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Original Research

Comparison of settlement between granular columns with and without geosynthetic encasement

Le Quan[*], Vo Dai Nhat, Nguyen Viet Ky, Pham Tien Bach

ABSTRACT

Granular columns have been used to improve load bearing capacity and to reduce the settlement of the soft soils for the past three decades. However, for soft soils with less than 15 kPa of undrained shear strength, the use of granular columns is ineffective because the soft soil does not mobilize sufficiently lateral confinement stress to balance the column lateral stress, which leads to the laterally deformed column (bulging) at the top section of the column. To overcome this limitation, many researchers have developed a new method of soil improvement using granular columns with geosynthetic encasement, which are actually an extension of the granular columns. This new approach, which is more advantageous than the granular columns, is thanks to geosynthetic providing additional confinement stress in conjunction with the soil surrounding the column. In this paper, the authors apply analytical solutions based on ``unit cell concept'' model in order to compare the effect of settlement between stone columns and stone columns with geosynthetic encasement implementing to reinforce the soft soil ground of Vifon II plant in Long An. The authors also investigate the effect on the column settlement due to variables of the column diameter, column spacing and embankment height. The results show that in all cases, the settlement of stone column is about 50 -80% higher than stone column with geosynthetic encasement, which have proved the superior efficiency of geosynthetic encased column (GEC) compared to conventional stone applied in soft soil improvement.

Key words: Granular column, Geosynthetic encased column (GEC), Soft soil, Settlement

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INTRODUCTION

Soft soil at site may not provide adequate bearing capacity or excessive settlement under loading of building/factory structures. The method which improves soft soil ground is granular columns with and without geosynthetic encasement. Granular column derives its load capacity through passive pressure from the surrounding soil due to the bulging of granular column [1]. The bulging of column when being installed in soft soil is cause of reducing loading capacity of granular columns owing to soft soil surrounding the columns do not provide adequate lateral confinement in the top section of the column [1–3]. To overcome the bulging and to improve the loading capacity of the column, granular columns is encased geosynthetic material is the solution because the geosynthetics provide additional lateral confinement conjunction with lateral confinement of soft soil surrounding the columns. Furthermore, granular columns with geosynthetic encasement increase the ground bearing capacity and reduce settlement. Otherwise, the geosynthetic encasement prevents intermixing of granular and surrounding soft soil, thus preserves drainage system [1,4–8].

An analytical solution for the total settlement of granular columns with and without geosynthetic encasement using the analytical axial symmetric model according to the "unit cell concept" is shown in Figure 1 with assumptions as (1) the soft soil is treated as an elastic material throughout the range of applied stress, (2) the column is treated as an elastic-plastic material using Mohr-Coulomb yield criterion with constant dilation angle, and (3) no shear stress between the columns and the soil along the column length taken into account [8–10].

This paper was to investigate the effect of column diameter, spacing and embankment height by using the analytical solution to evaluate the settlement of stone columns with and without geosynthetic encasement applying for ground site at Vifon II Factory, Long An Province.

ANALYTICAL METHODOLOGY [11]

In principle, the proposed method by Raithel and Kempfert (2000) [12] for the settlement calculation of granular columns and geosynthetic encased granular columns is based on the unit cell concept model as shown in Figure 1. The only difference between

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geosynthetic encased granular columns and granular columns model is the geosynthetic encased columns consider the contribution of geosynthetic encasement by providing additional lateral confinement to the column[11]. Thus, the authors present analytical solution for geosynthetic encased granular columns proposed by Raithel and Kempfert (2000) only[12].

In practice, the author implements the calculation of granular columns by using the same equations of geosynthetic encased granular columns but the tensile stiffness of geosynthetic is zero (J=0).

In granular columns, horizontal support is entirely mobilized by the passive earth pressure in the soft soil strata as a result of the increase in the column diameter (bulging). In very soft soils, this leads to considerable deformations. Using the geosynthetic encased column system, the radial or horizontal column support is guaranteed by the geosynthetic in conjunction with the support provided by the surrounding soft soil[13]. The proposed method by Raithel and Kempfert (2000)[12]; Jie-Han (2015)[11] was based on assumptions as the followings:

- The loading size is much larger than the thickness of the soft soil; therefore, the applied additional stress does not decrease with depth.
- The settlements on the top of the column and the soft soil are equal.
- No settlement is below the toe of the column.
- The column is at an active earth pressure state.
- Before loading, the soil is at an at-rest state, the earth pressure coefficient of the soil depends on method for column installation.
- The geosynthetic encasement has linearly elastic behavior.
- The granular column is incompressible.
- The design is based on a drained condition.

The radial stresses in the column and the soil are contributed by the overburden stresses of the column and the soil:

$$\sigma_{r,c} = \triangle\sigma_c K_{a,c} + \sigma_{z0,c} K_{a,c} \quad (1)$$

$$\sigma_{r,s} = \triangle\sigma_s K_{0,s} + \sigma_{z0,s} K_{o,s} \quad (2)$$

Where:

$\sigma_{z0,c}$= overburden stress of the column (kPa)

$\sigma_{z0,s}$= overburden stress of the soil (kPa)

$\triangle\sigma_c$= additional vertical stress in the column (kPa)

$\triangle\sigma_s$= additional vertical stress in the soil (kPa)

$K_{a,c}$= active earth pressure coefficient in the column

$K_{0,s}$= at-rest earth pressure coefficient in soil

Raithel and Kempfert (2000) assumed that the geosynthetic encasement has linearly elastic behavior with tensile stiffness, J. The hoop tensile force is:

$$T_g = J\frac{\Delta r_g}{r_g}\ (kN/m) \quad (3)$$

$\triangle r_g$ radius increase of the geosynthetic encasement (m)

r_g radius of the geosynthetic encasement (m)

The radial stress on the geosynthetic encasement equivalent to the hoop tensile force is:

$$\sigma_{r,g} = \frac{T_g}{r_g} = J\frac{\triangle r_g}{r_g^2} = J\frac{\triangle r_c - (r_g - r_c)}{r_g^2} \quad (4)$$

Where

r_c= radius of the column (m)

$\triangle r_c$= radius increase of the column (m)

The radial stress difference between the column and the soil is:

$$\triangle\sigma_r = \sigma_{r,c} - \sigma_{r,s} - \sigma_{r,g} \quad (5)$$

The radial displacement, $\triangle r_c$, can be calculated based on Ghionna and Jamiolkowski (1981) for a radially and axially loaded hollow cylinder:

$$\triangle r_c = \frac{\triangle\sigma_r}{E^*}(\frac{1}{a_s} - 1)r_c \quad (6)$$

$$E^* = (\frac{1}{1-v_s} + \frac{1}{1+v_s}\frac{1}{a_s})E_s \quad (7)$$

$$E_s = \frac{(1+v_s)(1-2v_s)}{1-v_s}D_s \quad (8)$$

Where:

D_s constrained modulus of the soil, which is equal to $1/m_{v,s}$(kPa)

$m_{v,s}$ coefficient of soil volumetric compressibility

E_s elastic modulus of the soil (kPa)

v_s Poisson's ratio of the soil

Substituting Equation (Equation (4)) and (Equation (5)) into Equation (Equation (6)) results in the following equation:

$$\triangle r_c = \frac{\sigma_{r,c} - \sigma_{r,s} + \frac{(r_g - r_c)J}{r_g^2}}{\frac{a_s E^*}{(1-a_s)r_c} + \frac{J}{r_g^2}} \quad (9)$$

The settlement of the soft soil can be calculated based on Ghionna and Jamiolkowski (1981):

$$S_{sl} = \left[\frac{\Delta\sigma_s}{D_s} - \frac{2}{E^*}\left(\frac{v_s}{1-v_s}\right)\Delta\sigma_r\right]h \quad (10)$$

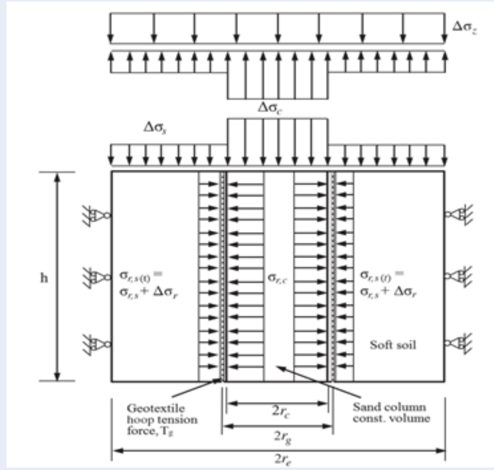

Figure 1: Unit cell model for a geosynthetic encased column [12].

Where h is the thickness of the soil or length of the column

Based on the constant volume assumption, the following equation for the settlement of the column can be obtained:

$$S_{cl} = \left[1 - \frac{r_c^2}{(r_c + \triangle r_c)^2}\right] h \quad (11)$$

Based on the equal strain assumption for the column and the soil:

$$S_{sl} = S_{cl} \quad (12)$$

Or

$$\left[\frac{\triangle\sigma_s}{D_s} - \frac{2}{E^*}\left(\frac{v_s}{1 - v_s}\right)\triangle\sigma_r\right] = \left[1 - \frac{r_c^2}{(r_c + \triangle r_c)^2}\right] \quad (13)$$

Equilibrium Equation (Equation (13)) is dependent on $\triangle r_c$, therefore (Equation (13)) can be solved iteratively.

SETTLEMENT OF COLUMN WITH AND WITHOUT GEOSYNTHETIC ENCASED: A CASE STUDY

Introduction of project

The project has total area approx. 64500 m^2, construction area approx. 38500 m^2 with two main workshops such as the flour workshop and the rice workshop. Figure 2 presents the general layout arrangement of the project. The composite foundation is designed with varying vertical loading ranges from 10 kN/m^2 to 40 kN/m^2.

In fact, the project was designed to reinforce the ground by stone column diameter is 0.65 m, average column length is 3.5 m through the soft soil of layer 1. However, in the paper the authors proposed two methods of reinforcing the soft soil by stone column and geosynthetic encased stone column for the purpose of comparing settlement performance of these two methods. For calculation the author using vertical loading apply on ground was 40 kN/m^2.

Geological Conditions

The soil layers and its parameters are shown in Table 1:

The Material of column and its parameters are shown in Table 2:

To study the effect of diameter, spacing and embankment height on settlement of the granular columns with and without geosynthetic encasement, a series of calculation was conducted based on soil parameters presented in Table 1 and material of column presented in Table 2.

RESULTS AND DISCUSSION

Effect of column spacing

The authors investigate the settlement of the column s with column diameter of 0.6 m, encasement tensile stiffness J = 3000 kN/m, embankment height H = 3.0 m and column spacing varying with a range from 1.2 m to 1.8 m, 2.4 m, 3.0 m; the columns are arranged in square pattern. The results are presented in Figure 3, which indicate s that settlement of stone columns increases from 40 mm to 70 mm, 87.15 mm, 99.41 mm and settlement of geosynthetic encased stone columns increases from 22 mm, 44.54 mm, 62.97 mm, 76.64

Figure 2: General layout of project (source from Le Ba Vinh, Le Ba Khanh) [14]

Table 1: Soil parameters of the ground site [14]

Soil Layer	Soil Type	Thickness (m)	γ_c (kN/m^3)	$\gamma_{c,sat}$ (kN/m^3)	E (kN/m^2)	c (kN/m^2)	φ (^{0})	v
1	Sand (Back fill)	0.5	18	18	20,000	0.1	30^0 0'	0.3
2	Clay	3.5	18.54	18.97	2,400	16.59	8^0 58'	0.35
3	Clay	3.6	19.75	20.05	12,500	25.2	20^0 25'	0.3
4	Sandy Clay	5.8	20.03	20.48	14,400	24.2	24^0 39'	0.3

Table 2: Stone Column Material [14]

Material Type	Thickness (m)	γ_c (kN/m^3)	$\gamma_{c,sat}$ (kN/m^3)	E (kN/m^2)	c (kN/m^2)	φ (^{0})	v
Stone Column	3.5	20	20	48,000	0.1	40^0 0'	0.3

mm with respective of spacing from 1.2 m to 1.8 m, 2.4 m, and 3.0 m. The results show that the settlement of stone columns are higher more than geosynthetic encased stone columns from 55% to 63,63%; 72.25% and 77.09 % with respective of spacing from 1.2 m to 1.8 m, 2.4 m, and 3.0 m. The results show that the huge beneficial effect of geosynthetic encasement in the study, the authors find that column spacing has effect on lateral bulging and settlement of the column, when increasing the spacing between columns, and thereby decreasing the area replacement ratios (Equation (14)), which leads to a significant increasing on settlement [8].

$$a_s = \frac{A_c}{A_e} = C(\frac{d_c}{s})^2 \quad (14)$$

Here:
a_s area replacement ratio
A_c cross-sectional area of the column (m^2)
A_e tributary area of the column (m^2)
d_c diameter of the column (m)
s center to center spacing between columns in square or equilateral triangular pattern (m)
C constant (0.785 for a square pattern or 0.907 for an equilateral triangular pattern)

Effect of column diameter

The authors investigate the settlement of the columns with series of diameter of 0.6 m, 0.8 m, 1.0 m, 1.2 m and columns are arranged in square pattern, column spacing is 3.0 m, geosynthetic encasement stiffness is 3000 kN/m, embankment height is 3.0 m. The results are presented in Figure 4 and shown that the settlement of stone columns decreases from 102.235 mm down to 85.57 mm, 71.37 mm, 57.87 mm and settlement of geosynthetic encased stone columns decreases from 76.24 mm down to 63.8 mm, 52.44 mm, 42.55 mm with respective of diameter from 0.6 m to 0.8 m, 1.0 m, 1.2 m. The settlement of stone columns are higher than geosynthetic encased stone columns from 74.57 % down to 74.56%, 73.48% and 73.5 % with respective of diameter from 0.6 m to 0.8 m, 1.0 m, 1.2 m. The results indicated that, although the diameter increases but the settlement variance between conventional stone columns and geosynthetic

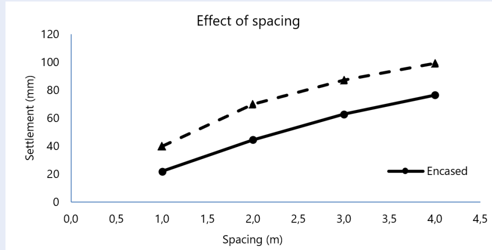

Figure 3: Settlement of stone column and geosynthetic encased stone column with varying column spacing.

encased columns have no significant difference.
This can be understood in equation (Equation (14)) that diameter increases, spacing between columns was unchanged and so that the area replacement ratio increases, which leads to reduce the stress reduction factor, this mean s that the less stress is applied on the soil [11] thus the ground bearing capacity increases.

Effect of embankment height

In this study, the authors investigate the column settlement with the following parameters, *e.g.*: column diameter is 0.6 m, spacing between columns is 1.2 m, geosynthetic encasement stiffness is 3000 kN/m and embankment height ranges from 3 to 6, 9 and 12 m. Columns were arranged in square pattern. The results are presented in Figure 5, indicated that settlement of stone column increases from 39.32 mm to 82.59 mm, 125 mm, 167.57 mm and settlement of geosynthetic encased stone column increases from 22 mm to 45.58 mm, 69 mm, 92.18 mm with respective of embankment height from 3 m to 6 m, 9 m, 12 m. The settlements of stone column are higher than geosynthetic encased stone column from 55.95% down to 55.19%, 55.20% and 55.01% with respective of embankment height from 3 m to 6 m, 9 m, 12 m. The results show that when the embankment height increases, the settlement variance between conventional stone column and encased column is only a little bit different. With increasing embankment heights, the vertical stress will be increased, which also results to a higher settlement and the ground bearing capacity is decreased.

CONCLUSION

In this study, the authors can conclude results of research as the followings:

- The model using in study is "unit cell concept" [12] under drained condition, the settlement between column and soft soil are equal. The column material follow Mohr-Coulomb criteria, geosynthetics is elastic material.
- The analytical analysis was performed to investigate to compare the settlement of the stone column with and without geosynthetic encasement.
- The case study indicated that the settlement performance of the soft soil reinforced by stone column is significantly higher than encased stone column, it shows that geosynthetic has a significant influence to reduce on settlement and increasing ground bearing capacity.
- The authors carried out to investigate the effect of column spacing, diameter and embankment height to the settlement. The results indicated that : (1) The settlement of stone column are higher more than geosynthetic encased stone column from 55% to 63,63%; 72.25% and 77.09% with respective spacing from 1.2 m to 1.8 m, 2.4 m, and 3.0 m; (2) The settlement of stone column are higher than geosynthetic encased stone column from 74.57% down to 74.56%, 73.48% and 73.5 % with respective diameter from 0.6 m to 0.8 m, 1.0 m, 1.2 m; (3) The settlement of stone column are higher than geosynthetic encased stone column from 55.95% down to 55.19%, 55.20% and 55.01% with respective of embankment height from 3 m to 6 m, 9 m and 12 m.

FUTURE WORK

- Study effect of shear stress at interface between soft soil and geosynthetic, between column and geosynthetic.
- Study the influence of soft soil thickness.
- Study the influence of geosynthetic stiffness.
- Study and compare the results of Analytical analysis and Numerical analysis method.
- Study effect of different column materials

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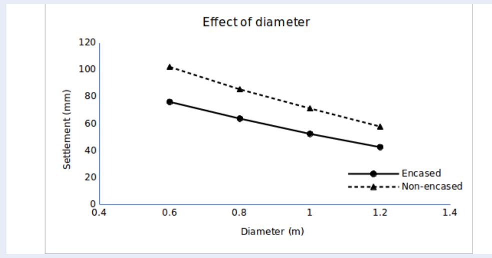

Figure 4: Settlement of stone column and geosynthetic encased stone column with varying column diameter.

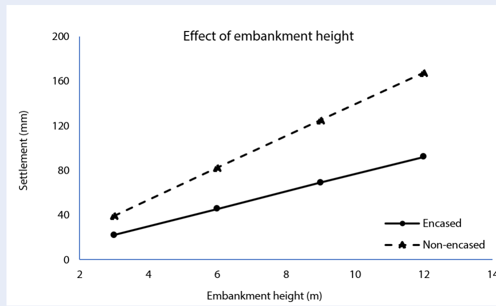

Figure 5: Settlement of stone column and geosynthetic encased stone column with varying embankment height.

CONFLICT OF INTEREST

The authors pledge that there are no conflicts of interest in the publication of the paper.

AUTHOR CONTRIBUTION

Le Quan presented the idea of study and carried out the collecting data, calculation analysis and writing the paper manuscripts. Dr. Vo Dai Nhat, Assoc. Prof. Dr. Nguyen Viet Ky participated in the scientific idea of research, guided to writing the paper, reviewed the results of study. Pham Tien Bach contributed to review the calculation sheets, input data, output data and reviewing the paper.

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Bài Nghiên cứu

So sánh độ lún giữa cọc bọc và không bọc vải địa kỹ thuật

Lê Quân*, Võ Nhật Đại, Nguyễn Việt Kỳ, Phạm Bách Tiến

TÓM TẮT

Cọc đá được sử dụng để cải thiện khả năng chịu tải và giảm độ lún của nền đất yếu trong khoảng ba thập kỷ gần đây. Tuy nhiên, đối với trường hợp đất yếu có sức kháng cắt không thoát nước nhỏ hơn 15 kPa thì việc sử dụng cọc đá không hiệu quả do đất yếu xung quanh không huy động đủ áp lực ngang để tạo cân bằng với áp lực ngang của cọc, điều này dẫn đến cọc bị biến dạng ngang (phình) ở phần đầu cọc. Để khắc phục hạn chế kể trên, các nhà khoa học đã phát triển phương pháp mới cải tạo đất yếu bằng cách sử dụng cọc đá kết hợp bọc vải địa kỹ thuật, phương pháp này thực ra là phương pháp mở rộng của cọc đá. Phương pháp mới này có ưu điểm hơn so với cọc không bọc vải địa kỹ thuật là vải địa kỹ thuật cung cấp bổ sung áp lực ngang cùng với đất xung quanh cọc. Trong bài báo này, nhóm tác giả sử dụng phương pháp giải tích dựa trên mô hình ``unit cell concept'' để nghiên cứu, so sánh độ lún giữa cọc đá không bọc và cọc đá có bọc vải địa kỹ thuật áp dụng trong cải tạo nền đất yếu cho công trình nhà máy Vifon II ở Long An. Nhóm tác giả đã thực hiện khảo sát ảnh hưởng của việc thay đổi đường kính cọc, khoảng cách cọc và chiều cao lớp đất đắp đối với độ lún của cọc đá bọc và không bọc vải địa kỹ thuật. Kết quả nghiên cứu cho thấy, trong mọi trường hợp thì độ lún của cọc đá không bọc vải cao hơn trong khoảng 50-80% so với cọc đá có bọc vải địa kỹ thuật. Kết quả tính toán đã chứng minh hiệu quả vượt trội của cọc đá bọc vải địa kỹ thuật so với cọc đá thông thường áp dụng trong cải tạo đất yếu.

Từ khoá: cọc đá, cọc bọc vải địa kỹ thuật, đất yếu, độ lún

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