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Test and numerical research on wall deflections induced by pre-excavation dewatering

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ABSTRACT

Numerous studies have been devoted to the performance of excavations and adjacent facilities. In contrast, few studies have focused on retaining wall deflections induced by pre-excavation dewatering. However, considerable inward cantilever deflections were observed for a diaphragm wall in a pre-excavation dewatering test based on a long and narrow metro excavation, and the maximum deflection reached 10 mm (37.6% of the allowable wall deflection for the project). Based on the test results, a three-dimensional soil–fluid coupled finite element model was established and used to study the mechanism of the dewatering-induced diaphragm wall deflections. Numerical results indicated that the diaphragm wall deflection results from three factors: (1) the seepage force around the dewatering well and the soil–wall interaction caused the inward horizontal displacement of the soil inside the excavation; (2) the reduced total earth pressure on the excavated side of the diaphragm wall above approximately 1/2 of the maximum dewatering depth disequilibrated the original earth pressure on both sides of the diaphragm wall; and (3) the different negative friction on the excavated and retained sides of the diaphragm wall led to the rotation of the diaphragm wall into the excavation.

1. Introduction

If an excavation is performed below the groundwater level, dewatering is generally adopted to prevent the excavation from flooding [1]. In a congested urban environment, dewatering is typically performed inside the excavation to reduce the impact of dewatering on the adjacent structures and facilities [2,3]. As to excavations that require a drawdown exceeding 5–10 m (e.g., typical metro excavations), the deep well is often employed [4]. Deep-well dewatering for excavations typically includes two stages: (1) pre-excavation dewatering and (2) staged dewatering with the staged excavation and bracing. Stage 1 is often used to develop the well [3,4], check the completion quality of the well [4] and examine the impermeability of the retaining wall (or cut-off wall). The duration of this stage ranges from several hours to several days [3,4]. For some projects, the pre-excavation dewatering lasts for weeks or months [5–7] to lower the level of phreatic water below the final excavation depth prior to excavation.

However, in practice, designers typically ignore the retaining wall deflections caused by pre-excavation dewatering when selecting and comparing schemes. Therefore, the final scheme chosen by designers may be unreasonable and even unsafe. Furthermore, wall deflections are rarely monitored during the pre-excavation dewatering until the excavation begins. Additionally, the current codes for excavation [8,9] still do not include a method of estimating the wall deflections induced by pre-excavation dewatering.

The effect of staged excavation and bracing on the excavation and soil has been investigated in depth in academia, including field studies [10], analytical and numerical analyses [11], and empirical or semiempirical approaches [12,13]. The soil settlements induced by dewatering is also received much attention [14,15]. In contrast, few academic studies have considered the effect of pre-excavation dewatering on the behavior of excavations. Shen et al. [6] ever reported a case history of dewatering in an unexcavated excavation and performed a numerical analysis. However, they mainly concentrated on the soil settlements induced by drawdown and did not investigate wall deflections during pre-excavation dewatering in detail. The characteristics and mechanism of dewatering-induced wall deflection are still unclear due to the lack of well-documented field data or theoretical analyses.

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In this study, an in situ test was conducted in a metro excavation in Tianjin, China to investigate the effects of pre-excavation dewatering. The diaphragm wall deflections during the pre-excavation dewatering were monitored and analyzed. Furthermore, a three-dimensional (3D) finite element (FE) model considering soil–fluid coupling was employed to simulate the pre-excavation dewatering test. The model was verified by the field observation results. Then, the computed soil deformation, stress path, earth pressure, and friction on the wall were analyzed to study the mechanism of wall deflection induced by pre-excavation dewatering.

2. In situ dewatering tests

2.1. Project description and soil conditions

Fig. 1 presents the plan view of the investigated excavation for the Beizhan Station of Metro Line 3 in Tianjin, China. This metro excavation consisted of three sections (i.e., Excavation A, Excavation B and the interchange shaft). The excavation depth for each section can be seen in Fig. 1.

The retaining structure was a reinforced concrete diaphragm wall that was 0.8–1.0 m thick (1.0 m for the end shafts and 0.8 m for the remainder) and 33–42 m deep (42 m for the interchange shaft and 33 m for the remainder).

Several buildings existed around Excavation B. Among them, a three-story brick building, resting on a shallow foundation and belonging to the China Third Railway Survey and Design Institute (TSDI), existed at a distance of less than 8 m on the south side of Excavation B.

The subsurface conditions and soil properties at the site were obtained from the geotechnical investigation and laboratory tests and are summarized in Table 1. The site generally featured soft-to-stiff silty clays and silts in the upper 37 m BGS, underlain by dense silty fine sands with sandy silt seams to a depth of 42 m BGS. The next layers were stiff clayey soils extending to a depth of 50 m BGS, followed by very dense silty fine sands to a depth of 55 m BGS. Beneath the sands, stiff silty clays were encountered until the termination depth of 70 m BGS.

From a hydrogeological perspective, there were one phreatic aquifer (hereinafter labeled as Aq0) and three confined aquifers (hereinafter labeled as AqI to AqIII). The aquifers were separated by four aquitards. The corresponding soil type and depth for the aquifers and aquitards are presented in Table 1. The long-term phreatic water level was observed at depths of 0.8–2.9 m BGS. The hydrostatic equilibrium for the AqI, AqII and AqIII was reached at 3.26, 4.12 and 5 m BGS, respectively.

2.2. Arrangement of the dewatering wells and observation instruments

Before the dewatering tests, diaphragm walls and dewatering wells were installed on site. As shown in Fig. 1, there were a total of 9 and 10 wells in Excavations A (S1–S9) and B (S10–S19), respectively. The wells were drilled with a diameter of 650 mm and were fitted with a steel well liner with a diameter of 273 mm. The liner had a section slotted (i.e., well screen) from 2 m BGS to approximately 3 m below the final excavation depth to ensure that the water table could be lowered below the final excavation depth during excavation. The borehole annuli were sealed above the screen level with clay. In addition, each well was equipped with a submersible pump. The pump can be allocated at different depths by practicing engineers.

Fig. 1 also presents the plan arrangement of inclinometers and observation wells. 14 inclinometers (C1–C6 for Excavation A and C7–C14 for Excavation B) were mounted on the diaphragm walls by fixing the inclinometers to the steel reinforcement cages of the diaphragm walls. Unfortunately, C5 and C6 were damaged during the construction of the diaphragm walls and their measurements were not available for this study. To monitor the water levels outside the excavation, 14 observation wells (G1–G4 for AqII and G5–G14 for Aq0) were employed around the excavation.

In addition, the soil and adjacent building settlement markers were also mounted around the excavation. However, their specific layouts and observation data will not be presented due to the limited paper length.

2.3. Pre-excavation dewatering tests

Two pre-excavation dewatering tests, T1 and T2, were carried out in Excavations A and B, respectively. This study focuses on test T1 in Excavation A, which had no struts installed at the top of the diaphragm wall during the test. In practice, a large number of excavations are not braced during the pre-excavation dewatering. Therefore, T1 simulated a common condition of pre-excavation dewatering.

T1 lasted 10 days, during which all of the dewatering wells in Excavation A were operating and the pumps were submerged at different depths (i.e., 4, 8, 12 and 16 m BGS) in four stages. Each stage lasted 2.5 days.

Because the flowmeter was not installed on the wells in T1, the discharge flow rate via a well (q) cannot be accurately measured. Fortunately, each well in T2 was equipped with a flowmeter, and due to the approximately identical site condition and well arrangement of T1 and T2, the q observed in T2 could directly reflect that in T1.

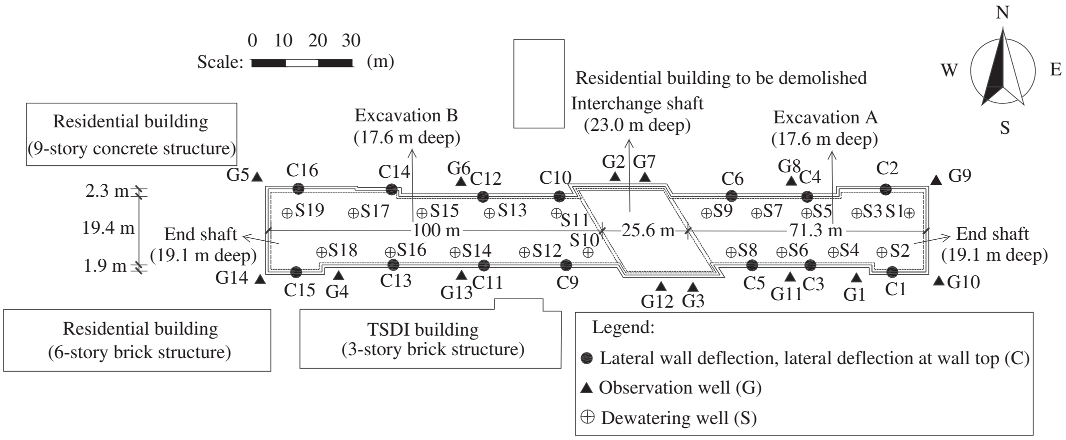

Fig. 1. Site plan and instrumentation layout.