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Numerical Analysis of the Reinforced Stone Column by Geosynthetic on Stability of Embankment

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Abstract **-** One of the best improvement methods of soft soils, especially in order to increase the stability of embankments in highway, big way, rail way and soil structures is using of stone column. The stone column into soft soils improves strengthen parameters against settlement and high displacements with increasing the bearing capacity, stability and flexibility of the embankment. Also using of Geosynthetic as reinforcement can reduce destructive displacements and increases stability of the embankment which constructed over soft soil. Therefore, in this study, in addition to providing the results of numerical experiments, the influence of a reinforced stone column by Geosynthetic in compare to when an ordinary stone column is used, has been investigated. The two-dimensional dynamic finite element program (PLAXIS8.2) is used to carry out all the numerical experiments. In this study, for achieving to optimum design, with analysing of the Primary Components such as Geometric parameters, stiffness of materials, stiffness of reinforcements and shear strength of the soft soil, some useful and technical comments have been presented.

Keywords**:** Geosynthetic, Numerical Models, Plaxis, Soil Improvement, Stone Column.

1. Introduction

In recent decades and in the following developments in Geotechnical engineering, loose soil improvement or strengthening of land has become as one of the new and important topics in relate to soil improvement. In general, strengthening of soil in order to improve the soil shear strength, could result in increasing the bearing capacity, settlement reduction, increasing resistance of embankments and soil structures, against liquefaction, sliding, shrinkage and swelling. Overly, the improvement takes place in soft cohesive soils with a low undrained resistance, ($Cu< 0.25\ kg/cm^2$), and loose sand with a low standard penetration test result, i.e., $N<10$. There are many methods for improving and strengthening of soils, but the choice of method depends on type of the soil. For granular soils, some methods such as Increasing surface density, Dynamic compaction, Vibratory compaction, Dense pile and also for cohesive soils some methods such as chemical methods, pre-loaded or pre-loaded with drainage are used, while other methods such as replacing poor soil with suitable soil, soil stabilization, and also, using of micro piles and stone columns can be used for this purpose. The most important cases for utilizing stone columns (Barksdale & Bachus, 1983) [1] are: (a) Improving slopes stability of both embankment and natural slopes, (b) Increasing the bearing capacity of shallow foundations constructed on soft soils, (c) Reducing total and differential settlements, (d) Decreasing the liquefaction potential of sandy soils. The cost of stone columns for reinforcing and improving of soil is easier and cheaper than other methods such as geotextile, grouting, and compaction [1].

The idea of using stone columns to improve clay soils, first came about 1940 and since then became the issue in many researches, especially around 1960 stone column were used to improve the properties of soil in Europe. Stone columns are normally constructed in multiple rows, depending on the soil properties. In 1978, for the first time in Japan, the stone column, were used to reduce the risk of liquefaction. Greenwood (1970) [3] Hughes & Withers (1974) [4], Aboshi et al. [7] (1979), have studied the issue, based on reinforcing the soil foundation with stone columns, and some solutions for estimating bearing capacity and settlement, have been suggested. According to studies, all models were made of gravel or rubble which including columns that built with diameter of 0.6 to 1.2 m and height of 4 to 15 m, and, finally, has created a support system in the vertical direction for foundation or upper embankment. It is found that stone column in addition to tolerate the horizontal and inclined stresses can also acts as a radial drainage system.

Construction of stone column with a depth less than 6 m would be far practical and economical, but the columns with depth greater than 15m in comparison to the conventional deep foundation (likes piles), it has been proved in projects, will not be efficient, in addition, the implementation of deep stone columns will bring some specific operational requirements in order to provide stable supply of excavation and providing appropriate stone column density in every project. Stone column increases the shear strength and safety against instability, improves the stiffness and reduce soil settlement, lowering the pore pressure and danger of liquefaction, and also accelerate the consolidation of drained soil and became as one of the most useful methods of soil improvement, in regards to construction of infrastructure, roads, embankment, highways, railways and similar cases. Another method of improvement and reinforcement, which todays has become increasingly popular, is reinforcing of soil with tensile elements that are placed in horizontal, vertical and inclined direction, and with advances in polymer engineering and production of new materials, Geosynthetic as an important material has been considered for soil reinforcement. Van Impe & Silence (1986) [5] were the first ones that raised the idea of stone column which is encased with Geosynthetic, then, some studies by other researchers to improve the properties of soft soils by reinforced stone column have been done, such as Li & Rowe (2008) [11], Chen et al. (2008) [10] ‹Bergado & Teerawattanasuk (2008) [9] ‹Liu et al. (2008) [8] and finally, some solutions to increase the bearing capacity of stone columns reinforced with Geosynthetic have proposed. In this regard, Fathi et al (2015) [16], have shown that increasing of Geosynthetic stiffness, resulted to increase in bearing and stability in soil structures.

K. Deb & S. R. Mohapatra (2015) [17], have studied on the behaviour of stone column supported by geosynthetic-reinforced in embankments and they observed from parametric studies that modular ratio or stiffness of the stone columns, space to diameter ratio, height of the embankment, depth of soft soil and stiffness of the geosynthetic reinforcement significantly affect the behaviour of reinforced stone column which supported embankments that resting on soft soil. Murugesan & Rajagapal (2006) [12], stated that the bearing of reinforced stone column in comparison to conventional stone column, has less dependence on the surrounding soil's resistance. Stone column method still known more as an experimental method and there is not a scientific framework in this regard and while the stone column technique widely has been known, but still little research on this method is done, so looks essential the need for further research to predict the exact effect of mechanical properties of soil in various conditions on reinforcing with this method.

2. Numerical Modelling

According to the theories put forward to model the stone columns, in this study for simplifying and reducing the volume of calculations in two-dimensional model the theory of unite cell is used. Base on this theory, the model with symmetry axial orientation condition is determined [13].

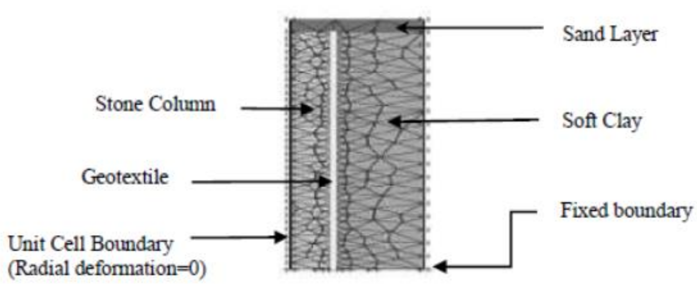

Fig. 1: Mesh and boundary condition in numerical model of stone column surrounded by geotextile.

Numerical modelling of two-dimensional finite element method in axisymmetric condition has been used. In this model the diameter of stone column is 1 m and the diameter of unite cell, according to A) Triangular pattern of the columns and B) considering centre to centre distance of columns 2,3,4, times the diameter of stone column i.e. S/d=2,3,4, has been determined. The impact area of the stone columns at the triangle pattern is considered as circles with a diameter equal to 1.05S.

According to Mitra & Chottopadhyay (1999) Theory [14] in order to full spreading of axial stress on the column, required that minimum ratio of length to diameter of the stone column, be equal to 4.5. Because the diameter of encased stone columns between 0.6 to 1.2 m, and the maximum length is 15 m, the length of stone column is equal to 10 m. Due to the fact that all columns can be assumed to load uniformly, displacement and deformation of the components in border area with neighbouring cells, is equal to zero.

As in figure 1 is observed, totally four categories of materials were used which include: 1. Due to the efficiency of the stone column in fine-grained soils, soft clay as existed weak ground and with Elasto-Plastic behaviour is considered, material properties are shown in table 1. Soft clay soil's shear strength is affected by soil moisture, as by increasing of moisture content the shear strength decreases, so in this study in order to determine the effect of shear strength on the behaviour of encased stone columns several soft clay soils with different shear strengths 5, 10, 30 Kpa, have been used [14]. 2. Rubble for stone columns, with assuming Elasto-Plastic behaviour and the specifications set forth in table 2, is considered. For considering the effect of internal friction angle on stone column behaviour, stone materials with internal friction angle 40 degree, is used [14]. 3. For creating a uniform distribution of stress on stone columns and making a vaulted form in them, 2 or 3 layers of 15cm of fine-grained material is used. Thus, with the aim to better simulation in the finite element model, a layer of sand with thickness of 50 cm, as backfill on top of stone columns and soft soil, is modelled. Also, sandy material modelled Elasto-Plastic and its properties are in the table below [15]:

Table 1: Model Clay soil properties (Soft Soil).

Clay Type	γ_{dry}	γ	E	ν	Cu	φ
	kN/ m^3	kN/ m^3	kPa		kPa	Degree
Clay 5	13.3	18.20	1900	0.45	5	0
Clay 10	14	18.65	2500	0.45	10	0
Clay 30	15.56	19.45	5500	0.45	30	0

Table 2: Rock material properties in Stone column.

Stone Type	γ_{dry}	γ	E	ν	C	φ	ϕ
	kN/ m^3	kN/ m^3	kPa		kPa	Degree	Degree
	16.55	19.05	55000	0.3	0	4 0	10

Table 3: Sandy soil properties.

Embankment (Sand)	γ_{dry}	γ	E	ν	C	φ	ψ
	kN/ m^3	kN/ m^3	kPa		kPa	Degree	Degree
	16	20	40000	0.33	5	38	0

Due to the different size between soil grains and columns, Geotextiles is considered as confining for columns while in addition to confining, has a separator role. 4. According to the Geosynthetic materials available on the market and study the effect of the model which made of various Geotextile materials as well, Geosynthetics with different tensile strengths: 2000, 3500 and 6500 KN/m were selected. These materials as linear elastic without bending tolerable (tensile element only) are assumed [2].

3. Validation of the Numerical Model

Narasimho et al. (1992) [6] made an experimental model (Axisymmetric model) with height of 350m and diameter of 650m of soil, and with a single stone column with a height of 225mm and diameter of 50mm (Figure 2), also, up to failure status loading by a rigid sheet with a diameter of 100mm is applied. According to the previous experimental model by Narasimho and the results of numerical model in this study, Load-Settlement curves are shown in figure 2, and the same results indicates the accuracy of the numerical model in this study. Characteristics of the materials which used by Narasimho et al. (1992) [6] is in table 4.

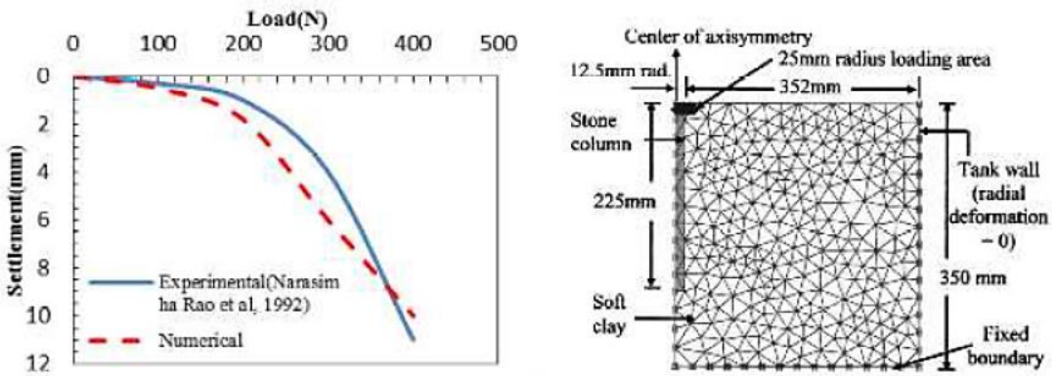

Fig. 2: Comparison of experimental model Narasimho et al. (1992) with physical model. A) Geometry, mesh and dimensions B) Compare of results between experimental and numerical model.

Table 4: The soil properties which used by Narasimho et al. (1992).

Material	E	ν	C	φ
	kPa		kPa	Degree
Clay	4000	0.45	20	0
Stone	45000	0.3	0	38

4. Results of Numerical Modelling

4.1. Shear strength influence of the soft soil

With regard to confirmation of the accuracy of numerical model, the influence of main basic parameters on behaviour of reinforced stone column with Geosynthetic is studied. Figure 3 is a diagram of load-settlement stone column with 1 m of diameter and a height of 10 m, for centre to centre of columns S=3d, and in Geotextile EA=3500 KN/m. In the ordinary stone columns (OSC), which surrounded by soft soil, undrained shear strengths (Cu) were 5, 10, 30 Kpa, and also Ultimate Bearing Capacity (q_u) were equal to 74, 185 and 485 Kpa respectively, But in Geosynthetic encased column (GEC), due to existence of geosynthetic casing which largely prevents lateral deformation and rupture in the stone column, approximately up to 1000 Kpa pressure no impact of failure was found. Ambily & Gandhi (2007) [14]. According to the figure 3 in both condition; 1) OSC or 2) GEC, with increasing of undrained shear strength of soft soil which is around the column, the bearing capacity increases.

The performance of encased stone column can be measured with the bearing capacity proportion;

$$\mathrm{BCR} = \frac{(\mathrm{qu})\mathrm{GEC}}{(\mathrm{qu})\mathrm{OSC}} \tag{1}$$

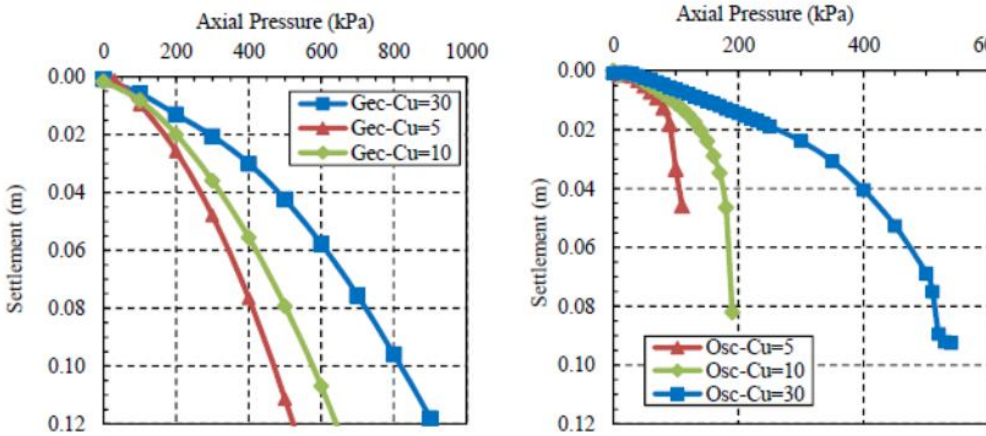

Fig. 3: Influence of undrained shear strength (Cu) on Load-Settlement diagram in soft clay soil.

Which BCR is bearing ratio, $(q_u)_{GEC}$ ultimate bearing capacity of the encased column and $(q_u)_{OSC}$ ultimate bearing capacity of ordinary column. As seen, figure 4, shown diagram of BCR changes to undrained shear strength of soil. It indicates that the significance of this method when soil is loose is more and with increasing the undrained shear strength of soil, the efficiency decreases, because with improving of stiffness and soil resistance, the materials practically prevents of deformation in stone column, and the need for reinforcement around the stone columns is elevated. However, the encased condition increases the bearing capacity for at least 57%.

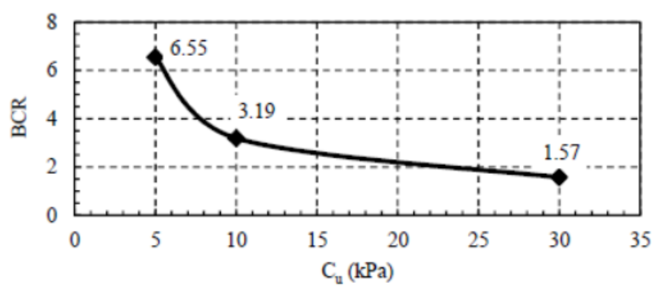

Fig. 4: Diagram of bearing capacity ratio (BCR) to undrained shear strength (Cu).

4.2. Effect of centre to centre distance to the diameter of stone column (S/d)

To study the simultaneous effect of centre to centre distance (S) and diameter of stone column (d), three different values; 2, 3, 4 for S/d is considered. Stone columns with the diameter of 1 m and 10 m height, undrained shear strength of soft soil Cu=10 Kpa, and tensile strength in encased stone column of geotextile; EA= 3500 KN/m. Axial pressure to settlement diagram is shown in figure 5. Ultimate bearing capacity when S/d is 2, 3 and 4 is equal to 195, 185 and 180 Kpa for the ordinary case, however in encased column, the failure does not occurred, and as is clear the ultimate bearing capacity of the columns for when S/d= 2, 3 and 4 it shows impressive increasing and they were equal to 560, 560 and 460 Kpa, respectively. Also, it has implied that in the stone column with increasing of S/d, relatively, the bearing capacity has a little reducing.

4.3. Tensile stiffness impact of Geosynthetic

Load-Settlement diagram of the encased stone column is compared with ordinary stone column (OSC) in Figure 6, Undrained shear strength of soft soil Cu= 10 Kpa, (S=3d), Ultimate bearing capacity for OSC is about 185 Kpa. The Ultimate bearing capacity amounts for (GEC) are 2.63, 3.15 and 3.68 times than OSC when tensile stiffness of geosynthetic is 2000, 3500 and 6500 KN/m, So, by increasing of tensile strength in Geosynthetic the bearing capacity increases as figure 7, but the effectiveness of reinforcement does not increase as well as the stiffness increased, for instance in this model while stiffness became more than three times, the efficiency improved less than 38%.

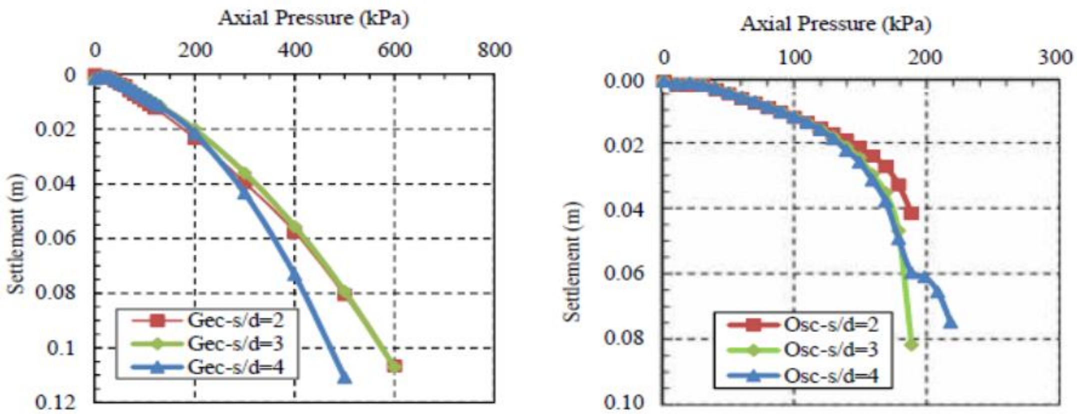

Fig. 5: Diagram of Load-Settlement of stone columns for different amount of S/d, A) Ordinary column B) Encased column.

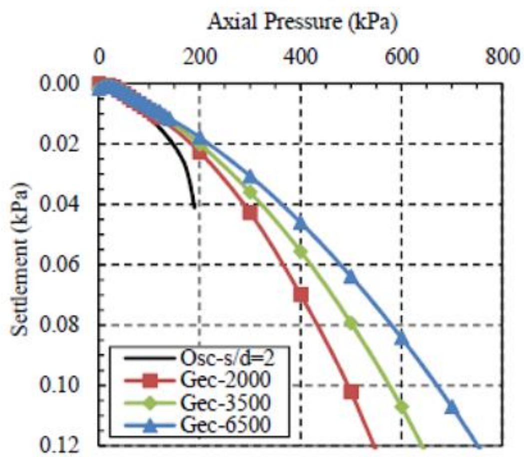

Fig. 6: Diagram of the effect of geosynthetic stiffness on ordinary and encased stone column.

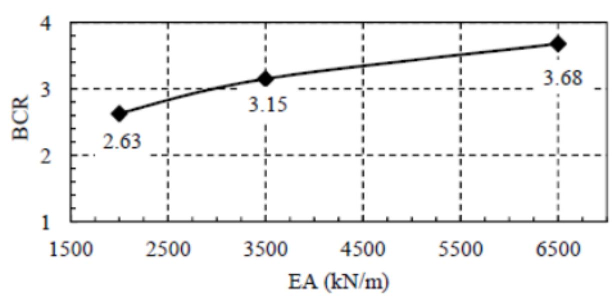

Fig. 7: Diagram of bearing capacity ratio (BCR) to tensile stiffness of geosynthetic.

5. Conclusion

In this study, the numerical models of ordinary stone column and encased stone column with Geosynthetic are made with using the finite element method, and after validation, the effect of soft soil resistance, centre to centre distance of columns to column's diameter, and tensile stiffness of Geotextiles is analysed, and the results show that:

1. With increasing the shear strength of surrounding soft soil for both ordinary stone column and encased stone column, the bearing capacity increases.

2. Encasing of stone column with geosynthetic prevents deformation and rupturing and cause to increasing the bearing capacity, the significance of this method when soil is loose is more, and the encased condition increases the bearing capacity for at least 57%.
3. With increasing the strength of surrounding soil, soil resistance against lateral deformation improved and requiring to reinforcement with columns greatly reduced. So the economical evolution for needing the stone columns in each project according to soft soil characteristics should done.
4. Behaviour of Stone column surrounded by geosynthetic is similar to conventional columns as with increasing the ratio between distances to diameter of the stone columns, the bearing capacity will reduce but the rate of decline for range of S/d equal 2 to 4, is not significant.
5. By improving tensile stiffness of geosynthetic, the bearing capacity will increase but the efficiency of encasing does not improve as the stiffness increases, thus with considering all possible choices the economical evolution should be determined.

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