Performance of Ordinary and Geotextile Encased Stone Columns in Partially Saturated Ash Fills

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Abstract - *Ground improvement techniques using stone column are popular method for the foundation of embankments or structures of soft soil. Vertical bore holes in the ground filled with gravels compacted by a vibrator. Stone columns are widely used as structural elements to transfer loads from the superstructure to the underlying softy soil. They are preferred in many loading situations due to the simplicity, short duration, and cheap cost of their construction. However, their performance is mainly affected by the lateral support exerted by the neighboring soil. The encased columns in which the inclusion of gravel, which has a higher strength, stiffness and permeability than the natural soft soil which helps to improve the load capacity of the soft soil. Thus enhancing stability of embankments reduces the settlement reduction. In the present study the author investigated the settlement reduction and increase in load capacity of stone column under different conditions such as OSC, GESC's and groups of columns. Load-settlement model developed in Daviet which is manually operated used for current study work to investigate the settlement reduction and increase in load carrying capacity of soil treated with an ordinary stone column (OSC), soil treated with an encased stone column (ESC) and also treated by using group of ordinary stone columns as well as group of (GESC) geotextile encased stone columns. The results shows stone column without and with encasement considerable effect on loose solid waste dump sites.*

Key Words: Ordinary stone column (OSC), Geotextile encased stone column (GESC), Group of stone columns using with and without encasement, (LCR) load capacity ratio and (SRR) settlement reduction ratio.

1. INTRODUCTION

Generally large areas of the world are covered with soft soil and clay deposits, especially coastal regions. As a result of economic growth, many infrastructure projects, such as roadway embankments, are being constructed in areas with weak soil deposits ground improvement techniques are used to alter and improve poor ground conditions. Stone column is one of the ground improvement techniques which were adopted in the recent past years. It is helpful to reduce settlement and increasing load capacity. Stone column is granular piles which are used to reinforce the ground to support the large structures, buildings and flexible structure. It is used to improve slope stability of embankments on soft grounds and helpful in time decreasing factor under primary consolidation. Saturated soils do have a lower load capacity than the predicted or assumed condition. Geo synthetic encased stone column GESC is the primary function of the radial restraining reinforcement of the granular column and secondly, it works as separation, filtration, and drainage. GESC helps to increase the load and settlement reduction. The improvement of soft soil using stone column can be much effective using geo synthetic encased column where pond ash deposit possess high compressibility. This is mainly due to expansion of the pond ash as the volume is increased with water. Depending on the type of soil and likely for most pond ash encountered for a foundation, that time can be considerable. When they are determined to be saturated or when the placement could not be made quickly enough, the excavation should be cleared of the loosened soils, mud and water sufficient to re-establish the soil-load capacity assumed for the design. Stone column is used in weak deposits to increase the load carrying capacity and reduce settlement of structural foundations. Stone column generally depends upon circumferential confinement provided by native soil or the weak peat deposits over the several deposits below the ground deposits. The loss or poor ground surface conditions are responsible for the failure under foundations so it is very important for ground surface that it should be treated by different ways so as to obtain the better result and helps to improve the better ground surface conditions. Pond ash has high water, moisture content present in it. Pond ash is the by-product of thermal power plant which is a waste material and its disposal is a major problem from a point of view of the environment as well as it requires a large disposal area. Pond ash is obtained through the combustion of coal while burning three different types of residue were left out after the combustion such as fly ash, bottom ash. The residue of the fly ash as well as the bottom ash was blended together on the water pond so as to minimize the residue left behind it and the formation of pond ash takes place. Although bulging is the most common failure in stone columns under concentrated load and composite loads when act over it as shown in Fig. 1.

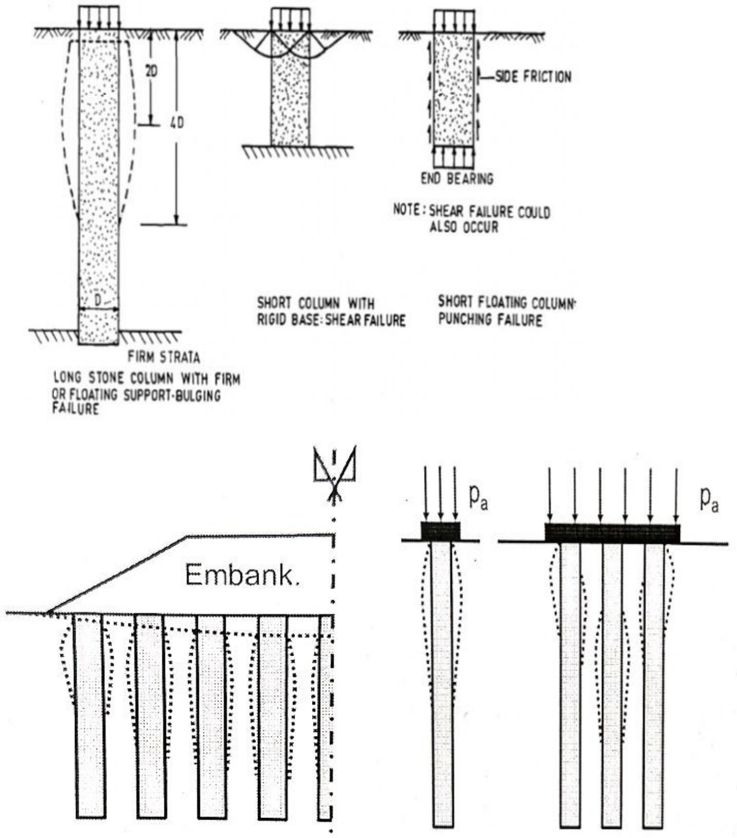


Fig.1 failure mechanism of bulging, shear and punching of stone columns. Also group of stone columns failure pattern under embankment (BIS 15284: 2003).

2. LITERATURE STUDY

The different researchers have been investigating the ultimate load carrying capacity and settlement load reduction of stone column under different situation such as soft soil, pond ash and clay. The work was conducted on analytical and numerical studies as well as experimental and field studies. In this literature study there is an overview of both ordinary stone columns OSC and encased stone columns ESCs.

Zukri.A and Nazir.R; (2018) studied over Sustainable material used as stone column filler. They have investigated that different types of material would be used such as crushed stone, tyre chips, fly ash, aggregates, PFA, recycled aggregates and coal bottom ash and is found that such materials are helpful in increasing the bearing capacity of the stone column.

Ghazavi.M. Yamchi. A.E. And Afshar. J. N; (2018) investigated that bearing capacity of horizontally layered Geosynthetic stone column. It is also observed that if encasement decreases with the increase in stone column diameter in VESC it is also increasing with the increase of stone column diameter in HRCs.

Castro.J; (2017) studied that group of encased stone column; influence of column length and arrangement. It is found that if the column position has a small influence over the settlement, then there is a group of columns are placed near the footing or the rigid portion of the footing toward its base. Due to the higher vertical stress so column would tend to support the higher load over the surface of its region.

Cengiz.C, and Guler.E; (2017) Seismic behavior of Geo synthetic encased columns and ordinary stone columns. The seismic behavior of the OSC and GESC is observed during and after seismic excitations. The experimental setup is formed in a large scale shaking table test GEC and OSC are installed in a Kaolinite clay bed (0.52m width X 2.5m length X 2.2m height) with a surcharge load is imposed over it and they have also used three different types of Geotextiles GT1,GT2 and GT3. It is also seen that gravel in fill reduced the settlements during the earthquake more effectively than sand fills. Thus it is found that GT2 and GT3 are more effective than GT1.

Debnath, P., Dey, A.K; (2017) Bearing capacity of Geo grid reinforced sand over encased stone column in soft clay. They have investigated that load act over the stone column is not sufficient due to the presence of circumferential confinement presence in the native soil. So they add vertical confinement to mitigate this problem, but further they introduced USB, GRSB placed over the group of VESC to achieve more load carrying capacity of the stone column

Dutta.S, Nadaf.M.B, Birali.R.R.L; (2016) Encased stone column for soft ground improvement investigated. Stone column installed whose undrained shear strength 6KPa. It is observed that capacity around 2.25 with overall settlement 12% of footing below 12KPa undrained shear strength the lateral support provided by surrounding soil is insufficient which cause bulging failure later on they have observed that increase in encasement length the column capacity increased which may due to the distribution of footing pressure to a higher depth.

Fattah.M.Y, Zabar.B.S; (2016) Experimental Analysis of Embankment on ordinary and encased stone columns and found that an embankment model, resting on soft soil reinforced by a group of encased stone columns, was tested. The results indicated that the bearing ratio of the system (for a particular height of embankment) increased with decreased spacing distances between the stone columns.

Parsad.S.S.G and Satyanarayan.P.V.V; (2016) Improvement of soft soil performance using stone columns with circular Geo grid disc. In this study a lateral circular disc is provided over the stone column over the plain clay bed over two different spacing, i.e. D 2.5 cm and D/2 2.5 cm over full column length.117% ultimate load capacity of soft soil has been increased by using stone column moreover 16% and 41% is increased by applying circular Geogrid over it. Which helps to decrease the settlement Load capacity is increased by 117% by densifying the soil. The settlement is reduced up to 9mm to 5.3mm by stone columns and by placing Geogrid it is decreased by up to 4mm and 3.8mm by the inclusion of circular Geogrid over i.e. D and D/2.

Ghazavi.M and Afshar.J.N; (2013) Bearing capacity of Geosynthetic encased stone column, lateral bulging decreases in encapsulated columns in comparison to conventional ones, as a result of the extra lateral confinement provided by Geosynthetic. The ultimate capacity and stiffness of the stone columns increase when increasing the length and stiffness of the reinforcing encasement.

Black.J.A, Kumar.V.S and Bell.A; (2011) The settlement performance of stone column foundation. They observe that small columns were beneficial for large area and large columns were beneficial for small area they have also found that area, replacement ratio 30%, 40% exists for the control of the settlement, and the soil structure interaction has a significant role in preventing excessive column deformation.

Black.J.A, Kumar.V.S and Madhav.M.R; (2007) Reinforced stone column in weak deposits; Laboratory model study. The observations from the present research shown that the stone column without reinforced bulges which tends to fail. But by the improvement method using bridging reinforced performed well in terms of both for load carrying capacity and initial stiffness based on the modulus on the sub base reaction. It can be investigated that the load carrying capacity of the stone column in peat can improve by jacketing with a tubular wire mesh, bridging reinforcement with metal rod and concrete plug.

Guetif.Z, Bouassida.M, Debats.J.M; (2007); improved soft clay characteristics due to stone column installation. The estimation of the radius in the influence zone shall lead to an optimize column spacing where the group effects better.

Trivedi. A and Sud.V.K; (2007) Settlement of compacted ash fills. They have investigated that the settlement of footing on dry side of critical is higher compared to that of compaction at the wet side of critical. A shear failure or a collapse may precede allowable settlement at a lower degree of compaction than 90%.

Murugesan and Rajagopal; (2006, 2007, and 2010) Conducted laboratory model tests on ordinary and encased granular columns extensively for both single as well as group and found that the encased granular column exhibited a stiffer response whereas the ordinary columns showed significant strain softening behavior.

3. MATERIALS DESCRIPTION AND EXPERIMENTAL METHODOLOGY

1). Aggregates.

Stone column is generally built with the help of crushed aggregates, gravels, recycled aggregates and different sizes of aggregates such as 20mm to 70mm size of aggregates used in the formation of the stone column. For present study the 20 mm size of aggregate required for stone column formation. The following preliminary test was conducted over the sample and their result as follows as shown in Table 1 and aggregates were shown in Fig 2.

Fig.2 Aggregates

Table 1 Physical property of aggregates

Characteristics	Values
Color	Grey
Shape	Angular
Maximum size	20mm
Water absorption	1.5%
Specific gravity	2.58
Crushed value	28.18 %
Impact value	15.27%

2). Pond ash.

It is the residue left behind from combustion of coal. It is usually obtained from the thermal power plant (fly ash and the bottom ash are mixed up in a pond which take on the shape of slurry to form pond ash). It contributes to two major environmental problems generation of reparable particulate matter (a major air pollutant) and pollution of soil and water due to leaching of heavy metals. For present study pond ash is collected from the Ropar thermal power plant. The following preliminary test were conducted their result prescribed Table 2 and within Fig 3.

Fig. 3 Pond ash

Table 2 Chemical properties of pond ash (Trivedi and sud 2007) along with Physical property

Chemical compound	%age
SiO_2	57.5
Al_2O_3	27.2
Fe_2O_3	5.4
CaO	3.1
MgO	0.4
Na_2K_2O	0.9
SO_3	-
Unburned carbon	4.1

Properties	Value
Sp. Gravity, Gs	1.928
Sieve analysis, Cu, cc	1.58, 1.5
OMC	26%
M.D.D g/cc	1.2
Classification	Non plastic

3). Non-woven Geotextiles.

They are made of synthetics and most often used in filtration, separation and reinforcement applications. Non-woven Geotextiles typically used for highway pavement layers for stabilization and reinforcement layers. The non-woven geotextile will break down faster than their woven counterparts. But, for projects where pooling water is a major concern, non-woven Geotextiles are likely the right choice. Properties of non-woven geotextile are as under Table 3 and Fig is prescribed in Fig 4.

Table 3 Properties of non-woven Geotextiles (M/S strata geo systems India PVT LTD)

Properties	Values
Ultimate tensile strength (KN/m)	6.8
Strain at ultimate strength %	55
Ultimate tensile strength from tests with seam (KN/m)	5.1
Strain at ultimate strength from test with seam %	45
Initial modulus (KN/m) from seam test.	12

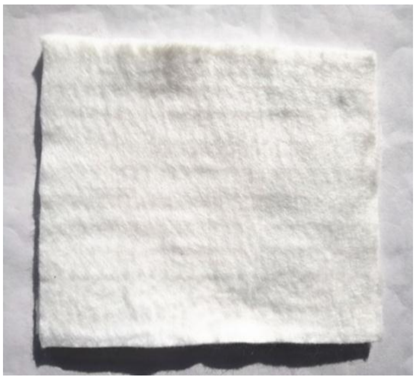


Fig. 4 Non-woven Geotextiles

A). Model Tank Set Up. .

A steel tank is used for the purpose of achieving the objectives of the study having dimension 830mm length x 680mm breadth x 600mm height(as shown in the Fig 5) 200mm circular plate fabricated to apply the load. It will fix to the hydraulic system at the centre of the steel tank. Sensors are attached to the loading hydraulic system through that reading of load and deformation will be displayed in the load cell.

Fig. 5 Model tank Experimental set up for Load - settlement and load cell indicator

Pond ash obtained from Ropar thermal power plant. The ash mixed up with water equal to 1.5 times the OMC (optimum moisture content) of the pond ash. (Murugesan.S and Rajagopal.K (2007) and Gupta.N, Yadav.K.K and Kumar.V (2015). This slurry is filled up in the tank and allowed to consolidate, by covering with plastic sheets and without losing water content.

The column is constructed at the centre of the tank (just below the circular footing) with the help of PVC pipe which is a slightly higher diameter than the stone column diameter. The column is filled with aggregates of size 20mm. Settlements of the pond ash are monitored using dial gauges having an accuracy of 0.01mm.

B). Details of pond ash bed and ordinary stone column (OSC) preparation.

1. To prepare the 100 mm thick layer, 50kg pond ash mixed thoroughly and uniformly with 30 liters of water and same slurry is placed in the tank.
2. The tank is properly covered with the help of plastic sheets so that there is no loss of water in the tank.
3. By repeating the same procedure tank is filled with ash and water slurry up to the height of 500mm.
4. With the help of PVC pipe, the column is built at centre and below the circular footing of size 200mm.
5. Aggregates of size 20mm filled in the PVC pipe subsequently compacted with the tamping rod of 20mm diameter. After every 100mm fill PVC pipe is lifted up. After completion of the column pipe is removed.

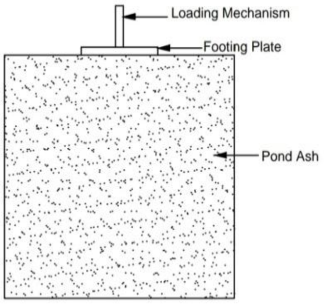
Geosynthetic encased column.

1. With the help of PVC pipe column is built for single and group columns.
2. Geotextile is wrapped around the PVC pipe and maintain the 100mm overlapped throughout the height of the column.
3. Once the column is filled with the aggregates PVC pipe is lifted out and the column is encased with the geotextile. Similar process is used for single and group of columns encased with geotextiles.

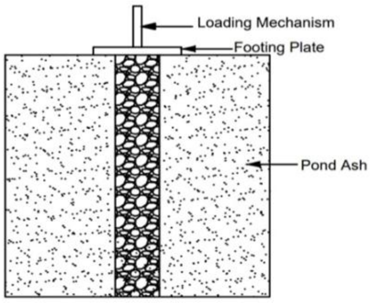
4. In group action of the column equilateral triangle followed for higher densification and spacing between the columns is equal to 2.5 times the diameter of the stone columns.

C). Different cases of stone column taken into study.

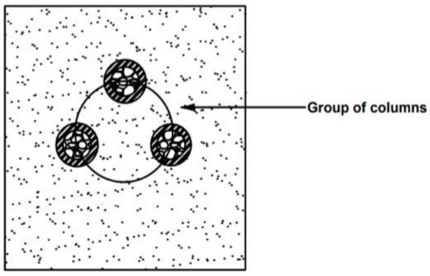
1). Plate load test for untreated pond ash under partially saturated condition.



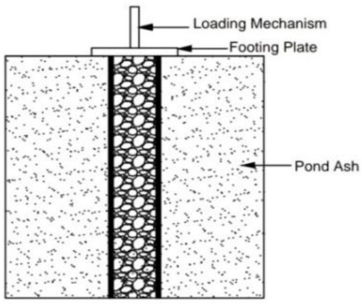
1(a). Plate load test for ordinary stone column.



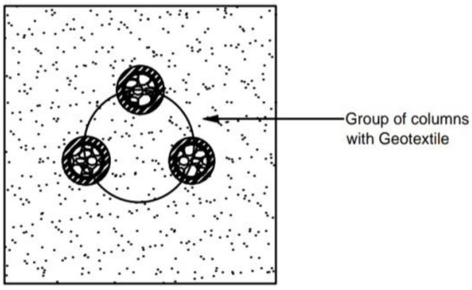
1(b). Plate load test for group of stone columns.



2(a). Plate load test for encased stone columns.



2(b). Plate load test for group action of stone columns with encased Geotextile.



4. RESULT AND DISCUSSION

A). Comparison of Load Settlement Behaviour for untreated pond ash, ordinary stone column and encased stone column.

From Fig 6 it shows that when the plate load test was conducted over the untreated pond ash the settlement for untreated pond ash alone was 0.72kN with settlement of 28mm. Loading machine was developed by AIMIL which is manually operated stone column was made at the center with the help of PVC pipe just below the hydraulic cell and plate load having a diameter 200mm which is placed over the stone column the deflection is recorded with the help of sensors. When pond ash is treated by using ordinary stone column (OSC) settlement increases up to 120mm the load bearing capacity increases up to 3.62 kN. As pond ash is a weak confinement material provided by it and decreases the strength of stone column while using Geotextile it provided the reinforcement to ordinary stone column there was a huge improvement in the strength of the column. The load carrying capacity also increases up to 9.53kN with settlement 150mm. It is found that in case of untreated pond ash having no column the load carrying capacity was 0.72kN were as after treating with OSC the load carrying capacity was increased up to 3.62 while it is again treated by using Geotextile the load carrying capacity increased up to 9.53kN. It should be clearly noted that un-reinforced stone column and reinforced stone column specially after treating have a huge difference there is a gain of ultimate load carrying capacity and settlement reduction.

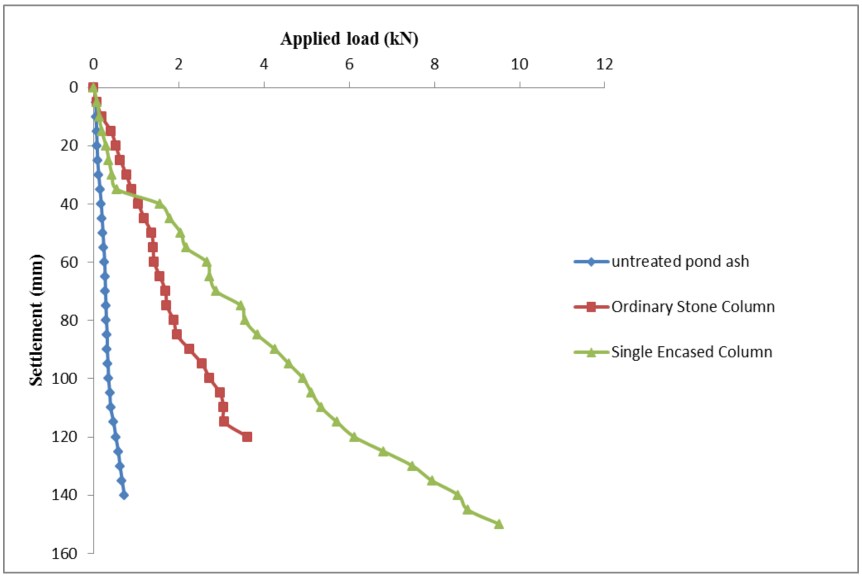


Fig 6 Load settlement relationship and comparison for untreated pond ash, OSC, single encased stone column.

B). Comparison of Load Settlement Behaviour of untreated pond ash, group of ordinary stone columns and group of Geotextile encased stone columns.

Fig 7 shows that when the plate load test was conducted for untreated pond ash then load was 0.72 kN at a settlement of 28 mm. Group of stone columns was made at the center by using 2.5D the spacing of the columns from center to center when pond ash is treated by group of columns and GESC in which settlement increases up to 150mm the load carrying capacity increases up to 13.54 kN. As pond ash is a weak material confinement provided by it is also less that also decreases the strength of stone column while using Geotextile it provided the reinforcement. There was a huge improvement in the strength of the column. The load carrying capacity also increases up to 14.72 kN with settlement 150mm. Thus G.OSC's and G.GESC's have a huge difference over their load carrying capacity they both provide the reinforcement to the partially saturated ash fills.

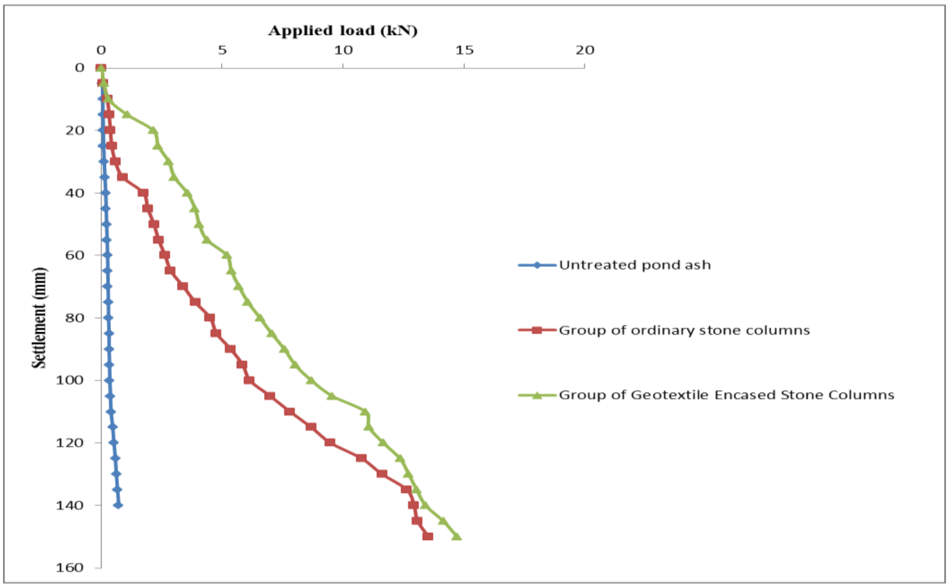


Fig 7 Comparison of load and settlement relationship values of pond ash alone, Group of ordinary stone columns and Group of Geotextile Encased Stone Columns.

C). Comparison of overall Load Settlement Behaviour for OSC, SEC,GOSC and GESC.

From Fig 8 shown that Comparison of overall Load Settlement result for load deflection at different cases and the settlement reduction and increase in load capacity ratio. It is very necessary to treat the pond ash under partially saturated ash fills so as to increase its load capacity and settlement reduction when OSC introduced the load capacity increases. When single encased column used load capacity increases up to 163%. But in case for group of columns it has shown some better result as compared to OSC it increased up to 274%, whereas group of GESC has much effective result as compared to OSC and increases up to 306%.

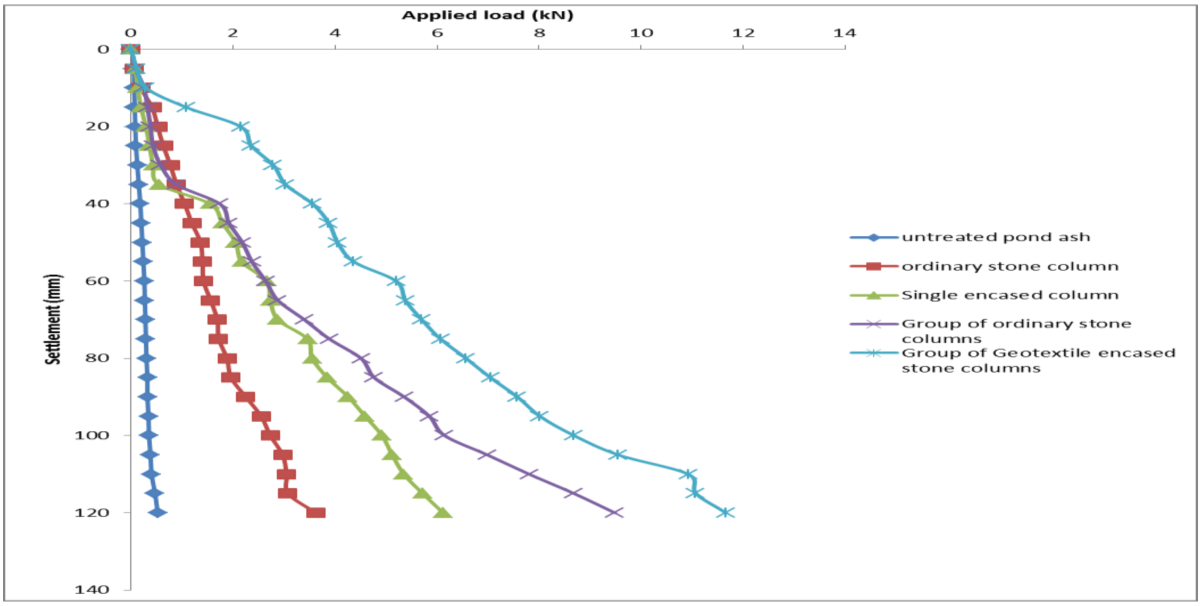


Fig 8 Applied Load vs Settlement Behaviour for Untreated pond ash, OSC, SEC,GOSC's and G.GESC's

In Fig 8 as seen all osc, sec, gosc's and group of gesc's increases the load carrying capacity of the soil. This is due to restrictions of column material used and the use of Geotextile which offers greater load carrying capacity by applying through its overall length. In addition the G.OSC improves the load capacity and settlement reduction, where as a group of GESC shows more effective result as compare to G.OSC.

D). Load carrying capacity for settlement reduction ratio under untreated pond ash, OSC and single encased stone column.

Load carrying capacity is the ratio of load and settlement reduction for un-treated pond ash over the treat pond ash.

$$LCR = \frac{\text{Load carried by the composite ground treated with column}}{\text{Untreated pond ash}}$$

Table 6 shows the load capacity ratio LCR at 100mm of different type of stone column.

Material	Pond ash alone	OSC	Single encased column	Group of OSC	Group of GESC
LCR value	1	8.49	14.63	19.97	27.31

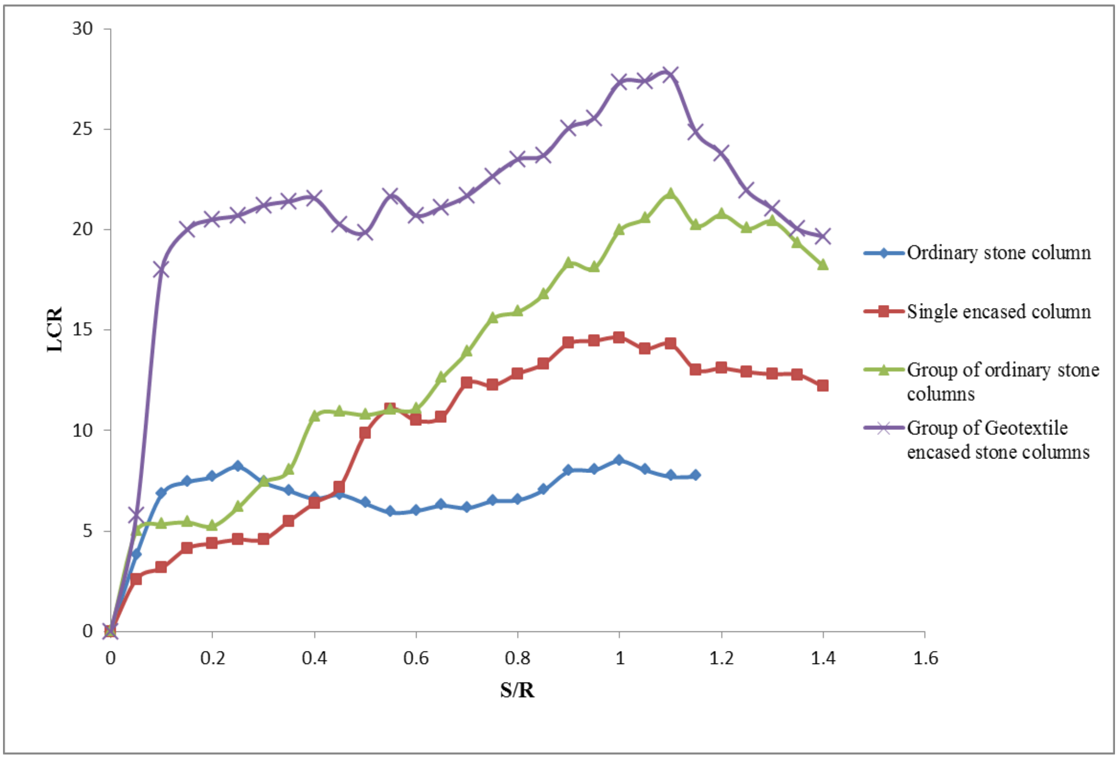


Fig 9 LCR values of pond ash alone, OSC, GESC, GOSC, GESC's

Fig 9 shows that the LCR value for pond ash is 1 under 100mm where as it increases upto8.49 in case of OSC that means increases in Load carrying capacity ratio of ash after the instalment of the column. After making single encased column it further increases to 14.63 and when a group of OSC is introduced there is a huge increase of 19.97 because of the effective confinement provided by group of columns that was absent in case of pond ash. The LCR value increases to 27.31 when a group of GESC used at the same time.

E). Settlement Reduction Ratio.

Settlement reduction ration decreases in the settlement of pond ash while using different types of stone column.

$$SRR = \frac{\text{Settlement of treated pond ash ,Sr}}{\text{Settlement of untreated pond ash,So}} X\ 100$$

$$SRR = \frac{Sr}{So} X\ 100$$

$$SRR = \frac{So - Sr}{So} X\ 100$$

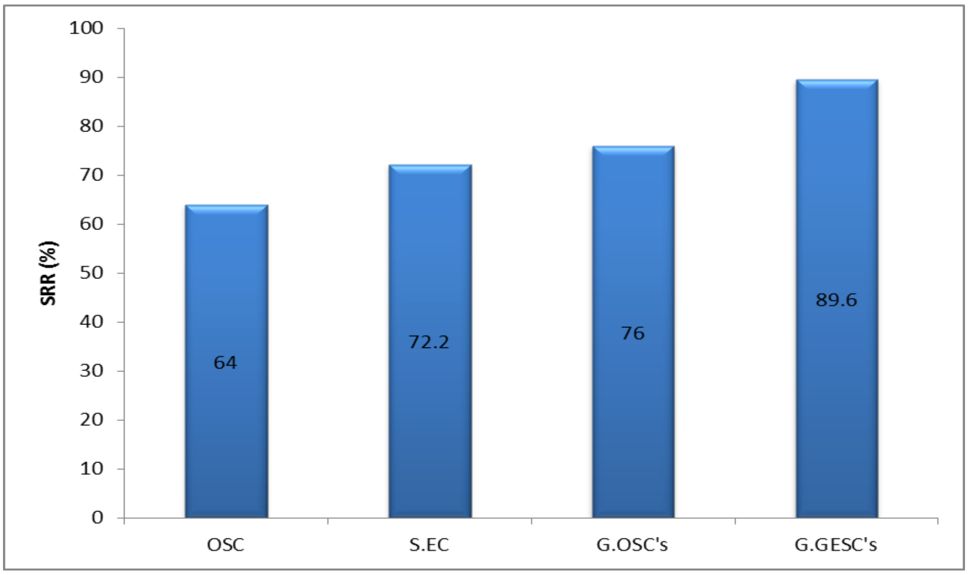


Fig 10 Increase in settlement reduction in successive cases

Fig 10 shows that SRR value for pond ash is 0 whereas it increase to 64% in the case of OSC that means an increase in settlement reduction of ash after the instalment of the column. After making SEC it further increase up to 72.2% and when the Group of OSC was made and the SRR value shows huge variation and increases to 76% because of the effective confinement provided by group of columns. SRR value increases up to 89.6% when GESC is made.

5. CONCLUSIONS

The plate load test was conducted on pond ash (untreated) and treated with OSC, GESC using plate of diameter 200mm and the result obtained were satisfactory. The following conclusion was drawn.

1. The untreated pond ash bears the load of 0.72 kN at settlement of 28mm. Whereas pond ash was treated with OSC and load is gradually increased up to 3.62 kN with overall settlement was 120mm.
2. When Geotextile encased stone column introduced the load carrying capacity increased up to 9.53 kN with settlement reduction up to 150mm.
3. When pond ash was treated with the help of a group of OSC it is found that bearing capacity is increased with load capacity increase in 13.54 kN under 150mm settlement.
4. Test on group GESC's of stone column has shown that the ultimate load carrying capacity up to 14.72 kN with huge gains in their load capacity.
5. The stiffness of the encasement has a considerable effect on the load carrying capacity.

6. Test on a group of OSC have shown that the load carrying capacity is much greater than the group of GESC.

6. REFERENCES

1. Alexiew.D, Brokemper.D and Lothspeich.S; (2005) "Geotextile encased columns (GEC) load capacity, geotextile selection and pre design graphs". (ASCE) Contemp. Issue in Found. Engg.
2. Black.J.A, Kumar.V.S and Bell.A (2011) "The settlement performance of stone column foundation". Geotech. 61,909-922.
3. Black.J.A, Kumar.S.V and Madhav.M.R; (2007) "Reinforced stone column in weak deposits; Laboratory model study" J. Geotech. Geoenviron. 133:1154-1161.
4. BIS 2003 IS 15284 "Design and construction for ground improvement guidelines part 1" Bureau of Indian Standers New Delhi India.
5. Castro.J; (2017**)** "Group of encased stone column; influence of column length and arrangement". Geotext and Geomem 45(2) 68-80.
6. Castro.J; (2017) "Modeling stone column" Mater 2017, 10,782.
7. Cengiz.C, and Guler.E; (2017) "Seismic behavior of Geo synthetic encased columns and ordinary stone columns" Geotext and geomem 46, 40-51.
8. Debnath, P., Dey, A.K ;(2017) "Bearing capacity of geogrid reinforced sand over encased stone column in soft clay" Geotext. Geomem.45, 653-664.
9. Dutta.S, Nadaf.M.B, Birali.R.R.L; (2016) "Encased stone column for soft ground improvement" ASCE Geo-Chicago GSP 271.
10. Fattah.M.Y, Zabar.B.S ;(2016) "Experimental Analysis of Embankment on ordinary and encased stone columns". ASCE J. Geomech 04015102.
11. Ghazavi.M, Yamchi.A.E, and Afshar. J. N; (2018), "Bearing capacity of horizontally layered Geosynthetic stone column." Geotext. Geomem. 46,312-318.
12. Ghazavi.M and Afshar.J.N; (2013) "Bearing capacity of Geosynthetic encased stone column." Geotext. Geomem. (2) 1-11.
13. Guetif.Z, Bouassida.M, Debats.J.M (2007); "Improved soft clay characteristics due to stone column installation." Comput. Geotech. 34(2007) 104-111.
14. Gupta.N, Yadav.K.K and Kumar.V (2015); "A review on current status of municipal solid waste management in India" Rese. Cen. Eco-Envir. Sci.
15. Murugesan.S and Rajagopal.K; (2010) "Studies on the behavior of single and group of Geosynthetic encased stone column".J. Geotech. Geo environ 136(1), 129-139.
16. Murugesan.S and Rajagopal.K; (2007) "Model tests on Geosynthetic encased column". Geosyn. Int. (2), 14 No. 16.
17. Murugesan.S and Rajagopal.K; (2006) "Geosynthetic encased stone column; Numerical evaluation".Geotext Geomem, 24 (2) 349-358.
18. Parsad.S.S.G and Satyanarayan.P.V.V; (2016) "Improvement of soft soil performance using stone columns with circular geogrid disc" IJST, Vol9 (30), DOI 10.17485/ijst/ (2)/v9i30/99186.
19. Trivedi. A and Sud.V.k (2007) "Settlement of compacted ash fills" Geot Geol Eng 2007 (25):163-176.
20. Zhan.Y, Jiang.G and Yao.H; (2014) "Dynamic characteristics of saturated silty soil ground treated by stone column composite foundation" Adv. in mater. Sci. and Engg.
21. Zukri.A and Nazir.R; (2018) "Sustainable material used as stone column filler" Adv. Mater. Sci, and Engg.

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