A STUDY OF GEOSYNTHETIC ENCASED STONE COLUMN USING FINITE ELEMENT APPROACH

DISSERTATION
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MASTER OF TECHNOLOGY

IN
GEOTECHNICAL ENGINEERING

Submitted by:

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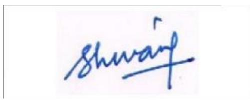
CANDIDATE'S DECLARATION

I, SHIVANG AGGARWAL, Roll No. 2K18/GTE/12 student of M.Tech (Geotechnical Engineering), hereby declare that the project/ Dissertation titled "**A Study of Geosynthetic Encased Stone Column using Finite Element Approach**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.



Place: Delhi **SHIVANG AGGARWAL**

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CERTIFICATE

I, SHIVANG AGGARWAL, Roll No. 2K18/GTE/12 student of M.Tech (Geotechnical Engineering), hereby declare that the Project/ Dissertation titled "**A Study of Geosynthetic Encased Stone Column using Finite Element Approach**" under the supervision of PROF. A. K. SAHU of Civil Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology has not been submitted elsewhere for the award of any Degree.

Place: Delhi

Date: 31.08.2020

PROF. A. K. SAHU

SUPERVISOR

ABSTRACT

Geotechnical engineers encounter various challenges and troubles while designing a structure over soft soils. These comprise of potential bearing failure, large lateral pressures and uncontrollable settlement and movement, and local or global instability. Geosynthetic encased system provides a more effective and reliable solution for the construction of various structures over soft soils especially during rapid construction or strict deformation of structure is required; such as embankments, retaining walls, storage tanks etc. The use of stone columns is popular as a ground-reinforcing technique for supporting flexible structures on soft to very soft soils. When the stone columns are installed in extremely soft soils, the lateral confinement offered by the surrounding soil may not be adequate to form the stone column. Consequently, the stone columns installed in such soils will not be able to develop the required load-bearing capacity. In such soils, the required lateral confinement can be induced by encasing the stone columns with a suitable geosynthetic or by placing horizontal strips of geosynthetics within the columns at regular intervals.

In this study a three dimensional numerical analyses, using finite element technique (ABAQUS) is carried out for simulating the response and behavior of an ordinary versus encased stone column installed in a soft soil. A numerical analyses is performed using Mohr-Coulomb's failure criterion considering elasto-plastic behaviour for soft soil and stone column. Load-Settlement response is selected as a criteria to compare the performance of ordinary versus encased stone columns. Also, parametric analyses is carried out to study the effect of stiffness of geosynthetic and diameter of stone column. The results indicate that the performance of the columns enhances, by increasing the tensile stiffness of encasement and observed that there isn't much of a difference in the load-settelement response of ordinary stone column of varying diameters.

Keywords: Stone Column, Geosynthetic encasement, Reinforcement; Ground Improvement, Finite Element analyses.

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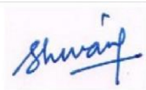

Date: 31/08/2020 **SHIVANG AGGARWAL**

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CHAPTER 1- INTRODUCTION

As the amount of population in congested urban area increases, so does the proportion of structures which must be constructed on poor soils, such as flood plains, coastal regions or seismic areas. Moreover, construction on sites with favourable ground conditions is severely limited by economical, social and other constraints. Consequently, ground improvement methods, such as stone columns, are necessary for safe and economical geotechnical design and construction. The available options in very soft soil are very less because of the environmental problems and high cost. There are quite some number of methods available to enhance the performance of soft soils such as stone columns, pre-consolidation method by prefabricated vertical drain and lime treatment and preconsolidation soil cement column. Among all these methods, stone column method is highly preferred as it offers added advantage of lower settlement and increase consolidation settlements due to decrease in flow path lengths. Moreover, ease of construction and its simplicity also make its more adaptable. Through bulging, stone columns develop load carrying capacity and induce near passive pressure consitions in the adjacent soils. A lot of research has been done on this domain, and it was observed that installation of piles, granular piles enhance the bearing capacity by as much as four times and increase the factor of safety by approximately 25%. It was however observed and reported that behaviour of soft soil is likely to be improved much with stone column than with prefabricated vertical drains.

When the loads are applied on the encased stone columns, the columns buckle laterally into the adjacent soil and owing to the bulging on top of the columns, failure occurs. They derive their load carrying capacity from the mobilisation of lateral earth pressure against bulging from adjacent soils. When the stone columns are installed in very soft soils, the lateral pressure offered by them is not enough in order to provide load bearing capacity. In all such cases, columns are reinforced with geosynthetics to enhance the load carrying capacity of the columns.

The columns may be encased by geosynthetics, Figure 1(b) shows vertical encasement of geosynthetics like a wick drain – or by placing horizontal strips of a geosynthetic within the column at regular intervals as showm in Figure 1(c)

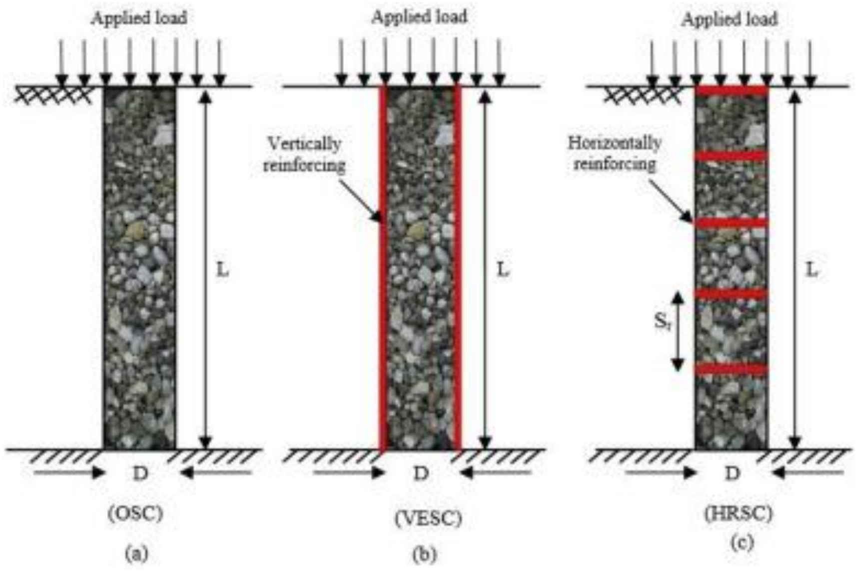

Figure 1: Representation of modes of reinforcement of stone columns
a) Ordinary Stone Column; b) Vertical Reinforcing; c) Horizontal Reinforcing

Encasement provides higher resitance against bulging through mobilisation of hoop stresses during loading of the columns. When the horizontal encasement is provided, bulging of the columns is restrained by mobilisation of frictional stresses on the surface of the encasement the effect of the reinforcement have been widely observed and confirmed through various numerical analysis, and major focus was laid on type of encasement used i.e. vertical or horizontal reinforcement however not much literature is available on the performance and increase in load carrying capacity in either of the cases. Much literature is available on full penetrating end bearing columns and its performance than reinforced floating or short columns.

1.1Problem Statement

Due to deficient lateral confinement provided by soft soils to the columns, the development and the application of granular columns became difficult. The problem can be resolved by applying geosynthetic encasement thus providing lateral confinement to the columns material.

The Granular Encased Column application is considered as a recent improvement approach.

The encasement provided through geosynthetics will improve and enhance the load bearing capacity of columns signifacntly due to the additional confinement provided by the encasement. Moreover, lateral squeezing of stones are also prevented when stone columns are installed into a very soft soils; using geosynthetics as encasement thus leading to a minimal loss of stones and quicker installations. The literature available on this area of subject is also limited. Thus, there is a requirement of better understanding of the method and its principal parameters which are of utmost concern to improve the column behavior.

1.2Objective of the study

The purpose of the study is to investigate and provide a better view and understanding of the behaviour and performance of ordinary and reinforced stone columns when installed into a collapsible soil using analytical modeling.

I. To analyse the effect of encasement on the behaviour of granular column using finite element method.

II. To evaluate the development achieved in load bearing capacity and settlement characteristics of ordinary column of different diameter and encased stone column.

III. To examine the influence of tensile stiffness of geosynthetic on the settlement characteristics of the column.

CHAPTER 2 – THEORY

2.1 Stone Column

The installation of stone columns by applying static and heavy vibrating poker to displace the in-situ ground and to compact the imported material is widely used within the countries as a successful ground improvement technique (Watts 2000). As the amount of congested urban areas increases, so does the proprtion of the structures which must be constructed on the porr soft materials. Subsequently, ground improvement techniques, such as stone columns are increasily required. For a change of different locations and ground conditions, the stone column technique has been found to be an adequate solution varying the type of the granular material introduced into the soil in terms of the grading or the stiffness of the material.

Aside from the economical aspect of the geotechnical design, the application of ground improvement methods should ideally in the case of soft soils, increase the shear strength and reduce the compressibility of the in-situ material. Additionally, in some cases the application of stone columns is designed to infuence soil permeability and to improve homogeneity. The stone column technique is an economical and environmental friendly method, which treats the ground in order to withstand various loading considitions. This type of improvement method froms continous columns from the maximum depth of penetration up to the ground surface, using a deep vibrator.

2.1.1 Application of Stone Column

Stone columns have been used in nearly every type of civil constructions, such as residential, commercial and industrial buildings, dams, storage tanks and silos, power stations, highways, airport taxiways and runways, road and railway embankments, pipelines, bridge abutments, landslide corrections and stabilisation of cofferdams. Granular columns have also been successfully utilised in offshore engineering, as a breakwater and quay walls, offshore bridge abutments, and in land reclamation projects, reaching typically up to a depth of 35m. The wide number of applications for this technique is intensified by the fact that stone columns can be used adjacent to exisiting structures without causing damage from vibrations. Nevertheless, for every geotechnical application stone columns should be carefully compared with other alternative methods to consider the advantage and limitations of each treatment. With the stone columns technique, columns of dense crushed stone are introduced into the soil in order to reduce settlement and to increase bearing capacity, allowing a reduction in the foundation size. The stone columns may also provide slope stabilisation and enable the construction of fills and shallow footings.

This type of ground improvement has proven to be successful in reducing total and differential settlements, as well as in increasing the rate of settlements. Installation of strone columns in loose sandy soils below the water table reduces the liquefaction potential and has an additional effect of draining of draining the deposit. The installation of granular columns helps to compact loose sand and gravel layers, reinforces soil that cannot be compacted and generally facilitates drainage (particularly in very silty sands to sandy silts).

In granular soils, the vibrations offer a significant improvement in the relative density of the surrounding material, thus significantly enhancing and improving the allowable bearing capacity and settlement characteristics. In cohesive soils, improvement in the geotechnical properties of clay occurs, when stone columns are installed due to the combine effect of weak soils and stiffer columns. Indeed, in senstive clays the installation may have a negative effect on the surrounding soils.

2.1.2 Limitations of Stone Column

The selection of the treatment technique, as well as the method of execution, is usually based on the local ground conditions, type of loading, and purpose of construction and preferences of the contractor.

The wet process can be used when the soil is not contaminated and when soil does not consist of a highly plastic clay, which could lead to a problem when handling the slurry and gravelly layers is required and these layers are loacted below the water table. Compaction is generally better accomplished with the wet rather than dry process, as the flushing water assists in compacting the sandy soil around the column. Finally, the wet technique is used where the dry top-feed process cannot be performed because of unstable ground, such as in running sand conditions. The predominant disadvantage of water is required to prevent collapse of the created cavity or contamination of the column, therefore environemental regulations may restrict drainage of the slurry in lagoons.

Organic soils tend to have a high moisture content, plasticity index and compressibility, hence it is difficult to reduce the settlement in these soils. Nevertheless, most organic silts and clays may be improved by introducing stone columns. If stone columns are chosen as the ground improvement method, some additonal considerations should be taken into account while planning the ground investigation in order to estimate the future difficulties with construction and serviceability of the structure.

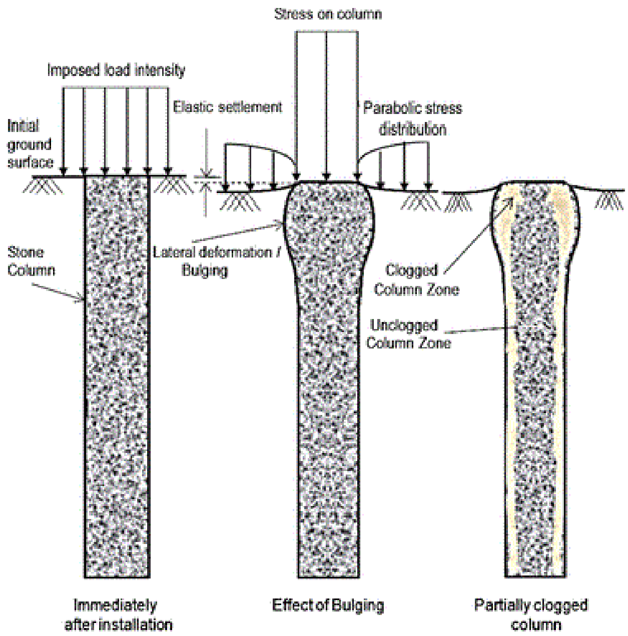

Figure 2: Stone column behavior in soft ground with emphasis on bulging. (Sudip Basack 2017)

2.2 Geosynthetic encased stone columns

In a very soft soil where undrained shear strength is less than 15 KPa, inadequate lateral support provided by the adjacent soil may cause extreme bulging of the column, majorly at the top portion and squeezing of clay particles into the stone aggregates, resulting in the deduction of the load bearing capacity of the stone column (Alexiew et al., 2005). To mitigate this issue, single stone column should be circumferentially wrapped with appropriate geosynthetic material (Tandel et al., 2013). Encasement minimizes material losses and keeps the drainage capacity of the granular column intact as it prevents the intermixing of the adjacent soil into the column materials (Almedia & Marques, 2013).

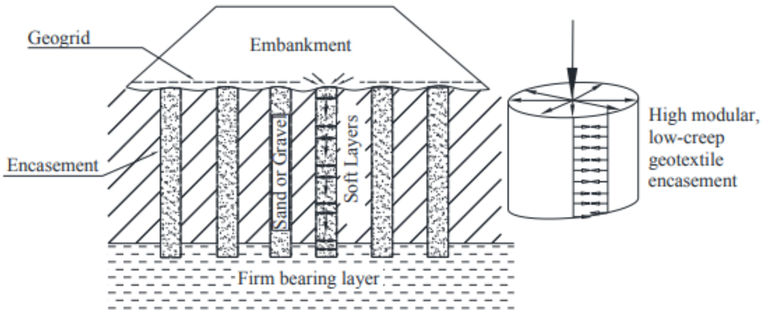

Figure 3: Mechanism of Geosynthetic Encased Columns (Alexiew et al., 2005)

2.2.1 Characteristics of Granular Encased Columns

- Primarily it provides radial confining reinforcement to the column. The other advantages are separation, drainage and filtration.
- It is an end bearing system transferring the loads to a hard underlying stratum and are not entirely settlement free.
- They are water permeable which altogether have environmental advantages as they don't effect the groundwater flow.
- GEC is a reinforcing element and can perform as high capacity vertical drain; capable of achieving high quality standards and design specifications.
- The spacing of encased columns is generally between 1.5m and 2.5m.
- The tensile stiffness (J) of the geosynthetic is typically in range of 1500KN/m and 6500KN/m.

CHAPTER 3- LITERATURE REVIEW

S. Murugesan, K. Rajagopal (2006). The investigation corrresponding to the effectiveness of geosynthetic encasement on the stone columns was performed using 'GEOFEM' a finite element approach. A cylindrical unit cell embodied with stone column and soil from influence area is used where idealisation of unit cell is done by preparing an axisymmetric model with radial symmetry around the vertical axis through the centre of stone columns. 8-node quadrilateral finite element mesh was prepared for all the components in the system. The stone columns and the soft soil is modelled using the hyperbolic non-linear elastic relation given by Duncan and Chang as it provided a better understanding and relation between the modulus of soil to the confining pressure and shear strength of the soil. The geosynthetic encasement around the stone column was modelled as linear elastic material and discretised as continuum elements around the stone column. The creep effect of the geosynthetic was not considered considering the hoop tension developed in the reinforcement is quite less than the tensile capacity of the reinforcement. Moreover the study did not consider the effects of stone column installation on development and dissipation of the pore pressures are neglected in the analyses. Lower shear strength values are given to the elements adjacent to the reinforcement equal to two-third of parent material strength in order to permit the relative deformation between the adjacent materials and the encasement. The analyses were carried out by applying uniform load on the stone column alone in order to assess the effect of confinement offered by the encasement provided. The loading was applied on the stone column in small increements.

Observation

It was observed, that because of the confinement offered and reduction in the lateral bulging, the load bearing capacity of the stone columns can be improved by encasing it with geosynthetic. The modulus of elasticity of geosynthetic plays a pivotal role in providing sufficient strength and stiffness to the reinforced columns. At a depth approximately twice the diameter of stone column, hoop tension forces are generated in the encasement. Diameter of the stone columns also have significant effect on the behaviour and performance, as mobilisation of higher stresses takes place in larger stone column, thus smaller columns are more superior than the larger ones. Moreover, to provide sufficient load bearing capacity it is suggested to reinforce the columns upto a depth equal to twice the diameter of stone columns to quite adequate to reinforce the columns upto a depth

K. Ali, J.T. Shahu and K.G. Sharma (2012). In this study, tests were performed on the columns installed at the centre of the clay bed and load was applied on the columns and the surrounding soil using a sand mat. The thickness of the soil was kept same throughout and 20mm thick sand mat was used in all the test. 26 model tests were carried out altogether, with different lengths of columns used i.e. end bearing and floating columns. Diameter of the columns were kept constant throughout. A clay paste with 40% water was settled in the tank in layers, hand moulded to ensure no air voids, followed by covering the bed with jute fabric for 48 hours to avoid any moisture loss. Undrained shear strength was then calculated using vane shear test at four different locations. Pipe of diameter equal to that of required stone column was used, stone chips were filled into the pipe and the pipe was withdrawn gentlly, which was then compacted by a rod till the thickness equal to the column's diameter was achieved. For reinforcing i.e. for vertical reinforcement, the columns with geosynthetics, outer surface and bottom of the pipe were covered with geosynthetic when the pipe was placed at required depth. Whereas for horizonatl reinforcement, geosynthetic strips were placed at equal intervals inside the column during the compaction of stone chips. To ensure undrained consition, strain at fast rate of settlement was carried out and proving ring is used to calculate the load applied.

Observation

Irrespective of the type of column, long unreinforced columns fail by bulging and short columns fail from punching. Moreover, higher failure stresses are observed for columns encased fully than for top half and quarter of columns length. The best configuartion for end bearing columns is to encase the top 50% of the column length at half diameter spacing. Reinforcent of end bearing columns are more effective and provides good improvement than floating columns. Encasing the columns vertically, proved to be more effective in end bearing columns whereas there were no signifcant difference observed in the performance of floating columns encased vertically or horizontally.

Marcio S.S. Almeida and Dimiter Alexiew (2014) - In this study, thrity six encased columns were installed at the trial embankment which is constructed as a test area. The test area consisted of a very soft soil extending from the ground surface to a significant depth. The soil and reinforced columns were instrument for various observations. Inclinometer (2 in number, installed at embankment toes) was used to account for lateral deformation and measure distribution, piezometer (3 at different depths) was used to measure pore water pressure, surface settlement plate (2 placed at top of soft soil and 1 on top of encased column) was used to record vertical displacement, radial extensiometer (3 in number, attached to the reinforcement at a deoth of 1 m below the column's top) was used to measure geosynthetic hoop strain and total stress cell (4 in number to assess soil arching) was used for vertical stresses. All the parameters were concentrated at the centreline of the test area where the maximum stress is applied.

Observation

It was found, maximum lateral deformations occurred in the middle of soil and it increased considerably as excess pore water pressure dissipated. After each construction of embankment layer, vertical stresses increased considerably. However, it was much for encased columns as the consolidation progressed but did not vary much for soft soil. As each layer was constructed, radial expansion of geosynthetic encasing increased which later on slowed as consolidation progressed.

J. Han, M.A. Gabr (2002) – According to the study, the required percentage coverage of the columns and pile caps depend greatly on the quality of the materail. By encasing the pile caps ofr columns with geosynthetics, it is expected to decrease the settlement of the embankment fill between the columns as compared to the unencased case. The shear stresses induced by embankment soil arching would also reduce due to the reduction in the displacement and settlement. Thus, the load tranfer is minimized by embankment soil arching to the columns.

A single geosynthetic layer behaves as a tensioned membrane while a multilayer system acts as a plate because of interlocking of reinforcements with the adjacent soils.

In this study, the analyses were carried out using FLAC. However, triangular or square patterns are used for the arrangement of piles, square pattern is followed in the analyses. Below the soft soil no deformation was assumed. A nonlinear hyperbolic elastic model was used, given by Duncan and Chang, as geotechnical properties of foundation soil and embankment fill are dependent on stress and redistribution of stresses is an important mechanism in the system. No creep factor for geosynthetic was accounted, and linear elastic materials were considered both for piles and geosynthetics.

Observations

The study demonstrated that the total and differential settlements above the pile heads can be reduced through the inclusion of geosynthetics and enable swift and efficient transfer of loads from soil to the piles and diminish the chances of soil yielding above the pile caps. Stress concentration and tension in the encasement increases considerably with the height of embankment fill, increasing the tensile stiffness of encasement which altogether increases the modulus of elasticity of pile material. It was found, that maximum tension appears near the edge of the pile.

Ali Falsafi and M.R. Motahari (2015). The numerical analysis of stone columns in improving the bearing capacity of footing with the length of 10m, and thickness of 0.5 m in fine-grained soil is analysed in this paper. The two-dimensional finite element method using Abaqus is used for investigating the behavior of stone columns. In this paper various parameters such as number of columns, influence of deformation in single column and stone column group, young modulus of the materials of stone column and soil, Poisson's ratio of column's material and soil have been analysed.

Observations

Increasing the stone column's elasticity module compared to soil's module, decreases the subsidence of grounds with stone columns. Poisson coefficient of soil and stone column is one of the factors that reduces the subsidence of grounds with stone columns however the effect of poisson coefficient is low. Numerical analyses about the influences of stone column's lengths indicate that increasing the length of column group reduces the subsidence of the ground.

Majid Khabbazian and Victor N. Kaliakin (2009) - In this paper 3D finite element analyses carried out to simulate the behavior of a single geosynthetic-encased stone column in a soft clay soil using the computer program ABAQUS. The influence of geosynthetic stiffness, column diameter, and the stiffness and friction angle of the column material were studied in this paper.

For all the observations and analysis, the thickness of the soil matrix and stone column length was considered to be 5m. It was assumed that a rigid layer was overlaid over the soil and pile. In order to account the effect of vertical boundaries on the observed results to be minimum, the lateral extent of soft soil around the column was selected intelligibly. 6 node, linear triangular finite element mesh was prepared both for column and soil matrix. Keeping in view the elastic behaviour, Mohr-Coulomb failure criterion was used to model the stone column as linear elastic perfectly plastic. Modified Cam Clay material is used to model the soft soil, consisiting of parameters such as slope of swelling line, void ratio, slope of virgin consolidation line, slope of critical state line and poission ratio. 4-node quadrilateral mesh was used to model geosynthetic encasement and was assumed to be isotropically lunear elastic material. Taking into consideration two sets of parameters and in between elements, interaction beahviour between the encasement and the stone column and encasement and the surrounding soil was modeled.

Observation

At a depth equal to a diameter of stone column, extreme bulging and hoop tension occurs and at a depth equal to three columns diameter, minimum values were found. The tensile stiffness of the encasement plays a pivotal role in enhancing and improving the load bearing capacity of the columns. Diameter of the stone column also have a considerable effect on the performance characterictics, as larger diameter columns reduces the load bearing capacity and was found that by changing the diameter from 0.5m to 1.5m, the stress resultant changed as much as 65% for 25mm settlement.

Aminaton Marto and Razieh Moradi (2013) – Plaxis 2D, using finite element approach was used in this paper. An axisymmetric model was prepared, Mohr Coulomb material was used to model stone column, geogrid used as an encasement was modeled as linear elastic material and continuum elements around columns. Load settelement analysis keeping in view the encasement and without encasement was performed, followed by paramteric analysis by changing the diameter of columns and stiffness of encasement used. 15 nodal traingular mesh was prepared for all the components in the model and boundary conditions are kept such as it allows only the vertical deformations and restricts the lateral deformations.

Observations:

By increasing the diameter of the column, the load carrying capacity of the stone column is increased. By providing the encasement, the stiffness and load carrying capacity of the column is increased and lateral bulging is minimized. Modulus of elasticity plays a pivotal role in improving and enhancing the behaviour of encased columns.

Mobin Afzalirad, Mehran Naghizadehrokni and Mojtaba Razaghnia (2019) – The analysis were carried out using ABAQUS, a finite element approach. For all the observations, thickness of soil matrix and length of column was taken to be 10m. 8 nodal finite element mesh was prepared for the soil matrix and stone columns. Modifield Cam Clay material is used to mdoel the soft soil whereas stone columns are modeled using Mohr Coulomb Criterion as a linear elastic material, 4 node quadrilateral mesh is prepared for geosynthetics, and is assumed to be linear elastic and isotropic material. The displacements at the bottom boundary of the mesh in the third direction is set zero.

Observations:

To lower the maximum and ultimate settlement the use of multi-layer geosynthetic with stone column is not much effective and constructive. However, it is considered to be effective and highly productive to decrease the ultimate settlement when stone columns are not used. Contrary to which, single layer of encasement with stone column proves to be more beneficial and effective in lowering the maximum settlement. 0.3 times the diameter of the column was observed to be optimum thickness and lateral bulging is signifcantly reduced by encasing the columns with geogrids, thus providing added confinement. Increasing the stiffness of the geosynthetic leads to increase in the column stiffness and the lateral confinement leading to the significant increase in the performance of the encased columns. Encasement by geosynthetic played a pivotal role in developing and improving the load capacity and also enabled greater transfer of loads to much deeper depths.

P. Mohanty and M. Samanta (2015) - In this paper, two types of layering systems are considered i.e. soft soil overlying stiff soil and vice versa. The tests were performed on 88mm diameter of the stone column positioned in the two layered soil matrix. The stone column was elongated to the full depth of the soil matrix to ensure length and diameter ratio greater than 4.5, which is required to develop the full axial stress in the stone column. The loading was applied on the entire unit cell and the stone column to evaluate the stress verus settlement response of the system.

A parametric study was also perfomed using finite element through Plaxis. In this analysis, Mohr Coulomb failure criterion (Elastic perfectly plactic) with drained conditions was considered both for the soil and the stone column.

Observations

It has been observed that the performance of the stone column greatly depends on the thickness of the top layer of soil, and the response of which is quite different for layered as well as homogenous matrix. Upto 4 times the diameter of column, axial stress of the entire system is found to be dominated by the top soil and beyond 4 times the diameter, and the thickness of top soil has a negiligible effect. For layered soil, axial stress incraeses with increase in the increase in the thickness of top soil, which is approximately 2 times the diameter of columns after which it gets constant. The stiffness enhances with the increase in area replacement ratio.

With the increase in the thickness of top soil, vertical stretch of bulging increases and it gets constant at twice the diameter of the column for both the system i.e. layered systems. At a depth of 0.5-0.8 times the diameter of column, maximum depth of bulging was observed and was found to be independent of top soil when thickness is considerably more than twice the columns diameter.

Jorge Castro (2017) - The paper assess the important modeling apaproach for ordinary stone columns as well as geosynthetic encased columns. For geometrical modeling, important options are unit cell, cylindrical rings of gravel in axial symmetry consitions, longitudinal gravel channel in plane strain strain conditions, homogenous soil with ameliorated properties and 3D models. It has been analysed that the critical length of the column depends upon the footing dimensions.

Observations

The behavior of an isolated column is different from that of a group of columns under distributed load. The critical column length depends largely on the loading area for the group of columns whereas for non-encased column it is for about two times the width of footing and for encased it is slightly higher. Installations of column usually increase the horizontal streses and is accounted for employing high value of earth pressure coefficient.

Moreover, the poisson's ratio for geosynthetic is also taken into account i.e. for a woven geotextile it could be close to 0.

Mounir Bouassida (2009) - The paper illustrates the decrease in displacement and load settelement behaviour of soil reinforced with geosynthetics in which a vibrocompacted group of stone columns are installed. PLAXIS, Finite element approach was performed and Mohr-Coulomb model as linear elastic material was prepared for soil reinforced with geosynthetics. The objective of the study was to analyse the extent of the zone influenced by reinforced stone column (1.1m in diameter).

Observations

Alteration of spacing between columns was significant to quantify stone material to be installed in soft soil and to ensure the improvement. The study observed that a spacing of 3 for a column diameter of 1.1m is most suitable to improve the quantity of material.Due to the installation of column, negligible horizontal displacement is observed at a spacing of 1.71m. This distance smears the influence of reinforced soil model analysed from the triangular pattern which signifies that no overlaping occurs between the respective influenced zones. The predicted decrease in the settlement of improved soil matrix put through a uniform load of 100 KPA is more substantial than that anticipated by constitutive cell model.

Rima Rostami Alkhorshid, Ennio M and George Luis (2018) – The paper demonstrates the skillfull advantage of encased stone columns to imrpove the performance and nature of highyly problematic soft soils i.e high compressibilities and low shear strength existing at the site. Finite element approach was adopted to assess the nature of encased columns with geosynthetics and conventional stone columns beneath an embankment. Parametric analysis is facilitated to calculate the effect of the fibre stiffness, column spacing, stress concentration ratio and column's material friction angle on the behaviour and performance of the columns.

Observations

Out of three analytical methods analysed, it was investigated that the results of Raithel and Kempfert show improved consensus with those of Finite element method in comparision with Zhang and Zhao method and Pulko method. Larger the values of geosynthetic stiffness, smaller the radius variations alongside the column length. However, largers values of stiffness don't affect the depth of maximum value of radius variations. It has been observed that with higher values of stiffness (J) the settlement recorded at the top of column is comparitively less than for lower values of J. Friction angle of column material plays a pivotal role in the behaviour and performance of encased columns. At similar stiffness, larger values of angle of friction aggravates stress concentration ratio and reduces the setllement and tensile forces in the column.

L. Keykhosropur, A. Soroush and R. Imam (2011)- The paper illustrates the three dimensional numerical analyses carried out through ABAQUS for simulating the behaviour of an ordinary group of stone column against encased group of stone column installed in a very soft soil. Parametric analysis were performed to assess the effects of stiffness, elastic modulus, and columns firction angle to account for the behaviour of sets of stone columns. A set of 25 geosynthetic reinforced stone columns, located in a 2m centre to centre spacing with a square pattern and of diameter 80cm is investigated. 10m thickness of soil matrix and length of stone column was used. 500KPA pressure through rigid foundation is applied on the group. CAM Clay model was used to model the soil matrix whereas Drucker Prager model was used to model stone column's material. 8 node finite element mesh was developed for the stone columns, soft soil and rigid foundation. 3 node triangular mesh was developed for geosynthetic encasement. The variation of stiffness is accounted by using the equation J=E*T; T= thickness of the encasement.

Observations:

By increasing the stiffness of the geosynthetic, the stone column becomes stiffer and there is a substantial increase in the performance of geosynthetic encased column group due to the lateral confinement and mobilised hoop tension force provided by it. The load carrying capacity of the geosynthetic encased columns is almost inconsiderate to the change of elastic modulus of the columns material. The settlement and lateral deformation of the column substantially decreases by enhancing the column's friction angle. However, the performance is less responsive to the values of column's friction angle.

Mehdi Mokhberi and Hossein Khademi (2017) - In this paper, the behaviour of stone column with and without geosynthetic is analysed using PLAXIS 2D numerical method of finite element. 90cm diameter with 2m c/c spacing is consdiered for conventional stone column and stone column reinforced with geosynthetics. The number of columns have been acquired by dividing the geotextile area into geotextile perimeter and is analogous to the ring thickness. The length of the column with two different sizes of 10m and 18m is considered. In dynamic state inorder to create the dynamic load it is very much important to develop the absorbent boundaries having the special conditions to define the soil as semi infinite environment. To circumvent the false reflection due to turbulence, the absorbent boundaries are determined on the bottom and right sides of the boundaries. To exert the dynamic load, a computational phase is used with dynamic analysis type and which is a type of displacement with an amplitude of 50cm and frequency of 10Hz.

Observations

It has been observed that increasing the diameter beyond 90cm doesn’t have much effect in reducing the settlement. Moreover, load capacity is not significantly affected by column’s diameter. Length of the column doesn’t have a significant effect on the bearing capacity. Moreover, bearing capacity remains constant and there is no substantial reduction in the settlement. By increasing cohesion there is a significant enhancement in the bearing capacity which can be even more effective by using the layer of geosynthetic. The use of geosynthetic layer leads to less displacement of soil around the column thereby increasing the bearing capacity.It was obeserved that a group of encased columns around 12 in number with a length of 10 meter are more effective in reducing the settlement and can decrease the settlement by about 50% in comparision to the single state. In dyamic state, with the increase in number of columns the bearing capacity in the first cyles of dynamic loading has a substantial increase than the next loading cycles.

Asskar Janalizadeh and Hossein Pichka (2012) - In this study, 2D numerical analysis is performed using finite element approach through PLAXIS 8.2. A comparative analysis is drawn between the single encased column and group of columns encased with geosynthetics to picture out the behaviour and the performance of the soil. Mohr-Coulomb constitutive model was prepared both for the surrounding soil and stone columns. Both the stone column and surrounding soil was considered to undergo same settlement. At the interface of columns encasement and reinforced soft soil, no elements has been used since along with deformation of the column, radial bulging also takes place but no significant shear is possible in this case. 15-node triangular mesh is prepared for all the models for much more accurate results. Elasto-plastic condition is used in the analysis, when there is no need to consider the effect of excess pore pressure with time and large deformation. For boundary condition, the bottom boundary displacement is restricted in both the directions and for vertical boundaries, 2 edges are restricted in horizontal direction and one is free in vertical direction.

Observations:

Because of the formation of pre-straining in enacsement, intial tension force is generated which enhances the confining pressure laterally and enduring capacity of stone columns. In the unit cell, the assumed boundary conditions, decreased the bulging signifacntly during loading which altogether reduces the relevance of using high magnitude of tensile stiffness of encasement in decreasing the displacement.

Yogendra Tandel, Jignesh Patel, Chandresh Solanki and Atul Desai (2016) - In this paper, a parametric study is performed by using finite element analyses through (PLAXIS 3D) to determine and study the behaviour of geosynthetic reinforced stone column. The boundary condition of the model allows only the vertical boundaries to displace in vertical direction whereas not allowing the movement of the bottom boundary both horizontally and vertically. Mohr Coulomb failure criterion was used to model soil matrix and column; as linear elastic material. For study, diameter and length of the columns were taken as 450mm and 5m respectively whereas geosynthetic tensile stiffness were taken as 6 KN/M, 10 KN/M and 23 KN/M.

Observations:

By reinforcing the columns with geosynthetic, the perfomance and nature of ordinary columns are improved and considerable effect can be observed. The tensile stiffness (J) of the geosynthetic plays a pivotal role in enhancing the performance of enhanced stone column. It has been observed that for increasing the enduring capacity, partial length of encasement can be used, which altogether proves out to be highly effective.

R.Ziaie Moayed and M. Hossein Zade (2017) - Most of the encased stone columns are subjected to vertical loading however they may also be subjected to an adequate amount of shear loading. In this paper, three dimensional analyses was performed using finite element approach through ABAQUS. The analyses was demonstrated on a direct shear box of 305mm*305mm*140mm; 50mm diameter, column was incorporated at the centre of shear box. To mitigate the limitation of the laboratory test, the finite element approach using ABAQUS was used for simulation of direct shear test. The soil matrix and stone column were modeled as elastic perfectly plastic material using Mohr-Coulomb failure criterion whereas geosynthetic was modeled as isotropic linearly elastic material as shell element type. It has been observed that shear loading on the encased columns depends upon the overnburden pressure acting on the soil and diameter of the column. In this study, the displacement of the horizontal boundary is confined in all the diretions whereas vertical boundaries are confined laterally and are free to displace in the vertical direction. Friction plays a pivotal role in the interaction between stone column and soil. According to Modified Coulomb's friction theory, the relation between normal pressure and shear force is $r = f \times p$; f= friction coefficient and p = normal pressure in lateral surfaces that changes in every level of soil. Thus, in this analyses, friction coefficient of 0.5 was adopted.

Observations:

Upon encasing the sand with stone columns, shear stresses are observed to increase because of the higher shear resistance and in both the cases of encasement and conventional stone column, with enhancement in normal pressure and diameter, peak stresses increase significantly. Due to geosynthetic encasement, the columns have a stiffer and stronger response and exhibits neglibile strain softening response. While ordinary stone columns show considerable strain softening and softer response. Diameter of the columns play a pivotal role in the performance of encased stone column in shear resistance however it doesn't have significant effect in case of ordinary columns.

Mohammed Y. Fattah, Raid R. AL-Omari and Haiffa A.Ali (2015) – The paper illustrates, geogrid is embedded in the soil as a treatment of expansive soil i.e. swelling and shrinkage characteristics. Geogrid incorporated inside the soil matrix is extended continously in order to control the swell and is oriented in the swell's direction. Bentonite base-Ca and bentonite base-Na samples, varied swell potential of soil are used in addition to kaolinite blend with bentonite. An approach was performed using finite element method through ABAQUS to observe the swelling behaviour of soil and investigate the distribution of pore pressures and stresses around the cells under the foundation (shallow). Drucker Prager model was used to model the soil matrix whereas linear elastic material is used for the analyses of geogrid surrounding the cells. The location where the stresses and deformations change signifcantly, mesh size was taken as fine as possible. The boundary condidtions are assumed to be hinged at each side of soil and at the end to prevent vertical and horizontal displacements. To describe the contact between the deformable surfaces and deformable and solid surface, surface-surface contact is used.

Observations:

It has been observed, as the geocell column's friction angle increases, there is a substantional decreement in the saturation and negative water pressure as sand fill leads to dissipation of pore pressure and accelerate the drainage. When the active depth and plascitity index increase, swelling potential and negative pore water pressure vary between one third of the active depth and at the top of the layer and then consolidates at the end of the active depth due to increase of axial forces. The tensile stiffness have a huge impact on the swelling, saturation and pore pressure, as they decrease slightly with the increase in elastic modulus, which gradually diminishes with the depth.

Sithara Pamangattu Muzammil, Renjitha Mary Varghese and Jerlin Joseph (2018)

In this paper, the performance of geosynthetic encased stone columns under circular oil storage tank and comparitive analysis of ordinary stone columns under the same condition is presented using finite element approach through PLAXIS 3D. The soil matrix of dimension 15m*15m*8m is taken and a layer of stone material is used under storage tanks in order to transfer the loads to the columns. 0.8m diameter stone column was used and placed at 2.4m c/c spacing and was used under the storage tank as per IS 15284 (Part I):2003. The soil matrix used in the approach was modeled with Mohr-Coulomb failure criterion, as an isotropic linearly elastic perfectly plastic. For bottom boundary and for planes of symmetry settlement was restricted

Observations

By enhancing radial distance from middle of storage tank, the columns settlement decreases and due to the variation in vertical stresses and confining pressures offered by the columns, there is substantional incresae in the lateral deformation. Increasing the stiffness of the encasement imparts adequate lateral confirnement and transfers more load from storage tanks to the encased stone columns, reducing the settlement and lateral deformations. To decrease the settlement, optimum length of reinforcement was found to be 6 times the column's diameter. And in order to lower the lateral deformation, the length of reinforcement required was found to be 4 times the diameter. The arrangement in which inner columns are reinforced upto a length of 5 times the column's diameter and outer columns encased upto a length of 3 times the column's diameter, 46% reduction in geosynthetic consumption is found but shows 15% more settlement than fully encased columns. Therefore, depending upon the requirements and site condition, optimum length could be used for a specified project.

Eiman Fathi and Reza Mohtashan (2016) - In this study, a comparative analysis is drawn to investigate the behaviour of ordinary and geosynthetic encased stone column. 2 Dimensional dynamic finite element approach in axisymmetric condition is used using PLAXIS 8.2. According to Mitra (1999) for the evenly distribution of axial stresses on the column, minimum lentgh to diameter ratio of 4.5 is required.
Soft soil is modeled as elasto-plastic behaviour. Geosynthetic encasement as linear elastic without bending tolerable and tensile stiffness equal to 2000 KN/m, 3500 KN/m and 6500 KN/m were used.

Observations:
By increasing the shear strength of the soil matrix and encasing the column with geosynthetic, bearing capacity increases significantly. For the later, it increases by 57%. Economical evolution should be investigated while using different tensile stiffness, though the bearing capacity increases but the efficiency of the encasing doesn't improve.

CHAPTER 4- METHODOLOGY

4.1 Modeling Technique

4.1.1 Overview

As discussed, the objective of the research illustrated in this thesis is to examine load settlement performance and behaviour of the stone column with and without encasement. The approach adopted in the analysis was to conduct computational simulations using finite element analysis program ABAQUS. Specifically, analysis were performed using ABAQUS version 6.41-1, following the directions in ABAQUS version 6.41 Documentations.

4.1.2 Finite Element Method

Finite element approach is a widely used method for civil, mechanical and other relevant engineering applications. It can be divided into two types, numerical and classic method. It basically helps in providing solutions to the most complex structure by solving partial differential equations by dividing the objects into number of elements (non-uniform) that are linked to the nodes.

It defines the functions relative to the dependent variables at the nodes linked with the specific elements.

$[K]_e \{U\}_e = \{F\}_e$

Where,

$[K]_e$ stands for element stiffness matrix, obtained by material, geometry and element property. $\{U\}_e$ stands for element displacement vector, elucidating the state of nodes under force. $\{F\}_e$ stands for element force vector, stating the force implemented on the elements.

The global equation can be solved by applying the boundary condition, and thus strain and stress can be obtained relative to the displacament of nodes liked to the element.

4.1.3 ABAQUS Program

ABAQUS is a combination of finite element programs developed by Hibbitt, Karlsson and Sorensen and presently maintained by SIMULIA Corp. It is a simulation tool, capable of solving a wide range of engineering problems as it contains material libraries efficient in modeling varities of geometry and material constitutive laws. ABAQUS/Standard, ABAQUS/Explicit and ABAQUS/CAE are the three main products of ABAQUS. ABAQUS/CAE provides a graphical room for pre and post-processing. ABAQUS/Explicit is used for temporary dynamic events, like blast and impact problems. ABAQUS/CAE is basically used for solving both linear and nonlinear problems as well as static and dynamic problems.

4.1.4 Structural Modeling in ABAQUS

Every analytical model in ABAQUS incoporates 10 modules such as Part, Property, Assembly, Step, Interaction, Load, Mesh, Job, Visualization and Sketch. It is mandatory to go through most of these modules as described below in order to create and analyse a model.

- Develop the geometrical structure under a domain of parts (Part, Sketch and Mesh Module)
- Develop element sections using (Property Module)
- Define and assign material properties to the sections of elements developed using (Property Module)
- Fabricate sections to develop the complete structure using (Assembly Module, Interaction Module and Mesh Module)
- Define steps and select analysis method using (Step Module)
- Define load and boundary conditions using (Load Module)
- Create Job and submit for analysis using (Job Module)
- Observe the results using (Visualization Module)

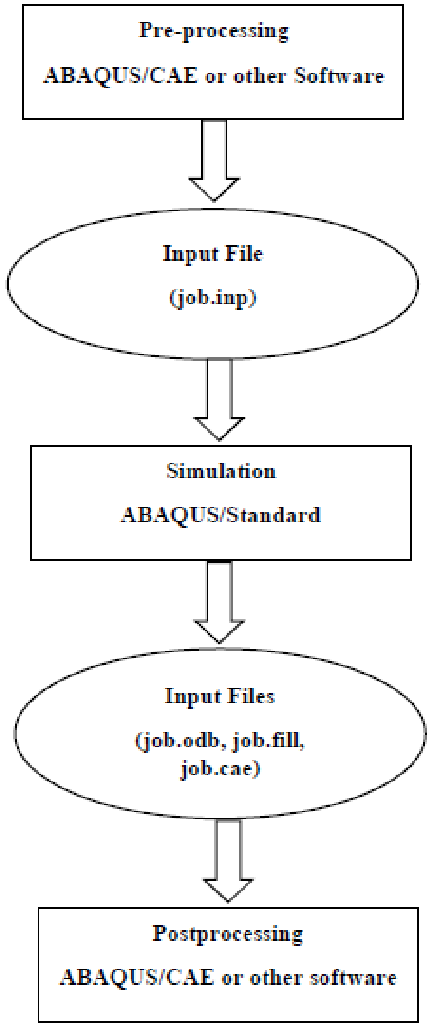

Figure 4: ABAQUS stages of complete simulation

4.2 Approach Established

All the numerical investigation were performed in three-dimensional space using finite element approach (ABAQUS). A clyindrical unit cell (comprising of soil matrix and the stone column) of dimension 450mm*450mm*450mm is used for design and analysis purpose. Two floating stone column of 2 inch diameter i.e. 5.08 cm and depth of 300mm, located in a 200mm centre to centre spacing were incorporated in the soil matrix. As recommended by IS 15284 (Part I): 2003 “To ensure the bulging failure, length of the stone column shall be greater than its critical length i.e. four times its diameter”. Because of this reason, length of the stone column is considered as 300mm. Using 5704 linear hexahedral elements and 1804 linear quadrilateral elements, mesh was prepared.

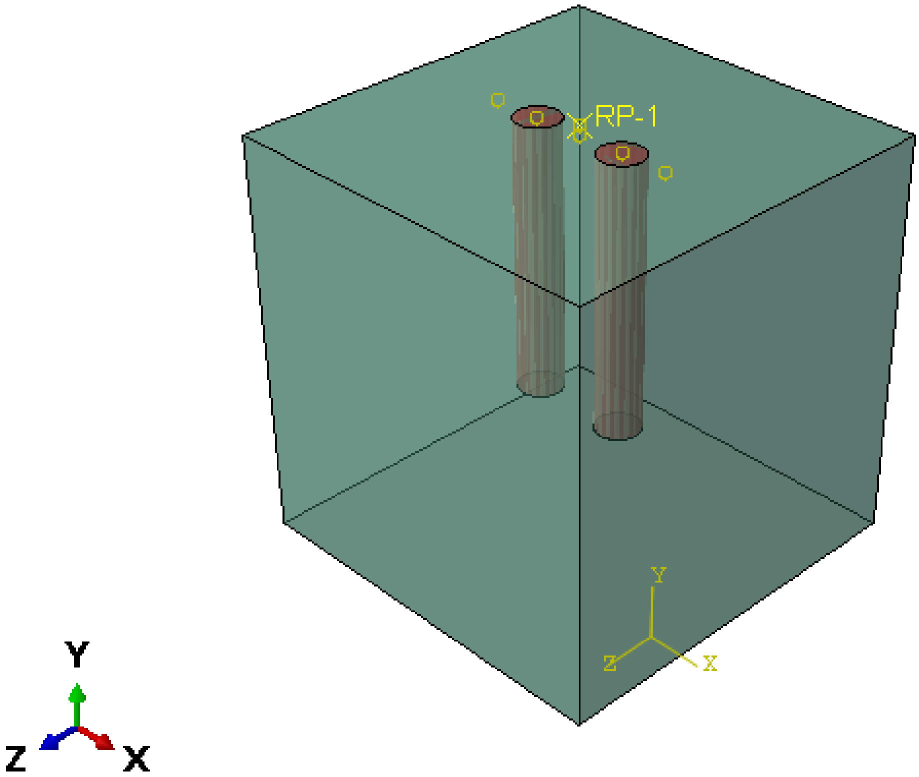

Figure 5: Representation of a 3D Model

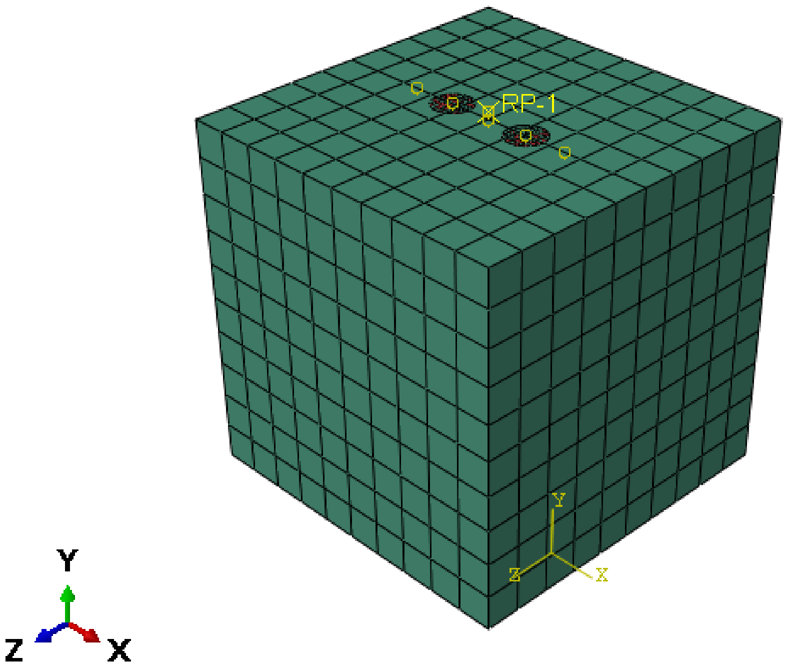

Figure 6: Finite Element Mesh

A 100KN loading was applied on the column and the surrounding soil. The boundary condition allows only vertical deformation. Moreover boundary condition should be carefully examined and chosen to present the entire real domain in terms of stresses and displacements.

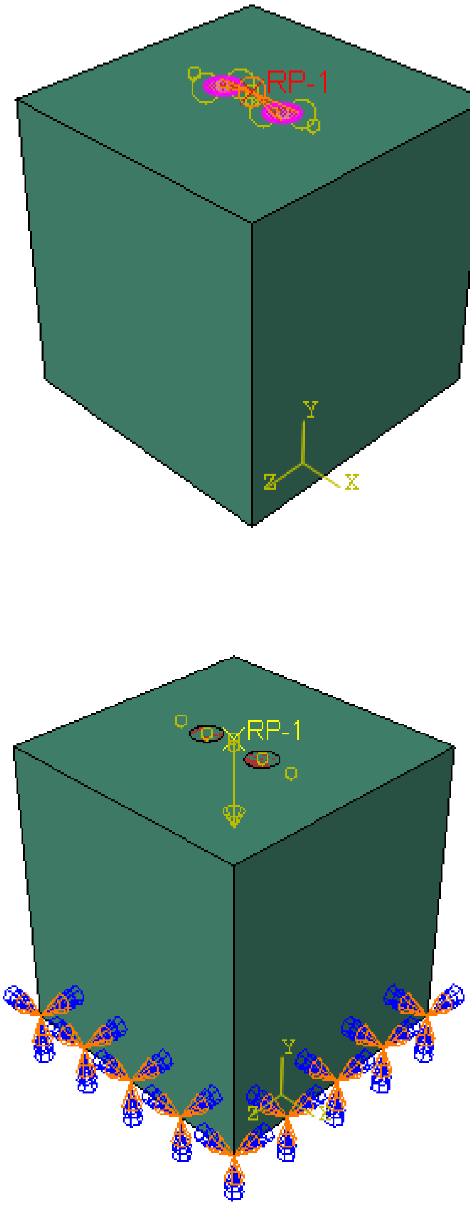

Figure 7: Representation of Coupling and Application of Load

Mohr-Coloumb material was used to model the stone column whereas geosynthetic reinforcement was modeled as linear elastic material using hexahedral and quadrilateral elements and regularized as kinematic elements around the columns. The soil is treated as undrained whereas stone column as drained material.

The material properties adopted in the analysis were established on the geotechnical properties that Malarvizhi and Ilamparuthi (2006) had used in their tests and are depicted in the table below.

Table 1: Material Properties used in numerical analysis

Properties	**Soil (Clay)**	**Stone Column**
Elastic Modulus (KPA)	20000	30000
Poission Ratio (μ)	0.3	0.35
Density (KN/M3)	12	16
Friction Angle (φ)	24	46
Cohesion (KPA)	3.5	0.1
Dilation Angle (Ψ)	0	20
Permeability (m/day)	2.39e-4	1

A typical domain of tensile stiffness (J) of geosynthetic reinforcement according to Alexiew (2005) lies between 2000KN/M and 4000 KN/M, therefore tensile stiffness of 3000 KN/M is used in the approach. 5mm thickness of the geosynthetic layer was kept constant throughtout the analyses, and thus elastic modulus was obtained from the equation (J=E*t), where E stands for modulus of elasticity and t is the thickness of the reinforcement (L. Keykhosropur et al., 2011).

ABAQUS furnishes models (more than one) to simulate the interlinkage between the surfaces. To define the contact between a solid and deformable surface and two deformable surfaces, surface-surface contact is used.

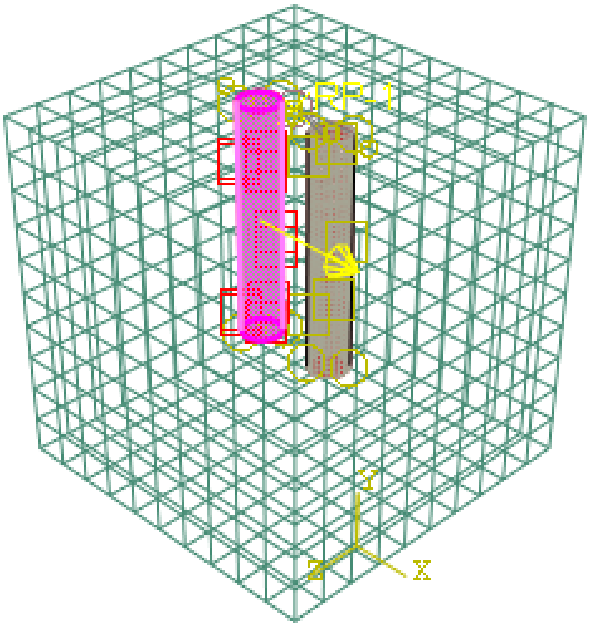

Figure 8: Surface-Surface Contact (Column and Geosynthetic)

The total settlement obtained for 2inch column diameter without reinforcing it with geosynthetic is shown in the figure 9 below.

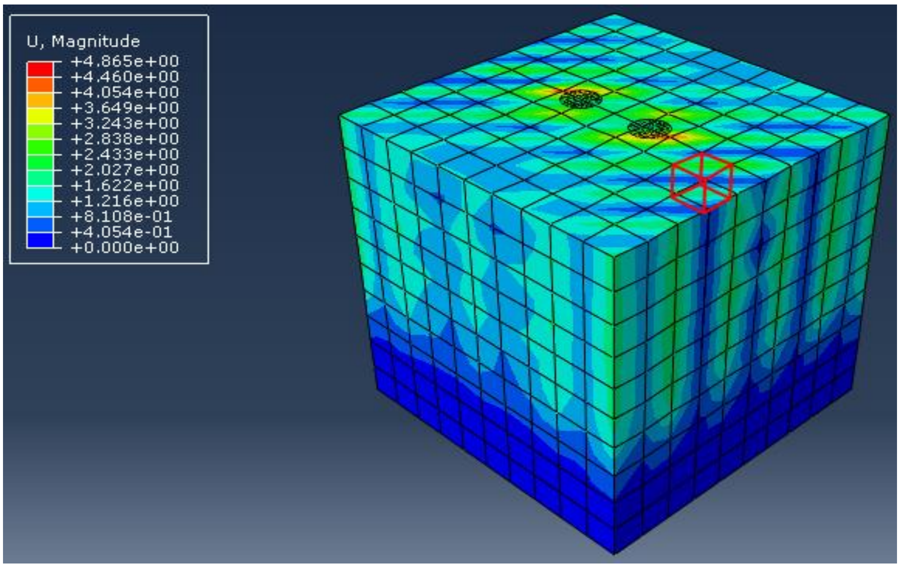

Figure 9: Displacement of 2inch column diameter (without geolayer)

The total settlement of 2inch column diameter with reinforced with geosynthetic of 3000KN/M tensile stiffness is shown in figure 10 below.

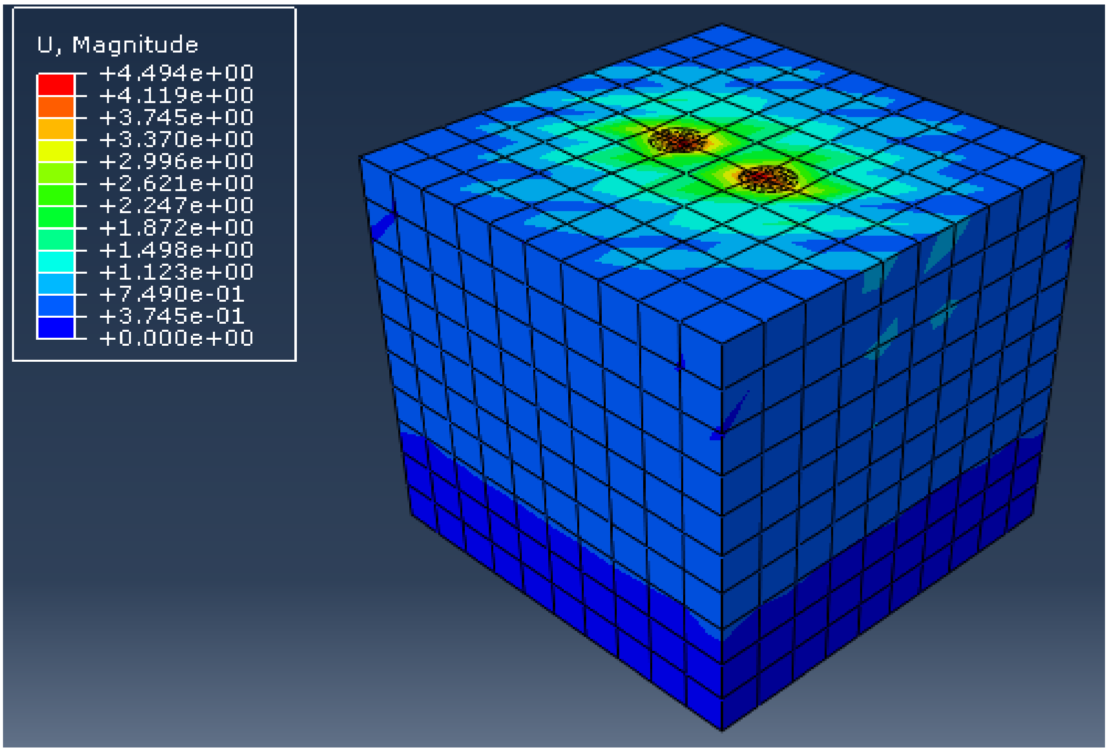

Figure 10: Displacement of 2inch column diameter with geolayer of 3000KN/M stiffness

Detailed parametric analysis were carried out by varying the diameter of the stone column and the stiffness of the geosynthetic encasement.

CHAPTER 5 - RESULTS

A finite element approach using 3D numerical analyses through ABAQUS was performed to understand the behaviour and performance of soft soil treated with an ordinary stone column and soft soil treated with geosynthetic encased stone column. Stone columns acquire the load carrying capacity from the confinement provided by the adjacent soil. With the addition of geosynthetic, additional lateral confinement is offered which altogether improves the load carrying capacity of the soil.

The effect of various important parameters with respect to the load carrying capacity were also assessed using ABAQUS.

5.1 Effect of Geosynthetic Encasement

The figure below represents the load-settlement behaviour of a soft soil, ordinary stone column and geosynthetic encased stone column obtained from 3D finite element approach. From this it can be inferred that settlement of soft soil with stone column and geosynthetic is quite much than the one with encasement.

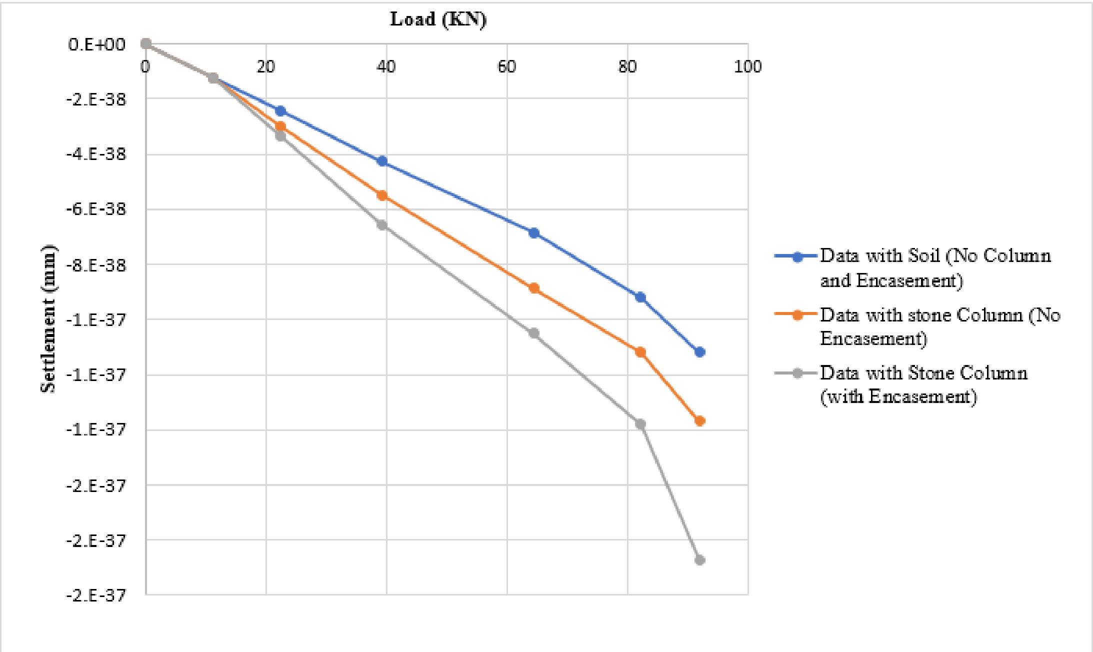

Figure 11: Load-Settlement response of Soft Clay, Ordinary Stone Column and Geosynthetic Encased Stone Column (with J=3000KN/m)

5.2 Influence of Encasement Stiffness

Tensile Stiffness (J) of geosynthetic reinforcement was varied between 3000KN/m – 10000KN/m. The elastic modulus was calculated using the equation J=E*t (L. Keykhosropur et al., 2011); where E= Modulus of Elasticity (MPA) and t= thickness of encasement (mm). Assuming the thickness of encasement to be 5mm.

By enhancing the tensile stiffness of geosynthetic, the columns becomes stiffer and under uniform load, hoop tension force gets mobilized and the lateral confinement offered by it, increases considerably. Thus, the total settlement decreases with the increase in encasement stiffness. The behaviour of the stone column improves considerably with the increase in the tensile stiffness of reinforcement.

From the figure below it can be inferred that load bearing capacity of the column is greatly dependent on the magnitude of reinforcement stiffness.

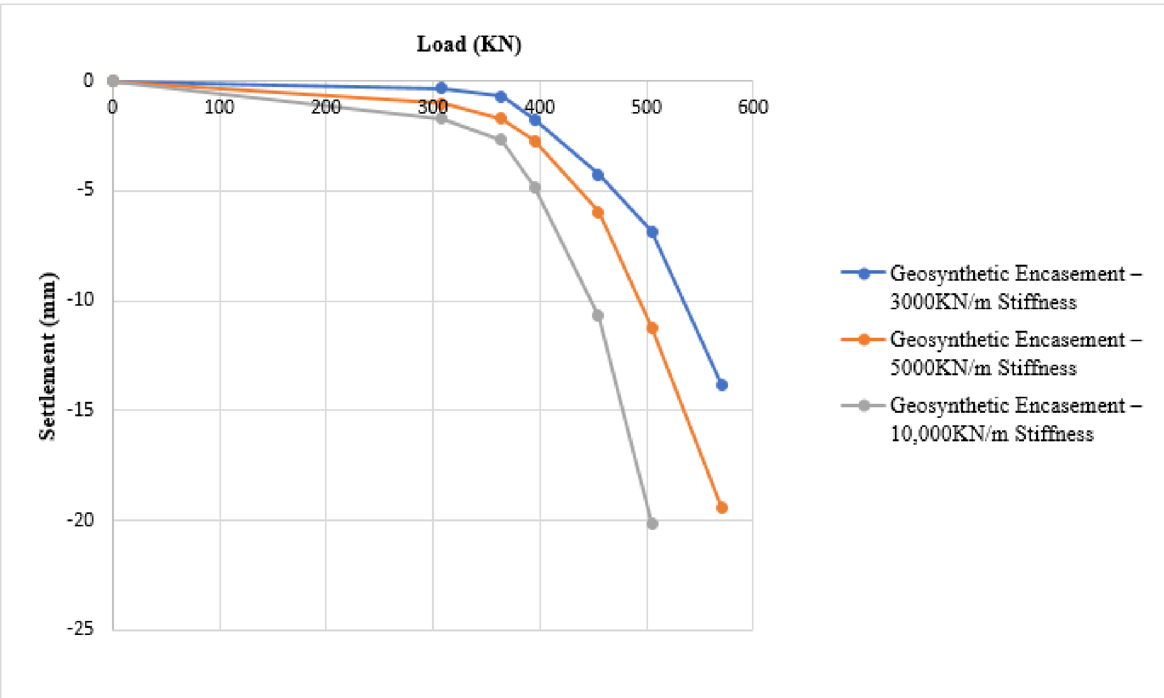

Figure 12: Load–Settlement response of Stone Column with varying Encasement Stiffness (J)

5.3 Influence of Diameter of Stone Column.

The effect of diameter of stone column was observed by performing the analysis with a 2inch and 3inch diameter, the load was appied on the column's surface only. It has been observed that load-settlement response of ordinary stone column is almost same for both the diameter.

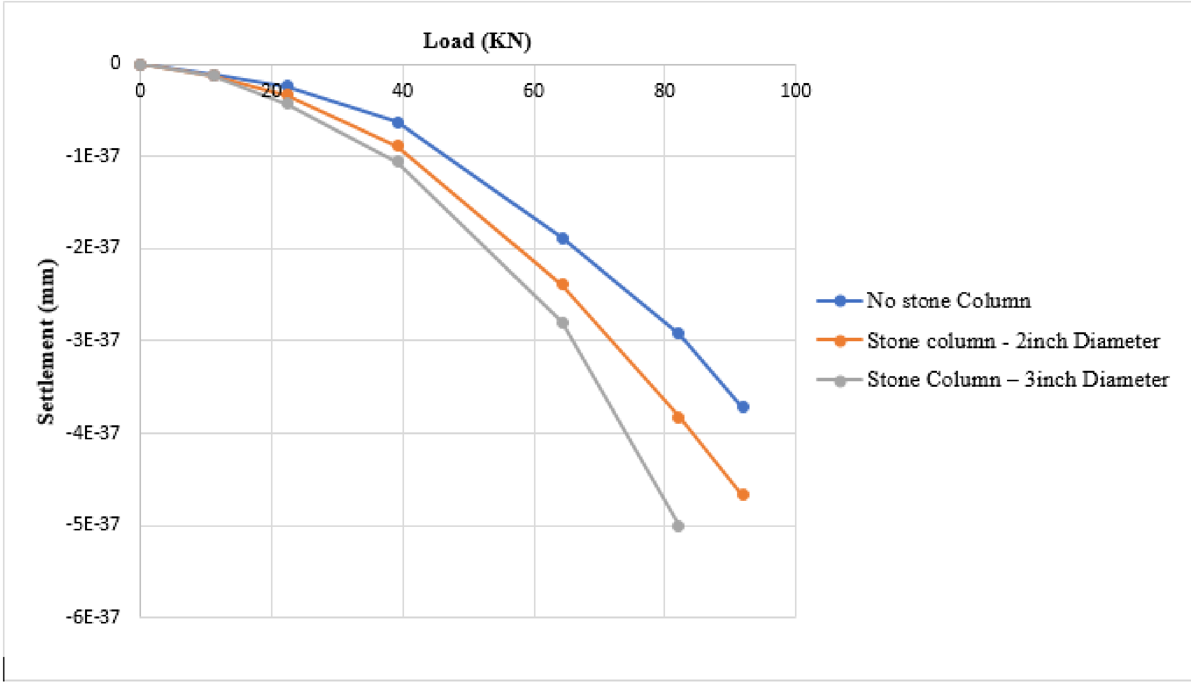

Figure 13: Load-Settlement response on varying diameter of Stone Column

CHAPTER 6 – CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

The present study illustrates the finite element analysis performed to study the behaviour and behaviour of stone columns reinforced with geosynthetics. The result from the parametric study is demonstrated to account the effect of confinement and the process of improvement in load bearing capacity due to reinforcement. The following conclusions are made based on the results derived from the study:

- By all-round encasement of stone column with geosynthetic, the load carrying capacity and stiffness of the stone column can be enhanced. It is observed, there is an improvement of 66.96% in load-settlement response of the soft soil incorporated with stone column and reinforced with geosynthetics.
- The tensile stiffness and modulus of elasticity of geosynthetic reinforcement plays a pivotal role in improving the load bearing capacity and tensile stiffness of reinforced columns. With increase in tensile stiffness, the lateral confining pressures are developed in the stone columns which altogether reduces the settlement. It is found, there is an improvement of 45.59% in load-settlement response of stone column encased with 5000KN/m and 10000KN/m tensile stiffness.
- According to the various studies, the behaviour of reinforced stone columns of smaller diameter is far more superior to that of larger one due to mobilisation of higher confining stresses in larger diameter column. However, in this study it is observed that there isn't much of a difference in the load-settelement response of ordinary stone column of varying diameters.

6.2 Future Scope of Work

- The performance and behaviour of group of stone columns with and without encasement using finite element approach can be assessed.
- Various parametric studies such as influence of encasement length, length of column, hoop tension force in geosynthetic encasement and horizontal circular reinforcement in encased stone column can be performed.

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