iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** VIII **Month of publication:** August 2025

DOI: https://doi.org/10.22214/ijraset.2025.73966

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VIII Aug 2025- Available at www.ijraset.com

Numerical Simulation of Geogrid Encased Stone Column beneath the Oil Storage Tank Using Plaxis-3D

B. Shirisha[1], G.V. Narsimha Reddy[2]
[1]*Post Graduate Student and* [2]*Principal & professor of Civil Engineering*
JNTUH University College of Engineering, Science and Technology, Hyderabad, India

Abstract: Geosynthetic Encased Stone Columns (GESCs) represent a significant advancement over traditional stone columns (OSCs), particularly in improving the performance of ground support beneath circular oil storage tanks. Using PLAXIS 3D simulations, it was observed that GESCs provide enhanced settlement control and lateral restraint due to the increased lateral confinement offered by the geosynthetic encasement. The study varied key design parameters including column length-to-diameter ratio (L/D), spacing ratio (S/D), area replacement ratio, and encasement length. Results showed that longer columns, especially when paired with high geogrid stiffness, significantly reduced both long-term settlements and lateral spreading of the ground. Among the spacing ratios tested, reducing S/D from 4 to 2 led to a 45.9% reduction in settlement for short columns (L/D = 2), a 63.5% reduction for medium (L/D = 4), and up to 82.5% for the longest columns (L/D = 6), emphasizing the stronger effect of spacing with increased column length. Similarly, increasing area replacement ratio improved overall ground stability and load distribution. Regarding encasement length, extending it from 2D to 8D resulted in a 32.1% reduction in settlement, with the most substantial improvement noted between 2D and 4D; further increases beyond 4D provided only minor benefits. Therefore, a 4D encasement is considered optimal, providing effective settlement control while remaining cost-effective. Settlement profiles across the tank's radial distance confirmed GESCs' superior performance over OSCs in reducing ground movement. Analyzing the effect of stone column by different area replacement ratios along with improvement factor and stress concentration ratio. Overall, GESCs designed with optimal parameters of column length, spacing, area ratio, and encasement length offer increased efficiency, stability, and cost savings for oil tank foundations on soft clay.

Keywords: Geogrid-encased stone columns · Circular Storage tank · Numerical analysis · Ground settlement control · 3D finite element modelling · Lateral ground deformation.

I. INTRODUCTION

The rapid rise in construction activities has intensified the demand for effective ground improvement techniques aimed at enhancing the performance of weak or problematic soils. Among various methods, granular columns have proven practical, economical, and reliable for stabilizing soft soils. Modern civil engineering faces increasing challenges in managing irregular and excessive settlement, particularly in soft soil environments where traditional methods are often inadequate. This has led to the development of advanced soil improvement solutions like Geosynthetic-Reinforced Stone Columns (GRSCs), which improve soil consolidation, reduce liquefaction susceptibility, and minimize settlement, making them ideal for infrastructure such as embankments, dams, tanks, and railways. Conventional Ordinary Stone Columns (OSCs), however, have limitations in very soft grounds like marine clays or peat due to poor lateral confinement causing bulging and reduced load capacity. To address these issues, reinforcement methods such as steel skirts, deep mixing, concrete caps, and geogrid reinforcements have been studied. Among these, Geosynthetic Encasement (GESC) has emerged as a promising technique. It strengthens columns laterally by hoop tension, maintaining drainage and preventing soil intrusion. The literature identifies three main simulation approaches for modelling stone columns (Kelesoglu & Durmus, 2022). The first approach artificially boosts the initial earth pressure coefficient (Ko) to represent the increased stiffness due to stone columns. While this method is popular, it can oversimplify the behaviour of the surrounding soil by assuming uniform stiffness throughout (Al Ammari & Clarke, 2016; Benmebarek et al., 2018). The second technique involves preloading the system to mimic stiffer column behaviour, treating the stone column as a linear elastic material with a modulus significantly higher than that of the surrounding soil (Ellouze et al., 2017; Guetif et al., 2007; Remadna et al., 2020). Although straightforward and practical, this method rests on the assumption of elastic behaviour, which may not be entirely accurate in very soft soils.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VIII Aug 2025- Available at www.ijraset.com

The third method models the stone column's outward expansion by prescribing a radial displacement proportional to its diameter. This approach more accurately captures the lateral behaviour of stone columns in soft soils, where such deformation is important (Nguyen et al., 2007; Elshazly et al., 2008), though determining suitable values for radial displacement can be technically challenging.

This study addresses a key gap by refining numerical models to better capture realistic soil GRSC interactions, as conventional approaches inadequately simulate lateral stress redistribution caused by column installation. The radial expansion approach is highlighted for its superior representation of actual behaviour. Practically, these findings equip geotechnical engineers with insights for improved GRSC design and performance, vital as construction increasingly occurs in poor soil conditions. The research also investigates the influence of geosynthetic properties, reinforcement layout, and construction methods, thereby enabling the design of safer, more efficient infrastructure in challenging geotechnical environments.

In summary, granular columns like GRSCs provide an effective, sustainable ground improvement solution. Advancements in modelling and reinforcement technology allow better prediction and optimization of soil behaviour, addressing the limitations of OSCs in very soft soils and supporting modern infrastructure demands.

II. FINITE ELEMENT MODELLING

In this study, PLAXIS 3D was employed to model a semi-infinite soil mass, with the clay bed represented as a 30 m by 30 m plane and a thickness of 10 m. While storage tanks conventionally rest on a granular layer designed to disperse structural loads onto the underlying stone columns, the numerical model was simplified by substituting the typical circular granular fill beneath the tank with a consistent 0.8 m thick granular blanket layer above the stone columns. Additionally, a bottom layer was included below the stone columns underneath the tank. The material properties used for both the stone columns and the surrounding soil are detailed in Table 1.

Soils were assumed isotropic and modelled with a linear elastic–perfectly plastic Mohr–Coulomb model. Key parameters are deformation (or shear) modulus (E or G), Poisson's ratio (ν), cohesion (c′), friction angle (φ′), and dilatancy angle (Ψ). Failure occurs when shear stress exceeds the Mohr–Coulomb limit.

Table 1. Properties of different materials incorporated in numerical modelling

Parameters	Granular Blanket	Soft Clay	Bottom Layer	Stone Column
Soil Model	Mohr Coulomb	Mohr Coulomb	Mohr Coulomb	Mohr Coulomb
Drainage Type	Drained	Undrained	Drained	Drained
Unit Weight (γ_{unsat}) (kN/m^2)	15.5	13.86	20	16.62
Unit Weight (γ_{sat}) (kN/m^2)	17.05	18.36	21	17
Young's Modulus (E') (kN/m^2)	20000	2150	26000	55000
Poisson's Ratio (μ)	0.3	0.4	0.3	0.3
Cohesion(C) (kN/m^2)	0	7	0	0
Angle Of Internal Friction (φ)(deg)	30	0	30	43
Dilatancy Angle (Ψ)(deg)	4	0	4	10

The foundation of the oil storage tank, which has a 5.5 m radius, was represented using a flexible plate element. A surface load, uniformly distributed based on the characteristics of the stored material, was applied to the plate. The specifications of the plate, responsible for transferring the load to the soil, are detailed in Table 2 and were derived from IS 803:1976. As per the guidelines in IS 15284 (Part 1): 2003, Stone columns with a diameter of 0.8 meters and a spacing of 1.85 meters were incorporated beneath the tank. In PLAXIS 3D, the soil incorporating Geosynthetic-Encased Stone Columns (GESCs) was first modelled, and the corresponding material properties were assigned.

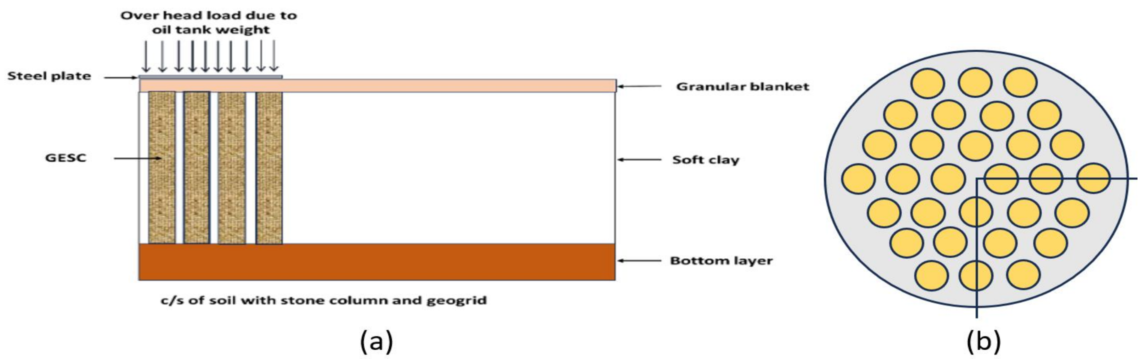


Fig.1 (a) Vertical c/s of Schematic model, (b) Top view of Reinforced Stone columns

In PLAXIS 3D, the geosynthetic layer for GESCs is modelled using geogrid elements where only axial stiffness is assigned, defined as the axial force per unit width divided by axial strain. This captures the geogrid's reinforcement effect along its length, enhancing column performance in the simulation.

Table 2 Parameters of the flexible foundation

Model	Modulus of elasticity (E) (kPa)	Poisson's ratio (m)	Thickness (mm)
Linear elastic	210	0.3	5

III.FINITE ELEMENT MODELLING

The settlement behaviour of ordinary stone column and geogrid encased stone column shown fig 2&3. It was observed that the centre columns experienced more settlement compare to outer column and settlement decreased with radial distance from centre of the tank. This is due to soil nature below the flexible plate.

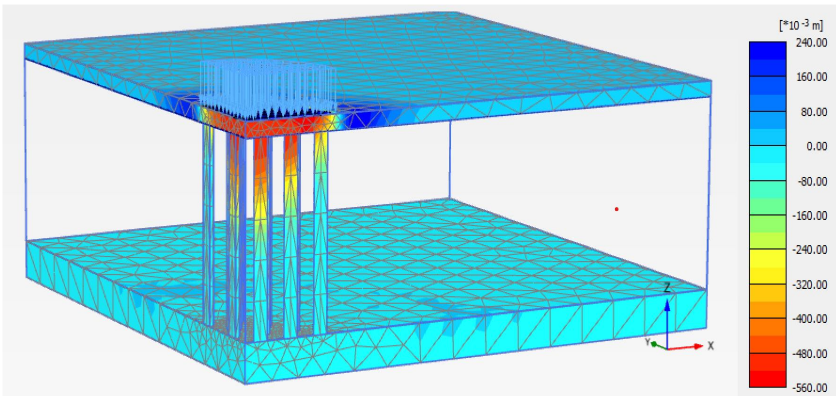


Fig. 2 Settlement of ordinary stone column in Z-direction.

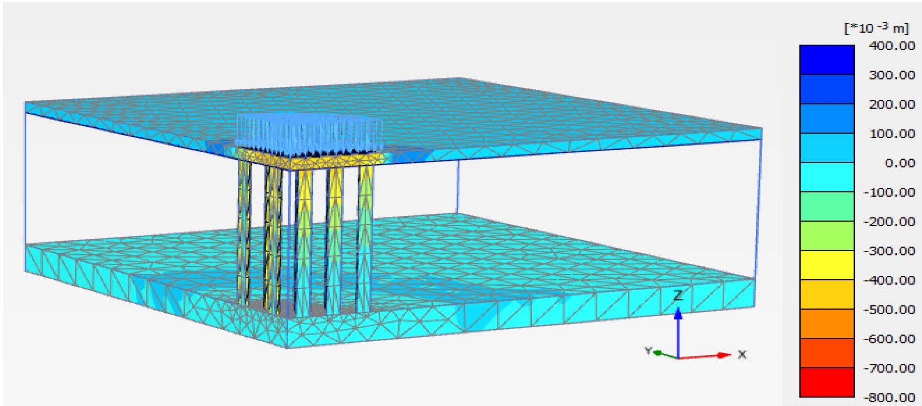
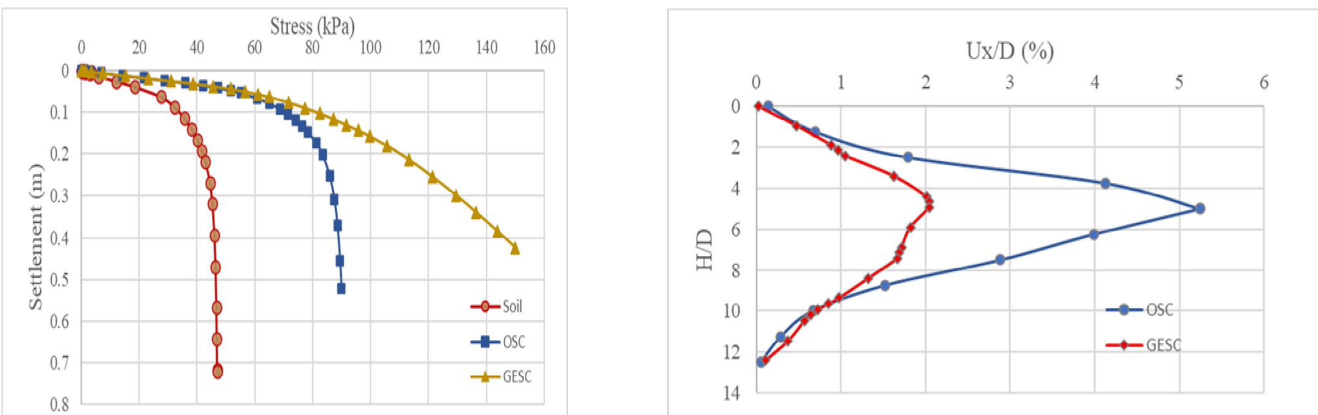


Fig .3 Settlement of geogrid encased stone column in Z-direction.

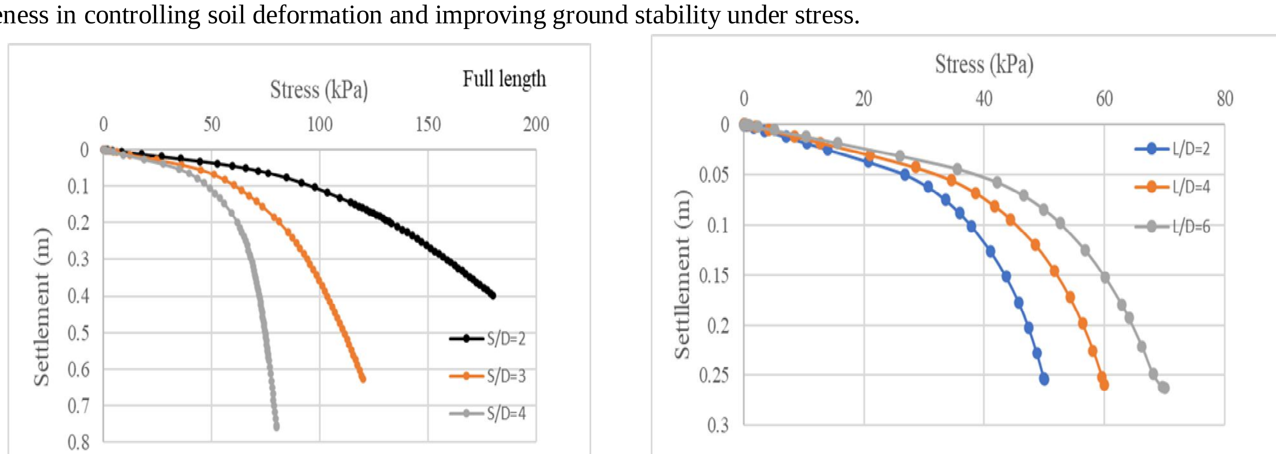
The following are the results that are obtained by modelling the stone columns using PLAXIS 3D



(a) (b)

Fig. 4 (a) Settlement vs. stress (kPa) plot for three different conditions: soil, OSC, and GESC. (b) 5 Lateral displacement along the depth of the stone column.

Figure 4 shows GESCs significantly outperform both untreated soil and OSCs, reducing settlement by 30 of OSC to 45% GESC (to ~0.4 m) and limiting lateral displacement to 2%, which is about 60% less than OSCs. This demonstrates GESCs' superior effectiveness in controlling soil deformation and improving ground stability under stress.

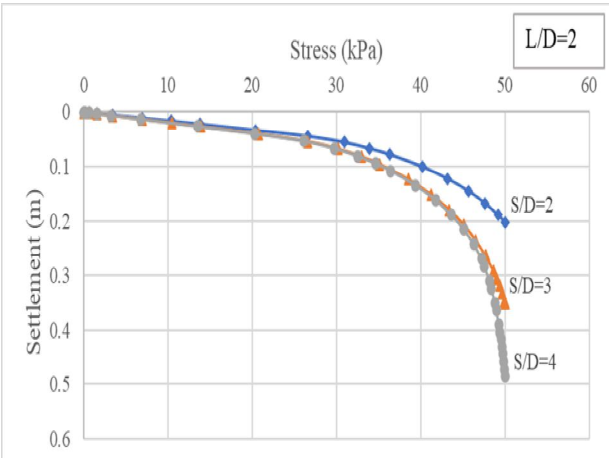


(a) (b)

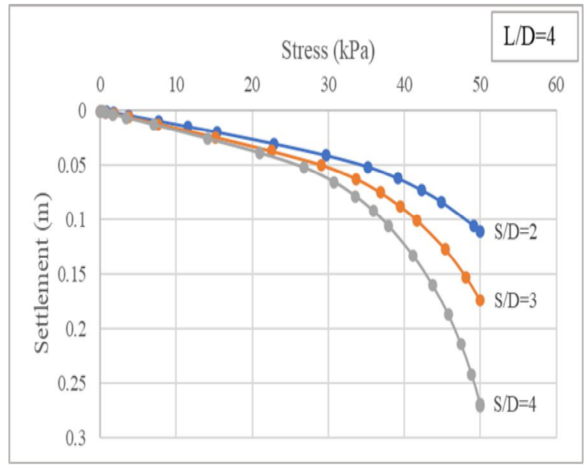
Fig .5 (a) Influence of Spacing on Load-Settlement Behaviour in Fully Encased Configurations. (b) Influence of Slenderness Ratio (L/D) on Stress Capacity at Fixed Settlement

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VIII Aug 2025- Available at www.ijraset.com

At the increasing stress level Fig 5 shows, reducing the spacing ratio between stone columns significantly lowers settlement. S/D=3 reduces settlement by about 19% compared to S/D=4, while S/D=2 achieves a 46% reduction versus S/D=4, and 33% less than S/D=3, showing closer spacing enhances settlement control. Additionally, higher length-to-diameter (L/D) ratios increase stress capacity at a fixed settlement. L/D=2 carries 50 kPa, L/D=4 supports 60 kPa, and L/D=6 handles 70 kPa, with L/D=6 offering 40% greater capacity than L/D=2 and best performance under higher settlements.

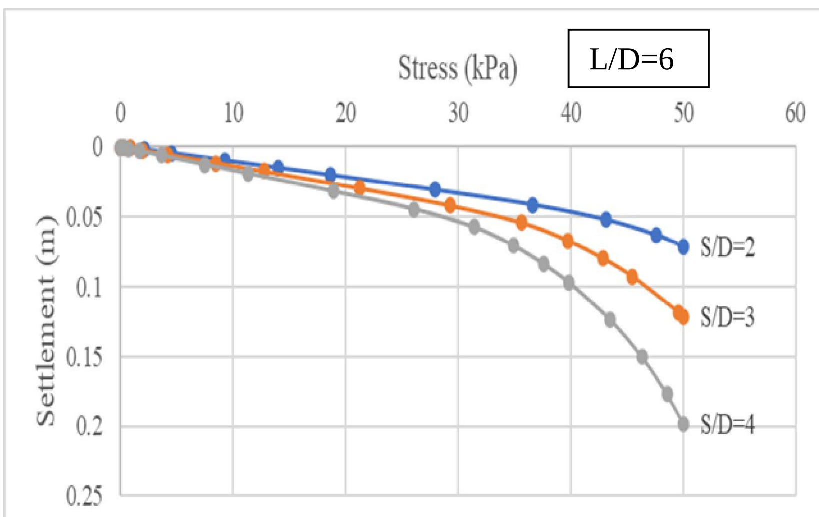


(a)



(b)

.



(c)

Fig .6 (a)Effect of S/D Ratio on Stress–Settlement Behaviour at Constant L/D = 2. (b)Effect of S/D Ratio on Stress–Settlement Behaviour at Constant L/D = 4. (c) Effect of S/D Ratio on Stress–Settlement Behaviour at Constant L/D =6.

Fig 6 shows that Reducing the S/D ratio consistently leads to a significant decrease in settlement for constant L/D values of 2, 4, and 6 under identical stress conditions. Fig.6(a) At L/D = 2, settlement at S/D = 2 is 60% lower than at S/D = 4 and 43% lower than at S/D = 3. Fig.6(b) For L/D = 4, settlement drops by 62% at S/D = 2 compared to S/D = 4, and by 40% relative to S/D = 3. This pattern demonstrates that tighter spacing promotes better stress distribution and load-bearing efficiency. Likewise, with. Fig.6(c) L/D = 6 under a 50 kPa load, the recorded settlements are 0.08 m, 0.13 m, and 0.20 m for S/D ratios of 2, 3, and 4, respectively, meaning settlement increases by 38.5% at S/D = 3 and by 150% at S/D = 4 compared to S/D = 2. These findings confirm that a lower S/D ratio effectively controls settlement and boosts overall performance, while larger spacing ratios result in greater settlement and diminished efficiency.

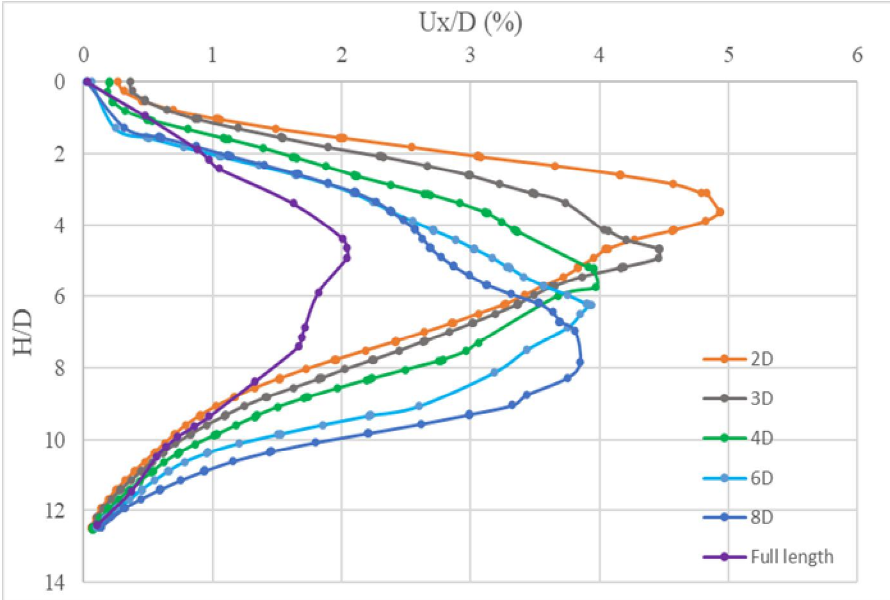


Fig.7 Lateral displacement along the depth of the stone column with different encasement length.

The graph shows that increasing geosynthetic encasement length from 2D to 8D progressively reduces lateral displacement, with 2D at 5% and 8D at 3.75%. Gains beyond 4D are minimal relative to material costs, making 4D the most cost-effective choice, balancing substantial lateral deformation reduction and moderate material use.

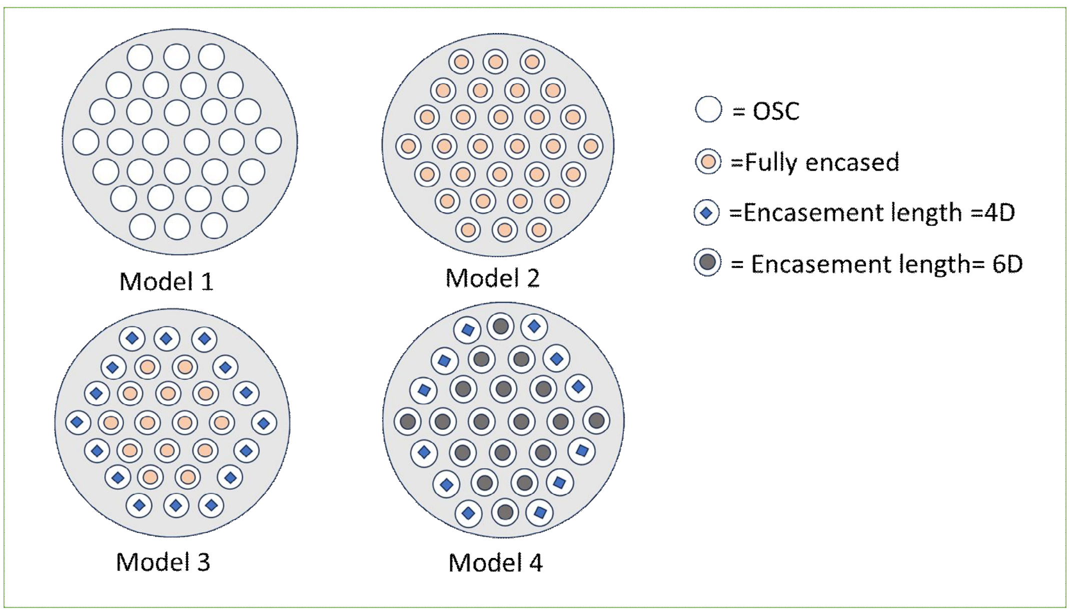
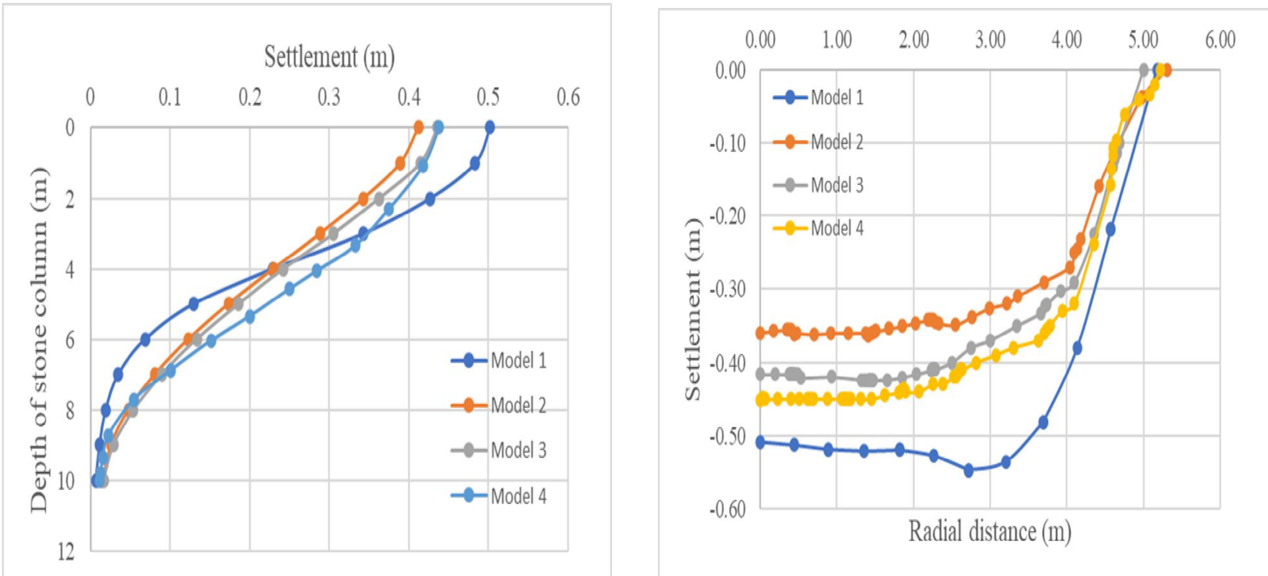


Fig.8 Stone column profiles of fifferent models

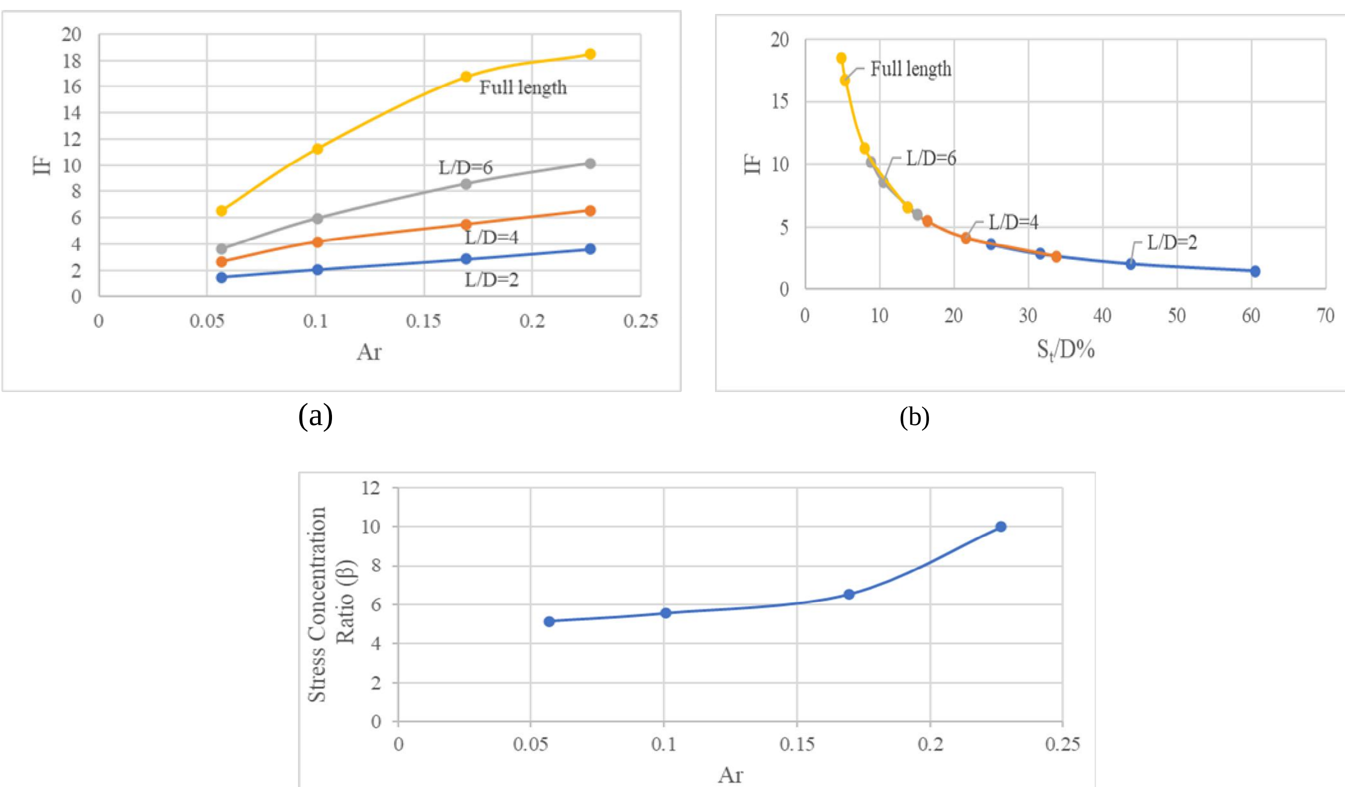
Model 1 contains only plain OSC (open steel circles) without any encasement. Model 2 features fully encased reinforcement throughout the cross-section. Model 3 combines both fully encased bars and partially encased bars with 4D encasement length, arranged in an alternating pattern around the perimeter. Model 4 includes, 4D encasement length bars, and 6D encasement length bars in a mixed configuration. The following graphs represent vertical settlements and settlements along radial distance from the centre of the plate.



(a) (b)

Fig .9 (a) Settlement profiles of different models along the depth of stone column. (b) Settlement profiles of different models

The graph shows settlement variation with depth and radial distance for four stone column models. Model 1 exhibits the highest settlement (~0.50 m), while Models 2 and 3 reduce it to around 0.40 m. Model 4 provides the least improvement despite more geogrid use. Settlement decreases with depth, converging near 0.05–0.07 m in all models. Radially, settlement is highest at the centre and decreases outward. Model 2 offers the best settlement control, followed by Model 3, which balances performance and cost-effectiveness.



(a) (b)

(c)

Fig.10 (a) Improvement factor vs Area replacement ratio. (b) Improvement factor vs Settlement. (c)stress concentration ratio vs area replacement ratio

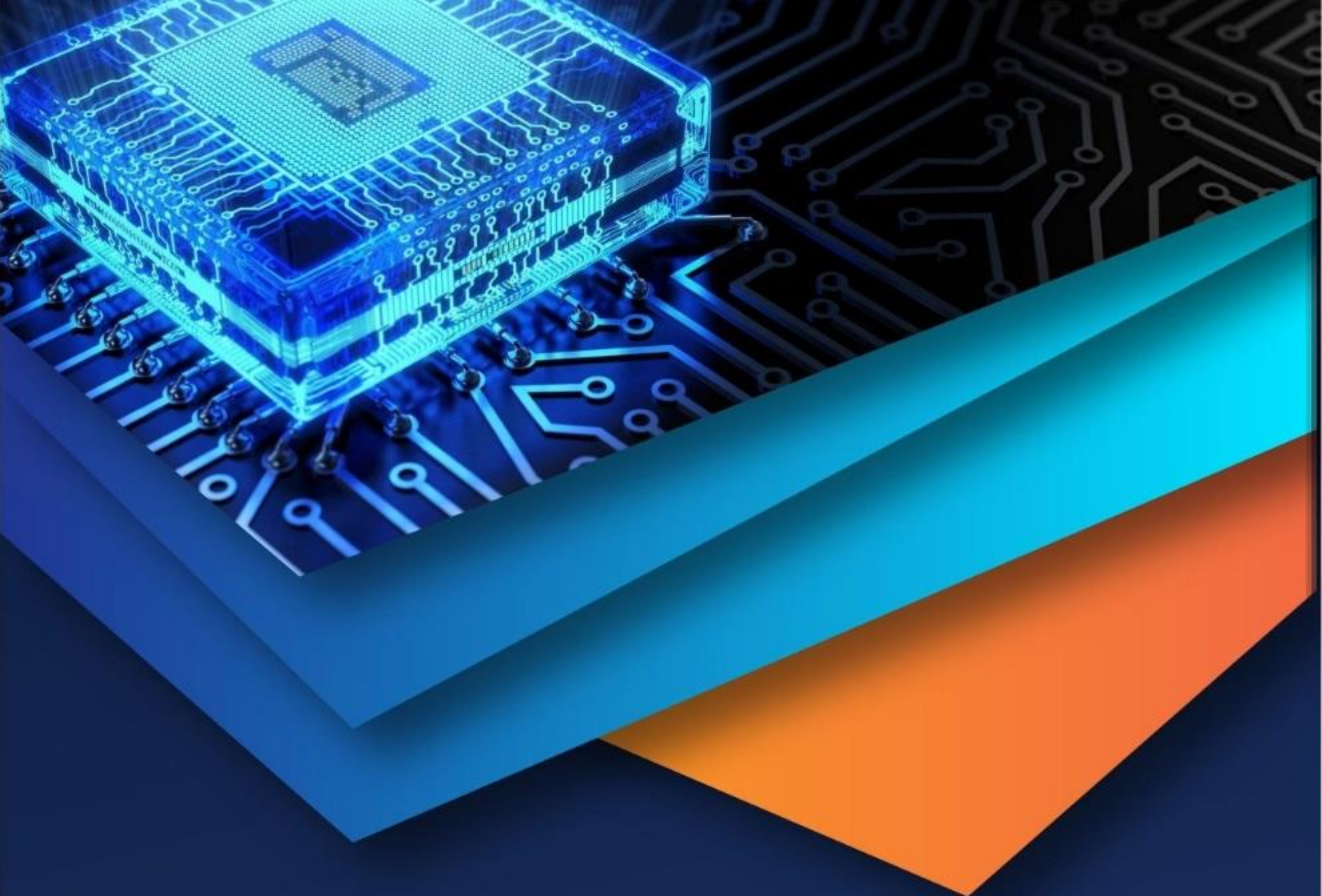
The improvement factor (IF) increases with area ratio for all encasement lengths, with full-length encasement achieving the highest IF. L/D=6 outperforms L/D=4 and L/D=2, demonstrating that longer encasements enhance soil improvement. IF decreases sharply as settlement ratio increases, indicating reduced performance at higher settlements. Full-length encasement maintains superior IF, especially at low settlement ratios, while L/D=6 performs well initially but diverges as settlement grows. Shorter encasements lose effectiveness faster, with L/D=2 being least efficient. Overall, longer encasements improve performance, with L/D=6 offering cost-effective alternatives. At low area ratios (0.05–0.15), stress concentration rises slightly, but beyond 0.17, it increases sharply, showing that larger stone column areas bear more load and improve soil reinforcement efficiency.

IV. CONCLUSIONS

1) Geosynthetic Encasement Stone Columns (GESCs) outperform Ordinary Stone Columns (OSCs) in settlement control, load-bearing capacity, and lateral stability beneath oil storage tanks.
2) Untreated soil shows the poorest performance, while OSCs improve settlement moderately. GESCs provide the highest improvement, sustaining greater loads while significantly reducing deformations.
3) GESCs also minimize lateral displacement, especially at mid-depths, enhancing overall structural stability.
4) Column spacing (S/D) strongly influences performance — closer spacing delivers better settlement control and more efficient load transfer. Increasing the length-to-diameter ratio (L/D) increases stress-carrying capacity, with longer columns mobilizing higher shaft resistance and end-bearing.
5) Partial encasement provides improved performance compared to OSCs, but full-length encasement offers the best results. However, partial encasement can be more cost-effective when material savings are considered.
6) Beyond a certain encasement length, improvements in displacement control become marginal, making moderate encasement depth the most practical solution.
7) Overall, full-length geogrid encasement at closer spacing with higher aspect ratios delivers the best performance, while partial encasement at optimized configuration serves as a balance between effectiveness and cost.
8) Model 2 provides the most effective settlement control, significantly reducing settlement compared to others. Models 2 and 3 both improve performance, with Model 3 balancing cost and effectiveness well. Settlement decreases with depth and radial distance across all models.
9) As the length increases, IF value increases with increase in L/D ratio and Ar, where settlement decreases. As the area ratio (Ar) increases, the stress concentration ratio rises gradually at first and then sharply, indicating that larger stone columns share more load and greatly improve soil reinforcement efficiency.

REFERENCES

[1] Van Impe W, Silence P (1986) "Improving of the bearing capacity of weak hydraulic fills by means of geotextiles". In: Proceedings of the 3rd international conference on geotextiles, Vienna, Austria, pp 1411–1416.
[2] Priebe, H. J. (1995). Design of Vibro Replacement. Ground Engineering, 31-37.
[3] McKelvey D, Sivakumar V, Bell A, Graham J (2004) Modelling vibrated stone columns in soft clay. Proc Inst Civil Eng Geotech Eng 157:137–149.
[4] Ambily AP, Gandhi SR (2007) Behaviour of stone columns based on experimental and FEM analysis. J Geotech Geoenviron Eng 133(4):405–415.
[5] Pulko, B., B. Majes, and J. Logar. 2011. "Geosynthetic-encased stone columns: Analytical calculation model." Geotext. Geomembr. 29 (1): 29–39. https://doi.org/10.1016/j.geotexmem.2010.06.005.
[6] Hamidi M., Lajevardi S. H. (2018). "Experimental study on the load carrying capacity of single stone columns", International Journal of Geosynthetics and Ground Engineering, 4(26).2018.
[7] Gniel, J., and A. Bouazza. 2009. "Improvement of soft soils using geogrid encased stone columns." Geotext. Geomembr. 27 (3): 167–175. https://doi.org/10.1016/j.geotexmem.2008.11.001.
[8] Keykhosropur L, Soroush A, Imam R (2012) 3D numerical analysis of geosynthetic encased stone columns. Geotext Geomembr 35:61–68.
[9] Schnaid F, Winter D, Silva AEF, Alexiew D, Kuster V, Hebmuller A (2014) "Geotextile encased columns (GEC) under bridge approaches as a pressure-relief system: concept, experience and measurements". In: 10th International Conference on Geosynthetics, Berlin, Germany.
[10] Zhang, L., Z. Xu, and S. Zhou. 2020. "Vertical cyclic loading response of geosynthetic-encased stone column in soft clay." Geotext. Geomembr.48 (6):897–911. https://doi.org/10.1016/j.geotexmem.2020.07.006.



10.22214/IJRASET

INDEX COPERNICUS
45.98

IMPACT FACTOR:
7.129

IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY