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Behaviour of Slopes Reinforced with Geosynthetic Encased Stone Column

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Abstract: Geosynthetic encased stone columns have the potential to contribute to the stability of soft clay embankments; however, there is a need to quantify the degree of this contribution. Ground improvement using stone columns is an important technique for foundation of embankments or structures on soft soils. Stone columns are vertical boreholes in the ground, filled with gravel compacted by a vibrator.
The inclusion of gravel, which has a higher strength, stiffness and permeability than the natural soft soil, improves the bearing capacity of the soft soil thus enhancing stability of the embankments and slope, reduces total and differential settlements, accelerates soil consolidation and reduces the liquefaction potential. Present study the author investigated the model study on Sloped Pond ash 45°(untreated), Sloped Pond ash with ordinary stone column (OSC), Sloped Pond ash with geosynthetic encased stone column (GESC).
The 85 mm diameter of ordinary stone column (OSC), geosynthetic encased stone column (GESC) was tested under the circular footing of 100mm diameter and 10mm thickness plate. The result show that load carrying capacity of sloped pond ash (untreated) was 226 N, sloped pond ash with ordinary stone column (OSC) was 552 N, sloped pond ash with geosynthetic encased stone column (GESC) was 1360 N. Columns can be used in embankment or natural slope to increase the slope stability, these can be used to release the pore water pressure and making the soil resistant to liquefaction.
Keywords: Ordinary stone column (OSC), Geosynthetic encased stone column (GESC), Sloped pond ash, Geogrid, Geotextile, Bearing capacity, Settlement, Encasement.

I. INTRODUCTION

A geotechnical engineer may encounter challenging problems while constructing an embankment on a soft soil deposit.Slope instabilityfailure of embankments istaken into account one amongst these major issues.Several ground improvement techniques have been widely used to avoid deep-seated failures including sand compaction columns, stone columns, and deep mixed columns. Ordinary stone columns (OSC) usually derive their load carrying capacity from passive resistance provided from the surrounding foundation soil against lateral bulging of stone columns as a result of axial load application. When embedded in soft clay, stone columns may bulge due to lack of confinement offered by the surrounding soft soil.

Furthermore, the soft clay may enter the voids between stones to cause clogging and reduce the permeability of stone columns for drainage. In order to avoid these consequences, additional confinement can be provided by usingStone columns are vertical boreholes in the ground, filled upwards with gravel compacted by means of a vibrator.

The inclusion of gravel, which has a higher strength, stiffness and permeability than the natural soft soil, improves the bearing capacity of the soft foundation thus enhancing stability of the embankments, reduces total and differential settlements, accelerates soil consolidation and reduces the liquefaction potential. Stone columns may not be appropriate in very soft soils that do not provide enough lateral confinement to the columns.

To increase the lateral confinement of the columns, and consequently, their vertical capacity, encasing the columns with geosynthetics has been a successful solution in recent years. More recently, stone columns have also been deployed beneath small isolated pad or strip footings at low or moderate loading conditions. Several authors have studied the bearing capacity anddeformations of these groups of stone columns.

 The columns, such as sand compaction columns, stone columns, and deep mixed columns, can fail due to shearing and bulging modes under embankment load. Bulging is the most common failure in stone columns under concentrated load and composite loads as shown in Fig. 1.
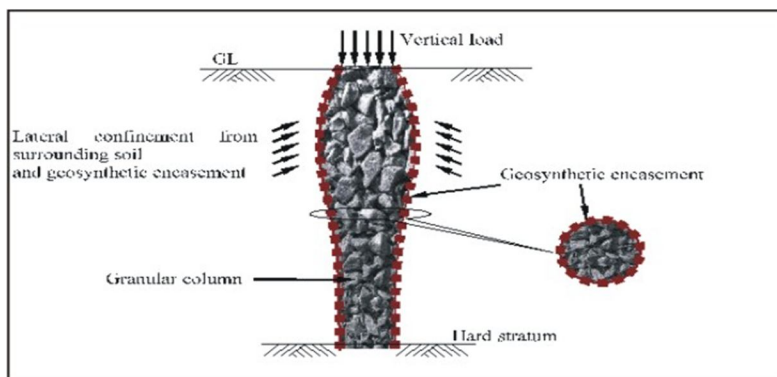
Fig. 1 Failure mechanism of stone column(Murugesan and Rajagopal 2006)

II. LITERATURE STUDY

The different researchers have been investigating the performance of encased granular columns. The work was conducted on analytical and numerical studies, experimental and field studies.

J.F.Chen.X.T. Wang,J.F.Xue, Y.Zeng, S.Z. Feng (2018), studied the Uniaxial compression behaviour of geotextile encased stone columns. It was found that the uniaxial compressive strength of the encased stone columns is not affected by the initial void ratio but mainlyby the tensile strength of the encasing geotextiles. The stress strain curves of the encased stone columns underuniaxial loading condition are nearly liner before failure, which is similar to the tensile behaviour of the geotextiles.

M.Gu M Zhao.L Zhang (2016) investigated the effects of geogrid encasement on lateraland vertical deformation of stone columns in model test. it was found that the lateral deformations of SC decreased due to additional confining stresses provided by geogrid encasement.

A. Burman, S. P. Acharya et. al (2015), studied the"Comparative study of slope stability analysis using traditional limit equilibrium method and finite elementMethod. It was found that The FOS values obtained using finite element method compare very well with that obtained from limit equilibrium methods. In finite element method, the FOS for critical slip surface is automatically obtained. In caseof limit equilibrium methods, several slip surfaces should be analyzed to find the critical slip surface. These types of trial and error calculations are not required with FEM to find out the critical slip surface because the failureoccurs through the zone of weakest material properties and automatically the critical slip surface is determined. Furthermore, finite element method satisfies the equations of equilibrium andcompatibility equationsfrom theory of elasticity.

Khaled Farah, Mounir Ltifi And HediHassis (2015), studiedthe Probabilistic FEMsFora Slope Reliability Analysis Using the Stress Fields. In this paper, it was found that they were concluded the perturbationmethod and the spectral stochastic finite element method(SSFEM) using random field theory are presented. Thesemethods are applied to analyze the stability of ahomogeneous slope assuming anelastic soilbehaviour. Toovercome the absence of the analytical solution of themean and standard deviation of the factor of safety

Miranda M., Da Costa A. (2015), conducted Laboratory AnalysisofEncased Stone Columns and it was found that the Effect of theGeotextile Is Noticeable Once A Certain Axial Strain Is Developed.

Zhang L., Zhao M. (2015.) analysis the deformation of Geotextile Encased Stone Columns. It was found that Selection Of The Geotextile Stiffness For Encased Stone Columns Should Be Done In Relation To Column Diameter And Spacing Because Increased And Decreased Spacing Have A Great Effect On Settlement Reduction

BozanaBacicn (2014), studied the slope stability analysis. In that paper it was found that they conclude a methodology of slope stabilityanalysis and provide an insight into the basic of landslides and their general terms. Natural process ofconstant affected by change in relationship for shearingstress and resistance.

Carol Matthews and Zeena Farook, Arup; And Peter Helm (2014), studied the slope stability analysis limits equilibrium or the finite element method. It was found that The both have their advantagesanddisadvantages with the choice of which method to usedepending on some of the considerations describedbelow the method the user selects should be based on thecomplexity of the problem to be modelled

Choobbsti A.J &PichkaH. (2014) Arab. J. Geosci , studied the Improvement of Soft Clay Using Installation ofGeosynthetic-Encased stone column. He was analysis the single as well as group column results and compare the both results when the total surfaces are loaded

Reginald Hammah et, all (1999), investigated the Model Test Study on Behaviour ofGeotextile Encased Sand Pile in Soft Clay Ground. It was found that Bearing Capacity Of The Soft Clay Ground Reinforced By The GESP (GEOTEXTILE ENCASED SAND PILE) Is Larger Than That Of The Soft Ground Reinforced By The Conventional Sand Piles And The Failure Mode Of The GESP IS Buckling Different From The Bulging Of The Sand Piles.

III. MATERIAL AND EXPERIMENTAL SET UP

1) *Pond Ash:* Ash is the residue after combustion of coal in thermal power plants. Particle size of the ash varies from around one micron to around 600 microns. Unused fly ash and bottom ash (residue collected at the bottom of furnace) are mixed in slurry form and deposited in ponds. Pond ash was used as the soft soil material in the experiment and it was taken from Ropar thermal power plant, Ropar, Punjab. Relative density of 40% was maintained in placing pond ash in model tank.Relevant properties of pond ashverifying its physical properties, chemical properties are tabulatedin Table 1.

Table 1- Physical and chemical properties of pond ash*(Trivedi and sud, 2007)*

Colour	Grey	Chemical components %	Ropar ash
Physical form	Fine grained	SiO_2	57.5
Specific gravity	1.6	Al_2O_3	27.2
Max. dry density	0.97g/cc	Fe_2O_3	5.4
Uniformity coefficient	2.15	CaO	3.1
Curvature coefficient	1.12	MgO	0.4
		Na_2O, K_2O	0.9
		SO_3	-
		Unburned carbon	4.1

2) *Recycled Concrete Aggregates:* Recycling of concrete is a relatively simple process. It involves breaking, removing, and crushing existing concrete into a material with a specified size and quality.Recycled aggregate is produced by crushing concrete, and sometimes asphalt, to reclaim the aggregate. Particle size of aggregates lies in range of 2 mm to 20mm. Aggregates classified as non-uniform well graded(as per USCS).

Fig. 2 Pond ash, recycled aggregates (From Construction & Demolition waste) and Geogrid

3) *Geogrid:*Geogrids are made up of polyethene (HDPE), commonly used to reinforce retaining walls as well as sub bases or subsoil's below roads or foundations. Geogrids are imparts the tensile strength (Fig. 2). The tensile strength of the geogrid is 33KN/m in longitudinal and lateral direction. The properties are displayed in Table 2.

Table 2- Properties of Uniaxial Geogrid *(SGi-040: Courtesy M/S Strata Geosystems (India) Pvt. Ltd, Mumbai, India)*

Aperture size	25mmx25mm
Cross Machine Direction	
Single rib tensile strength	33.4 KN/m
Single rib elongation at 30 KN/m	10.30%
Machine Direction	
Single rib tensile strength	33.4 KN/m
Single rib elongation at 30 KN/m	11%

Table 3- Properties of Non-woven Uniaxial Geotextile

Property	Value
Tensile strength	1kN/m
Elongation	50%
Trapezoidal Tear	0.13kN
CBR Puncture strength	0.78kN
Permittivity	2.2 per Sec
Water flow rate	150gpm/ft

A. Model Tank Set Up

A model test tank with the dimensions having length (Lt) 830 mm, width (Bt) 680mm and depth (Dt) 630mm is designed and fabricated to perform the test as shown in Fig. 4. The sides of themodel tank are made 12mm thick iron metal sheets. It is stiff enough toprevent any deformation of the ash during the process of compaction and at application of the load as well. The inside of the tank is smooth to reduce the side friction.

Fig. 3 Model tank for flat and slope cases including loading plate and dial gauges

Loading machine was developed by AIMIL for load settlement test. It is a manually operate machine and dial gauge (50mm) of least count 0.01mm are used for displacement reading and digital load cell for load measurement. A circular footing of100 mm diameter 10mm thick plate attached verticallyfor slope at 45°cases used.

B. Tank bed and Stone column Preparation

Pond ash tested in the laboratory in order to find out the physical parameters of the Pond ash. The ash was uniformly and thoroughly placed in the tank usingraining technique to maintain 40% relative density,For the compaction purpose the authorhadused raining technique. After placing the ash uniformly in the tank, the tank circular plate load using footing of diameter 100 mm for slope surfacewas conducted on pond ash (untreated) at 40% relative density to determine the load settlement behaviour. In second series with the help of small auger kind of device used to create the bore hole. Bore hole was immediately encased with the PVC pipe so that ash should not cave in. In this case author tested OSC (ordinary stone column) on sloped surface, that is encased(geogrid+geotextile) bore hole filled with the recycled concrete aggregates. The aggregates were filled in layers and tamping rod of 20mm diameter was used to compact the aggregates in the column and simultaneously encased PVC pipe was pulled out as column was filled. Circular plate load test was performed on sloped surface (45°) withOSC to determine the load deformation behaviour of the composite pond ash. In the third case(slope with GESC),with the help of small auger kind of device used to create the bore hole. Bore hole was immediately encased with the PVC pipe so that ash should not cave in.In this case author tested GESC(Geosynthetic encased stone column) with slope (45°),that is encased(geogrid+geotextile) bore hole filled with the recycled

concrete aggregates. The aggregates were filled in layers and tamping rod of 20mm diameter was used to compact the aggregates in the column and simultaneously encased PVC pipe was pulled out as column is filled and PVC pipe rapped with the geogrid lowered the pipe into the column. Filling the column with aggregates, slowly PVC pipe was pulled by leaving the geogrid and geotextile inside the wall of the column. At most care was taken at this stage and aggregates were filled in the column.Circular plate load test was performed to understand the behaviour of the ultimate bearing capacity and settlement of geosynthetic encased stone column with slope of 45°.

C. Cases taken into study
1) Plate load test on Sloped Pond ash (45°) (UNTREATED),
2) Plate load test on Sloped Pond ash (45°) with ordinary stone column (OSC)
3) Plate load test on Sloped Pond ash (45°) with geosynthetic encased stone column (GESC)
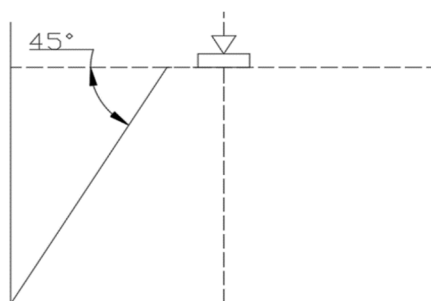

FIG.4 - Model tank maintained with 45° slope

IV.   RESULTS AND DISCUSSION

A. Load and Settlement Relationships

Fig 5 shows that when plate load test was conducted then load at settlement of 50 mm in case of sloped pond ash (45°)(untreated) was 226 N and when Model tank test of slopedpond ash with OSCwas done, the load correspondence to settlement was 552 Nand when Model tank test of slopedpond ash with GESCwas done,the load correspondence to settlement was 1360N.Loading was done with plate of diameter 100mm and thickness 10mm.The interval between settlements was constant at 1 mm.Plate load test was done up to 50mm settlement for sloped pond ash with GESC and the load at that settlement was 1360 N showing increase of501% in load at same settlement, as comparedto the case of Plate load test on sloped pond ashuntreated.Plate load test was done up to 50mm settlement for sloped pond ash with OSC and the load at that settlement was 552 N showing decrease of 146% in load at same settlement, as comparedto the case of plate load test on sloped pond ash with GESC. As pond ash is a weak material confinement, it also decreases the strength of stone column.By using geosynthetic encased stone column as vertical reinforcement on slope there was huge improvement in strength of column and load reached to 1360 N at settlement of 50mm showing load gain of 501% as compare to sloped pond ash untreated and 146% increase as compare to sloped pond ash with OSC.
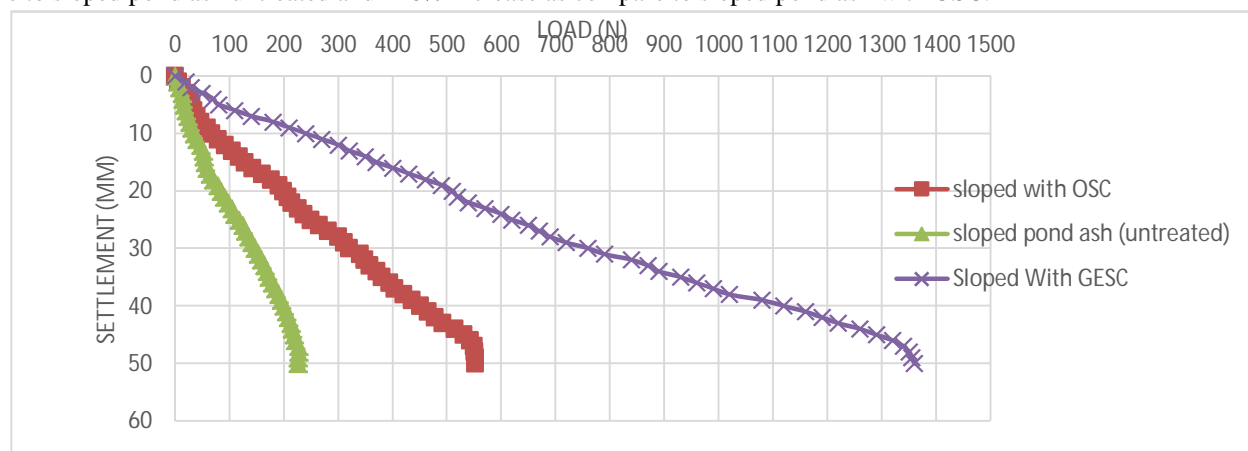

Fig 5 Comparison of load to settlement values of sloped pond ash (untreated), sloped Pond Ash with OSC, SlopedPond Ash with GESC

B. Bearing capacity ratio (BCR)

Bearing capacity ratio is the ratio of bearing capacity of ordinary stone column to the bearing capacity of Pond ash.

$$BCR = \frac{bearing\ capacity\ of\ reinforced\ stone\ column}{bearing\ capacity\ of\ pond\ ash\ (untreated)}$$

values of B.C.R. obtained while performing plate load test on different materials used for stone column are tabulatedbelow.

Table 3- BCR values of pond ash alone, OSC, HESC, GGESC, HESC+VESC at 50mm settlement

Material	BCR value
Sloped Pond ash (untreated)	1.0
Sloped with OSC	2.44
Sloped with GESC	6.01

Fig 6 shows that BCR value for Sloped Pond ash (untreated) is 1,whereas it increases to 2.44 in case of sloped pond ash with OSC that means increase in bearing capacity of ash after the instalment of column, and BCR value increases to 6.01 in case of Sloped Pond ash with GESC that means increase in bearing capacity of sloped pond ash after the instalment of encased column.
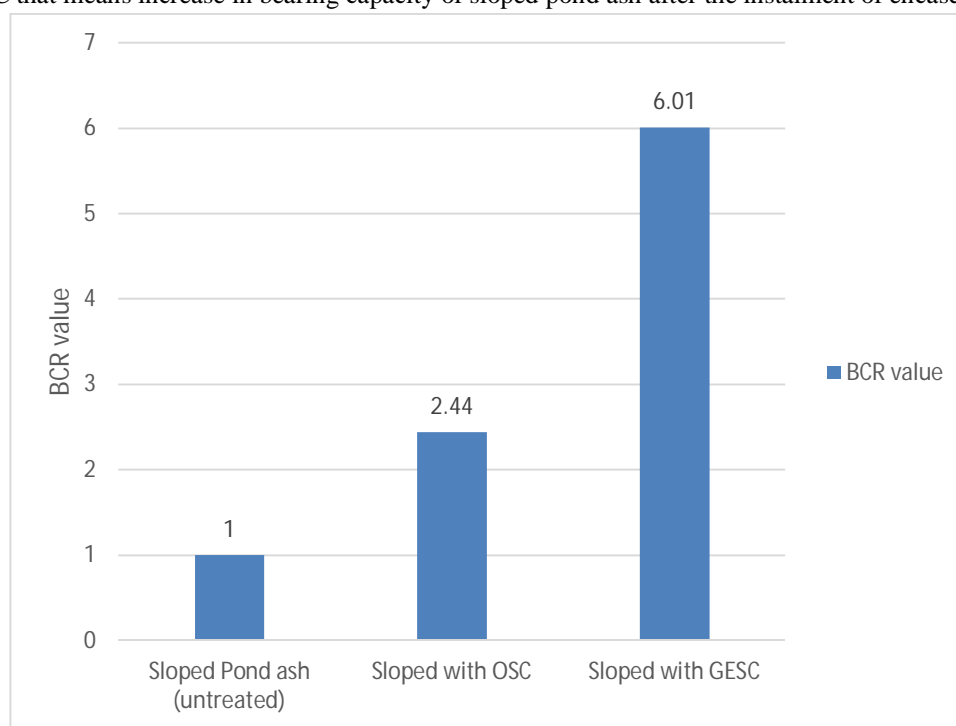

Fig 6BCR values of pond ash alone, Pond ash with GESC, Slope without GESC, slope with GESC

V. CONCLUSIONS

From the study of plate load test on slopes made of pond ash usingwithout and with stone columns the following conclusions are made: -

A. Load carrying capacity of sloped pond ash (untreated) case is 226 N at the settlement of 50mm at 40% relative density.
B. Load carrying capacity of sloped pond ash with OSC case is 552 N at the settlement of 50mm at 40% relative density.
C. Load carrying capacity of sloped pond ash with GESC case is 1360 N at the settlement of 50mm at 40% relative density.
D. The increment of load carrying capacity of sloped pond ash having ordinary stone column (OSC) to the sloped pond ash (untreated) is 144%.
E. The increment of load carrying capacity of sloped pond ash having geosynthetic encased stone column (GESC) to the sloped pond ash (untreated) is 501%.
F. The increment of load carrying capacity of sloped pond ash having geosynthetic encased stone column (GESC) to the sloped pond ash with ordinary stone column is 146%.

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