXIS 2D program. The material properties for the soil layers are consistent with those presented in Table 1 [14, 15], while the material properties for the CDM columns are specified in Table 2 [16, 17, 18, 19, 20].

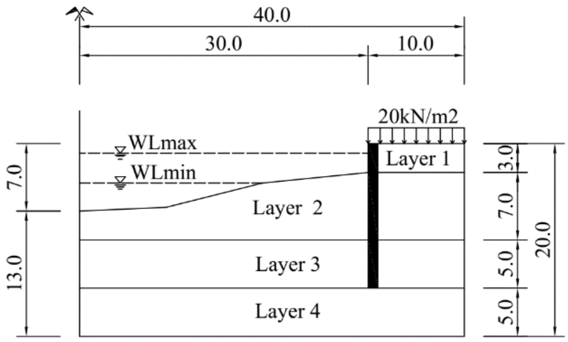

Fig.4 Cross section of Cho Gao canal at Quon Long commune

Table 1 Properties of soil layers

Parameters	Layer 1	Layer 2	Layer 3	Layer 4
Gravel, (%)	-	-	-	-
Sand, (%)	11.9	18.2	15.6	18.7
Silt, (%)	43.0	43.5	43.1	37.2
Clay, (%)	45.1	38.4	41.4	44.2
Water content, W(%)	38.41	60.69	32.03	22.51
Unit weight, γ(kN/m^3)	18.3	16.0	18.5	19.9
Dry unit weight, γ_d (kN/m^3)	13.2	10.0	14.0	16.3
Specific gravity, G_s	2.73	2.63	2.73	2.74
Void ratio, e_0	1.068	1.633	0.950	0.681
Liquid limit, LL (%)	46.0	54.1	44.7	38.6
Plastic limit, PL (%)	23.5	28.7	23.6	19.4
Plasticity index, IP (%)	22.5	25.4	21	19.2
Friction angle φ(^{o})	7^{o}46’	3^{o}53’	11^{o}36’	14^{o}23’

Table 2 Properties of CDM columns

Parameters	Name	Value
Material Model	Model	Mohr - Coulomb
Type of Material behavior	Type	Drained
Soil unit weight above phreatic level (kN/m^3)	γ_{unsat}	11.5
Soil unit weight below phreatic level (kN/m^3)	γ_{sat}	18.4
Young’s modulus (MPa)	E_{ref}	75; 100; 125; 150
Poisson’s ratio	ν	0.333
Cohesion (kPa)	c_{ref}	175

4. RESULTS AND DISCUSSION

The results of the unconfined compressive test are shown in Fig.5 to Fig.10.

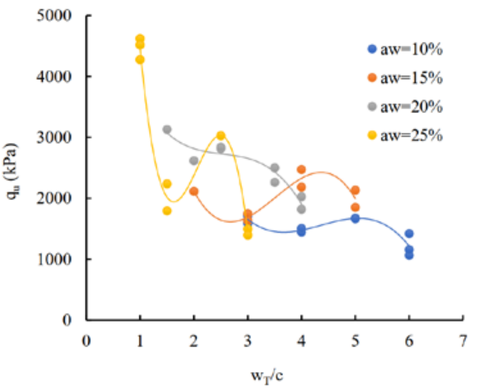

Fig.5 Relationship between q_u and w_T/c at varying percentages a_w= 10%, 15%, 20%, 25%

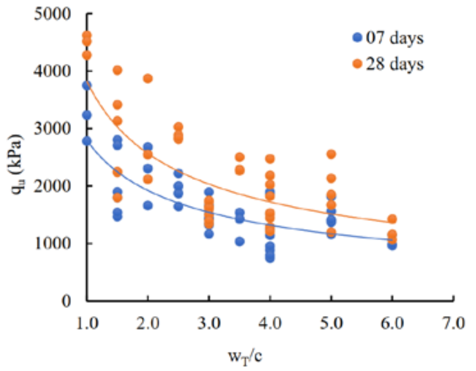

Fig.6 Relationship between q_u and w_T/c at 7, 28 days curing

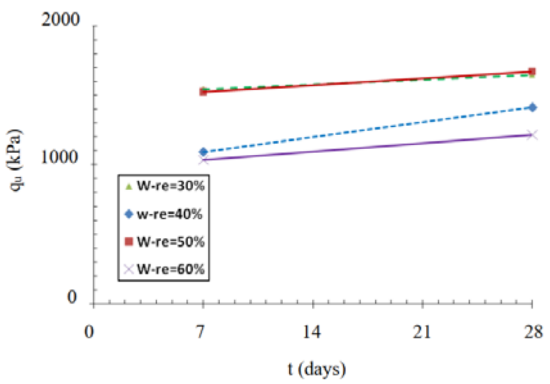

Fig.7 Effect of total water content on q_u for a_w=10%

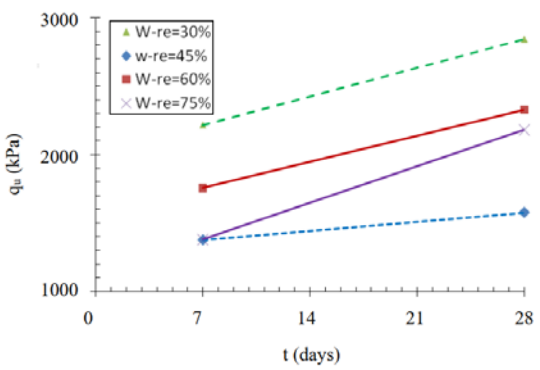

Fig.8 Effect of total water content on q_u for a_w=15%

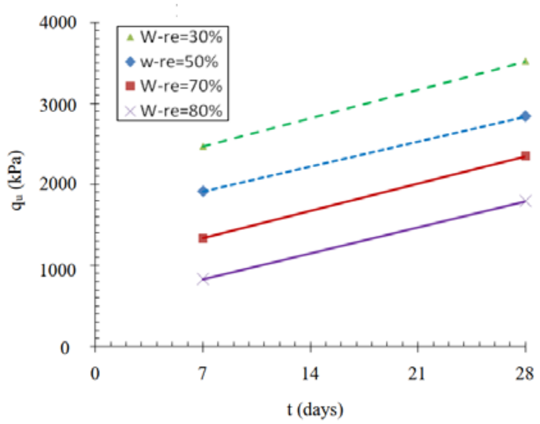

Fig.9 Effect of total water content on q_u for a_w=20%

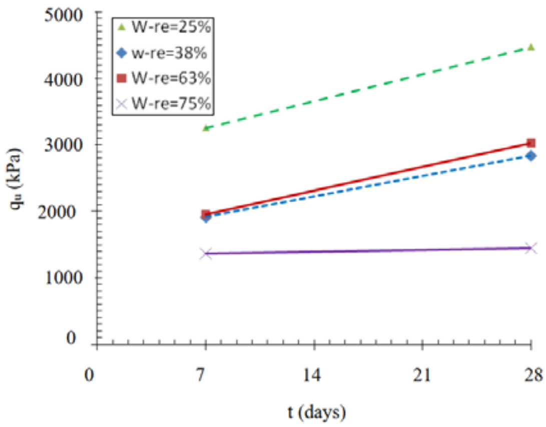

Fig.10 Effect of total water content on q_u for a_w=25%

The results have demonstrated that by adjusting the water content to nearly the upper liquid limit with a specific cement content, the strength increases as the water content rises. However, for a constant cement content and curing time, the strength decreases with an increase in remolding water content, but this trend is observed only within the range of remolding water content up to the upper liquid limit.

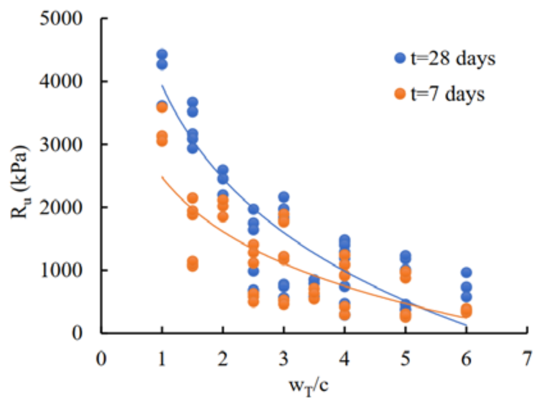

Fig.11 Relationship between R_u and w_T/c at t=7, 28 days curing

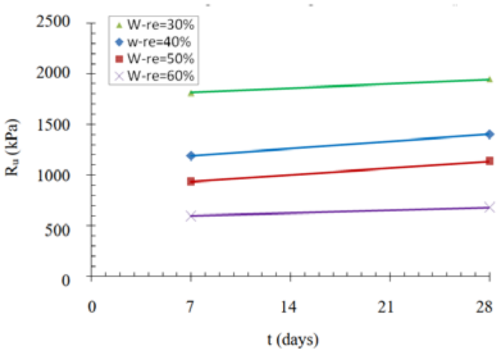

Fig.12 Effect of w_T/c on R_u for a_w=10%

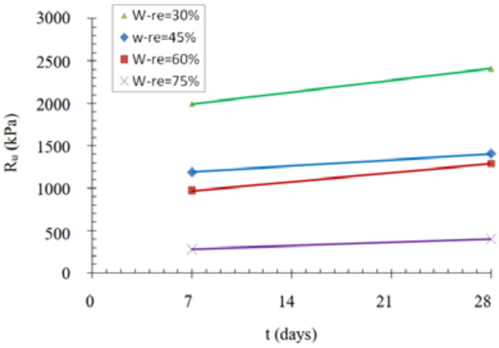

Fig.13 Effect of w_T/c on R_u for a_w=15%

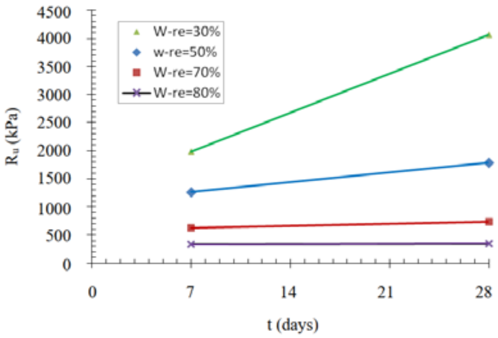

Fig.14 Effect of w_T/c on R_u for a_w=20%

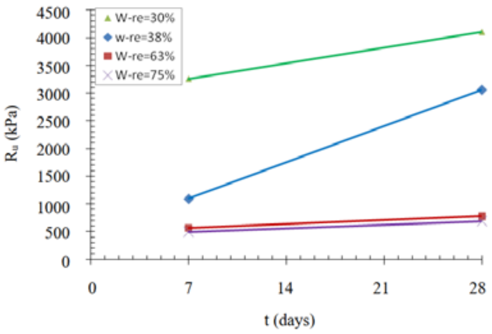

Fig.15 Effect of w_T/c on R_u for a_w=25%

The bending strength of the soil-cement mixtures are shown in Fig.11 to Fig.15. Bending Strength (R_u): The bending strength of the treated soil was assessed using laboratory-manufactured rectangular column specimens. It was observed that the bending strength of the treated soil ranges between 0.4 and 0.6 times the unconfined compressive strength (q_u).

Determining the deformation of ground stabilized with CDM columns is predicated on a fundamental condition. The treated soil, reinforced by CDM columns, is conceptualized as an ideal elastic compressive material, demonstrating failure conditions akin to the Mohr-Coulomb yield. In this study, the calculation of stabilized CDM columns, crucial for mitigating riverside landslides, adopts a perspective where both the columns and the ground function as integral parts of an equivalent foundation block. This foundation system undergoes evaluation for equivalent load capacity and shear resistance. Viewed through this lens, two potential failure modes are considered: the failure of the equivalent foundation block and the failure of the circular arc at the edge of the block. As anticipated, the CDM columns appear to significantly reduce the settlement of the soft ground layer under a horizontal load, as illustrated in Fig.16 to Fig.21.

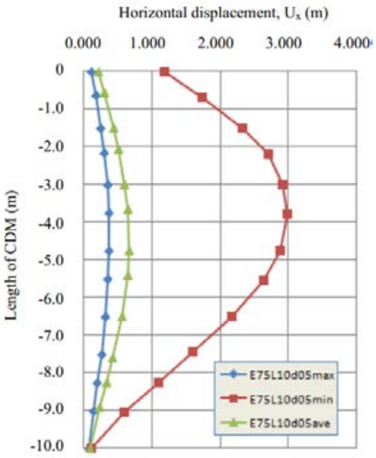

Fig.16 Horizontal displacement of CDM columns when changing water level

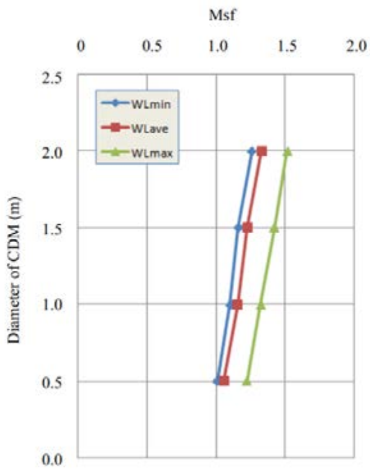

Fig.17 Factor of safety when changing the water level and diameter of CDM columns

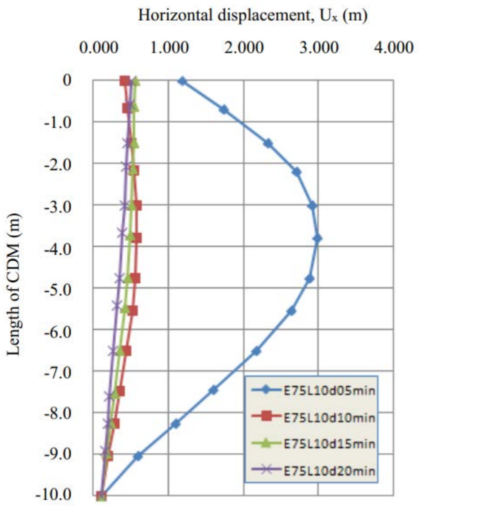

Fig.18 Horizontal displacement of CDM columns when changing diameter

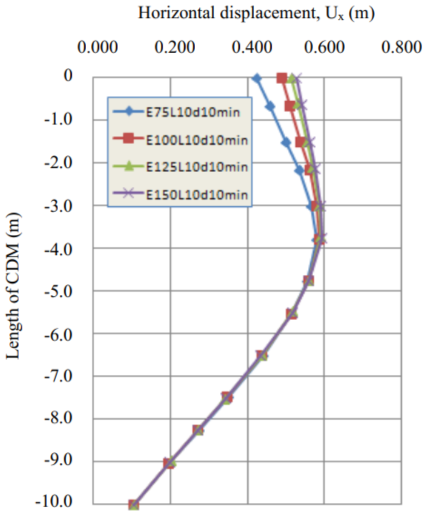

Fig.19 Horizontal displacement of CDM columns when changing Young's modulus

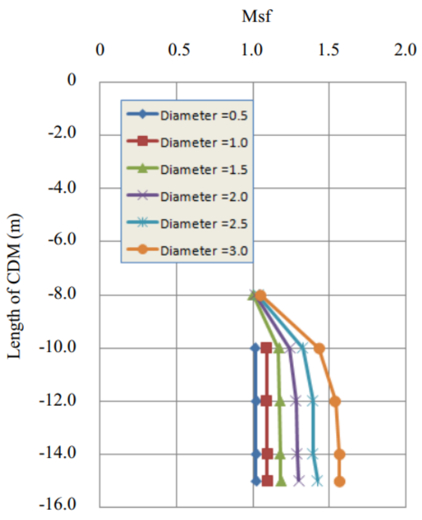

Fig.20 The FS of the road foundation along the Cho Gao canal at E=75 MPa

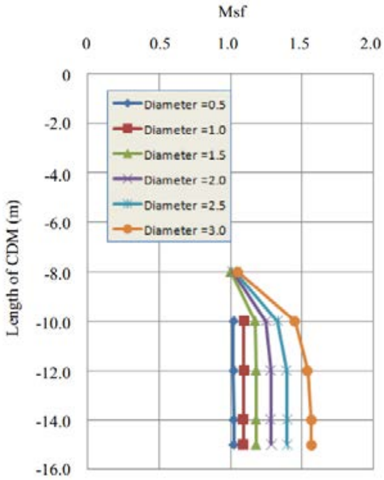

Fig.21 The FS of the road foundation along the Cho Gao canal at E=150 Mpa

The results demonstrate the capability of the nonlinear FEM to accurately simulate the stabilization of the soft soil using CDM columns. The minimal changes observed in these responses suggest that the model may be considered an optimal configuration for stabilizing soft soil layers in the Mekong Delta region.

5. CONCLUSIONS

The unconfined compressive strength of soil mixing samples reaches its highest value when the cement content is 25% and when the samples are cured in air. The results have confirmed that, with total water content close to the upper limit of the liquid limit, increasing the total water content leads to higher strength. However, for a specific cement content and curing duration, the strength decreases with an increase in total water content, but this decline is observed only within the range of total water content near the upper limit of the liquid limit.

The optimal configuration for stabilizing the slope of the Cho Gao canal involves CDM columns with a diameter of 0.5 meters, arranged in three rows with a spacing of 0.5 meters, and each column having a length of 10 meters. Utilizing FEM analysis, the key factors influencing riverbank stabilization through the application of the CDM column method aim to scrutinize. This method is employed to fortify the soft soil foundation of riverbanks. The factors under consideration include the tide and water level of the Cho Gao canal, the river's water environment, the water-to-clay ratio in the cement slurry, the mixing technique, the configuration and length of CDM columns, as well as the lateral loads induced by ship-generated waves and confining pressure.

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