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Effectiveness of Mono Sand Piles in Soft Cohesive Ground †

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Abstract: Soft cohesive formations are extensively distributed across the earth's land mass. They mainly comprise medium to high plastic clays deposited by thousands of years of geological activity. In Pakistan, the upper and lower plains of the Indus Valley have several square kilometers of cohesive ground. The cohesive soils are vulnerable to moisture variations and lack friction. Hence, they are not considered an ideal ground for foundation support. The raft foundation and traditional reinforced concrete piles are effective solutions, but are uneconomical. Sand piles can replace these expansive foundations for moderately loaded structures; however, their effectiveness is required to be supported by field and research investigations. This study presents FEM-based numerical investigations on the performance of a single sand pile on soft cohesive ground. The pile is loaded with the 100 kPa pressure, representing a moderately loaded structure. The stress–strain behaviors and overall pile settlement results are graphically presented. The sand pile, the stiffer material, could hold most of the stresses while maintaining volumetric strains up to 10%, thus allowing better load transfer to the naturally soft ground.

Keywords: cohesive soil; foundation settlement; numerical modeling; sand pile; stress distribution

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1. Introduction

Fine-grained soils (less than 0.075 mm in size) are problematic when they comprise medium to high plastic clays. The fertile agricultural plains of Punjab and Sindh mainly consist of cohesive soils formed by the alluvial deposits of the river Indus and its tributaries. Cohesive soils have threaded particles that lack friction but have reasonable cohesion in a dry state; however, under moist conditions, they lose their strength and become soft. Therefore, they are considered inadequate for sustaining foundations [1]. Traditional solutions like raft foundations and reinforced concrete piles function well. However, they might not be economically viable, especially for moderately loaded structures. On the other hand, conventional RC piles sometimes require unique and complex driving techniques [2]. Sand piles have been proposed as a potential replacement for conventional deep foundations up to a certain degree. Sand piling is a ground-improvement technique that replaces the inadequate soil layer with sand piles produced by drilling holes into the ground and filling them with dense sand [3]. These piles are used to construct a sequence of columns that support the foundation. Since they can reduce settlement and increase the bearing capacity of the soft ground, sand piles are a possible replacement for traditional deep foundations. The performance of sand piles can be affected by several variables, including the pile's size and shape, the soil's characteristics, and the load circumstances. Therefore, numerical modeling is a valuable tool for analyzing the performance of sand piles under various conditions [4]. Nevertheless, sand piles cannot be applied to structures subjected to complex loading and specific drainage requirements [5]. Numerical simulations utilizing various codes, such as PLAXIS and COMSOL [6], have become an effective tool for researching the behavior of soils under various loading circumstances; these models can assist engineers in designing more stable and dependable soil structures. Recent studies have stressed the importance of taking time-dependent behavior into account when evaluating the stability and performance of soil by utilizing numerical simulations [7].

Research investigations to assess the efficacy of sand piles in soft cohesive ground are limited; an effort has been made in this brief study to analyze stress–strain behaviors and overall sand pile settlement. An FEM-based numerical model using COMSOL Multiphysics code has been used in this perspective. This will give readers an insight into how sand piles perform under static loads.

2. Materials and Methods

The natural ground was represented by fine-grained soil with a soft consistency, whilst dense sand simulated the sand pile. The fundamental properties of geomaterials were determined in the laboratory, and elastic properties were estimated using classical correlations [6]. The mechanical properties of both components of the sand pile system are shown in Table 1.

Table 1. Soil characteristics of natural ground and the sand pile.

System Component	Unit Weight (Y) kN/m^3	Soil Friction Angle (Φ)	Soil Cohesion (C) kPa	Elastic Modulus (E) MPa	Poisson's Ratio (n)
Natural Ground	14.71	-	50	40	0.3
Sand Pile	19.60	32	-	75	0.25

The 2-D model was developed to analyze the 6 m long sand pile embedded in a 12 m deep natural ground comprising soft cohesive soil. The analysis was carried out using the COMSOL Multiphysics program's geomechanics module. The model geometry's main features and boundary conditions required to precisely reproduce pile behavior can be seen in Figure 1. A moderately loaded structure was simulated using 100 kPa applied stress.

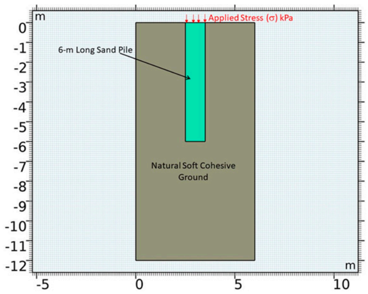

Figure 1. Cross-section of the sand pile and boundary conditions.

3. Results and Discussion

The sand pile stress absorption was examined through the resultant stress diagram. Figure 2a depicts the stress variation in the sand pile system, demonstrating the lower stress distribution in the natural ground compared with that in the sand pile. The stress distribution around the sand pile is focused on the applied stress contact point, demonstrating that the pile holds most of the stresses and facilitates better load transfer to the natural ground. Since the sand pile is stiffer than the surrounding soft soil, there is stress concentration around the pile cap. The sand pile stress distribution and soil displacement behavior are, respectively, illustrated in Figure 2a,b. The soil displacement behavior is a key performance indicator of the sand pile in soft cohesive soils. The analytical results show slight displacement within the sand pile system under the specified load settings. Compared with the nearby soil, the displacement is predominantly centered around the pile and is relatively minimal. The increased stiffness of the sand pile, which prevents the surrounding soil from deforming, is the reason for the sand pile system's displacement behavior.

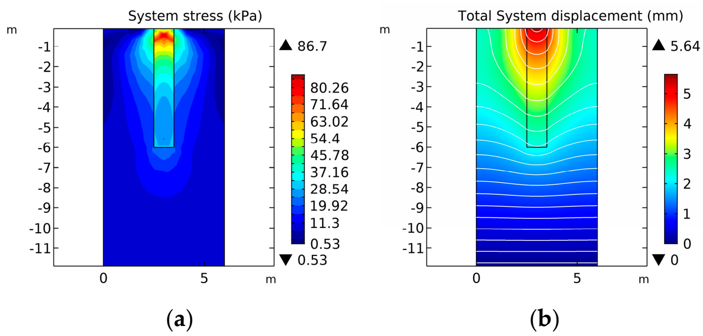

Figure 2. Stress-displacement behavior of the sand pile system. (**a**) Stress Distribution, (**b**) Soil Displacement.

The stress–strain range at the cap and tip of the pile is shown in Figure 3. The analysis's findings show the pile's ability to support loads and its distortion. The volumetric strain gauges the volume change in the soil surrounding the pile. The pile's cap and tip's negative values for volumetric strain indicate soil compression around the pile; the volumetric strain is more significant at the pile cap than the pile tip.

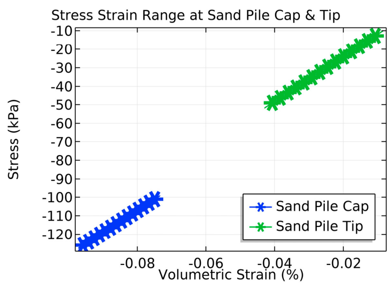

Figure 3. Stress–strain range at pile extremes.

The sand pile was subjected to a static load. However, the consolidation phenomena in cohesive material affected the overall performance. The settlement rate was measured using the system displacement measured at the start, i.e., 0 min, and at 30 min and 60 min intervals. Figure 4a demonstrates how the applied load deforms the sand pile. The displacement of the pile increases over time, reaching its maximum displacement at 60 min. This implies that the pile deforms more with time, proving that a time-dependent deformation under a sustained load is occurring.

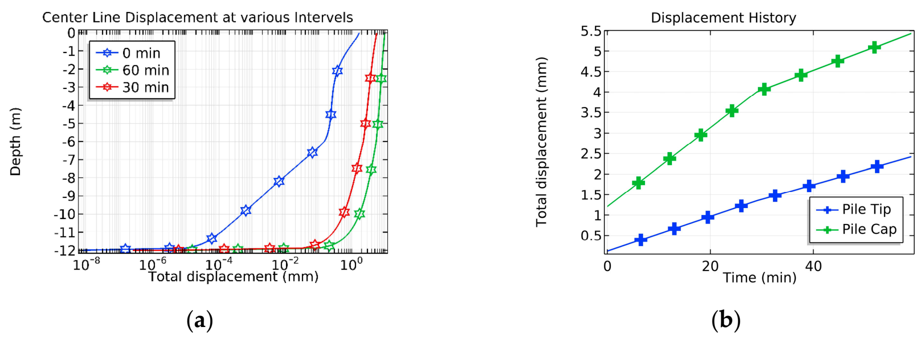

Figure 4. Consolidation effects of the sand pile system. (**a**) Depth (m) vs. displacement (mm), (**b**) Displacement history.

It is also important to note that the deformation rate changes over time. At the start of the simulation, the deformation rate is the fastest. As time goes on, the displacement increases at a slower phase (see Figure 4b). This non-linear behavior is typical for soils since soils display complicated stress–strain behavior based on the type, moisture content, and applied load. Overall, the results shed light on the sand pile's time-dependent behavior and emphasize the significance of considering it for the stability of structures.

4. Conclusions

The following conclusions can be drawn from the presented results.

- Numerical simulations can be economically used to predict the mechanical behavior of complex soil systems such as sand piles in soft cohesive ground.
- The sand pile, a stiffer material, can bear most of the imposed stresses while reflecting low strain values, resulting in overall low settlements of the foundation system.
- The time-dependent or consolidation behavior of the foundation remains a challenge in cohesive ground even after the installation of the sand pile.

The research outcomes can be a benchmark for analyzing the substructures required to be built in complex soil conditions.

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