Optimization method and application research of dewatering design for complicated foundation pits

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Abstract: The groundwater control system of complex deep foundation pit engineering is designed based on experience and analysis of items such as dewatering, anti-inrushing, water-recharging, etc. Three-dimensional numerical simulation methods are used to optimize the design. By repeatedly adjusting the design items and simulating the working system, a safer, more reasonable and economical design scheme can be confirmed by comparing the analysed results.

Introduction

Super high-rise building projects often entail the large-scale deep and complicated foundation pit. Dewatering is widely used to reduce the piezometric levels around foundation pits while these pits excavating; if improperly handled, however, it can easily cause land subsidence, geological disasters, and major security incidents.

Design and optimization of dewatering to these complicated foundation pits are difficult and complicated. The three-dimensional numerical simulation method is believed to be the basic theory of optimization design of engineering structures of dewatering in deep foundation pit.

1. The site Project introduced

1.1 Engineering background

The site is located near Jinji Lake in Suzhou City of Jiangsu Province, China. The area of the site is 25,000 m². The buildings on the site are a super high-rise tower which is planned to be 700+ m high, a 8-storey commercial annex, and a large area 5-storey basement (Area I) and a two-floor basement (Area II). The site and its surroundings are presented in Fig. 1.

1.2 Geological conditions

The foundation mainly consists of saturated clayey soil, silty soil, and sandy soil, with layers ⑧, ⑩, and ⑫ divided into several sub layers. The strata distributions are listed in Table 1.

1.3 Hydrogeological condition

As show in the Fig.2, the groundwater basin of the site is composed of several aquifers separated from each other by multi-aquitards. The confined water in ⑨ and ⑪ should be taken into considered while the pit is excavated.

Fig.1. Site information and environment.

Table 1. The distribution of soil layers.

Strata serial	Name of soil layer	Layer thickness (m)	Elevation of layer top (m)	Elevation of layer bottom (m)	Permeability coefficient by indoor test (cm/s)
① ₁	impurity fill	0.7~8.2	0.6~-0.7	2.15~-5.10	
④	silty clay	1.1~6.1	2.15~-4.22	-2.09~-5.52	1.0E-6
⑤	sandy silt	2.6~12.4	-2.09~-5.52	-6.49~-16.86	8E-04
⑥	silty clay	4.1~22.4	-6.49~-16.86	-17.60~-31.20	5E-05
⑧ ₁	silty clay	1.1~5.3	-17.6~-21.04	-20.96~-24.42	1E-06
⑧ ₂	Sandy clay and silt	1.2~11.6	-20.96~-30.03	-28.82~-33.69	3E-05
⑨	silt	5.2~16.4	-28.75~-33.69	-35.96~-46.45	2E-03
⑩ ₁	silty clay	4.2~23.6	-35.96~-46.45	-49.72~-61.87	3E-06
⑩ _t	Silty sand	1.5~5.7	-49.72~-57.83	-53.83~-60.44	1E-03
⑩ ₂	silty clay	1.2~14.0	-51.05~-60.44	-56.69~-71.38	5E-06
⑪	Silt and silty clay	1.1~15.6	-55.42~-68.05	-66.88~-72.36	3E-04
⑫ ₁	clay	6.7~13.0	-66.88~-72.36	-78.03~-81.83	3E-06
⑫ ₂	silty clay	4.4~10.7	-78.03~-81.83	-85.26~-89.57	
⑬	Silty sand	0.9~10.8	-85.26~-89.57	-97.53~-101.44

Fig.2 Site typical soil profile and properties

2 Introduction of pit engineering

2.1 Foundation pit partitions

Fig. 3 and Fig.4 present the foundation pit partitions. Area I is the foundation area whose basement are five floors. The basement of Area II is two floors.

The whole area of the foundation pit is about 26260 m², the foundation pit of Area I is 23430 m², and the area of Area II is 2830 m². The circumference of the foundation pit are 695 m (length).

2.2 Pit enclosure design

Fig.3 shows the layout plan of the foundation pit enclosure design. The diaphragm wall of Area II can cut off the groundwater flow of layer ⑤. The diaphragm wall of Area I is about 63 m deep, which can cut off the groundwater flow of layer ⑨. The high-pressure jet grouting piles inside the diaphragm wall are designed to block the groundwater leaking from outside through the gap of the wall.

Fig. 3. Foundation pit enclosure design layout plan.

Fig.4. Avenger Excavation depth of partitions (max depth: Tower 36m, Annex 32m, Area II 14m).

2.3 Construction methods of foundation pits

According to the construction arrangement, Area I will be dug first and then its underground-structure will be built, with the construction of Area II postponed.

The excavation depth of the foundation pits is presented in Fig. 4.

3 Initial design scheme of groundwater control system

3.1 Dewatering design schemes

3.1.1 The dewatering design of Area II

The pit depth of Area II is about 13.1 m (Fig. 3). The groundwater level while digging should be controlled 1 m below the working plane, so the numbers of the dewatering wells are 11, which is one well per 250 m² according to the experiments and the calculated results.

3.1.2 The dewatering design of Area I

There are five floors in the basement of Area I, and their pit depth is about 27 m~36 m. because of the diaphragm wall cutting off the water movement of layers ⑤ and ⑨ mainly, supplement to the groundwater of layers ⑤ and ⑨ is limited.

According to the experiments, the numbers of the dewatering wells are 93, and the depth of the wells are designed to be different for the tower area and the podiums area.

The dewatering initial design schemes for both Area I and Area II is presented in Fig. 5.

Fig.5. The design schemes of dewatering wells.

3.2 Design for anti-inrush

The groundwater in layer ⑪ has high pressure and the diaphragm wall is not deep enough to block the water

movement. Formula 1 can be used to judge if the water-inrush will happen.

$$\frac{\gamma_m(t + \Delta t)}{P_w} \geq 1.1 \quad (1)$$

Where:

γ_m is the saturated unit weight of the soil above permeable stratum(kN/m³).

$t + \Delta t$ is the depth between the top of permeable stratum to the bottom of the foundation pit(m).

P_w is the aquifer pressure(kPa).

Table 2 shows the results whether the in-rush will be possibly happened while being in the process of foundation pit construction.

Table 2. The judgment of in-rush to confined groundwater in layer⑪.

pit Partition	Max Excavation depth(m)	Elevation of confined aquifer top(m)	Groundwater lever table (m)	$\frac{\gamma_m(t + \Delta t)}{P_w}$	True or false
Area I-Tower	36	55.6	11.1	0.88	true
Area I-Annex	32			1.04	true
Area II	30			1.11	false

The de-pressuring initial design schemes for Area I is presented in Fig.6.

Fig.6. The design schemes of De-pressuring wells.

4 Optimal Design of Dewatering

4.1 Introduction of the optimization method

On the basis of the initial design scheme, an optimization procedure should be taken.

Numerical simulation methods are used to analyze how the groundwater control system working, and to judge whether the scheme meet the construction requirements. These adjustment measures usually include the wells' numbers, location, length, diameter, and structure, etc.

By repeatedly adjusting, simulating, and comparing the results, and a safer, more reasonable, and more economical design scheme can be confirmed.

4.2 Numerical simulation of foundation pit dewatering

The commercial software Visual Modflow which is a kind of finite difference method (FDM), is adopted as a numerical tool for this case.

The 3D mathematical model of confined aquifer unsteady flow is as follows:

$$\begin{cases} \frac{\partial}{\partial x} \left(k_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_{zz} \frac{\partial h}{\partial z} \right) - W = \frac{E}{T} \frac{\partial h}{\partial t} \dots\dots\dots (x, y, z) \in \Omega \\ h(x, y, z, t)|_{t=0} = h_0(x, y, z) \dots\dots\dots (x, y, z) \in \Omega \\ h(x, y, z, t)|_{\Gamma_1} = h_1(x, y, z, t) \dots\dots\dots (x, y, z) \in \Gamma_1 \\ \left. k_{xx} \frac{\partial h}{\partial x} + k_{yy} \frac{\partial h}{\partial y} + k_{zz} \frac{\partial h}{\partial z} \right|_{\Gamma_2} = q(x, y, z, t) \dots\dots\dots (x, y, z) \in \Gamma_2 \end{cases} \quad (2)$$

where

$$E = \begin{cases} S & \text{confined aquifer} \\ S_y & \text{unconfined aquifer} \end{cases} \quad (3)$$

$$T = \begin{cases} M & \text{confined aquifer} ; \\ B & \text{unconfined aquifer} \end{cases} \quad (4)$$

$$S_s = \frac{S}{M}; \quad (5)$$

where

S is the storage coefficient; S_y is the specific yield; and M is the thickness of confined aquifer (m).

B is the thickness of unconfined aquifer (m).

k_{xx}, k_{yy} and k_{zz} are the x, y, z main direction osmotic

coefficients (m/d).

h is the hydraulic head value of point (x, y, z) at time $t(m)$.

W is a source and sink term ($1/d$); h_0 is initial hydraulic head of computational domains (m);

h_1 is hydraulic head value of the first boundary (m); S_s is the storage coefficient ($1/m$).

t is time $t(d)$.

Ω is computational domain; Γ_1 is the first boundary, Γ_2 is the second boundary.

n_x, n_y, n_z is unit vector of the outward normal of the boundary in the x, y, z direction.

q is the lateral supply per unit area of $\Gamma_2(m^3/d)$.

The results show that the optimization depressurizing scheme can meet the requirement of pit excavation construction.

5 Economic comparison

The comparison between optimization scheme and initial scheme are presented as table 3:

Table 3. The comparison between optimization scheme and initial scheme.

Area	purpose	Optimizati on scheme		Initial scheme	
		N	D(m)	N	D(m)
Area II	dewatering	5	19	11	19
Area I	dewatering	102	31~48	93	48
	anti-inrush(Area-Tower)	8	73	14	73
Pit outside	recharge(layer⑨)	--	48	13	49
	recharge(layer⑪)	7	73	13	73

N=number, D= depth

The comparison between the initial design scheme and the optimization design scheme are presented in Table 4. This data shows that the economic effect of the optimization is obvious and the dewatering system costs would decrease by about 35% after optimization.

Table 4. The comparison between initial design and the optimization design.

Partition		Optimization design			Initial design		
		Well numbers	Well diameter	Well length	Well numbers	Well diameter	Well length
			mm	m		mm	m
Area II	dewatering	5	273	19	11	273	19
Area I	dewatering	102	273	31~48	93	273	48
	anti-inrush	8	273	73	14	273	73
	recharge(layer⑨)	0	273	48	13	273	49
	recharge(layer⑪)	7	273	67~73	13	273	73
Back and watch		10			15		
Collection		132	---	5951	159	---	7281
Construction costs		About 5.40 million yuan			About 8 million yuan		

6 Conclusions

The dewatering design of complicated pit excavation should take many factors into consideration. Adjusting the arrangement and analyzing the dewatering system with numerical simulation many times allows a relatively superior design to be obtained.

The 3D numerical simulation analysis method is an effective analytical method for finding the most optimal theoretical selection. However, considering the deviation of software calculation and the complexity of engineering practice, it is reasonable to combine the analysis results with engineering experience to determine the final selection.

Project practice shows that this method can meet practical requirements and obtain better economic benefits.

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