Influence of Geometrical Parameters of Soil-Cement Columns on the Average Settlement of Embankment on Reinforced Soft Soil – Numerical Analysis

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ABSTRACT: This article contributes to analyze the behavior of foundation on soft soil improved by soil-cement columns (SCC). Axisymmetric model is used in foundation settlement analysis by finite element method with geotechnical characteristics gathered from some typical projects in Viet Nam. Influence of geometrical parameters such as SCC diameter, SCC spacing and SCC length are considered in these evaluations. The results clarify the behavior of reinforced ground base and offer recommendations for the choice of relevant geometrical scheme of SCC system to improve soft soil in transportation projects in Viet Nam.

KEYWORDS: Soil-cement columns, Model, Embankment, Soft soil, Strain, Stress, Settlement, Viet Nam, Spacing, Length, Diameter.

1. INTRODUCTION

Deep Mixing Method (DMM) is a widely used soft soil improvement method in the construction of road, port, and tunnel foundations, etc. Deep mixing of cement with soil and water, forming Soil Cement Columns (SCC) in situ, has been applied in many projects in Viet Nam in recent years; it has proved many advantages compared with other applied methods in the site.

At present, Vietnamese engineers are concerned with finding out recommendations for an optimal choice of SCC scheme as well as control of the local behavior of reinforced soft soils in many transportation projects. Design standards are not of good use in this case. Hence, numerical simulation should be used to model the behavior of reinforced soft soil by SCC. The influence of the SCC length, SCC diameter and SCC spacing on the settlement of reinforced soil can be easily evaluated by performing parametric studies.

This paper analyzes the influence of main geometrical parameters of SCC including the length, the diameter, and the spacing on the behavior of reinforced soft soils by numerical method based on material parameters gathered from some construction projects in Viet Nam. The results will be an important basis for recommendations on the choice of rational schemes of SCC for soft soil improvement in Viet Nam.

2. BEHAVIOR ANALYSIS OF SOFT SOIL REINFORCED BY SCC

2.1. Approaches for modeling the behavior of soft soil reinforced by SCC

Behaviour of soft soil reinforced by SCC can be modelled by different approaches by using finite element method.

Two main methods namely equivalent convertible method and non-convertible method have been used to calculate foundations improved by SCC (Han & al, 2007; Huang & al, 2006; Nguyen & al , 2012; and Paulo & al, 2011). The first method is only appropriate for general stability analyses of ground base, while the second allows to analyse the separated behaviour of SCC and soft soil around them in foundation.

Nowadays, the behaviour of soft soil reinforced by SCC can be analysed by three common approaches in numerical calculation: plane strain analysis, axisymmetric analysis, and spatial analysis.

Plane strain analysis can be used to consider the behaviour of the system of SCC working separately with soft soil without converting into an equivalent foundation. However, this approach only relevant for sections passing through the centerline of SCC (Figure 1).

The 3D model is the most appropriate to describe the behavior of improved soft soil due to its performance. However, the 3D model is so complex and time-consuming to calculate.

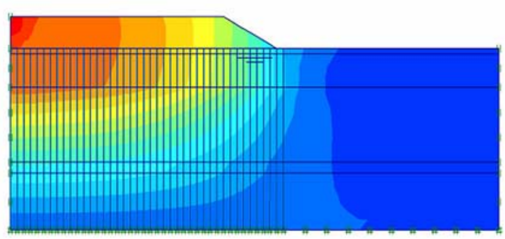


Figure 1 Plane strain analysis

Axisymmetric analysis by finite element method has been proved as relevant approach thanks to its simplicity, its precision as well as its rapidity in comparison with spatial analysis. With the circular structure, the symmetric loads in all directions around the central axis (axis through column centreline) and the performance of the system of columns are suitable for axisymmetric analysis (Nguyen & al , 2012; Paulo & al, 2011)

In the axisymmetric analysis, strain and stress state are totally similar with all of directions which are around central axis; the axis x denotes axis of radius and the axis y corresponds to central axis (Figure 2).

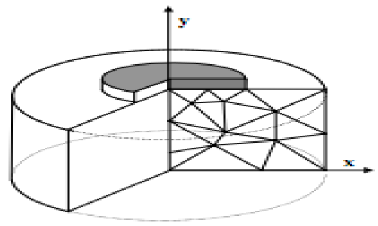


Figure 2 Axisymmetric analysis

The calculated area of soft soil around SCC is shown in the Figure 3. The circle area of soft soil around SCC (Figure 3b) is equal to the square area above (Figure3a).

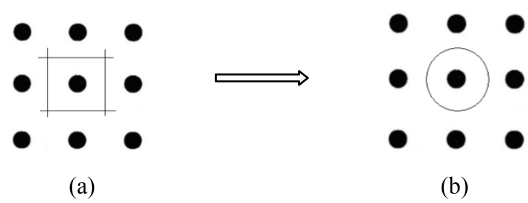


Figure 3 The diagram to convert the equivalent areas of the combination of a column and around soft soil

The axisymmetric model is especially appropriate for the large areas of soft soil which needs reinforcing.

2.2. Material-related models

In order to solve geotechnical problems, there are a lot of material models for soil behavior simulation: Elasto-perfectly plastic model (eg: Mohr-Coulomb), creep model of soft soil or durability recovery model (hardening model), etc (Venda & al , 2011).

The Mohr-Coulomb model is widely applied in reality due to its simple, easy calibration of necessary material parameters and acceptable results; this model is, therefore, used in this study.

The creep and consolidation of soft soil can be considered with time-depending model given in Plaxis finite element code (Plaxis V8.2).

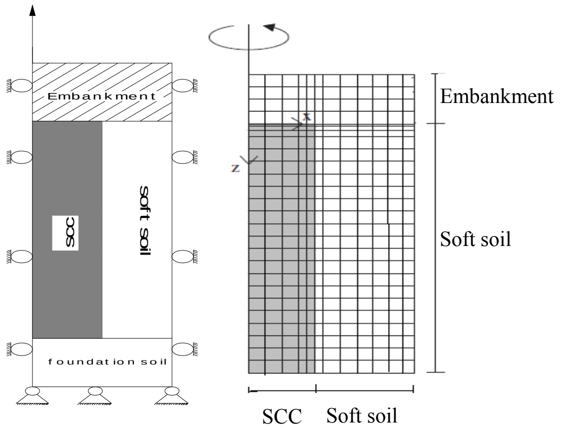
The around soft soil, filled embankment, and foundation soil are assigned with the Mohr-Coulomb model. The SCC is appropriate for linear elastic model due to its greater rigidity compared with around soil.

Mechanical parameters of the two above material models are gathered from technical documents of typical projects using SCC in Viet Nam, all these parameters are clearly explained in the material model description document of Plaxis V8.2.

3. ANALYSIS OF THE INFLUENCE OF GEOMETRICAL PARAMETERS ON THE BEHAVIOR OF SCC

3.1. Problem Description

The calculation scheme with boundary conditions is presented in the Figure 4. The finite element mesh includes six nodes quadrilateral elements. The connection between elements: SCC and ground base as well as soft soil, SCC and filled embankment is assumed to be continuous.



(a) (b)

Figure 4 Calculation scheme and boundary conditions (a) and finite element mesh (b)

The geometrical boundary conditions include roller supports to the right and left of filled embankment, pinned support at the bottom.

The boundary condition for load is denoted by vertical displacement which applies on the top of embankment as surcharge load, lateral displacement of SCC isn't considered. The values of the vertical displacements are respectively 0.1 m; 0.2 m; 0.3 m; these values are considered based on the consultation of Vietnamese standard 22TCN-262:2000, in which the maximum allowable settlement of filled soil base on soft soil is about 0.1 m – 0.3 m.

The physical-mechanical parameters of materials including soft soil, foundation soil, filled embankment, and soil-cement are given in the Table 1. The respective parameters are associated with different parts of materials in the calculation diagram. The elasto-perfectly plastic model Mohr-Coulomb is assigned for overall parts of soil including soft soil, foundation soil, and filled embankment while linear elastic model is assigned for SCC. A perfect bond between SCC and around soft soil are supposed in this study. Soil creep and consolidation are considered after a period of 200 days.

In these analyses, the axisymmetric approach is applied to evaluate the influence of SCC diameter, SCC spacing, and SCC length on the settlement of ground base after being reinforced.

Table 1 Material characteristics of soft soil, SCC, filled soil and foundation soil (TDD)

Material	Young's Modulus E (kPa)	Poisson's Ratio ν	Unit weight ρ (kg/m^3)	Friction angle φ(o)	Cohen -sion c (kPa)	Dilatancy angle ψ
Soft soil	3150	0,35	1440	8,6	15	0
SCC	150000	0,2	2000	-	-	-
Embankment	50000	0,2	1900	30	0	0
Foundation soil	30000	0,3	2010	20	250	0

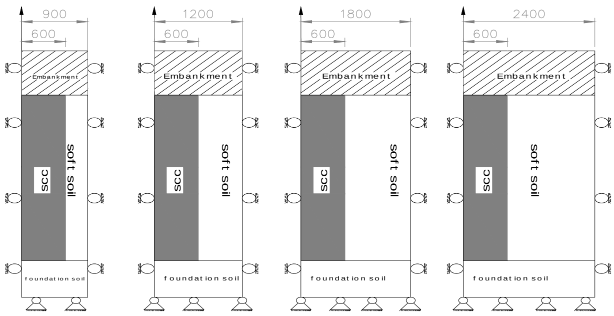
3.2. Numerical analysis and results

Two cases of consideration in these numerical analysis.

3.2.1. Change the value of the SCC spacing and the SCC diameter while its length remains unchanged

The SCC diameter (D) and SCC spacing (d) should be pre-determined according to the current values being widely applied in Viet Nam, concretely D = 0.6; 0.7; 0.8 m; d = 0.9; 1.2; 1.6 m. However, other values of D and d are also used for parametric studies: D = 1.2 m and 1.6 m; d = 1.8 m and 2.4 m.

First investigation process starts with fixing D = 0.6 m, the SCC length L = 6 m, and the foundation soil depth L = 4 m; change the ratio d/D with different values, d/D = 1.5; 2; 3; 4 (or respectively d = 0.9 m; 1.2 m; 1.8 m; 2.4 m) (Figure 5). The results show the settlement of the natural ground base's surface in Figures 6, 7, 8, 9, and 10.



(a) *(b)* *(c)* *(d)*

Figure 5 Calculation scheme of column spacing change

Second investigation process starts with fixing of the SCC spacing d = 2.4 m; the SCC length L=6 m, and the foundation soil depth L = 4 m; change the SCC diameter alternately: D = 0.6 m; 0.8 m; 1.2 m; 1.6 m (Figure 11). The results of the settlement of the natural ground base's surface with embankments top surface is presented in the Figures 12, 13, 14, 15, and 16.

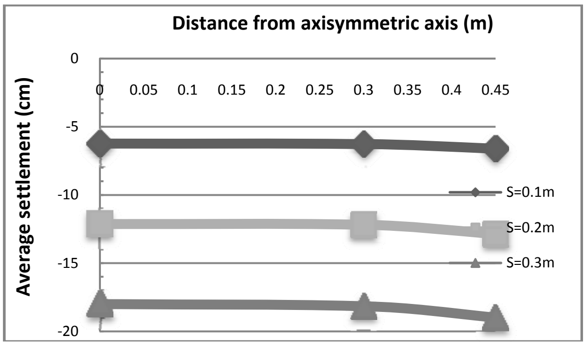


Figure 6 The settlement of the reinforced soft soil surface (D = 0.6 m; d = 0.9m)

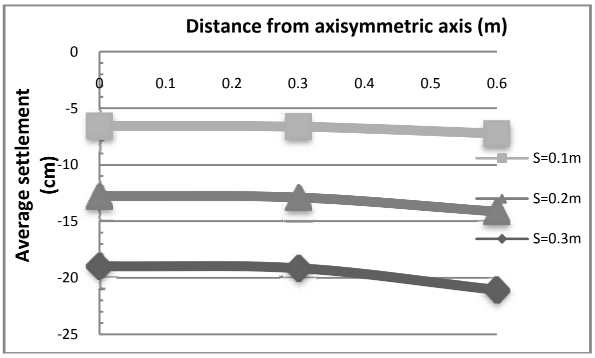


Figure 7 The settlement of the reinforced soft soil surface (D = 0.6 m; d = 1.2 m)

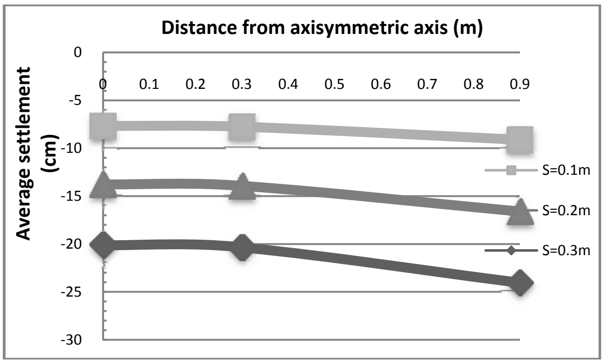


Figure 8 The settlement of the reinforced soft soil surface (D = 0.6 m; d = 1.8 m)

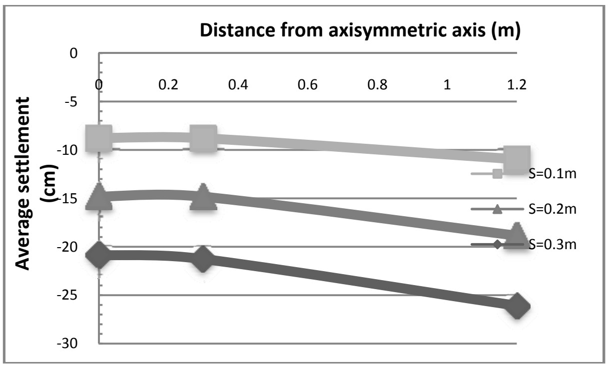


Figure 9 The settlement of the reinforced soft soil surface (D = 0.6 m; d = 2.4 m)

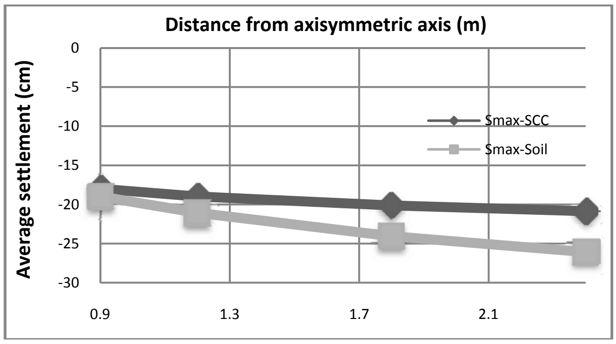
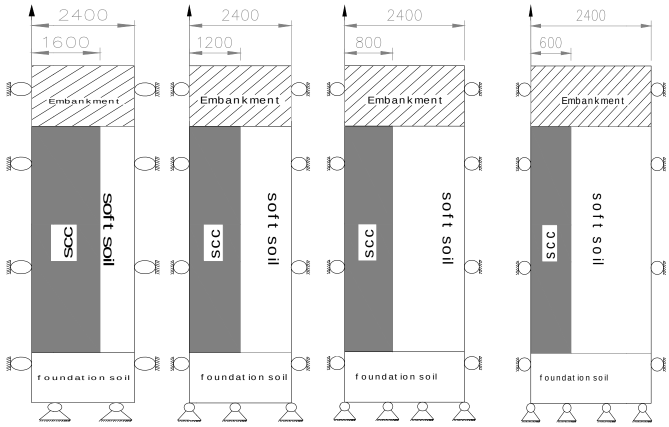


Figure 10 The correlation of SCC settlement and around soft soil settlement when the SCC spacing change from 0.9 to 2.4 m (D= 0.6 m)



(a) (b) (c) (d)

Figure 11 Calculation scheme of column diameter change

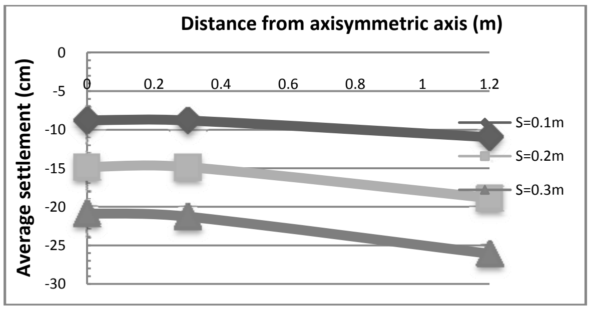


Figure 12 The settlement of the reinforced soft soil surface (D = 0.6 m; d = 2.4 m)

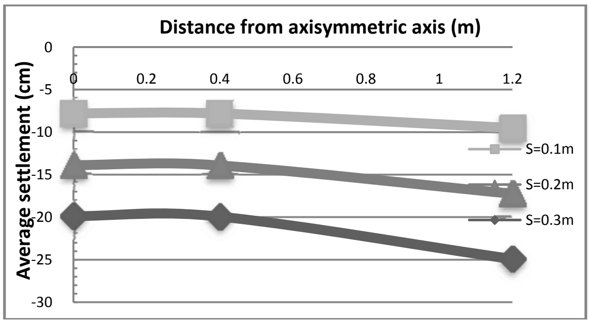


Figure 13 The settlement of the reinforced soft soil surface (D = 0.8 m; d = 2.4 m)

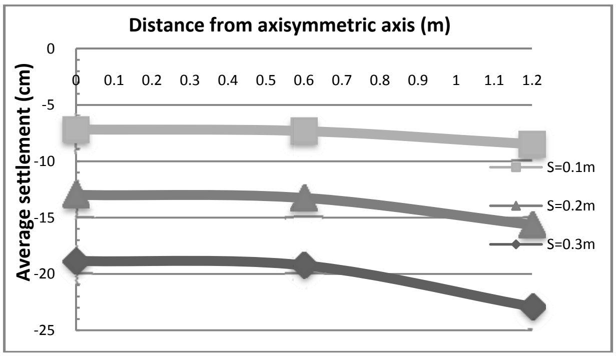


Figure 14 The settlement of the reinforced soft soil surface (D = 1.2 m; d = 2.4 m)

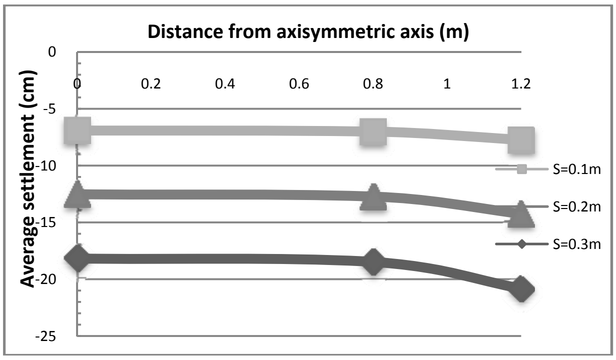


Figure 15 The settlement of the reinforced soft soil surface (D = 1.6 m; d = 2.4 m)

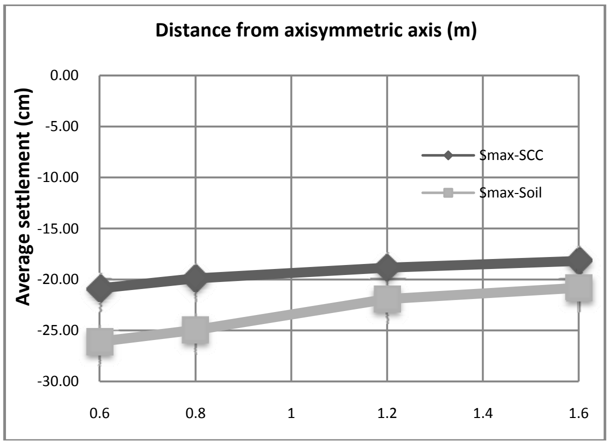


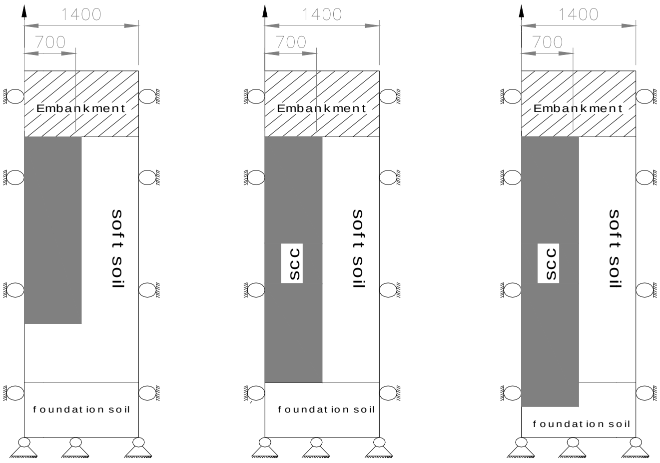
Figure 16 The correlation of SCC settlement and around soft soil settlement when the SCC diameter change from 0.6 m to 1.6 m (d = 2.4 m)

Figures 6 to 9 and 12 to 15 show the increase of the soft soil settlement when the ratio d/D increases; that can be explained by the higher value of SCC elastic modulus compared to the value of around soft soil; SCC settlement is as consequence small and almost constant along its width while the soft soil settlement increase with the distance from the axisymmetric axis.

Figure 10 and Figure 16 show the influence of SCC spacing and SCC diameter on the average value of ground base settlement. When the SCC spacing is less than or equal to two times of SCC diameter, the settlement of the SCC part has the same rate with the soft soil part; over this threshold, the difference becomes significant.

3.2.2. Changes in the value of the SCC length while the spacing and diameter remain unchanged

The SCC spacing d = 1.4 m and the SCC diameter = 0.7 m. The SCC length varies from 4 m to 10 m, and the foundation soil depth L = 4 m (Figure 17). The results are presented in the Figure 18.



(a) (b) (c)

Figure 17 Calculation scheme of column length change

The influence of SCC length on both the settlement of SCC part and the soft soil part is clarified. Indeed, settlements decrease when the SCC length increases up to the depth of soft soil layer; after this threshold, the average settlement becomes almost constant despite the increases of the length.

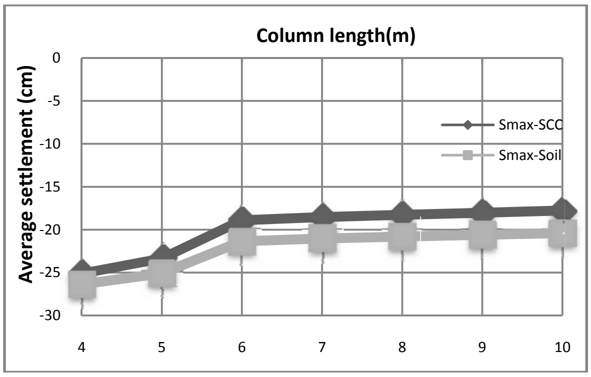


Figure 18 The relationship between the settlement of soft soil and of the SCC with SCC length

4. CONCLUSION

When the SCC spacing increases and the diameter remains unchanged or when the diameter decreases and the spacing is constant, the total settlement of reinforced soft soil with SCC increases including the increase of both SCC part and soft soil part. The settlement deviation of SCC part and soft soil part also increases with the ratio spacing/diameter (d/D).

The ratio d/D = 2 can be used as a critical value to ensure the settlement of reinforced soft ground base be uniform and restrain the ability of settlement and the crack of the upper foundation part.

The length of SCC should be chosen equal to soft soil layer depth to have the smallest settlement of reinforced soft soil ground base.

The above results on the influence of SCC geometrical parameters including the length, the diameter and the spacing on settlement of reinforced soft soil area are an useful reference for Vietnamese engineers in the preliminary design stage of structures foundation on soft soil improved by SCC.

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