Numerical simulation of screw piles under axial loads in a cohesive soil

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ABSTRACT
In this paper, six full scale screw pile tests in a cohesive soil were simulated using a numerical method. The results of the simulations show that, during relatively low loads, the simulated load distribution along the pile agreed well with tested data measured from strain gauges. When the loading increased, the results of the simulations were lower than the test results at deeper locations due to some simplification of the skin friction along the pile in the simulation. Overall, the result of the simulations, including the bearing capacity, deformation, and load distribution, closely matched the results of full scale tests with sufficient accuracy.

RÉSUMÉ
Cet article présente les résultats de six essais sur pieux à pleine échelle effectués dans des sols cohérents et simulés utilisant des méthodes numériques. Les résultats simulés démontrent que les charges relativement basses appliqué sur les pieux, concorde bien avec les données examinées avec des jauges de contrainte. La simulation numérique, démontre que la charge augmente en profondeur due au frottement latéral le long du pieu. En général, les résultats numériques (incluant la portance, déformation et distribution de la charge) sont similaires aux résultats des essais sur le terrain.

1 INTRODUCTION

Screw piles, also known as screw anchors or helical piles, are helixes along a steel shaft. There are a wide variety of shaft diameters available, ranging from 89 mm to 200 mm, for axially loaded pile (Hoyt and Clemence 1989). They are primarily designed and constructed for anchoring purposes. Therefore, they are commonly called ‘screw anchors’. During field installation, the screw piles are rotated into the ground to the desired bearing level.

Advantages of screw piles over conventional piles include:

- The screw piles may be removed by reverse rotation. As long as the helixes are below the frost depth, screw piles do not need extra depth of embedment to resist frost jacking, which is another advantage over other pile types. The frost jacking force that may develop on the screw pile shaft in frozen soils is relatively small compared to the frost force developed on the helix embedded in soil below the frozen zone;
- Screw piles can be easily transported and reused; and
- Screw piles are installed into the ground via drive head motors using rotary hydraulics attached to a variety of equipment. It can be loaded immediately after installation.

The mechanism of load transfer from screw piles to the surrounding soil medium is complex and is still not fully understood. In general, current design theories typically consider that for all types of piles (applicable to screw piles as well), total bearing capacity consists of end bearing and skin friction. Multi helix screw piles are more complicated. Factors, including pile geometries, soil conditions and installation depths (Bradka1997), affect the bearing capacity of screw piles and have to be taken into consideration.

In general, two methods, the cylindrical shear method and individual bearing method, are commonly used as indirect means to determine the capacity of screw anchors based on conventional geotechnical engineering principles. Both methods assume elastic-plastic conditions. The cylindrical shear method, which is currently used by some screw pile manufacturers, assumes a cylindrical shear resistance surface, connecting the uppermost and lowermost helixes, plus an end bearing resistance as shown on Figure 1. The individual bearing method, which is for widely spaced helixes, assumes that bearing failure occurs at each individual helix as an end bearing failure, and the failure surface between helixes is along the interface between the pile shaft and adjacent soils. For both methods to calculate the end bearing capacity are based on standard bored or driven piles. During our literature review, no information was found to indicate that these methods can also be used calculate the screw pile end bearing capacity accurately.

Most current design methods used for screw piles are partially empirical. Further research and refinement are still required. Full scale screw pile tests can be performed to obtain the actual bearing capacity. However, field testing is limited by technical and economic factors. Thus, the numerical simulation becomes an important tool to supplement full scale tests.

In this paper, numerical modeling is used to simulate full scale tests and the results are compared with those obtained by others to verify the accuracy of the results of the simulations.

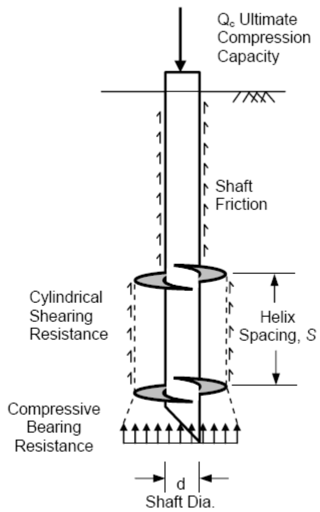

Figure 1. Cylindrical Shear Method for Multi-helix Screw Piles (from Almita, 2004)

2 SIMULATION MODEL AND INPUT PARAMETERS

Zhang (1999) at the University of Alberta completed a geotechnical investigation on the site where the field tests were also conducted. The soil conditions at this site consisted of firm clay to a depth of 1.2 m underlain by stiff clay with an average undrained shear strength of 100 kPa to a depth of 7.5 m. The cohesive soils had a bulk unit weight of 18.5 kN/m^3. During the tests, six (6) full scale screw piles were tested under axial loading. Three (3) of these piles were tested under compressive loads (C1, C2 and C3) and the other three (3) piles were tested under tensional loads (T1, T2 and T3). Strain gauges were installed on four (4) of these piles (C1, C2, T1 and T2) to measure the forces along screw piles. A typical screw pile used for this test is shown on Figure 2. The test pile geometry is provided in Table 1. The maximum loads listed in Table 1 are provided based on the results of Zhang (1999). In his full scale tests, the ultimate loads (maximum loads) was defined as the load corresponding to a pile top settlement greater than 10 % of the helix diameter.

To model the test results, numerical simulations were conducted using FLAC3D (Itasca 2002), a finite difference commercial software package. Mohr–Coulomb models were used to simulate properties the cohesive soil and elastic models to simulate the piles. To save computing time, axis-symmetric condition of screw piles was considered and only one quadrant (in plan) of the pile was created. Models were created with the same geometry as the full scale tests outlined in Table 1. A typical model (C2) is shown on Figure 3. The properties of the screw piles and the soil used for the simulation are summarized in Table 2. Details of the finite difference model can be found in the FLAC3D manual.

Table 1. Summary of the Test Pile Geometries and Test Results (from Zhang, 1999)

Pile No.	No. of Helixes	Helix Diameter (mm)	Helix Spacing (mm)	Top Helix Depth (m)	Max. Load (kN)
C1	3	356	533	3.79	180
C2	3	356	533	1.67	150
C3	2	356	1067	3.79	210
T1	3	356	533	3.79	210
T2	3	356	533	1.67	140
T3	2	356	1067	3.79	210

The axial compressive or tensional bearing capacity of screw piles is a function of the skin friction resistance along the screw pile shaft and the bearing capacity provided by helixes. The skin friction resistance in this study is modeled by placing a layer of interface elements between the pile walls and the soil. The friction and cohesion properties of the interface represent the frictional resistance between the pile and the soil.

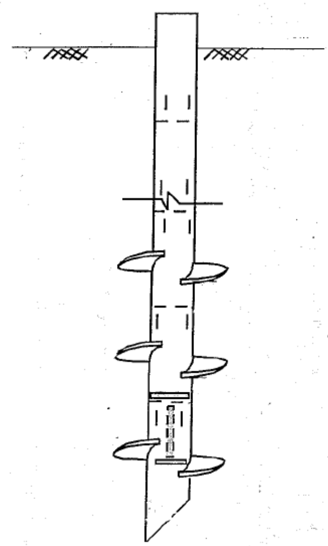

Figure 2. Typical Tested Screw Pile (from Zhang, 1999)

Table 2. Properties of Simulated Screw Piles and Soil

	Screw Piles	Soil
Unit Weight (N/m3)	78000	18500
Poisson's Ratio	0.3	0.3
Bulk Modulus (MPa)	175000	41.7
Shear Modulus (MPa)	80800	19.2
Cohesion (kPa)	N/A	100
Friction Angle (degree)	N/A	0

The shaft resistance per unit length for a pile installed in cohesive soil is often approximated by empirically applying a reduction factor to the shear strength of the adjacent soil (Stewart and Kulhawy 1981, Tomlinson 1957, and Randolph and Wroth 1982). In addition, Mooney et al., (1985) concluded that the shaft adhesion for screw piles in uplift conditions ranged from 0.3 C_u (stiff clays) to 0.9 C_u (soft clays), in which C_u is the undrained shear strength of soils.

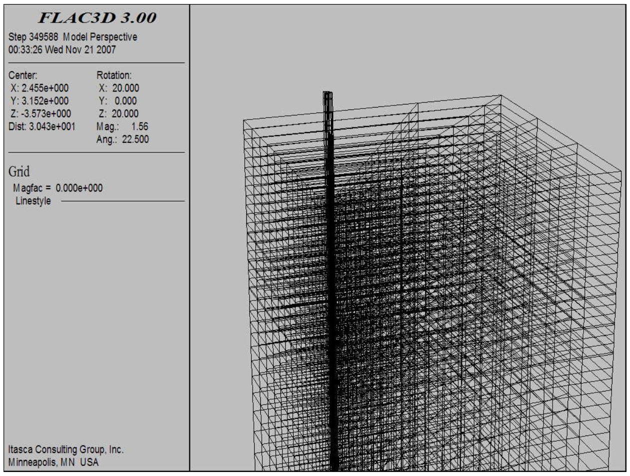

Figure 3. Typical Screw Pile Numerical Model

In this simulation, shaft adhesion ranging between 0.3 C_u and 0.9 C_u was used to model screw piles under compressive and uplift loads. It should be noted that although the skin friction resistance may not be constant along the screw piles, consistent skin friction resistance is used in this simulation due to insufficient information regarding the skin friction resistance distribution along the piles.

It should be noted that the rotary action during screw pile installation may disturb the surrounding cohesive soil (Zhang 1999). A decrease in the undrained shear strength should be considered for a remolded cohesive soil (Bhanot 1968). In this simulation, this disturbance was not considered due to insufficient information regarding the undrained shear strength of the remolded soils of the test site.

3 RESULTS OF SIMULATIONS

Similar to the full scale tests, in this simulation, displacements were imposed at the top end of the screw piles. The simulated axial displacement and loading results at the top of the model were compared with the test results to evaluate the accuracy of the simulation. In addition, the simulated loads along the screw piles, during the loading, were compared with the full scale test results of four (4) piles (C1, C2, T1 and T2), on which strain gauges were installed.

During simulation, the skin friction value was found to have a significant effect on the accuracy of the results of the simulations. The results of our simulation compared with the tests showed that the most accurate simulated bearing capacities can be obtained when 0.55 C_u was used to simulate the shaft adhesion for this site. It is likely that the recommendations provided by Mooney et al. (1985) are suitable for this full scale test simulation.

The ultimate load in this simulation was defined as the load corresponding to a point where pile top settlement becomes significant. The ultimate loads of the six (6) simulated and tested screw piles are shown on Table 3. Two load-settlement curves of the simulation and test results (C2 and T1) are shown on Figures 4 and 5. The test loads at different loading stages, measured by the strain gauges installed on the two screw piles (C2 and T1), compared with the results of the simulations of the piles are presented on Figures 6 and 7.

Table 3. Comparison of Test and Simulation Loads

Screw Pile	Simulation Ultimate Load (kN)	Test Ultimate Load (kN)
C1	180	180
C2	145	150
C3	205	210
T1	195	210
T2	140	140
T3	205	210

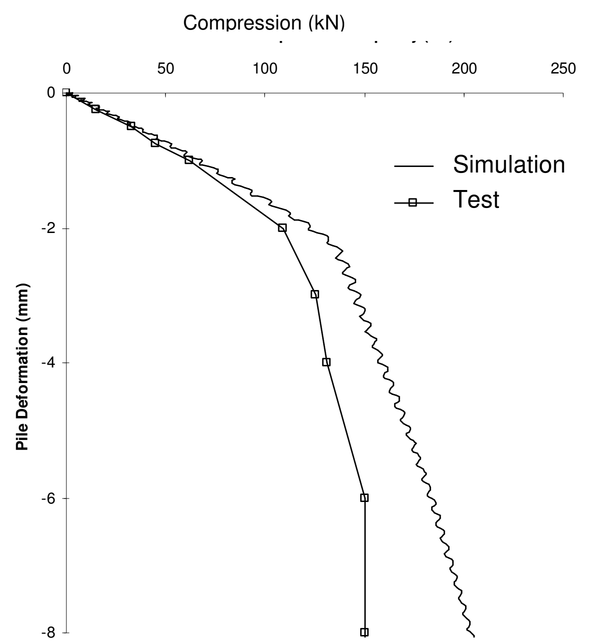

Figure 4. Loading - Deformation Curves of Screw Pile C2

It is clearly shown from the above results that the simulation load and settlement curve closely matched the test data before pile failure. The small differences before piles failure may be partially due to the measurement errors of the full scale test equipment. After the failure, the simulation and test results have some differences. This may be due to the Mohr–Coulomb models used in this simulation which do not have the ability to consider the soil strain hardening /softening. It is likely that the current Mohr-Coulomb model is not suitable for the analysis of failed piles.

The result of the simulations and the data measured by strain gauges installed on the full scale test screw piles, as shown on Figures 6 and 7, are generally in good agreement. The small differences may be due to the skin friction resistance distribution along the pile not being consistent along the piles as assumed by this simulation. The skin friction may be relatively low at shallow depths because of the soil disturbance during pile installation. In addition, the soil disturbance due to pile installation, which was not considered in this simulation, may also affect the accuracy of the simulation.

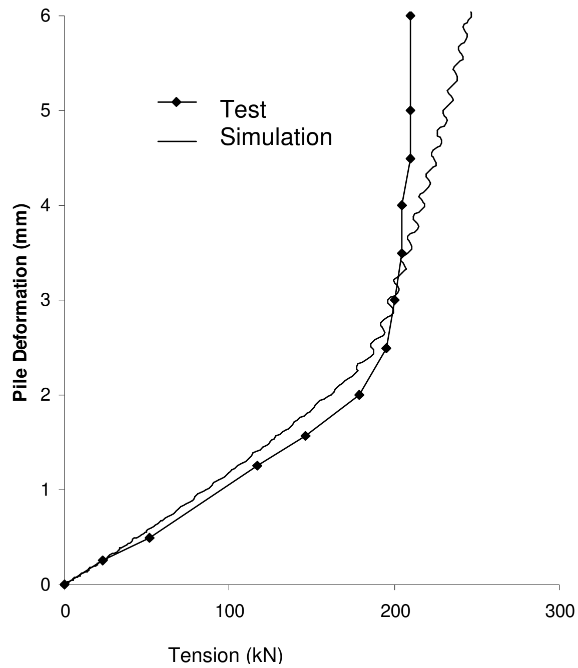

Figure 5. Load - Deformation Curves of Screw Pile T1

4 CONCLUSION AND DISCUSSION

This paper presents a numerical model, which is sufficiently accurate to simulate screw piles in a cohesive soil. The results of the simulations, including the bearing capacity, deformation, and load distribution, closely matched the full scale test results up to pile failure. After the failure, the results of the simulations varied somewhat from the test results which may be due to the Mohr-Coulomb model not being suitable where there is strain hardening / softening of clay. It can also be concluded that the current Mohr-Coulomb model is not suitable for simulating conditions after pile failure.

From these results, it can be concluded that the result of simulations are reasonably accurate prior to the pile failure. It can also be concluded that this model can be used for engineering analysis in similar conditions.

The result of the simulations and the data measured by strain gauges installed on the full scale test screw piles are generally in good agreement. The small differences may be due to the skin friction resistance distribution along the pile not being consistent along the piles. Further research, including full scale tests is required to obtain more accurate screw pile skin friction.

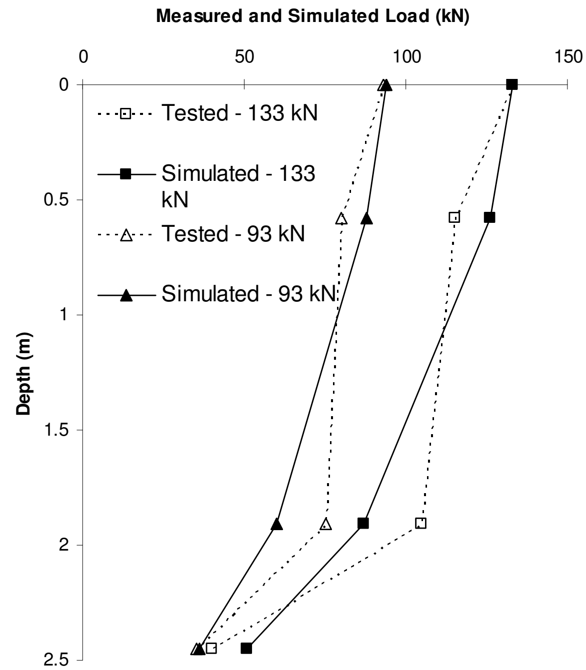

Figure 6. Load Distribution of Screw Pile C2

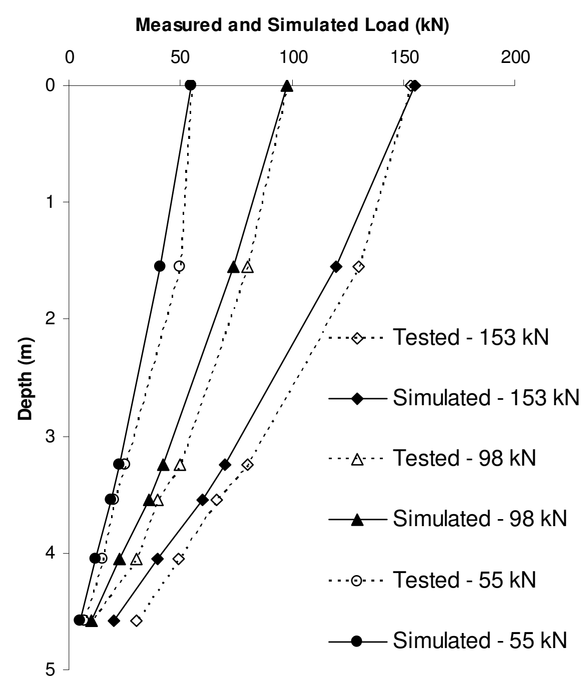

Figure 7. Load Distribution of Screw Pile T1

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