Study on the Installation Characteristics of the Screw Pile with Grooves on Hard Ground

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Abstract. The anti-flood screw pile is difficult to be installed on hard ground. In order to improve the installation characteristics of the screw pile, grooves are fabricated on the conical surface of pile tip. Based on a coupling algorithm of finite element method and smoothed particle hydrodynamics, the software ANSYS/LS-DYNA is used to simulate the process of installing grooved and un-grooved screw pile. It is found that compared with un-grooved pile, the grooved pile tip completely installation time reduce 8.85% and the grooved screw pile installation torque increase by 1.7%. Furthermore, the compaction effects of screw pile to the soil do not have much change before and after grooving. The research results in this paper provide a reference for the optimization of veritable anti-flood screw pile structure design.

1. Introduction

Anti-flood screw pile is a kind of portable efficient emergency supplies. Designed according to the requirements of water conservancy department, the screw pile is mainly used in anti-flood project such as embankment reinforcement, curtain hanging, barrier setting in fissure, ship and cable hanging operation [1-2].

The tip of screw pile consists of hollow cone and screw helix, its manufacturing process is as follows: firstly, the hollow cone and the screw helix are obtained by rolling, and then, they are welded to form a screw pile tip. When screw pile is being installed on hard ground, the helix of the pile tip is difficult to touch the ground, because the helix is some distance from the top of the cone. And the helix should be driven into the soil as soon as possible, as it can provide downward force for screw pile by pushing up the soil. This dilemma would not appear on the pile foundation engineering, because the installation equipment of which is heavy enough to push the pile tip helix into the soil [3].

As we all know, the weight of the pile foundation engineering equipment is usually from tons to dozens of tons. Such enormous weight cannot satisfy the flexible requirement of screw pile, which is an essential requirement in the flood control procedure [4]. In order to make it easier for the screw pile to be installed, the grooves are fabricated on the conical surface of pile tip. Getting inspiration from the twist drill, the grooving design add a new function of cutting the soil into the process of screw pile-soil interaction, the original functions of which are merely densification and friction. The screw pile has been fabricated grooves is called grooved pile, while the original screw pile is called un-grooved pile.

The integrated screw pile is mainly composed of pile tip, pile body, screw helices, transition section and cable hanging section. Their geometric models are shown in figure 1, the total height of the pile is 1000 mm. The three-dimensional bottom views of grooved and un-grooved screw pile are shown in figure 2. The anti-flood screw pile is installed into the ground by mechanical energy, which
is converted from hydraulic energy by a hydraulic motor. Before that, the hydraulic energy is generated by a portable diesel engine driven hydraulic pump.

![Structure Drawing of Screw Pile](image1)

![Bottom View of Screw Pile](image2)

**Figure 1.** Structure Drawing of Screw Pile  
**Figure 2.** Bottom View of Screw Pile

At home and abroad, great progress has been made in using numerical simulation to investigation the effect of soil cutting and compression [5-7]. In this paper, the software ANSYS/LS-DYNA is used to model and simulate the installation process of grooved and un-grooved screw pile.

2. Finite Element Analyses

2.1. Assumed Conditions

1. An anti-flood screw pile is welded from several parts that is mentioned previously, this paper just simplifies the pile as a whole model to reduce computational effort. Since there is not necessary to consider the stress distribution inside the screw pile, it is assumed that the screw pile is an isotropic elastic-perfectly plastic continuum.

2. Since the screw pile has very little deformation compared with the soil during pile installation process, it is assumed to be a rigid material.

3. The soil is assumed as an isotropic continuum, and it is assumed that the soil physical parameters such as moisture content, density and elastic modulus are consistent.

2.2. Mesh Generation

The three-dimensional model of anti-flood screw pile is established using 3D design software, and then imported the model into ANSYS software for mesh generation. The screw pile is divided by tetrahedral meshes, which compared with hexahedral meshes, the mesh fragmentation and distortion can be greatly improved. The screw pile is calculated utilizing finite element method (FEM). Finally, the grooved screw pile is modelled with 2541 nodes, while the un-grooved screw pile is modelled with 1285 nodes, as shown in figure 3.

![Transition section](image3)
![Cable hanging section](image4)

**Figure 3.** Mesh Generation

Smoothed particle hydrodynamics (SPH) algorithm is a grid-free pure Lagrangian method based on interpolation theory, the discrete particles of the continuum are solved separately during calculation, hence the SPH algorithm is suitable for solving large deformation problems [8-10]. In this paper, the soil SPH particle model is using ANSYS directly generated a cylinder with a diameter of 400 mm and a length of 1000 mm, which has 76895 nodes as the figure 4 shown.
2.3. Constraint and Loading
What analysed in this paper are the screw pile installation torque and time, as well as the stress distribution of the soil around pile. In order to simplify the calculation, screw pile are modelled as rigid material with a density of $7.8 \times 10^3$ Kg/m$^3$.

The soil material model that is selected in this paper [11] can not only determine the relevant material parameters through reasonable tests, but also reliably predict the elastic properties, volume compression properties and yield characteristics of soil with fewer required parameters than other material models. Referring to relevant literature [12], the soil is assumed to have a bulk unit weight of $1.8 \times 10^3$ Kg/m$^3$ and a volume modulus equal to 16.7 MPa, the yield function constant is considered as $5.33 \times 10^{10}$, and the cutoff pressure for tensile failure is -0.1 MPa. Moreover, the shear modulus of soft soil is set as 7.7 MPa, and that of hard soil is set as 28 MPa [13].

The contact state between screw pile and soil is nodes to surface. The SPH soil particles are set as affiliate contact point, and the main contact area is associated to the surface of screw pile model. In the meantime, the pile-soil contact parameters are using the recommendation of Hongchen Pang [12], according to which the dynamic friction coefficient is set as 0.54, the penetration factor is set as 0.1, the quadratic term coefficient of artificial viscosity is 1.5, and the linear coefficient is 0.06. In terms of boundary conditions, except the upper surface, the soil boundary of SPH particles is prevented from moving in any direction.

Since the impact of pile installation speed to the installation torque is negligible, in order to reduce operation time, the rotating speed of screw pile is increased by 10 times to 31.4 rad/s [12]. The total weight of the anti-flood screw pile supporting equipment is 400 N, so a constant compression load of 400 N is applied to the screw pile in the environment of finite element software.

3. Results and Discussion

3.1. Comparative Analysis of Pile Installation Time
The stress distribution of soil particles about the grooved and un-grooved pile tip completely installs into soft and hard ground is given in figure 5, respectively. When the pile tip just touches the soil, under the constant compression load generated by the gravity of pile supporting equipment, the top of the pile tip is forced a little into the soil. The un-grooved screw pile relied on the power provided by hydraulic motor rotate squeezes the soil. Coupled with the compression load of gravity, the power makes the pile tip of un-grooved screw pile sinks comparatively slowly, because the gravity is not huge enough as the pile foundation engineering equipment. As for grooved pile is installed into the soil with the same loading condition, the grooves edge of the grooved pile tip cut the soil as twist drill.
the cut chip of the soil is removed upward through the grooves, meanwhile the area of the tip surface having not grooves squeezes the soil, thus the soil vertical resistance on the grooved screw pile is reduced. As the helices of the grooved and un-grooved pile are embedded into the soil, the soil gives the rotating helices a downward reaction force, which together with the gravity of installation equipment, push the pile body down into the soil. It can be seen from the number and range of obvious stress changing soil particles in figure 5 that, in the same soil conditions, the stress of the soil being forced by grooved pile tip is similar to that being forced by un-grooved pile tip. Meanwhile, the stress of the hard soil is obviously increased compared with the soft soil as the same screw pile is being installed.

![Figure 5. Soil Particle Stress when the Cone of Pile Tip just fully Installed under the Ground](image)

The time from pile tip just touches the ground to the cone of pile tip just fully installed under the ground, is denoted as pile tip completely installation time \( t_1 \). The value of \( t_1 \) is shown in figure 5. We can find that on soft ground, the \( t_1 \) of grooved screw pile decrease by 11.6% than the un-grooved; on hard ground, the \( t_1 \) of grooved screw pile decrease 6.1% than un-grooved screw pile. Compared with the un-grooved screw pile, pile tip completely installation time \( t_1 \) of grooved pile is dramatically reduced. The time from pile tip just touches the ground to the pile body completely installed under the ground is defined as the pile fully installation time \( t_2 \). On soft ground, the \( t_2 \) of the grooved screw pile is 1.331 s, has a decrease of 0.8% compared to 1.320 s for the un-grooved screw pile; on hard ground, the \( t_2 \) of the un-grooved screw pile is dropped to 1.335 s from 1.352 s for the grooved screw pile, that means a decrease of 1.3%. On soft ground, the effect of grooves cutting soil cluster is relatively significant, so the reduction of \( t_1 \) on soft ground is larger than it on hard ground. After the pile tip is
completely installed, the grooves will be filled with soil, making the grooves lose their function, hence they have little influences on the subsequent pile installation time.

3.2. Comparative Analysis of Pile Installation Torque
For the anti-flood screw pile with and without grooves, the pile installation torque is analysed respectively under soft and hard soil conditions, then the figure 6 is came out. In the process of pile installation, the installation torque of the screw pile has huge fluctuation, which would have a bad influence on the result analysis. Therefore, the method of taking the digit 5 as the movement period to get average figures is adopted to filter the results, thus the filtering curve in figure 7 is obtained. The increased trend of torque is relatively gentle before the pile is installed to a depth of 300 mm, because the overburden pressure of the soil is relatively small during this period, and a part of the soil cluster existing in the upper layer is easy to be broken under the rotating force of helices, making the friction resistance produced by the soil-pile contact relatively small. After the pile is installed to the depth of 300 mm, the area of the pile body surrounded by soil cluster is increased greatly, and the frictional resistance existing on the upper surface of the helices is also continuously increased, thus the rising speed of installation torque would be accelerated.

On the hard ground, the maximum installation torque of un-grooved screw pile is 578 N-m, and that of grooved screw pile is 588 N-m. As the anti-flood screw pile has been grooved, the maximum pile installation torque is only increased by 1.7%, and the maximum torque is no more than the rated load of the original anti-flood screw pile installation equipment [12], hence the grooving process for the screw pile will not increase the power requirement of the pile installation equipment.
3.3. Comparative Analysis of Soil Stress

Anti-flood screw pile is special materials used for emergency purposes. Compared with the traditional hammer-driven pile, the screw pile would not produce strong vibration but densify the soil around the pile slowly [14]. This compaction effect can play the role of strengthening the embankment and increasing the load resisting capability of the screw pile. As shown in figure 8, at the time that the screw pile installation process is completed exactly, the range of the soil under great stress is roughly a cylinder with a radius of 130 mm. The force on this soil range is complicated, while the soil outside this range is mainly subject to extruding load that is relatively easy to be analysed. In the cylindrical surface where is 150 mm distances from the axis of pile, take two points which under the ground 200 mm and 300 mm as research points. Studying the stress change of soil particles at the two points varying with installation depth respectively, the stress curves as figure 9 shown are obtained.

![Figure 8. Soil Stress when Anti-flood Pile Installation is Completed](image1)

![Figure 9. Soil Particles Stress Varying with Installation Depth](image2)

As shown in figure 9, at the point that is 200 mm below the ground, both grooved and un-grooved screw pile have the maximum value as pile top is driven to the depth of 300 mm, the maximum value of grooved screw pile is 0.102 MPa, while the maximum value of un-grooved screw pile is 0.075 MPa; at the point which is 300 mm below the ground, the maximum value of grooved and un-grooved screw pile occurring at the depth of 410 mm, the maximum value of grooved screw pile is 0.091 MPa, while the maximum value of un-grooved screw pile is 0.105 MPa. This phenomenon could be explained by Vesic cavity expansion theory [15]. According to this theory, the effect of pile tip acting on the soil mass is obtained in figure 10. As the screw pile keep being installed, in the time of the plastic region sweeping through the soil particles which are being studied, the soil particles have the maximum stress.
Figure 10. The Effect of Pile Tip on Soil

The stress of the soil particles that are being studied is much less than the shear modulus of the soft soil 7.7 MPa, so the screw pile with or without grooves will not cause shear damage to the soil region where these soil particles are included. Moreover, the stress variation trend of grooved and un-grooved screw pile is the same and the stress value of them is similar, indicated that grooving process has little influence on the compaction effect of screw pile acting on soil.

4. Conclusions
Based on the FEM-SPH algorithm, the finite element model of anti-flood screw pile-soil is established in this paper. Different pile and soil parameters have used for simulation analysis by controlling variables and the obtained conclusions are as following:

(1) During the anti-flood screw pile is sunken into the soil, the time spending in that process of the grooved pile is 8.85% less than that of the un-grooved pile on average, demonstrated that grooving can effectively accelerate the installation process of screw pile on hard ground.

(2) Being grooved on the screw pile tip only result in a 1.7% increase in the pile installation torque, so it is no need to replace the original anti-flood screw pile installation equipment. The compaction effect on the soil around grooved pile is not significantly changed compared with that around the un-grooved pile.

(3) The successful application of numerical analysis in this paper indicates that, it is appropriate to use the FEM-SPH algorithm to simulate the pile-soil interaction under the action of cutting, friction and extrusion.

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