

Field tests of pumping-recharge technology for deep confined aquifers and its application to a deep excavation



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ABSTRACT

The execution of deep excavation above confined aquifers asks for dewatering measurements to reduce the hydrostatic pressure so that the safety of the deep excavation can be assured. Dewatering will inevitably cause deformations in the surrounding strata. To reduce the dewatering-induced strata movement, an innovative pumping-recharge technology has been developed in which the dewatering is carried out in the excavation and the recharge is conducted near the protected facilities. However, the capacity and efficiency of this technology in deep confined aquifers need to be further investigated. This paper presents two in-situ pumping-recharge tests in a deep confined aquifer under a deep foundation pit. The feasibility of artificial recharge in the deep confined aquifer has been verified by conducting a single-well pumping and multi-well recharge test with different discharge and injection rates. Then a multi-well pumping-recharge test was carried out in accordance with the requirement and circumstance of construction to evaluate the capacity and efficiency of recharge in controlling the drawdown and ground settlement. The results showed that multi-well recharge could form a water curtain which has a water-proof function to reduce the groundwater drawdown. Meanwhile, by controlling the groundwater head of the confined aquifer during the recharge, the pumping-induced settlement of the surrounding area can be reduced or even eliminated. The pumping effect in the pit would be affected by the recharge around the protected facilities, so it is necessary to take in-situ pumping-recharge tests to determine the layout of wells and the discharge and injection rate. Finally, the artificial recharge was applied to the construction of a deep excavation in Shanghai, and the drawdown and the ground settlement around the protected buildings were effectively controlled by recharge.

1. Introduction

Although more than hundreds of kilometers of metro lines have been constructed in Shanghai, China, the traffic jam is still a big issue and calls for more metro lines to relieve the traffic congestion. These circumstances inevitably lead to situations where two or more metro lines intersect at one station, and result in deep excavations during the construction of these metro stations. The execution of deep excavation above confined aquifers asks for dewatering measurements to reduce the artesian water level so that the safety of the excavation can be assured. Consequently, strata deformations, including vertical and horizontal deformations, caused by dewatering may cause irreparable damage to adjacent facilities if the construction of the deep excavations is conducted in a congested metropolitan area (Zhou et al., 2010; Serrano-Juan et al., 2016; Pujades et al., 2017). To prevent adjacent facilities from damage, it is important to propose innovative techniques and adopt appropriate countermeasures to relieve or even eliminate the

dewatering-induced soils compression and ground settlements.

Several techniques were proposed and investigated by many researchers, e.g., sealing curtain technique (Chen et al., 2013; Wang et al., 2013; Pujades et al., 2012a,b, 2014b;) and artificial recharge technique (Wang et al., 2012; Lu and Miao, 2015). In the sealing curtain technique, the sealing curtain is penetrated into the pumped aquifer. Thus, the groundwater seepage path is lengthened and the groundwater is blocked from flowing into the excavation. Consequently, the pumping-induced drawdown and settlement outside the excavation can be reduced. Moreover, if the sealing curtains completely cut off the groundwater flow in the confined aquifer, pumping within the excavation will impact little on the surrounding environment. However, the defects on the walls are frequent and it will result in the groundwater drawdown outside the excavation (Vilarrasa et al., 2011; Pujades et al., 2016). Moreover, it is difficult and uneconomic to construct sealing curtains deep enough to completely cut off the confined aquifers if the aquifers are located deep under the ground surface with a large

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thickness. Alternatively, the sealing curtain partially embedded into the confined aquifer is prevalent in practice (Tang et al., 2008a, 2008b; Sun et al., 2011; Ren et al., 2012; Wang et al., 2013). However, dewatering using this type of sealing curtain will inevitably cause a decrease of the artesian head outside the excavation and result in settlements of the surrounding facilities (Hsi and Small, 1992; Forth, 2004; Roy and Robinson, 2009; Pujades et al., 2014a).

In the artificial recharge technique, the pumped water is injected into the aquifers. Thus, a water curtain is formed around the recharge wells and the piezometric head is raised. Consequently, the pumping-induced drawdown and ground settlement can be relieved and even eliminated. The artificial recharge was originally proposed to supply the groundwater and mitigate land subsidence induced by the excessive groundwater extraction (Phien-wej et al., 1998; Bouwer, 2002; Missimer et al., 2011; Zhang et al., 2015). The recharged water, mainly comes from surface waters, stormwater runoff, treated sewage effluent, etc., will cause adverse impact on the groundwater and recharge effect, e.g. contaminating the groundwater, the clogging of wells and aquifers, the high cost of sewage treatment, and so on (Vigneswaran and Suazo, 1987; Lindsey et al., 1992; Baveye et al., 1998; Händel et al., 2014;). In recent years, artificial recharge has been applied to deep excavations for environment protection (Wang et al., 2012). To improve its applicability and capacity in deep excavation, a pumping-recharge integration technology was proposed (Lu and Pan, 2014; Lu and Miao, 2015; Lee et al., 2016).

The sketch of the pumping-recharge integration technology is shown in Fig. 1. In the proposed technology, apart from relieving the artesian water pressure inside the pit to safeguard the excavation by pumping, the pumped groundwater is injected into the pumped aquifer around the facilities by recharge wells through pumps to reduce the pumping-induced drawdown after treatment. The treatment involves the following steps: (1) Groundwater aeration treatment is carried out by air compressor. (2) The water after aeration will be filtrated through the filtration equipment, e.g., mechanical filter water treatment units, etc. Additionally, as the recharged water comes from the pumped aquifer and can be injected into the aquifer after simple treatment, the proposed technology has the following advantages: (1) allowing groundwater to be reused; (2) protecting the groundwater from polluting; (3) reducing the cost of recharge and treatments. In Shanghai soft deposits area, there are one phreatic aquifer and five confined aquifers (hereinafter labelled as confined aquifer I to Confined aquifer V), and the aquifers are separated by six aquitards (hereinafter labelled as aquitard I to aquitard VI) (Xu et al., 2009). By carrying out the in-situ pumping and recharge tests of confined aquifer I (shown in Fig. 1) in Shanghai, and performing the corresponding numerical simulation, Wang et al. (2012) investigated the pumping-recharge effect of shallow confined aquifers and the combined effects of pumping, curtain and recharge. However, the tests only focused on the recharge in confined

aquifer I as well as the groundwater level control, while no attention was paid to the efficiency on controlling the ground settlement. Most of the existing studies focused on the pumping and recharge in phreatic aquifers and confined aquifer I, and few investigated the artificial recharge in deeper confined aquifers during the excavation (Phien-wej et al., 1998; Ni et al., 2011; Wang et al., 2012; Zhou and Burbey, 2014; Wang et al., 2015; Zhang et al., 2017).

This paper presents two in-situ pumping-recharge tests performed in the confined aquifer II (shown in Fig. 1) for a metro station in Shanghai. The tests included a single-well pumping and multi-well recharge test and a multi-well pumping-recharge test. The feasibility of artificial recharge to the deep confined aquifer and the efficiency in controlling the groundwater drawdown and the ground settlement are studied. Furthermore, the artificial recharge in confined aquifer II was applied to a deep excavation in Shanghai, and the effect of recharge on controlling the drawdown and ground settlement in a deep excavation is analyzed.

2. Site characterization

2.1. Project description

The investigated project was the Hanzhong Road station of Metro line 13, a transfer station of three Metro lines (Metro line 1, 12, 13) located at Jing'an District, Shanghai, China. It was a five-story underground island platform station with the maximum excavation depth of 33.1 m. A temporary partition wall was installed to divide the deep excavation of the station into two relatively small pits, zone Ia and Ib. The environmental conditions around Hanzhong Road Station were very complex and required a high level of protection. The excavation was surrounded by four roads and adjacent to four high rise buildings, one subway station (the Hanzhong Road Station of Metro Line 1) and several existing underground service pipes. The southeast of the deep excavation was adjacent to the Suzhou River. The distribution of these buildings is presented in Fig. 2. To protect the nearby facilities, diaphragm walls were installed as retaining walls with the thickness of 1.2 m and maximum depths of 62 m in zone Ia and 59 m in zone Ib, respectively.

2.2. Subsurface soil formations

Fig. 3 depicts the typical sectional view. The Quaternary deposits on the site are stratified. The first layer is an uncontrolled fill in the upper 2.0 m below the ground surface. Under the fill layer, a sequence of layered sand is present at the site, to the depth of 15.5 m. These are underlain by multilayered soft soil, including silty clay and clay, with the thickness of about 16.2 m. Beneath the soft soil layers there are two layers of sand to the depth of 45.6 m. The next layer is a soft clay layer extending to the depth of 58.6 m, underlain by a layer of silty clay with

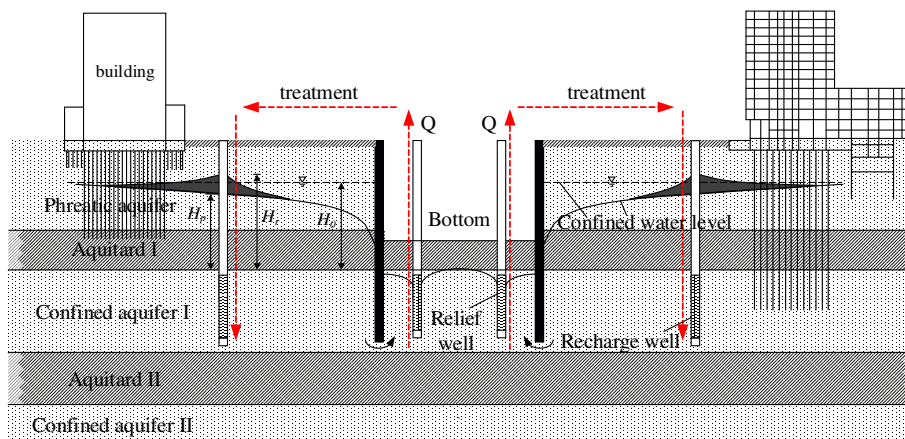


Fig. 1. The sketch of the pumping – recharge integration technology.

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