An Analytical Stabilization of Landslide on Road Foundation Soft Ground Improvement by SDCM Columns

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ARTICLEINFO

ABSTRACT

The deep cement mixing (DCM) method is a solution for reinforcing soft ground and has been applied in many countries. In Vietnam, the DCM 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 (SDCM) column has barely been researched and experimented on. For this reason, the research on theory and design method for the SDCM column, especially using the SDCM column for reinforcing road foundation on soft ground is the main topic of this paper. The result from analysis using the finite element method has shown that the factor of safety of soft ground reinforced by the SDCM column has increased from 0.532 to 1.746.

Keywords : SDCM, FEM, road foundation, 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 work. 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 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, many sites on soft ground 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) researched stress distribution in soft ground reinforced by DCM columns in combination with geotextile fabric under embankments using the 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 the settlement time chart.

Research on calculating the deformation of DCM columns for reinforcing and preventing landslide on riverside road embankments 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 the overpass [2]. On the other hand, Nguyen, N. T. (2023b) did a study using the 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.

To increase stress tolerance, reduce settlement, and stabilize the foundation, the DCM columns used to reinforce the ground are supplemented with solid cores in the middle made from materials like concrete,

composite, and steel. These are then called SDCM columns [4].

The research of Dong, P. et al. (2004) used concrete-cored DCM columns to increase stress tolerance and reduce the settlement of soft ground. Results were observed using static loading tests and finite element methods [5]. Results showed that the 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 the working condition of DCM and SDCM columns when reinforcing road embankments on soft ground using the full-scale loading model and 3D finite element method [6]. Voottipruex, P. et al. (2019) also researched the usage of DCM and SDCM columns for reinforcing earth retaining walls when doing deep excavation using field experiments and 3D digital simulation [7].

Li, H. et al (2018) studied the field investigation of the performance of composite foundations reinforced by DCM-bored columns under lateral loads [8]. Zhang, C. et al (2022) has a study a modified equal-strain solution for the 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 the behavior of anchored sheet column quay wall improved by cement-soil: Centrifuge and numerical modeling [11], Zhu, S. et al (2022) used analytical modeling for the load-transfer behavior of SDCM column with rigid cap in layer soils [12]. Wongglert, A. et al (2018) built the bearing capacity and failure behaviors of floating SDCM columns under axial load [13].

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

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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, and 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 into 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 methods, which are mathematically rigorous. SLOPE/W offers many different calculation methods so users can choose the most suitable method for a specific problem.
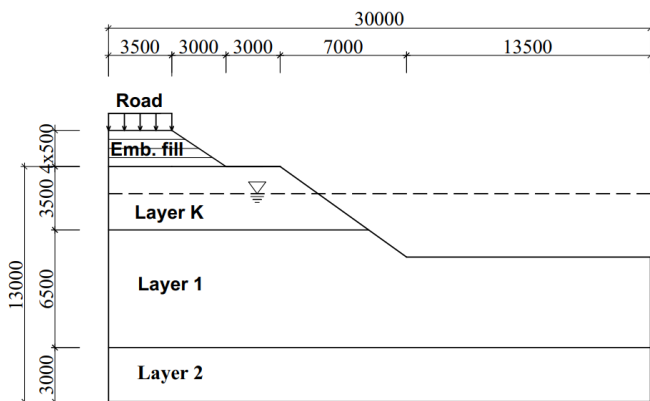

Figure 1. Cross section of unreinforced road embankment

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 below.

Table 1. Parameters of soil layers and DCM columns

Parameters	Soil layer				DCM column
	Emb. fill	Layer K	Layer 1	Layer 2	
Unit weight, γ (kN/m³)	18.00	18.54	15.41	20.01	12.53
Cohesion, c (kPa)	10.0	4.0	9.5	21.8	175.0
Friction angle, φ (°)	25°	25°44'	5°49'	14°57'	30°

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 m cross-section, length = 4.0 m, distance between pile centers s = 2.0 m. In the 2D problem, the row of columns in the earth is regarded as a sheet pile wall, with stiffness per unit of wall width.
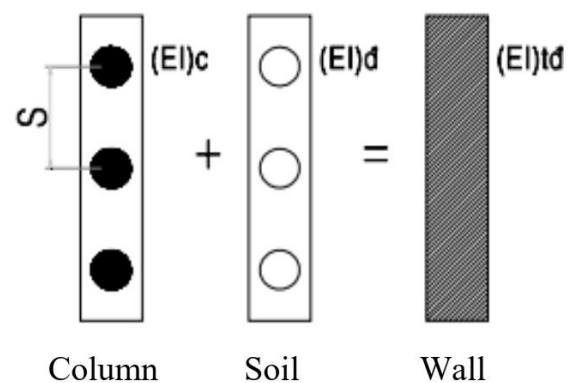
Figure 2. Equivalent exchange of hardness between piles and ground

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 SDCM column. The problem is

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simulated with ground water levels at 0.0 m; - 1.5 m; - 3.5 m; and -10.0 m.

III. 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 a factor of safety FS between 1.533 and 1.746, which is highly stable but not economically efficient.

After reinforcing the ground with SDCM columns and ensuring 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.
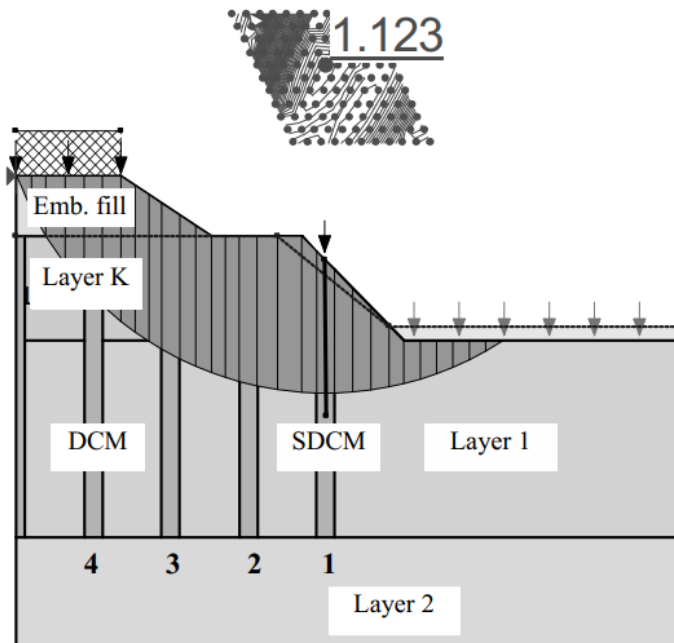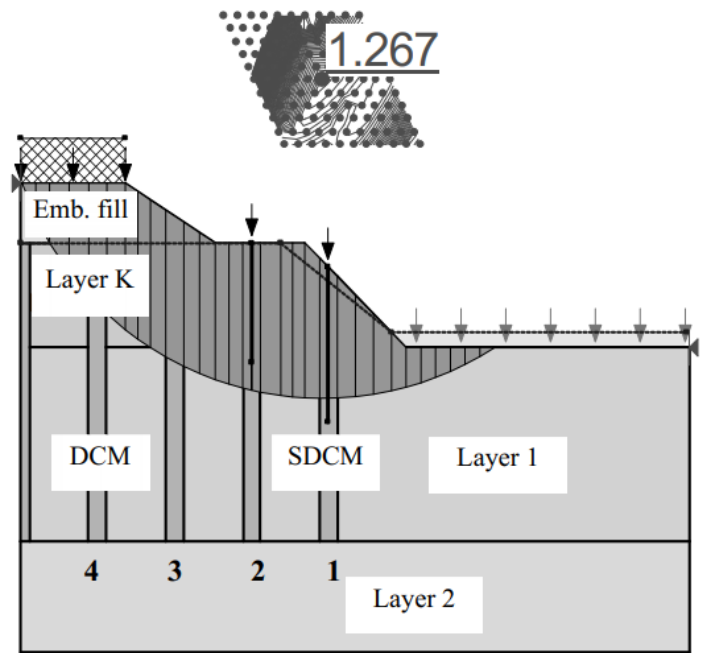

Figure 4. The factor of safety when the SDCMs are at positions 1 and 2

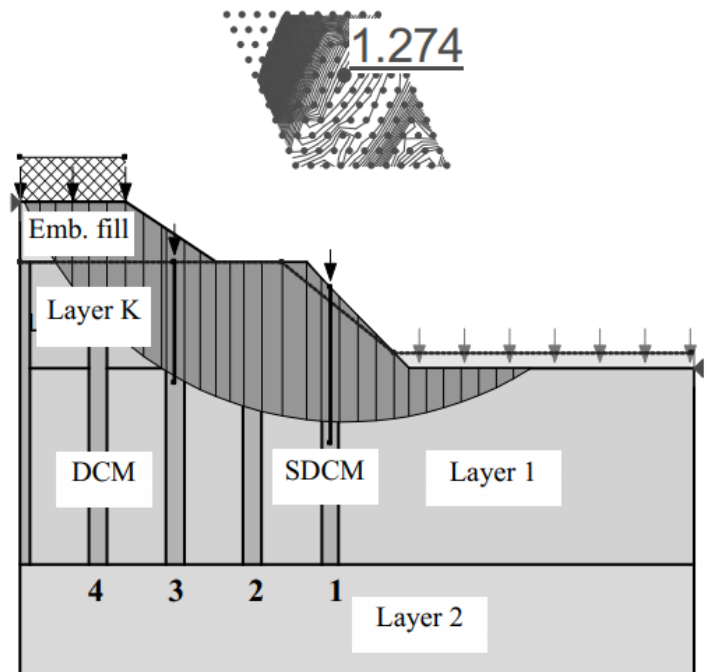Figure 5. The factor of safety when the SDCMs are at positions 1 and 3

Figure 3. The factor of safety when the SDCM is at position 1

The simulation result shows that enhancing piles with stiff cores at position 1 gives FS= 1.123, at positions 1 and 2 gives FS= 1.267, and at positions 1 and 3 gives FS= 1.274.

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

IV. CONCLUSIONS

The factor of safety of the ground without reinforcement is 0.532, and after using SDCM columns is 1.746. Calculations of factors of safety with various combinations of DCM and SDCM columns show that when only position 1 is reinforced with a stiff core, the factor of safety FS= 1.123; when 1 and 2 are reinforced FS= 1.267; when 1 and 3 are reinforced FS= 1.274. Through these results, we choose the solution of reinforcing the piles at positions 1 and 3 while the rest are normal DCM columns.

The SDCM method is a new solution with promising results, which increase the factor of safety for road embankments, ensuring stability. Using the software based on the finite element method 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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