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Behaviour of Geogrid Encased Stone Column in Pond Ash Fills

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Abstract: ***Ground improvement using stone columns is a popular 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, reduces total and differential settlements, accelerates soil consolidation and reduces the liquefaction potential. Present study the author investigated the model study on Ordinary stone columns (OSC), Geogrid encased stone columns (GGESC), Horizontal geogrid layered stone column (HESC) and Horizontal and Vertical encased stone column (HESC+VESC) on ash fills. The 85mm diameter OSC, GGESC, HESC, HESC+VESC are tested under the circular footing in the model tank set up. The results show that load carrying capacity was increased at significance level and settlement was reduced in case of horizontal and vertical encased stone columnin comparison with thegeogrid encased stone columns, horizontal geogrid layered stone column, ordinary stone columns and Pond ash.***
Keywords: Ordinary stone column (OSC), Geogrid encased stone column (GESC), Horizontal geogrid layered stone column (HESC), Horizontal and Vertical encased stone column (HESC+VESC), Bearing capacity, Settlement, Geogrid.

I. INTRODUCTION

Stone 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 geotextiles or other geosynthetics has been a successful solution in recent years. Using horizontal geosynthetic disks placed in regular vertical intervals through the column length has also shown to be efficient alternative Stone columns and encased stone columns (ESC) are typically employed under embankments or large uniformly loaded areas. 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 and deformations 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.

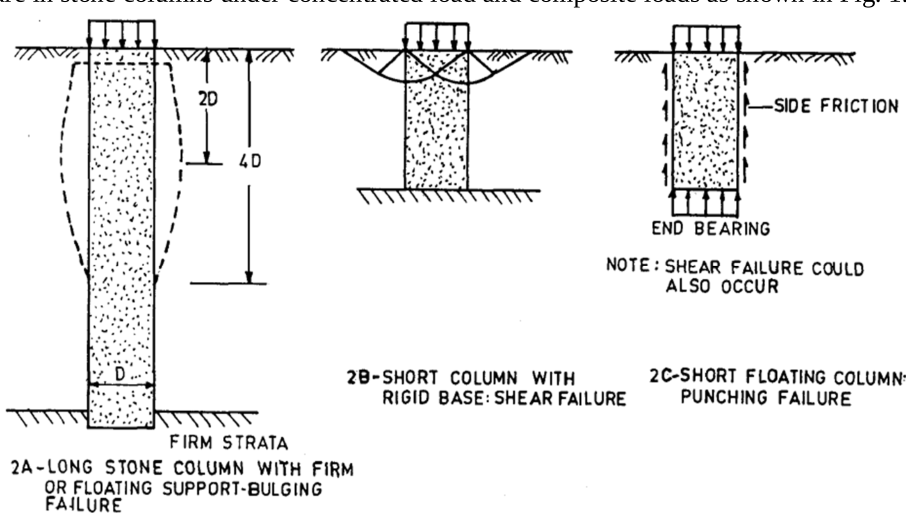

Fig. 1 Bulging, shear and punchingFailure mechanism of stone column *(IS 15284: 2003)*

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.

Kwa, Kolosov and Fattah (2018), studied the stone columns are encased with geogrids in soft soils. It was found that encasing the stone column with geogrid results in an increase in load carrying capacity and reduction in a settlement in comparison with the case without geogrid.

With the geogrid the ultimate bearing capacity increased by 60% compared to that without geogrid and load bearing capacity increased by 20% for 10mm settlement.

Prasad and Satynanarayana (2016), investigated on stone columns reinforced with the circular geogrid discs surrounded by soft soils. The results presented that improving the soft soil with the above concept that is the ultimate load of the soil has been increased by about 117% and is increased by 16% and 41% by placing the circular geogrid reinforcement at diameter spacing and half diameter spacing.

Ali et al.(2010, 2014) conducted laboratory experiments on granular columns with and without encasement on floating and full penetration basis.

Parametric studies revealed that smaller diameter columns gave better performance and there was no improvement in bearing capacity for a granular column length greater than 6 times diameter in the study conducted. The authors observed that full encasement increases the failure stress in the columns when compared to partial encasement.

Dash and Bora (2013) investigated the effect of reinforcement length on bearing capacity through laboratory tests on floating and end bearing granular columns.

The floating columns exhibited a 5 fold increase in capacity with 60% coverage length of column, whereas the improvement was 3 fold for full coverage (length) of encasement. For end bearing columns full encasement showed a better response than partial encasement.

Dheerendra et al (2010) studied the load settlement of stone columns with circumferential nails. Series of plate load tests are performed in laboratory in rigid unit cell tank. It has observed that these circumferential nails provide restraint to the lateral displacement of stones leading to improvement in the load carrying capacity.

Gneil and Bouazza (2009, 2010) conducted laboratory experiments to verify the effect of partial encasement in both single and group of granular columns.

A steady reduction in vertical strain was observed for increase in length of encasement for the above mentioned categories of granular columns.

Murugesan and Rajagopal (2006) have numerically investigated the advantages of encased granular column over ordinary granular columns using the program GEOFEM and concluded that the elastic modulus of the geosynthetic encasement plays an important role in enhancing the load carrying capacity and stiffness of the encased columns.

Black, Sivakumar and Madhav (2007) studied on the performance of stone columns in a weak soil deposit such as peat. Stone columns are treated with jacketing with tubular wire mesh, metal internal bridging rod and concrete plug installation. Of the three methods, bridging reinforcement performed exceptionally well in terms of load carrying capacity and moduli of subgrade reaction.

Murugesan and Rajagopal (2006, 2007, 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.

Malarvizhi and Ilamparuthi (2004) observed the load versus settlement relationship of ordinary and encased granular column through laboratory studies.

The settlement decreased with increase in stiffness of the encasement. For lesser and higher loads the settlement reduction is observed better for ordinary and encased granular columns.

Raithel and Kempfert (2000) investigated numerically the use of compacted sand columns in peaty soils and brought out models based on numerical and analytical forms. For single columns, axisymmetric model and for a deformation behavior of the whole system a cross model was preferred and used.

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III. MATERIAL AND EXPERIMENTAL SET UP

1) *Pond Ash:* Pond ash was used as the soft soil material in the experiment and it was taken from Ropar thermal power plant. Relative density of 60% was maintained in placing pond ash in tank. Relevant properties of pond ash (Ropar, Punjab) verifying its physical properties, chemical properties are tabulated below.

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

Colour	Grey
Physical form	Fine grained
Specific gravity	1.6
Max. dry density	0.97g/cc
Uniformity coefficient	2.15
Curvature coefficient	1.12

Chemical components %	Ropar ash
SiO_2	57.5
Al_2O_3	27.2
Fe_2O_3	5.4
CaO	3.1
MgO	0.4
Na_2O, K_2O	0.9
SO_3	-
Unburned carbon	4.1

2) *Recycled Aggregates:* 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 20 mm. Aggregates were non-uniformly well graded aggregate mix.

Fig. 2 Pond ash field (in thermal power plant), 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)*

Thickness	0.27mm
Aperture size	30x20mm
Cross Machine Direction	
Single rib tensile strength	33.9 kN/m
Single rib elongation at 30 kN/m	10.3%
Number of ribs per meter	38
Machine Direction	
Single rib tensile strength	43.4 kN/m
Single rib elongation at 30 kN/m	11%
Number of ribs per meter	37

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 the model tank are made 12mm thick iron metal sheets. It is stiff enough to prevent 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 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 (25mm) of least count 0.01mm are used for displacement reading and digital load cell for load measurement. A circular footing of 200 mm diameter 14mm thick plate attached vertically.

B. Tank bed and Stone column Preparation

Pond ash tested in the laboratory in order to find physical parameters. The ash was uniformly and thoroughly placed in the tank using raining technique to maintain 60% relative density. The compaction purpose author used raining technique. After placing the ash uniformly in the tank, the tank circular plate load using footing of diameter 200 mm was conducted on ash alone at 60% 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. Third level author tested only ordinary stone columns, that is encased bore hole filled the recycled concrete aggregates. The aggregates filled in layers and used the 20mm tamping rod to compacting the aggregates in the column and simultaneously encased pvc pipe was pulled out as column is filled. Circular plate load test applied on ordinary stone column to determine the load deformation behaviour of the composite ash. Fourth level aggregates removed from the column, 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 inside the wall of the column. Atmost care was taken at this stage and aggregates are filled in the column with the compaction.Circular plate load test was applied to understand the behaviour of the ultimate bearing capacity and settlement of geogrid encased stone column (GGESC). Fifth level again aggregates along with geogrid were removed from column andinstead of vertical encasement of geogrid horizontal discs of geogrid were placed at interval of 1.5D (where D is diameter of column) along the length of column while filling aggregates inside the column. Circular plate load test was applied to understand the behaviour of the ultimate bearing capacity and settlement. Sixth level again aggregates along with geogrid were removed from column and both vertical encasement and horizontal encasement of geogrid were provided to column.PVC pipe rapped with the geogrid lowered the pipe into the column andfilling the column with aggregates was done in layers, at end of each layer horizontal disc was placed and then slowly pvc pipe was pulled by leaving the geogrid inside the wall of the column and horizontal discs along the length of column at interval 1.5D. Circular plate load test was applied to understand the behaviour of the ultimate bearing capacity and settlement.

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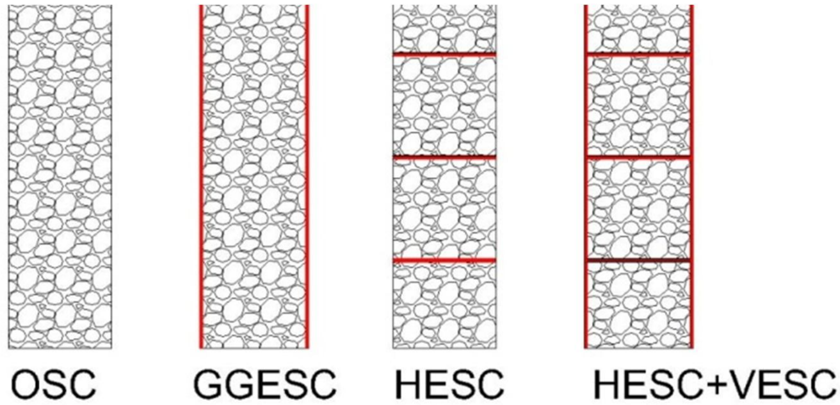

Fig 4 Different cases of stone column taken into study

IV. RESULTS AND DISCUSSION

A. Load and Settlement Relationships

Fig 5 shows that when plate load test was conducted then load at settlement of 28 mm in case of pond ash alone was 160 N and when an ordinary stone column was made at the centre then load increases to 390 N showing increase of 143% in load at same settlement. In case of HESC Load further increase to 410 N showing a increase of 5% as compare to ordinary stone column and 156% compared to pond ash alone. As pond ash is a weak material confinement provided by it is also less that also decreases the strength of stone column while using geogrid as vertical reinforcement to ordinary stone column there was huge improvement in strength of column and load reached to 1140 N at settlement of 28mm showing load gain of 192% as compare to ordinary stone column and 612% increase compare to pond ash alone. While further strengthening GGESC column by providing horizontal reinforcement load increases to 1240 N showing increase of 218% as compare to ordinary stone column and 675% increase as compare to pond ash alone.

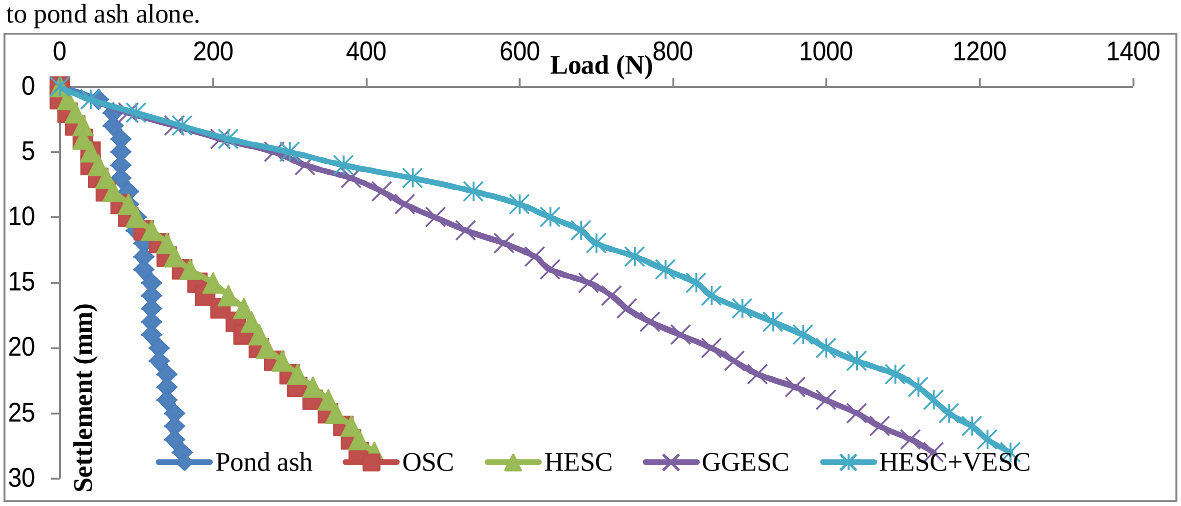

Fig 5 Comparison of load to settlement values of pond ash alone, OSC, HESC, GGESC, HESC+VESC

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.

$$\text{BCR} = \frac{\textit{bearing capacity of ordinary stone column}}{\textit{bearing capacity of pond ash}}$$

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

Table 3- BCR values of pond ash alone, OSC, HESC, GGESC, HESC+VESC at 28mm settlement

Material	Pond ash	OSC	HESC	GGESC	HESC+VESC
BCR value	1	2.44	2.56	7.13	7.75

Fig 6 shows that BCR value for pond ash is 1 where as it increases to 2.44 in case of OSC that means increase in bearing capacity of ash after the instalment of column. After making HESC it further increase to 2.56 and when vertical encasement was done to the column the BCR value shows huge variation and increases to 7.13 because of the effective confinement provided by geogrid that was absent in case of pond ash. BCR value increase to 7.75 when both HESC and VESC used at same time.

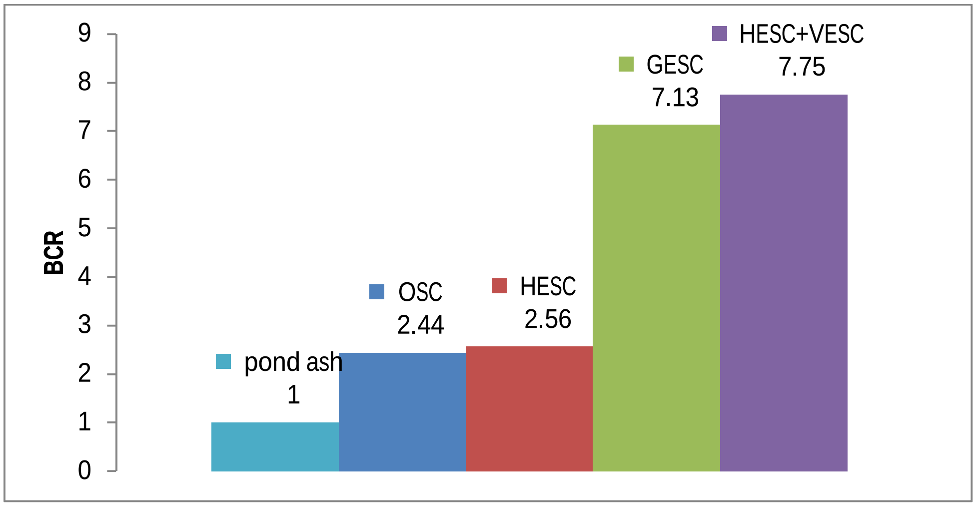

Fig 6 BCR values of pond ash alone, OSC, HESC, GGESC, HESC+VESC

C. *Settlement reduction ratio (SRR)*

Settlement reduction ratio tells us about the decrease in settlement of pond ash while using different type of stone columns. To find SRR first a load is fixed then settlement is various cases at that load are noted. Let the settlement of pond ash as S_0 and settlement in other cases as S_r . Then settlement reduction ratio will be

$$\text{Settlement reduction ratio (SRR): -} \frac{S_r}{S_0} X100$$

Table 4 shows the settlement and SRR of different type of stone column at load 160N.

Material	Pond ash	OSC	HESC	GGESC	HESC+VESC
Settlement (mm)	28	14	13.4	3.2	3
SRR	100	50	51.79	88.57	89.29

Fig 7 shows that SRR value for pond ash is 0 where as it increase to 50% in case of OSC that means increase in settlement reduction of ash after the instalment of column. After making HESC it further increase to 51.79% and when vertical encasement was done to the column the SRR value shows huge variation and increases to 88.57 because of the effective confinement provided by geogrid that was absent in case of pond ash. SRR value increase to 89.29 when both HESC and VESC used at same time.

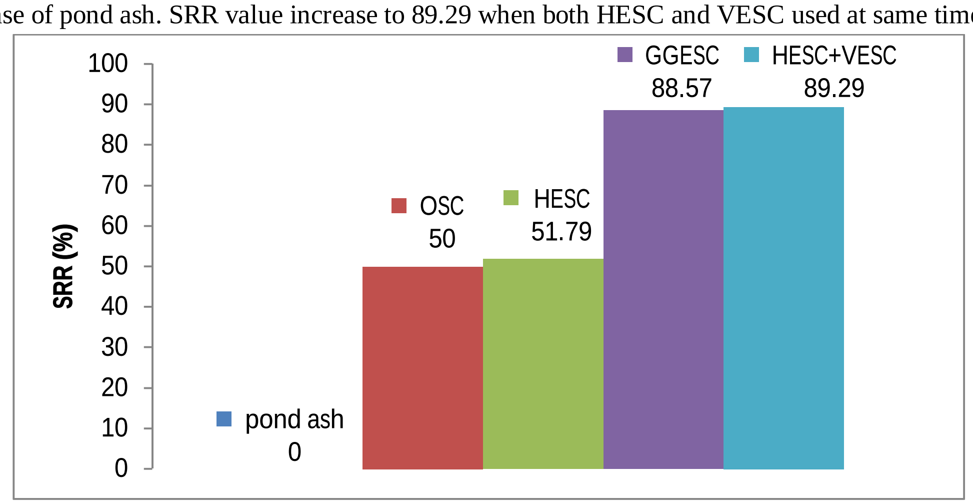

Fig 7 Increase in settlement reduction in successive cases

D. *Improvement Factor*

Improvement factor (IF) is the ratio of bearing capacity of ordinary stone column and bearing capacity of pond ash.

$$\text{Improvement factor} = \frac{\textit{bearing capacity of ordinary stone column}}{\textit{bearing capacity of pond ash}}$$

Fig 8 shows that the improvement vs settlement ratio values, it is very clear to understand that at 0.1 settlement ratio values the improvement factor for only pond ash is 1, where as in other composite column encasement cases the IF values are 2, 2.08, 6.54 and 7.69 times improved in OSC, HESC, GGESC and VESC+HESC respectively.

Table 5 shows the values of improvement factor at S/D 0.1.

Material	Pond Ash	OSC	HESC	GGESC	HESC+VESC
IF	1	2	2.08	6.54	7.69

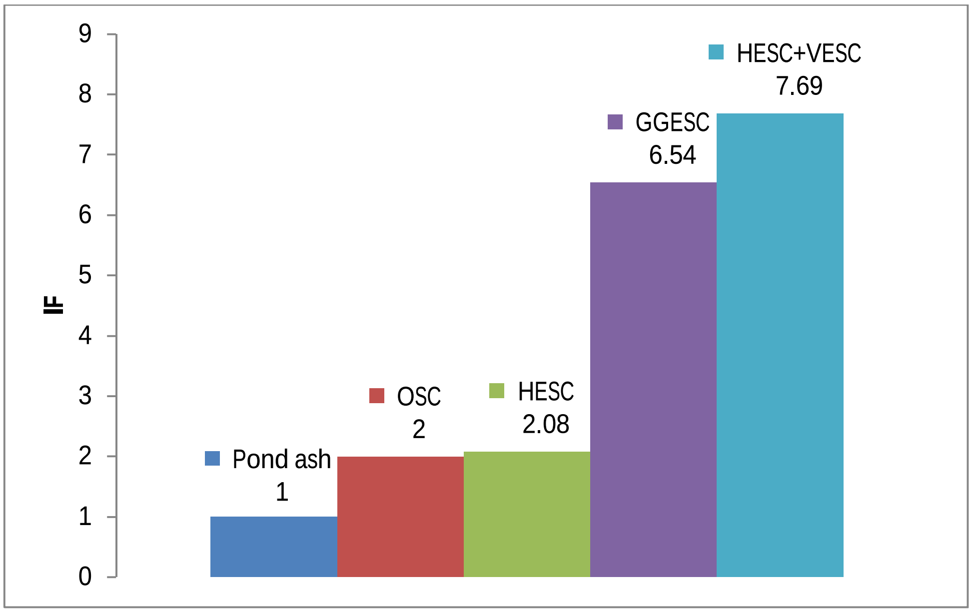

Fig 8 Increase in IF w.r.t S/D in successive cases of pond ash alone, OSC, HESC, GGESC, HESC+VESC at S/D 0.1

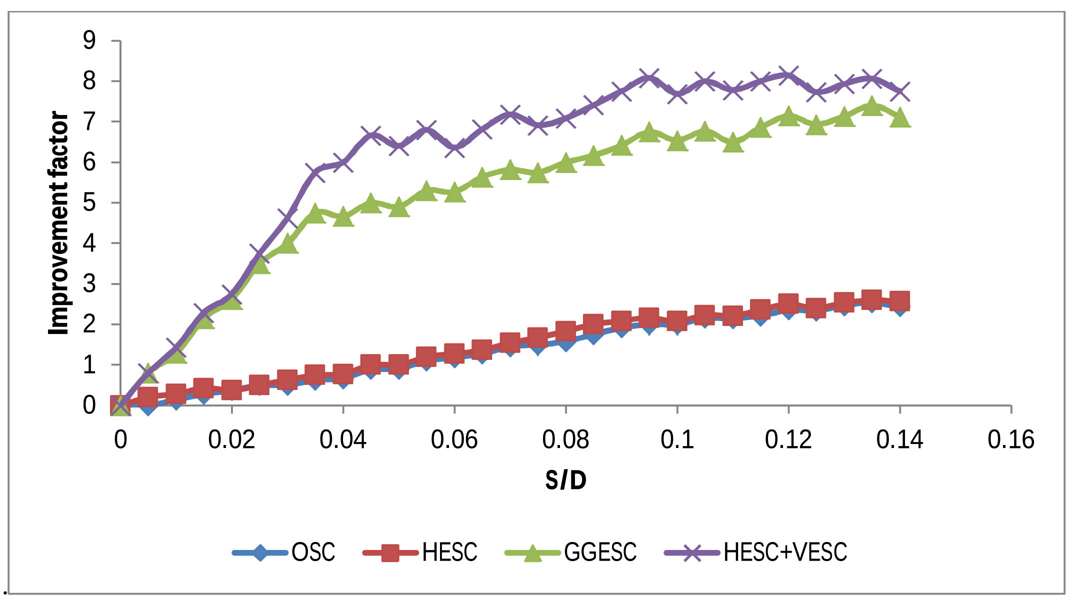

Fig 9 Increase in IF w.r.t S/D in successive cases of pond ash alone, OSC, HESC, GGESC, HESC+VESC

V. CONCLUSIONS

After performing the plate load test on pond ash using different types of stone column following conclusions are made:-

A. There is increase of 143% and 156% in load taking capacity of pond ash after instalment of ordinary stone column and horizontally encased stone column respectively.
B. There is increase of 612% and 675% in load taking capacity while using geogrid as vertical encasement and when used both as horizontal or vertical encasement in stone column.
C. There is reduction in settlement by 50% and 51.79 % at same load of 160 N in case of OSC and HESC as compared to pond ash without any column.
D. Maximum reduction in settlement is 89.29% when geogrid was used as encasement in both vertical and horizontal direction.
E. There is more than 7 times improvement in load taking capacity while using horizontal and vertical encased stone column as compare to pond ash without column.

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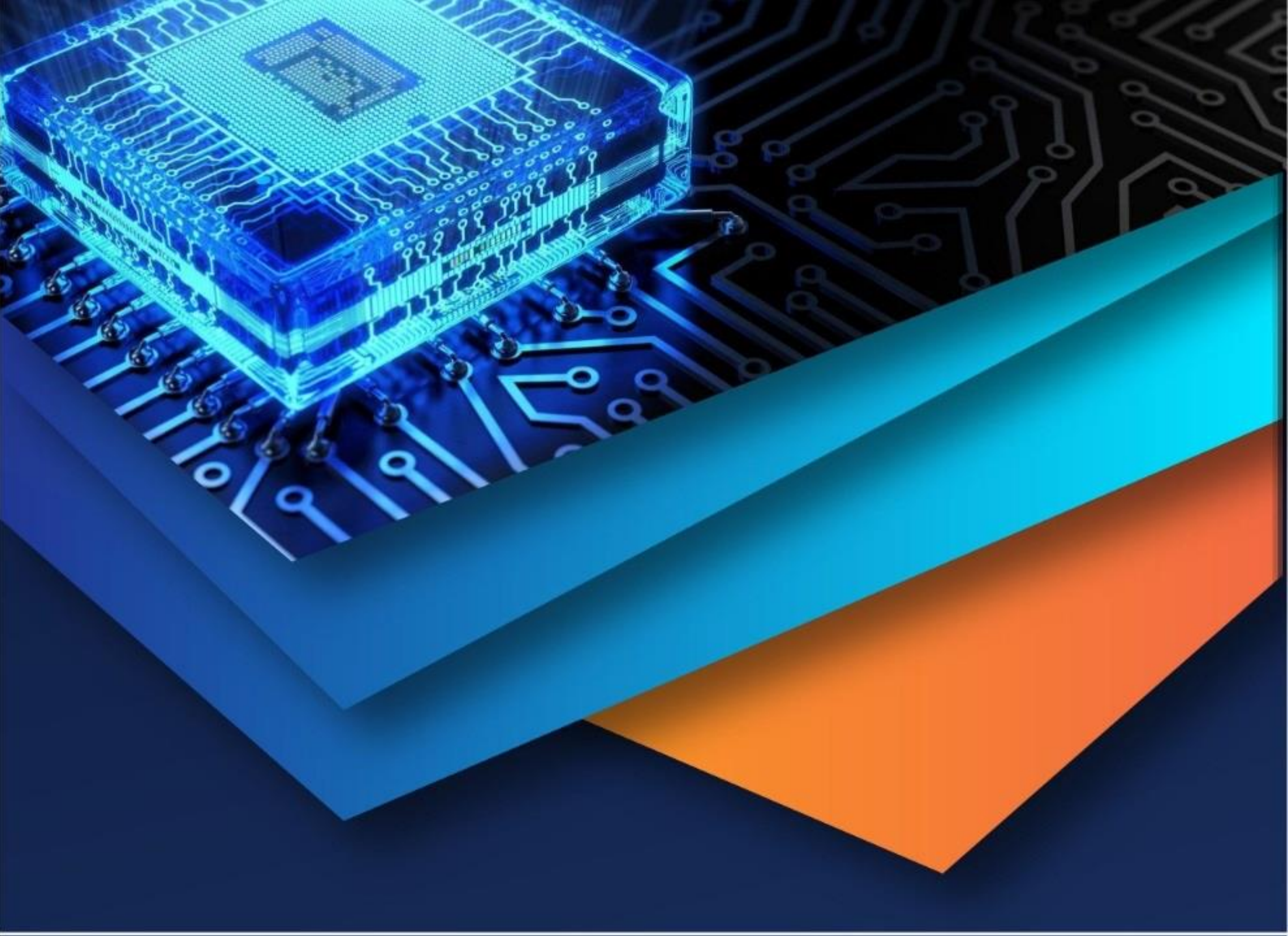

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