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Research on calculation for stabilizing landslide of road foundation on soft ground reinforced by stiffened deep cement mixing columns

Thang Ngoc Nguyen
Tien Giang City University
119 Ap Bac Street, My Tho City,
Tien Giang Province, Viet Nam.

Tuan Anh Nguyen*
Ho Chi Minh City University of Transport
2 Vo Oanh Street, Binh Thanh District,
Ho Chi Minh City, Viet Nam.

Hen Nguyen Hoang
Long An university of Economics and Industry
938 Highway 1, Tan An City,
Long An Province, Viet Nam.

Abstract - **Deep cement mixing method is a solution for reinforcing soft ground and has been applied in many countries. In Vietnam, deep cement mixing method has also been experimented on and obtained positive results, especially in medium scale and below construction sites in the Mekong Delta where there is a thick layer of soft sediment soil. However, stiffened deep cement mixing column has barely been researched and experimented on. For this reason, the research on theory and design method for stiffened deep cement mixing column, especially using stiffened deep cement mixing column for reinforcing road foundation on soft ground is the main topic of this paper. The result from analysis using finite element method has shown that the factor of safety of soft ground reinforced by stiffened deep cement mixing column has increased from 0.499 to 1.68.**

Keywords- SDCM, DCM, concrete-cored, SLOPE/W, Mekong Delta.

I. INTRODUCTION

Soft ground is ground that cannot bear the load, has insufficient strength and suffers major deformation when stressed, which makes it unsuitable for construction works. When building civil buildings and public infrastructure in the Mekong Delta, soft ground is often present. Depending on the conditions of the soft soil layer there and the specific characteristics of the building, a suitable ground reinforcement method is devised to improve the ground load bearing capacity, reduce settlement, and ensure normal working conditions for the construction work.

In actual construction works, there are many sites on soft ground that have subsided, collapsed, and damaged because of unsuitable ground reinforcement methods and failure to assess the physical and mechanical properties of the soft ground. Therefore, an accurate and solid assessment of the soft ground's properties as the basis for proposing suitable ground reinforcement methods is a very difficult task, demanding both scientific knowledge and practical experience to solve. Once completed, it would help minimize accidents and damage when building on soft ground.

Nguyen, A.T (2022) did research on stress distribution in soft ground reinforced by deep cement mixing (DCM) columns in combination with geotextile fabric under embankments using finite element method. The result showed the behaviors of DCM columns indicated by stress distribution and settlement of the DCM columns and soft soil layers. At the same time, the settlement of road foundation construction is also observed using settlement time chart.

Research on calculating deformation of DCM columns for reinforcing and preventing landslide on riverside road embankment has been done by Nguyen, N. T (2023a) using Plaxis V8.2 in different conditions of water level and the shape of the DCM column used to reinforce riverside road embankment [2]. At the same time, the effects of cement content on the formation of the DCM columns were also observed in this research. The result showed that DCM columns with 20% cement content, 0.6 m diameter, arranged in 5 rows which are 1.0 m apart and 10.3 m long are suitable for preventing landslides on riverside road embankment.

Lin, K. Q. and Wong, I. H (1999) used DCM columns to reinforce soft ground at the slope leading to overpass [2]. On the other hand, Nguyen, N. T (2023b) did a study on using finite element method to simulate the construction of the slope leading to an overpass to calculate and check the stability and deformation of the soft soil layers under soft ground [3]. These calculation results showed that to shorten construction time and limit settlement compensation of the slope leading to an overpass using geotextiles and DCM columns with 0.6 m diameter, 1.2 m apart and 15 m long, then the settlement is 0.013 m and factor of safety is 2.739.

In order to increase stress tolerance, reduce settlement and stabilize the foundation, the DCM columns used to reinforce the ground is supplemented with solid cores in the middle made from materials like concrete, composite, and steel. These are then called stiffened deep cement mixing (SDCM) columns [4].

The research of Dong, P. et al. (2004) used concrete-cored DCM column to increase stress tolerance and reduce settlement

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of soft ground. Results were observed using static loading tests and finite element method [5]. Results showed that concrete-cored DCM column acts as an economical and effective friction column for reinforcing soft ground. Voottipruex, P. et al. (2011) studied the behavior of and simulated working condition of DCM and SDCM columns when reinforcing road embankment on soft ground using full scale loading model and 3D finite element method [6]. Voottipruex, P. et al. (2019) also researched usage of DCM and SDCM columns for reinforcing earth retaining wall when doing deep excavation using field experiment and 3D digital simulation [7].

Li, H. et al (2018) studied the field investigation of the performance of composite foundations reinforced by DCM-bored column under lateral loads [8]. Zhang, C. et al (2022) has a study a modified equal-strain solution for consolidation behavior of composite foundation reinforced by precast concrete columns improved with cement-treated soil [9], Yu, J. et al (2021) studied the shaft capacity of prestressed high strength concrete (PHC) pile-cemented soil column embedded in clayey soil [10], Chen, S. et al (2023) have studied the investigation on behavior of anchored sheet column quay wall improved by cement-soil: Centrifuge and numerical modelling [11], Zhu, S. et al (2022) used analytical modeling for the load-transfer behavior of stiffened deep cement mixing (SDCM) column with rigid cap in layer soils [12]. Wongglert, A. et al (2018) built the bearing capacity and failure behaviors of floating stiffened deep cement mixing columns under axial load [13].

This paper used finite element method to analyze stability of road foundation on soft ground reinforced by SDCM columns to increase the factor of safety of road embankment, ensuring its stability.

II. FEM MODEL ANALYSIS

SLOPE/W is one of the programs developed by GEO-SLOPE, Canada, focusing on slope stability. The program allows calculations on slopes in all possible conditions like pore water pressure, soil anchoring, geotextile, external load, earth retaining wall.

The SLOPE/W is designed in the form of a CAD system, making it easy to use, and most of the data can be entered directly on the drawing. SLOPE/W is applied for calculating and designing of mines, construction and geographical works. There is no limit on the problem size, because SLOPE/W was developed using dynamic memory distribution. The maximum size of the problem is determined by the computer's memory size.

SLOPE/W was built upon many theories related to slope stability: ordinary (or Fellenius) method, simplified Bishop method, simplified Janbu method, Spencer method, Morgen-price method, general limit equilibrium (GLE) method, finite element stress method. The main difference between the different methods is the assumption regarding tangential and normal formal forces between the bands. Furthermore, many functions representing the relationship between the forces between the edges of the bands are used in the GLE and Morgenstern-Price method, which are mathematically rigorous. SLOPE/W offers many different calculation methods so user can choose the most suitable method for a specific problem.

DCM column diameter is d = 0.6 m, length = 10 m, steel reinforced concrete pile with compressive strength 23 MPa with 0.2 m x 0.2 mm cross section, length = 4m, distance between pile centers s = 2.0 mm. In 2D problem, the row of columns in the earth is regarded as a sheet pile wall, with stiffness per unit of wall width (Fig. 1).

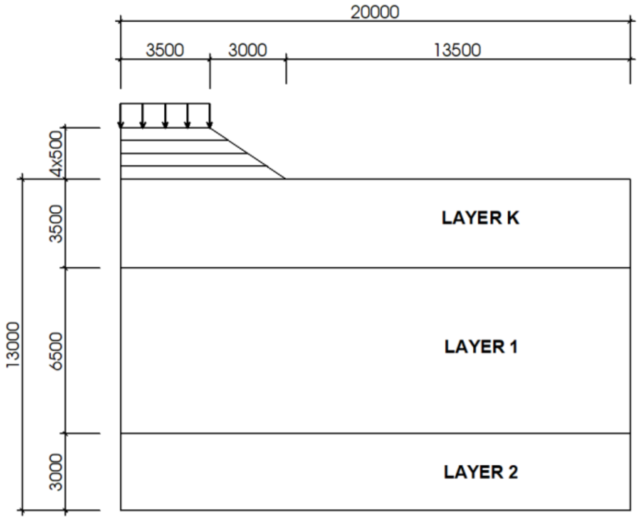

Figure 1. Cross section of unreinforced road embankment

The inputs are taken from geological records and experiment results of soil layers, with the main parameters for calculations of soil layers, embankment, and DCM columns being shown in table 1.

TABLE 1. PARAMETERS OF SOIL LAYERS AND DCM COLUMNS

Parameters		Unit Weight, γ (kN/m^3)	Cohesion, c (kPa)	Friction angle, φ (°)
Soil layer	Emb. fill	18.00	10.0	25°
	Layer K	18.54	4.0	25°44’
	Layer 1	15.41	9.5	5°49’
	Layer 2	20.01	21.8	14°57’
DCM column		12.53	175.0	30°

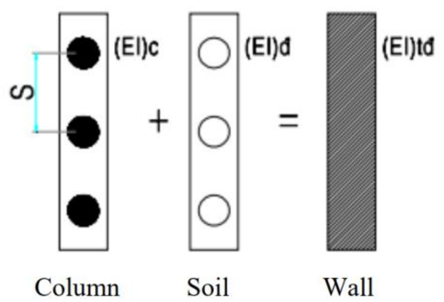

Figure 2. Equivalent exchange of hardness between piles and ground

Using the classic fragmentation method of Bishop with the help of Geo-Slope.

Case studies: Case 1_Unreinforced ground; Case 2_Ground reinforced bt DCM column; Case 3_Ground reinforced by

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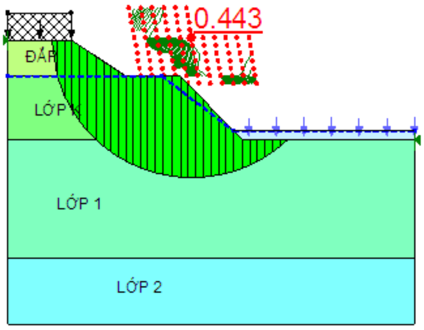
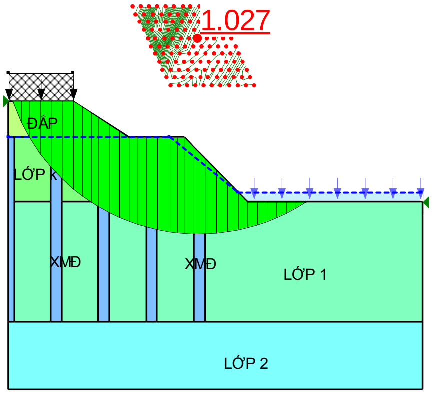
SDCM column. The problem is simulated with ground water level at 0.0 m; - 1.5 m; -3.5 m; and -10.0 m.

IV. RESULTS AND DISCUSSION

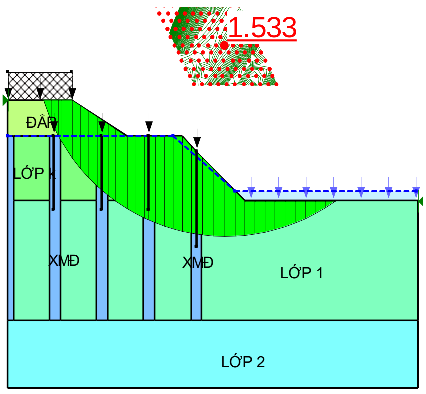
In all of the cases where the ground was not reinforced or reinforced with DCM columns, the factor of safety FS < 1.25, the foundation of the road is not stable according to the standard stated by QCVN 04-05-2010. The construction site must receive a ground reinforcement. The road foundation after being reinforced with SDCM columns has factor of safety FS between 1.533 and 1.746, which is highly stable but not economically efficient (Figs 3-6).



a) Unreinforced ground

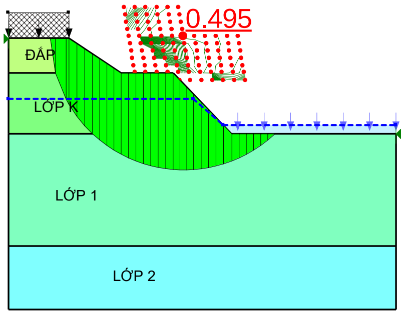


b) Ground reinforced with DCM columns

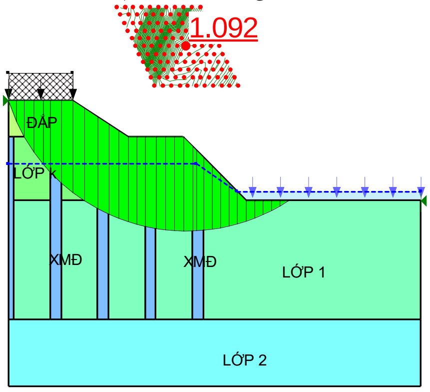


c) Ground reinforced with SDCM columns

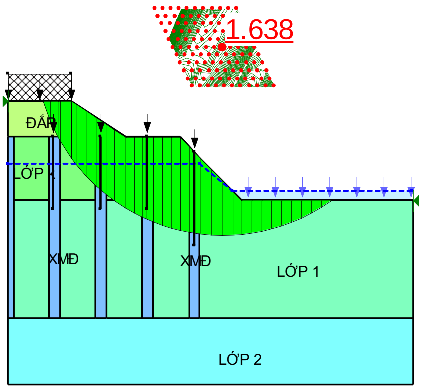
Figure 3(a,b,c). Factor of safety at the groundwater level of 0.0 m



a) Unreinforced ground

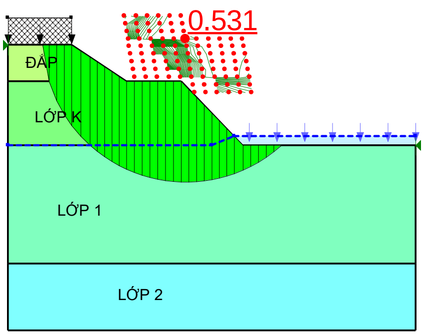


b) Ground reinforced with DCM columns



c) Ground reinforced with SDCM columns

Figure 4(a,b,c). Factor of safety at the groundwater level of -1.5 m



a) Unreinforced ground

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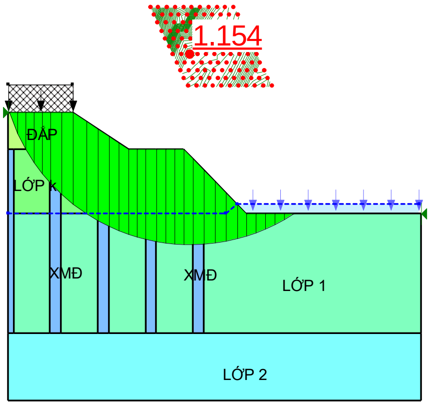
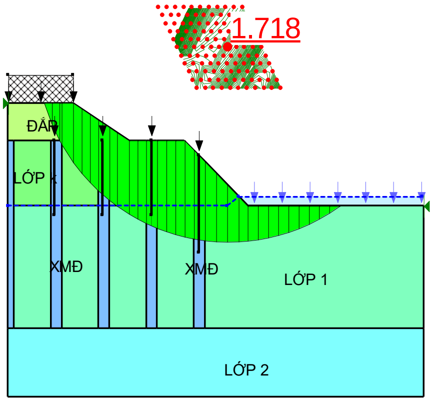
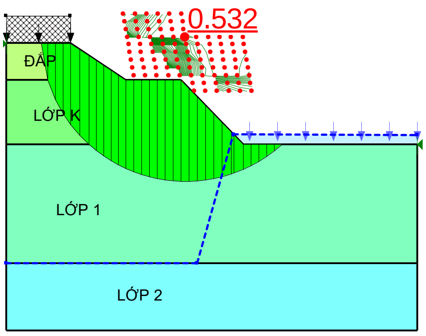


b) Ground reinforced with DCM columns

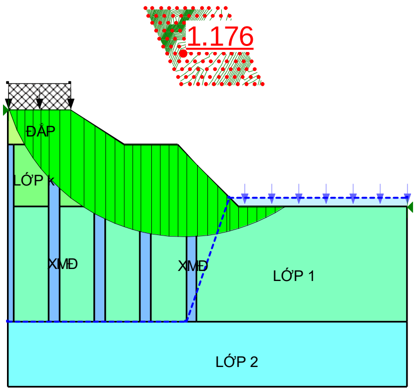


c) Ground reinforced with SDCM columns

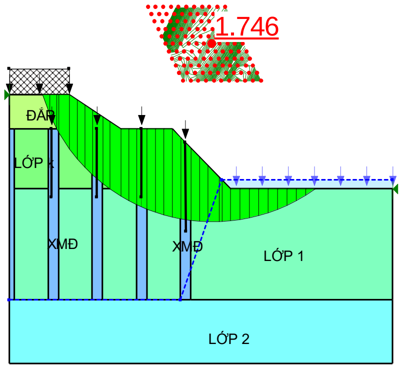
Figure 5(a,b,c). Factor of safety at the groundwater level of -3.5 m



a) Unreinforced ground

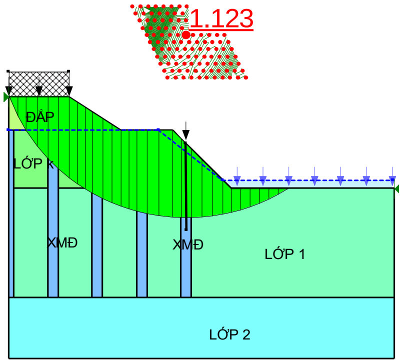


b) Ground reinforced with DCM columns

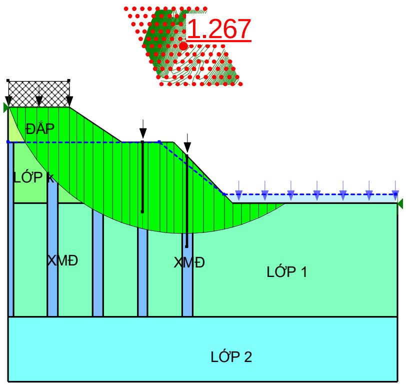


c) Ground reinforced with SDCM columns

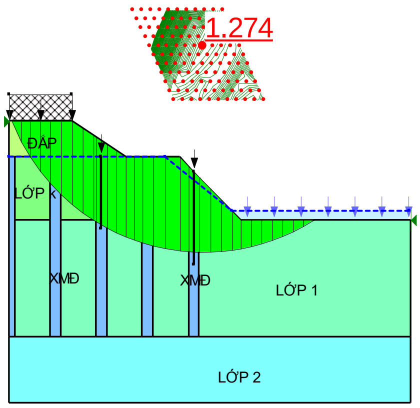
Figure 6(a,b,c). Factor of safety at the groundwater level of -10.0 m



a) Stiff core at position 1



b) Stiff cores at positions 1 and 2



c) Stiff cores at positions 1 and 3

Figure 7(a,b,c). Factor of safety when DCM columns is reinforced with stiff core

After reinforcing the ground with SDCM columns and ensure stability, the most dangerous water level of -10.0 m is chosen to calculate cases where DCM columns are reinforced with stiff cores at position 1, positions 1 and 2, positions 1 and 3, while the rest are normal DCM columns to find out the optimal positions where both stability and economic efficiency are considered. The results are shown in Fig. 7.

The simulation result shows that enhancing piles with stiff cores at position 1 gives FS = 1.123, at positions 1 and 2 gives FS = 1,1267, and at positions 1 and 3 gives FS = 1.274.

Road embankments is one of the most frequently damaged infrastructure and suitable solutions must satisfy continuously higher quality standards for road embankment on soft ground. Therefore, analysis and calculation of stable solutions are vital for meeting these standards. It involves many input parameters, complex calculations, various simulation models of ground behavior, so the result is adequately accurate.

V. CONCLUSIONS

The factor of safety of the ground without reinforcement is 0.499, and after using SDCM columns is 1.68. Calculations of factors of safety with various combinations of DCM and SDCM columns shows that when only position 1 is reinforced with stiff core, the factor of safety FS = 1.18, when 1 and 2 are reinforced FS = 1.28, when 1 and 3 are reinforced FS = 1.278. Through these results we choose the solution of reinforcing the piles at positions 1 and 3 while the rest are normal DCM columns.

SDCM method is a new solution with promising result, which increase factor of safety for road embankment, ensuring stability. When using the software based on the finite element method, it gives the designer the ability to analyze various problems with different design parameters to pick the most suitable method for ground reinforcement.

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