STUDY THE EFFECT OF GEOSYNTHETIC ENCASED STONE COLUMNS ON SOFT AND LOOSE SOILS

Sudheer Kumar J[1], Saurabh Rawat[2]

[1]DAV Institute of Engineering and Technology, Jalandhar, India
2 Jaypee University of Information Technology, Solan.(H.P), India

ABSTRACT. In recent past the rapid growth of the population, economy and developments has forced to use lands which are not suitable for engineering construction activities. The precious land (two lacs of Hectares) in thermal power station occupied with industrial waste products such as fly ash and pond ash. Near about nine lacs hectares of precious land occupied by the solid waste dumps in fifty nine cities. In this paper stone column ground improvement technique is discussed to stabilize the weak and unconsolidated sites. The ordiary stone column (OSC) and geosynthetic encased stone column (GESC) effect on surrounding weak, compressible and unconsolidated soils presented. OSC and GESC's load carrying capacity and settlement on surrounding weak soil are discussed. Failure mechanism of end bearing, floating type stone columns with and without GESC's are presented. Stone columns are one of the suitable techniques with geosynthetic encasement to strengthening the pond ash and solid waste dump sites.

Keywords: Ordinary stone column, Geosynthetic stone column, bearing capacity, settlement, loose soils.

Sudheer kumar J is a Assistant Professor in department of civil engineering, DAV Institute of Engineering and Technology, Jalandhar, Punjab.

Dr Saurabh Rawat is a Assistant Professor in department of civil engineering, Jaypee University of Information Technology, Solan, (HP)

INTRODUCTION

In the design of the foundation of structures, shear strength, bearing capacity and settlement are the major influence factors. Construction of the highways, railways and most of the engineering structures on soft soils causes the problems and damage the structures due to excessive deformations and structural instability. The pore water pressure building and slow consolidation process in soft clay soil decrease the shear strength. Due to excess pore water pressure development in silt and fine sandy soils the effective stress and shear strength reduces there by chances of liquefaction occurs is high. In order to reduce the settlement and increase the bearing capacity of soft soils various cost effective ground improvement techniques are practicing in the geotechnical engineering field. Considered the all the problems, in recent past most effective solution was found through granular stone columns. The stone columns are semi rigid piles and packed with dry granular aggregates (without binder) of various sizes, insert into the loose weak soil deposits. Stones (aggregates) in the column may or may not be confined with various geosynthetics. Many researchers have been investigating on ordinary and encased stone columns and studied the various parameters. Here the author presenting various parameters of the stone columns that influence the strength and deformability of the surrounding soils. Those are surrounding soil, size of the aggregates, space and pattern, diameter of the stone columns, tensile strength of the aggregate confinement system and the type of the stone columns (end bearing and floating).

Undrained Strength of the Surrounding Clay

In order to validate to the field soil, many researchers experimented in the laboratory model tests on the clay soils having moisture content - undrained shear strength of 25% - 15kPa (Naderi et al, 2018), 28% - 15kPa (Ghazavi et al., 2018), 75% - 5kPa (Cengiz and Guler, 2018), 34.5% - 10kPa (Fattah et al, 2016), 40% - 6kPa (Ali et al 2014), 28% - 15kPa (Ghazavi and Nazari, 2013), 36% - 5kPa (Dash and Bora, 2013), , 47% - 2.5kPa (Murugesan and Rajagopal, 2010), 63% - 5kPa (Gniel and Bouazaa, 2009), 25% - 30kPa, 30% - 14%, 35% - 7kPa (Ambily and Gandhi, 2007). Many of the experimental investigation carried on higher moisture content and corresponding undrained strength of the clay which was replicate the field soft soil condition. Single and grouped stone column capacity was observed on the same soft clay soils. Some of the stone column tests were conducted float type and end bearing. Bulging failure mostly occurs at a depth of 1.5 to 2d (d is diameter of stone column) irrespective of moisture content and undrained strength in both float type and end bearing types stone columns.

Effect of Stone Aggregates

A natural aggregate has been using in stone column filler materials, in order to improve the loose and soft soil bearing capacity and stability of slopes. Stone aggregates in stone columns functioned in decreasing the compressibility of loosely packed fine silt and sandy soils, accelerate the consolidation in cohesive soils by providing the drainage path for pore water pressure, reduces the liquefaction potential during the earthquakes. It can reinforce the soft soils and increasing the stiffness of the soils. Stone columns are filled with the different sizes of the natural aggregates. Table 1 explained diameter of the stone column and sizes of the aggregates were used.

Table. 1 Diameter and size of the natural aggregates used in stone columns**.**

S.NO	DIAMETER OF THE STONE COLUMN, D (MM)	LENGTH OF COLUMN (M)	SIZE OF THE AGGREGATES USED IN SC	ANGLE OF INTERNAL FRICTION (ϕ)	SPACING OF GROUPED SC (M)	AUTHOR (S)
1	60, 80, 100	0.9	2 – 10mm	46^0	2.5d	Ghazavi et al. (2018)
2	168	0.25, 0.65, 0.95, 1.25	Sand = 0.47 – 2mm Gravel = 5 – 7.9mm	37^0 44^0	-	Cengiz and Guler (2018)
3	50	0.3	2 – 6mm	42^0	125mm c/c	Debnath and Dey (2017)
3	60	0.4	2 – 10mm	45^0	-	Naderi et al. (2017)
4	50, 100	0.14	0.24 – 4.5mm		0.1	Mohapatra et al. (2016)
5	70	0.7	2 – 14mm	41.5^0	2.5d, 3d, 4d	Fattah et al. (2016)
6	100	0.1, 0.3, 0.5, 0.7	2 – 10mm	48^0	1.5 – 3d	Dash and Bora (2013)
7	30	0.3	Sand = 0.6 – 1mm Gravel = 1 – 4.75mm	38 - 45^0	15mm	Ali et al. (2014)
8	60, 80, 100	L, 0.5L	2 – 10mm	46^0	2.5d	Ghazavi and Nazari (2013)
9	50, 60, 70, 80, 90, 100	0.3	2 – 10mm	46^0 9.86 kN/m2		Das and pal (2013)
10	50, 75, 100	0.6	2 – 10mm	41.5^0	150mm	Murugesan and Rajagopal (2010)
11	100	0.45	2 – 10mm	43^0		Ambily and Gandhi (2007)
12	30		2 – 6.35mm	48^0		Malarvizhi and Ilampurthi (2007)

From Table 1 previous authors all are used the diameter of the column vary from 30mm to 100mm, and size of the aggregate particle 2mm to 10mm. Column filler materials normally consist of stone aggregates, gravel and sand are compacted into vertical hole. Crushed stones or gravel for column fill should be clean, hard and unweathered free from organics trash or other deleterious materials. In the field stone columns are compacted with rammers or vibro compaction techniques. The angle of internal friction was varied 37 to 48^0. The relative density was maintained 60% and above in order to develop the compaction and achieve higher shear strength. Experimental investigation conducted on partial rubber tyre chips instead of stone aggregates, the size of the tyre chips were 10mm x 10mm. When columns are formed with granular fill, their load capacities become highly dependent on the strength of the fill material and the confining stress of the surrounding soils. Sustainability in environmental perspective lot of other recycled materials can be used in the stone columns. Latest researchers used the different recycled materials like recycles aggregates. The solid waste has great potential to be utilize in the as stone column filler materials, for example crushed concrete, railway ballast, crushed glass, fly ash, bottom ash and quarry dust.

Effect of Confinement with Geotextiles and Geogrids

The load carrying capacity and bulging behaviour of stone columns will depends on the surrounding soils undrained strength. So far many researchers were worked on the surrounding soil which is having undrained shear strength is less than or equal to 15 kPa. The undrained strength is much smaller and very soft soils stone columns techniques will not work out. In order to stiffening the stone columns researchers have been using various encasing methods. Table 2 shows the stone column encasing details by various researchers. The geosynthetic encasement plays a great role in increasing the stiffness of the stone columns, preventing the loss of stone into the surrounding soft soils and preserves the drainage and frictional properties of the stone aggregates.

Table 2 Stone column Encasement details by researchers

RESEARCHERS, (YEAR)	ENCASEMENT MATERIAL	STRENGTH	.OVERLAPPING	BULGING DISTANCE FROM THE SURFACE
Yoo and Lee (2012)	Polyster geogrid	120 kN/m (BX)	30% circumferential	2d to 4d
Debnath and dey (2017	Geogrid Geotextile	125 kN/m (BX) 50 Kn/m	20mm overlap+sticking with glue	
Ghazavi et al., (2018)	Geogrid Geotextile	250 kn/m 16.36, 35kn/m		D to 2D
Cengiz and Guler (2018)	Geotxtile (GT1, GT2, GT3)	1.25, 21, 60 kN/m @5% strain	Overlapping	
Chen et al., (2018)	Woven Geotextile (5 types)	33, 44, 52, 65, 91kn/m	Tubes manufactured (300 dia. x 600mm high)	
Naderi and Dehghani (2017)	Polyethylene	8 kn/m	20mm overlap + sticking with glue	L/D = 4 – is required for control of bulging failure mode.
Mohapatra et al., (2016)	Woven geotextile, Socks and Paper	34 kn/m 4.28 kn/m 0.28 kn/m	15 – 20mm, socks is tubular product, no seam.	

Ghazavi. M, Yamchi. A. E, and Afshar. J. N (2018) studied the bearing capacity of stone columns in very soft soil which was having very low confinement. The undrained shear strength of surrounding clay soils is 15kPa in all cases. For the laboratory investigation the diameter of the stone columns were 60, 80 and 100mm height was upto of 30, 40 and 50cm respectively. Single and group action of stone columns was tested. The diameter and spacing of the group stone columns were 60mm and 150mm (centre to centre) respectively. Stone columns were reinforced horizontally with geogrids and vertically confined with the geotextiles. Results from Fig.1 published that the ordinary stone column ultimate bearing capacity and stiffness of could further increases with the use of horizontal geogrid reinforcement. The bulging failure was very limited in case of single horizontal reinforced stone columns. Tests on group of stone columns has published the ultimate bearing capacity of horizontally reinforced stone columns was greater than that of group of ordinary stone column. Use of geogrids in horizontal layers and geotextile as a vertical confinement has significant effect on bearing capacity and stiffness.

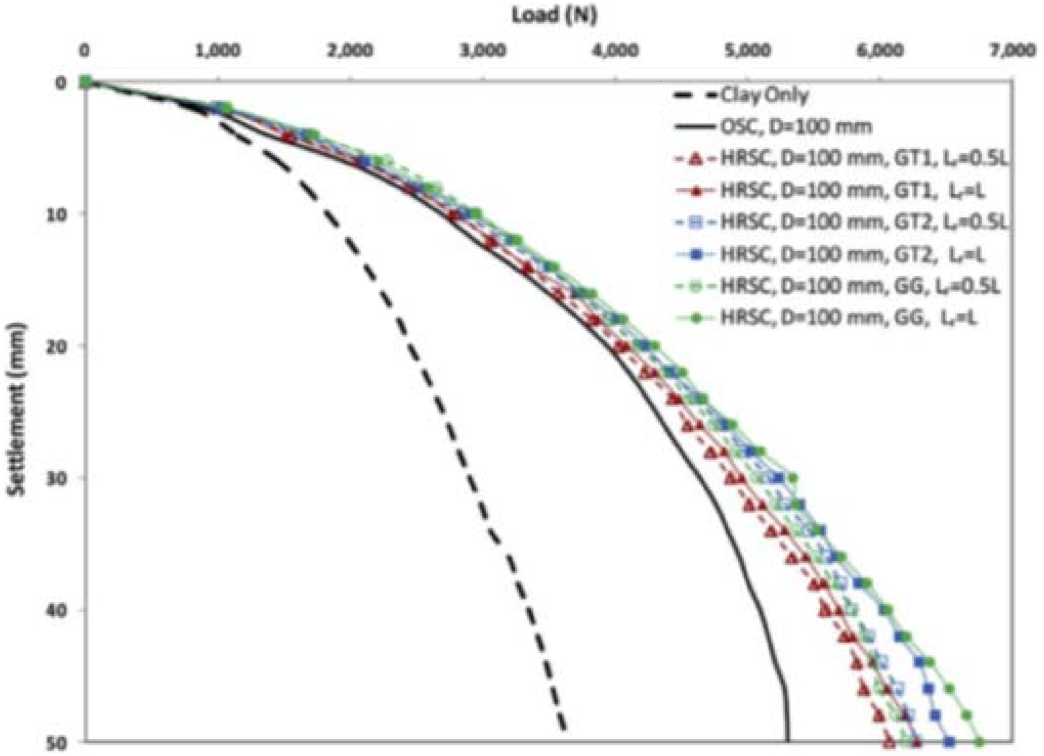

Figure 1 Load- Settlement of single stone column with diameter 100mm (Ghazavi et al 2018).

Gu. M, Zhao. M, Zhang. L and Han. J (2016) research carried on to investigate the effect of geogrid encased stone columns, its lateral and vertical strains and load transfer mechanism which was surrounded by soft clay bed. Two types of tests were conducted one is individual (200mm diameter) and another composite foundation (600mm diameter) which consists of column and its surrounding soil. HDPE geogrids were used for encasement purpose and all were end bearing stone columns. Ordinary and geogrid encased stone columns compared. By varying the encasement length stress and strain characteristics of the stone columns measured and analysed. Results presented Fig. 2 that the ultimate bearing capacity of soil was significantly increased by the geogrid encased stone columns (GESC) in the very soft clay soil where undrained cohesion is 3.4 kPa. From the test results the encasement length was three times the diameter of the stone columns. Due to geogrid confinement the lateral bulging failure location was changed and lateral deformations was decreased. The stress concentration ratio for the GESC was higher than OSC.

Mohapatra. S. R, Rajagopal. K, and Sharma. J (2016) studied the geosynthetic encased stone columns (GESC's) subjected to lateral loads. The GESC's (single and group) tested in a direct shear box which is having size of 305mm x 305mm x 203.2mm. Two different diameters of the stone columns 50mm and 100mm were used for testing purpose. Three different kinds of encasement materials, woven textile (E1), cotton socks (E2) and paper towel (E3) used to investigate the effect. From the test results, GESC's increases the lateral load capacity of than the ordinary stone columns due to tensile strength of wrapping material. The stone column group arrangement shown higher shear resistance compared the single columns.

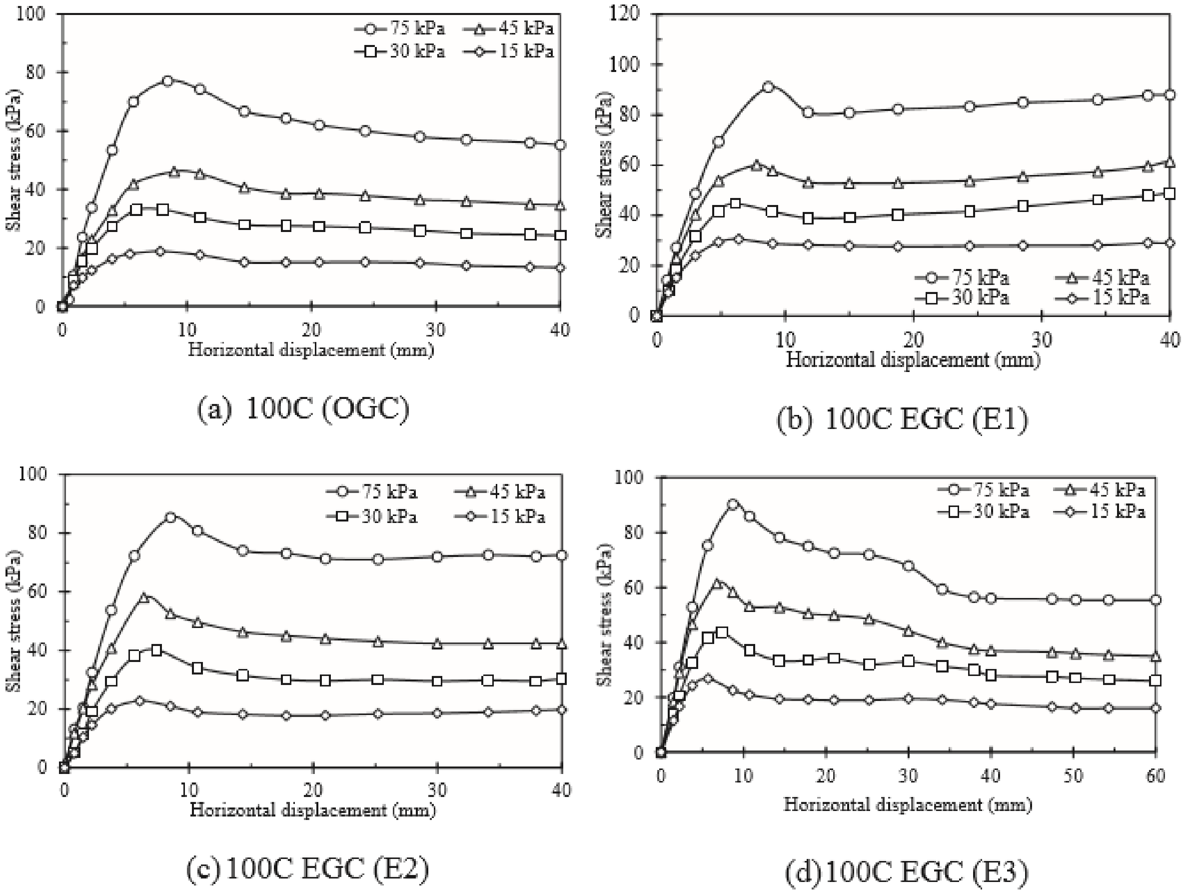

Figure 2 Variation of shear stress and horizontal displacement behaviour on Stone columns (OSC & GESC) at different normal stress (Mohapatra and Rajagopal 2016).

Fattah. M. Y, Zabar. B. S and Hassan. H. A (2016) The embankment models were studied which were rested on soft soil reinforced with ordinary and encased stone columns (ESC's). Experiments were performed kept spacing between the stone columns, length to diameter ratios and heights of embankment were variables. The mode of failure for an embankment was close to local shear failure, mode gradually changed towards the general shear failure when using the ESC's. The bearing ratio increases with decrease in the spacing of columns at all embankment heights. The effective spacing between columns were s = 1.5d (d – diameter of column).

Miranda. M and Costa. A. D (2016) studied the stone columns without and with encasement under drained triaxial tests. Triaxial compression tests were performed on 200mm high and 100mm diameter specimens of gravel with two different relative densities of R_D = 50% and 80%. Two different kinds of geotextiles were used for specimen confinement. The strength is evaluated by the axial stress increment for both the encased and non encased specimens. The strength is significantly improved at low confining pressures for higher relative densities and high tensile geotextile. The radial strain decreases in case of geotextile confinement.

Effect of Floating Type and End Bearing Stone Columns

Dash. S. K and Bora. M. C (2014) Investigated on influence of geosynthetic encasement on the behaviour of stone columns floating in soft clay. Many researchers worked on end bearing stone columns, this paper presents the floating type (frictional) stone columns. The diameter of stone column was 100mm and four series of model tests were investigated. Series 1 load deformation behaviour on only clay beds, series 2 and 3 stone columns reinforced in clay bed, its length and spacing is varied and series 4 different length of geosynthetic encasement were studied. The concluding remarks were floating stone columns can improve the bearing capacity of foundation in soft clay by about 3.5 folds. The column longer than 5 times their diameter did not continue to increase the bearing capacity. Therefore critical length of floating stone columns giving maximum performance improvement is at 5 times diameter of column. The optimum spacing of stone columns was 2.5 times diameter of column. Only 60% length of column encasement gives the maximum performance beyond that length no significant bulging.

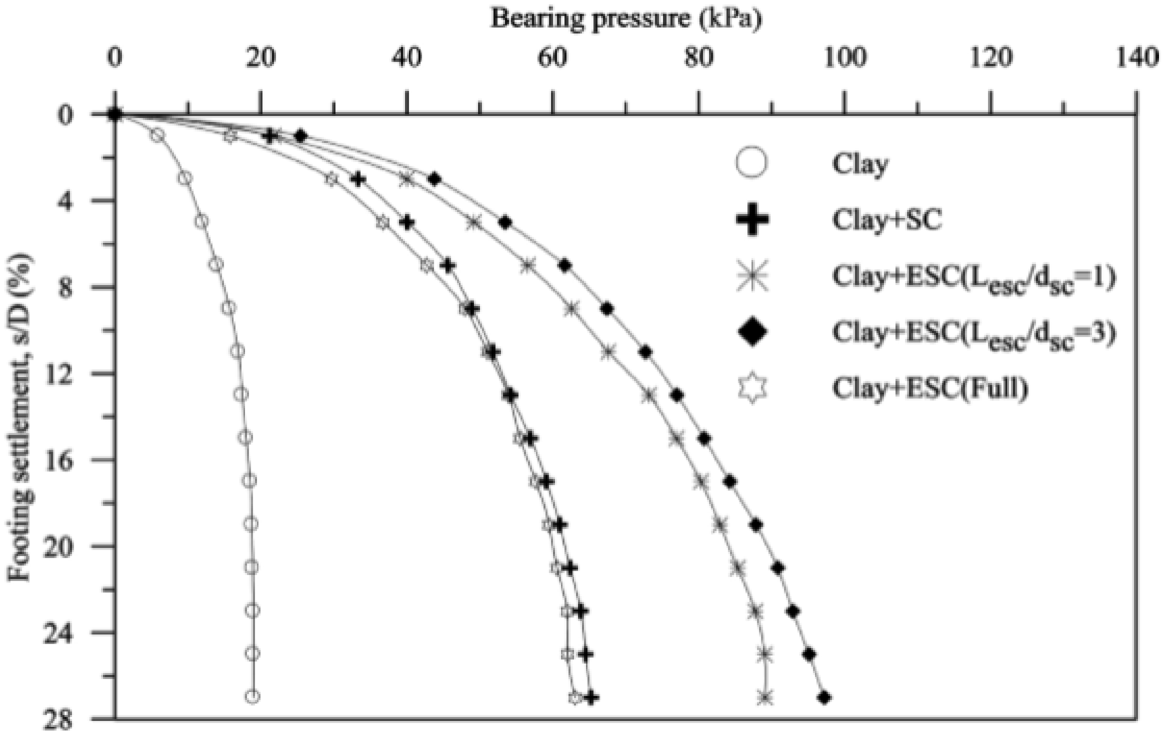

Figure 3 Bearing pressure *vs* Footing settlement: Effect of geosynthetic encasement (Dash and Bora 2012).

Stone Column Effect on Slope of the Embankment

Naderi. E, Asakereh. A and Dehghani. M (2018) investigated experimentally and numerically on clay slope reinforced with ordinary and geosynthetic encased stone columns. The bearing capacity of strip footing was observed for both reinforced and unreinforced stone columns. By changing the location of stone columns on the slope the effect of load-settlement behaviour of strip footing rested on top of the slope was investigated. The length and diameter of the column is 40 and 10cm respectively. The slope was 45 degrees kept constant in all the cases. The results were presented Fig.4 increasing the bearing capacity of strip footing in both experimental and numerical investigation. It was very well observed that the bearing capacity of strip footing on geosynthetic encased stone columns increased than the ordinary stone columns. The maximum capacity was carried by the stone column which was axially loaded, and with increase the distance between the columns, footing the load carrying capacity decreases.

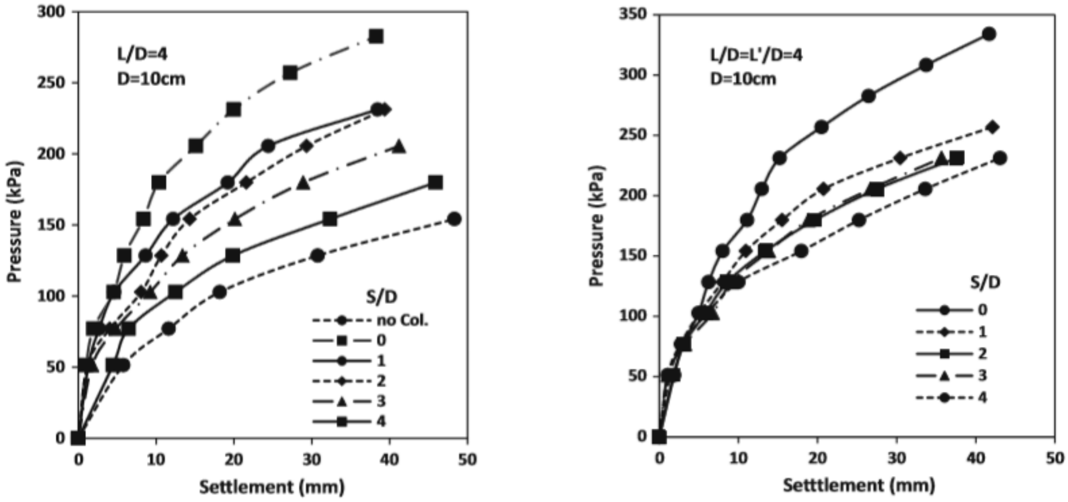

Figure 4 Pressure vs Settlement : Slopes reinforced with OSC and GESC (Naderi et al. 2018)

Vekli. M., et al. (2012): Investigated on slopes reinforced with ordinary stone columns. Soft soils slope embankments of hypothetical cases studied the slope stability, bearing capacity and settlements. Variation of the distance between the vertical axes of stone column/ diameter of stone column (S/D = 2,3,4), footing rested on the top of the slope and studied the factor of safety of slopes, ultimate bearing capacity and settlement. All the stone columns are tested with only without encasement. Results published in Fig. 5.

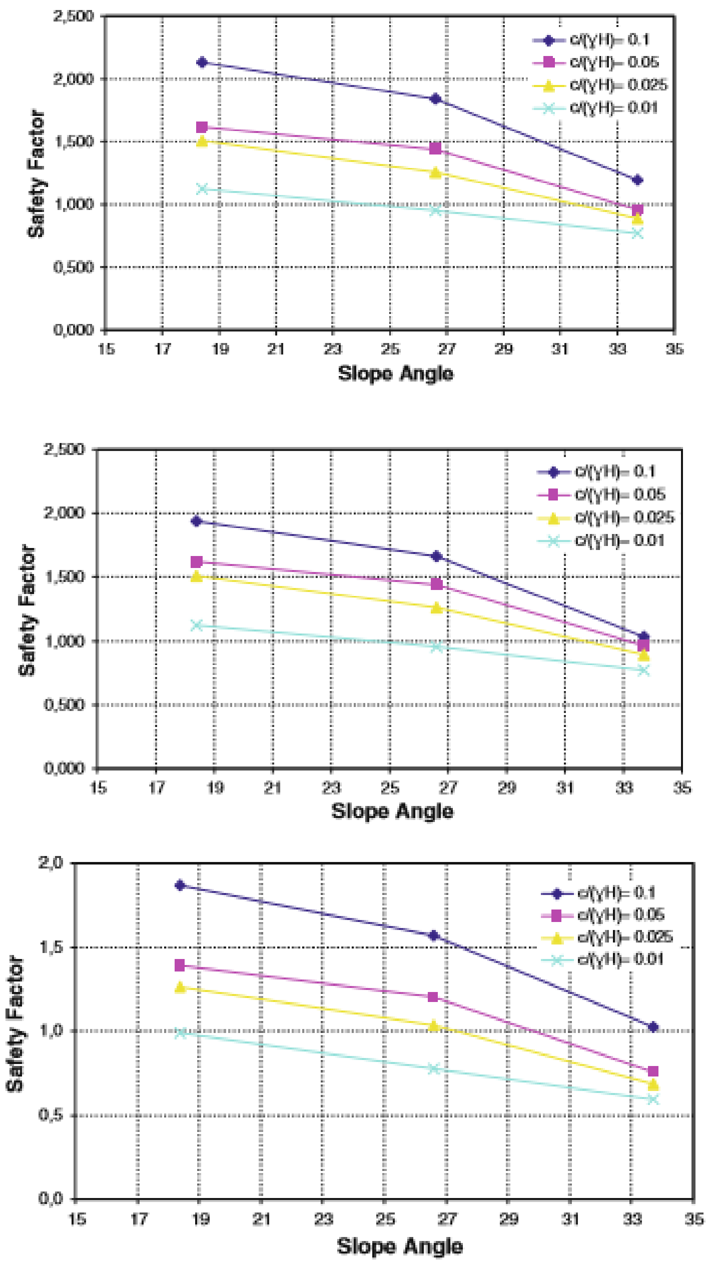

Figure 5 Factor of safety vs slope angle: Slopes reinforced with stone columns(Vekli et al. 2012).

Al-Shukur. A. H and Alturrfy. U. A (2015) Research was carried on slope stabilization with combined effect of stone columns and tie back support. Analytical and SLIDE V.5.00 programme was used to check the factor of safety of slopes. Parametric studies carried on to understand the effect of stone column diameter, friction angle of stone column material and distance between stone columns. Results presented those safety factor increases, if slope is reinforced by a row of column and when the column is close to topmost of slope maximum safety factor is achieved. Further moving the column towards the toe side safety factor is reduced.

Effect of Stone Columns on Liquefaction Mitigation

Cengiz. C and Guler. E (2018) the research was conducted on the performance of geosynthetic encased stone columns (GESC's) and ordinary stone columns (OSC's) during and after seismic excitation. The tests were carried on large scale shake table test. The load carrying capacity of GESC's and OSC's after seismic excitation were measured with the help of stress controlled load tests. There were three different types of geotextiles (GT1, GT2 & GT3) used to understand the behaviour of strains (deformation). The results presented that GT2 reinforced column exhibited distinct maximum straining zones under seismic impact and GT3 reinforced column shown under small amplitude of strains are even in many locations. GT1 column is same as OSC's in vertical loading behaviour after seismic excitation.

Salem. Z. B, Frikha. W and Bouassida. M (2017) presented the observations on stone columns as a liquefaction remediation. The stone columns as seismic energy breakers, it will works like good drainage, reinforced stiffening and densification of the surrounding soils. The authors investigated on 24 case studies where ordinary (OSC's) and geosynthetics encased stone columns (GESC's) were installed. The SPT and CPT data collected from the field and studied the liquefaction effect. Authors presented concluding remarks that the installation of stone columns in slity sand increases the density than the silty and clayey soils. Stiffening was improved significantly. Densification and stiffening effects considerably improved the assessment of liquefaction potential of soil by stone columns.

CONCLUSIONS

Previous researchers explored and found the ordinary and geosynthetic encased stone columns were very significant. Few researchers were investigated with both experimental and numerical programme. They improve the various parameters like bearing capacity, effectively reduction of settlement and better understanding on bulging behaviour on soft clay. Very less amount of work was conducted on slopes were reinforced with stone columns. And almost no work was conducted on ash fills and solid waste dumps reinforced with geosynthetic reinforced stone columns. Geosynthetic encased stone columns can effectively increases the bearing capacity of loose and weak soils.

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