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Performance of Geotextile Encased Sand Column in the Field

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Abstract. The Stone columns (or sand columns) have been utilized to enhance bearing capacity and accelerate soft soil consolidation. To increase the bearing capacity of ordinary sand column, the geotextile encased sand column technique was recently developed. Furthermore, encasing inhibits lateral squeezing of sand into surrounding soft soil, contributes in the easy formation of sand column, preserves sand frictional properties, and the sand column's drainage function. Through field stress experiments, this research analyses the enhancement of load carrying capacity of ordinary and geotextile encased sand columns. Tests were conducted with various encasement stiffness, sand column diameters, and reinforcement lengths. The results of a field load test showed that the GESCs had a greater load carrying capacity than OSCs. The increase in load carrying capacity is influenced by the encasement length, encasement stiffness, and diameter of the sand column. Furthermore, it was revealed that the partial encasement, which extended from the top of the sand column for a length of two to four times its diameter, had a considerable influence on the performance of the sand column.

Keywords: Ordinary sand column, Geotextile encased sand column, filed load test.

1 Introduction

One of the ground improvement methods that is frequently used for soft ground improvement is the stone column (or sand column). However, the application of the Ordinary Stone/Sand Column (OSC) is debatable in extremely soft soil. Recently, Geotextile Encased Stone/Sand Column (GESC) was developed to overcome this limitation.

Numerous studies have been conducted on the use of GESC for improving soft soil. The investigations concentrated on field tests, numerical analysis, laboratory model testing, and analytical solutions.

Al-Joulani and Bauer [1] reported an increase in the load capacity of GESCs that was related to the dilatancy of the column material and strain-dependent. The cohesion intercept on the Mohr-Coulomb strength envelope was used to express the improvement in the shear strength of the GESCs. Trunk et al. [2] conducted static and dynamic load testing on geogrid encased vibro-stone columns without lateral support. The performance of small-scale stone columns reinforced with metallic tubular wire mesh was examined by Black et al. [3]. Lee et al. [4] used model experiments in sandy ground to explore the failure process and load bearing capability of GESCs. The studies' findings suggested that the geogrid-encased stone column had a higher bearing capacity than the traditional stone column method without an encasing. The performance of the end bearing GESCs was examined in laboratory investigations by Murugesan and Rajagopal [5]. They reported that the Hoop strain in the bulging area closer to the top of the column is greater and would decrease with depth. Based on medium scale laboratory unconfined compression tests, Gniel and Bouazza [6] proposed a method for constructing geogrid-reinforced stone columns. Large-scale model experiments were conducted by Ou Yang et al. [7] to investigate the failure mode of the fully-encased stone column composite ground. The test findings showed that the fully-encased stone column composite ground fails due to column punching into the top gravel mat rather than excessive bulging in the column's radial direction. Shaking table experiments were carried out by Cengiz and Guler [8] and Cengiz et al. [9] to evaluate the distribution and amplitude of reinforcing stresses in the horizontal (hoop) and vertical directions of a single column, rather than the failure mechanism of the composite ground. Yoo and Abbas [10] investigated the stress concentration ratio of GESC reinforced sand under static and cyclic loading in the laboratory. Zhang et al. [11] conducted laboratory tests to assess the responses of an GESC-supported embankment under vertical cyclic stress. The excess pore water pressure of the soil, stone column deformation, soil-column stress distribution, and settlement of the loading plate were all investigated.

For the design of the geotextile encased sand column foundation system, Raithel and Kempfert [12] developed a numerical and analytical calculation model. They made the assumption that a composite foundation made of GECSs would satisfy the equal strain condition and rest on a rigid layer, and that the column's volume would remain constant. To determine the ultimate bearing capacity of encapsulated stone columns placed in the collapsible soil, Ayadat and Hanna [13] developed an equation. In order to explain the mechanical properties of the stone column materials, Wu et al. [14] established analytical methodologies to analyze the axial stress-strain response of geosynthetic encased stone columns. Zhang et al. [15] used a unit cell approach to develop a theoretical elastic solution for the stresses and displacements of a foundation reinforced with an encapsulated column. Pulko et al. [16] suggested an updated elasto-plastic solution for a fully encased column. They have disregarded how the radial stresses at various points affect the soil's radial deflection. Castro and Sagaseta [17] have proposed a closed form approach to investigate the acceleration of consolidation and decrease of settlement brought on by encased stone columns. They came to the conclusion that column reinforcing has little impact on an elastic column and only becomes effective after column yielding.

Axisymmetric finite element calculations were carried out by Murugesan and Rajagopal [18] to investigate how ordinary stone columns and geosynthetic encased stone columns behaved. They claimed that the stone column's load carrying capacity could be significantly increased by encasing it to a depth that is equivalent to twice its diameter. In order to predict the behavior of a single geosynthetic-encased stone column in a soft clayey soil, Khabbazian et al. [19] performed 3D finite element calculations. They argued that choosing an encasement with greater stiffness would be more effective than improving stone column material. Yoo and Kim [20] conducted a study comparing several modeling approaches (such as axisymetric, 3-d unit cell, and fully 3-d). Tandel et al. [21] conducted 3D finite element analyses for an embankment rested on geosynthetic encased stone column and provided an equation for determining embankment settlement. Tang et al. [22] used numerical simulations to evaluate the efficacy of the GESC on minimizing liquefaction-induced lateral ground displacement.

Despite the fact that several researchers have investigated various aspects of geosynthetic encased stone columns, comprehensive study on the variables influencing its performance in the field is still limited. The behavior of OSC and GESC in the field is examined in detail in this work. The results and discussion of field load testing are presented.

2 Methodology

All the field load tests were conducted at Althan Creek in Surat, India (Fig. 1). The site's soils are composed of a 0.5 m thick layer of highly plastic clay, a 3.5 m thick layer of blackish non-plastic silt, a yellowish plastic silty clay with sand and gravel up to the termination level of the bore hole. Up to the termination depth, there was no evidence of the groundwater table. The site's standard penetration test value ranged from 3 to 38, with 3 to 5 at the top 4 m depth.

Clean river sand with a frictional angle of 36° was utilized to construct the sand column. For the encasement of the stone column, two woven geotextiles with 10% secant stiffness of 121.90 and 450 kN/m were utilized.

In the current study, 15 field load tests were performed, which included one test on untreated ground, two tests on OSC (0.30 and 0.45 m diameter), and twelve tests on GESC (0.30 and 0.45 m diameter) with varying geotextile stiffness.

Fig. 1. Site location.

All of the stone columns were constructed using the replacement method proposed by Gniel and Bouazza [6] based on medium scale laboratory model testing. An auger was used to excavate the borehole to the desired depth in the ground. The geotextile tube was inserted into the excavated hole when the excavation was completed. The sand necessary to construct the column was measured in advance and charged into the geotextile tube in layers to obtain a compacted height of 30 cm. The ramming method was used to compact each layer of sand, as described by Datye and Nagaraju [23]. The process was continued until the column reached its entire height. The density was calculated to be 1.76 g/cm^3.

All field load testing were carried out in accordance with the guidelines of IS: 15284-Part 1 [24]. To investigate the load-deformation of a single sand column, a circular steel plate with a diameter equal to the diameter of the stone column and a thickness of 25 mm was kept concentric along the top of the test sand column. Steel girders were used in the load test setup, with concrete blocks of sufficient weight acting as kentledge. Kentledge's overall load was at least 30% more than the maximum test load. These blocks were symmetrically set on a platform of steel plates supported by secondary ISMB girders. The load was applied to the test sand column using a hydraulic jack flush with the principal girder and the test plate (Fig. 2).

Fig. 2. Load test in progress.

3 Results and Discussion

3.1 Influence of geotextile encasement

Figure 3 depicts the stress-settlement response of a 300 mm diameter untreated ground, ordinary, and geosynthetic encased sand column. Geotextile stiffness of 440 kN/m was employed to encapsulate the sand column. This figure clearly illustrates that GESC does not fail even at 50 mm settlement. However, with untreated ground, an obvious failure is evident. The increased load carrying capacity of the GESC is assumed to be owing to the increased lateral pressure imposed by the geosynthetic encasement. Furthermore, the load carrying capacity of the GESC is approximately 85% greater than that of the OSC.

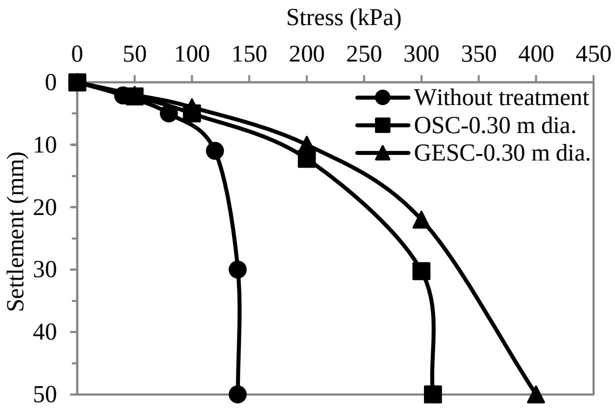

Fig. 3. Stress-settlement response of untreated ground, OSC, and GRSC

3.2 Analytical solution

The analytical solution suggested by Murugesan and Rajagopal (2007) [5] is summarized as under.
The ultimate load carrying capacity of the OSC is computed by the Eq. 1.

$$q_{OSC} = \left(\sigma_{ro} + 4C_u + \sigma_{vo} \cdot K_p\right) K_{pcol} \tag{1}$$

The ultimate load carrying capacity of the GESC can be calculated by Eq. 2.

$$q_{GESC} = \left(\sigma_{ro} + 4C_u + \sigma_{vo} \cdot K_p + \frac{2T}{d}\right) K_{pcol} \tag{2}$$

Where,

σ_{ro}	=	initial effective radial stress
C_u	=	undrained shear strength of clay surrounding the column
ϕ_c	=	angle of internal friction of sand column material
K_0	=	average coefficient of lateral earth pressure for clays (assumed 0.6)
σ_{vo}	=	average initial effective vertical stress
ϕ	=	angle of internal friction of soil surrounding the column
K_p	=	passive pressure coefficient of soil surrounding the column
K_{pcol}	=	passive pressure coefficient of sand column material
T	=	tensile force generated in geotextile corresponding to given hoop strain

3.3 Influence of sand column diameter

Figure 4 depicts the effect of sand column diameter on stress at 50 mm settlement for various stiffness of the geosynthetic encasement. This figure clearly shows that for OSC, as the diameter of the column decreases, so does the stress on the sand column. However, with GESC, as the column diameter decreases, the stress on the sand column increases, regardless of the stiffness of the geosynthetic encasement. This is due to an increase in hoop stress as the sand column diameter decreases. For example, the highest increase in stress with decreasing diameter is about 25%. The present work predicts a slightly lower stress for OSC but stresses are in close agreement for GESC with analytical solution. Figure 5 depicts the percentage reduction in settlement of GESC over OSC for two diameters (0.30 and 0.45 m) of sand columns under 300 kPa vertical stress. Figure 5 shows that at a secant stiffness of 450 kN/m, the percent reduction in sand column settlement tends to significantly increase with decreasing diameter of the sand column. However, with reinforcement stiffness of 121.90 kN/m, settlement reduction with diameter was minimal.

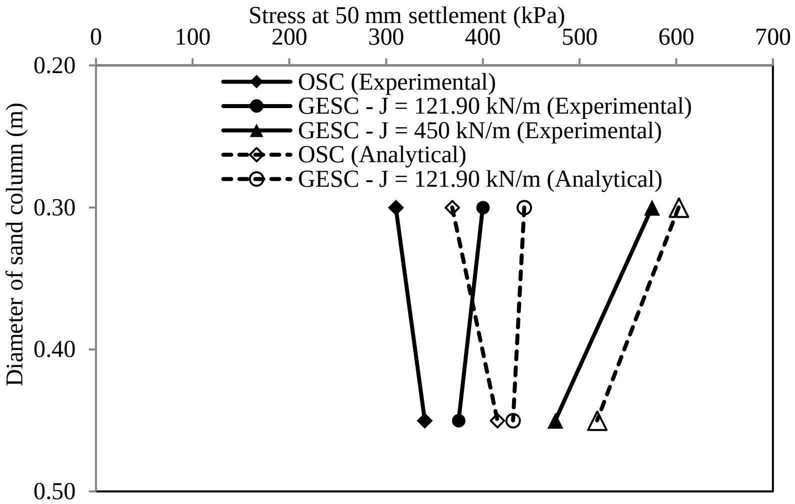

Fig. 4. Influence of sand column diameter on stress.

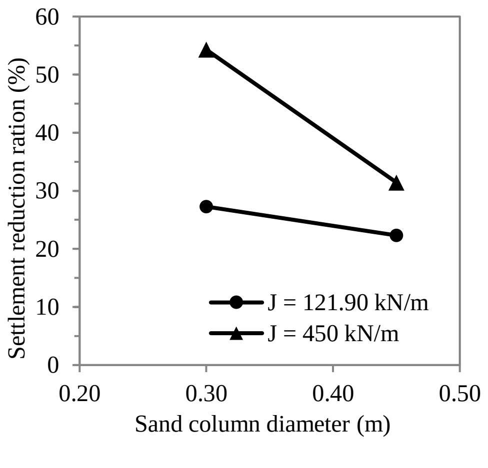

Fig. 5. GESC diameter vs. Settlement reduction ratio.

3.4 Influence of reinforcement length

Figure 6 depicts the influence of encasement length on the column stress improvement factor. The stress improvement factor is defined here as the ratio of treated ground stress to untreated ground stress at 50 mm settlement. It can be shown that for GESC with 450 kN/m geosynthetic stiffness, the stress improvement factor increases up to four times the diameter of the column (i.e., encasement length), then after the amount of increase in stress improvement factor is not significant.

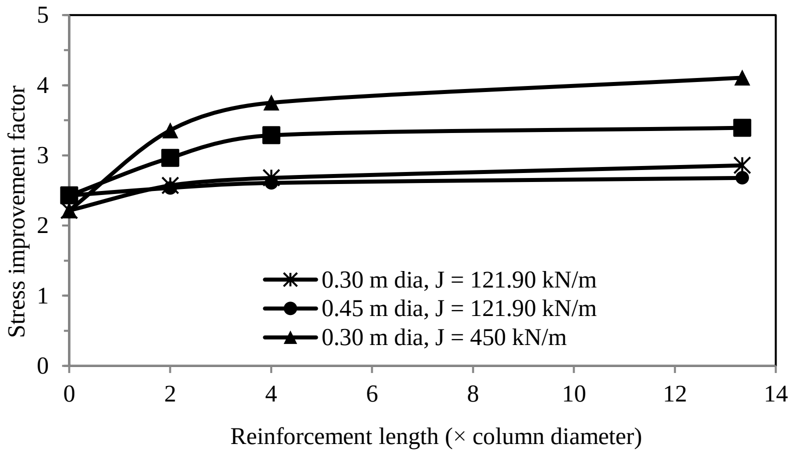

Fig. 6. Influence of reinforcement length on stress improvement factor.

4 Conclusions

Based on full scale field load tests performed on a geosynthetic encased sand column, the following conclusions may be derived.

- By using an appropriate geotextile encasement, the load carrying capacity of the ordinary sand column may be increased.
- The load carrying capacity of the geotextile encased sand column is approximately 85% more than that of an ordinary sand column, depending on the column diameter and geotextile stiffness.
- The load carrying capacity of a geotextile encased sand column increases by 25% as the sand column diameter decreases from 0.45 to 0.30m.
- Encasement length up to four times the sand column diameter is adequate to significantly increase load carrying capacity of ordinary sand column.

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