



Numerical Simulation of Bored Piles Treatment Scheme for Foundation of Large Drainage Pump Station on Soft Ground

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Abstract. The settlement and deformation caused by structural self-weight during the construction of pump station located on soft ground along the rivers is a key consideration in water transportation engineering. This study focuses on a newly built large-scale flood control and drainage pump station along the Yangtze River. Basic physical and mechanical property tests are conducted on representative soil layers at different depths through on-site sampling. Large-scale finite element software is used to build a 3D model of the pump station to simulate the structural force, settlement and deformation of the pump station treated with bored piles of varying lengths. The finite element calculation results showed that the bored pile foundation improvement scheme can effectively control the settlement deformation and the maximum uneven deformation between structural joints. The maximum Mises stress values are less than 10 MPa at typical locations, such as pump house section along the end of the water flow direction, track beams, gate piers, base plates, diversion piers, and other structures. The study indicates that bored pile foundation treatment on waterfront sedimentary soft ground could effectively control settlement, deformation, and structural stress concentration.

Keywords: soft ground; bored piles; numerical simulation

1 Introduction

With the development of water transportation and water conservancy projects in China, embankment and lock station projects increasingly face the challenge of waterfront silty foundations. Silty soil under external loading tends to settle and deform over time, different foundation improvement methods are widely used in soft ground treatment in long-term engineering practice [1]. Wu (1997) proposed applying the grouting method

to pile foundations as an innovation to the traditional pile foundation construction process^[2]. Ai (2001) presented an extended Mindlin solution through computer program calculations, demonstrating that analyzed results closely matched the measurements^[3]. Zeng (2003) discussed several common methods to determine the bearing capacity of single piles from the testing curves^[4]. Pu (2008) studied the load transfer mechanism and bearing behavior in bored piles in place^[5]. Zhang (2012) analyzed load transmission behavior in large-diameter-, super-long bored piles^[6]. Wan (2018) investigated the effects of combined grouting in side piles and pile tips in extra-thick silty fine sand layers for the Shishou Yangtze River Highway Bridge engineering project^[7]. The bearing behavior and load transfer mechanism of the piles are analyzed with super-long bored piles in Nanjing Hexi field^[8].

The results of national and international studies indicate that using bored piles for settlement control in soft ground is a prominent research topic. Settlement deformation is closely related to the structure type and soil layer characteristics, especially for the control of deformation of large structures on soft soil layers deposited along the river needs further in-depth. In this study, an overall model of the pump structure is developed to clarify the settlement, deformation, and stress concentration characteristics of a new large-scale flood control and drainage pump station along the Yangtze River. The research results provide a technical reference for similar soft ground engineering construction using bored pile foundation treatment scheme.

2 Calculation Parameters and Finite Element Model

Typical soil samples are collected at different depths of the engineering site through boreholes, and triaxial shear tests are conducted to investigate the stress and strain characteristics. The calculation parameters of the soil model are subsequently obtained.

The pile body is made of concrete and a linear elastic model conforming to the following generalized Hooke's law is used in the simulation. The soil-structure interaction is mainly the contact between the pile surface and the soil body, so hard contact is used in the normal contact, and the tangential direction is the penalty function contact surface modeling. All calculation parameters have been calibrated before adoption. The 3D finite element model of the pump house and outlet flood gate is shown in the Figures 1 and Figure 2 below.

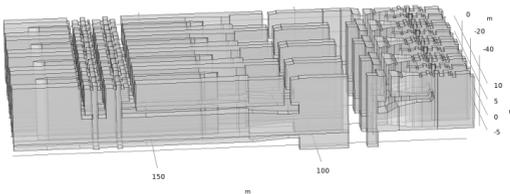


Fig. 1. Finite element model of pump house.

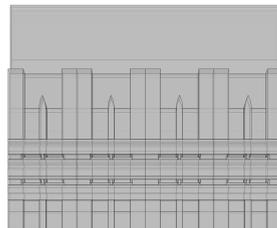


Fig. 2. Pump station forebay model.

3 Finite Element Simulation Results of Deformation Characteristics

3.1 Initial In-Situ Stress Analysis

The initial vertical and horizontal in-situ stress distributions are shown in Figure 3 and Figure 4, respectively. The horizontal earth pressure coefficient is 0.67, and the numerical results indicate that the maximum vertical stress is 1.29 MPa and the maximum horizontal stress is 0.53 MPa. The calculated results align well with the actual stress conditions.

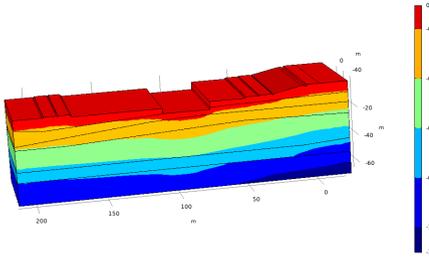


Fig. 3. Vertical in-situ stress (MPa).

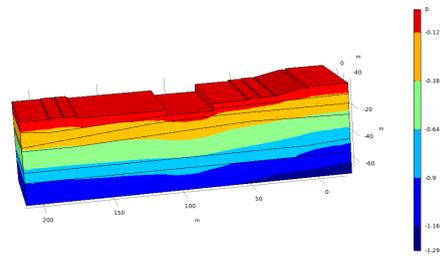


Fig. 4. Horizontal in-situ stress (MPa).

3.2 Deformation of Foundation Soil After Bored Pile Construction

The results of foundation settlement and deformation after treatment using bored piles of 35m, 40m, 45m lengths, and bored pile driven into the lower gravel layer, are shown in Figure 5 to Figure 8. The simulation results reveal that the overall settlement and deformation of the foundation are minimal, with maximum settlements close to 100 mm, 60 mm, 40 mm, and 1 mm, respectively.

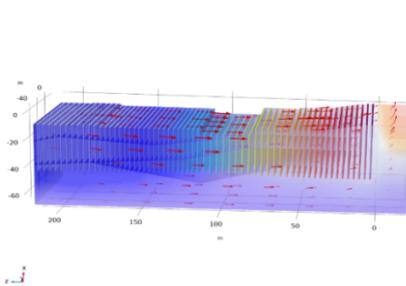


Fig. 5. Bored pile length 35 m.

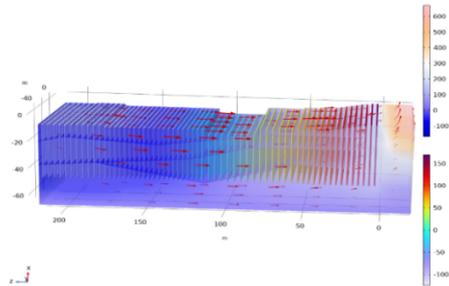


Fig. 6. Bored pile length 40m.

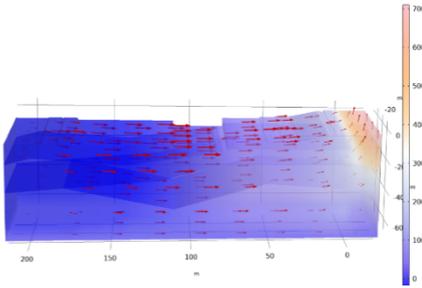


Fig. 7. Bored pile length 45 m.

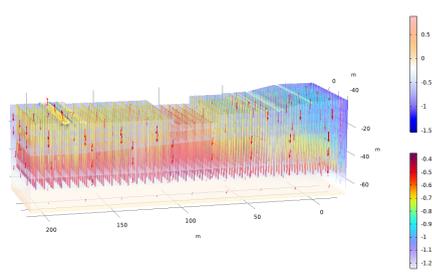


Fig. 8. Bored pile driven into gravel layer.

These simulations demonstrate that increasing the pile length effectively reduces the settlement deformation and the uneven settlement at the bottom of the pump station. Moreover, settlement can be reduced to nearly 1 mm when piles are driven into the lower gravel layer.

3.3 Pump Station Settlement after Applying the Concrete and Metal Structure Loads

Calculation results of the overall settlement distribution of the pump station after upper concrete structures are constructed and other major metal structures are installed under different pile length conditions are shown in Figure 9 to Figure 12 below.

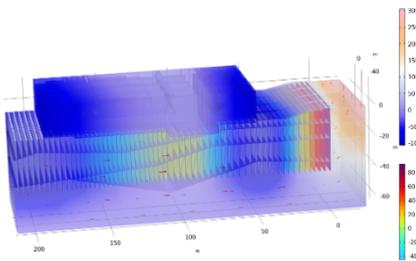


Fig. 9. Bored pile length 35 m (mm).

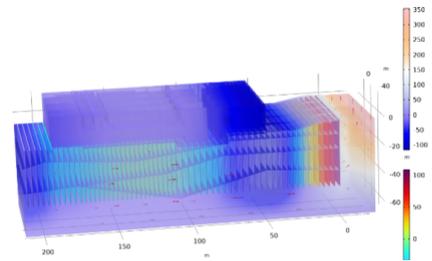


Fig. 10. Bored pile length 40 m (mm).

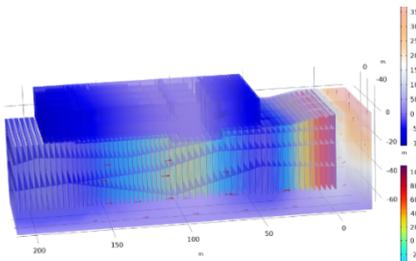


Fig. 11. Bored pile length 45 m (mm).

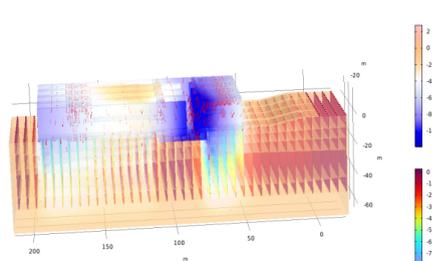


Fig. 12. Bored pile to gravel layer (mm).

Finite element calculation results show that the overall settlement and deformation are minimal after applying the concrete and metal structure loads to the foundation after the construction of bored piles, with the maximum settlements in the bored pile reinforced area close to 100 mm, 90 mm, 80 mm, and 10 mm.

It can be seen that the settlement deformation decreases by 20mm after the pile length is increased from 35m to 45m, and the settlement deformation decreases by about 90mm when the pile enters the lower holding layer. It can also be seen that the enhancement of end bearing in soft soil layer is the key factor to control the settlement deformation of the structure.

3.4 Deformation of Pump Station Bottom Plate

In the foundation strengthening scheme when using bored piles of 35 m, 40 m, and 45 m lengths, which did not reach the lower bearing layer, the settlement and deformation of the concrete body of the station and the metal structures installed did not meet the design requirements.

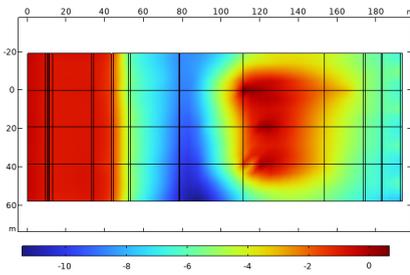


Fig. 13. Settlement and deformation distribution of base plate (mm).

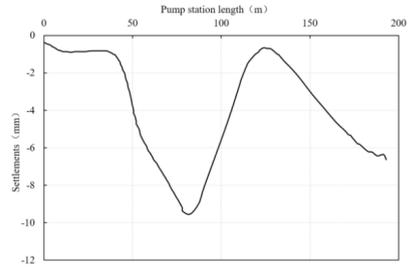


Fig. 14. Settlement curve along the length of the pump station (mm).

The calculation results of bottom plate deformation while the piles are driven into the lower gravel layer are given in Figure 13 and Figure 14. The settlement deformation of the bottom plate is basically consistent with the foundation deformation, exhibiting settlement at the inlet and outlet and buckling in the middle. The maximum uneven settlement between structural joints is approximately 10 mm.

4 Finite Element Simulation Results of Stress Analysis

4.1 Side Wall Stress Analysis

Figure 15 shows the Mises stress distribution simulation results in different sections of the pump station side wall along the water flow direction after construction. The stress is relatively uniform along the inlet pool before the pool section, pump house section, outlet culvert, and flood gate section. Stress concentration occurs in the pump house section along the end of the water flow direction, with a maximum stress of about 2 MPa.

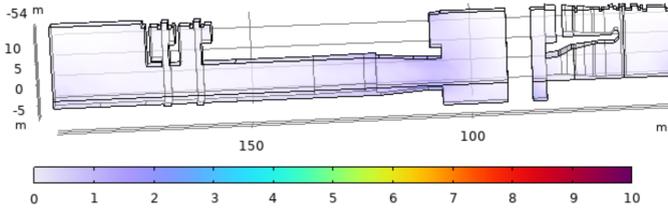


Fig. 15. Stress distribution of pump station side wall (MPa).

4.2 Track Girder Stress Analysis

Figure 16 provides the finite element calculation results of the Mises stress distribution of the track beams in the section before the pump house after construction. The track beam stress is relatively uniform, with a maximum Mises stress of about 2 MPa.

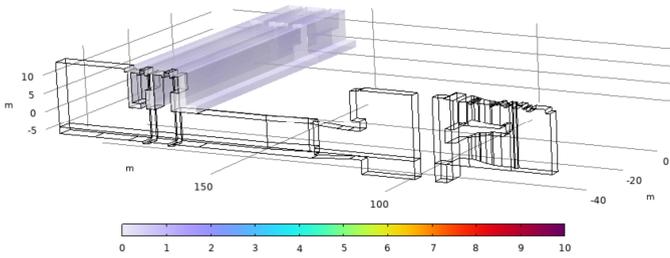


Fig. 16. Stress distribution in track girder structure.

Figure 16 also shows the finite element calculation results of the Mises stress distribution of the crane gate piers and breast wall of the pump house section after construction. The gate piers experience relatively large stress, while the breast wall smaller stress. The maximum Mises stress of the gate piers is about 2 MPa, and that of the breast wall of the floodgate is about 1 MPa.

4.3 Structural Force Analysis of the Pump Station Base Plate

Figure 17 shows the finite element calculation results of the Mises stress distribution in the bottom plate of different pump station sections after construction.

The floor plate stress concentration occurs primarily in the middle of the upstream side, with other locations showing minimal stress concentration.

Further analysis with the pump station structure setup indicates that the stress of the bottom plate concentrations in the lower part of the front end of the pump house section, where machinery and equipment are installed. Due to the greater self-weight of the equipment, stress concentration is more pronounced herewith a maximum Mises stress of about 10 MPa.

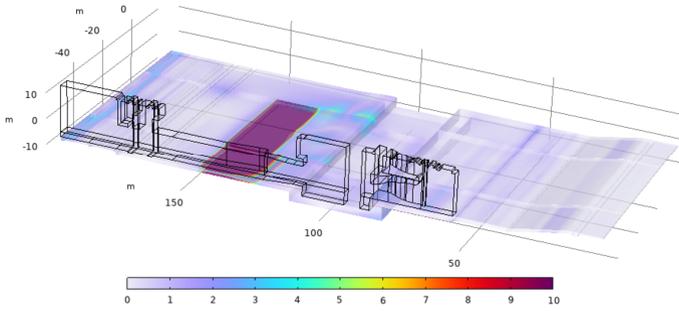


Fig. 17. Stress distribution of the pump station base plate.

4.4 Stress Distribution on the Roof of the Inlet Channel of the Pump Station

Figure 18 shows the finite element calculation results of the Mises stress distribution on the roof of the inlet channel of the pump station after construction. The concrete structure experiences concentrated forces at this location, with a maximum Mises stress of about 10 MPa.

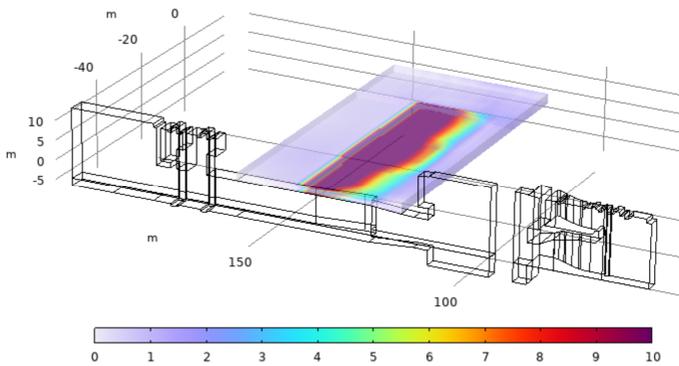


Fig. 18. Stress distribution on the roof of the inlet channel of the pump station.

5 Conclusion

This study focuses on a newly built large-scale flood control and drainage pump station along the Large-scale finite element software is used to build a 3D model of the pump station to simulate the structural force, settlement and deformation of the pump station treated with bored piles of varying lengths. The conclusions are as follows:

(1) The bored pile foundation improvement scheme can effectively control the settlement deformation and the maximum uneven deformation between structural joints.

(2) Finite element calculation results show that the overall settlement and deformation are minimal after applying the concrete and metal structure loads to the foundation after the construction of bored piles, with the maximum settlements in the bored

pile reinforced area close to 100 mm, 90 mm, 80 mm, and 10 mm. These results illustrate that the gravel layer at the bottom of the pile effectively reduces overall settlement deformation of the pump station.

(3) The maximum Mises stress values are less than 10 MPa at typical locations, such as pump house section along the end of the water flow direction, track beams, gate piers, base plates, diversion piers, and other structures.

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