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THE SIMPLIFIED DESIGN METHOD TO FIND OUT THE OPTIMUM CEMENT DEEP MIXING COLUMNS CONFIGURATION IN IMPROVING SOFT GROUND

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Abstract. The soil improvement technique, called Deep Mixing Method (DMM), is often applied for improve the strength of the treated soft ground in Delta areas. In recent years design and construction of infrastructure facilities arising due to extensive urbanization and industrialization in soft clay zones has considerably increased. During the course of the development over the past few decades, at various stages, well documented stage of the art reports dealing with the techniques of improving ground conditions, design methodology, and specific records of adopting different methods. Among these methods, Cement Deep Mixing (CDM) columns formed by DMM is an economical and effective methods to treat the soft soils under embankment. In this research the configuration of the CDM columns, which is embedded in the soft ground layers, is investigated for different sizes of diameter, spacing and length of CDM columns. By this research, a new method to find out the optimum configuration using the formula in the current design is proposed as the Simplified Design Method.

Keywords: Soil improvement, Deep Mixing Method, Simplified Design Method, Mekong Delta

1. INTRODUCTION

In recent years design and construction of infrastructure facilities arising due to extensive urbanization and industrialization in soft clay zones has considerably increased. The properties of the soil in this area are high water content, low stiffness and less frictional angle and less cohesion as well. This type of soil, in geotechnical engineering point of view, is known as an unstable soil since the soil will cause relatively large settlement when it is loaded, due to high excess pore pressure and reduction of effective stress within soil mass. The large settlement of the embankment, which is one of typical example of civil structure constructed on the soil layer, is the unstable behaviors of the soft soil during heavy loading.

There are several methods used for stabilizing the soft soil such as Mekong Delta soil. Soil improvement technique is often needed to rapidly improve the strength of the treated ground. Bergado, D.T et al.(1996), the DMM is an in situ soil treatment and improvement technology whereby the ground is blended with cementitious and/or other materials to form a vertical stiff inclusion in the ground [1]. These materials are internationally referred to as “binders” and can be introduced in slurry or dry form.

They are injected through hollow, rotated mixing shafts tipped with some type of cutting tool. In this technique, physical and chemical reactions between cement, clay minerals, and water including hydration, pozzolanic reaction, ion exchange, flocculation, precipitation, oxidation, and carbonation are allowed to take place deep below the ground to produce a high-strength product quickly which will continue to strengthen with time and lower permeability, and lower compressibility than the native ground.

In the chemical point of view, CDM method is used to reduce the high water content in the soil mass by absorbing the water molecule during the cementations of CDM columns. In the mechanical point of view, the CDM method is used to increase the stiffness of soil mass by the high stiffness of CDM columns. CDIT (2022), in these methods, the settlement of the soil layer is calculated by the consolidation index and the bearing capacity is check by the strength of the CDM columns and the bearing capacity of the soil [2].

Anucha W. et al. (2018) studied the bearing capacity and failure behaviors of floating stiffened deep cement mixing columns under axial load [3]. This research aims to clarify and gain an insight into the impact of the length of the stiffened core and the strength of the CDM socket on the behaviors of floating stiffened deep cement mixing columns. The observed behaviors include the axial ultimate bearing capacity, settlement and failure mode. The study begins by conducting a series of physical model tests as a preliminary investigation. The results reveal that the strength of the CDM socket can be reduced to a certain value by inserting a sufficiently long reinforced core to achieve the highest possible load-carrying capacity, indicating an optimum length of the stiffened core for a specific CDM socket strength.

Nguyen Ngoc Thang, Nguyen Anh Tuan (2018), Hong-Son Nguyen et al. (2020), and Nguyen Anh Tuan, Nguyen Thanh Dat (2020) studied the nonlinear FEM analysis of cement columns configuration in the foundation improved by deep mixing method. In this study, the stress distribution and the deformation in the foundation improved by DMM are analyzed using nonlinear FEM in which the stress-strain relation is elastoplastic to apply to more detailed specification of the configuration of CDM columns [4, 5, 6].

2. MECHANISM OF CEMENT DEEP MIXING METHOD

2.1. Load transfer mechanisms

CDM columns is installed as isolated columns constructed using single-axis equipment, depending on the purpose and ground conditions, CDM columns can be configured in typical arrangement patterns panels of overlapping columns, cells of overlapping columns, or blocks of overlapping columns. Column type is separately installed most easily under the pattern of square, triangular, or hexagon grid and the construction machine is simple. Regardless of the CDM columns arrangement, the

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concepts of area replacement ratio and stress concentration ratio, are common to all design procedures. For isolated CDM columns, the area replacement ratio is defined as the ratio between the area of the CDM columns, A_{col}, and the total area, $A_{col}+A_{soil}$ (Figure 1). Considering distribution of load on CDM columns and soft soil under a road embankment are shown in Figure 2).

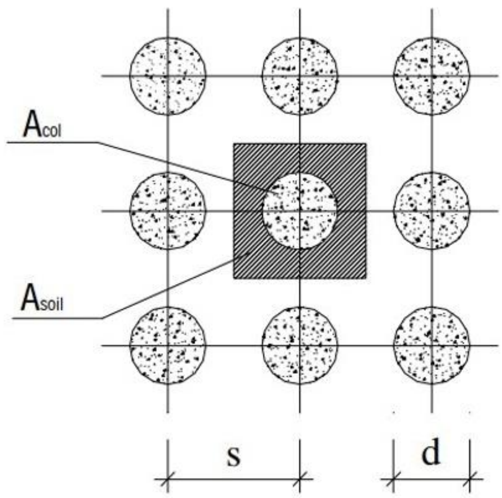

Figure 1. Area replacement ratio

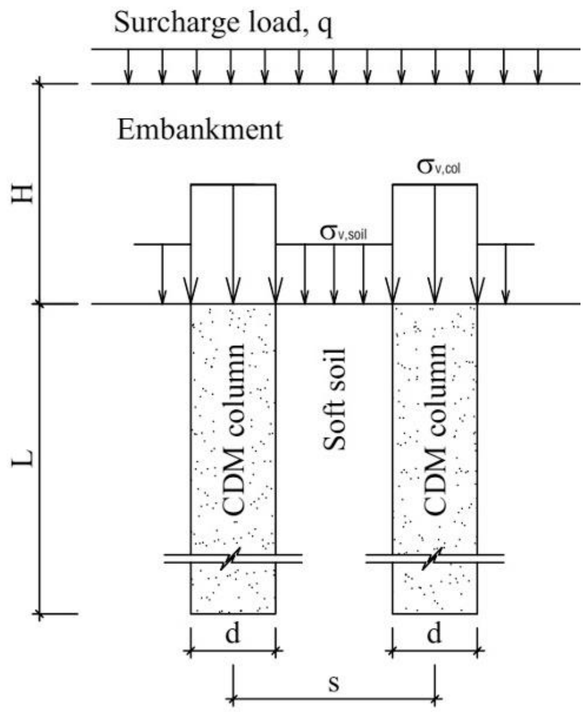

Figure 2. Illustration of load distribution for CDM columns

2.2. The ultimate bearing capacity of the single CDM columns:

Examination of practice design aspects for stability of embankment stabilized by DMM columns, Bengt B. H. (1999) took precaution that the DMM columns failures can occur in rupture or and collapse due to bending and tilting, and thus internal stability of DMM columns should be also considered in design [7]. Consequently, evaluating the failure of DMM columns beneath the embankment under many differential conditions, such as, due to bending, shearing, compression etc. is necessary work in practice design of embankments. The ultimate bearing capacity of a single CDM columns depends both on the skin friction resistance along the surface of the CDM columns and on the end resistance.

2.3. The undrained compression strength of soil-cement mixture:

The undrained compressive strength of soil stabilized with cement is usually higher than that of the undisturbed soil about 1 to 2 hours after the mixing. The undrained

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shear strength of the stabilized soil under favorable condition is as high as 0.5 to 1.0 MPa. 10 to 50 times increase of the strength is expected.

3. OPTIMUM CDM COLUMNS CONFIGURATION

A configuration of CDM columns generally depends on several factors such as allowable settlement, soil capacity requires preventing failure of civil structures such as embankment and dimension of the CDM columns. The simple method is one of limit equilibrium method where the applied load must equal to resistant of the CDM columns and soil layer beneath the civil structure, such as embankment. The resistance of the CDM columns is analyzed by Terzaghi’s equation and settlement is evaluated by using consolidation theory.

3.1. Model of a case study

The model to be analyzed is shown in Figure 3. The model consists of three soil layers, i.e., 11 m soft soil layer, 4 m silty clay and 5 m silty sand, respectively. A 5 m high embankment structure is constructed on soft soil layers. The embankment is planned to pass a transportation highway. Since the model is analyzed in two dimensional, only cross section of the model is given here.

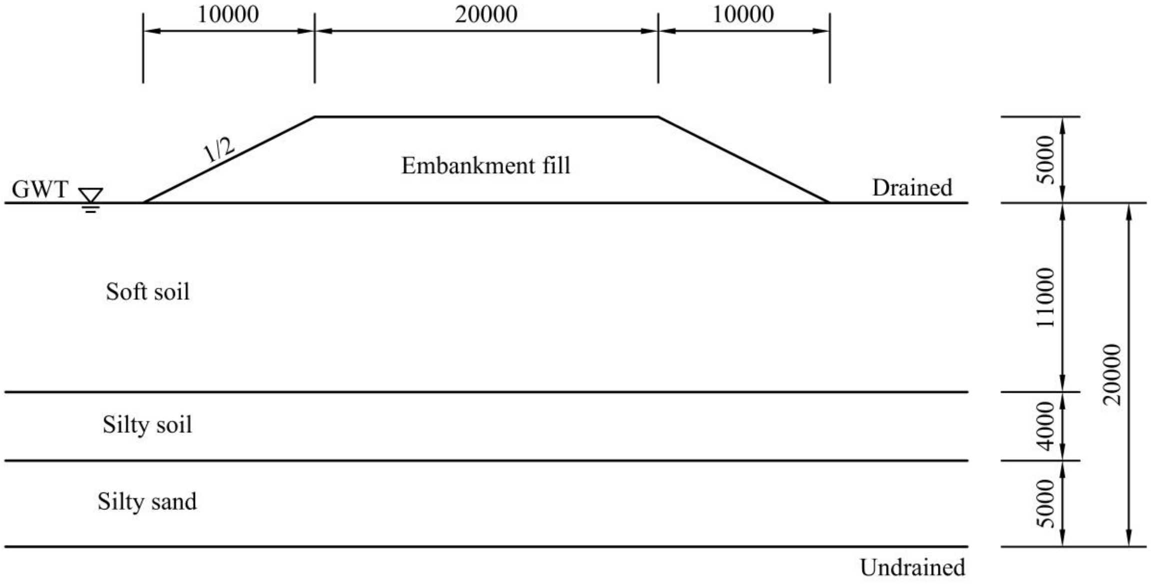

Figure 3. Cross section of the embankment model

The parameters of soil layers are defined according to field and laboratory test for the soil mass cored from the Mekong delta soil from Engineering Geological Report at Chau Thanh district – Tien Giang province [8]. Detailed soil properties used in this study is given in Table 1.

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Table 1. Soil properties of soil layers

ID	Soil Parameters	Soft Soil	Silty clay	Silty sand	Unit
1	Saturated unit weight, γ_{sat}	17.450	19.680	19.860	kN/m^3
2	Young's modulus, E	3.100	4.290	4.610	MPa
3	Cohesion, c	0.0032	0.0429	0.0461	MPa
4	Void ratio, e_0	2.419	0.685	0.424	-

3.2. Optimization of configuration of the CDM columns by using Simplified Method

The optimization of the CDM columns configuration using simplified method is conducted to define optimum diameter of CDM columns, the spacing (center to center of CDM columns) and length of CDM columns, when the applied load beneath the embankment is 120 kN/m^2. The optimum configuration has to satisfy allowable maximum settlement 0.4 m beneath the embankment according to Vietnamese Standard for transportation road, TCVN 22TCN 262-2000 [9]. The simplified method is started by evaluating the bearing capacity of soil layers using Terzaghi equation. The bearing capacity calculated in depth of soil layers below the embankment structure. A maximum bearing capacity of soil layer on the level -11 m (soft soil layer) is around 115 kN/m^2. The capacity is relatively low comparing with the applied load beneath of embankment, which is 120 kN/m^2.

Using material properties given in Table 2, the minimum ratio of area of the CDM columns in square of stabilized area is investigated for the different dimensions of CDM columns.

Table 2. Material properties of CDM columns.

ID	Parameter	CDM columns	Unit
1	Saturated unit weight, γ_{sat}	15.270	kN/m^3
2	Young's modulus, E	40.000	MPa
3	Cohesion, c	0.200	MPa
4	Frictional angle, φ	30.00	degree
5	Void ratio, e_o	1.432	-

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In this study, the application of the simplified method is done by varying the diameter of CDM columns of 0.6 m, 0.8 m, 1.0 m, 1.2 m and 1.4 m, respectively; the spacing of center of CDM columns of 0.8 m, 1.0 m, 1.2 m, 1.4 m, 1.6 m and 1.8 m, respectively; length of CDM columns of 7.0 m, 9.0 m and 11 m, respectively. The calculation results according to this simplified method are plotted as shown in Figure 4 to 6. Based on the results in Table 3, the optimum configuration for stabilizing soil layer for this case is indicated that the diameter is 0.6 m, spacing is 0.8 m for the length of 7.0 m, 9.0 m and 11.0 m.

Table 3. Values of ratio of CDM columns area

Length L	**Spacing s= 0.8 m**	**Spacing s= 1.0 m**	**Spacing s= 1.2 m**	**Spacing s= 1.4 m**
7.0 m	d: 0.6 m a_s: 0.442	d: 1.0 m a_s: 0.785	d: 1.2 m a_s: 0.785	-
9.0 m	d: 0.6 m a_s: 0.442	d: 0.8 m a_s: 0.502	d: 1.0 m a_s: 0.545	d: 1.4 m a_s: 0.785
11.0 m	d: 0.6 m a_s: 0.442	d: 0.8 m a_s: 0.502	d: 1.0 m a_s: 0.545	d: 1.2 m a_s: 0.557

The final step in this simplified method is evaluating the settlement beneath the embankment after using CDM columns. The total settlement after stabilizing is accumulation of the settlement of stabilized soil and original soil.

4. CONCLUSIONS

The analytical study for design the optimum configuration of the CDM columns to stabilize the soft soil layer on the Mekong delta area has been described. In this study, the Simplified Design Method derived based on established formulations in soil mechanic is proposed to defined initial configuration of the CDM columns embedded on soft soil layer.

The optimum configuration of the CDM columns to stabilize an embankment is determined by the Simplified Method in which settlement and bearing capacity are estimated by the formula used in the current design.

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The optimum configuration of CDM columns is the diameter of 0.6 m, the spacing of 0.8 m and the length of 11.0 m. The total settlement is 0.352 m for this case and this settlement is less than the allowable maximum settlement.

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