Simulation Analysis on Pile-driving Process of Anti-flood Bionic Screw Pile

Fanfei Jia, Yanqin Tang, Kun Hu and Yuxing Wang*
School of Engineering, South China Agricultural University, Guangzhou, China

*Corresponding author

Abstract. In order to reduce the dynamic energy consumption of pile-driving of the anti-flood screw piles, the unsmoothed surface is applied to the screw pile tip to form an anti-flood bionic screw pile. In ANSYS, the FEM-SPH coupling algorithm is used to model and simulate the pile-driving process of bionic screw piles, and the simulation results of soil stress distribution, radial displacement of soil particles and pile-driving torque are obtained. The results of the pile-driving test show that the test torque is less than the simulated torque, and the soil pressure is consistent with the simulation results. The correctness of the simulation model is verified, which provides a theoretical basis for further improving the bionic screw pile and the pile-driving equipment.

Keywords: bionic; screw pile; pile-driving; simulation.

1. Introduction

The screw pile pile-driving is a new type of anti-flood pile-driving. Compared with traditional impact pile-driving, screw pile pile-driving has the advantages of the faster pile-driving and pile-up speed, low vibration and noise, and no secondary disaster etc.

The unsmoothed surface of the body surface of soil animals has the function resistance reduction [1], which has already formed a consensus in the academic circle. In order to reduce the pile-driving torque, the unsmoothed surface is applied to the tip of screw pile to form the anti-flood bionic screw pile. When the bionic screw pile is driving, it is very difficult to theoretically analyze the pile-soil effect. It is necessary to combine the numerical simulation with the field test to carry out the study of the pile-driving process.

Poulos studied the bearing capacity characteristics of pile foundation by finite element method and theoretical analysis [2]. Chen Jing used ABAQUS to construct pile-soil friction piles and analyzed the bearing capacity transmission of screw piles [3]. Zhang Mingyi proposed the displacement penetration method, and used ANSYS to simulate the pile-driving process of static pressure piles [4]. Wei Xicen optimized the pitch and width of the helical blade by ANSYS finite element software and designed the geometric parameters of the screw pile [5]. Pang Hongchen took measures such as reducing the diameter of the pile body and the length of the helical blade. The results show that the pile-driving resistance can be reduced [6], but at the cost of reducing the firmness of the pile.

The predecessors are all researches on the pile-driving process of ordinary screw piles, but there is no progress in the research on the pile-driving process and the pile-driving test of the bionic screw piles. This paper is to study the pile-driving process of the anti-flood bionic screw piles.
2. Numerical Simulation

2.1. Basic Assumption
The pile-soil model is a point-to-face contact method in which the pile is used as the main contact surface and the soil is used as the contact surface. During the pile-driving process of the bionic screw pile, the friction coefficient between pile-soil is constant [7].

The bionic screw pile is a rigid body without any strain and stress, and adopts the tetrahedral solid element. The soil is an isotropic and continuous homogeneous elastoplastic material, adopting the Mohr-Coulomb model [7].

2.2. Parameters of Bionic Screw pile and Soil
Bionic Screw Pile Parameters. The screw pile consists of a tapered pile tip, cylinders of different diameters, a trapezoidal convex, a round shaft and helical blades. According to the unsmoothed surface study, a certain size of the bionic surface has a function resistance reduction superior to the smooth surface [8]. The biggest difference between a bionic screw pile and a common screw pile is that the pile tip is uniformly bionic convexes. The bionic screw pile includes 1 meter pile and 1.5 meter pile. This paper refers to the 1 meter pile.

Soil Parameters. The Mohr-Coulomb model is suitable for yielding under maximum shear stress, but the maximum shear stress depends only on the maximum principal stress and the minimum principal stress, while the second principal stress does not affect the yield; it is more suitable for loose or cemented granular materials [9] (Soil, rock and concrete). Therefore, the soil selects the Mohr-Coulomb model and sets the material parameters. The specific values are shown in Table 1 [10].

Table 1. Soil parameters

| Parameter name                  | Selection  |
|--------------------------------|------------|
| Density(g•cm⁻¹)                 | 1.85       |
| Cohesion(KPa)                   | 100        |
| Poisson's ratio                 | 0.3        |
| Elastic modulus(MPa)            | 20         |
| Unconfined compressive strength(KPa) | 400    |
| Shear modulus(MPa)              | 7.7        |
| Bulk modulus(MPa)               | 16.7       |
2.3. Simulation Model Establishment

2.3.1. Finite Element Model of Bionic Screw Pile. The tetrahedral mesh is used to divide the bionic screw pile to improve the problems of mesh fracture and distortion, and reduce the possibility of penetration. The model has 6494 nodes and 20881 units. In order to solve the rust problem of common screw pile, the bionic screw pile is made of 304 stainless steel, and the mechanical parameters are shown in Table 2.

| Parameter name | Material       | Density   | Elastic modulus | Poisson's ratio |
|----------------|---------------|-----------|-----------------|-----------------|
| Selection      | 304 stainless steel | 7930Kg/m³ | 193000MPa       | 0.31            |

2.3.2. Soil Finite Element Model. The sinking pile of the bionic screw pile belongs to the process of large deformation of the soil, and the SPH meshless algorithm is suitable for the deformation of the continuous structure such as rupture, dissolution and brittle fracture. In this paper, the SPH soil model is established, and particles are arranged uniformly and regularly. Each particle is isotropic, and the total number of particles is 83,300.

2.3.3. Pile-Soil Simulation Model Constraint Setting. In contact, the contact of the bionic screw pile with the soil is of the point-to-face type. Set the contact penetration factor of 0.1. For better contact astringency, set the time step factor for the simulation calculation to 0.31. Apply a 400N vertical uniform load to the pile end. Ignore the gravitational acceleration of the bionic screw pile and set the gravitational acceleration of the soil model to 9.8m/s². For the sport, the X and Z axes of the bionic screw pile are fully constrained. Constrains the degree of freedom of the peripheral particles of the SPH soil model. In order to shorten the simulation calculation time, the speed of the bionic screw pile is increased from the actual 2 rad/s to 8 rad/s, and the whole simulation time is 4 s.

3. Simulation Results

3.1. Soil Stress Distribution
Comparing the simulation results of the pile-driving processes of common screw piles and bionic screw piles, the soil stresses distribution in the two models are analyzed, as shown in Figure 4.
Figure 4. Soil stress distribution
The surface soil stress of common screw piles is very large, and there is almost no change in soil stress from top to bottom. The surface soil stress value of the bionic screw pile is normal, and the soil stress increases gradually from the top to the bottom about the pile. The soil stress at the pile tip reaches the maximum and is hemispherical. The soil stress at the bionic pile tip is 100KPa, which is smaller than the soil stress at the common pile tip 400KPa, and the pile-driving resistance of the bionic screw pile is small. Considering the difference of structure and parameters between the two simulation models, the soil stress difference is large, which has certain guiding significance for the comparison of pile-driving resistance.

3.2. Radial Displacement of Soil Particles
Four groups of soil particles with a radial distance of 150 mm and a depth of 300 mm were selected, and the angle between adjacent particles was 90°. Figure 5 shows the radial displacement of soil particles.

Figure 5. Radial displacement of soil particles
The soil particles are all squeezed during the pile-driving process of the bionic screw pile and forced to radially displace. The displacement change of A particle is large, but the total displacement is not large, indicating that it is subject to large disturbance. The displacement of B particle increases linearly, and the total displacement is relatively large, indicating that it is strongly squeezed. For C and D particles, the effect of extrusion is small. In summary, the radial displacement of B particles is the largest, and it is easier to detect the stress change of soil, which provides a theoretical basis for the pile-driving test of bionic screw piles.

4. Pile-driving Test
The bionic screw pile is made of 304 stainless steel, as shown in Figure 6. The test soil is a naturally deposited laterite. Select the four corners and the center with a side length of 1.7m square as the pile-driving point. The upper end of the pile is equipped with strain gauges for measuring the strain of the bionic screw pile, and measuring with the soil pressure sensor at the position of the B particles, and conducting the pile-driving test, as shown in Figure 7.
The test data was taken into the equations of the torque calibration and the soil pressure to obtain the average value. The pile-driving torque curve of the bionic screw pile was obtained, as shown in Figure 8; the pile-driving torque curve of the simulation model is shown in Figure 9.

During the pile-driving process, the overall test torque increases, accompanied by the large fluctuation of the torque. It indicates that the bionic pile tip pierces the soil, and the helical blade shears the soil, then the soil has large deformation and weakens the effect of adhering the pile, and the pile-driving torque reduces. At the same time, the helical blade sinks and has a pressing effect on the soil. The soil is gathered and compacted, and has a reaction force on the helical blade. It and the bionic screw pile generate the large friction, then the pile-driving torque increases.

Both the test torque and the simulation torque are increased, and the overall variation is not much different, and the test maximum torque is 500 N•M less than the simulation maximum torque of 700 N•M. The pile-driving test cannot be consistent with the simulation, resulting in errors, and the correctness of the simulation model is verified to some extent.

From the soil pressure test, the maximum value of 50KPa is smaller than the soil stress of the simulation model. The embedding of the soil pressure sensor causes extrusion hardening of the soil, and the
sensitivity of the sensor also has the error. It is impossible to analyze the soil pressure through accurate values. Due to the embedding of the sensor, the initial pressure of the soil is so small. Between 1s and 9s, the pressure of the soil fluctuates sharply. When the bionic pile tip sinks and squeezes the soil, the soil pressure increases linearly, then the pressure drops and fluctuates slightly, showing the state of tension timely. When the bionic pile tip passes here, the soil pressure is basically stable. The test soil pressure and the B particle simulation soil pressure have similar changes, which realizing the same process of bionic screw pile-driving, and also verifies the correctness of the simulation model to some extent.

5. Conclusion

(1) SPH-FEM coupling simulation can better simulate the deformation of soil due to pile extrusion and helical blade shearing.

(2) During the pile-driving process, the bionic pile tip penetrates and destroys the soil, and the large deformation of soil weakens contactation with the pile tip, then the pile-driving resistance reduces. The helical blade sinks to gather and compact the soil, resulting in huge friction, and pile-driving resistance increases. The bionic pile tip crushes and destroys the soil, and the soil pressure fluctuates sharply, showing the state in which the soil is pressed and pulled. After the bionic pile tip passes through the soil, the soil pressure drops but remains at a certain value.

(3) Through the pile-driving test, the change of torque and soil pressure can show the same trend with the simulation results, and the correctness of the simulation model is verified.

Acknowledgments

Subject was supported by Guangdong water conservancy science and technology innovation project (NO.2017-31).

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