Study on Stability Analysis of Steel Cylinder Retaining Structure

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Abstract. The steel cylinder structure is generally used as a wharf revetment structure. It is necessary to evaluate the safety and stability of the steel cylinder structure as the retaining structure for offshore foundation excavation. In this paper, a large finite element software PLAXIS is used to simulate the safety factor and the structural displacement of the steel cylinder structure in the wave load and the excavation of the foundation. The calculation results show that the overall stability of the steel cylinder is 1.7 when the most unfavorable condition of excavating from the foundation to the bottom of the steel cylinder. The lateral displacement is 572mm, which meets the safety requirements of the structure. The steel cylinder structure can play a role as the water retaining structure of the cofferdam and the support structure of foundation when it was put into the non-permeable layer.

1 Introduction

Large diameter steel cylinder is a new type of port engineering structure. The insert type large diameter cylinder has the characteristics of simple structure, reasonable force, low material consumption, fast construction speed and strong adaptability to foundation, so it has been developed rapidly in China in the past ten years. The abroad research on the mechanical behavior and working mechanism of large diameter cylindrical structures is earlier than China [1]. During the construction of Le Havre port in Le Havre, France in 50s, French engineers have begun to study the model experiment of thin shell structure. The relationship between the density of the inner packing and the bearing load, and the contact friction between the backfill and the wall are analyzed, and the influence factors of the change of the lateral pressure in the thin shell [2-3] are discussed.

China began to carry out the relevant experimental research and engineering design is from [4-5] in 1980s. The project has been completed in Fangchenggang, Guangdong, Fangchenggang, 30 thousand tons grain terminal, Shandong Arashiyama port liquid chemical wharf, as well as the 50 thousand ton container terminal of Nansha Panyu, and the large cylinder test section of the Yangtze Estuary. This new structure has a good development prospect in port engineering.

2 Engineering Survey

An underground comprehensive pipe gallery is built in a city. The extension section of the city is built in the sea and which is connected to the high speed around the city. According to the design plan, the excavation method of the cofferdam is adopted. In accordance with the design scheme, the steel cylinder cofferdam is used as the supporting structure and seepage proof structure. The purpose of this paper is to analyze the structural stability of steel cylinder structures under wave loads and soil pressure of excavation.

The engineering area is located in the transition zone between the land and shallow bay of the intertidal zone. It belongs to the coastal shoal geomorphology. The water depth is 0.50m to 4.80m when the tide rises, and the height of the engineering area is -3.8m to -4.0m when the tide is low. No fracture structure in and near the engineering area. The soil properties from top to bottom are artificial fill, marine sedimentary layer, marine-continental alternating sedimentary layer, Alluvial-diluvia layer, residual layer and bedrock layer.

3 Design Scheme

A steel cylinder was laid along the axis of the embankment on average (about -3.85m), and the diameter

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of the steel cylinder was 30.0m. The top of the steel cylinder is 3.0m, the height of the bottom is about -16.0m, and the long of the steel cylinder is about 19.0m.

Through the temporary steel cofferdam, water-proof curtain and large excavation foundation, the dry construction of internal foundation can be realized. The steel cylinders are connected by welded web. The area between the steel cylinder and the cylinder and the web is filled with sand backfill. A large excavation scheme is adopted in the internal foundation pit of the steel cylinder cofferdam. The 8m working platform is reserved for the original mud surface down to the height of the steel cylinder bottom, and then the foundation pit is excavated according to the slope ratio 1:3.

4 model establishment

4.1.Parameter selection

According to the geological data of typical sections, the small strain soil hardening model is used to select the calculation parameters as shown in Table 1.

Table 1 Summary table for calculating parameter selection

Soil hardening model							
Soil type	heavy （kN/m³）	cohesion （kN/m²）	friction angle （°）	E_{50}^{ref}(kN/m²)	E_{oed}^{ref}(kN/m²)	E_{ur}^{ref}(kN/m²)	e_{init}
silt	15.1	10	20	3000	2000	16e3	0.5
Clay	18.9	26.1	11	5000	5000	25e3	0.5
Gravel sand	20.5	9.9	6.5	10e3	8642	20e3	0.5
Silty clay	18.3	38.3	18.8	3720	3720	21e3	0.5
fully weathered	21	30	15	39e3	39e3	12e4	0.5
Inner cylinder backfill	20.5	9.9	6.5	1e4	8642	2e4	0.5
Linear elastic model							
Soil type	heavy （kN/m³）	Elastic modulus （kN/m²）	Poisson ratio	G (kN/m²)	E_{oed}(kN/m²)	cohesion （kN/m²）	friction angle （°）
strong weathering	22	3e5	0.25	12e4	36e4	1500	37
medium weathering	26	2e7	0.2	8.3e6	2.2e7	1500	37

The PLAXIS3D finite element analysis software is used in this calculation. It has a more comprehensive and rich specialized rock soil constitutive model and an easy to use operation interface designed for the characteristics of geotechnical engineering analysis. Since its introduction, it has been widely recognized in the international geotechnical field because of its high reliability. It is widely used in various geotechnical projects, such as foundation, slope sliding, retaining wall, tunnel, wharf engineering, etc.

The Moore Coulomb model is used for foundation, backfill sand. It is suitable for elastoplastic, nonlinear material, and the mechanical behaviour of general rock and soil, such as slope stability and underground excavation. The Mohr-Coulomb model is based on the irrelevant flow rule, the fully plastic Mohr-Coulomb yield criterion and the material tension limit of soil.

4.2.Boundary Condition

In the process of cofferdam forming, the steel cylinder can be regarded as the retaining wall structure of continuous wall. To simplify the calculation, a cylinder width along with length is used for analysis. The displacement boundary conditions of the model along the wall direction are constrained by the roller, that is, the normal displacement of the two sides of the soil and the structure is constrained, and the other two directions are free of displacement. The whole section of the model is calculated. For drainage conditions, the two sides of the model and the bottom are impermeable, and the top is drainage.

The model size is X direction 100m and Y direction 30.8m. This model is based on the water surface, for the diameter of the steel cylinder is 15m, the height of the cylinder 22m, the bottom of the steel cylinder is -22 (to the gravel bottom), the vice lattice is built on both sides of the steel cylinder which is not permeable; the 24kN concentrated load is applied to the 1.6m underwater as the wave load; excavation of foundation pit to steel cylinder bottom elevation -22 (to gravel bottom); considering the precipitation of internal foundation pit after the formation of steel cylinder cofferdam, final excavation surface is impermeable surface; the construction process are :stress balance / steel cylinder setting (wave loading) / foundation vertical excavation / stability and safety analysis / steel cylinder safety analysis / safety of steel cylinder total of five construction steps. The calculation model is shown in Figure 2.

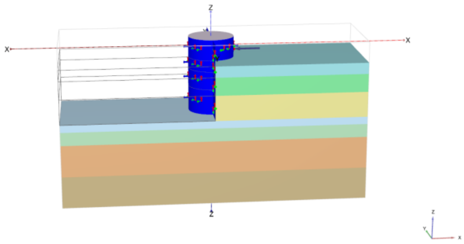

Fig.2 Calculation model for completion of foundation excavation

In numerical calculation, the stress balance is first determined and the initial stress distribution is determined. The initial stress in the soil is affected by the historical influence of the material, which is usually expressed by the vertical effective stress. The horizontal effective stress is related to the vertical effective stress and the side pressure coefficient. In PLAXIS, the initial stress can be generated by the K_0 process, and it is usually assumed that the K_0 of the normally consolidated soil is related to the friction angle. Through the K_0 process, the weight of the soil is all activated and then goes to the construction stage. After the calculation is completed, the deformation of the soil in the foundation and the steel cylinder is output and the safety analysis is carried out.

5 Results

After the steel cylinder is finished, the excavation of the foundation in the cofferdam is necessary, so the drainage and part of the excavation should be carried out in the foundation pit. This analysis needs to calculate the stability of the steel cylinder under various working conditions.

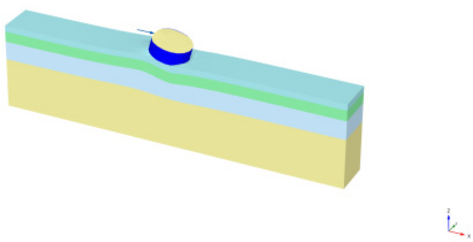

Fig. 3 Displacement diagram of steel cylinder after wave loading

Figure 3 is the displacement diagram of the steel cylinder under the action of the wave load after completion of the steel cylinder. According to the calculation results, the steel cylinder will produce lateral displacement 17mm to the inner direction of the foundation pit under the action of the wave load. At this time, the stability safety factor of the steel cylinder is 3.0.

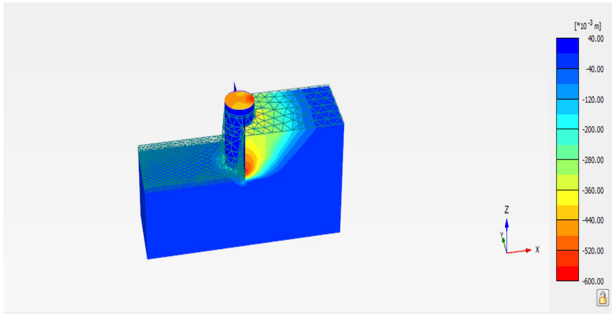

Fig. 4 Images of steel cylinder and ground displacement during excavation of foundation pit

According to the design requirements, Figure 4 is the cloud chart of the steel cylinder and ground displacement when the foundation pit is excavated to the bottom of the steel cylinder. According to the calculation, the maximum lateral displacement of the steel cylinder after the excavation is 572mm, and the overall stability safety factor of the steel cylinder is 1.7. Figure 5 is a displacement Images of a steel cylinder.

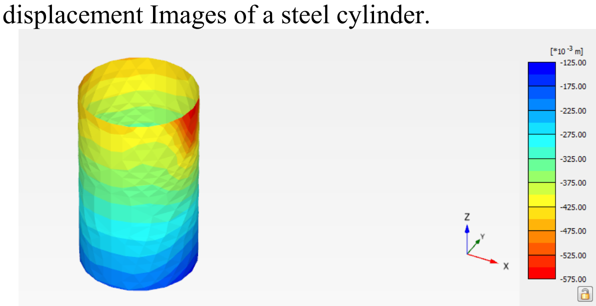

Fig. 5 Displacement cloud chart of steel cylinder structure

As shown in Figure 6, at a certain height, the safety factor increases with the increase in diameter. This is also easy to understand. For the increase of the diameter of the gravity structure, the downward gravity and anti-overturning arm can be increased at the same time. However, for Figure 7, the safety factor decreases with the increase of depth when the diameter is fixed, which is obviously contrary to common sense. As for the gravity type anti overturning calculation, the anti-overturning gravity of the packing in the cylinder increases slightly with the height, but the overturning moment of the active earth pressure on the right side of the steel cylinder increases with the height of two times, causing the overturning moment rapid increase and the safety factor to decrease . However, the safety factor increases slowly when the height of steel cylinder is greater than 35m. Therefore, the anti-overturning checking calculation of gravity structure is only suitable for the case where the insertion depth is small and the filler in the cylinder can participate in the anti-overturning effect to a great extent.

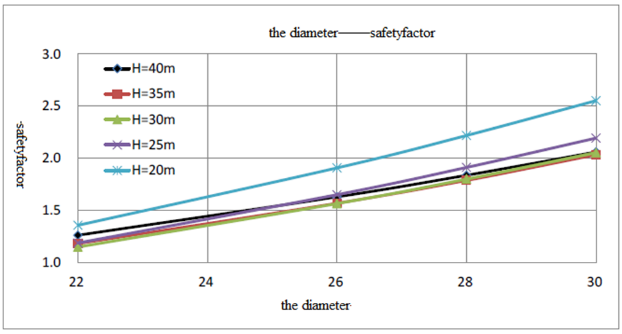

Fig. 6 Relationship between safety factor and diameter

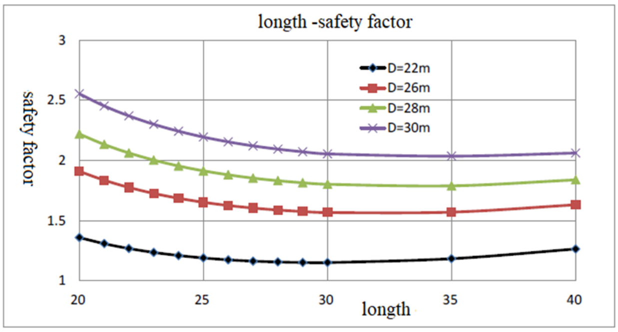

Fig. 7 Relationship between safety factor

6 Conclusions

(1) The construction of steel cylinder structure to impervious layer can act as water retaining structure at the sea and retaining structure for foundation pit.

(2) When the foundation pit is excavated to the bottom elevation of the steel cylinder, the overall stability of the steel cylinder is 1.7, and the lateral displacement is 572 mm, which meets the structural safety requirements.

Acknowledgements

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