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Numerical simulation of deep foundation pit dewatering and optimization of controlling land subsidence

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ABSTRACT

Shanghai is a typical area of soft soil distribution, Metro railway construction is now being developed in Shanghai City on a large scale and the planning of Metro stations are often located in densely populated districts with tall buildings. Metro station constructions are mostly taking pit dewatering measures, while the dewatering of aquifer may cause soil layer compression, land subsidence, foundation's deformation, cracking and tilting of the buildings, and so on. In order to control the land subsidence effectively, the underground continuous concrete wall is often used in the deep foundation pit dewatering. The depth of underground continuous concrete wall and the filter tube position of pumping well affect drawdown outside the pit and land subsidence directly. This study refers to the deep foundation pit dewatering project of Hangzhong Road station of Shanghai Metro Line No.10. The excavation depth of foundation pit is 15.60–17.60 m, and the design depth of underground continuous wall is 28 m in the standard part and 30 or 31 m in the end well. Three-dimensional finite differences method is used to simulate the pit dewatering through the inversion of permeability parameters based on the field pumping tests. The hydraulic barrier function of the underground continuous wall is simulated at four different depths including primary design depth, increasing 3 m, 4 m and 6 m. The result of the numerical simulation indicates that the drawdown of the aquifer decreases with the increase of the underground continuous concrete wall depth. When the underground continuous concrete wall increases 4 m on primary design basis, the drawdown outside the pit and land subsidence can be controlled effectively. The monitored results indicate that the drawdown outside the pit at a distance of 1–5 m to the wall is less than 2 m, while the maximum land subsidence is 7.97 mm, which is of nearly no influence on the environment around the pit during dewatering.

1. Introduction

Shanghai is one of the most economically developed cities in China. In recent years, with the rapid development of the national economy and the continuous expansion of urban construction, the development of underground space has received more and more attention. Metro construction is an important way of development and utilization of underground space. Metro station construction is often requiring dewatering measures. Water inflow and drawdown are the most care requiring in the construction. In order to calculate water inflow of pit, numerical methods are often used. Based on the two dimensional finite element method, the seepage field and penetrating flow at different stages of the pit construction were analyzed (Yu et al., 2002). The seepage near the hydraulic barrier was studied with two dimensional finite element method (Wang et al., 2001). The confined aquifers of high head are buried below the base of foundation pit, dewatering is exceedingly easy to make a dramatic decrease of the underground water level surrounding the dewatering area and cause land subsidence and geologic disasters (Luo et al., 2008a,b; Wang et al., 2009). According to the different positions of the bottom of the underground continuous wall in an aquifer, three types of seepage around the foundation pit were proposed (Wu et al., 2003, 2009). Therefore, based on the characteristics of three-dimensional geological body, it has become a priority to design rationally the entire engineering structures of dewatering, if economic and technological conditions are available, so that the demand of decrease of the underground water level in deep foundation pits can be met and meanwhile the decrease of the underground water level around foundation pit is incapable of causing land subsidence and geologic disasters.

Dassargues et al. (1991) once studied geotechnical properties of the Quaternary sediments in Shanghai. There are many scholars who

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studied the pit dewatering and land subsidence (Burbey, 2003; Shi et al., 2008; Thomas and Holzer, 1989; Hawkins, 2005; Zhang et al., 2007), their achievements can provide much help in the study of pit dewatering of Hangzhong Road station of Shanghai Metro No. 10.

The main objectives of this paper are: (1) to calculate hydrogeologic parameters of aquifer based on the pumping tests; (2) to simulate groundwater level at different depths of underground continuous concrete wall during dewatering; (3) to calculate the maximum land subsidence at different distances away from the foundation pit; (4) to optimize dewatering model of deep pit and control land subsidence.

2. Engineering background

Shanghai Metro Line No.10 consists of 28 stations from Northeast (Yangpu district) to Southwest (Hongqiao district) in Shanghai City, for a total length of about 28.8 km. Hangzhong Road station is one station of the Metro Line No.10 and is located at the cross of Wuzhong Road and Hangzhong Road (Fig. 1), where the terminal station of Metro Line No.10 is located. The length of the Metro station is 344 m and the width is 20–24 m, the buried depth of bottom plate is 15 m. According to the original design, the underground continuous concrete wall is used as supporting structure and the construction technology is open-excavation with normal construction method, the thickness of the underground continuous concrete wall is 1.0 m, and its depth is 28 m in the standard part and 30 or 31 m in the end well.

The environmental conditions are more complex around Hangzhong Road Metro station, because there is water-supply line (Φ1000 and Φ300), a gas pipe line (Φ500), a rain-water pipe (Φ600) and a sewer line (Φ400), which are 25.9 m, 29.2 m, 36.0 m and 40.0 m away from the foundation pit respectively. Also, there are many 2–6 storied buildings around the station. All buildings and roads have a strict requirement for land subsidence control, which is mainly caused by dewatering of the aquifer.

3. Study area

3.1. Strata distribution

According to the investigation research report of geotechnical engineering of Hangzhong Road station, the foundation soils are all Quaternary unconsolidated sediments in 70 m exposed depth. The foundation mainly consists of saturated clayey soil, silty soil and sandy soil, with layer ①, layer ② and layer ⑤ divided into several sublayers. The strata distributions are listed in Table 1.

Table 1
The distributions of soil layers.

Strata serial	Name of soil layer	Elevation of layer bottom (m)	Buried depth of layer bottom (m)	Layer thickness (m)
①$_1$	Artificial fill	3.57–1.88	1.00–2.80	1.00–2.80
①$_2$	Creek bottom silt	1.20	3.30	0.00–1.80
②$_1$	Clay	1.68–0.86	3.00–4.10	0.70–2.40
②$_3$	Sandy silt	−0.92 to −1.54	5.50–6.30	1.90–2.80
③	Muddy silty clay	−1.98 to −3.02	6.60–7.80	1.00–1.50
④$_1$	Muddy clay	−8.32 to −9.48	13.00–14.30	5.80–7.10
④$_2$	Sandy silt	−9.32 to −11.82	14.00–16.80	0.80–2.50
⑤$_1$	Silty clay	−12.00 to −14.72	16.50–19.40	1.50–5.00
⑤$_{2-1}$	Clayey silt intercalating silty clay	−17.17 to −25.85	21.70–30.60	3.50–13.60
⑤$_{2-2}$	Fine sand	−41.91 to −44.34	46.50–49.00	16.90–26.00
⑦	Fine sand	−44.29–<−50.34	48.80–>55.00	2.30–>6.00
⑧	Silty clay	No exposed	No exposed	No exposed

Table 2
Permeability parameters obtained by indoor penetration test.

Layer	Composition of each layer	The coefficient of permeability by indoor test (cm/s)	
		Kz	*Kx*
②$_1$	Clay	1.6×10^{-7}	9.3×10^{-8}
②$_3$	Sandy silt	2.3×10^{-4}	4.6×10^{-4}
③	Muddy silty clay	4.4×10^{-8}	1.4×10^{-7}
④$_1$	Muddy clay	5.7×10^{-8}	1.4×10^{-7}
④$_2$	Sandy silt	1.2×10^{-4}	3.9×10^{-4}
⑤$_1$	Silty clay	2.5×10^{-7}	3.7×10^{-7}
⑤$_{2-1}$	Clayey silt intercalating silty clay	1.3×10^{-5}	3.2×10^{-5}
⑤$_{2-2}$	Fine sand	6.5×10^{-4}	1.3×10^{-3}
⑦	Fine sand	2.94×10^{-3}	4.15×10^{-3}

3.2. The hydrogeological condition

The main types of groundwater in the foundation pit are the unconfined water in the shallow clay aquifer, the sub-confined water in the shallow aquifer of silty soil (④$_2$ and ⑤$_2$) and the confined water

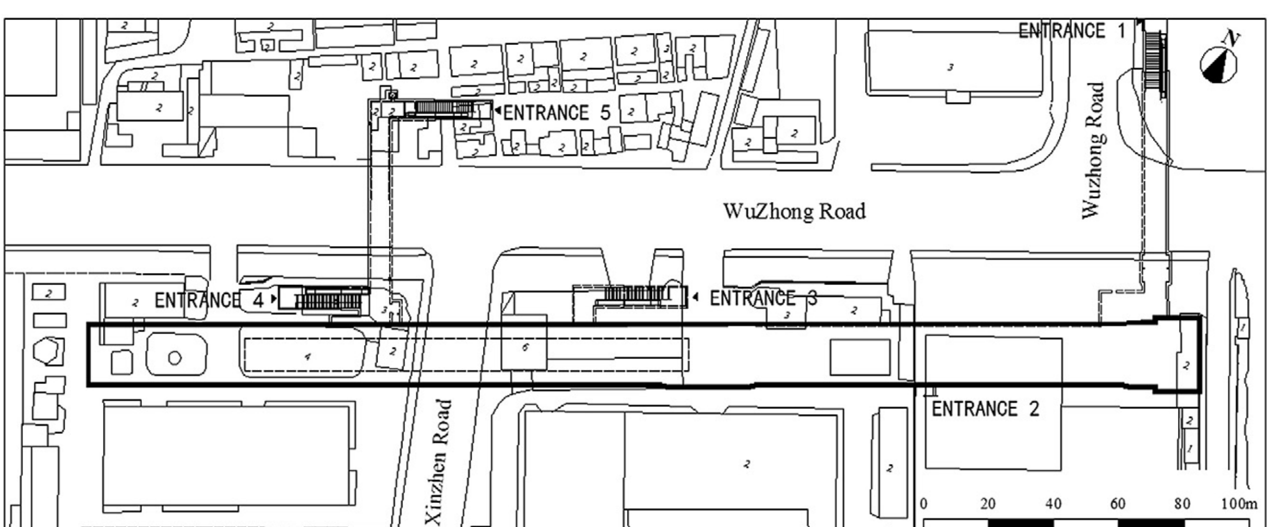

Fig. 1. The location of Hangzhou Metro station and surrounding environment.