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Interface Interaction of Granular Columns- Soft Clay Composite

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ABSTRACT

Using encased granular columns is one of the best techniques to improve the carrying capacity and reduce settlement of soft clay soils, especially in case of embankments in highway and rail way projects. The present study, presents the results of numerical analysis for the Interaction between granular columns and soft clay in case of granular column with and without encased geosynthetic. Single granular column-soft clay has been modeled, taking the effect of variation of column length and diameter into consideration. The analysis is conducted with 2D-Plaxis 20 Program. The influence of geosynthetic encasement, variation of column length and diameter on shear stress and the axial forces as well as the stress concentration ratio based on interface criterion have been investigated. Based on the results of the current numerical analysis, correlation has been proposed for estimating the granular column maximum load with variation of column length and diameter.

Keywords: Granular columns, Interaction, Numerical Models, Stress transfer, Geosynthetic, Plaxis 2D.

INTRODUCTION

Few literatures discussed the interface interaction between granular column and soft in a clay composite. For end bearing granular columns, negative skin friction develops due to the subsidence of the surrounding soil deposits relative to the granular columns. However, the developed negative friction is significantly affected in case of ordinary granular columns compared to the encased ones.

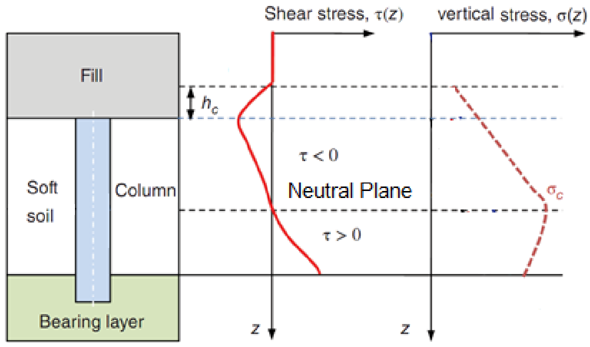

Figure (1) Stress transfer in column-supported embankment (Simon and Schlosser, 2006).

Mode of stress transfer between columns and surrounding soil in the composite foundation depends on the rigidity of loading, the rigidity of columns relative to soil, and the end-bearing condition. Simon and Schlosser (2006) studied the deformations in column supported embankments as shown in Figure (1), which is considered an intermediate condition between flexible loading and rigid loading. The critical height (hc) in range of 1.0–1.5 times the clear spacing of the columns Chen et al. (2010). Due to the relative difference between the granular column settlement and the soft clay soil settlement, the negative shear stress develops along the column in the upper the depth of neutral plane, but the positive shear stress develops below the lower the depth of neutral plane. The vertical stress above the column increase by increasing the depth until the depth of neutral plane and after that the vertical stress decreases, while the highest vertical stress corresponding the depth of neutral plane.

Stress Concentration Factor as shown in Fig. (2) is the ratio (n) between the stress carried by a granular column (σg) and that carried by the treated soil (σc),and is found to be in the range of 2 to 5 (Barksdale and Bachus (1983), and may reach higher values as 9 (Bergado et al., 1987). However, the stress concentration ratio of 2 was observed and was found to decrease to 1. 45 with the increasing of applied loads (Bergkok et al., 1988).

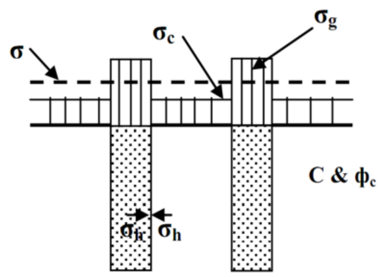

Figure (2) Diagram of composite ground.

The overall objective of the present study is to investigate the granular column behavior in consolidating ground using 2D finite element analyses for a single column. Conventional no-slip continuum and slip analysis were conducted to examine the effects of soil yielding at the granular column–soft clay interface on drag load. The effect of axial loading on drag load changes was also investigated.

This paper aims at study the Interface Interaction between granular columns - Soft Clay composite, and to determine the axial forces in the granular columns with the effect of geosynthetic encasement, as well as, the effect of variables column Length and diameter.

Numerical model

2-D numerical model was used to simulate single granular column-soft clay using the Plaxis 20. The geometric dimensions and physical parameters of the finite element
2-D model are shown in Figure (3). The characterized properties of granular column and soil elements are listed in Table (1) as previously studied (Merzk et. ai, 2021).

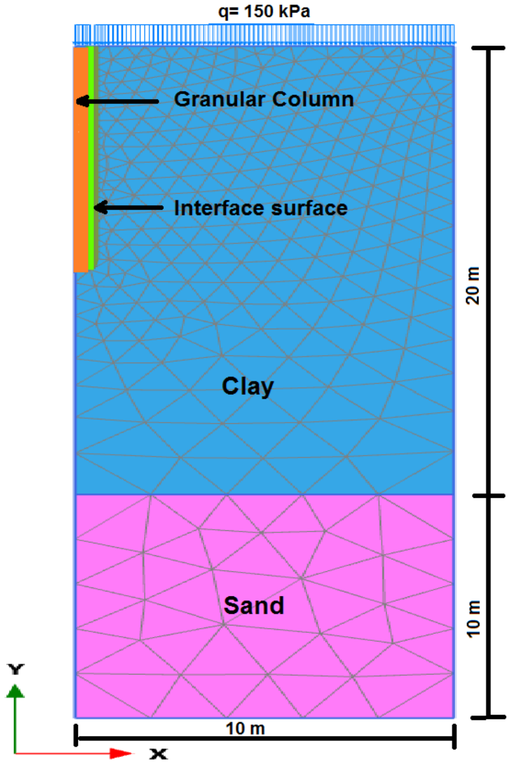

Figure (3) Two-dimensional FE meshes used for a single floating granular Column

Table (1) Summary of material properties used in numerical analysis.

Properties	Granular Columns	sand	Clay
Constative model	Mohr-Coulomb	Mohr-Coulomb	Soft soil
Saturated unit weight, γsat (kN/m3)	20	20	14.4
Poisson's ratio of soil, υ	0.30	0.30	0.30
Modulus of elasticity E, (MPa)	80	30	--
Coefficient of compression, Cc	--	--	0.98
Coefficient of swelling, Cs	--	--	0.025
Drained cohesion, c′ (kPa)	0	0	4
Friction angel at the critical state, ϕ'	45	38	26
Angel of dilation, ψ'	15	8	0
The initial void ratio, e_o	--	--	2.81
OCR Value	--	--	1.35
Coefficient of the horizontal permeability, k_h m/d)	10	1	1.6×10^{-5}
Coefficient of the vertical permeability, k_v (m/d)	10	1	5.2×10^{-6}

Soft clay is modeled as a soft soil characterized by two parameters namely, Cc and Cr. The bottom sand layer and granular column are modeled as the Mohr-Coulomb model whereas; the interface element is installed between the granular column and the surrounding soft clay soil to simulate the interaction behavior in accordance with the Coulomb model as shown in Figure (4).

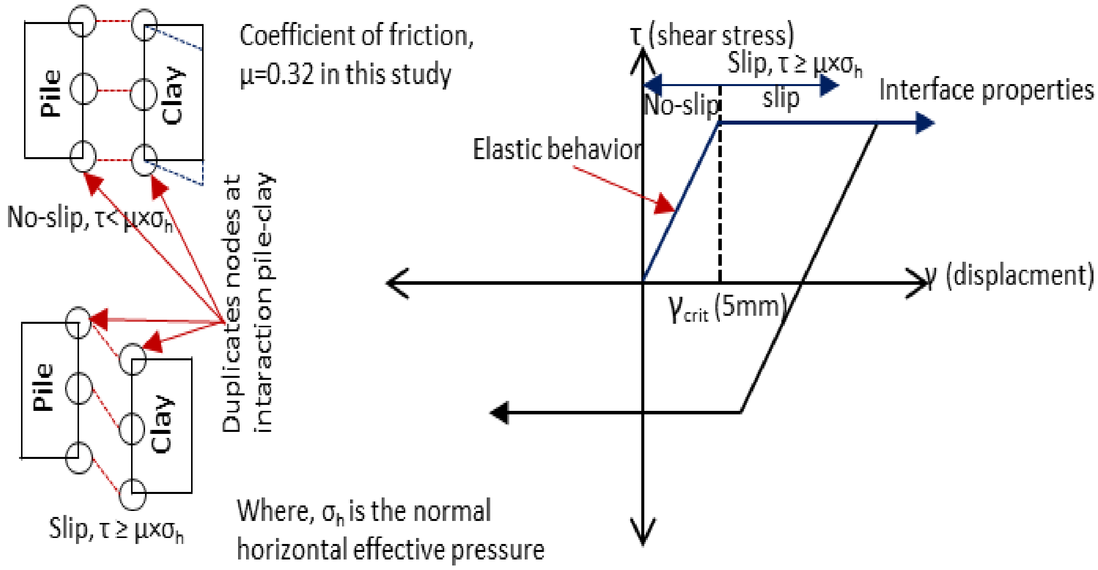

Figure (4) Behavior of interaction at pile-soil interface (Lee J, 2010).

The model has symmetry along the y-axis. 16-node element with reduced integration elements is used for modeling the granular column. The bottom boundary condition of whole model is assumed to have a fixed support in all directions. The side boundary condition of soil domain is limited from laterally displacement, whereas along the symmetry Y axis, the boundary conditions are restrained from deformations along the perpendicular direction.

A surcharge load of (q) = 150 kPa, the value represents the embankment) is applied on upper surface of the soil. The Interface Interaction performance of various configurations of columns was investigated with the effect of variation of column diameter (d) and length (L), as well as, the effect of confinement by geosynthetic casing.

Results and Discussion

Influence of Geosynthetic Encasement

The effect of confinement of granular column by geosynthetic Layer on the distribution of interface friction, and axial force against the normalized depth (Z/L) was carried out for ordinary and encased granular columns. The column diameter and length were chosen = 0.80 m & 15.0 m respectively as the optimized economic diameter and length obtained from previous study (Merzk et. al., 2021). Figures (5-a to 7-a) shows the distribution of shear stress along the side surface of the granular column against the normalized depth (Z/L). The depth of neutral plane (the point of zero shear stress) decreased in case of confinement by geosynthetic Layer. The normalized depth of the neutral plane changes from 0.63 to 0.58 when used the Geosynthetic Layer. This is possibly associated with the settlement of the soil deposits around the granular column due to consolidation process, which increases the vertical effective stresses ($\sigma' = \gamma' . z$) along the normalized depth of the granular column. Figure (5-b to 7-b) shows the distribution of axial force developed along the normalized depth of the granular column also increase with used Confinement granular column by Geosynthetic Layer

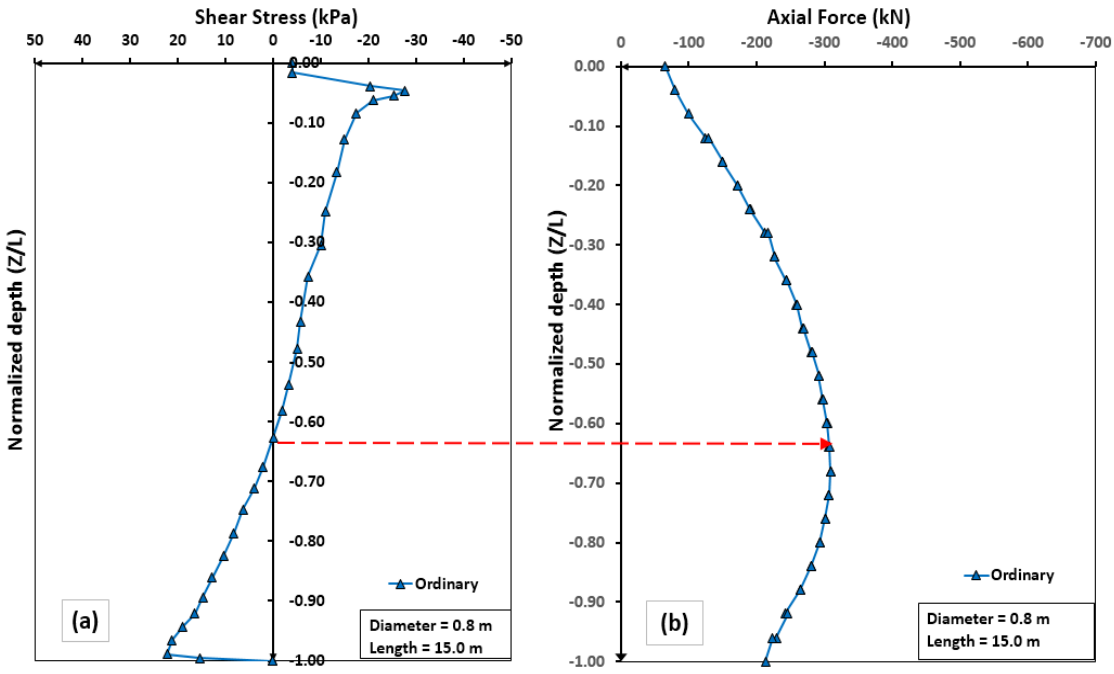

Figure (5) Interface stresses for ordinary granular column (a) shear stress and (b) axial Force.

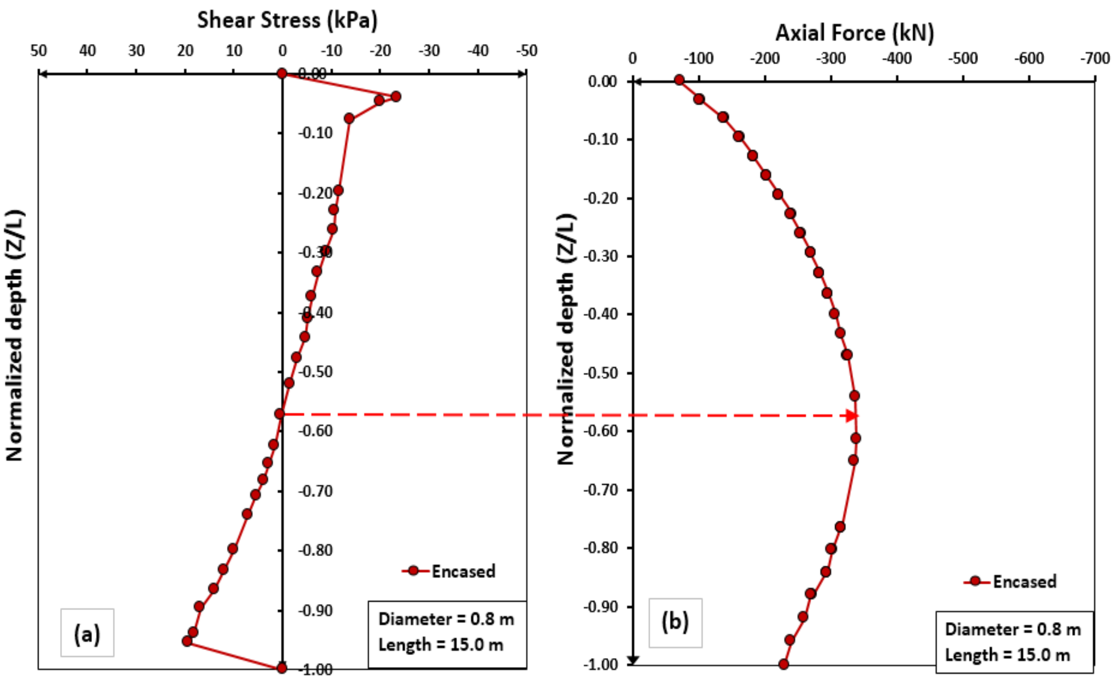

Figure (6) Interface stresses for encased granular column (a) shear stress and (b) axial Force.

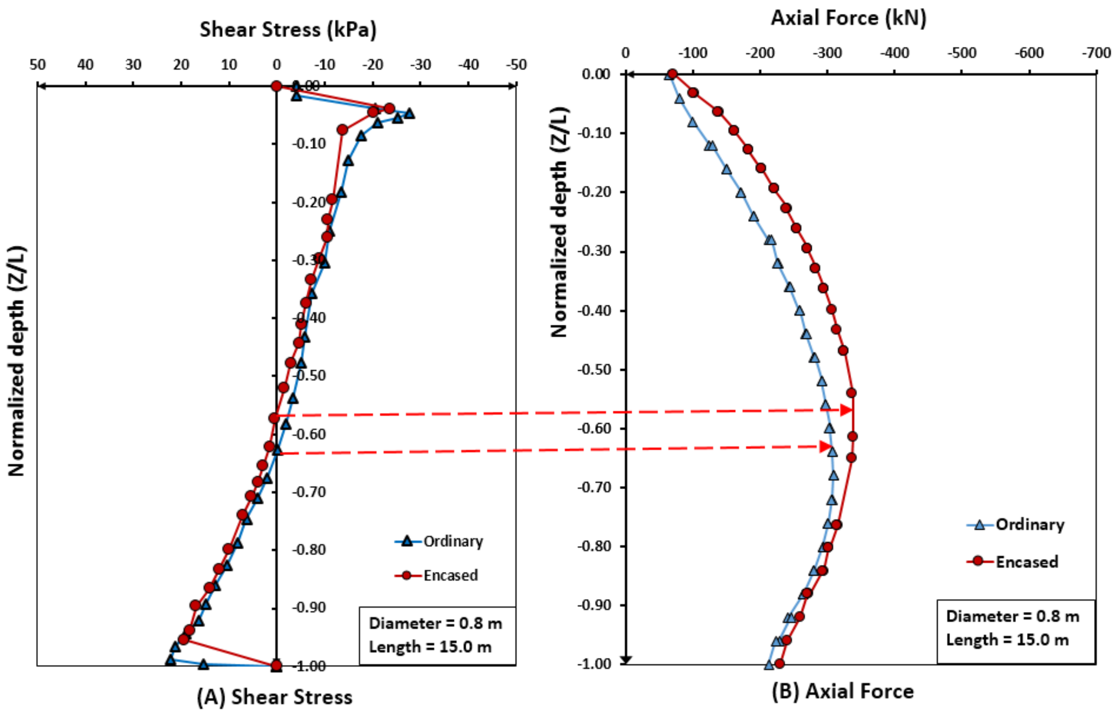

Figure (7) Comparison illustrated the effects of Confinement by Geosynthetic on the induced interface stresses.

Influence of Granular Column Length

The effect of length of encased granular column was investigated for lengths of (L) = 5. 10. 15 and 20 m. The column diameter was chosen = 0.80 m as the optimized economic diameter obtained from previous study (Merzk et. al., 2021). The distribution of interface friction and axial force against the normalized depth (Z/L) is shown in Figure (8-a) & (8-b) respectively.

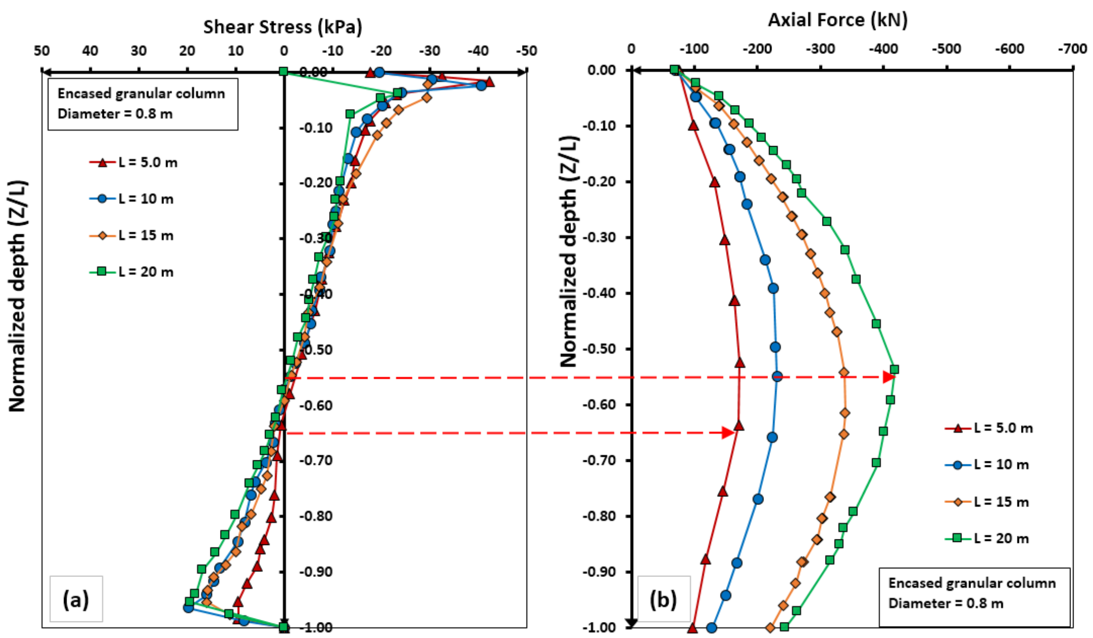

Figure (8) Effects of Granular Columns Length on: (a) shear stress and (b) Axial Force.

From these figures it can be observed that, the depth of neutral plane increases with increase of granular columns Length. The depth of the normalized neutral plane decreased from 0.65 to 0.55 with the increase of encased column length. With the increase of length of encased column, the negative skin friction decreases. Taking into consideration the negative skin associated with consolidation process of the surrounding soft soil is more significant for end bearing columns, such as column with depth of 20.0 m compared to other floating columns with lesser length.

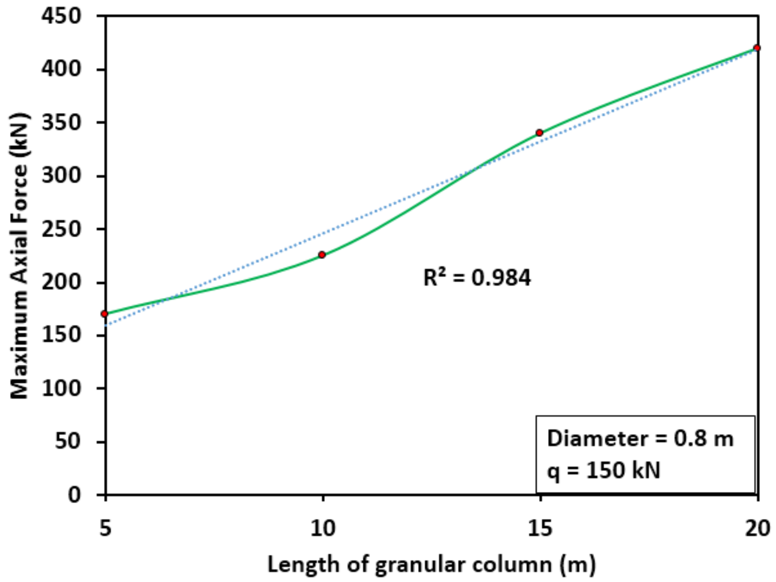

Figure (9) Effect of maximum axial forces on the Length granular column.

The relationship between maximum axial force of encased column and column length for diameter of 0.80 m is shown in Figure (9). It can be observed that, the maximum axial forces in the granular column increases with increase granular columns length. The maximum axial load increases 2.5 times as a result of the increase granular columns Length from (5 m to 20 m). The maximum axial load is generally expressed according to values as:

$$\mathbf{F_{max} = 17.3\ L + 72.5 \ldots\ldots\ldots\ldots\ldots\ldots (1)}$$

where Fmax = The maximum axial load, L= granular columns length on condition that the length ranges from 5.0 m to 20.0 m and that it is not equal zero.

Tables (2) show the effect of granular columns length on stress concentration ratio (stress carried by granular column (σg) to the average applied load, (σ) for different lengths of 5 m, 10 m, 15 m and 20 m, for encased Geosynthetic layer. It can also be observed that, the stress concentration ratio increases with increase of granular columns length. The stress concentration ratio varies between 1.27 and 3.27 at the end of consolidation stage, with an average value of about 2.40.

Table (2) Stress concentration ratio (*n*) for different column lengths.

Initial stress (σ) kPa	Granular Columns Length (m)	Final stress (σ_g) kPa	Stress Concentration ratio (*n*)
150	5	190	1.27
150	10	300	2.00
150	15	440	2.93
150	20	490	3.27

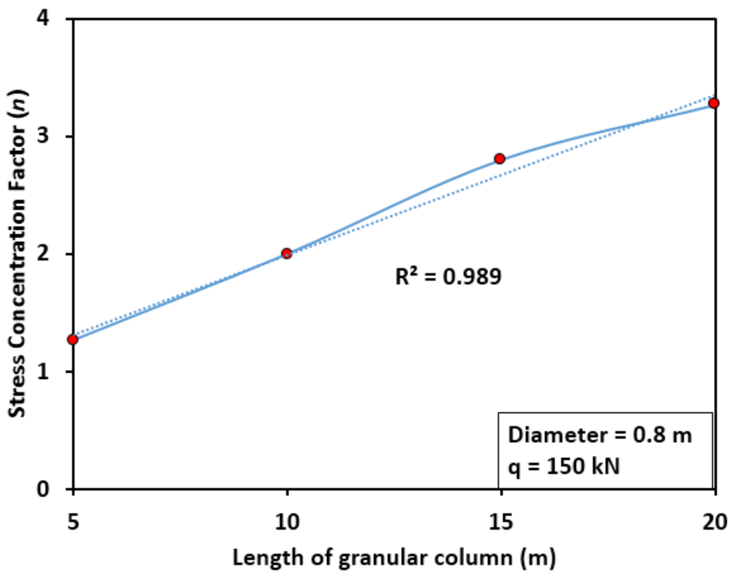

Figure (10) Effect of Stress Concentration ratio (*n*) on the Length granular column.

Figure (10) shows that the stress concentration ratio increases with the increase of granular columns length. The stress concentration ratio is generally expressed according to values as:

$$n = 0.14\,L + 0.63 \quad \text{.................} \quad (2)$$

where ***n*** = The stress concentration ratio, **L**= granular columns length on condition that the length ranges from 5.0 m to 20.0 m and that it is not equal zero.

Influence of Granular Columns Diameter

The effect of diameter of geosynthetic encased granular column on the distribution of interface friction and Axial Force against the normalized depth (Z/L) for diameters (D) of 0.6, 0.8, 1.0, and 1.2 m are shown in Figure (11-a). The column length was chosen = 15.0 m as the optimized economic length obtained from previous study (Merzk et. al., 2021). normalized depth of the neutral plane (the point of zero shear stress) decrease with increase granular columns diameters. The normalized depth of the neutral plane changes from 0.66 to 0.56 with the increase of encased column diameter. This is possibly associated with the settlement of the soil deposits around the granular column due to water reduction, which increases the vertical effective stresses ($\sigma' = \gamma'.\ z$) along the normalized depth of the granular column. Figure (11-b) shows the distribution of axial force developed along the normalized depth of the granular column also increase with increase columns diameter.

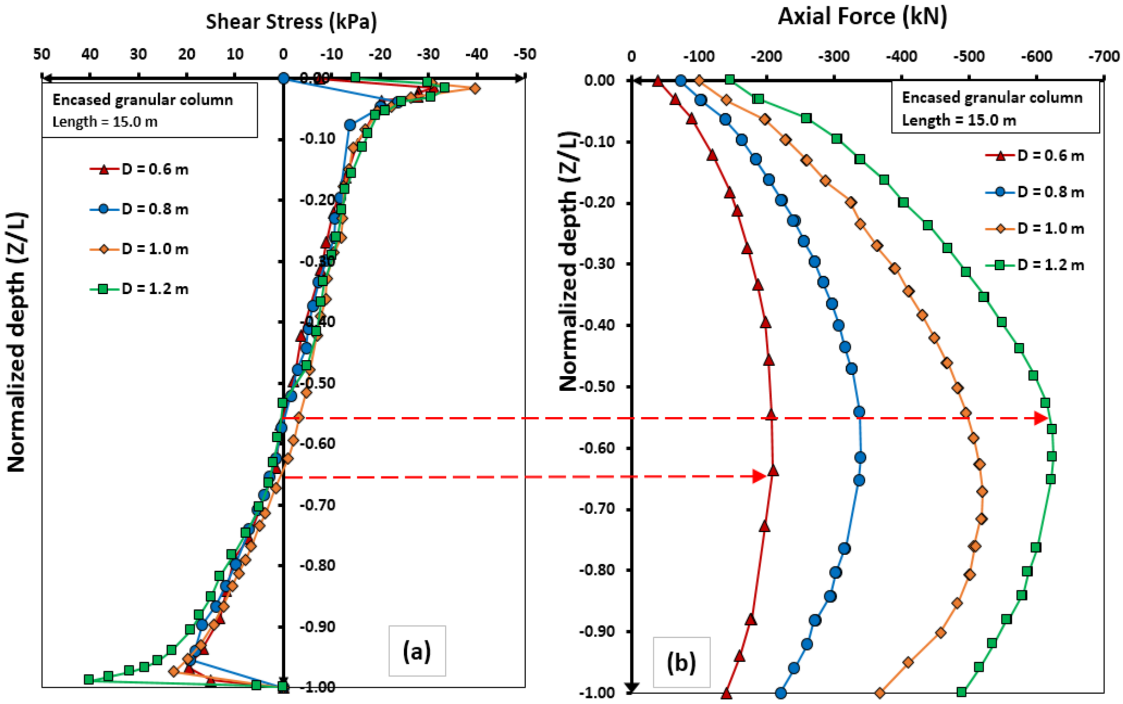

Figure 11. Effects of Granular Columns Diameter on: (a) shear stress and (b) Axial Force.

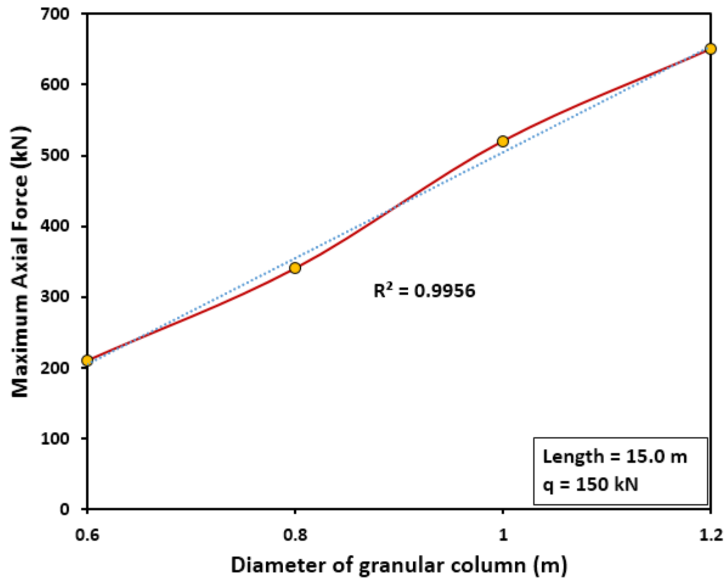

Figure 12. Effect of maximum axial forces on the Diameter granular column.

Figure (12) shows that the maximum axial forces in the granular column increase with the increase of granular columns diameter. The maximum axial load is generally expressed according to values as:

$$F_{max} = 750\ D - 245 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where F_{max} = The maximum axial load, D= granular columns diameter, on condition that the diameter ranges from 0.6 m to 1.2 m and that it is not equal zero.

Tables (3) show the effect of granular columns diameter on stress concentration factor for different diameter of 0.6 m, 0.8 m, 1.0 m and 1.2 m, for encased Geosynthetic layer. It can also be observed that, the stress concentration ratio semi constant with increase of granular columns diameter. The stress concentration ratio varies between 2.94 and 3.07 at the end of consolidation stage, with an average value of about 3.00.

Table (3) Stress concentration ratio (*n*) for different column Diameters

Initial stress (σ) kPa	Granular Columns diameter (m)	Final stress (σ_g) kPa	Stress Concentration ratio (*n*)
150	0.60	441	2.94
150	0.80	457	3.05
150	1.00	458	3.06
150	1.20	460	3.07

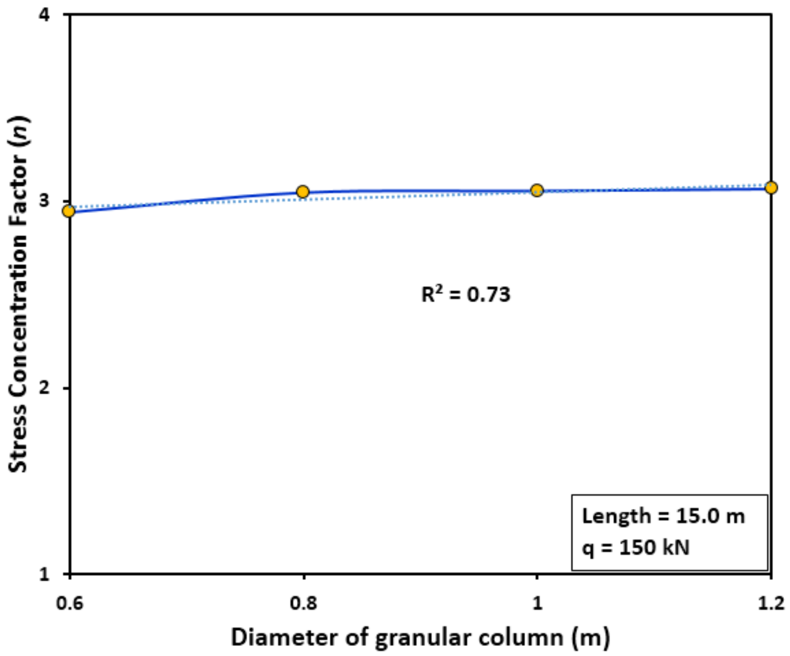

Figure (13) Effect of Stress Concentration ratio (*n*) on the Diameter granular column.

Figure (13) shows that the stress concentration ratio semi constant with the increase of granular columns diameter. The stress concentration ratio is generally expressed according to values as:

$$\boldsymbol{n = 0.19\,D + 2.86 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (4)}$$

where ***n*** = The stress concentration ratio, **D**= granular columns diameter, on condition that the diameter ranges from 0.6 m to 1.2 m and that it is not equal zero.

4- Conclusions

From the present study, the following conclusions may be drawn:

1. Encasement of granular column by geosynthetic has a significant effect on the developed negative friction and axial forces in the granular column- soft clay composed.

2. Increasing the length and diameter of encased granular column has significant effect on the developed interaction friction, maximum axil force and the normalized depth of the neutral plane.

3. The maximum axial load increases 2.5 times as a result of the increase granular columns Length from (5 m to 20 m).

4. A simplified equation is proposed to estimate the maximum axial force developed in a single encased granular column considering influences from length and diameter of granular column.

5. The stress concentration ratio (n) between the load carried by the granular column to the applied average load is with an average value of about 2.40 and 3.00 for the variation of column length and diameter respectively.

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