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GEO REINFORCED STONE COLUMN TECHNIQUE FOR SOFT CLAY SOIL IMPROVEMENT-A REVIEW

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ABSTRACT

A very fast development of Infrastructures sector i.e. construction of mega structures like Express highways and railways and tunnels, bridges and tall buildings in all parts of the world, the availability of suitable ground for the construction of civil engineering mega structures becomes a challenge for today's geotechnical engineers. There is various ground improvement techniques are present to strengthen the weak and soft soils based on the type of application. One of the most extremely used ground improvement method is a Stone column technique for soft clay soils. Where the bearing capacity of soft soils can be improved and also the stability of structure and reduces the settlement issues up to some permissible limits. This method was adopted in European countries since 1950s. But now days, the utilization of geo synthetic materials are very popular because of their various multi functions based on the applications like reinforcement, separation, filtration and confinement, containment etc. This article presents a review of previous experimental studies on the performance of unreinforced soft soils improvement the bearing capacity with reinforced sand bed over stone column. The paper explores the new ideas where more research can be done by using geo reinforced stone column technique to improve the bearing capacity and stiffness of soft clay soils.

KEYWORDS: Ground Improvement, geo synthetic, stone column, soft soil, reinforced sand

I. INTRODUCTION

Stone column is one of the most commonly used soil improvement technique. Which has been utilized worldwide to increase the bearing capacity of soft soils and reduce the settlement of super structures constructed over it, improve slope stability, reduces seismic subsidence also reduce lateral spreading and liquefaction potential etc. Many researchers have been carried out to study the behavior of stone column – reinforced ground over the past three decades. Conventional stone columns are typically used to improve the engineering properties of soft soils for the support of lightly and moderately loaded structures such as a motorway embankments and large diameter storage tanks. When the stone columns are installed in very soft clays, they may not derive significant load capacity due to the low lateral confinement. McKenna et. al.(1975) reported that where the stone column was not restrained by the surrounding soft clay which lead to excessive bulging and also the soft clay squeezed into voids of the aggregate. In such situations, the stone column itself may need to be provided with additional confinement for its improved performance.

A number of methods are available to improve the load carrying capacity and decreases the settlement issues of soft soils. Such as Stone columns (Greenwood,1970; Hughes et.al., 1975), Lime treatment(Rajasekaran and Rao, 2002) soil cement columns(Rampello and Callisto,2003)vacuum pre-consolidation (Indraratna et. al.,2004) pre-consolidation using pre-fabricated vertical drains (Shen et. al.2005) etc. From all these techniques, the stone column method is a preferred because it gives the benefit of reduced settlements and increasing the consolidation process due to reduction in flow path lengths. The main advantage of this method is the easy and simple in construction (Murugesan and Rajgopal, 2006). Further Development in the stone column technique is reinforcing the column using either horizontal layers of reinforcement (Sharma.R.S. et.

al.2004) or encasing the individual stone column by geo synthetic (Raithel and Kempfert,2000; Raithel et. al. 2002) over the full or partial height of the column. The geo synthetic encasement will increase the load carrying capacity of stone columns by many folds due to the additional confinement from the geo synthetic. The geo synthetic encasement also prevents the lateral squeezing of stones when the stone column is installed in extremely soft soils, leading to minimal loss of stones and quicker installation.

The granular bed can be further reinforced with geogrid to enhance the load carrying capacity and reduce the settlement of the stone column –improved soft clay. Han and Gabr (2002) performed a numerical analysis of geosynthetic –reinforced and pile –supported earth plat forms over soft soil. Based on lumped parameter modeling approach, models have been developed for single layer (Deb et. al., 2007) and multilayer (Deb et. al., 2008) geo synthetic–reinforced granular bed resting on stone column improved soft soil. Malarvizhi and Ilamparuthi (2004) reported that the improved performance of geo synthetic –encased stone columns based on small –scale laboratory tests on end bearing as well as floating columns. Raithel and Kempfert (2000) and Raithel et. al. (2002) studied the performance of geo synthetic –encased sand columns through numerical and analytical models. Aydat and Hanna (2005) performed experimental investigation on the load carrying capacity of a stone column increases with an increase in the stiffness of the geo fabric material used to encapsulate the sand column.

Stone columns in compressive load fail in different modes such as bulging Huges and Withers (1974), Huges et.al(1976) general shear failure Madhav and Vitkar(1978) and sliding failure Aboshi et.al (1979). A long column having length more than its critical length i.e about 4 times the diameter of the column fails by bulging. McKelvey et.al (2004) has carried out experimental studies on a group of five stone columns and reported that the central column deformed or bulged uniformly, whereas the edge columns bulged away from the neighboring columns. The unit cell concept has also been used by Abhijit and Das (2000),Goughnour(1983) and Sathish et.al (1997).Alamgir et.al(1996) proposed an elastic approach to predict the load sharing and resulting settlement of ground improved by stone columns assuming free strain condition. Shahu.et.al (2000) find out the effects of a granular mat over the improved ground on its over response within the framework of equal strain theory and unit cell concept

Based on various literature review studies on the behavior of stone columns have been studied. The research studies have been conducted on different parameters like

- Behavior of stone columns with geo grid encasements.
- Behavior of stone column in various types of soils.

Table 1. Shows some relevant latest research literatures

REFERENCES	EXPERIMENTAL DETAILS	REMARKS
Mahmoud Ghazavi et.al (2018)	• Model test tank Dimensions Length - 1200 mm Width -1200 mm Depth -900 mm • Classification of soil :CL • Stone column Data:	• The ultimate bearing capacity stiffness of ordinary stone columns has increased by the use of horizontal reinforcing geo synthetic materials.
	Diameter : 60,80,100 mm Depth :300,400,500 mm • Geo synthetic used: Non woven Geotextile, Biaxial geogrid etc • Internal reinforcements: Vertical encasement Horizontal reinforcement	.The horizontally reinforced layers placed at spacing of 0,25D of stone column has bearing capacity is 30% greater than the vertically encased stone column bearing capacity.

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Prasenjit Debnath and Ashim Kanti Dey (2017)	Model test tank Dimensions Length –1000 mm Width -1000 mm Depth -1000 mm Classification of soil :CL Stone column Data: Diameter :50 mm Depth : 300 mm Spacing: 125 mm c/c Geogrid , Geo textile etc. Internal reinforcements: Geogrids are used in layers Geotextiles are used as encasement of stone columns. Geo synthetic used: Biaxial	The bearing capacity of the soft clay soil was increased with geo reinforced sand bed as compare with ordinary stone columns without reinforced sand bed and also found that the optimum thickness of unreinforced sand bed and geo rein forced sand bed can be taken equal to 0.2 times and 0.15 times the diameter of the footing. • The reduction in bulging effect and increased in bulging depth with the provision of geo rein-forced sand bed.
Mahmoud Ghazavi and Javad Nazari Afshar (2013)	Model rigid footing Data: Rigid Steel plate Diameter : 200 mm Thickness : 15mm • Model test tank Dimensions Length -1200 mm Width -1200 mm Depth -900 mm • Classification of soil :CL • Stone column Data: Diameter : 60,80,100 mm Depth : mm • Geo synthetic used: Non woven poly propylene geotextiles • Internal reinforcements: Encasement of geotextiles • Model rigid footing Data: Rigid Steel circular plate Diameter : 200 mm • Thickness : 30 mm	• The optimum length of a group of floating with geo reinforced sand bed is six times the diameter of the stone column. The optimum depth of encasement of the group floating stone column is three times the diameter of the column. • The ultimate load carried by soft soil increases by using ordinary stone columns. The ultimate load and stiffness of the treated soil can be further increase by use of vertical encased stone column reinforcing material. The lateral bulging amount decreases in vertical encased stone columns with ordinary stone columns due to additional lateral confinement provided by geo synthetic materials. With increasing the length and strength of reinforcing encasement, the ultimate capacity and stiffness of stone columns increases. The bulging failure usually occurs at a depth of D to 2D from the stone column top.

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Lakshmikant Yadu and Tripathi .R.K (2013)	• Model test tank Dimensions Length -1820 mm Width - 305 mm Depth -914 mm • Classification of soil :CL • Model rigid footing Data: Length : 305mm Width : 76.2 mm Thickness : 25.4mm • Geo synthetic used: Bi axial polyester Geogrid • Internal reinforcements: Horizontal layers of geo grid, Granulated Blast furnace slag.	• Reinforced GBS bed overlay on soft soil bed improves load bearing capacity & decreases the settlement of the soft subgrade soil bed. Geogrid reinforced GBS of ratio to width of tank to the width of footing at two increases the settlement reduction ratio as 84% at ultimate bearing capacity of soil. Based on the bearing capacity ratio value and economy in the field application the of width of the tank to width of footing of four is considered as effective length of geogrid.
Koushik Deb.et.al (2010)	• Model test tank Dimensions Length -525 mm Width -525 mm Depth -400mmm • Classification of soil :CL • Stone column Data: Diameter : 50 mm, Depth : 300 mm • Geo synthetic used: Geo grid • Internal reinforcements: Geo grid used as a layer • Model rigid footing Data: Rigid Steel circular plate • Diameter : 100 mm, Thickness :12.5mm	The presence of stone columns in soft clay improves the load carrying capacity and decreases the settlement of the soft clay. The placement of sand bed further increases the load carrying capacity and decreases the settlement of the stone column improved soil. • The inclusion of geo grid as reinforcing element in the sand bed significantly improves the load carrying capacity and reduces the settlement of the soil. The optimum thickness of unreinforced sand bed placed over the stone column improved soft clay is 1.7 times the optimum thickness of the geo grid reinforced sand bed. The optimum thickness of un reinforced and geogrid reinforced sand bed is 0.5 and 0.3 times the diameter of the footing.

II. CONSTRUCTION METHODS OF STONE COLUMNS

Construction of stone columns can be done by the following two methods

- Vibro Compaction Method
- Vibro Replacement method

The first method is used for the densification of soiI whose particle size is varying from 0.02 mm to 80 mm. The main aim of this method is densification of soil where the density would be increases and significantly improve the bearing capacity of the treated soil. This method is only suitable for coarse grained soils e.g. .sand and gravel

The second method is used for the fine grained soils whose particle size is less than 0.02 mm. To overcome the problem of vibro compaction this method was introduced. In this method, the density is not enhanced by

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vibrations. There are different types of installations methods of stone columns are: 1. Dry methods 2.Wet methods The dry method is sub divided into two methods a) Dry Top feed method b) Dry Bottom feed method.

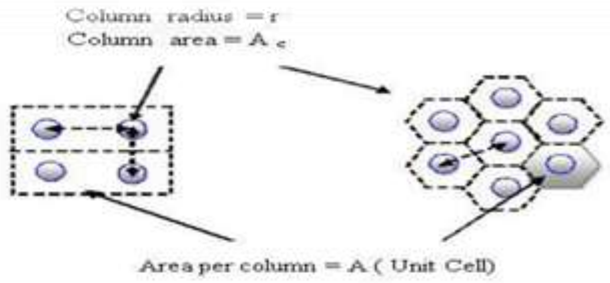
III. APPLICATIONS OF STONE COLUMNS

- Increases the soil bearing capacity and shear strength of soils
- It reduces the settlements in soils
- Increases the resistance to Liquefaction
- Improve the slope stability of embankments
- Increases the friction angle and shear modulus
- In storage tank foundations
- Footings – Isolated / Raft

IV. DIFFERENT PATTERNS OF STONE COLUMN TECHNIQUE

Stone column should be installed preferably in an equilateral triangular pattern which provides the densest packing also a square pattern may be used.

Figure: 1 Plan of stone column, Square pattern and Triangular pattern (Cabe,2007)

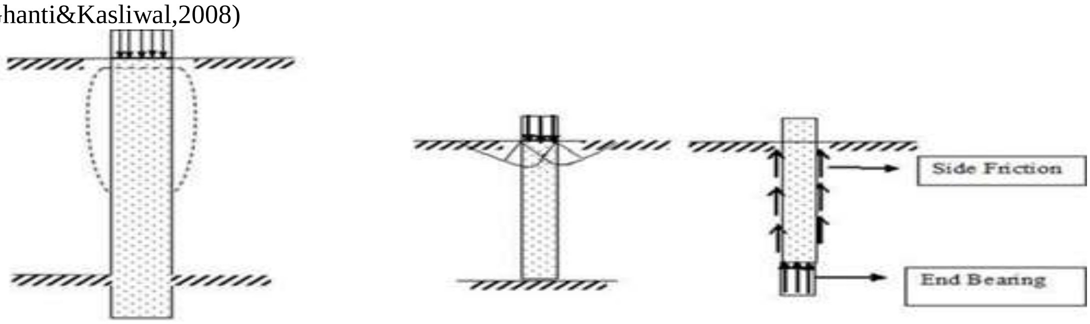


V. STONE COLUMNS FAILURE MECHANISM

The results and discussion may be combined into a common section or obtainable separately. They may also be broken into subsets with short, revealing captions.

The failure mechanism of a single stone column loaded above its area significantly depends on the length of the column. Many researchers have done work on this parameter and found that about four times diameter lengths of the columns were significantly strained. If the stone column installed in layered soils, the maximum bulging was observed at a depth of one times the column diameter from the top and the total length of the stone column subjected to bulging was observed to be two to three times the column diameter. The ultimate strength of an isolated column loaded at its top is primarily governed by the maximum lateral reaction of the soil around the bulging zone. If the length diameter ratio is less than four then column would fail in end bearing before bulging. For the short columns, the punching failure was reported whereas bulging was significant in long columns. Fig 2-I.The area which has been shown with dash-lines is most probable to have bulging effect within. In the case where a rigid short column is assumed (Fig 2-II),the main criteria which controls the failure is bearing capacity of failures which are denoted by stress and strain bulbs which follows Terzaghi and Meyerhof type of analysis.

Figure 2: Failure mechanism of a single stone column in a homogeneous soft layer (Ghanti&Kasliwal,2008)



I. Long stone column with firm or floating support

II. Short floating column (Punching failure)

III. Short floating column (Punching failure)

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(Bulging failure)

VI. CONCLUSION

Based on the critical review of the available literature on stone columns some specific conclusions have been found.

- Stone column technique is the economical method for improving the load carrying capacity of soft clay soils and decreases the settlement rate. It can be constructed by any two methods.
- Stone columns with geo reinforcement have impr oved the bearing capacity of soft clay soils.
- The stone column bearing capacity has increased with increasing the friction angle of granular materials and stone column diameter.
- The bearing capacity improvement of soft clay soils may not be give better results due to low lateral confinement. To resolve this issue geo synthetic materials are used for encasement of stone columns so that it improved the performance.
- The ultimate bearing capacity of the reinforced stone column increases with the stiffness of the reinforcement.
- By using geo synthetic materials in stone columns as encasement proves reduction in settlement.
- Much research work has been carried out to study the behavior of columns without reinforcement as well as with reinforcement

When the ordinary stone columns are installed in soft clay soils, the load carrying capacity is less due to low confinement. Such kind of issues can be resolved by adopting suitable latest geo synthetic material encasement of stone column so that it can provide sufficient confinement.

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