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Numerical Modeling on Behavior of Annular Stone Column in Layered Soils

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Abstract. In the past, many studies on the improvement of soft soils to increase the load-carrying capacity and reduce settlements found that ordinary and encased stone columns have been increasingly used. In this present work, an annular-structured stone column is introduced into the ground to study the behavior of the column in layered soils. Two types of layering systems, i.e., soft clay overlying stiff clay and vice versa, are considered for the present study. To know the performance of an annular stone column, numerical models were carried out by taking the internal and external diameters of 40 mm and 80 mm, respectively, with geo reinforcement and varying the thickness of the top layer as well as the bottom layer. To know the load-carrying capacity of an annular stone column by giving a prescribed displacement, a detailed parametric study was carried out using the finite element-based software Plaxis 3D. For the soil and stone columns in the numerical analysis, the elastic-perfectly plastic Mohr-Coulomb failure criterion with drained and un-drained conditions was used.

Keywords: Annular stone column, Layering system, Geo reinforcement, Varying thickness, Load carrying capacity, Mohr-Coulomb failure criterion.

1 Introduction

At present, the ascending order of growth in the population leads to huge construction in every area of land. Whichever soil type it may be, there will be no free land available. In the meantime, low shear strength and high compressible soils pose high settlements, which leads to failure of the structure. Engineering applications, which are the remedy for those types of complications for the failure of structures, In particular, geotechnical engineers made a possible solution for the improvement of soil by the application of stone columns. Many past studies dealing with stone columns refer to multiple methods of trials in the field before execution (Ambily & Gandhi, 2004)[1]. The stone column is designed with past performing knowledge and no proper guidelines or codes are available. By drilling a borehole in diameter, granulated stones are poured into the borehole. Ordinary and encased stone columns were used in the ground modifications. The stone columns, which are placed under moving loads, can give the deformation behavior with analytical calculations. In the clayey soils, experimental results with the making of models by the implementation of stone columns, proved the un-drained shear strength and young's modulus can be acceptable (Wissem Frikha et al, 2015)[3]. The small area of group columns under the pad footings, the settlement and confinement analysis were done by using 3D models in PLAXIS. The author concludes that along the total length of the column, small areas performed well compared to large areas in spacing of columns (Micheal and Bryan, 2014)[2]. By using the same software, another author performed settlement and bulging analysis with field data by changing the length of the column. They reported that the L/D ratio at 8.3 had an impact on the settlement performance of the column with optimum bulging and stress ratio (Al-Ani et al, 2015)[4].

In another research under transport infrastructure the retarding of settlements and pore water pressure were analyzed by using analytical and numerical models with effects of arching, clogging and smear zone in soft soils (Basack et al, 2016)[6]. Stone column behavior in c- soils was observed in a study on embankment height and the presence of fines in embankment soil. Numerical models were performed using FLAC software (Kumar Das and Dev, 2019)[8]. Improved train critical speed, length of the stone column under cyclic loads with dynamic amplification factor, and parametric analysis performed with 3D numerical models (Fernandez-Ruiz et al, 2021)[9]. A numerical study was carried out to find out the critical length of the encasement provided for stone columns. The study reveals the encasement length should be slightly lower compared to the stone column length. (Miranda et al, 2021)[10]. In this present manuscript, the modification of stone columns with the provision of geo-reinforcement will be described. Annular stone columns are modified stone columns, which have an internal and external diameter with a hollow at the centre of the column. In the area of circular thickness, stone aggregates are placed, and the remaining area will be filled with soil. This type of stone column is going to be analyzed by using numerical models in the geotechnical software. The model is performed in 3D using finite element analysis in PLAXIS software. The deformation behavior and load carrying capacity of a solitary annular stone column are investigated with numerical models. These models are performed in layered soils and two layered systems were considered. Complete numerical models created in a 3D application were used for this study's model test in order to fully capture the potential of the novel approach. The paper does not include constructability for experiments or installations.

2 Methodology

To ascertain the loading capacity of an annular stone column under a given displacement, the finite element analysis approach is applied. PLAXIS 3D is the software used in the research of analysis for computational modeling. The work done by A.P. Ambily and S.R. Gandhi is taken into consideration for validating the finite element model. The load carrying test was numerically analyzed. The taken model is 210 to 420mm diameter and height of soft clay bed is 450mm. The stone column diameter as 100mm and height 450mm isplaced at the center of the soft clay bed with prescribed displacement of 30mm. The validation result plotted between experimental model and numerical model. The Load vs Displacement graph obtained from PLAXIS 3D program (Fig.1) shows well matched with experimental model.

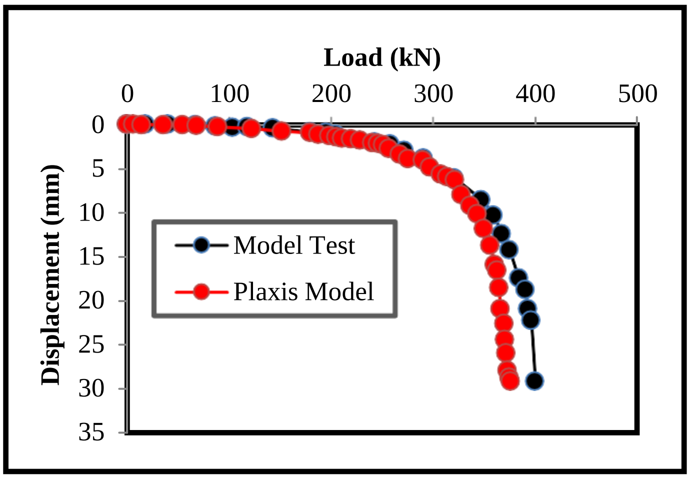


Fig. 1. Validation of PLAXIS 3D program

2.1 Numerical model of Annular stone column 3D

A 3D program is used to analyze the singular annular stone with thickness variation of two soil strata. The properties of the clayey soils, annular stone column and parameter properties were considered as per (Tandel et al, 2013)[7] and (Mohanty and Samanta, 2015)[5]. With the results obtained, the column's capacity for supporting loads can be assessed. The inner and outer diameters of the column were measured at 0.4 and 0.8 m, respectively, for the model construction. The diameter (D) of a stone column is taken into account in the modeling process along with variations in the overlying soil's thickness. The upper soil thickness varies in a dual soil system as 1D, 2D, 3D, and 4D.

The model is a unit cell model with dual soil strata and an annular stone column placed at the centre of the soil body. In the procedure of numerical analysis for load identification, prescribed settlement is taken as 50mm on the surface of a stone column. The column is covered with geo-reinforcement along the length of 10m inside and outside of the annular portion. The geo-reinforcement stiffness (J) is 3000 kN/m. The dual soils considered for model testing are soft clay and stiff clay. A Mohr-Coulomb failure criterion model with drained and un-drained conditions in 3D analyses was done. The soil model material properties are taken for the analysis given below.

Properties:
The dual soil system is considered with 2 types of clay. The soil conditions with some specifications are taken with stone properties.

Table 1. Specifications for model

Considerations	Soft Clay	Stiff Clay	Annular Stone Column
γ_{dry}	17	19	20
γ_{wet}	17	19	20
E_c	2500	15000	45000
μ	0.4	0.35	0.15
s_u	25	-	-
C	-	75	0
ϕ	0	2	40
ψ	0	0	10

Table 1 represents the specifications of the soil model which are used in PLAXIS program for the load carrying behavior of the annular stone column. The above table specifications or properties are considered from literatures (5 and 7). The changes in the thickness of dual soils will affect the stone column performance that will be presented in the outcome of the analysis. The parametric study was also done by considering the internal friction angle of the stone column. The established outcomes will be presented in graphical representation with a comparison of conventional and annular columns. As the internal friction angle is considered, the specifications are in the ranges given as and considered values are 35, 40, and 45 (ϕ). The established outcomes will be presented in graphical representation with a comparison of conventional and annular columns. The outcomes will generate a conclusion at last.

3 Outcomes and Colloquy

The specifications study outcomes present the load carrying strength of the column in changing of dual soil width at top of each case. From the all model verification plotted the result as graphical presentation. The displacement and load are considered in x and y coordinates respectively. The generated graphs will expose the stone column condition, according to given terms of soil characters.

3.1 Alteration of thickness effect on Annular column in S1 series

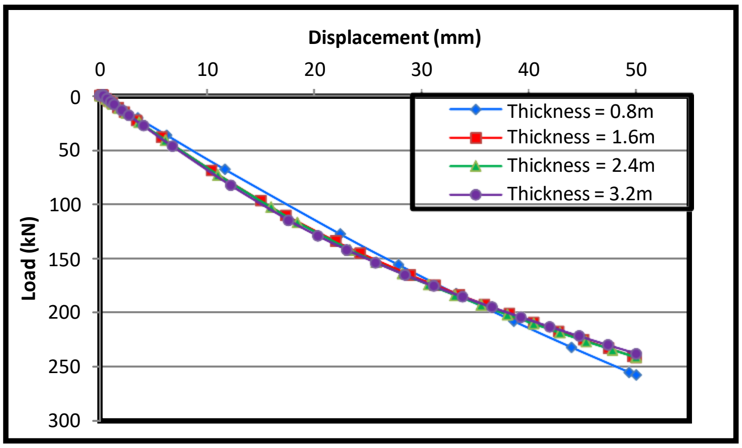


Fig. 2. Single annular column - Load vs Displacement for change in upper soft clay thickness covered with geo-reinforcement.

The above figure 2 indicates s1 series load vs displacement graph. S1 series exhibit the soft clay as top soil and stiff clay is bottom one. For each case of thickness alteration of top soil, express the software result in the form of graphical curves. Outcome indicates the loading strength of the column gradually slowdowns, by enhancement of soft clay thickness from 1D to 4D. That is the alteration of loading strength due to low stiffness soft clay. The prescribed displacement given for the column and due to low stiffness of soft clay, loading will be slowdowns as the increment in thickness of top clay soil.

3.2 Alteration of thickness effect on Annular column in S2 series

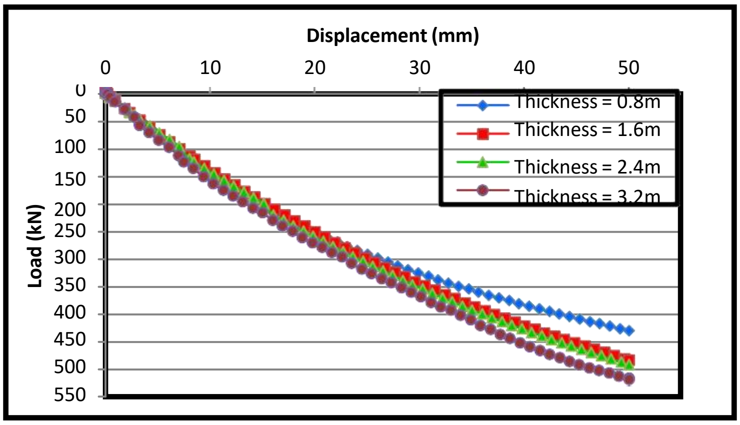
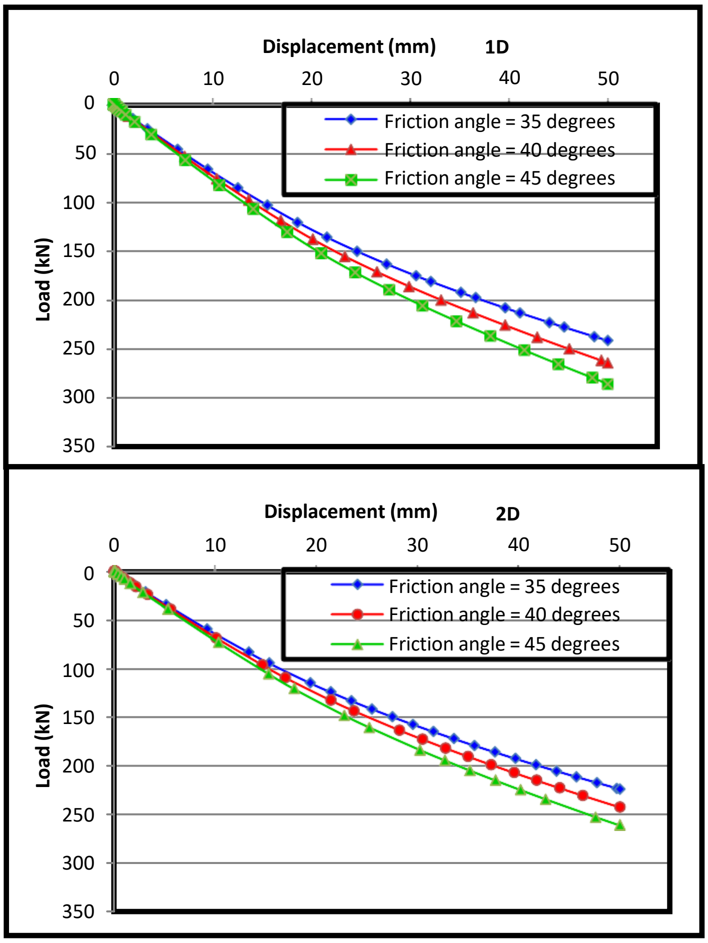


Fig. 3. Single annular column - Load vs Displacement for change in upper stiff clay thickness covered with geo-reinforcement.

The above figure 3 conveys the load carrying strength of the annular column graph with prescribed displacement of 50mm. The alteration of top soil is stiff clay and soft clay is bottom. Due to soil more stiffness of stiff clay exhibits the enhancement in loading strength of the column. In the same way the thickness alteration from 1D to 4D the load gained up from 431 kN to 519 kN respectively. The provided geo cover with stiff clay enhances the strength of the column loading ability.

The annular column condition varied for dual soil alteration with soils different specifications. Soft clay at upside of the stiff clay as series 1 presented the solution for loading strength of column has shrink for enhanced thickness of soft clay. Stiff clay at upside of the soft clay as series 2 represents the outcome for column loading strength has gained up for improved thickness of stiff clay.

3.3 Alteration of Internal friction angle effect on Annular column in S1 series



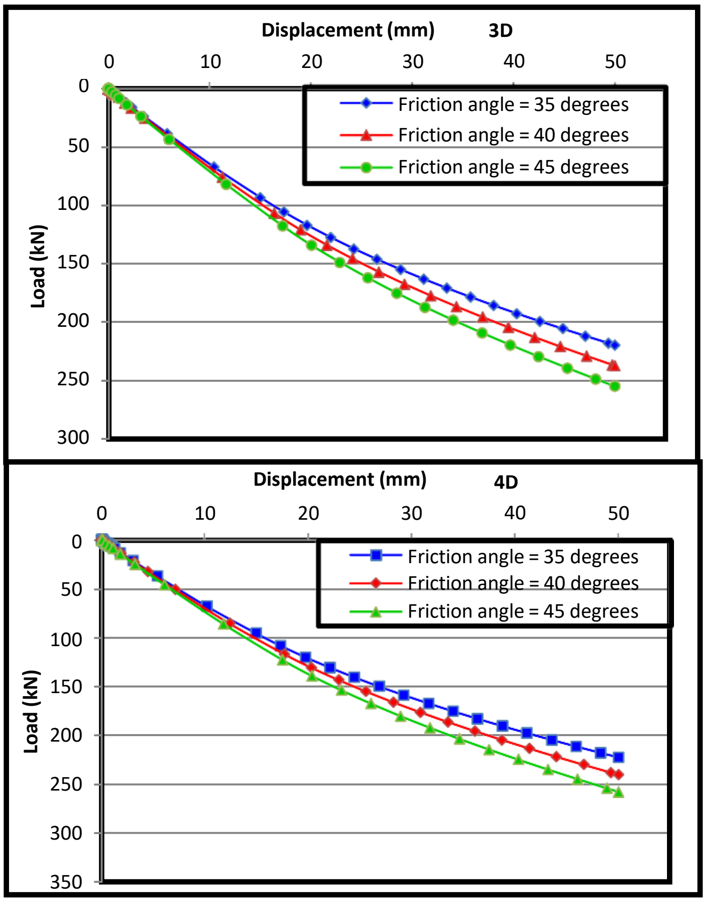
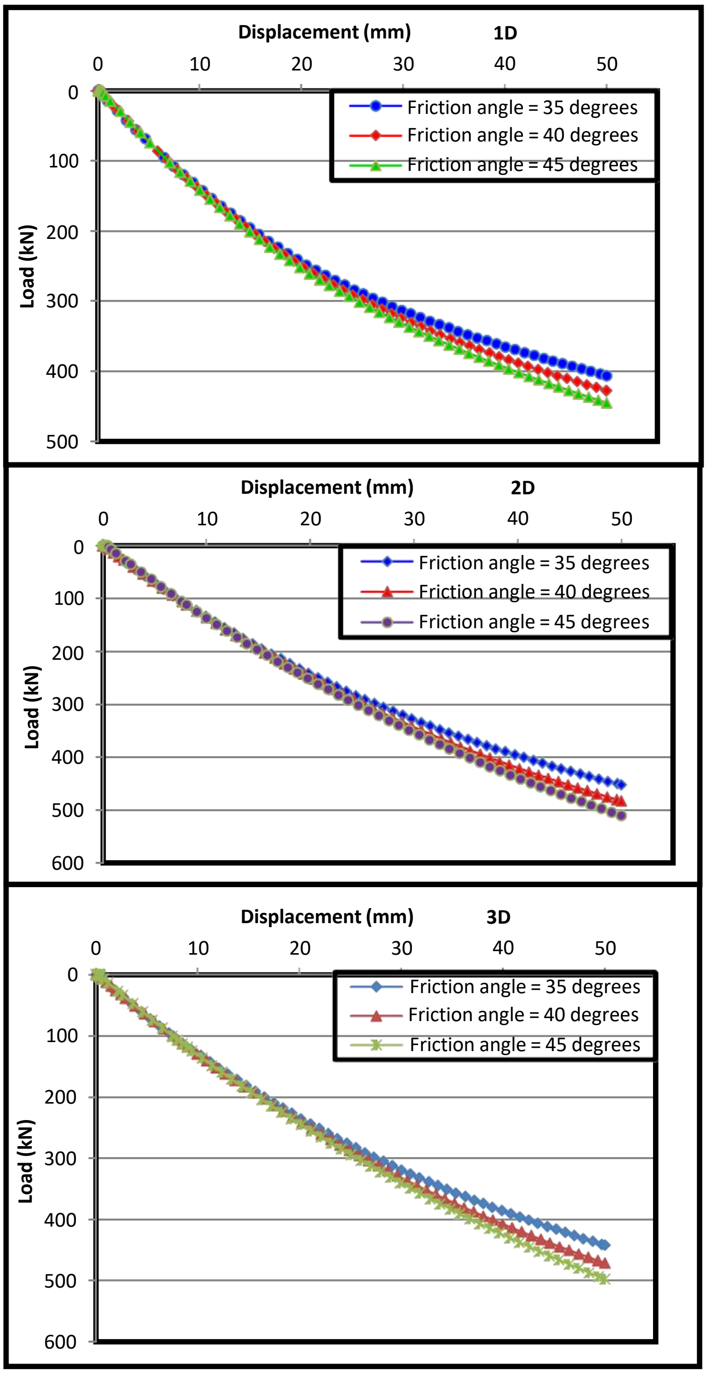


Fig. 4**.** Single annular column - Load vs Displacement for change in internal friction angle of column covered with geo-reinforcement at 1D, 2D, 3D and 4D in series 1.

Figure 4 presents the alteration of internal resistance angle of stone column. As the soft clay overlies on stiff clay, the loading strength of the annular column was increased with an enhancement of internal friction angle of stone. The friction increment in stones of column will catch the geo-reinforcement with dual soils. For each enhancement of friction angle from 35 to 45 degrees, the load carrying strength also gained up 22% for 45 degrees friction angle than 35 degrees at 1D, 2D, 3D and 4D thicknesses of soft clay.

3.4 Alteration of Internal friction angle effect on Annular column in S2 series



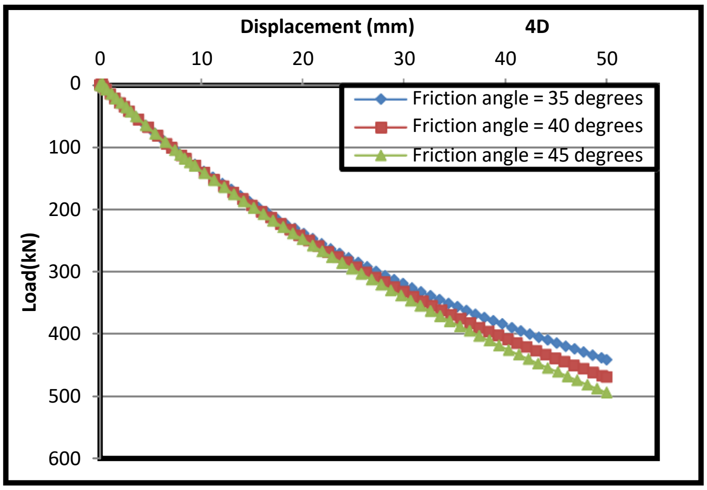


Fig. 5**.** Single annular column - Load vs Displacement for change in internal friction angle of column covered with geo-reinforcement at 1D, 2D, 3D and 4D in series 2.

Figure 5 shows the alteration of internal resistance angle of stone column. As the stiff clay overlies on soft clay, the loading strength of the annular column was increased with an enhancement of internal friction angle of stone same as in the series 1. The friction increment in stones of column will catch the geo-reinforcement with dual soils. For each enhancement of friction angle from 35 to 45 degrees, theload carrying strength also gained up 30% for 45 degrees friction angle than 35 degrees at 1D, 2D, 3D and 4D thicknesses of stiff clay. This reveals that stiff clay hasmore stiffness that loading values are higher than soft clay at up in dual soils.

For the confirmation of annular structure of column in the field application, the comparison is made analyzed for both conventional and annular stone columns with elastic clay soil model specifications.

3.5 Annular column and Conventional column Comparison

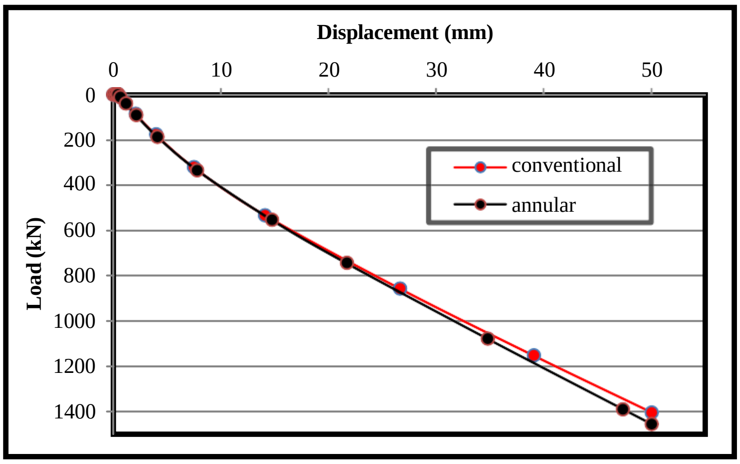


Fig. 6. Load versus Displacement comparison for Annular and Conventional columns.

The figure 6 exhibits the comparison graph for both annular and conventional stone columns. The geometry for the 3D modeling taken the dimensions for both columns as mentioned below

Conventional column:

Length of the column: 10m

Diameter of column: 0.7m

Soft clay: along full length of the column

Annular column:

Length of the column: 10m

Diameter of column: 0.8m

Soft clay: along full length of the column

The stone and soft clay specifications are considered as same in the above table 1 for two models with covered geo-reinforcement of stiffness 3000 kN/m.

The above graph (figure 4) indicates loading strength of the columns for the prescribed displacement of 50mm. The compared loading strength of two columns represents that the annular structured column having more ability than the conventional column in soft clay soil.

4 Conclusions

The behavior of annular stone column by alteration of crest thickness in dual soil system by implementing cover around the column concludes that:

1. The column analysis in 3D exhibits accurate outcomes for the loading strength. Geometry for the model analysis considered as unit cell model for proper execution of stone column as in field.
2. As the soft clay soil at upside of stiff clay in dual soil system the annular stone column loading ability was slow downed due to low stiffness of soft clay in every case of alteration of thickness.
3. The loads of series 1 are in descending order of 7.8% decreased with enlargement of thickness of soft clay between 1D and 4D.
4. As the stiff clay soil at upside of soft clay the column loading ability was gained up due to thickness enlargement of top soil and stiff clay is stiffer than soft clay.
5. The loads of series 2 are in ascending order of 17% raised up between 1D and 4D thickness of stiff clay.
6. The comparison results shows that annular column can be executes better loading strength than conventional column due to the structure variation, that may leads to an isolator for moving loads on surface of annular column.
7. At last outcomes conclude that annular column can be applicable for load carrying in the field.

References

1. A.P. Ambily and S.R. Gandhi: Experimental and Theoretical evaluation of stone column in soft clay. ICGGE-(2004).
2. Michael M. Killeen, Bryan A. Mc Cabe: Settlement performance of pad footings on soft clay supported by stone columns; A numerical study. The Japanese Geotechnical Society (Soils and Foundations):2014;54(4):760-776.
3. Wissem Frikha, Mounir Bouassida and Jean Canou: Parametric study of a clayey specimen Reinforced by a granular column: International Journal of Geo-mechanics: doi:10. 1061/(ASCE)GM.1943-5622.000049, (2015).
4. W. Al- Ani et al.: Numerical Modelling of stone columns in soft soil: Geotechnical Engineering for infrastructure and Development: doi:10.1680/ecsmge. 60678, (2015).
5. P. Mohanty, M. Samanta: Experimental and Numerical studies on Response of Stone Column in Layered soil: Int. J. of Geosynth. And Ground Eng. Doi: 10. 1007/s40892-015-0029-z. (2015).
6. Sudip Basack, Buddhima Indraratna and Cholachat Rujikiatkamjorn: Analysis of behavior of stone column stabilized soft ground supporting transport infrastructure: Centre for Geomechanics and Railway Engineering: doi: 10.1016/j.proeng.2016.06.044: (2016).
7. Yogendra K. Tandel, Chandresh H. Solanki, and Atul K. Desai: 3D FE Analysis of an Embankment Construction on GRSC and Proposal of a Design Method: Hindawi Publishing Corporation, ISRN Civil Engineering Volume 2013, Article ID 348973, 11 pages: http://dx.doi.org/10.1155/2013/348973.
8. Amit Kumar Das and Kousik Deb: Response of stone column – improved ground under c – φ soil embankment: Soils and Foundations: doi 10.1016/j.sandf.2019.01.003, (2019).
9. Jesus Fernandez-Ruiz, Marina Miranda, Jorge Castro, and Luis Medina Rodriguez: Improvement of the critical speed in high-speed ballasted railway tracks with stone columns: A numerical study on critical length: Transportation Geotechnics: Doi: 10.1016/j.trgeo.2021.100628, (2021).
10. Marina Miranda, Jesus Fernandez-Ruiz, and Jorge Castro: Critical length of encased stone columns: Geotextiles and Geomembrane: Doi. 10. 1016/j.geotexmem.2021.05.003, (2021).