Bearing Capacity and Settlement Response of Pervious Concrete Column without and with under Reamed Bulb: Numerical Investigation

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Abstract -_*Granular stone columns are widely used to improve the weak soil and provide the drainage path but their effectiveness depends upon on the confinement provided by the surrounding soil due to the discrete nature of the stone aggregates. The pervious concrete on the other hand increases the stiffness and so does the bearing capacity. This paper describes the two dimensional (2D) numerical analysis of various ground improvement techniques used in a saturated clay soil. The numerical analysis was done in a rectangular soil strip with reinforcement provided at the centre line. Various ground improvement techniques used in this paper include ordinary stone column(OSC), geosynthetic encased stone column(GESC), Pervious concrete column(PCC) and under reamed pervious concrete column(UPCC). The finite element analysis was done in Plaxis 2D software. The results showed that the vertical as well as horizontal settlement of the reinforced soil is less than the unreinforced soil. The settlement is minimum for under reamed pervious concrete column (reduces by 52.8%). For PCC, GESC and OSC, the settlement reduces by 30.5%, 25.3% and 19.5% respectively. The bearing capacity increased in the order of OSC<GESC<PPCP<UPCP. The bearing capacity for OSC, GESC, PCC and UPCC treated soil improved by 17%, 21%, 30% and 83% respectively.*

1. Introduction

Practically all civil engineering construction is carried in or with soil. The decreasing availability of good construction sites is building up pressure on the engineers to utilize even the poorest of sites either by special type of foundation or by improving the ground. The weak subsoil deposits pose the problem of low bearing capacity and excessive settlement over long periods of time. The developed methods of ground improvement can be effectively utilized to force the soil to behave according the project requirements. The basic concepts of ground improvement include drainage, densification, cementation and reinforcement. The various techniques developed and used at the deeper depths are dynamic compaction, blasting, consolidation by pre loading and or vertical drains, electro-osmosis, lime piles, jet grouting and granular piles/stone column. The advanced new ground improvement technique of pervious concrete columns in place of stone columns will be useful in multiple purpose of drainage and bearing strength. Pervious concrete (also called as no-fines concrete and porous concrete) is a special type of concrete primarily made of coarse aggregate (single sized) and cement paste with minimum amount of fine aggregate or no fine aggregate. The omission of fine aggregate in the pervious concrete leads to the creation of a large number of internally connected voids that allow the water to pass through the concrete with a permeability equivalent to the granular material. Geosynthetics have been used in the recent past for the partial and full encasement of the granular columns to enhance the stiffness of the column[1],[2],[3]. Experimental as well as numerical methods have been used extensively to study the behaviour of conventional and encased granular columns[4], [5], [6]. Cemented stone columns were introduced to increase the stiffness of the granular material[7]. In this paper, authors are trying to numerically analyse the behaviour of pervious concrete as column material because pervious concrete has more stiffness and permeability comparable to granular material. Finite element analysis has been carried out by Plaxis 2D.

2. Literature Background

The unconfined compressive strength of the pervious concrete material is more than 10 times than that of the confined granular columns; and the permeability coefficients of the pervious concrete material and granular columns were comparable[8]. Pervious concrete has more stiffness and permeability comparable to granular material [9], [10]. Pervious concrete pile has greater aseismic effects and can avoid excess pore water pressure generation during an earthquake[11]. Standard penetration value (SPT) value was found to be largest for pervious concrete pile (PCP) composite foundation and minimum for soil cement mixed pile (SCMP) composite foundation which indicated the method of vibrating sinking tube can significantly improve the bearing capacity of soil around piles. Horizontal acceleration was observed to be least for PCP and largest for SCMP. Excess pore water pressure in PCP was least and that of SCMP was largest[12]. Pile-soil stress ratio was found to be maximum for PCP and smallest for granular column (GC). Also, lateral displacement was found to be maximum for GC resulting in lower strength. Total settlement was found to be maximum for GC and minimum for PCP [13]. It was found that the lateral displacement was more for precast pervious concrete pile and less for cast in-situ pile (55% of precast)[14]. In case of stone column, the bulging failure usually occurs at a depth of D to 2D from the top of the stone column head. The failure mode in group of stone columns was a combination of bulging and lateral deformation [15]. The strength values of different mixtures of pervious concrete increased in the following order: single < binary < ternary mixtures. Results also showed that even though the densities of two pervious concrete mixtures are similar, the pore structure plays an important role in controlling the flexural strength. The single-sized aggregate mixtures showed low toughness irrespective of other mixture variables [16].

3. Materials and Modeling

The materials and their properties used in the modeling are given in table 1. The finite element analysis is done in a saturated clay sample reinforced with different ground improvement techniques such as ordinary stone column(OSC), geosynthetic encased stone column(GESC), pervious concrete column(PCC) and under reamed pervious concrete column(UPCC). The vertical and horizontal settlement undergone by the clay soil under loading is obtained by performing plastic analysis by Plaxis 2D. The schematic representation is shown in Fig 1(a, b, c, d, e)

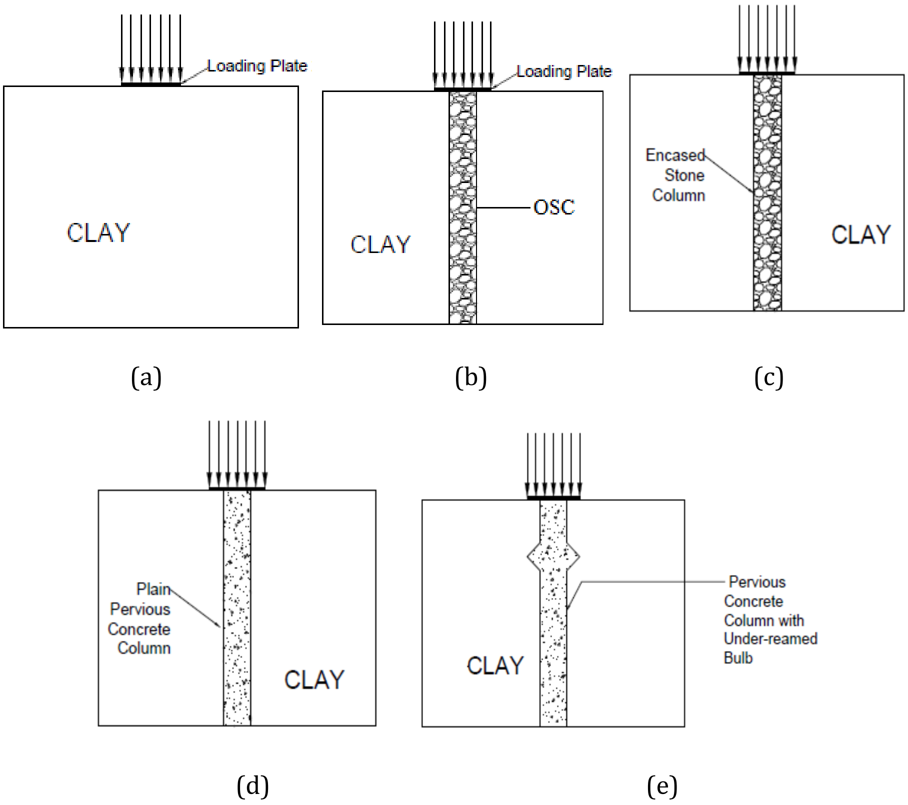


Fig 1. (a) clay soil (b) OSC treated soil (c) GESC treated soil (d) PCC treated soil (e) UPCC treated soil

Table 1 Materials and properties used in the modeling

Material Properties	Peat	Clay	Sand	Embankment	Pervious concrete column
Model	*Soft Soil (SS)*	*Soft Soil (SS)*	*Hardening Soil (HS)*	*Hardening Soil (HS)*	*Mohr Columb (MC)*
γ_{unsat}	8	15	17	16	18
γ_{sat}	12	18	20	19	20
$C^{/}$ (kN/m^2)	10	28	0	29.3	5
$\phi^{/}$	23	17.8	33	30	31

Ψ/	0	0	3	0	1
Permeability K(m/s)	$0.8x10^{-8}$	$1.22x10^{-8}$	0.74	-	$7.14x10^{-3}$

4. Results and discussion

Clayey soils are prone to total and differential settlement because of the high water retaining capacity. The clayey soils undergo large deformations under imposed loading and are not advisable for construction purpose unless reinforced with some other stiff material. In case of untreated clay soil, it undergoes a vertical settlement of 80 mm and horizontal settlement of 12mm. The schematic representation of vertical deflection of the soil under loading is shown in Fig 2

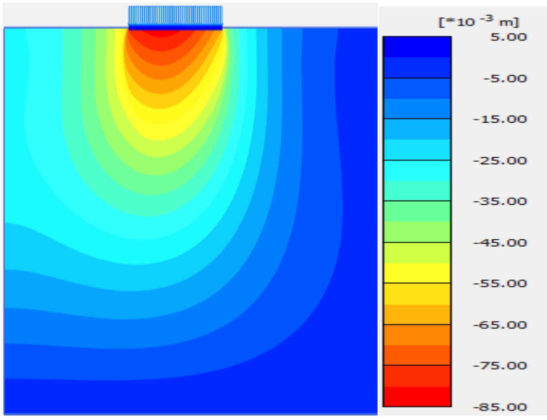
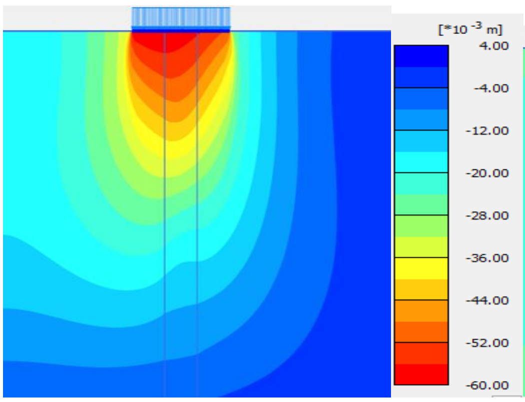


Fig 2 Vertical settlement of untreated clay

a. Clay soil treated with ordinary stone column

Stone aggregates have higher stiffness and strength than the clay soil. When clay soil is treated with ordinary stone column, both horizontal as well as vertical settlement is reduced. The composite soil undergoes a vertical settlement of 60 mm and a horizontal displacement of 9mm as shown schematically in Fig 3 and Fig 4



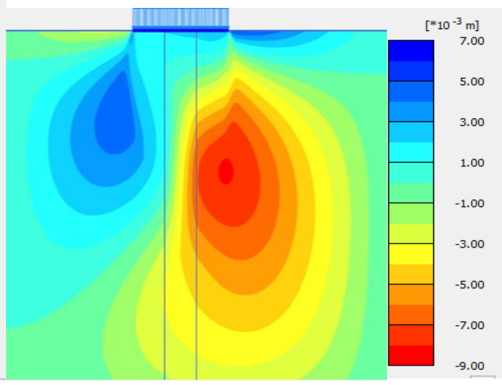


Fig 3 vertical settlement of OSC

Fig 4 Horizontal settlement of OSC treated soil treated clayey soil

Because of the more strength of the stone aggregates, more load is shared by stone column. The composite soil undergoes a total settlement of 60 mm at the incoming load of 100 kN.

b. Clay soil treated with geosynthetic encased stone column

Ordinary stone column is constructed with discrete stone aggregates without any binding material and the tend to get displaced laterally upon the application of the load. In order to contain the stone aggregates in a definite volume, geosynthetic is used along the periphery of the stone column. When the ordinary stone column is encased in geosynthetic, the stiffness of the column increases and thus the vertical as well as all horizontal settlement decreases and got a value of 58 mm and 7 mm respectively as shown schematically in Fig 5 and Fig 6

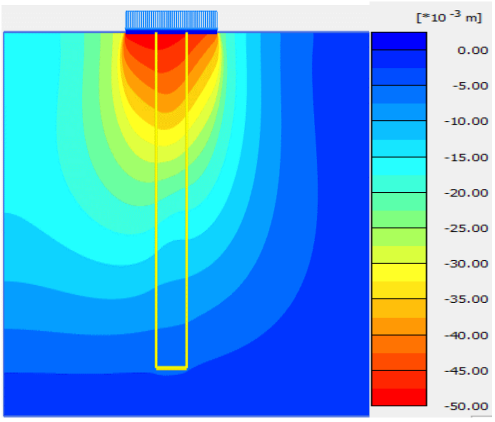


Fig 5 Vertical settlement of

GESC treated clay

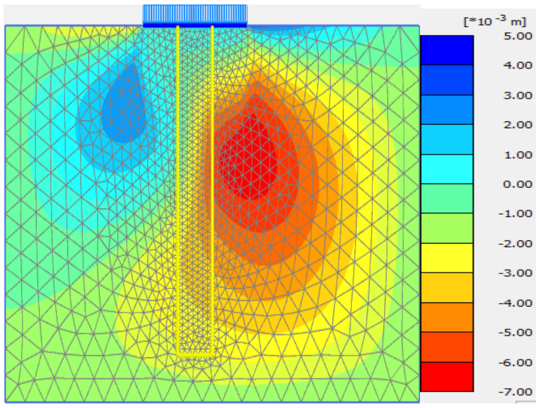


Fig 6 Horizontal settlement of

GESC treated clay soil

c. Clay soil treated with pervious concrete column

The stiffness of the pervious concrete column is significantly higher because of the cementing material. The pervious concrete column does not need lateral encasement. Due to more stiffness, pervious concrete column can carry higher vertical load and will reduce the horizontal settlement. The vertical settlement reduces to 52 mm and horizontal settlement reduces to 8 mm schematically shown in Fig. 7 and Fig.8

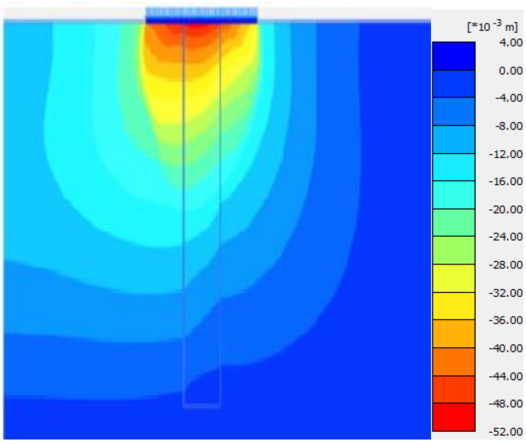


Fig. 7 Vertical settlement of PCC

treated soil

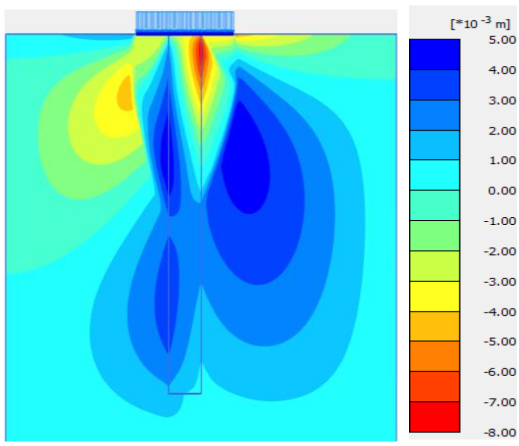


Fig. 8 Horizontal settlement of PCC

treated clay soil.

d. Clay soil treated with under reamed pervious concrete column (UPCP)

The load capacity of Plain shafted pile is enhanced by providing an under-reaming bulb. The bulb provides more bearing resistance to the pile and thus the vertical settlement is reduced. Moreover, the bulb is provided at a depth, which is more prone to bulging failure, and thus horizontal settlement or bulging failure reduces. Vertical and horizontal settlement of UPCP treated soil is minimum of all the cases and got the value of 34 mm and 4 mm respectively. The pictorial representation is shown in Fig.9 and Fig. 10

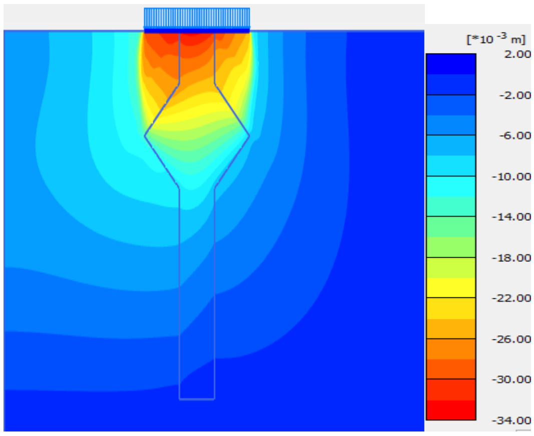


Fig 9 Vertical settlement of UPCP treated clay soil

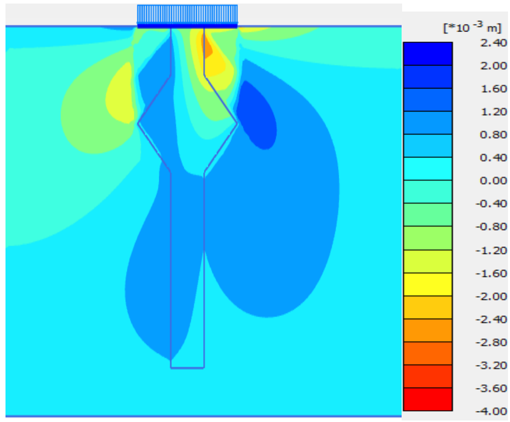


Fig 10 Horizontal settlement of UPCP treated clay soil

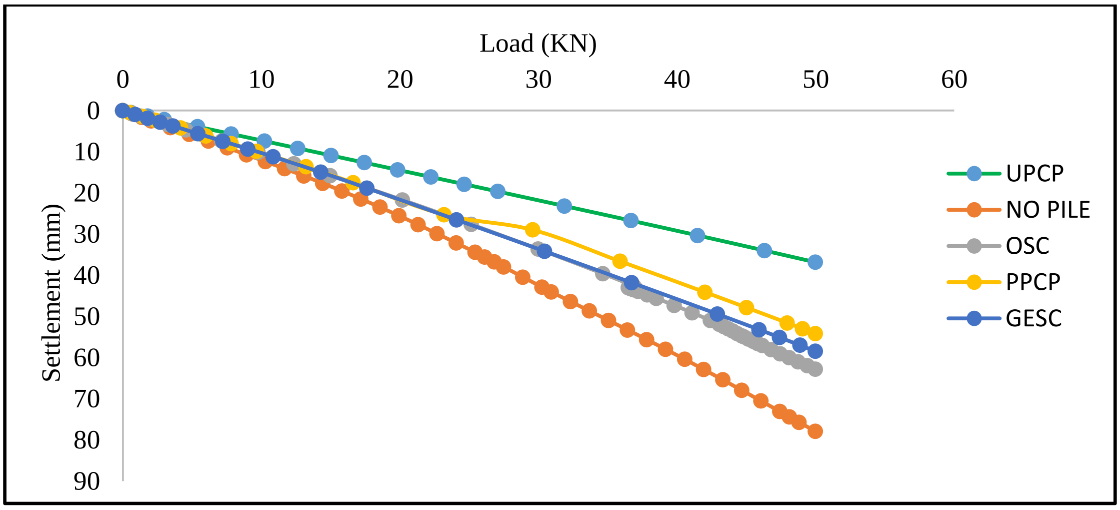


Fig 11 Comparison of load vs settlement of different ground improvement techniques

From Fig.11, it is clear that for the same vertical loading, the undisturbed clayey soil undergoes maximum settlement whereas the settlement for other ground improvement techniques reduces in the order of OSC<GESC<PPC>UPCP

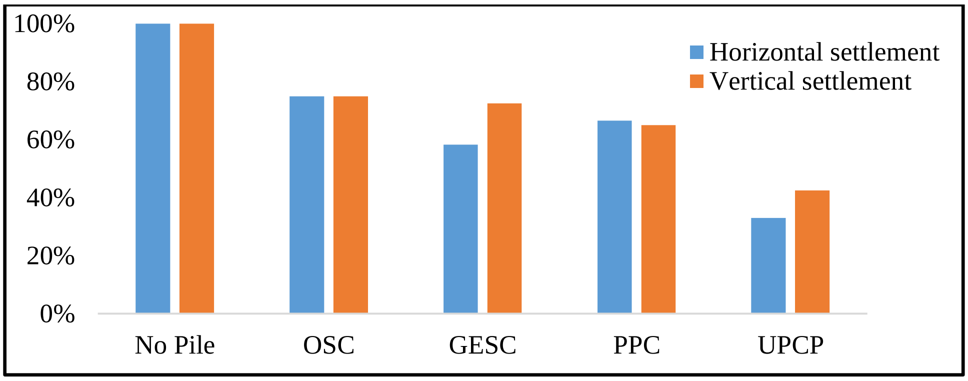


Fig 12 Comparison of vertical and horizontal settlement of different ground improvement techniques with respect to untreated clay soil

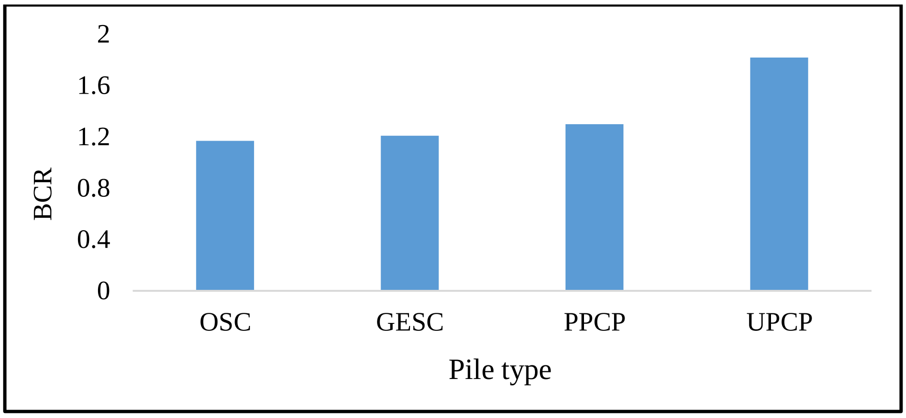


Fig 13 Variation of bearing capacity ratio of different GI techniques

The improvement in the bearing capacity (bearing capacity ratio) of various ground improvement techniques is shown in Fig 13. The bearing capacity increases in the order OSC<GESC<PPC<UPCP

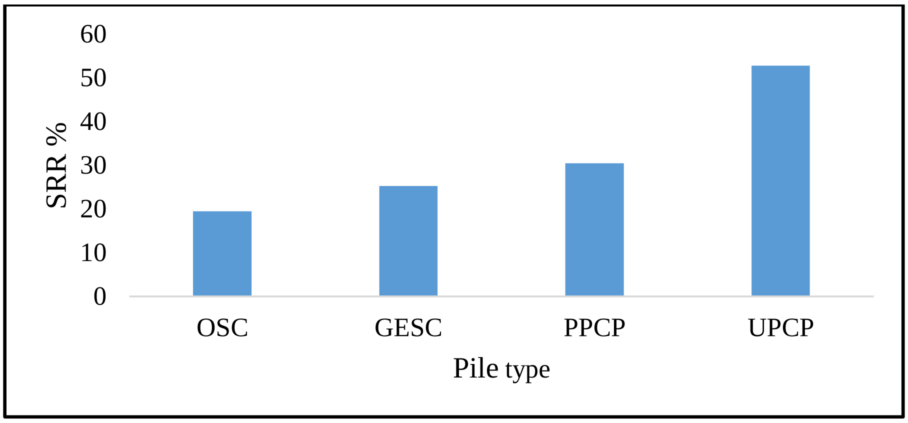


Fig 14 Variation of settlement reduction ratio (SRR) of different pile types

The improvement in the settlement reduction (settlement reduction ratio) of various ground improvement techniques is shown in Fig 14. The settlement reduction increases in the order OSC<GESC<PPC<UPCP

Conclusions

1. Pervious concrete column can help in the reduction of the liquefaction of the soil because of the greater permeability. The excess pore water pressure generated in the soil can dissipate more quickly.
2. Important structures which require speedy construction, pervious concrete column installation in the foundation soil can be a best alternative because of the early attainment of the required consolidation.
3. The vertical settlement of untreated clay soil is 80 mm. The vertical settlement for OSC, GESC, PCC and UPCC is 60mm, 58mm, 52mm and 34 mm respectively. The total settlement was reported to be maximum in untreated soil and minimum in the UPCP.
4. The horizontal displacement is 12 mm for untreated clay soil while as the horizontal displacement for OSC, GESC, PCC and UPCC is 9mm, 7mm, 8mm and 4mm respectively.
5. Bearing capacity increased in the order OSC<GESC<PPCP<UPCP. The bearing capacity improvement ratios for OSC, GESC, PCC and UPCC are 1.17, 1.21, 1.3 and 1.82 respectively.
6. The settlement reduction capacity increases in the order OSC<GESC<PPCP<UPCP. The settlement reduction ratios for OSC, GESC, PCC and UPCC are 19.5%, 25.3%, 30.5%, and 52.8% respectively.

References

[1] M. de S. S. de Almeida, M. V. R. Filho, I. H. Babaei, and D. Alexiew, Geosynthetic Encased Columns for Soft Soil Improvement, no. November. 2018.

[2] J. F. Chen et al., "Centrifuge modeling of geosynthetic-encased stone column-supported embankment over soft clay," Geotext. Geomembranes, vol. 49, no. 1, pp. 210–221, 2021, doi: 10.1016/j.geotexmem.2020.10.021.

[3] L. Zhang and M. Zhao, "Deformation Analysis of Geotextile-Encased Stone Columns," Int. J. Geomech., vol. 15, no. 3, p. 04014053, 2015, doi: 10.1061/(asce)gm.1943-5622.0000389.

[4] S. R. Mohapatra and K. Rajagopal, "Undrained stability analysis of embankments supported on geosynthetic encased granular columns," Geosynth. Int., vol. 24, no. 5, pp. 465–479, 2017, doi: 10.1680/jgein.17.00015.

[5] C. Cengiz and E. Güler, "Seismic behavior of geosynthetic encased columns and ordinary stone columns," Geotext. Geomembranes, vol. 46, no. 1, pp. 40–51, 2018, doi: 10.1016/j.geotexmem.2017.10.001.

[6] I. Hosseinpour, C. Soriano, and M. S. S. Almeida, "A comparative study for the performance of encased granular columns," J. Rock Mech. Geotech. Eng., vol. 11, no. 2, pp. 379–388, 2019, doi: 10.1016/j.jrmge.2018.12.002.

[7] Y. Sambhaji Golait and A. Harihar Padade, "Enhancement in Effectiveness of Cemented Stone Columns for Soft Clay Ground Improvement by Providing Underreamed Bulbs," Int. J. Geomech., vol. 18, no. 11, p. 04018149, 2018, doi: 10.1061/(asce)gm.1943-5622.0001282.

[8] M. T. Suleiman, L. Ni, and A. Raich, "Development of Pervious Concrete Pile Ground-Improvement Alternative and Behavior under Vertical Loading," J. Geotech. Geoenvironmental Eng., vol. 140, no. 7, p. 04014035, 2014, doi: 10.1061/(asce)gt.1943-5606.0001135.

[9] T. Divya Bhavana, S. Koushik, K. Uday Mani Kumar, and R. Srinath, Pervious concrete pavement, vol. 8, no. 4. 2017.

[10] V. R. Schaefer, J. T. Kevern, B. Izevbekhai, K. Wang, H. E. Cutler, and P. Wiegand, "Construction and performance of pervious concrete overlay at Minnesota Road Research Project," Transp. Res. Rec., no. 2164, pp. 82–88, 2010, doi: 10.3141/2164-11.

[11] J. Zhang et al., "Dynamic Performance Characteristics of Pervious Concrete Pile Composite Foundations under Earthquake Loads," J. Perform. Constr. Facil., vol. 31, no. 5, p. 04017064, 2017, doi: 10.1061/(asce)cf.1943-5509.0001056.

[12] J. Qing et al., "In situ evaluation and analysis of improvement effects of pervious concrete pile on alluvial silt ground," Geomech. Geoengin., vol. 16, no. 3, pp. 212–222, 2021, doi: 10.1080/17486025.2019.1651404.

[13] J. Zhang, X. Cui, D. Huang, Q. Jin, J. Lou, and W. Tang, "Numerical Simulation of Consolidation Settlement of Pervious Concrete Pile Composite Foundation under Road Embankment," Int. J. Geomech., vol. 16, no. 1, pp. 1–10, 2016, doi: 10.1061/(asce)gm.1943-5622.0000542.

[14] L. Ni, M. T. Suleiman, and A. Raich, "Behavior and Soil–Structure Interaction of Pervious Concrete Ground-Improvement Piles under Lateral Loading," J. Geotech. Geoenvironmental Eng., vol. 142, no. 2, p. 04015071, 2016, doi: 10.1061/(asce)gt.1943-5606.0001393.

[15] M. Ghazavi and J. Nazari Afshar, "Bearing capacity of geosynthetic encased stone columns," Geotext. Geomembranes, vol. 38, pp. 26–36, 2013, doi: 10.1016/j.geotexmem.2013.04.003.

[16] A. K. Chandrappa and K. P. Biligiri, "Pore Structure Characterization of Pervious Concrete Using X-Ray Microcomputed Tomography," J. Mater. Civ. Eng., vol. 30, no. 6, p. 04018108, 2018, doi: 10.1061/(asce)mt.1943-5533.0002285.