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Research on Steel Sheet Pile Cofferdam Based on Stress Seepage Coupling Analysis

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Abstract. Steel sheet pile cofferdam is widely used in sandy soil, viscous soil and deep foundation pit because of its advantages of low cost, strong overall stiffness, short construction period, easy penetration into hard soil and good waterproof performance. Due to complex working conditions and many uncontrollable factors in the construction process, it is necessary to simulate and analyze the construction conditions in advance. The steel cofferdam in the soft soil area is a weathering layer, which is difficult to construct. In order to ensure the structural safety of steel sheet pile cofferdam and control its water use area, the influence of multiple design parameters on the deformation of cofferdam was studied by single factor sensitivity analysis method, and three-dimensional finite element model was calculated by Midas software. The finite element numerical simulation method is used to simulate and calculate each construction condition, analyze the deformation and stress changes of cofferdam and surrounding soil, and the deformation and internal force conditions of steel sheet pile cofferdam and internal support structure in the construction process. Through comprehensive analysis of theory and on-site construction conditions, the construction factors affecting steel sheet pile cofferdam, internal support structure and surrounding soil are obtained. The change of soil gravity stress caused by precipitation during construction leads to excessive deformation and stress concentration. And the establishment of internal support has played a good deformation control phenomenon.

Keywords. Steel sheet pile cofferdam, Numerical simulation, deformation analysis, soft soil engineering

1. Introduction

The section from Xintang to Hongmei in the intercity of Suiguan-Shenzhen-Shenzhen. The construction of the main span (75+125+125+75)m continuous beam of the large bridge in the north main stream of the Dongjiang River is very difficult [1]. Once-in-a-century design flow Q=3456m^3/s, corresponding to the design water level of 3.09m, and the design flow rate v=0.93m/s. 5-year high water level +3.29m, 5-year low water level -0.36m; The construction water level adopts the 20-year design tidal flood level +3.36m, and the 20-year flood flow velocity v=1.5m/s. The bridge site area belongs to the hilly valley and valley terrace landform [2]. The water depth is 10~20m, and the

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soil layer in the bridge site area is mainly distributed as plain filled soil, pebbles, fragments of strong wind fossil quartz schist [3], stroke fossil quartz schist . The finite element is shown in figure 1.

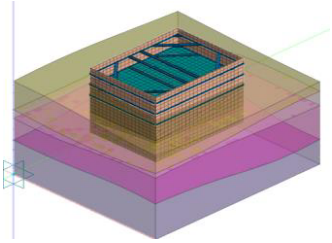

Figure 1. Schematic diagram of a numerical model.

2. Steel Sheet Pile Construction Introduction

2.1. Difficulty in Construction

Table 1. Rectangular tower external shape factor.

Item	Advantage	Shortcoming
Steel sheet pile cofferdam	Simple construction, recyclable; Construction does not require ship machinery equipment; Steel sheet pile can be leased, the resources are rich;	The structural force is complicated and the internal support force is large. It is difficult to drive into highly weathered strata, so pilot holes are needed.
locking steel pipe pile cofferdam	Simple construction, recyclable; Construction does not require ship machinery equipment; Filling sand inside the steel pipe can increase the bending strength; The ability of penetrating hard soil layer is strong	The structural force is complicated and the internal support force is large. The lock of pipe pile needs processing, and the welding quality is high. It is difficult to drive into highly weathered strata, so pilot holes are needed. It is difficult to seal water below the mud surface
double-wall steel cofferdam	The double wall stiffness is large, and the construction safety is high. Good water sealing performance;	Construction is more complicated, cofferdam can not be recovered; Construction requires a large number of ship machinery and equipment; It also requires a pilot hole or blasting down;

The submerged caps are all low pile caps, among which the 76# pier cofferdam needs to be buried about 10m, and the buried soil layer is weathering layer, so the construction is difficult. During the construction of cap, the difference of water head between inside and outside is relatively large, the maximum difference of water head is 17.8m, which is very unfavorable to the force of cofferdam [4]. If double-wall steel cofferdam is used for construction, the processing of cofferdam is difficult, the construction requires a large number of ship machinery and equipment, and requires blasting excavation, which has great influence on the channel and surrounding area. The ship transportation in the waterway is busy, which interferes greatly with the construction [5]. In view of the above difficulties, it is necessary to adopt a construction method of cap cofferdam which is fast, safe and controllable and relatively low cost [6]. According to the construction experience of low pile cap in China, the following methods can be adopted: 1.Steel sheet pile cofferdam [7]. 2, locking steel

pipe pile cofferdam [8]; 3, double-wall steel cofferdam. Comparison of cofferdam technology are shown in table 1.

Steel sheet pile cofferdam: long spiral pilot hole (10d) -- > Overall installation and lowering of internal support (10d) -- > Steel sheet pile lowering (10d) -- > platform removal (5d), a total of 35d.

Locking steel pipe cofferdam: percussion drilling or rotary drilling pilot hole (20d) -- > overall installation and lowering of internal support (10d) -- > Steel pipe lowering (10d) -- > platform removal (5d), a total of 45d.

Double-wall cofferdam: rotary drilling or blasting lead hole (20d) -- > Platform removal (5d) -- > protection cylinder removal (5d) -- > Cofferdam floating positioning and sinking (30d) -- > A total of 60d.

2.2. Field Test Situation

Geological description of strongly weathered pebbly sandstone: gray-black, joint fissure development [9], rocks and minerals have been partially weathered and altered, the original rock structure is clear, the core is fragmented or cake, the rock is soft, the rock can be broken by hand [10], the largest node up to 20cm (figure 2). The recommended basic bearing capacity is 300KPa.

The figure 3 shows that the weathered sandstone is easily softened by water and has no strength after being softened [11]. However, the strength of strongly weathered sandstone after soaking in water has no effect, but the strength increases from the touch sense.

Figure 2. Weathered mudstone with sandstone.

Figure 3. Silty clay.

The geological data provided by the design is basically consistent with the reality, but it fails to reflect the silty clay layer, and it is difficult to excavate the silty clay layer underwater. The heavily weathered sandstone is hard and it is difficult to drive the steel sheet pile directly, but the mechanical pilot hole method is feasible [12]. The permeability of sand layer and all weathering layer is poor, and dry excavation of cofferdam is feasible. Fully weathered sandstone is easy to soften when exposed to water, so it is necessary to strengthen drainage and reduce soaking time during dry digging [13].

3. Steel Sheet Pile Cofferdam Construction Process

3.1. Calculation Condition Introduction

The calculation of steel sheet pile cofferdam takes 76# pier as an example, and the main calculation conditions are as figure 4:

Working condition 1: After the lowering of the support in the 1-4 layers and dug to the support in the 5th. Working condition 2: After the installation of the support in the 5th, the foundation pit is excavated to the support in the 6th. Working condition 3: the foundation pit is excavated to the bottom of the cap. Working condition 4: the inner support of the sixth layer is removed. Working condition 5: After the concrete pouring completed, the internal support of the fifth layer is removed.

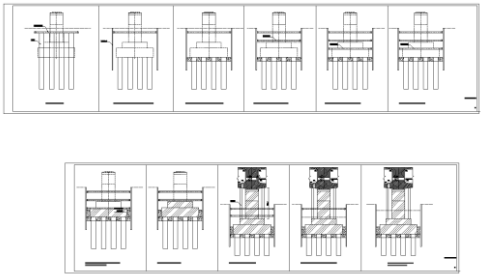

Figure 4. X direction tower body stress diagram.

Figure 5. Steel sheet pile welding.

Figure 6. Steel sheet pile sinking.

The steel sheet pile shall be welded with the same type of steel sheet pile and other strength. When welding (figure 5), first weld or repair the joint of the interface, and then weld the reinforced plate.

Steel sheet pile using floating crane or construction on the platform steel sheet pile construction will use some equipment, the main equipment is: vibration pile hammer (figure 6), crawler crane or floating crane. If the steel sheet pile is inserted in the water, it is generally inseparable from the transport ship and the water construction platform.

3.2. Result of Finite Element Calculation

The finite element software Midas GTS NX was used to establish a three-dimensional overall model for spatial analysis of the steel sheet pile structure. The interaction between soil layers and them and the difference of internal and external water pressure were considered as loads [14].

In general, in order to verify the safety of the enclosure structure itself, the internal force and stress of the enclosure structure will be looked at. In this model, the stress of the ground wall and the inner support will be looked at. The internal forces of the envelope and support structure under MCC architecture are shown in the figures 7-14 below:

When the height of the tension zone of the elastic stress figure is greater than 2/3 of the height of the transverse plane of the structure, the cross-sectional area of the

tension steel bar should be calculated according to the full area of the square projection figure of the elastic principal tension force [15].

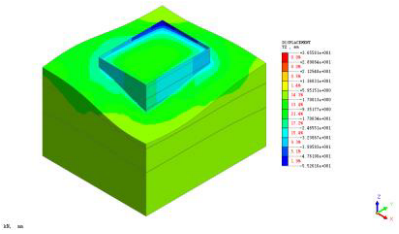

Figure 7. Displacement of Z direction.

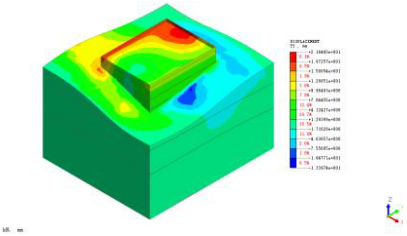

Figure 8. Displacement of Y direction.

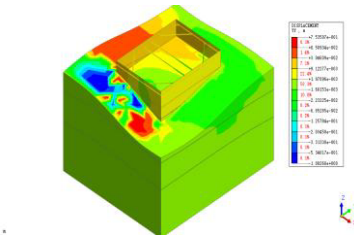

Figure 9. Displacement of Y direction-step4.

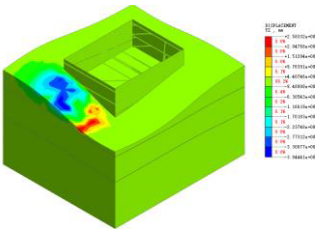

Figure 10. Displacement of Z direction-step4.

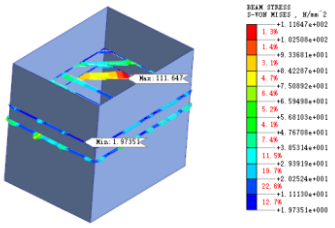

Figure 11. Internal support von Mises force-step2.

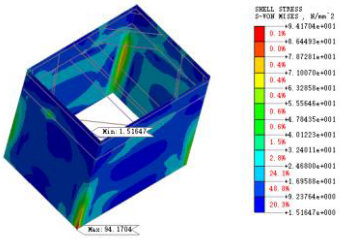

Figure 12. Steel sheet pile von Mises force-step2.

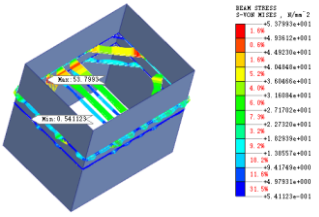

Figure 13. Internal support von Mises force-step4.

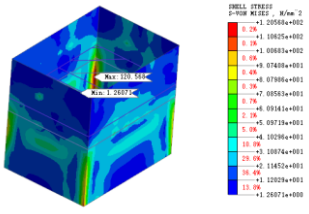

Figure 14. Steel sheet pile von Mises force-step4.

4. Conclusions and Recommendations

In this paper, the computer constitutive parameterization algorithm is used to calculate and analyze the engineering example, and the differential constitutive model is adopted for geological strata, considering the role of multi-layer support and the simulation of

step excavation, the deformation of the whole foundation pit project can be quantitatively analyzed, and the constitutive sensitivity of the deformation of the supporting structure can be analyzed. The results are as follows:

1) Suggestions for rebound calculation

During the excavation of foundation pit, the maximum rebound of MMC, MC and MCC was analyzed respectively. MC can not distinguish the modulus of unloading and loading, so its displacement trend is poor, while MMC and MCC have a good settling trend. However, it is difficult to select the parameters of MCC. The parameter selection of MCC can directly refer to the compression modulus and shear test value, so MCC is the most suitable for simulating foundation pit in terms of settlement trend.

2) Horizontal displacement calculation suggestions

From the perspective of horizontal displacement of surrounding rock, the maximum horizontal displacement of MC, MCC and MMC all appear in the center of surrounding rock, and their values are 34.63mm, 19.03mm and 10.04mm, respectively. From the perspective of trend, the displacement trend of MC and MMC is better, and the displacement of MCC in the roof position is larger. On the one hand, the excavation of narrow foundation pit will produce surface uplift (which can be confirmed by some observations); On the other hand, the horizontal displacement trend of the enclosing wall of MC constitutive system is reasonable. Therefore, without considering the settlement around the foundation pit or the absence of structures around the foundation pit, MC constitutive system or MCC can be used to simulate the excavation of the foundation pit. The time and convergence of MC constitutive calculation are better than MMC.

3) Comprehensive calculation scheme

From the internal force of the envelope structure and the support structure, if we pay attention to the axial force and bending moment of the internal support, we can choose the calculation results under the MC constitutive method; If we are concerned about the internal force of the floor wall, we can choose the MMC constitutive method for simulation. From the above numerical simulation results, it can be seen that both MMC model and MCC model can effectively simulate foundation pit engineering, and the coupling of the numerical results is good, and can simultaneously give more reasonable deformation of supporting structure, soil deformation and surrounding environment deformation, which can meet the requirements of three-dimensional finite element numerical simulation of engineering cases. However, from the point of view of convenience, safety, economy and practicability, MMC model has certain advantages over MCC model: wide range of applicable strata and convenient provision of required parameters (empirical formulas can be derived from geotechnical parameters).

Acknowledgments

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