

Effect of Sand Blanket Reinforced with Geogrid Over the Stone Column in Compressible Clay Soils: 3D Numerical Study



Sudheer Kumar Jala, Sudhanshu Sharma, and Aijaz H. Bhat

Abstract The present study is on stiffening the soft cohesive soils with a sand blanket, sand reinforced with geogrid layer and reinforced with geotextile encased stone columns (GESCs). The three-dimensional numerical investigation was conducted on sand reinforced without and with a geogrid effect. And below the sand bed, the ordinary and encased columns are studied. The circular footing (uniform distributed load) rests on a multi-layered soil model. The significant parameters investigated through these models are load improvement factor (LIF), bearing capacity improvement ratio (BCR), settlement reduction ratio (SRR), modulus of subgrade reaction and stiffness improvement ratio. From the results, it is evident that sand bed with ordinary stone column and GESC cases gives a considerable improvement. The percentage of improvement in the case of sand bed reinforced with geogrid layer followed by GESC installed is 148% than the untreated cohesive soil. This study is useful for highway subgrades and raft slabs that rest on soft cohesive soils to control total settlement and non-uniform settlement.

Keywords Sand bed · Ordinary stone columns · Geotextile encased stone columns · Stiffness · Modulus of subgrade reaction

1 Introduction

Compressible soils like clay soil and peat with a higher plasticity index give an excessive settlement. Several methods are adopted to reduce the plasticity index of the soil. Particularly at foundation and pavement subgrade constructions, regular practice is to replace the expansive soils with the granular soil and reinforce the soil mass below the foundation/subgrade by various inclusions like a geosynthetic group

S. K. Jala (✉) · S. Sharma · A. H. Bhat
Department of Civil Engineering, DAV Institute of Engineering and Technology, Jalandhar, India
e-mail: sudheeritd@gmail.com

S. Sharma
e-mail: sudhir.jala@gmail.com

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2023
A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 1*, Lecture Notes in Civil Engineering 280,
https://doi.org/10.1007/978-981-19-4739-1_36

397

of material, horizontal steel strips, fiber material, etc. And the famous practice in the recent past is to install the stone columns at shallow depths. They not only enhance the bearing strength but will also reduce the settlement of the footing/subgrade.

1.1 Background

Several researchers [1–4] have reported an increase in bearing capacity and reduced settlement behavior of foundations by the inclusion of reinforcements. Stone columns are constructed by replacing poor soil with crushed stone aggregate to construct a vertically resistant system. The stone column technique is a useful, environment-friendly and cost-effective method for resolving settlement issues in the ‘soft’ soils. Stone columns also increase the consolidation rate in soft soils because of high permeability. It is observed from the literature that the location of inclusions (influence depth) significantly affects the reinforcing action. Biaxial geogrids and granulated blast furnace slag (*GBS*) were tested to determine the optimum depth for the first layer of reinforcement from the footing base and its effect on bearing capacity ratio (BCR). Gill et al. [5] reported that the bearing capacity of a coal ash slope with coal ash used as an embankment fill material is found to yield an increase in bearing capacity using geogrids. The bearing capacity improvement with number of geogrid layers ($N = 1, 3, 4$) in sand underlain by silt clay reported as 44.44%, 61.11% and 72.22% respectively [6]. Laboratory model test results for the ultimate bearing capacity of a strip foundation supported by multi-layered geogrid-reinforced sand at one relative density were also compared with theoretical results.

The previous researchers worked experimentally and numerically on ordinary stone columns and geosynthetic stone columns. The published literature is proven that they are very effective in increasing the bearing capacity and controlling the settlement in expansive clay soils when they were at their liquid limit and undrained shear strength is less than 15 kPa [7–10].

Mehrannia et al. [11] examined a granular blanket with two thicknesses of 40 and 75 mm which were reinforced by geogrid and also use stone column which was reinforced by geotextile encasement which helps to increase stress concentration ratio, bearing capacity and the stiffness of stone column. Sudheer et al. [12] reduced the amount of lateral deformation up to 92 and 74% in the case of HC-2 and HC-1 encasement systems with a comparison of the OSC case. The bearing capacity of encased stone columns was done numerically. Hataf et al. [13] with the help of graphical representation showed that the maximum value of load factor which was equal to 1.4 means encasing the stone columns increases the bearing capacity of the stone column by 40%. Using loaded strip footing resting on mattress-strips fly ash slopes, [2] examined maximum to minimum percentage variation of bearing capacity from 6.96 to 0.54. Lateral bulging is reduced when horizontal reinforcement is used in stone columns because of additional support provided by frictional and interlocking interaction of geogrids [14]. It was found that under-reamed cemented stone columns are highly effective in enhancing the bearing capacity and stiffness of

soft clay ground. Bearing capacity improvement factor in case of under-reamed SC increases about 45–50% [15].

In the present study, authors are numerically comparing the load-carrying capacity of the sand blanket, geogrid at the interface of the two layers and vertical stone column without and with geosynthetic encasement in soft soils. The total six cases were studied in the current research that are presented graphically in Fig. 1. Case 1. clay without any reinforcement, case 2. compressible clay with 0.5m coarse sand blanket at top of the surface, case 3. geogrid was applied for reinforcing the soils at the interface of the two layers, case 4. ordinary stone column in the full thickness of clay underneath the sand blanket and there is no geogrid used at the interface of the two layers, case 5. encased stone column in the full thickness of clay underneath the sand blanket and there is no geogrid used at the interface of the two layers and case 6. encased stone column with geogrid at the interface clay -sand.

2 Materials

For the numerical analysis purpose, clay as foundation soil, sand blanket as a top layer, geogrid and stone aggregates are used in the column as fill material. Table 1 presented the properties of materials used for the study.

3 Numerical Modeling Considerations—Plaxis FE Analysis

Plaxis 3D program was used to perform finite element analyses. In all the FE analyses, the thickness of the soft soil was kept as 8 m in the 1st case and later a 0.5 m sand layer was laid on top of the clay. The stone column having a diameter of 1 m extends to the full depth of the clay layer. The Mohr–Coulomb parameters used in the numerical analyses are similar to the typical values used by other researchers. The clayey soil was also modeled as Mohr–Coulomb material. The geosynthetic was modeled as an elastic membrane element. The geosynthetic was assumed to be an isotropic linear material, with an assumed Poisson's ratio of 0.3. For the geosynthetic used to encase granular columns on different projects, the design tensile modulus (J) values ranged from 300 and 10,000 kN/m. Hence, a value of $J = 4500$ kN/m was used in the numerical analyses. The software which the authors used (Plaxis 3D) defines the interaction factor. The angle of shear resistance depends on the interaction coefficient value.

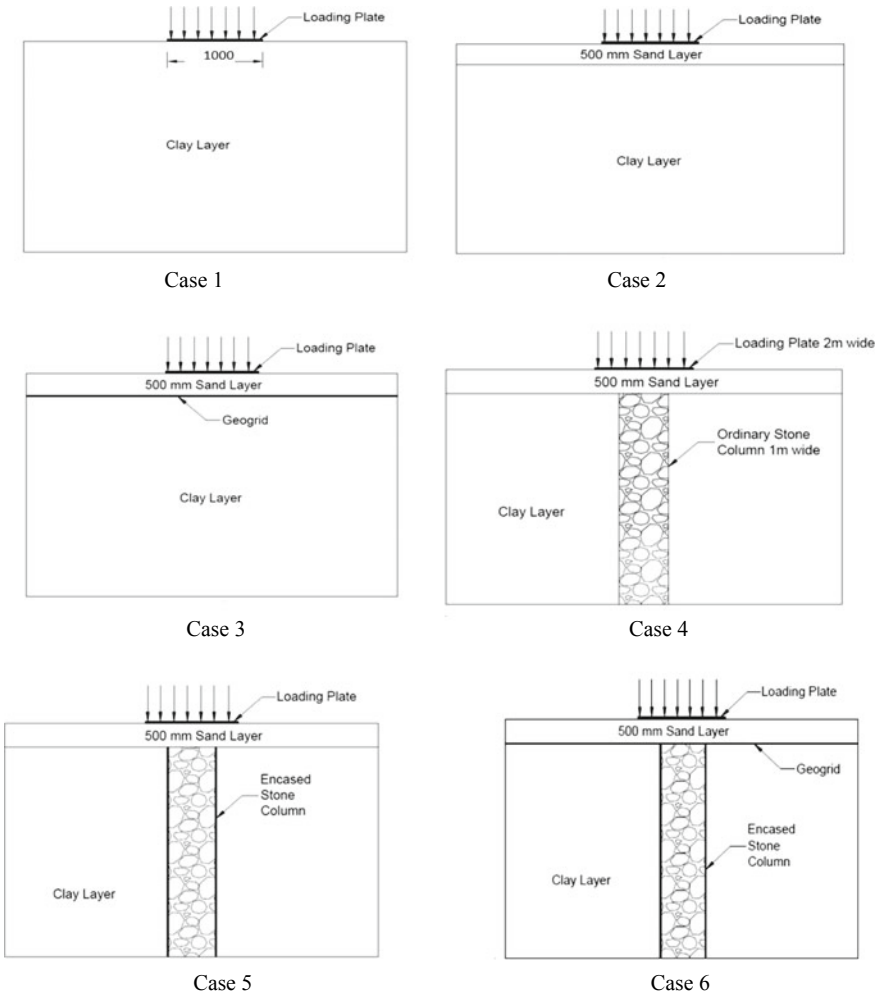


Fig. 1 Graphical representation of the cases studied

4 Results and Discussions

To determine the stress–settlement behavior on top of the soil model, soil nodal points corresponding to the top of the column were subjected to a series of vertical downward displacements by applying a uniformly distributed load.

The surrounding soil nodes were left to displace freely because the analysis was done to examine the behavior of a single column that is being used to support an applied structural load. Corresponding to the load applied at the top, the resultant settlement was recorded and a load-settlement graph was drawn for each case as shown in Fig. 2.

Table 1 Material properties used in the analysis [7–9]

Test parameter	Sand (drained)	Geogrid	Clay (undrained)	Stone aggregate (drained)
Eref (modulus of elasticity) kN/m ²	20,000	–	5000	40,000
Tensile strength (kN/m)	–	4500	–	–
V (Poisson’s ratio)	0.3	–	0.33	0.3
Φ (angle of internal friction)	34°	–	30°	44°
Ψ (psi)	4°	–	0	14°
C	1	–	15	0
Unsaturated unit weight (kN/m ³)	17	–	17	17
Saturated unit weight (kN/m ³)	20	–	18	22
K _x (m/day)	1	–	0.0100	1
K _y (m/day)	1	–	0.0100	1

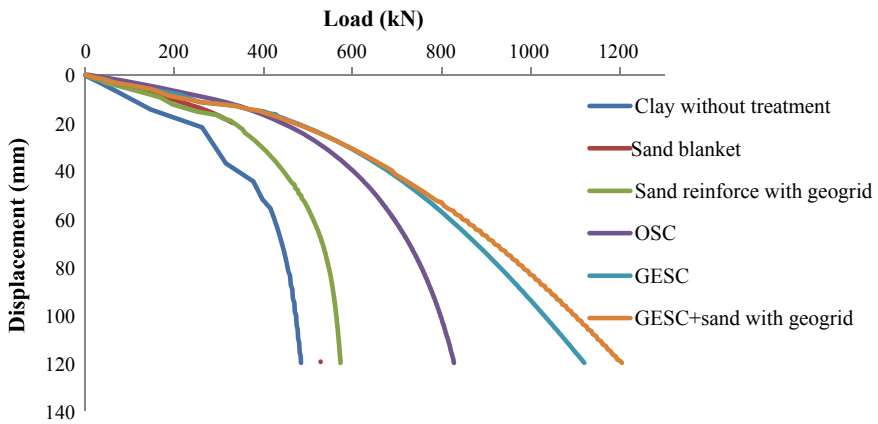


Fig. 2 Effect of sand blanket, geogrid and stone column on a load-carrying capacity of compressible clay soils

From Fig. 2, it is evident that untreated clayey soil undergoes larger deformations under smaller load values. The sand layer is provided at the top of the clay; it carries more load (12.5% more) for the same value of displacement. The geogrid is placed between the clay and the sand layer; the value of the load is 25% more than untreated soil. In another case, ordinary stone column (OSC) is placed in the clay underneath the sand layer without any geogrid and the load carried by the composite soil is 100% more than untreated soil. In another case, GESc is placed in the clay underneath the

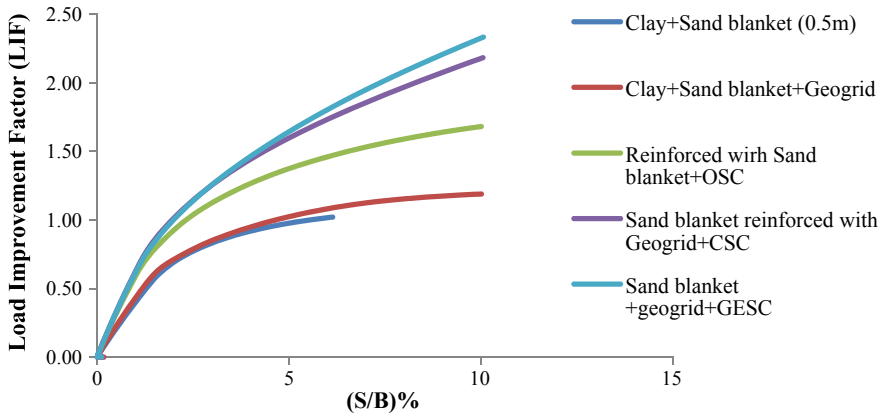


Fig. 3 Variation of load improvement factor with (S/B) ratios

sand layer without geogrid and the value of the load is 162% more than untreated soil. In the last case, GESC is placed in the clay-sand soil having an interface between them; the value of the load is 187% more than the untreated soil.

Figure 3 shows the plot between the load improvement factor (LIF) and the settlement upon width for all the cases discussed earlier. The value of LIF is lowest for clay soil having a top layer with a 0.5 m sand layer. The geogrid is placed between the sand and the clay layer, and the LIF increases by 20%. The OSC is placed in the clay under the sand layer without geogrid, and the LIF increases by 70%. When the OSC is encased, the LIF value increases by 120%. In the last case, GESC is placed with geogrid at the interface of the sand and clay layer, and the LIF value increases by 130%.

The relative improvement in the load-carrying capacity of various improvement techniques is computed in terms of bearing capacity improvement ratio or bearing capacity ratio (BCR) which is equal to the ratio of bearing capacity of treated soil to the untreated soil resulted presented in Fig. 4. The BCR value increases with different ground improvement techniques. The BCR value is high when soil is reinforced with GESC, and geogrid is placed in between the clay and sand layer. It is evident from Fig. 5 that the settlement reduction ratio increases from case 1 to case 6. The highest settlement reduction is possible with the OSC, GESC and sand reinforced with the geogrid followed by the GESC. This may be due to the geogrids, the settlement reduced considerably, and also because of interlocking and high tensile strength of the geogrid ribs in transverse and machine direction, it contributes to the load-carrying capacity of the soil.

Figure 6 shows the variation of stiffness of the treated soil which is an indicator to determine the tendency for material to return to its original position after being subjected to load. The stiffness is defined as the ratio of the load applied on a boundary through a loading area divided by the displacement experienced by the loaded area. From Fig. 6, the stiffness of the composite ground steadily increases in all cases

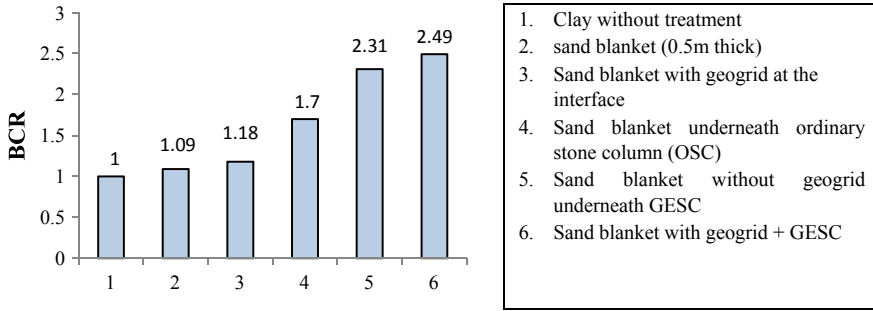


Fig. 4 Bearing capacity ratio variation with the treatment of the compressible clay soil

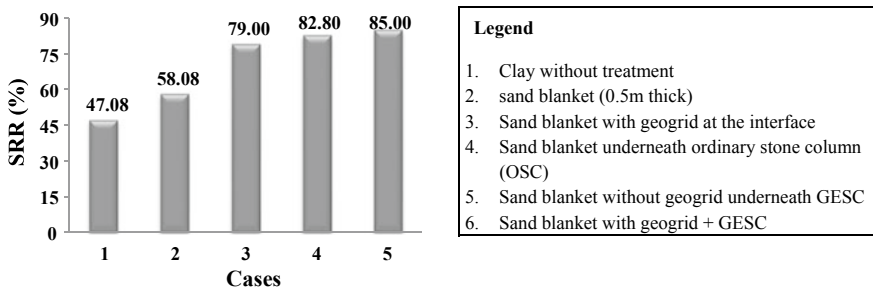


Fig. 5 Effect of the sand blanket, geogrid, CSC and GESC treatments of incompressible clay soils

when compared to the clay soil without treatment. The percentage increases of the stiffness when compared to the clay without treatment are 18% in the case of sand with geogrid, 70% in the case of OSC, 131% in the case of GESC and 148% in the case of sand reinforced with the geogrid plus GESC case. The stiffness of the subgrade and composite soil is a very important parameter to design the rigid pavements and raft or mat foundations. This study may be useful to improve the stiffness factor of the composite ground.

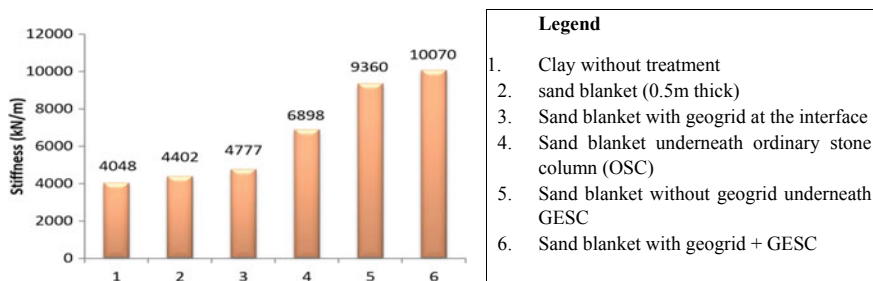


Fig. 6 Variation of stiffness of the treated compressible soils

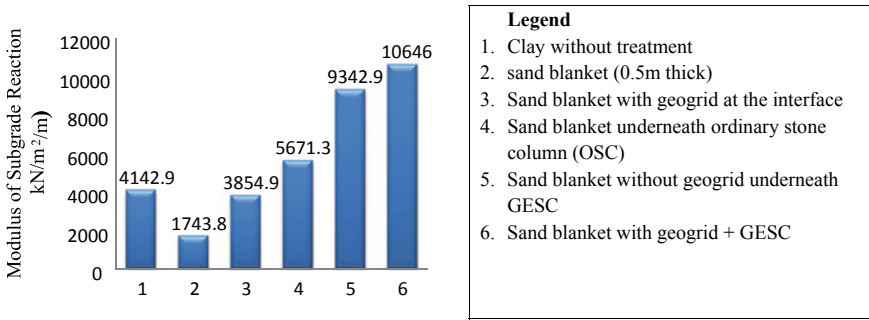


Fig. 7 Comparison of modulus of subgrade reaction of the treated compressible soils

Figure 7 shows the modulus of subgrade reaction of the treated compressible soils. The conceptual relationship between the applied pressures against settlement at that particular point is used vastly in the analysis of foundation members. It is expressed as $K_s = p/s$. It can be defined as the initial slope of the applied pressure to the settlement of the plate load test curve. The unit of the subgrade modulus is $\text{kN/m}^2/\text{m}$. In the present study results, as shown in Fig. 6, the subgrade reaction is reported very less when the upper compressible layer is replaced with the 0.5 m thick sand. This may be due to the looseness of the granular particles, and compression is higher at the immediate of the footing load. Subgrade reaction is improved consistently in the remaining cases. The improvement of the subgrade reaction from OSC to GESC with a sand bed is significant. It is useful in piles subjected to lateral load, strip footing, mats and rigid pavement design and other types of foundation member's design.

5 Failure Mechanism of Reinforced Soil

The mode of failures of all the six cases are presented in Fig. 8; it is evident that just below loading plate settlement is higher due to higher compression; and it is following Terzaghi's failure model. The depth of the failure zone increases as reinforcement is incorporated through the sand, sand with geogrid, sand with OSC, sand with GESC and sand with geogrid and GESC cases.

6 Conclusions

The load-settlement characteristics of the parent clay soil can be enhanced by providing a sand blanket on the top of the clay by 12.5% more for the same value of displacement but when GESC is placed in the clay-sand soil having geogrid at the interface, the value of the carrying load is 187% more than the untreated soil. Encasing

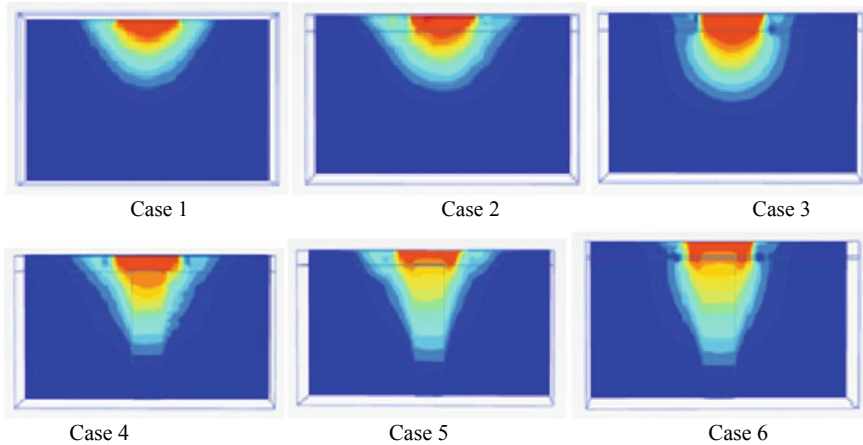


Fig. 8 Mode of failure of the clay without and with sand, geogrid and stone columns

the stone column with geogrid increases the bearing capacity of the composite foundation and reduces the settlement. The maximum value of bearing capacity is reported for an encased stone column with geogrid at the clay-sand interface.

Although the modulus of subgrade reaction was reported to be less when a sand blanket was applied on top of the clay, it significantly increases when a stone column was introduced. The modulus further increases when a stone column was encased and geogrid was introduced at the clay-soil interface.

This study shows the value of modulus of subgrade reaction of the last case as clay and sand with GESG and geogrid at interface is $10646 \text{ kN/m}^2/\text{m}$ which is more effective than other cases especially than clay and sand with CSC and geogrid at the interface by 14%.

The stiffness of the composite soil follows the same trend as the bearing capacity ratio. The stiffness is highest for an encased stone column with geogrid at the clay-sand interface.

References

1. Kumar A (2018) Behavior of strip footing resting on pretensioned geogrid reinforced ferrochrome slag subgrade. Doctoral dissertation, NIT, Jamshedpur
2. Nadaf MB, Mandal JN (2017) Model studies on fly ash slopes reinforced with planar steel grids. *Int J Geotech Eng* 11(1):20–31
3. Yadu L, Tripathi RK (2014) Effect of depth and number of layers of reinforcement on bearing-capacity ratio of strip footing resting on granulated blast-furnace slag reinforced with geogrid. In: *Geo congress: geo-characterization and modeling for sustainability*, pp 3605–3614
4. Prasad PS, Ramana GV (2016) Feasibility study of copper slag as structural fill in reinforced soil structures. *Int J Geotext Geomem* 44(6):623–640

5. Gill KS, Choudhary AK, Jha JN, Shukla SK (2013) Large model footing load test on multi-layer reinforced coal ash slope. In: *Geo-congress: stability and performance of slopes and embankments III*, pp 489–498
6. Kolay PK, Kumar S, Tiwari D (2013) Improvement of bearing capacity of shallow foundation on geogrid reinforced silty clay and sand. *J Const Eng*
7. Ghazavi M, Yamchi AE, Afsar JN (2018) Bearing capacity of horizontally layered geosynthetic reinforced stone columns. *Geotext Geomembre* 46:312–318
8. Murugesan S, Rajagopal K (2006) Geosynthetic-encased stone columns: numerical evaluation. *Geotext Geomembr* 24(6):349e358
9. Malarvizhi SN, Ilamparuthi K (2007) Comparative study on the behaviour of encased stone column and conventional stone column. *Soils Found* 47(5):873–885
10. Black JA, Sivakumar V, Madhav MR, Hamill GA (2007) Reinforced stone columns in weak deposits: laboratory model study. *J Geotech Geoenviron* 133(9):1154–1161
11. Mehrannia N, Kalantary F, Ganjian N (2018) Experimental study on soil improvement with stone columns and granular blankets. *J Cent South Univ* 25:866–878
12. Sudheer KJ, Rawat S, Gupta AK (2021) Loose ash fills reinforced with the high confined encased stone columns—experimental and numerical investigation. *Int J Geotech Geolog* 39:2503–2520
13. Hataf N, Nabipour N, Sadr A (2020) Experimental and numerical study on the bearing capacity of encased stone columns. *Int J Geo-Eng* 11:4
14. Naderi E, Asakereh A, Dehghani M (2018) Bearing capacity of strip footing on clay slope reinforced with stone columns. *Arabian J Sci Eng*
15. Fatma KS, Kolosov ES, Fattah MY (2019) Behavior of different materials for stone column construction. *J Eng Appl Sci* 14(4):1162–1168
16. Dash SK, Bora MC (2013) Influence of geosynthetic encasement on the performance of stone columns floating in soft clay. *Can Geotech J* 50:754–765
17. Prasad S, Satyanarayana PVV (2016) Improvement of soft soil performance using stone columns improved with circular geogrid discs. *Ind J Sci Techn* 9(30)