Design of the dewatering project of pit with pensile curtains in the floodplain area near Yangtze River

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Abstract. The sand layer of the floodplain area near Yangtze River is thick and rich in water content. It is difficult to cut off the groundwater hydraulic connection inside and outside the pit with anti-water curtain. Hence, it is necessary to determine the depth of the pensile curtains rationally and economically. The three-dimensional motion model of groundwater can effectively simulate the dewatering and provide a basis for the selection of the depth of the pensile curtains. Reasonable dewatering-recharge arrangement is cost-saving and time-saving. Its good economic and social benefits demonstrate the feasibility in follow-up construction.

1. Introduction

The control of groundwater has become one of the key issues in the design and construction of underground projects globally. Once improperly disposed, it may easily lead to groundwater surge and cause huge loss of property and personnel.

In the floodplain area near Yangtze River, due to the existence of thick sand layer with high permeability, it is difficult to cut off the groundwater and hydraulic power inside and outside the pit. In this condition, the foundation pit has a large amount of water and rapid groundwater recharge, and the groundwater control is extraordinary difficult. Therefore, controlling the influence of foundation pit dewatering on the surrounding environment effectively has become an important topic in the process of constructing the underground project near Yangtze.

For the pensile curtain, under the premise of satisfying the structural check such as anti-overturning and anti-bumping requirement, the designed depth mainly considers the influence of dewatering of foundation pit on the surrounding environment. Therefore, if the dewatering-recharge design can effectively control the subsidence around the foundation pit, the depth of pensile curtains can be reasonably adjusted in order to save the project cost and bring good economic and social benefits.

2. Overview of project

Nanjing Heyan-road-crossing-river-passage is located between Nanjing Yangtze River Bridge and the Second Nanjing Yangtze River Bridge. The geological conditions are complex, mainly including fine sand layer, full-section hard rock, soft and hard uneven formation and long-distance karst area. The starting point of the passage (South Section) is at the intersection of Heyan Road and Yanheng Road, and the end point is located at Puyi Baguazhou Interchange. The excavation depth of the foundation pit for the exit of Tunnel Boring Machine is shown in Table 1.
The foundation pit is only 500m away from the Yangtze River. The phreatic layer is a silty soil layer with a thickness of 5-20m. Its permeability and water-richness are poor. The shallow micro-confined aquifer is silt and fine sand layer, and the deep micro-confined aquifer is coarse sand and gravel layer with high permeability and abundant water. The thickness of micro-confined aquifer is extremely large, so it is hard for the curtain to cut off the hydraulic connection between the inside and outside of the pit. The schema is shown in Fig. 1. It is necessary to calculate the appropriate depth of the curtain to meet the needs of the project construction and to reduce the cost reasonably.

![Figure 1: Schema of tensile curtain (1.pumping wells; 2.curtain)](image)

### Table 1 Details of Pit

| Part No. | Mileage (m)       | Length (m) | Depth of pit (m) |
|----------|-------------------|------------|------------------|
| NMW12    | ZK4+691 ~ ZK4+712 | 21         | 25.7             |
| NMW11    | ZK4+715.5 ~ ZK4+760 | 48        | 19.894 ~ 22.136  |
| NMW10    | ZK4+760 ~ ZK4+804  | 44         | 14.099 ~ 15.84   |

3. Three-dimensional groundwater motion model

The pumping wells of this project should be arranged inside the pit and the bottom depth of the filter of the pumping wells should be close to or above the bottom depth of the curtain. At this time, the seepage type of the pit is a three-dimensional flow, and a three-dimensional seepage model needs to be established by a numerical method (finite element method or finite difference method).

According to the basic assumptions of groundwater dynamics, the following mathematical models of three-dimensional groundwater unsteady flow are established:

\[
\begin{align*}
\frac{\partial}{\partial x} \left( k_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( k_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( k_z \frac{\partial h}{\partial z} \right) - W &= \frac{E}{T} \frac{\partial h}{\partial t} \quad \text{in} \quad \Omega \\
h(x, y, z, t)|_{x=a} &= h_0(x, y, z) \quad \text{on} \quad \Gamma_1 \\
h(x, y, z, t)|_{z=h_1} &= h_0(x, y, z) \quad \text{on} \quad \Gamma_2
\end{align*}
\]  

(Eq.1)

Here: \( E = S_y \), \( T = kB \)

- \( S_y \) stands for specific yield; \( B \) stands for the thickness of aquifer (m);
- \( k_{xx}, k_{yy}, k_{zz} \) stands for the permeability in different directions (m/d);
- \( h \) stands for the water level at the point \((x, y, z)\) at time \( t \) (m);
- \( W \) stands for source and sink terms; \( h_0 \) stands for the water level at the start (m);
- \( h_1 \) stands for the water level at the boundary of first type (m);
- \( t \) stands for time (d); \( \Omega \) stands for the computational domain;
- \( \Gamma_1 \) stands for the boundary of first type.

After the whole seepage area is discretized in the computational domain, the above mathematical model is discretized by the finite difference method, and the numerical model can be obtained to...
calculate and predict the spatial and temporal distribution of groundwater level caused by dewatering. In this project, three-dimensional groundwater simulation software Modflow is used to calculate the groundwater flow.

4. Comparison of Three Designed Cases

Because there are protected building near the pit, it is necessary to control the water level and the subsidence outside the pit in conditions of satisfying the dewatering in the pit. In this paper, the three designed cases are calculated and compared, and the most economical and reasonable penitile curtain and dewatering scheme are selected.

Case 1: The depth of the ground wall in the NMW 12 area is 49m, the depth of the ground wall in the NMW 11 area is 43.5m, and the depth of the ground wall in the NMW 10 area is 31m. At this time, the water level in the pit should be dewatered to 1m below the excavation surface.

The number and depth of wells calculated from the three-dimensional groundwater movement are shown in Tab.2.

| Part No. | Depth of curtain(m) | Number of pumping wells | Depth of pumping well(m) | Number of recharge wells | Depth of recharge well(m) |
|----------|---------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| NMW12    | 49                  | 8                       | 43                      | 10                      | 25                      |
| NMW11    | 43.5                | 12                      | 38                      | 15                      | 25                      |
| NMW10    | 31                  | 8                       | 25                      | 11                      | 25                      |

Case 2: The depth of the ground wall in the NMW 12 area is 54m, the depth of the ground wall in the NMW 11 area is 48m, and the depth of the ground wall in the NMW 10 area is 36m. At this time, the water level in the pit should be dewatered to 1m below the excavation surface.

The number and depth of wells calculated from the three-dimensional groundwater movement are shown in Tab.3.

| Part No. | Depth of curtain(m) | Number of pumping wells | Depth of pumping well(m) | Number of recharge wells | Depth of recharge well(m) |
|----------|---------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| NMW12    | 54                  | 6                       | 43                      | 8                       | 25                      |
| NMW11    | 48                  | 10                      | 38                      | 11                      | 25                      |
| NMW10    | 36                  | 8                       | 25                      | 9                       | 25                      |

Case 3: The depth of the ground wall in the NMW 12 area is 49m, the depth of the ground wall in the NMW 11 area is 43.5m, and the depth of the ground wall in the NMW 10 area is 31m. The bottom of the foundation pit is reinforced downward by 6m (the permeability coefficient of the reinforced soil is 0.1m/d and the gravity is 20kN/m³). At this time, the water level in the pit only needs to meet the anti-surge stability calculation. In this case, the safe water level in different part is shown in Tab.4.

| Part No. | Initial water level(m) | Depth of impervious layer(m) | Critical Depth(m) | Excavation Depth(m) | Safety Factor | Safe water level(m) |
|----------|-------------------------|-----------------------------|------------------|---------------------|--------------|---------------------|
| NMW12    | -1.8                    | 31.7                        | 16.0             | 25.7                | 0.40         | -20.2               |
| NMW11    | -1.8                    | 28.1                        | 14.3             | 22.1                | 0.46         | -16.7               |
| NMW10    | -1.8                    | 21.8                        | 11.3             | 15.8                | 0.60         | -10.4               |

The number and depth of wells calculated from the three-dimensional groundwater movement are shown in Tab.5.

| Part No. | Depth of curtain(m) | Number of pumping wells | Depth of pumping well(m) | Number of recharge wells | Depth of recharge well(m) |
|----------|---------------------|-------------------------|-------------------------|-------------------------|-------------------------|

Table 2. Well parameters in case 1

Table 3. Well parameters in case 2

Table 4. Safe water level in different part

Table 5. Well parameters in case 3
The deepened grounding wall is made of plain concrete, and the unit price is about 1500 yuan/m$^3$. The reinforcement zone is reinforced with three-axis agitation, the cement content is 15%, and the unit price is about 300 yuan/m$^3$. The unit price of the pumping well is about 1,440 yuan/m, and the unit price of the recharged well is about 1,620 yuan/m.

Comparison of construction cost and construction period of three designed cases is shown in Tab.6.

| Part No. | Cost of curtain (X) | Cost of pumping wells (1440000) | Cost of recharge wells (1458000) | Cost of reinforcement (0) | Total cost (X+2898000) | Total construction period (Y) |
|----------|---------------------|-------------------------------|---------------------------------|--------------------------|------------------------|-----------------------------|
| NMW12    |                     |                               |                                 |                          |                        |                             |
| NMW11    | X+2040000           | 1206720                       | 1134000                         | 0                        | X+4380720              | Y +23                       |
| NMW10    | X                   | 1134720                       | 526500                          | 3200000                  | X+4861220              | Y +17                       |

5. Conclusions
The application of groundwater three-dimensional motion model can effectively calculate the number and location of wells required to ensure the construction of pit and the environment outside the pit. Under the condition of pensile curtain, the influence of the foundation pit on the surrounding environment can be controlled, and the subsidence caused by the pit dewatering is small. Compared with the longer pensile curtain, the shorter curtain has obvious advantages in quality assurance, for example, its verticality is easy to ensure; its groove formation and construction time are short; the adverse effects of long-term exposure of the groove wall on the surrounding environment are reduced.

According to the comparison of the three possible cases, reasonable dewatering-recharging design can effectively save the cost and construction period. Finally the first case was chosen and the project was finished successfully. Due to its good economic and social benefits, it has good application and promotion value in the follow-up project construction.

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