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Research paper

Design and Manufacturing Loading Rig Machine for Testing Screw Pile Models

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Abstract

The main objective of this paper is to design, manufacturing and testing of new loading rig machine to install and testing (i.e. compression and tension load capacity) of screw pile models in both cohesive and cohesionless soil layers. The mainframe was fabricated from thick steel sections, 8mm steel plates that welded together to construct a heavy and strong frame, that able to resist the expected loads during installation (linear and rotational movement at the same time) and testing of the screw pile models (model of loading test). Two independent gearbox motors (actuators) are used to supply the rotational and vertical movement. To provide precise control of velocity, the master gearbox motor, that can convert the rotary motion to a linear motion for vertical displacement along two screw bars via two ball screw systems, and four stainless guided rods to prevent rotation or inclination the bearing plate (rig) which manufactured from high stiffness stainless-steel was used. The second gearbox motor ('slave') mounted on the bottom loading plate that rotates the multi-plate screw pile. It was observed that the measured compression and tension load capacity of screw pile models illustrated the actual behavior of such kind of piles and this machine can be used in both conventional piles (i.e. pipe piles) and screw pile model.

Keywords: *Cohessionless, compression capacity, loading rig, Sand, Screw pile.*

1. Introduction

Many studies were conducted on different soil specimens using principles of physical modeling to investigate different engineering problems, particularly in the cohesionless soil in both dry and saturated state. Installation and testing of screw pile models are commonly investigated problems. These kinds of piles consist of one or more flange plate(s) (Helix) welded to a central steel shaft. The design of a screw pile involves the choice of its shaft length and diameter as well as a specific arrangement of flanges including their number, diameter, D_h, spacing to diameter ratio, S/D_h, and the embedment depth to diameter ratio (H/Dh) of the top flange. All these parameters can be influenced on the pile ultimate capacity (Wang et al., 2017).

The screw piles are become at front of the experimental studies in geotechnical laboratories to investigate the resistance for compression or pull-out forces and how these piles behave under the axial loads from the structure itself. Screw piles also have a good tension capacity and compression (2-3 times of conventional pile capacity, AL-Baghdadi et al., 2017) and can be used for a wide range of soil strata over and under water. The other advantage is the screw pile has quick installation comparing with the driven piles, easy to install, no noisy and no heavy carinas is needed during installation (Gavin et al., 2011). However, there are many significant challenges to be addressed by geotechnical researchers. Screw piles are appropriate to resist for both the tension loads (i.e. as a foundation of wind energy turbine, electrical energy transmission towers, and communication towers) and compression loads (i.e. clarifiers of distilled water, wastewater treatment plant, multi-story building, and under bridge piers). The design of screw piles also involves the selection of a reliable method and consideration of specified performance and loading criteria.

2. Installation methods of screw piles

Experimentally, the piles can be installed in two main methods into the soil layers which may be used in all physical modeling tests to simulate the prototype installation behavior; monotonic (pushed) method and jacked installation method. In the monotonic (pushed) installation method, the pile models is installed under continuous push into the soil layer at a constant rate (Ramadan et al., 2013 at a rate 6mm/min; Lehane and White, 2005 at rate 12mm/min; De Blaeij, 2013, Deeks, 2008 and De Nicola & Randolph 1999 at rate 30mm/min; and Lundberg et al, 2012 and Dijkstra, 2009 at rate 60mm/min). The jacked installation can be conducted on pile (s) model by a series of driven strokes where the pile pushed into the soil at a constant rate (Lundberg et al., 2012 at rate 10 mm/sec; and Lehane and White, 2005 at rate 0.2mm/sec). The monotonic pile installation (pushed) leads to a larger increase in the lateral stresses in the soil in comparison with the jacked pile installation (Lehane and White, 2005). In this paper, new screw pile installation and loading system are designed and manufactured using a monotonic (pushed) installation method at a constant rate of 40 mm/min. This speed (rotational) rate was selected to be consistent with the screw pile flange plate pitch (i.e. between p=7.9 mm and p=10 mm).

Many loading systems have been developed for both centrifuge modeling and even under 1g; both single axis (axial or vertical movement) and double-axis movement (vertical and horizontal movements at the same time) to investigate different complicated geotechnical problems. These loading systems have been performed in geotechnical centrifuge model tests including cone penetration test, CPT, pull-out of anchors, mono-piles, deep excavation and other geotechnical tests. Many of these systems were studied carefully and considered prior to developing the new screw pile loading rig machine in University of Wasit (UoW). Klotz & Taylor (2001) developed a new pile driving loading rig at City University, UK. A servo motor with a gearbox to increase the torque and a ball screw system to convert the rotational movement into a linear motion are used. This system was required for conventional pile installation and test with 50kN driving force at 400mm displacement with penetration speeds between 0.25-1mm/s. Patra et al. (2014) developed a single servo actuator monotonic at the University of Dundee to test anchors and carry out a series of cone penetration tests (CPTs). This actuator consisted of a servo-controlled motor in order to control the actuator remotely, a screw jack system that converted the rotational movement into an axial (linear) motion that was required for installation and testing of the CPTs. This loading system produced a driving force up to 50kN and a minimum pull-out speed 3.1 mm/s over 300 mm stroke.

The next section describes the new (modified) loading system machine for installation and testing of screw piles elements under 1g using the requirements and the principles that were reviewed above.

3- Modified screw pile loading rig apparatus

New loading rig machine for screw pile installation is designed, manufactured and tested in this study. The mainframe was fabricated from thick steel sections, 8mm steel plates that welded together to construct a heavy and strong frame, that able to resist the expected loads during installation (linear and rotational movement at the same time) and testing of the screw pile models (model loading test). Based upon what have been understood from art-of-literature and according to field installation of screw piles, the rotational and vertical speeds need precise control and the choosing of these limitations are strongly influenced by the screw pile model itself (i.e. screw pile configurations) and soil properties to create minimum disturbance to the soil surrounding the pile and to avoid fighting to occur and also to control the vertical force “crowding load”. Therefore, it was decided to use two independent gearbox motors works to supply the rotational and vertical movement. To provide precise control of velocity, the master gearbox motors, that can translate the rotary motion into a linear motion for vertical displacement along two screw bars via two ball screw systems, and four stainless guided rods to prevent rotation or inclination the bearing plate (rig) which manufactured from high stiffness stainless-steel. Gears group that connected by a chain were used to support master gearbox motor for increasing the torque supplied. The second gearbox motor (‘slave’) mounted on the bottom loading plate that rotated the multi-plate screw pile. The speed of the gearbox actuator was controlled by AC Drive (speed regulator) to increase or decrease the revolutions number per minute that control by used turn on-off button. Also, the gearbox motors connect with timer system to limit required penetration depth or settlement. This system allowed a high lead accuracy, with maximum and minimum downward - upward linear movement speed of 65 mm/min and 0.3 mm/min vertically. The installation speed of the screw pile models that used in this study as a constant rate was 40 mm/min whereas the screw pile loading test (in both compression and pull-out tests) was 0.3mm/min. The maximum tension and compression capacities were about 10 kN (i.e. 1 ton). Based on the length and screw pile model configuration, 5 kN load used and fixed at the loading rig (i.e. 0.5 ton) to measure the compression and tension capacity of the screw piles models.

During the installation processing, both gearbox motors work together at corresponding motion according to a number of revolution and settlement, to ensure penetration of screw pile model such a pitch per revolution as much as we can. At the stage of the screw pile compression or tension test, slave gearbox actuator that made to rotate motion was shut down while the master gearbox motor was operating to move the loading rig with a constant rate of penetration (CRP) as shown in figure (1) and (2).

Fig. 1: Screw piles installation and loading apparatus

Fig. 2: Screw pile installation and loading machine with soil container and data collection via data logger

4. Instrumentations and accessories

4.1. Control board:

The control board contained main On/off switches, two-speed invertor buttons to control on both actuators two actuators, motors are used, one for vertical movement with ball screw system and is called Master and the second for pile installation and is called slave). Time and speed monitoring system attached as well so that the speed of the actuators can be controlled by the machine operator. An emergency stop button is provided in case of emergency. Four guided stainless steel rods are used also to ensure that the main bench that carries the slave motor is moving up and down perpendicularly. Low-speed rate reaches up to 0.3mm/min can be obtained for the screw pile model loading. Displacement control system is provided also by using an electrical circle and limit switch instrument so that it can be controlled on the maximum drop can the machine reaches without making any damage may occur and this will make the machine off automatically. Figure (3) shows the control board and all buttons.

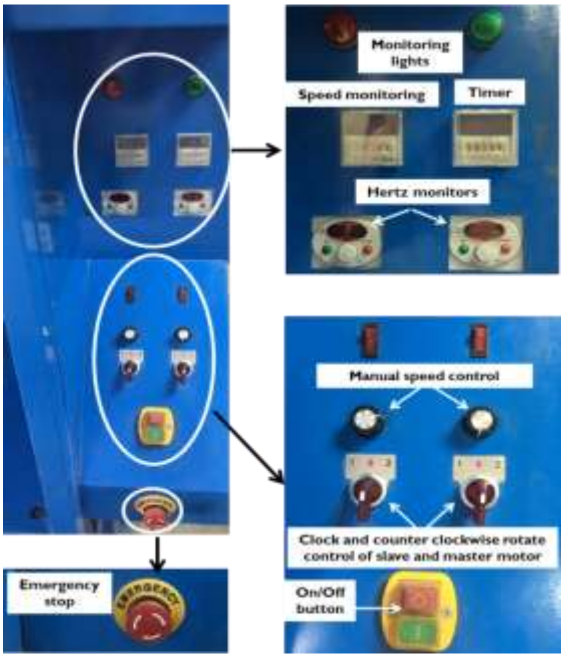

Fig. 3: Control board of the machine

4.2. Slip ring technique

The Screw pile should be installed by applied pressure at the head and screwing. Thus, a special technique is used to prevent the wire of the load cell from spinning during installation. This slip ring is manufactured locally in the electrical engineering laboratories for this purpose. It is consisting of two main parts, the first movable (able to rotate with the load cell during installation of the screw pile). In this part, four copper rings are used with PVC main body and all four wires come out from 1mm hall made in each ring. The other part of the slip ring is the fixed one at the frame and consisting of four carbon braches and these poles are contacted with the four rings at the first part to ensure capturing of the electrical signal from the load cell during the installation. Details of the slip ring are shown in figure (4a).

4.3. Jaw lathe chuck

To make the screw pile model attached correctly during both the installation and loading tests, it should be fixed and tied with the load cell movable bench of master-slave. Jaw lathe chuck is bought and fixed at the bottom-center of the bench. It can catch the screw pile from the head (from three points) and it has an ability to prevent the sliding particularly during tension capacity tests and simulate a pile cap during loading. A detail of this part is shown in figure (4b).

4.4. Limit switch

Two digital limit switch is used to increase the safety by determining and setting the maximum drop of the bench during installation of the screw models and it can be (i.e. the system) switched off automatically when the main bench touch the switch during both installation and re-installation. Each one is fixed at the bottom of the movable bench and at the fixed main bench of the machine. Figure (4c) shows the limit switch instrument.

4.5. Load cell

An axial load cell specially manufactured by Sewha Korea, ideally suited for a wide range of applications is used to measure the compression and tension forces of the screw pile models. SS300 S-type load cells provide high accuracy and minimum deformation was chosen to measure the force during the installation and load testing (see Figure 4d). Maximum working capacity of 5 kN, with rated output (R.O.) is 2.0 ± 0.005 mV/V, combined error is 0.03%, and excitation 10-15V (10 recommended). Nickel plated steel body with IP66 environmental protection (IP is an Ingress Protection rating, here against both the solid objectives, by preventing ingress of dust sufficient to cause harm and against the liquid, against powerful water jet). The load cell was mounted directly above the model screw pile to allow direct measurement of the axial load applied to the pile during installation and to allow load testing after installation in one operation.

4.6. LVDTs

DC Linear Variable Differential Transformer (LVDTs) transducers to measure vertical movement, displacement are used in this study. It can measure the screw pile model settlement during loading and pull-out tests up to 10 mm. Type ELE fully encapsulated electronics, sealed in a stainless steel case (see figure 4e). It is supplied complete with a 5-pin DIN type connector for direct connection to the Data acquisition system.

4.7. Data acquisition system (DAQ) (data logger)

Type lab jack T7-Pro combines our highest performance 24-bit analog inputs with the convenient Ethernet or Wi-Fi communication interface is used in this study (see figure 4f). Two Analog Outputs (12bit, 0-5V) was measured via this data acquisition (DAQ) for the output signals from the load cell and LVDT. National Instruments Lab view software (version 11.0) was used to control the DAQ unit by making a simple subroutine.

Fig. 4: (a) The slip ring details; (b) The jaw lathe chuck; (c) Limit switch; (d) S-shape load cell; (e) LVDT and (f) Lab-jack data logger

4.8. Lab VIEW sub-routine software

New lab view sub-routine version 2011 is utilized to measure and save the screw pile capacity during compression and tension loading. This subroutine was specially made for the tests in this study and two main graph monitoring can be inspected during the tests, one for the loading of the piles and the other for the displacement of the pile. The expected data for both channels (i.e. for the load of the screw pile resistance and the displacement) can be collected and saved directly from the button and from the plots, it can be observed any fail or non-desirable event may occur during the loading tests. See figure (5).

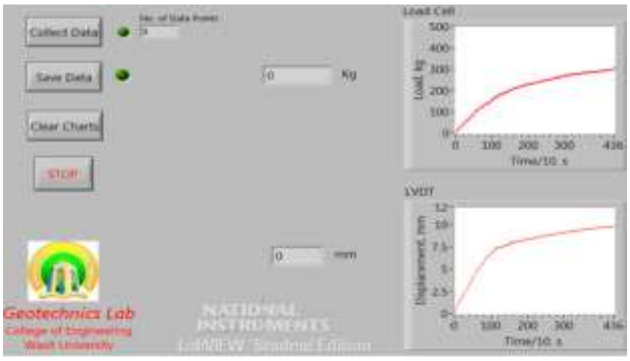

Fig. 5: Window of the results monitoring during the tests

5. The steel container

The container used in this study was made from steel to prepare the soil layer in all models. It has dimensions of (600mm × 600mm × 700mm height). All parts of steel plates, different steel sections and the pulley (movable container) are welded together. Each face of the container is made of 2mm thickness steel plate. The container sits on a movable angled steel base which has four small steel wheels. The container is supported by angle steel frame that welded on plates to resist any lateral deformation during the preparation of the soil bed and during the test. As shown in figure (6), the dimensions of the tank are chosen to provide fully mobilized pressure within the soil during the loading testing.

Fig. 6: The container used in the installation of screw pile models

6. The screw pile models

More than 15 screw pile models were designed and manufactured. They were manufactured from mild steel with 20 mm fixed diameter steel shaft; 1.5 mm wall thick; 2mm thick individual plates/flanges or helices (helical plates). Three main different helix spacing (S) are used in this big project (not included in this paper), single, double and triple helix and they were welded onto a shaft. Different helix diameters are used to investigate how the capacities of screw pile behave under compression and tension (i.e. effect of wing ratio, D_h/d). Pitch of the helix was change also in some cases. Figure (7) shows the screw pile models configurations that installed using the modified loading system during extensive model tests which they are not shown here in this paper.

Fig. 7: Screw pile models; (a) all manufactured models and (b) dimensions and configurations

7. Installation and testing procedure

The procedure followed in the installation and testing the model screw piles using the new loading machine can be described in the following steps:

1. Preparation of sand deposit using the pluviation technique and then weight the container for the density checking and then move the container to be underneath the loading machine (keep the center of the container exactly at the expected loading center of the loading rig). Figure (8a).
2. Connect and fix the screw pile model via jaw lathe chuck and tied them carefully with the load cell (figure 8b). Keeps the screw model straight using the leveling kit.
3. Connect all the necessary units (i.e. the load cell and the LVDT) to the data logger which should be connected to the computer (i.e. figure 8c). Run the LabVIEW subroutine to be ready for data collection.
4. Operate the master-slave actuator for starting the loading rig (all the bench) to dropped down under constant speed rate (40mm/min) and rotate by shaft connect the lathe chuck with slave motor to install the screw pile model into sand deposits to the required depth.
5. The installation speed of the screw pile as it was kept constant at rate 40 mm/min vertically with rotation 10 rpm during the installation to be consistent with a vertical movement of one times the pitch of the screw pile flange (from 6 to 10 mm) per revolution. This is a methodology typically used in onshore field installation and recommended by previous researchers (Perko, 2009 and Tsuha et al., 2012) and According to the British standards institution 2015, the penetration rate of screw pile per revolution of the pile should satisfy $0.85pitch \leq v \leq 1.15pitch$ to minimize soil disturbance during installation.
6. Once the installation completed, put the LVDT (figure 8d) on pile cap (lathe chuck) to measure the settlement by operate the master motor to move loading rig downward for compression test or upward for tension test via load cell with slow motion a constant rate of penetration.
7. The test is performed using a controlled strain for compression, the rate was kept constant at (0.4-0.75 mm/min) according to STM. D1143M-07 procedure E: constant rate of penetration test (CRP) for granular soils (0.75mm-2.5mm) per minute, and STM. D3689-07 procedure E: constant rate of penetration test (CRP) = (0.5mm - 1mm) for tension.

Fig. 8: Steps of screw pile model installation and testing

8. At the end of the screw pile loading tests (i.e. figure 8e), press the save button for the collected data from the main window in the computer screen and select the suitable folder to save the data.

Before starting the installation, the screw pile was attached in the jaw lathe chuck holder unit to fix and preventing any undesirable inclination of the pile and then to maintain straight. Three –jaw self –centering chucks of the lathe chuck that manufactured to resist high pressing and rotating stress is used for this purpose. This technique was a good approach that used to hold the screw pile in situ.

To check the serviceability of the loading rig machine, a series of screw pile tests under both compression and tension forces are performed to investigate the geometry effects on both the compression and tension ultimate capacity. Only the effect of helix diameter (or wing ratio, D_h/d), which represent the main configurations of the screw pile that are considered in the next section.

8. Effect of helix diameter on compression and tension capacity

The effect of helix diameter on the compression and tension capacity is also called the effect of wing ratio or helix to shaft ratio. The compression and pull-out tests were carried out on single (1helix at the end of the screw pile) and multi-helix (3helix) of screw piles models for different diameter, (40mm, 50mm, 60mm, 80mm), (30mm, 40mm, 50mm) for single and multi-helices respectively to investigate the effect of wing ratio on load capacity, and compare with the conventional pile ultimate capacity. Figures 9 from a to d shows the measured compression and tension load capacity versus the settlement and the displacement respectively for both single helix model and multi helices models.

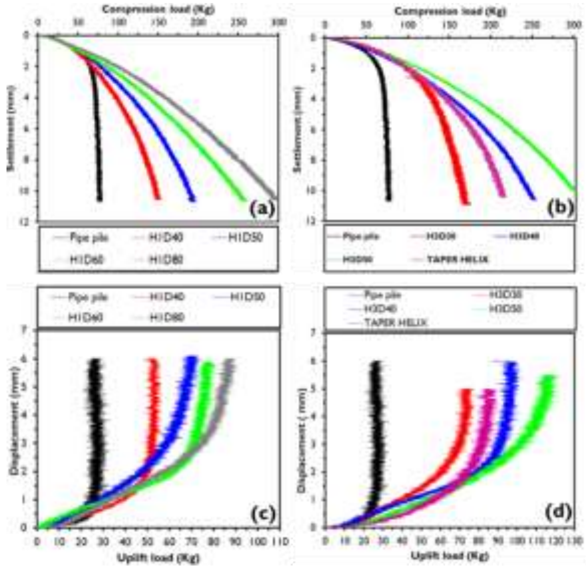

Fig. 9: Compression and tension capacity for single and multi-helices screw piles

From all the figures above, it can be seen that when the diameter of the helix increases, the compression capacity of the pipe pile increases clearly. To compared the results of capacity that investigate in single helix case (i.e. figure 9a), the pipe pile capacity is added to the curves (i.e. No helix pile or shaft model only), it was found that the screw pile model that has a wing ratio 4 (i.e. H1Dh=80 or helix diameter 80mm) was about 11.5 higher for a piles (H1D60) that have diameter 60mm (i.e. wing ratio 3) whereas it was 31.5% higher than the measured value for the model that has diameter 50mm (i.e. wing ratio 2.5) and 55% higher than the model of that has diameter 40mm (wing ratio 2) while the load capacity was 130% higher than the conventional (pipe, shaft or no helix) model that has a zero wing ratio.

For pull-out or tension tests (i.e. figure 9c), it was found that pile H1D80 for diameter 80mm (wing ratio is 4) was about 11%, 22.5%, 65.5%, and 200% higher than the pull-out capacity for piles (H1D60; 60mm ; wing ratio 3) and (H1D50;50mm wing ratio 2.5) and (H1D40; 40mm; wing ratio 2) and pipe pile respectively.

For multi-helix screw pile model groups (i.e. three helices, figure 9 b), it was observed the same behavior that investigated in the single helix case; but the increase in compression capacity was found for the screw pile model that has a diameter 50mm (wing ratio 2.5) was about 7.5% and 61.5% higher than the measured value for the model that has a wing ratio 2 (i.e. D_h=40mm) whereas it was 27% higher than the determined value of the model that has a diameters 30mm (i.e. wing ratio 1.5), while the compression capacity was 161% higher than the determined value for the pipe pile (i.e. no helix pile). Similar behavior is observed for the multi helices screw pile models in tension tests (i.e. figure 9d).

The increase of load capacity can be attributed to the increase of sand densification during the screw pile installation as the soil displaced volume increases with increasing helical plate diameter (Tsuha et al., 2012). Special screw pile model is manufactured and tested (called taper) to validate the interpretation above (see figure 9 b and d). This taper model has a single continuous helix with three configuration diameter (30, 40 and 50mm). It was noted that the compression capacity for the screw model that has a wing ratio 2 (i.e. three 40mm helices) is 9% higher capacity than the special kind of the screw pile model (i.e. taper model), however, though it has an average diameter equal (2) but the compression capacity decreases because of the disturbance soil zone in conical form, thus caused non uniform in the compact layer in correlation between compact soil layers in bottom of first helix and last helix, as well the soil below bottom helix have little disturbance and more compact but for small area because of small of bottom helix diameter.

9. Conclusions

In this paper, the physical modeling of the screw pile was discussed in detail. Also, a review of previously-developed loading system was used to develop a new loading rig machine. The instrumentation and the accessories of the screw pile installation and loading system procedure were detailed in this paper. The summary of this paper is outlined as follows:

1. A new controlled installation and loading system was developed at the University of Wasit (UoW) to allow full installation and axial load testing (compression and tension) of screw pile model element.
2. This system can apply a vertical movement and rotational motion (via remotely independent controlled motors) to allow controlled installation and testing of a screw pile (or other foundation such as conventional pile and anchoring systems).
3. A single operation procedure was used to install and test the straight-shafted (conventional or pipe) piles and screw piles models. This technique is considered fundamental to capture the pile performance during the installation and for even quantifying the force and torque required for future in-situ installation and loading systems for larger, higher capacity piles (i.e. in prototype scale).
4. The remotely controlled installation and loading system have been designed to provide a maximum load of 5 kN in compression or tension and a maximum simultaneous torque of 18 N.m. The installation torque and force can be recorded also using a combined bespoke load cell (not included in this paper) capable of measuring both force and torque at the same time and then allowing estimation of the torque required during installation of the screw pile elements and the influence of crowding loads.
5. The measured compression and tension forces for different configuration of screw pile models replicated the actual behavior of such kind of pile in situ. Larger helix diameters increase both the compression and tension capacity.

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