Study on stability of bucket foundation under backfill

Xinyuan Zhang¹,a, Jinsong Gui¹, b,*

¹ College of Ocean and Civil Engineering, Dalian Ocean University, Dalian Liaoning 116023 China

a18742514875@163.com, bguis@163.com (*corresponding author)

Abstract: Bucket foundation is a new type of port hydraulic structure that has emerged in recent years. Currently, it is used more and more in coastal engineering. However, due to its complicated structure, the stability of the bucket foundation structure has not been solved. This sinking bucket foundation relies on its own weight and soil mass to resist external force to maintain its stability. In this paper, the finite element numerical simulation method is used to study the more reasonable arrangement of bucket foundation through the analysis of slippage resistance, capsizing ability and instability form of bucket foundation under different diameter-height ratio and different rear backfill. It provides reference for stability analysis and research of bucket foundation.

1. Introduction

With the continuous development of shipping industry, the displacement of ships is increasing, which requires port construction to start from shallow water to deep water. At present, the excellent harbors in the coastal areas of our country have been exhausted. The other coastal areas are widely distributed with soft soil geology, which makes the port hydraulic structure must adapt to the adverse conditions such as large waves, rapid flow and soft soil foundation, etc. The bucket foundation is a new type of port hydraulic structure that has emerged in recent years. It is suitable for coastal conditions with deep waters and soft soil foundations. The new structure has less on-site workload, simple construction and short construction period [1]. Because the new structure has a short time, complicated structure and few engineering examples. The research on its related theory is not perfect enough, especially for the study of the bearing characteristics under the backfill. It is necessary to conduct in-depth and meticulous research on the barrel foundation under the action of soil. Therefore, this paper uses numerical simulation method to study the stability characteristics of bucket foundation with different aspect ratios under the action of rear backfill and provides reference for the design, optimization and improvement of new bucket foundation structure.

Yang Ligong, Cai Zhengyin, Ding Hongyan believe that the anti-overturn stability of the submerged bucket foundation breakwater is an important part of its stability calculation under the wave load. It is assumed that the stability of the bucket foundation breakwater sinking into the deeper soil layer is mainly maintained by the earth pressure on the barrel side, the side friction resistance of the barrel, the reaction force of the bottom soil of the barrel and the bottom friction resistance of the barrel. The working principle is similar to that of the retaining wall. It is assumed that the barrel rotates around the center of rotation. The shore side is the passive earth pressure. The sea side is the active earth pressure and the passive side bucket bottom soil is assumed to reach the limit state. Since there are many partition walls inside the lower barrel. It is assumed that the structure of the lower barrel and the soil in the barrel are co-deformed, that is, the barrel is regarded as a whole with the soil
inside the barrel. Based on the above assumptions, the expressions of the soil pressure and frictional resistance of the bucket wall, the reaction force of the bottom soil of the bucket and the frictional resistance are derived by means of analysis. A three-dimensional calculation method for the submerged bucket foundation breakwater to meet the anti-overtur stability requirements is established [2].

2. Numerical simulation

2.1. Model establishment

ABAQUS is three-dimensional finite element software applied to Geo-technical engineering deformation and stability analysis. It is one of the world's most famous nonlinear finite element analysis software [3]. The silt layer of the physical model test consists of three types of silt. To facilitate the modeling of the finite element, the silt layer of the model is combined into one layer. The barrel foundation structure is composed of an upper barrel and a lower barrel. The upper barrel is two empty drums of the same diameter. The lower barrel is composed of a long oval barrel wall and a cover plate, and the lower barrel is divided into 9 positions by a well-shaped partition. An elliptical caisson resembles an inverted buckle. The upper drum and the lower bucket are just attached. The stability of the barrel model is analyzed by ABAQUS finite element software. The finite element model of the barrel is shown in Figure 1. The finite element model of the soil is shown in Figure 2.

![Fig. 1 Bucket foundation](image1)

![Fig. 2 Soil finite element model](image2)

2.2. Numerical model verification

There are three cases in the model test. In this paper, the finite element analysis of the third group of model tests is carried out and the P-S curve is drawn and compared with the measured values of the model. As shown in Figure 3, the dot in the figure is the test result in the literature, the square point is the simulation result of other finite element software and the solid line is the calculation result of this paper. It can be seen from the figure that the load-displacement curve at the initial stage of loading is basically linear and this stage can be continued until the horizontal load is 2.4KN. When the load exceeds this limit, it begins to enter the nonlinear relationship phase. But the structural displacement growth rate is still less than the load growth rate. It indicates that the structure can still work normally. So the nonlinear phase can still be used as the normal use. But when the load exceeds 2.8 KN, the structural displacement growth rate exceeds the load growth rate and the structure rapidly undergoes overturning damage. This is the same as the variation of the model test load displacement curve [4]. The finite element calculation results are in agreement with the measured results which verify the feasibility of the finite element model numerical simulation method established in this paper.
3. Parameter analysis

3.1. Anti-sliding stability study
Under the backfill soil is not changed, only the diameter-to-height ratio of the barrel foundation is changed. The diameter-height ratios are calculated as 1.27, 1.05, and 0.84, respectively. The calculation results are shown in Figure 4 is shown.

As can be seen from Figure 4, it can be seen that the base diameter-to-height ratio is sensitive to the influence of displacement. Especially when the aspect ratio is changed from 0.84 to 1.05, the displacement is shortened by nearly 2/3. But when it is changed from 1.05 to 1.27, the displacement is reduced very slowly. When the load is in the range of 120 kPa, the displacement of the two barrel foundations is basically the same. Only when the load is larger, the 1.27 barrel foundation exerts its more stable advantages. But its displacement shortening is close to a sixth of the previous one. This indicates that the selection of the aspect ratio is a key factor in numerical simulation and it is also the key to affect the displacement of the structure during use. At the same time, if the design requirements are satisfied, the foundation with a diameter to height ratio of 1.05 can meet the normal service requirements. So the original foundation can be optimized to make it play a greater role. From the perspective of structural bearing capacity, when the aspect ratio is changed from 0.84 to 1.05, the bearing capacity increases by 2 times. But when the aspect ratio changes from 1.05 to 1.27, before reaching the ultimate bearing capacity, the bearing capacity basically did not change. So it also shows that the design can be properly optimized based on the design requirements.

3.2. Anti-overturning stability study
Under the condition that the diameter of the bucket foundation is changed without changing the index of the foundation soil and backfill soil, the overturning conditions are calculated under the conditions of 1.27, 1.05 and 0.84, respectively. The calculation results are shown in Fig. 5.
As can be seen from Fig. 5, it can be seen that the foundation rotates around a certain center of rotation of the lower bucket\cite{5} and the aspect ratio is sensitive to the influence of the displacement. Especially when the aspect ratio is changed from 0.84 to 1.05, the corner shortening is close to 5/6. But from 1.05 to 1.27, the corner reduction speed becomes very slowly. When the load is in the range of 40 kPa, the rotation angles of the two barrel foundations are basically the same. Only when the load is larger, the 1.27 barrel foundation exerts its more stable advantage. This indicates that the selection of the aspect ratio is a key factor in numerical simulation and it is also the key to affect the corner of the structure during use. At the same time, in the case that the design requirements are satisfied, the bucket foundation with an aspect ratio of 1.27 has a positive corner value. (In this paper, the positive rotation angle is the rotation on the sea side and the negative rotation angle indicates the rotation on the shore side) This kind of structure cannot satisfy its stability. The base-to-height ratio is 0.84, the negative rotation angle has been occurring and the rotation angle value is greater than the corresponding rotation angle of 1.05. This basis is too stable. However, when the ratio of diameter to height is 1.05, the negative turning angle occurs first, and with the increase of load, it turns into a positive turning angle. This kind of foundation is a more reasonable structure under the condition of satisfying the design requirements. From the perspective of structural bearing capacity, it is basically consistent with the above horizontal slipping conclusion. Therefore, it is also indicated that the basic optimization can be optimized when the design requirements are met.

3.3. Research on the form of instability

Through the study of the above working conditions, it is shown that the form of instability of the bucket foundation is more complex in the process of increasing the load. Due to its own weight and the influence of soil, it will settle in the vertical direction. The amount of settlement is related to its own weight and the soil quality of the foundation soil. Under the action of the active earth pressure of the rear soil, the barrel foundation will occur horizontally to the sea side. The displacement is related to the soil quality of the rear backfill. At the same time, the foundation will have a corner in the vertical plane and there is a center of rotation inside the barrel. The numerical simulation can be seen that around the center of rotation, the barrel can be rotated to the sea side or to the shore side. The reason can be simplified as follows: on the barrel foundation, the side bucket will be subjected to the moment M1 of the backfill to the sea side and the rear cover will be subjected to the downward moment M2. It can be seen that when the moment acts M1 > M2, the whole body receives the torque and the torque to the sea side and has a tendency to rotate toward the sea side, as shown in Figure 6. On the contrary, the foundation as a whole receives the moment when the moment acts M1 < M2. On the bank side, there is a tendency to turn to the shore side, as shown in Figure 7. The magnitude of the moments M1, M2 is related to the aspect ratio of the structure itself and the parameters of the rear backfill. From the simulation of this paper, when the diameter of the foundation structure is relatively large and the friction angle of the rear backfill is large, M2 plays a leading role and the structure rotates to the shore side. When the structural diameter is relatively small and the friction angle of the rear backfill is small, M1 plays the leading role, and the structure rotates to the sea. Therefore, the stability of the structure can be improved by selecting an appropriate aspect ratio and backfill.

![Fig. 6 Displacement cloud map](image1)

![Fig. 7 Displacement cloud map](image2)
In order to continue to study the influence of rear backfill on structural stability, the experimental research is continued in this paper. Without changing the structure and other parameters, only the internal friction angle of the rear backfill is changed and the internal friction angles are respectively taken as 0 degrees, 30 degrees and 45 degrees. The horizontal displacement and the angle of the barrel take the curve as a function of the load, as shown in Figures 8 and 9.

![Fig.8 Stress-displacement curve](image1)

![Fig.9 Stress-angle curve](image2)

From the information shown in Figure 8, we can see that with the increase of the internal friction angle, the displacement of the bucket foundation in the horizontal direction shows a significant decrease trend. Therefore, selecting the soil with a larger internal friction angle can increase the structure of anti-sliding stability. At the same time, in Figure 9, with the friction angle, the corner has a tendency to decrease significantly. However, the turning angle increases when the critical angle exceeds a certain critical angle. It can be seen that the internal friction angle and the anti-inclination ability of the structure are not a linear development relationship, and there exists a range which can make the anti-inclination ability reach the maximum. However, due to the large number of influencing factors, it is necessary to further study this range.

4. Conclusion

The barrel foundation structure is very complicated under the action of backfill. The classical structure calculation has been difficult to meet its calculation. The numerical simulation method provides a new way to solve the stability of the barrel foundation. Through the numerical simulation method, the instability form of the overturning and slipping of the bucket foundation and the main control factors are given.

1. Under the action of the backfill of the bucket foundation, the unstable form can be simplified into the process of vertical settlement and horizontal seaward slip, accompanied by overturning damage. The direction of overturning is affected by many factors. This paper mainly explores the influence of the aspect ratio and the friction angle of the backfill after the barrel.

2. According to the comprehensive analysis and calculation results, there is a limit value range for the aspect ratio. When the value is larger than this interval, it will have less influence on the slippage, overturning and structural bearing capacity under normal use. The specific scope can be designed and checked according to the specific working conditions.

3. The friction angle and structural anti-tilt ability is not a linear development relationship, there is a middle range, which can maximize the anti-overturning ability.

In summary, through the numerical simulation method, some control factors affecting the stability of the bucket foundation are explored, which provides some references for further exploration.

References

[1] Li Wu, Cheng Zekun. Bucket structure design for silt coast [J]. Journal of water conservancy and transportation engineering, 2015 (1): 43 - 47.

[2] Yang Ligong, Tsai Zhengyin. Calculation of overturning Stability of submerged Bucket Foundation Breakwater [J]. Journal of Water Conservancy and Water Transportation Engineering (4): 61-68.
[3] Fei Kang, Zhang Jianwei. Abaqus in geotechnical engineering [M]. China Water Conservancy and Hydropower Press, 2012

[4] Li Wu, Chen Qian and so on. Stability Study of Bucket Foundation under Horizontal Load China Harbour Construction, 2012 (5): 15 - 18

[5] Li Wu, Wu Qingsong, et al. Experimental study on stability of bucket foundation [J]. Journal of Water Conservancy and Water Transportation Engineering 2012 (5): 43-47.