Model study of screw pile installation impact on ground disturbance and vertical bearing behaviour in dense sand

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Abstract. The purpose of present study was to understand the behaviour of model scale close-ended single helix pile using dense ground conditions with a special focus on installation impact it creates on the nearby ground disturbance and its associated vertical bearing characteristics. To understand ground disturbance behaviour, model scale pile load testing was conducted both with and without installation mechanism. Screw piles having large helix to shaft diameter were also incorporated in the study to investigate helical size impact on nearby ground disturbance; and therefore, variation in their bearing behaviour. Variation in installation effort (installation load and torque) for piles having large helix to shaft diameter was also investigated. Based on experimental results, it was observed that the installation of screw piles disturbed the ground significantly along the pile shaft whereas ground disturbance below the pile tip was almost negligible. In addition, with the increase in helix to shaft diameter, ground disturbance ratio was increased. With the increase in helix to shaft diameter, installation effort requirements increased significantly. Moreover, with the increase in helical diameter, end bearing of the pile was increased but there was no effect on skin friction owing to the same shaft diameter.

1. Introduction
Screw piles are piled foundations mostly composed of high strength steel which, as their name suggests, are screwed into the ground. These piles differ from conventional piles owing to helices attached to the shaft at specific spacing [1]. Previously, usage of screw piles was limited to anchoring purpose and thus was centred around light structures subjected to tensile loads such as sign gantries and transmission lines. However, owing to the provision of good resistance in compression along with in tension, this practice has been expanded to structures subjected to compressive loading as well [2]. Malik et. al [3] investigated that the performance of screw pile is better than straight pipe pile under similar shaft diameter and ground conditions. Moreover, the thickness of helix also affects the performance of screw pile under dense ground conditions if it is deflected or deformed [4-5].

In deep foundation system, screw piles accomplish today’s construction industry demands including cost-effectiveness, rapid installation with a reduced level of noise and minimized vibration to nearby structures [6-7] and are considered as an alternative to conventional deep foundations. Being a new piling solution, the screw pile is not well understood in terms of its design and necessitate further research.

Installation of Screw pile into the ground is achieved using torque application to the pile shaft usually by a rotatory motor coupled with pile head. Pressing system for the application of download force (crowd force) also accompanied a rotation system for starting the installation and to advance the pile into the stratum. According to Perko [8], crowd force applied should be sufficient to ensure that the
helical pile advances into the ground a distance equal to at least 80 percent of the blade pitch during each revolution. Al-Mhaidib [9] indicated that single model pile bearing capacity in cohesionless soil increases with an increase in the rate of loading. Ghaly and Hanna [10] investigated model screw anchor’s installation in cohesionless soil. They indicated that geometry of screw element, properties of soil and installation depth affect the installation torque. Yadong Chen et al. [11] stated that installation of screw piles is limited to soils that have a maximum grain size that is noticeably less than the pitch of the helices. Otherwise, the grains often get stuck in the spiral spaces and prevent the proper advance of the pile. Another limitation to screw piles installation is the torque rating of the screw pile, although the installation equipment used has a much higher torque capability [12]. Because of these structural limitations, the screw pile is not ideally suited to stiff strata. Also, Schmidt and Nasr [13] stated that rocky soils, bedrock and boulders are unfavourable soil conditions for screw piles. However, Arup [1] identified the mitigation for these unfavourable soil conditions, for example, a sharp toe surface can be utilized in case of encountered weak rock to improve the passage into the rock. Similarly, Sakr [14] established that trimming the screw pile helices to assist its installation into gravel containing cobbles lowered the axial capacity of these piles owing to reduced bearing area. Nasr [15] stated that there is an impact on the soil stress state due to the installation thus this may impact the vertical bearing behaviour of screw pile. Lutenegger [16] also supports the influence of installation on the soil. According to Vickars and Clemence [17] and Aydin et al. [18], load transferred to helical plates in terms of bearing resistance is way more than that of shaft resistance. Nasr [13] also outlined that load transfer occurs via both skin and end bearing, yet he did not claim whose contribution is large.

The purpose of the present study was to understand the behaviour of model scale close-ended single helix pile using dense ground conditions with a special focus on installation impact it creates on nearby ground disturbance and associated vertical bearing characteristics. Vertical bearing characteristics of pile included load settlement (P–S) curve, skin friction and base resistance. In order to understand ground disturbance behaviour, model scale pile load testing was conducted both with and without installation mechanism. The effect of the large helix on the nearby ground disturbance was also investigated for which different sizes of helices were used in this study. Installation effort (pressing load and torque) which is required to install the pile up to desired depth was also monitored.

2. Test Outline

2.1. Model Container

In model pile load testing, the size of the container is very critical because it can affect the pile capacity during the axial loading. Previous studies proposed that the zone in which the soil is affected by loading is usually 3 to 8 times the pile diameter (Dₚ) [19-20]. J. Yang [21] suggested that the influence zone in clean sand above the pile tip is 1.5 to 2.5Dₚ and 3.5 to 5.5Dₚ below the pile tip. Randolph and Wroth [22] suggested that the zone of influence around the pile is 0.9 to 1.4 times the length of the pile. According to them Poisson’s ratio and distribution of soil shear modulus with depth affect the influence zone. In this study, the cylindrical steel container having a diameter of 1000 mm and height 1100 mm was used (Figure 1). The container diameter was 15Dₜ – 23Dₜ and vertical clearance beneath the pile was 9Dₜ – 14Dₜ for piles having helix diameter of 43mm and 65mm respectively.
2.2. Model screw pile

The screw piles having helix diameter ($D_h$) of 43mm and 65mm were used. The helix to pitch ratio ($D_h/P$) was 2.15 (Figure 2). Screw piles consisted of hollow central shaft. Single helix was mounted at the tip of shaft. Pitch of helix was measured from the inner edge of the upper and lower helix blade. Two sets of strain gauges were used to measure the frictional and tip resistance of the screw piles. These strain gauges were installed at the inner wall of the shaft, as the central shaft is hollow. Quarter bridge 3-wire system was used for the measurement of strain.

![Figure 1. Model testing equipment](image1)

![Figure 2. Model screw pile](image2)
2.3. Testing procedure
The model ground was prepared with dry Toyoura sand (fine-grained). The properties of Toyoura sand were: Specific gravity ($\rho_s$) = 2.651, average particle size (D$_{50}$) = 0.20 mm, maximum void ratio ($e_{max}$) = 0.977, minimum void ratio ($e_{min}$) = 0.597. According to Garnier et al.[23] and Rakotonindriana et al.[24], if the ratio of pile tip diameter to D$_{50}$ is greater than 35, then there will be no scale effect for the tip resistance. In the present study, the D$_{ratio}$/D$_{50}$ was in between 215 and 325.

In case of experiments incorporating installation mechanism (WI), sand was compacted by rammer to develop the model ground. Each compacted layer had 200 mm thickness having a relative density of 80%. Therefore, the total depth of the model ground after compaction was 1000mm. Preparation of model ground was followed by measurement of the initial condition of the ground. A 3mm thin steel needle was inserted into the ground with the help of hand-held load cell. The penetration load (PL) was recorded during the insertion of the needle. The needle was inserted up to 450mm depth at a distance of 2D$_S$ (2 times the pile shaft diameter), 3D$_S$, 4 D$_S$, 6 D$_S$. Afterwards, pile was installed, using pressing and rotation technique, into the model ground up to an embedment depth of 400mm. The penetration rate for installing the piles was 15mm/min for both piles. The settlement (S) of the pile during installation was measured with the help of displacement transducer whereas the installation load (I) and Installation torque (T) were measured on the pile head with the help of load cell. According to Perko [8], the constant axial force applied should be sufficient to ensure that the helical pile advances into the ground a distance equal to at least 80 percent of the blade pitch during each revolution. Therefore, the pressing rate and rotation were adjusted in such a way that 1 pitch penetration was achieved in 1 rotation of helix. After installing the pile, 3mm thin steel needle was again inserted into the ground with the help of hand-held load cell and penetration load (PL) was recorded during the insertion of the needle at same distances as it was done before the installation of the pile.

In case of experiments without incorporating installation mechanism (WOI), the compacted model ground was prepared till the depth of 600mm followed by pile placement after which remaining layers were prepared adopting similar relative density. Model ground preparation was then followed by measurement of ground condition in a similar manner as it was done in experiments incorporating installation mechanism.

In the end, pile load tests were conducted and load-settlement behaviour was observed. During pile load testing, the penetration rate of the pile was reduced to 2mm/min. The settlement (S) of the pile during pile load test was measured with the help of displacement transducer whereas the compressive load (P) was measured on the pile head with the help of load cell.

3. Test results and discussion

3.1. Installation impact on ground disturbance and pile bearing behaviour
To understand the installation impact that close-ended single helix pile creates on the nearby ground disturbance and its associated vertical bearing characteristics, testing was conducted both with and without installation mechanism. In order to achieve homogeneity between soils conditions for both scenarios, model ground was carefully prepared. In Figure 3(a), it can be seen that penetration load measured at different depths at a distance of 6D$_S$ (6 times the pile shaft diameter, D$_S$=21.7mm) from the edge of the pile was almost similar in both test scenarios. Similarly, homogeneous and analogous ground conditions were achieved at various distances. From the test results, it was observed that the installation of the screw pile into model ground negatively impacted the ground (loosened the original ground) as shown in Figure 3(b). This loosening of the ground is also supported by Lutenegger [16], according to which soil disturbance and subsequent reduction of strength can be attributed to the installation.
Pile load tests were also performed to understand the impact of installation on vertical bearing behaviour. It was observed that the ultimate bearing capacity was reduced with installation as shown in Figure 4(a). This reduction might have occurred because of the loosening of soil by installation. It was also observed that the ultimate bearing capacity of screw pile with installation was more than without installation up to 3.4 mm settlement after which it was reduced as compared to without installation. On exploring the contribution of skin and end bearing, it was observed that skin resistance didn’t undergo any change. However, end bearing of the pile was decreased with installation as shown in Figure 4(b). Also, it was observed that end bearing capacity accounted for increased bearing behaviour till 3.4mm settlement in case of with installation mechanism than that of without installation mechanism.

Figure 4. Installation impact on pile bearing behaviour

3.2. Large helix to shaft diameter impact on ground disturbance
Screw piles having large helix to shaft diameter were also incorporated to investigate helical size impact on nearby ground disturbance and therefore variation in their bearing behaviour. Two screw piles having the same helix diameter (Dh) to pitch (P) ratio (Dh/P = 2.15) but different helix diameters (Dh =43, 65mm) were used for this purpose.

To understand the ground disturbance caused by the installation of large helix to shaft diameter screw piles, testing was conducted both with and without installation mechanism. Homogeneity in ground
preparation was maintained in all tests and was evaluated as explained in section 3.1. The ground disturbance caused by these helices was compared using their respective ground penetration ratio (Equation 1).

\[
GPR = \frac{P_{\text{After}}}{P_{\text{Before}}}
\]  

\[GPR = \text{Ground penetration ratio}
\]

\[P_{\text{After}} = \text{Penetration load after pile installation}
\]

\[P_{\text{Before}} = \text{Penetration load before pile installation}
\]

Ground penetration ratio (GPR) values represent the conditions as described below:

- GPR = 1  No change in ground condition
- GPR < 1  Loosening of the ground
- GPR > 1  Densification of the ground.

From the results, it was observed that ground penetration ratio of screw pile having small helix (D_H=43mm) was less as compared to that having large helix (D_H=65mm) as shown in Figure 5(a-d). Model ground which was near the pile showed more disturbance than that which was away from the pile. The Ground was disturbed till the depth of installation (400mm) however, the ground which was below pile tip was disturbed negligibly small by installation of screw pile.

![Figure 5](image-url)
3.3. Large helix to shaft diameter impact on installation effort

Influence of large helix to shaft diameter was also investigated in terms of effort required for installation. Installation load as well as installation torque required for screw pile installation were recorded during the test. It was observed that the installation load was increased with depth in both cases as shown in Figure 6(a). Similar behaviour was followed by installation torque as shown in Figure 6(b). The increase in installation torque is also supported by Ghaly et al.[10], according to which the value of installation torque increases with an increase of soil strength parameters and/or the installation depth. Additionally, results indicated that greater load was required for installing bigger helices. Likewise, the installation torque requirement was also increased for bigger helices. Installation load was increased by approximately 15% whereas torque requirement was increased by 44% for bigger helix as shown in Figure 6. Ghaly et al.[10], also supports the increase of installation torque with an increase in shaft to helix diameter.

![Figure 6](image)

Figure 6. Comparison of installation effort (a) Installation Load (b) Installation Torque

3.4. Large helix to shaft diameter impact on pile bearing characteristics

Pile load tests were also conducted for screw piles having large helix to shaft diameter, both with and without installation mechanism and their vertical bearing behaviour was compared, as shown in Figure 7. The results showed that with installation (WI), bearing behaviour of pile was reduced both for small as well as for large helix. It was also observed that the ultimate bearing capacity of screw pile with installation, for both small as well as large helix, was more than without installation up to 3.4 mm settlement after which it was reduced as compared to without installation. Also, with increase in the helix diameter, pile bearing capacity was increased. Contribution of skin resistance was very less and was not increased that much owing to the same shaft diameter. However, end bearing contribution was more than skin friction and was improved with an increase in helical diameter. This result is also in line with Vickars and Clemence [17] and Aydin et al.[18]. According to them, the contribution of skin resistance in screw piles is usually very less as compared to end bearing. Increase of pile bearing is also in line with Sakr [14] finding according to which trimming the helices of piles reduces the axial capacity of piles owing to reduction in bearing area.
4. Conclusion

This study attempted to investigate the behaviour of model scale close-ended single helix pile using dense ground conditions with a special focus on installation impact it creates on nearby ground disturbance and its associated vertical bearing characteristics. To understand ground disturbance behaviour, model scale pile load testing was conducted both with and without installation mechanism. Screw piles having large helix to shaft diameters were also incorporated in the study to investigate helical size impact on nearby ground disturbance and therefore variation in their bearing behaviour. Variation in installation effort (installation load and torque) for piles having large helix to shaft diameter was also investigated. The conclusions drawn from this study are as follows:

- Installation of screw pile into dense model ground negatively impact the ground (loosen the original ground). Moreover, the ultimate bearing capacity of the pile reduces with installation under initial dense ground condition.
- Ground penetration ratio of screw pile having small helix ($D_H=43\text{mm}$) is less (i.e. loosening of the ground) as compared to that having large helix ($D_H=65\text{mm}$).
- Model ground which lies near the pile shows more disturbance than that which lies away from the pile. Installation of pile disturbs the ground till the depth of installation whereas ground below the installation depth shows negligibly small disturbance.
- Installation load and torque increases with depth. Greater load and torque are required for installing bigger helices.
- With the increase in helical diameter from 43mm to 65mm, installation load increases by approximately 15% whereas the installation torque requirement increases by 44%.
- With installation, bearing behaviour of screw pile having both small as well as large helix reduces. Also, with increase in helix diameter, pile bearing capacity increases. Contribution of skin resistance does not increase owing to the same shaft diameter however, end bearing contribution is more than skin friction and increases with an increase in helical diameter.
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