SETTLEMENT AND STRESS CHARACTERISTICS OF IMPROVED SOIL BY SAND COMPACTION PILE

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ABSTRACT

Sand compaction pile (SCP) is receiving wide popularity these days for stabilizing weak soil deposits located underneath important structures to ensure the safe uses of such structures against excessive settlement and bearing failures. Evaluating the settlement and stress characteristics of improved soil through the utilization of SCP has been and will be of paramount importance while deciding the suitability of SCP for critical infrastructure projects. To address this issue, this paper presents a simplified analysis approach for estimating the settlement and stresses of improved soil by SCP. Since large-scale testing and analytical solutions for this kind of soil-structure condition are cumbersome and have inherent limitations such as budget, load control mechanism, etc., the authors choose to take advantage of available high-fidelity finite element software to model the soil-structure system and carried out the target settlement and stress computation. Three typical superstructure load conditions are taken into account and dry cohesionless sand is considered for the sake of simplicity and explicit interpretation of results. Settlement and stresses of improved soil are compared with the same parameters of typical unimproved or weak soil. A considerable reduction in the total settlement is observed for soil with SCP compared to the original weak deposit. Corresponding stress results show an analogous trend with settlements as induced stresses in soil are found higher in improved soil compared to unimproved soil. This current study will enhance the use of a simplified approach in order to understand the performance of soil improved by SCP utilizing available hands-on resources.

Keywords: Sand compaction pile, finite element method, improved soil, soil settlement, soil stress

1. INTRODUCTION

Geographically Bangladesh is a low-lying riverine delta. The delta plain of the Ganges (Padma), Brahmaputra (Jamuna), Meghna Rivers, and their tributaries occupy the majority of the country's land formation (Allison & Kepple, 2001). Its capital and other major metropolises are densely populated, and home to most of the country's population. The built environment of these cities has developed over the last 50 years period on mostly marshy water-logged soft soil deposits. The rapid economic and industrial growth over the years has seen large-scale infrastructural developments. Facilities like nuclear power plants, container and freight terminal, industrial zones, super dykes, rail networks, and airports are noteworthy. For safe, efficient, and sustainable operation of such components, it is a prerequisite that they must be founded on adequately strong soil which is scarce in this part of the world. Therefore, ground improvement becomes an inevitable choice for engineers. There are many techniques to achieve improved soil such as dynamic compaction, stone column, sand compaction pile (SCP), deep cement mixing, etc. which have gained popularity in recent times (Kasper, 2009; Basack, 2016; Ezoe, 2019). A comprehensive comparative investigation is always essential to decide the most plausible improvement technique from the available ones and then to optimize the design of the selected option (Arthi & Dodagoudar, 2021). Engineers and researchers are working relentlessly to produce hands-on simple solutions (Hussein, 2021; Kitazume et al., 2016) to achieve that as performing laboratory-scale and full-scale experiments is not always viable due to loading and control mechanism aptness and, moreover, the limitations of funds during the pre-decision phase of a project. However, credit to the development of computing techniques (Ahn & Kim, 2012; Zhen et al., 2023) over the years through high-fidelity professional simulation software, design houses can take advantage to calculate the required parameters rationally to understand the target behavior of a ground improvement solution through appropriate mimicking of the actual problems.

This work is carried out focusing on the performance evaluation of SCP improved soil. The main objective of the introduction of SCPs into a soil deposit is to elevate its denseness so that the possibility of future settlements is reduced, and its load-carrying capacity is increased. Thus, it is important to compute these parameters with a higher degree of accuracy before commencing construction. This study investigates and compares the settlements and stress characteristics of an unimproved deposit and an improved deposit with SCP. Finite element (FE) software simulations are adopted to do the analysis by considering the appropriate soil model to produce the target behavior of the soil deposits with an easy-to-use approach. Typical loading of three different amplitudes covering a wide range of structural load is applied on the free-soil surface.

2. FINITE ELEMENT MODELLING

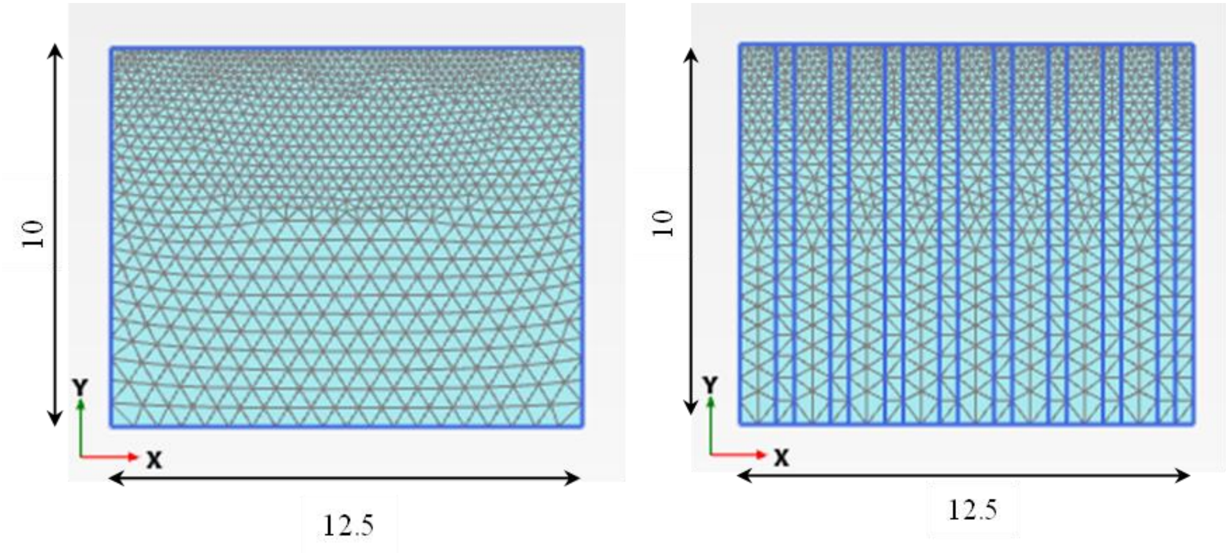
Two soil models are prepared in a 2D framework namely the unimproved soil and improved soil with SCP utilizing finite element modeling software. Each soil model is prepared of size 12.5 m in lateral direction and the depth of the soil body is taken as 10 m as depicted in Figure 1. The material properties used for the unimproved soil and the properties of dense sand used in the sand compaction piles are listed in Tables 2.1 and 2.2. The unimproved soil model only contains sands, whereas the improved one contains columns of dense sand as SCP of diameter 500 mm at 1m interval. Mohr-Coulomb model is considered to simulate the soil shear behaviour [Carter et al., 2000]. Three different uniformly distributed loads of amplitude 75 kN/m^2, 150 kN/m^2, and 225 kN/m^2 respectively are applied vertically on the soil surface as inputs. For these three loading cases, the settlements of soil & stresses throughout the whole depth of the soil body are computed utilizing static plastic analysis.

Table 1: Unimproved Soil properties

Parameter	Value	Unit
γ	14	kN/m^3
E	35	MPa
ν	0.25	
ϕ	32	degree

Table 2: Sand compaction pile material properties

Parameter	Value	Unit
γ	16	kN/m^3
E	45	MPa
ν	0.3	
Φ	39	degree

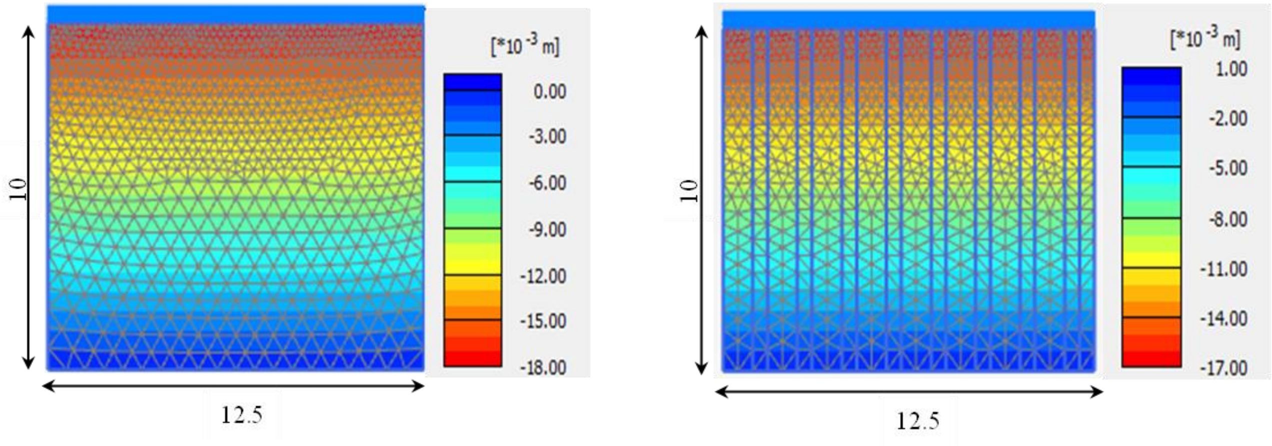


(a) (b)

Figure 1: Soil models (a) unimproved soil, (b) improved soil with SCP; (all dimensions in m)

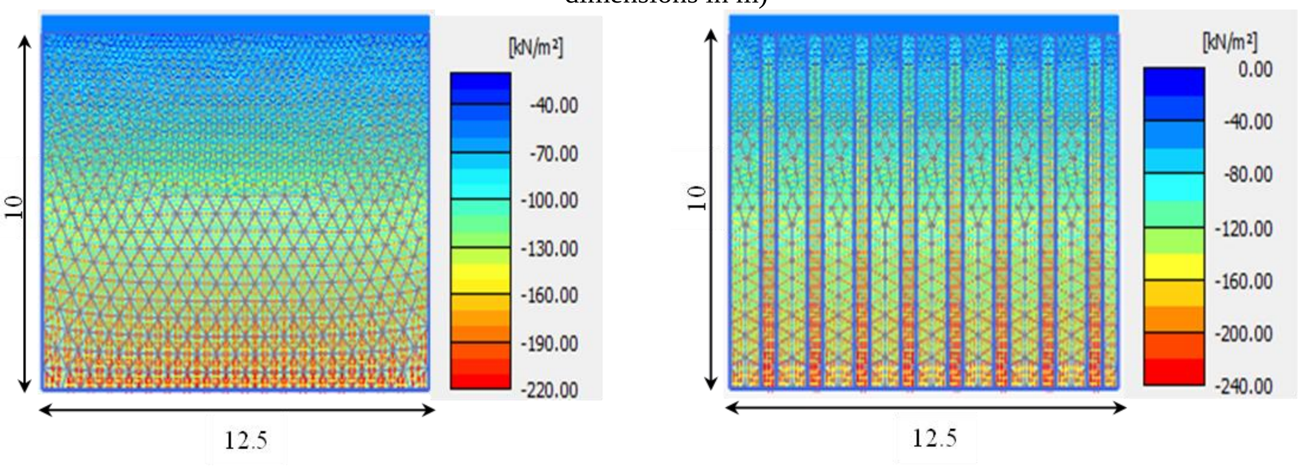
3. SETTLEMENT AND STRESS RESULT'S

The contours of vertical settlements and stresses obtained through FE simulations for unimproved soil and improved soil with for all three loading cases are presented in this section sequentially through Figures 2 to 7. For all loading cases, it is clearly seen that the settlements are reduced throughout the whole depth of soil mass for improved soil while compared to unimproved soil and the maximum settlement for each loading case for improved soil is lesser than the unimproved soil. For example, the maximum settlement for 75 kN/m^2 loading is 17.86 mm in unimproved soil as in Figure 2(a) whereas it is 16.82 mm for SCP improved deposit as in Figure 2(b). Similarly, for loading amplitude 225 kN/m^2 the settlements are 56.43 mm and 51.43 mm for the aforementioned two soil cases, respectively as in Figure 6(a) & 6(b). The comparison maximum settlements for each loading cases are further depicted in Figure 8. Similarly, increase in stress results is observed for improved soil compared to unimproved soil, which indicates that the load carrying capacity of soil increases due to the introduction of SCP or in other words densification of soil. The comparison between maximum stresses between two soils for each loading cases are shown in Figure 9.



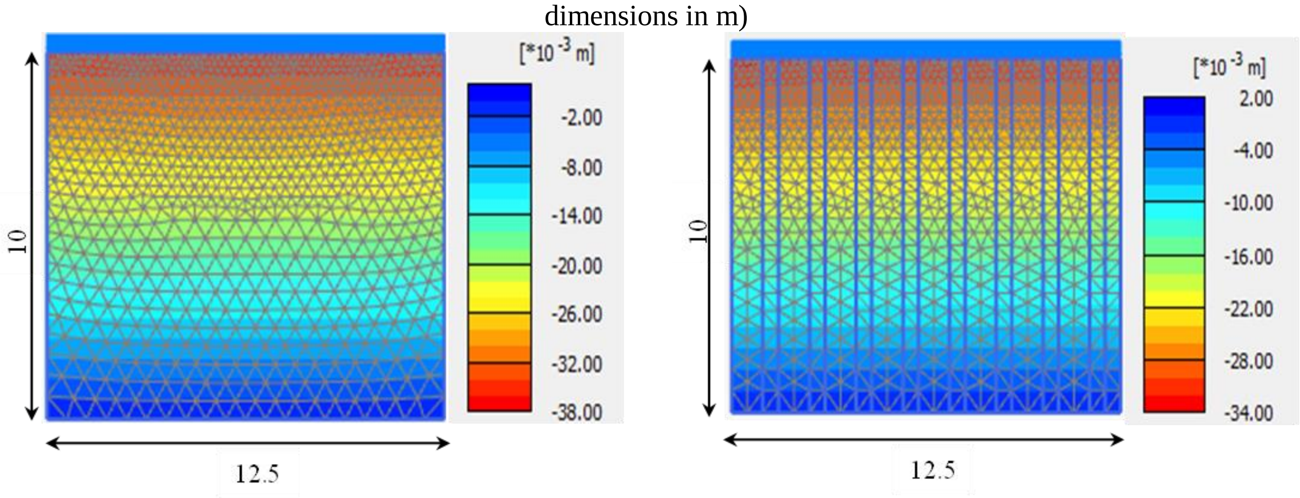
(a) (b)

Figure 2: Settlement of unimproved soil (a) and improved soil with SCP (b) for loading amplitude 75 kN/m^2; (all dimensions in m)



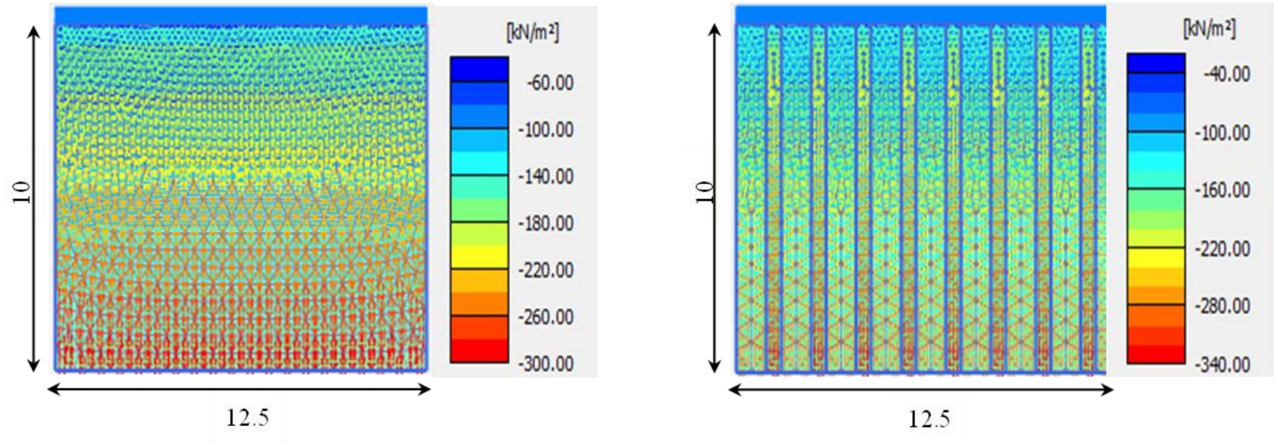
(a) (b)

Figure 3: Stresses in unimproved soil (a) and improved soil with SCP (b) for loading amplitude 75 kN/m^2; (all dimensions in m)



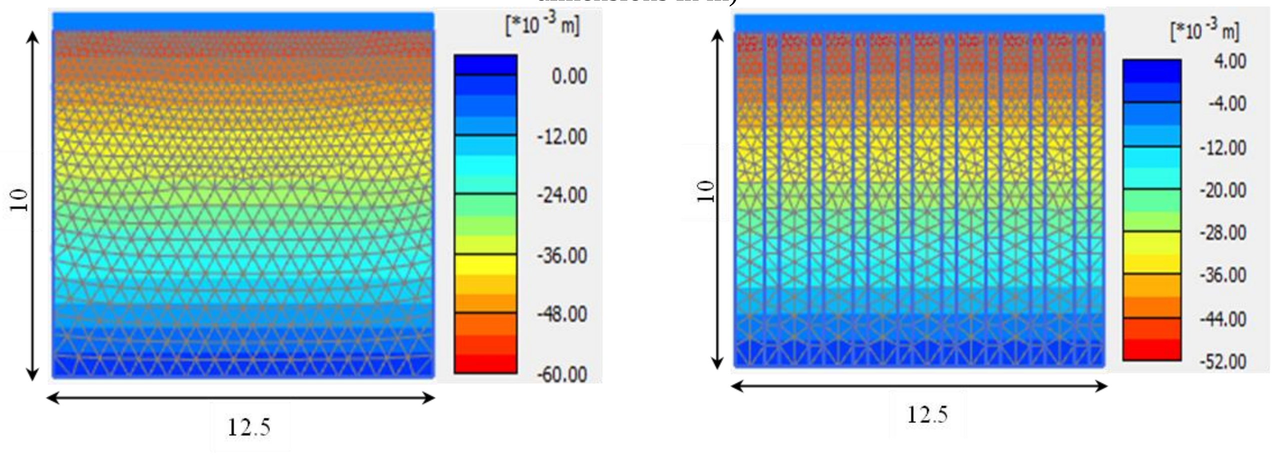
(a) (b)

Figure 4: Settlement of unimproved soil (a) and improved soil with SCP (b) for loading amplitude 150 kN/m^2; (all dimensions in m)



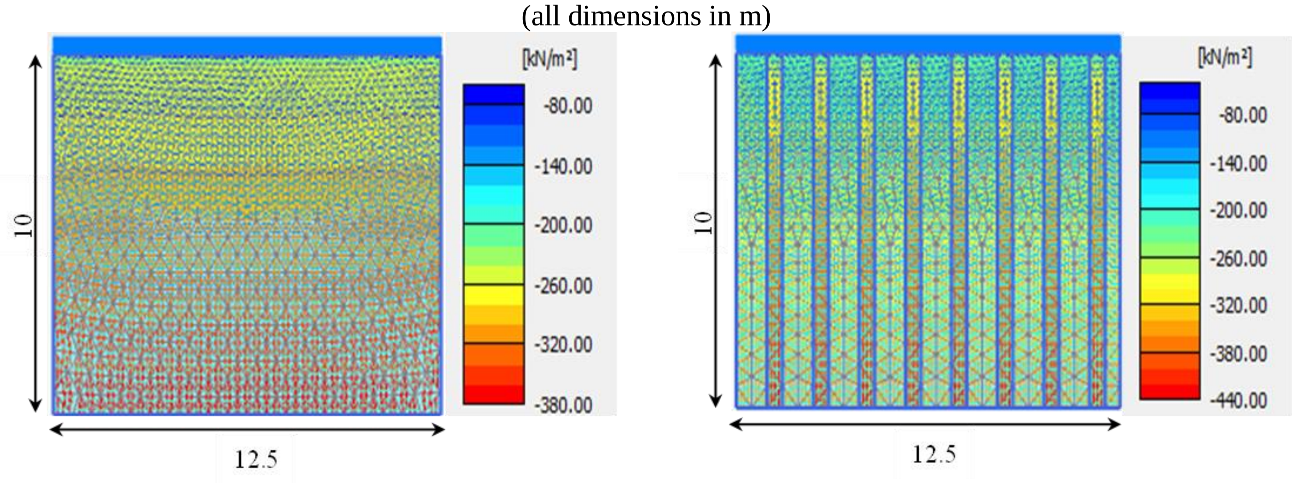
(a) (b)

Figure 5: Stresses in unimproved soil (a) and improved soil with SCP (b) for loading amplitude 150 kN/m^2; (all dimensions in m)



(a) (b)

Figure 6: Settlement of unimproved soil (a) and improved soil with SCP (b) for loading amplitude 225 kN/m^2; (all dimensions in m)



(a) (b)

Figure 7: Stresses in unimproved soil (a) and improved soil with SCP (b) for loading amplitude 225 kN/m^2; (all dimensions in m)

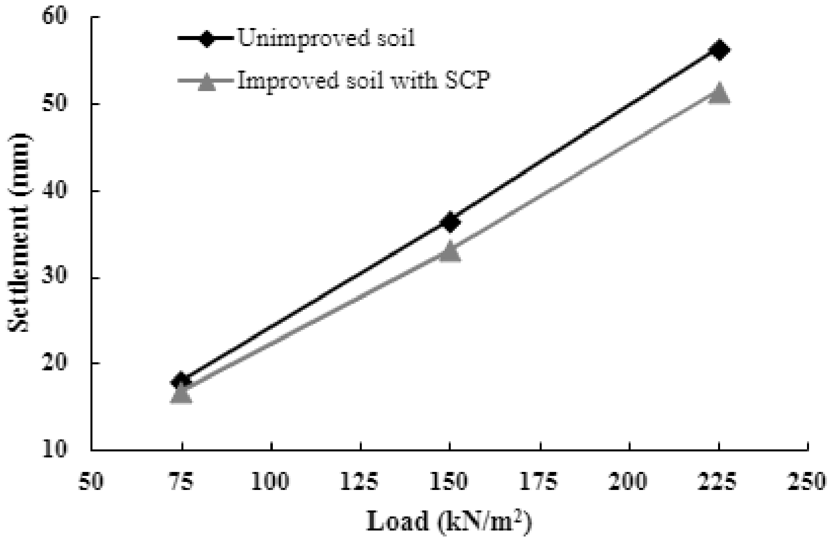


Figure 8: Maximum settlement for all the loading cases.

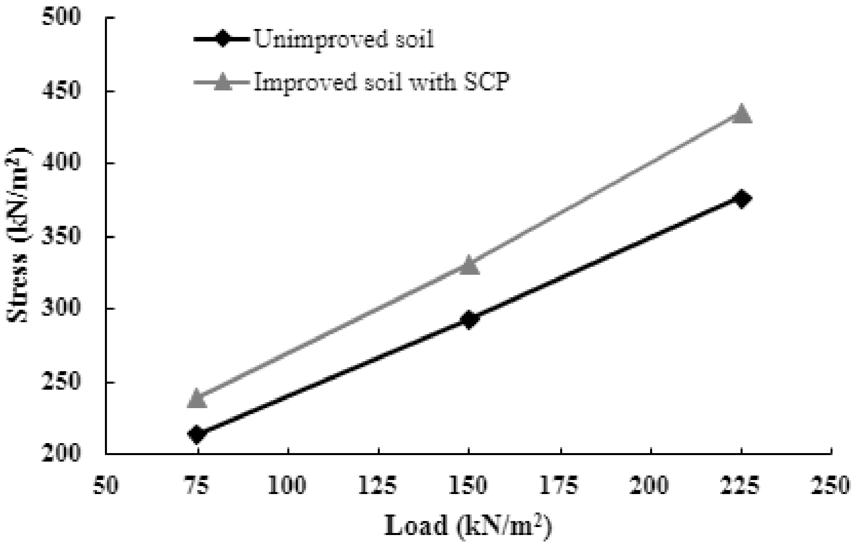


Figure 9: Maximum stresses for all the loading cases.

The vertical stress increases are computed analytically also using conventional Bousinesq solution [Arora, 2003]. These computations also yield results closer to the one seen in the numerical simulations. For example, the vertical stress in unimproved soil for 75 kN/m^2 loading is obtained 214.6 kN/m^2 (Figure 9) through FE simulations whereas it is found as 201 kN/m^2 using Bousinesq solution.

4. CONCLUSIONS

A simplified and easy-to-use finite element modeling approach is presented here to evaluate the settlement and stress characteristics of improved soil by sand compaction pile (SCP) over typical unimproved soil. Dry cohesionless soil is considered for the sake of simplicity and explicit interpretation of the results. Three different magnitudes of vertical load covering a range of typical structure loads are applied to the soil mass. The settlement and stress behaviour are found to be enhanced due to the introduction of SCP in soil. The simulated results also show an analogous trend with results computed using widely accepted analytical solution. The technique discussed here will enable design house engineers to evaluate the performance of SCP-improved soil through fast and reliable hands-on resources.

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