Simulation Calculation on the Failure Mode of the Big-size Sandbag Cofferdam on Soft Foundation

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Abstract. The offshore engineering develop fast in recent years, a new method named “big-size sandbag cofferdam” is applied to many practical projects in China. The sandbag is made of geotextile with large sizes in length and width. Sandbags are filled with pumped sea sand and stacked together layer by layer. Many theoretical obstacles remain unsolved, which has restricted the application of this advanced technology. Based on an instability project located in Bohai Bay, the failure mode of the big-size sandbag cofferdam on soft foundation was studied. The results show that the deformation of cofferdam was concentrated on the bottom sandbag, under the action of insufficient foundation bearing capacity and overburden load, the stress of the geotextile at the bottom layer increase sharply during the fast filling, then exceed its ultimate tensile strength, and the cofferdam would be pulled apart from the bottom to top, lead to a continuous penetrating sliding surface failure of big-size sandbag cofferdam.

1 Introduction

It is a common method to construct cofferdams for land reclamation, under the condition of soft soil foundation in offshore waters. As a systematic engineering, the formation of cofferdam is a key technology for the reclamation of sea and land, and is the basic link of the whole project. How to build cofferdam quickly and safely is a difficult task with many technical problems. Therefore, the research and development of offshore cofferdam construction technology is an urgent need for the development of engineering construction[1]. Due to the land reclamation area become larger, and the construction progress faster, the traditional cofferdam construction methods such as grass-soil cofferdam, riprap cofferdam and steel sheet pile cofferdam are no longer applicable. The big-size sandbag cofferdam is made up of geotextile covers the sand and overlaps with each other to fill, which not only has the functions of water permeability, isolation and filtration, but also greatly improves the cohesion and integrity, which can better resist the wave erosion and adapt to the deformation of soft soil foundation, and has been widely used[2-5].

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2 Instability of big-size sandbag cofferdam

2.1 Scale and layout

The reclamation project is located in the west of Bohai bay. The cofferdam is constructed with a large sand bag slope embankment. The total length of cofferdam is 6.75 kilometers. The typical cross-section of the cofferdam embankment is illustrated in Figure 1.

The geomorphic features of the construction area of the project are mainly littoral sedimentary facies, supplemented by terrestrial sedimentary facies and estuarine delta sedimentary facies. Affected by the terrain, the coastal underwater terrain in this area is relatively flat, and the elevation of the mud surface from west to east gradually decreases from -1.19~4.27m, showing a trend of high west and low east. The thickness of the silt layer gradually thickens with the increase of water depth from north to south. The seabed deposit can be divided into seven layers: ①₁mud, ①₂muddy clay, ①₃clay mixed with shell; ②₁ silty clay, ②₂silt; ③₁ silty clay, ③₂silt. The characteristic of main soil layers are listed in Table 1.

Fig. 1. The bending deformation of shield tunnel

Table 1. Characteristic of soil layers (Tianjin project)

soil layer number	thickness (m)	moisture content (W%)	unit weight (kN/m ³)	plasticity index I _p	C _q (kPa)	Soil strength		
						φ _q (°)	C _{cu} (kPa)	φ _{cu} (°)
① ₁	3.0~8.0	60.7	16.21	23.5	6	0.2	13.8	16
① ₂	3.0~8.0	45.5	17.42	21.2	13	2.5	12.7	16.1
① ₃	0.5~2.0	27.4	18.61	12.8	16	12.6	27.5	27.0
② ₁	0.5~3.0	26.6	19.13	13.3				
② ₂	0.2~2.0	25.1	19.12	7.4			33.0	29.6
③ ₁	3.5~17.5	23.9	19.93	13.0	19	17.0	38.5	23.2
③ ₂	2.0~6.5	23.5		7.4				

2.2 Instability during the construction

In the construction process of the cofferdam supported by the large sand bag, an accident occurred in both of the two bidding sections, the geotextile was pulled off and the filling bag collapsed and lost its stability.

The collapse and instability of the cofferdam of a large sand bag in one of the bidding sections occurred two days after the filling of the large sand bag in the main body was completed. When the cofferdam was filled to +3.0m (the height of the mud surface was about -2m, the blowing filling construction started. At this time, the tide level is low, about 1.19m. The large sand bag cofferdam near the filling area collapsed and became unstable, and the geotextile was pulled down along the axis of the cofferdam. Before the instability accident in the first bid section, there has been a case of collapse and instability in the second bid section of the supporting project. At that time, the main cofferdam was filled up to +2.5m, but the blowing filling in the closed area had not been carried out. The

geotextiles were pulled apart and the sandbags collapsed. Figure 2 shows the photos of collapse area taken on site.

Fig. 2. Pictures of collapse status in construction site

3 Calculation model

A full-section model was adopted for the analysis. The model simulated three layers of foundation soil, including silt layer (8m), silty clay layer (10m) and silty clay layer (8m). Plastic drainage board was set in the foundation with a depth of 12m. Medium coarse sand cushion is set at the bottom of cofferdam, and its thickness is 1m; A total of 6 layers of large sand bags were simulated, each layer being 1m thick, in which the tensile strength $N=14\text{kN}$ and stiffness $EA=140\text{kN/m}$ of geotextile. During the calculation, the calculation boundary of left and right sides of the model is enlarged to eliminate its influence on the location shift of the reinforcement.

Mohr coulomb model was used to simulate the packing of large sand bag and the soil layer of the bottom foundation, and soft soil simulation was used to simulate the silty layer and silty clay layer. The corresponding physical and mechanical parameters of the sampled foundation soil and sand filled soil were determined through laboratory geotechnical tests. Table 2 shows the physical and mechanical parameters of each soil layer.

Fig. 3. Finite element model and grid division of big-size sandbag cofferdam

Table 2. Physical and mechanical parameters of each soil layer

Soil layer	γ kN/m	k m/day	E kPa	μ	λ^*	κ^*	c kPa	Φ °
Filling soil	18	1	20000	0.3			1	30
silty clay	19	0.00025	2500	0.33			21	8
silt	16	0.00001			0.105	0.013	5	3
mucky clay	17.3	0.00001			0.093	0.011	6	5

4 Calculation results and analysis

4.1 Deformation analysis

Figure 4 shows the comparison of large sand bag cofferdam before and after deformation in each construction stage. It can be seen from the figure that the deformation of cofferdam

and foundation is small when the large sand bag cofferdam is filled up to the second layer of sand bag. When the fourth layer is filled with large sand bags, the foundation and cofferdam have been deformed, and the uneven settlement is obvious, and mainly concentrated at the foot of the cofferdam slope. When the filling reaches the sixth layer, the cofferdam deformation is further intensified, the uplift of the foundation at the foot of the slope is more obvious, and the silt foundation is extruded.

Fig. 4. Deformation diagram of sandbag cofferdam during layered filling

Fig. 5. Settlement displacement cloud chart of sandbag cofferdam

The settlement amount of cofferdam in each stage of construction is calculated. Figure 5 shows the settlement displacement cloud chart. It can be seen from the cloud chart that the

deformation of cofferdam and foundation is mainly vertical settlement at the initial stage of filling, namely, when the large sand bags from the first to the third layers are laid. There is no uplift site at the foot of the cofferdam slope, and the maximum settlement is about 15cm at the central axis of the cofferdam. However, when the large sand bag of the fourth layer is filled, the deformation trend changes, and the maximum deformation position is concentrated from the center of the cofferdam to the two slope feet, with obvious uplift at the foot of the slope. The maximum settlement is about 70cm, and the uplift is 40cm. Compared with the previous construction stage, the deformation of cofferdam and foundation continued to develop when the large sand bag of the sixth layer was filled, and the deformation area and influence scope gradually expanded, mainly spreading to both sides from the foot of the slope. The maximum settlement at the center of the cofferdam was about 160cm, and the uplift at the foot of the slope was about 120cm.

The horizontal displacement of cofferdam in each stage of construction is calculated, shown in figure 6. It can be seen from the figure that, at the initial stage of filling, namely when the first and second large sand bags are laid, the horizontal displacement in the foundation is small and mainly concentrated in the deep silty clay layer. The maximum horizontal displacement is about 3.2cm, and the influence on the cofferdam is almost negligible. When the third layer of large sand bag is filled, the horizontal displacement in the foundation develops, especially the lateral deformation at the foot of the cofferdam slope increases rapidly, which is about 6.0cm, and has a certain impact on the stability of the cofferdam. When the fourth layer of sand bag is laid, similar to the change trend of vertical settlement, the horizontal displacement at the foot of the slope increases sharply with a large increase, and the maximum displacement is about 70cm. With the filling of the fifth and sixth layers of sand bags, this trend developed further. The horizontal displacement at the foot of the cofferdam slope continues to increase, and the final volume is about 180cm.

Fig. 6. Horizontal displacement cloud chart of sandbag cofferdam

4.2 Development of plastic zone

Figure 7 shows the development process of the plastic zone of soft soil foundation in the cofferdam filling process. The red point in the figure is the stress point in the plastic state. The square indicates that it is on the coulomb failure envelope, and the connected area is the plastic zone. The blue grid points are the cap points in the soft soil model, indicating that they are in the normal consolidation state.

Fig. 7. Development of plastic zone in foundation during the cofferdam construction

As can be seen from the figure 7, when the first and second layers of large sand bags are laid at the initial stage of filling, the foundation deformation is mainly self-weight consolidation, and there are basically no plastic points in the foundation soil. When the sand bag of the third layer is filled, the soft foundation deformation continues to develop, and a small plastic zone appears at the slope feet of both sides of the cofferdam, but the zone is not connected, and the foundation remains stable. Fill up to the fourth layer of sand bag, the plastic zone in the foundation can be expanded, and develop to the cofferdam slope foot, the plastic zone basically through; With the increase of the fill height of cofferdam, the plastic zone in the foundation continues to expand and develops rapidly from the foot of the cofferdam slope.

4.3 Process of cofferdam instability

When the cofferdam is filled to the fourth layer of sand bag, the plastic zone in the foundation is through, the displacement at the foot of the slope is abrupt, the foundation deformation is large, and the foundation has been in a state of instability. Although the foundation has been destroyed, since there is a 20-day construction interval before filling the fifth layer of sand bag, the cofferdam deformation can be controlled without sustainable development, and the stress of large sand bag does not exceed its tensile strength, so there is no phenomenon of cofferdam collapse and instability at this stage. When the filling height continues to increase, but the foundation consolidation is not sufficient and the strength is insufficient, the geo cloth at the bottom layer is pulled off when the filling reaches the fifth layer of sand bag, and the cofferdam becomes unstable.

Fig. 8. Process of the big-size sandbag cofferdam lose instability

As can be seen from the figure 8, when the lowest geotextile is pulled off, the stress of the adjacent second geotextile increases sharply and is concentrated at the position where the lower geotextile is pulled off. The insufficient tensile strength causes this position to be pulled off rapidly, and the cofferdam as a whole slides downward along the pulled position. The results show that the big-size sandbag cofferdam will slide along the broken part, and the geotextile will be pulled down from bottom to top to form a through sliding surface, which will lead to collapse and instability of the cofferdam.

5 Conclusion

The whole process of foundation construction is simulated by numerical calculation, and the deformation and plastic zone development of soft soil foundation at each stage are calculated, some conclusions are obtained as follows.

The deformation of big-size sandbag cofferdam foundation is mainly concentrated at the foot of slope, the uplift of both sides is obvious, and the foundation at the center of cofferdam has almost no lateral displacement. The stress of geotextile is mainly concentrated in the large sand bag at the foot of the lower slope, while the stress of the upper geotextile is small

Due to the low strength of the silt foundation on site and the fast construction speed, the soft soil foundation has a large deformation during the filling process, and the failure of the penetration of the plastic zone in the foundation at the foot of the slope. As the filling height continues to increase, the underlying geotextile will be subjected to a sharp deformation and stress increase, and its tensile strength will be insufficient. The geotextile will be pulled down from bottom to top, forming a continuous penetrating sliding surface at the position where each layer is pulled down. The collapse and instability of the cofferdam with large sand bag are consistent with the observation results on the site.

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