ATLANTIS PRESS
Advances in Engineering Research, volume 162
3rd International Conference on Advances in Materials, Mechatronics and Civil Engineering (ICAMMCE 2018)

Elasto-plastic Deformation Analysis of Caisson Cofferdam Based on Plaxis3D

Binbin Xu[1,2,,3,4,a*] and Naishou Zhang[2,b]

[1]Tianjin Port Engineering Institute Ltd. of CCCC, Tianjin, China

[2]CCCC First Harbor Engineering Co. Ltd., Tianjin, China

[3]Key Lab. of Geotechnical Engineering of Tianjin, Tianjin, China

[4]Key Lab. of Geotechnical Engineering, Ministry of Communication, Tianjin, China

[a]xubinbin@tpei.com.cn, [b]zhangnaishou@yhj.com.cn

*Corresponding author

Keywords: Elasto-plastic, deformation, caisson cofferdam.

Abstract. With the development of economic, the construction of offshore artificial island is more and more developed. As one of the common cofferdams, the gravity cofferdam has been widely used in the wharf and breakwater engineering. The deformation is analyzed using finite element method and the results show that the final settlement at the end of the construction is 46.3cm and the horizontal displacement keeps around 12.4cm, which occurs at the top of the caisson.

1. Introduction

In the coastal area, especially in the flouring area, the land shortage is more and more obvious. After several decades of construction along the coastline, there is nearly no ascendant land for the land resource. Recently, the land reclamations are popular to satisfy the land shortage and the construction of the artificial island is to be unfolding. One of the merits of the artificial island lie in the minor disturbance to the ecological environment. The main usages of the artificial island can be categorized into industry, transportation, storage and entertainment functions, including offshore energy base, offshore oil exploitation, airport etc.

The caisson structure is a large-scale hollow concrete structure with backplane, which is subdivided into several cabins using longitudinal and lateral concrete wall. After the caisson is located on the design position, the blocked stone or sand is put into the caisson to enlarge the weight and improve its stability. The physical model experiment has been the most feasible method to research the behavior of the gravity caisson. Hu [1] gave a detailed research about the stability and the maximum tensile force on the silty seabed under the combined action of wave and tide. The motion phenomenon and regulation of the caisson before and after the reaching the seabed are summarized according to the experimental datum, which provides valuable advice and guidance for the construction procedure and technology. Ma et al. [2] researched the sail stability of the caisson through physical model test to provide basis for its undocking and haulage. Ma and Wang [3] researched the sink problems using the semi-submersible barge to verify the new technology of the caisson's sinking. Deng et al. [4] carried out the theoretical research on the vertical withdrawal resistance of the suction caisson using finite element analysis, in-situ experiment and indoor experiments and the semi empirical solution of the withdrawal resistance is obtained. Andersen [5] proposed the limiting equilibrium analysis method of the withdrawal resistance of the suction caisson under the combination of static and dynamic load based on the triaxial compression test, triaxial tension test and direct shear test. Although the method took multiple factors into consideration, the amount of work is too heavy to actually carry out.

The plenty of experience in the construction of the artificial island in Japan can be imitated and absorbed. According to the previous construction experience, the selection of the structure of cofferdam is one of the most important governing factors. Considering that the initial starting of artificial island is relatively late in China and there are still many obstructions in the future, the numerical simulation about the deformation and stability of the cofferdam wall of the island is very necessary for the future design and construction. In this paper, the deformation of caisson cofferdam is analysed numerically to accumulate experience.

2. Calculation conditions

2.1 Calculation model

According to the design documents and ground survey materials, the gravity caisson structure is adopted for the cofferdam of the artificial island. The strength grade is C30. The supporting course is jackstone bedding and the sand compaction piles are installed beneath the bedding. The weight of 10~100kg block stone is thrown in the caisson. The jackstone bedding is composed of 10~500kg block stone with 6~10m width. In the rear of the caisson, the 10~100kg stone is placed. The dimension of the caisson is 28m, 15m and 18m in the length, width and height direction respectively and the weight of each caisson is 3800t. The altitude at the top of the caisson is +3.0m, on which the wave wall is casted in-situ with the altitude of +5.0m. In the front of the caisson, the block stone of 300~500kg weight is placed to protect the bedding. The skeleton map of the caisson is shown in Figure 1.

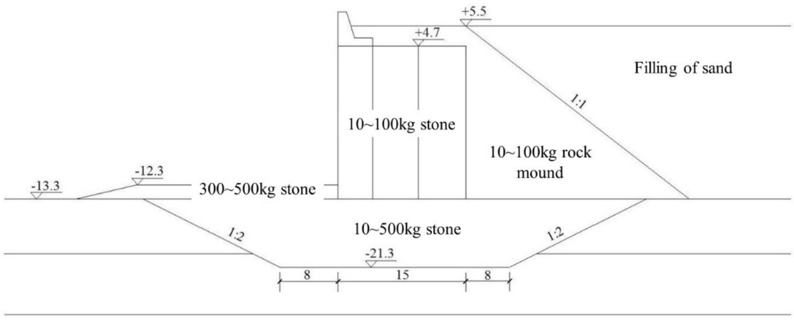

Figure 1 Skeleton map of caisson

2.2 Calculation parameters

The determination of the in-situ soil parameters is based on the indoor experiments, in-situ test results and drilling documents of nearby engineering. The parameters of the bedrock are determined by the uniaxial compression strength of the rock. The relative parameters of the caisson and the stone utilized in the calculation are listed in Table 2.

Table 1 Recommending parameters of soils for the artificial island

Name	Density ρ(g/cm^3)	Triaxial test				Modulus of compression	Permeable coefficient
		Cohesive strength Cuu (kPa)	Internal frictional angle φ_{uu} (°)	Cohesive strength C_{cu} (kPa)	Internal frictiona l angle φ_{uu} (°)	$E_{s1\text{-}2}$ (MPa)	k（cm/s）
②$_1$Silt	1.58	1.66	5.45	3.35	12.34	2.2	6.0e-7
②$_2$Silt	1.6	1.96	8.59	3.79	12.81	2.4	8.0e-7
②$_{2\text{-}2}$ Silty clay	1.83	-	-	-	-	4.1	3.1e-7
②$_3$ Mucky soil	1.71	7.2	10.3	7.43	14.32	3	4.0e-7

Table 2 Parameters in calculation

	Elasticity modulus (kPa)	Poisson's ratio	Bulk Density (kN/m^3)	Friction angle	Cohesive strength (kPa)
Caisson	3×10^7	0.2	24.0	-	-
Rubble-mound foundation	1×10^5	0.3	15.0	35°	5
Block stone	5×10^5	0.3	18.0	35°	5

In order to consider the interaction between the caisson and the ground, the contact surface is set up at the side and bottom surfaces. According to the load in the practical engineering, the magnitude of the load is assumed to be 20kPa during the construction period. Considering the symmetry of the model, the normal constraints are applied on the front and rear surfaces, the fixed constraints are applied on the bottom surfaces and the free boundary is on the top surface, as shown in Figure 2.

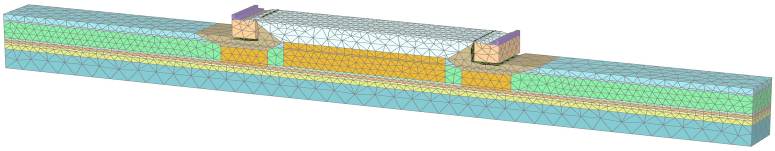

Figure 2 Finite element model of caisson cofferdam

2.3 Calculation scheme

The construction procedure of the caisson cofferdam includes installation of SCP, excavation of foundation trench, refilling of block stone in the trench, installation and filling of caisson, refilling of sand in the island etc. Considering the poor bearing capacity of the soft seabed, the sand compaction piles are installed under the caisson cofferdam to satisfy its stability. Similarly, to satisfy the stability of the ground during the refilling of the sand, the refilling of the sand, the sand compaction piles are also installed in the ground.

3. Calculation results

3.1 Settlement

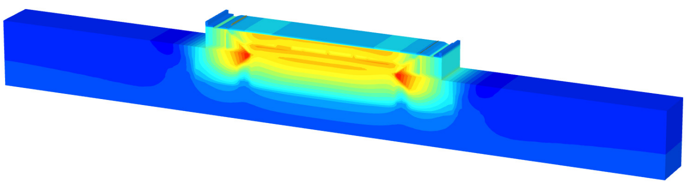

Figure 3 Three dimensional settlement at the end of construction

Figure 3 gives the three-dimensional settlement contour after the installation of the wave wall. As can be seen, the maximum settlement at the end of the construction is about 46.3cm, which is relatively small compared to the previous cases. As the construction goes on, the settlement inside the ground gradually increases. Due to the drainage of the sand compaction piles, the excess pore pressure dissipates quickly and at the end of the construction, the degree of consolidation is relatively high.

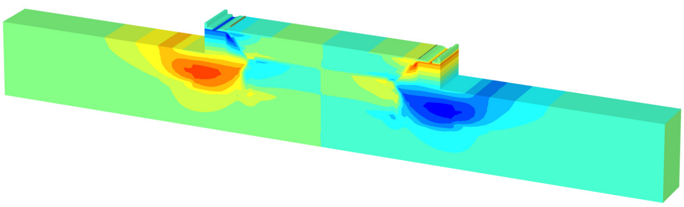

Figure 4 Three dimensional horizontal displacement at the end of construction

3.2 Horizontal displacement

Correspondingly, the distribution of horizontal displacement inside the ground is shown in Figure 5. As can be seen, the maximum horizontal displacement is around 12.4cm, which occurs at the top surface of the caisson. The displacement mainly concentrates at the range of sand compaction pile under the caisson, which represents that the installation of sand compaction pile can prevent the possible horizontal failure of the ground.

4. Conclusions

This paper aims to analyse the engineering property of the caisson cofferdam via numerical calculation. According to the design materials and geological exploration, the finite element model and soil parameters are determined. A serial of calculation is carried out to research the detailed characteristics of the caisson and the conclusions are as follows:

(1) Using the finite element model, the whole construction stage of the artificial island is simulated numerically and the engineering property can be monitored at each stage. As the construction proceeds, the settlement and the horizontal displacement both increases gradually. Due to the drainage effect of the sand compaction piles, the excess pore pressure caused by the filling of the sand in the ground dissipates quickly and at the end of the construction, the degree of consolidation is very high, which means the residual deformation is very small during the operation of the engineering.

(2) After the ground is reinforced by the dewatering and surcharge sand, the final settlement at the end of the construction is 46.3cm and the horizontal displacement keeps around 12.4cm, which occurs at the top of the caisson.

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