The Relationship between the Depth Embedded Pipe Pile and the Force of Clamping Jaw

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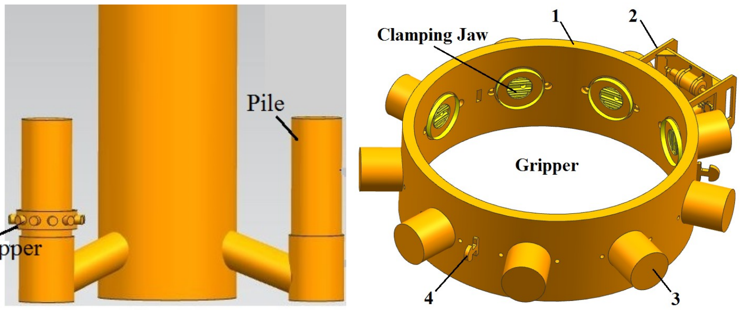
Abstract. Underwater pile gripper plays a role in clamping the pipe pile when the jacket platform is installed on the offshore platform. In this paper, ANSYS software was used to simulate the process of holding the pipe pile under the underwater pile gripper. The clamping jaw was equivalent to a rigid head and pressed into the surface of the pipe pile. During the process of studying the pipe pile being clamped and fixed, the clamping claw is embedded in the pipe. The relationship between the insertion depth of the pile surface and the stress of the pipe pile surface was calculated. The depth of the clamping jaws is too shallow to clamp the pipe pile effectively, and the depth of the insert is too deep, which can cause damage to the pipe pile. Therefore, the relationship between the two has a crucial role in the installation of pipe piles and even the entire jacket platform. In this study, the relationship between the depth of the jaws embedded in the pipe pile and the surface strength of the clamping jaw was obtained, which provided theoretical support and assistance for future engineering applications.

1. Introduction

The underwater pile gripper is an underwater working implement for the installation of the jacket platform. During the installation, underwater pile grippers are needed to clamp the pipe piles to ensure that the pipe piles have no displacement in the horizontal direction and directional displacement is limited to a certain range after completing the piling of a pipe pile. During the clamping process, the clamping jaws will be embedded in the surface of the pipe pile under the action of external forces. The depth of the clamping jaw embedded in the surface will affect the pipe pile.

The gripping function of pile gripper is mainly accomplished by hydraulic cylinders and clamping jaws connected to hydraulic cylinders. In this study, a 72-inch underwater pile gripper was used as the study object. The 72-inch underwater pile gripper was evenly distributed with 10 hydraulic cylinders in the circumferential direction. The front plunger of each hydraulic cylinder was connected to the clamping jaws. Under the action of hydraulic pressure, the jaws stick out and hold the pipe pile. At this moment, the jaws will be embedded in the surface of the pipe pile, and the surface deformation of the pipe pile will change from elastic deformation to plastic deformation. Underwater pile gripper structure diagram is shown in Fig.1.



1 Body 2 ROV control panel 3 Hydraulic cylinder 4 Lifting lug

Figure 1. Structal diagram of pile gripper.

As shown in Fig. 1, the underwater pile gripper is composed of a body, a ROV control panel, a hydraulic cylinder and four lifting lugs. The ROV control panel is connected with a water-surface control system, and the water-surface source provides oil for the entire system.

2. Critical load calculation before failure of pipe pile

Before calculating the relationship between pipe piles and clamping jaws, the critical pressure of pipe pile needs to be calculated to ensure that the pipe pile do not destabilize with the increase of external loads during the simulation. The material of pile gripper is alloy steel, whose Young's modulus is 2.06×10^5 MPa, Poisson's ratio is 0.3.

The wall thickness t of pipe pile is 45mm, the radius of the middle surface R is 937mm, and the wall thickness of the pipe pile is a small amount relative to the diameter of the pipe pile, satisfied the relationship $t/R = 0.048 < 1/20$. Therefore, the pipe pile can be regarded as a thin shell structure. The thin shell structure has very good load-bearing properties and can withstand considerable loads with a small thickness. This paper studies pipe piles as the medium and long shells, i.e. z>2.85 [1-2].

2.1. Critical external stress calculation

In the underwater pile gripper, 10 hydraulic cylinders are uniformly distributed in the circumferential direction, and the pipe piles are clamped during operation. The pipe piles are subjected to radial uniform external loads, and the force diagram is shown in Fig.2.

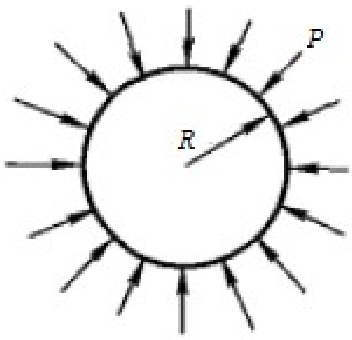


Figure 2. Pipe pile radial load diagram.

For radial uniform external pressure spherical shells, according to the classical theory [3], critical load can be obtained, as in

$$P_c = \frac{2Et^2}{R^2\sqrt{3(1-\nu^2)}} \tag{1}$$

Where P_c is the critical load, ν is Poisson's ratio with the value 0.3, E is Young's modulus with value 2.06×10^5 MPa.

Substitute the data into (1), critical load can be obtained

$$P_c = 575.12\text{MPa}$$

2.2. Critical moment calculation

Under the action of a hydraulic cylinder that is uniformly distributed in the circumferential direction, the pipe piles are subjected to bending moments in the longitudinal plane of symmetry, and the force diagram is shown in Fig.3.

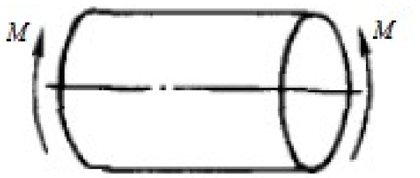


Figure 3. Pipe bending moment.

Pipe pile critical bending moment

$$M_c = \frac{\pi ERt^2}{\sqrt{3\left(1-\upsilon^2\right)}} \tag{2}$$

The definition of each parameter is the same as (1), critical bending moment can be obtained

$$M_c = 7.13\times10^8\,\text{N}\cdot\text{m}$$

The 72-inch pile gripper is evenly distributed with 10 hydraulic cylinders in the circumferential direction, that is, there are 5 pairs of symmetrically clamped forces in the circumferential direction of the pipe pile. The superposition principle is used to solve the multiple symmetrical internal forces [4]. In reference [4], the unified formula for bending moments of *n* pairs of symmetrical forces is as follows

$$M_n(\theta) = PR\left(\frac{2}{\pi} - \frac{\sin\theta + \sin(\frac{\pi}{n}-\theta)}{2}\right) \tag{3}$$

Where $0 \le \theta \le \pi / n$, $n>1$

Mapping with force P as the axis requires mapping times k

$$k = \frac{2\pi}{\pi / n} = 2n \tag{4}$$

It can be seen that the five pairs of symmetric clamping forces require 10 mappings with force P as the axis, so that PR=1Nm, and the bending moment diagram can be obtained, which is shown in Fig.4.

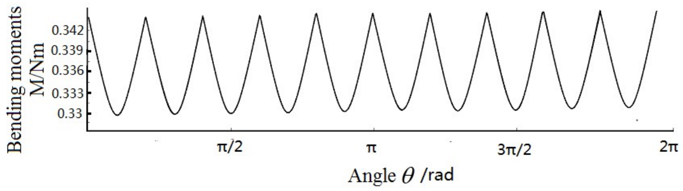


Figure 4. Bending moments with five symmetrical forces.

It can be seen from Fig.4 that under the action of five pairs of symmetry forces, the bending moments of the pipe piles are all greater than zero, that is, the pipe piles do not have any tensile bending moments.

According to the previous design experience, the maximum working pressure of the hydraulic cylinder is 40MPa, the known area of the hydraulic cylinder is used, and the data can be substituted into (3), bending moments can be obtained

$$M_n = 6.31\times10^5\,\mathrm{N\cdot m}$$

The result satisfied the moment conditions.

It can be seen from the above calculations that the pipe piles studied in this paper will not fail, so the following simulation calculations are valid.

3. The Establishment of a Mechanical Model

Under the action of hydraulic pressure, the teeth of the jaws press into the surface of the pipe pile [5]. Because the wall thickness of the pipe pile is much larger than the height of the jaw teeth, it can be considered that the pipe pile is a half-space object, and when the plastic deformation is far greater than the elastic deformation, the elastic deformation can be neglected, so the pipe pile is treated as the ideal rigid plastic material [6]. The hardness of the clamping jaw is much greater than the hardness of the pipe pile, and then the teeth of the clamping jaw can be treated as a rigid hard indenter. At this time, the pipe pile is completely restrained and the tip of the tooth presses into the surface of the pipe pile under the influence of external pressure. Select one jaw and one-tenth arc length of pipe for modeling. The contact form between the gripper jaws and the pipe piles is bonded. In a actual project, the gripper needs to provide vertical clamping force of 1500t, so in the emulation, the pipe pile is subjected to a vertical downward force *F*, acting on the upper end of the pipe pile, the lower end of the pipe pile is fixed, and compression only support is applied on both sides to simulate the internal stress of the pipe pile. The gripper jaw surface is subjected to a given stress. The finite element model of pipe piles and jaw is shown in Fig.5. The value of *F* can be obtained, as in

$$F = \frac{1500\times9800}{10} = 1470000\mathrm{N}$$

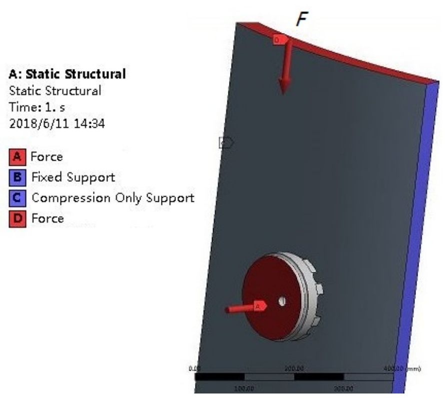


Figure 5. Finite element model of jaw and pipe pile.

4. Analysis of simulation resul

The normal load is applied on the surface of the jaws. Since the entire loading process in the actual project is very slow and the pipe is static, the analysis time does not affect the final analysis result. The analysis time is 0.1s. The jaw material is an alloy steel 20CrMnMo with a Young's modulus of 200GPa, a Poisson's ratio of 0.3, and a yield limit of 1175MPa. The Young's modulus of the pipe pile is 206GPa, the Poisson's ratio is 0.3, and the yield limit is 365MPa.

1) The loading surface of the jaws is loaded with 250,000N. The graph of the load changes over time is shown in Fig.6. The displacement of the jaw tooth and the surface stress of the pipe pile are shown in Fig.7 and Fig.8.

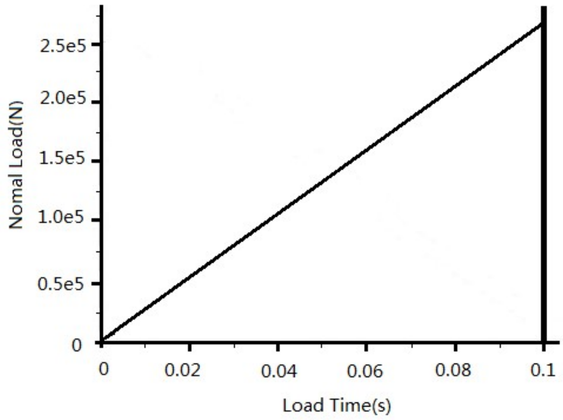


Figure 6. Apply a normal load on a rigid body/N.

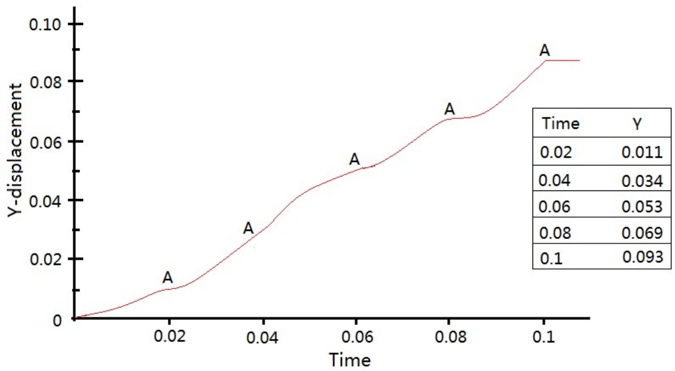


Figure 7. Y-displacement of jaw tooth/mm.

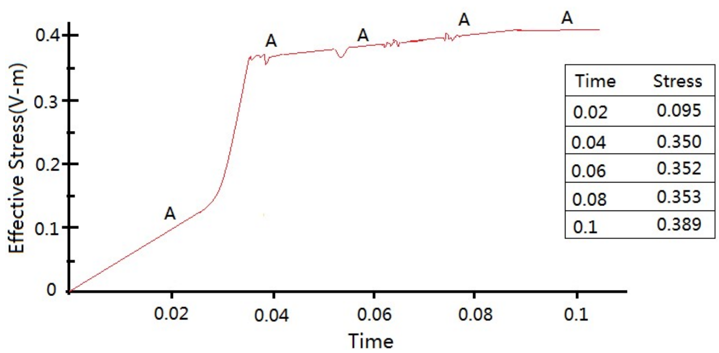


Figure 8. Yield curve of pipe pile /GPa.

2) Similarly, a load of 300,000N was applied to the surface of the jaw, and the loading manner was similar to that of Fig.6. From this we can get the tooth displacement and yield curve of the pile contact unit as shown in Fig.9 and Fig.10.

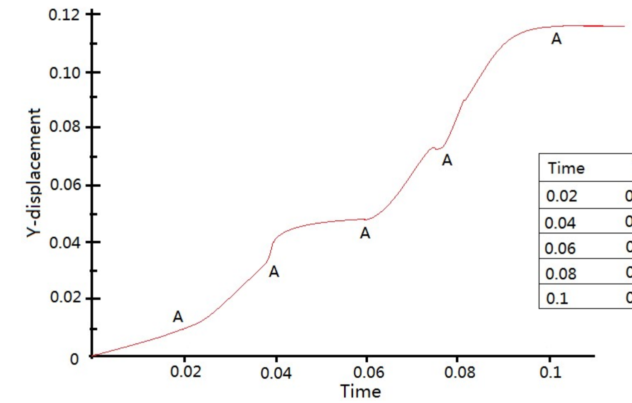


Figure 9. Y-displacement of jaw tooth /mm.

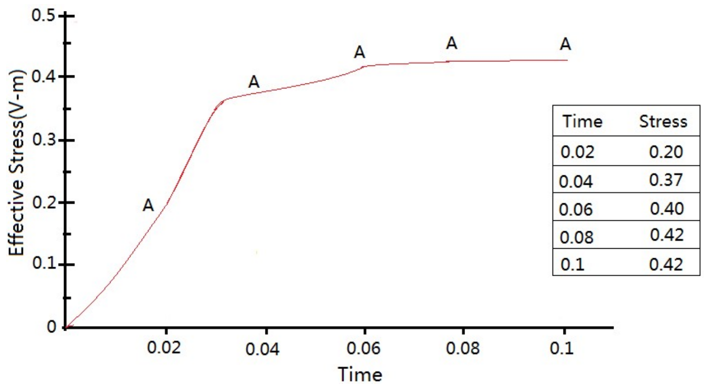


Figure 10. Yield curve of pipe pile /GPa.

3) Similarly, a load of 400,000N is applied to the surface of the clip teeth, and the loading method is as shown in Fig.6. From this we can get the tooth displacement and yield curve of the pile contact unit as shown in Fig.11 and Fig.12.

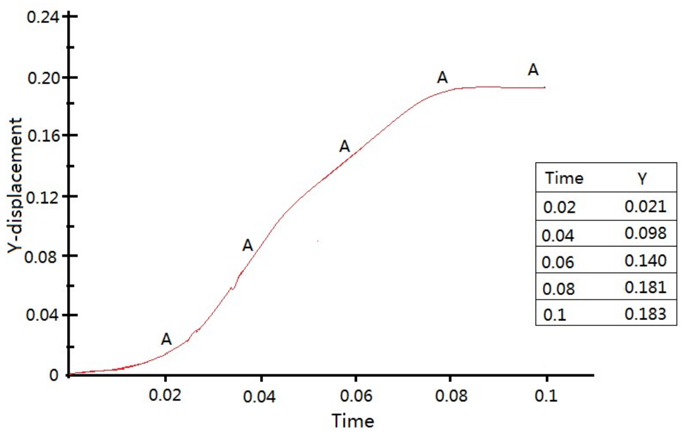


Figure 11. Y-displacement of jaw tooth/mm.

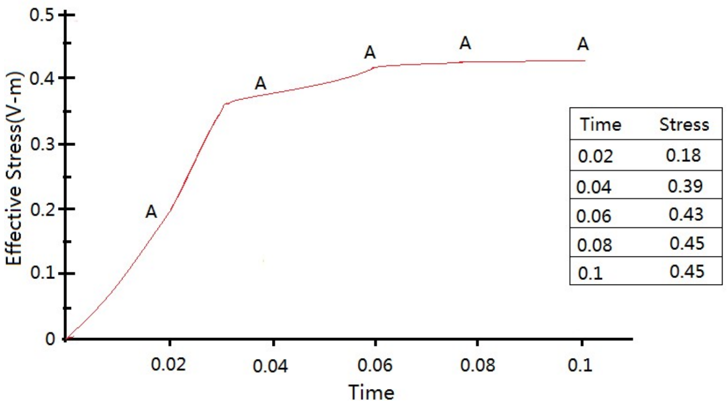


Figure 12. Yield curve of pipe pile /GPa.

Based on the above analysis results, it can be seen that as the load on the jaw surface increases, the deformation of the pipe pile changes from the elastic deformation to the plastic deformation under the pressure of the clamping jaw. After the pipe pile deforms to plastic deformation, the volume is approximately linearly distributed. The jaw is equivalent to a rigid body and the entire interior does not deform. It can be seen that the depth of the jaw tooth embedded in the pipe pile surface is linearly related to the normal load on the jaw surface. Fig.13 shows the relationship between the depth of the teeth embedded in the pipe pile surface and the normal load.

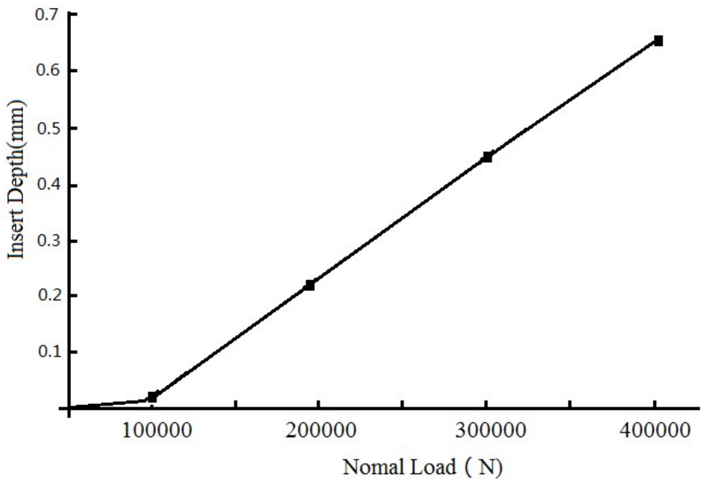


Figure 13. Normal force and embedded depth relationship.

From this, the relationship between the force effected on the surface and the depth embedded in the pipe pile of jaws can be obtained, as in

$$h = \frac{2.29}{1200000} F - 0.091 \quad (5)$$

Where, F is normal clamping force, N; h is tooth depth embedded in pile, mm.

According to the hydraulic principle, the required hydraulic pressure P, as in

$$P = \frac{F}{A} \tag{6}$$

Where, A is clamp cylinder area, mm^2.

Using the results obtained from the analysis above, it is possible to further calculate the embedding depth of the pipe pile under the action of the gripper in the actual project.

The working face of the hydraulic cylinder involved in the article is a round face with a diameter of 250mm, so A=49087.36.

Combining (5) and (6), the relationship between hydraulic pressure and embedding depth can be obtained, as in

$$h = 0.094P - 0.091 \tag{7}$$

Considering the actual conditions involved in this paper, the underwater pile gripper is required to provide a 1500t force for the pipe pile in the up-down direction. The force of the clamping jaws on the pipe pile is the horizontal direction that is perpendicular to the surface of the pipe pile. The friction force between the jaws and the pipe pile is used to provide the up and down direction force for the pipe pile. According to the principle of hydraulic pressure, the relationship between the pressure P' on the jaw surface and the clamping force is known, as in

$$P'Afn = 1500 \times 9800\text{N} \tag{8}$$

Where, f is friction coefficient between pipe pile and jaw 1.2; n is the number of hydraulic cylinders, 10.

Substitute the data into (8), P' can be obtained

$$P' = 24.96\text{MPa}$$

In the actual design process, the pressure is rounded to 25MPa. Substituting the data into (7), the value of h can be obtained

$$h = 2.26\text{mm}$$

The force exerted on the pipe pile surface does not affect the clamping depth of the jaw and the force acting on the surface of the pipe pile, so (7) is still satisfied.

5. Actual calculation

In order to ensure that the underwater pile gripper can really meet the actual needs, the gripper needs to be verified experimentally. During the test, the hydraulic cylinder test pressure is 1.25 times the actual working pressure. According to the above calculation results, the test pressure of the hydraulic cylinder is 32MPa. Substitute the pressure value into (7), the embedded depth of the pipe pile during the test can be obtained, as in

$$h' = 2.917\text{mm}$$

The uniform distribution of the pipe piles in the circumferential direction is much smaller than the critical stress value. At this time, the pipe piles are still safe and do not fail.

With the finite element model of Fig.6, the jaw and pipe piles were subjected to finite element simulation under the test pressure, and the stress cloud diagrams of the pipe piles and jaws were obtained as shown in Fig.14 and Fig.15. The embedded depth of the pipe pile surface is shown in Fig.16.

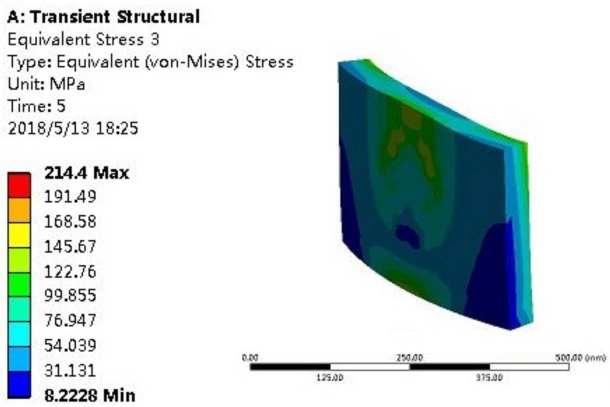


Figure 14. Stress cloud diagrams of pipe pile.

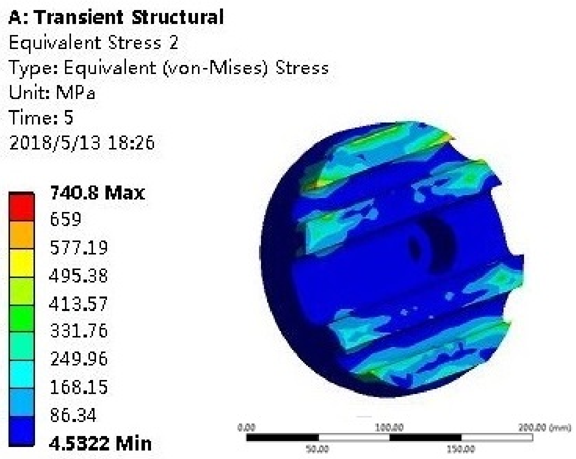


Figure15. Stress cloud diagrams of the jaw.

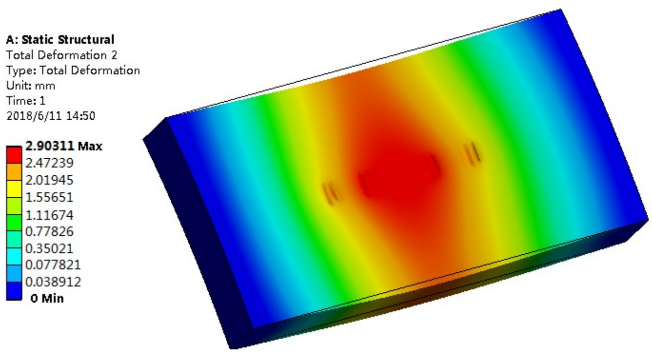


Figure 16. The embedded depth of the pipe pile surface.

From Fig.14 to Fig.16, it can be seen that the maximum stress on the pipe pile surface is 214.4MPa, the yield limit of the pipe pile is $\sigma_s = 500\text{MPa}$, and the safety factor is n=2 [7]. Therefore, the allowable stress of the pipe pile is $[\sigma] = 250\text{MPa}$. The pipe piles meet the strength requirements; the maximum stress at the jaws is 775.83MPa, the jaws yield limit is $\sigma_s = 1320\text{MPa}$, the safety factor is n=1.25, and the allowable stress of the jaws is $[\sigma] = 1056\text{MPa}$, it is available to meet the strength requirements. The depth of the embedded depth of the pipe pile surface is 2.903mm, which is basically the same as the calculated result of 2.917mm. It is proves that the results of this paper are reliable.

6. Conclusion

In this paper, ANSYS software was used to study the jaw teeth and pipe piles of underwater pile gripper. In this paper, the relationship between the external force exerted on the surface of jaw and the depth of the jaws embedded in the pipe pile surface is obtained. Using the research results of this paper, the depth of jaw embedded in the pipe pile and the stress on the surface of the pipe pile under the condition that the jaws are affected by the external force can be obtained. In that case, the external load can be controlled in order to ensure that the pipe pile does not damage. The research in this paper provides a guarantee for the safe construction of pipe piles and helps the rapid development of the underwater pile gripper.

Acknowledgments

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