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Environmental protection using dewatering technology in a deep confined aquifer beneath a shallow aquifer

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ABSTRACT

This paper presents an innovative technology referred to as Dual Function Well (DFW), which has been developed in order to reduce the construction costs of dewatering when excavation is conducted in an aquitard over a confined aquifer. DFW technology is a method to lower both shallow groundwater and deep groundwater, either separately or simultaneously, using one well. The DFW includes two or more independent screens corresponding to each aquifer, and a valve is located between the screens inside a steel pipe. When the valve is closed, groundwater is pumped from the upper screen in the shallow aquifer. When the valve is open, groundwater is pumped from the screens in both the shallow and deep aquifers. DFW technology is used to replace the traditional method involving two sets of wells, in which the first set of wells pumps groundwater from the shallow aquifer, and a second set pumps groundwater from the deep aquifer. To investigate the effectiveness of DFW, field pumping tests using a DFW were conducted, and both groundwater head and settlement were monitored. Numerical simulation was adopted to simulate the results of the pumping tests. Comparison between the results from the DFW and from an ordinary mixing well indicates that the use of a DFW with the valve closed can reduce the pumping time from a deep aquifer and can reduce the ground settlement caused by dewatering. The results indicate the DFW technology is feasible and effective.

1. Introduction

With the rapid development of urban underground space, a large number of deep excavations have been constructed in the soft Quaternary deposits of the coastal regions of China. These soft Quaternary deposits generally consist of multi-aquifer–aquitard systems (MAAS) having a large depth of aquifer and high groundwater levels (Xu et al., 2012a,b, 2013; Wang and Jiao, 2012). The groundwater basin in Shanghai, which is located in the east of China, is composed of a phreatic aquifer (referred to as Aq0) and five confined aquifers (AqI–AqV), which are separated by six aquitards (AdI–AdVI) with clayey soils (Chai et al., 2004; Hong et al., 2006; Xu et al., 2009; Yin and Chang, 2013; Wu et al., 2014). Fig. 1 gives a sectional view of the typical hydrogeology in Shanghai. For deep excavations, retaining walls, e.g., deep mixing piles (Shen et al., 2008; Huang and Han, 2009; Chen et al., 2013), jet grouting columns (Shen et al., 2013b,c,d; Wang et al., 2013b), and diaphragm walls (Pujades et al., 2012a,b, 2014b; Tan and Wang, 2013a,b) are all employed to retain the surrounding soils and to block the groundwater from penetrating the pits. The existence of retaining walls has a great influence on the behaviour of groundwater seepage (Butler and Liu, 1991; Jiao et al., 2006, 2008; Xu et al., 2008; Vilarrasa et al., 2011).

The dewatering–retaining systems employed in Shanghai can be divided into the following five patterns, according to the insertion depth of the retaining wall into an aquifer (Wu, 2003; Xu et al., 2014): *i*) Pattern 1: the retaining walls are shallowly buried in AdI and the wells are set in the foundation pit to drain the phreatic water; *ii*) Pattern 2: the retaining wall extends into AdI and the thickness between the base of the foundation pit and the top of Aq I is small. Some wells are set in the pit to drain the phreatic water, and others are set outside the pit to lower the groundwater head of AqI; *iii*) Pattern 3: the retaining wall enters the upper part of AqI, and wells are set both inside and outside the pit; *iv*) Pattern 4: the retaining wall extends almost fully into of AqI, and wells are set within the foundation pit to withdraw the phreatic water as well as the confined water; and *v*) Pattern 5: the retaining wall cuts off AqI completely, and wells are set within the foundation pit to withdraw both phreatic water and confined water.

In Shanghai, Pattern 1 is commonly applied to excavations with a depth of less than 10 m; Pattern 2 and Pattern 3 are occasionally used in the suburbs of Shanghai for AqI, with a reduced or no blocking effect from the retaining walls. Both Patterns 4 and 5 can be adopted for excavations with a depth greater than 20 m in Shanghai. As it is difficult and uneconomic to construct retaining walls deep into AdII in practice,

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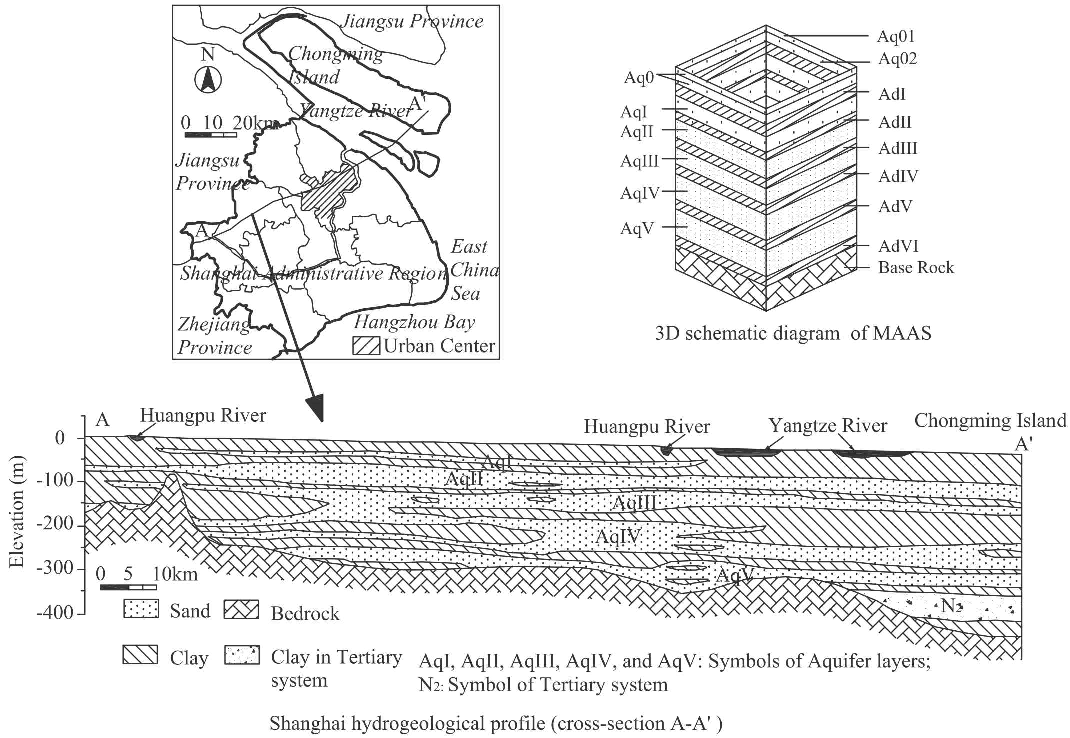

Fig. 1. Typical hydro-geological profile of Shanghai.
Recreated based on Xu et al. (2014).

Pattern 5 has seldom been used. Pattern 4 is the most common way to reduce the water level in AqI for deep excavations (Tang et al., 2008a, b; Sun et al., 2011; Ren et al., 2012; Wang et al., 2013a).

Pumping groundwater using Pattern 4 inevitably causes a decrease in the groundwater level outside the pit, resulting in settlement of the surroundings (Hsi and Small, 1992; Forth, 2004; Gue and Tan, 2004; Roy and Robinson, 2009; Pujades et al., 2014a). In general, ground settlement around the foundation pit is mainly caused by dewatering as well as by the excavation. In order to reduce the dewatering-induced settlement, two sets of wells are employed: one set of wells pumps groundwater from the phreatic aquifer, another set pumps groundwater from the confined aquifer. The former is adopted throughout the excavation process, whilst the latter starts pumping when the excavated depth reaches the critical depth of piping failure, and stops when the base floor reaches the target strength. Although pumping times in the phreatic aquifer are very long, the ground settlement caused by dewatering phreatic water is very small because of the existence of the retaining wall. Any ground settlement caused by dewatering is mainly due to withdrawal of the confined water. The dewatering scheme in which two sets of wells are used minimises the time period of pumping groundwater in a confined aquifer, and protects the surrounding environment. However, the two sets of wells are constructed and managed separately; and the pumping wells consume more materials and result in higher construction costs.

To minimise construction costs, a combined well known as a mixing well has been developed, which has screens corresponding to each aquifer combined in one well. With this type of well, groundwater can be pumped from both a shallow aquifer and a deep aquifer at the same time. Comparing the two sets of wells, the mixing well scheme requires fewer wells to meet the dewatering requirements but takes a longer time. When a deep aquifer is partially blocked by a retaining wall, significant ground settlement will occur in the surroundings. Consequently, it is better to have a well which can lower both shallow groundwater and deep groundwater, either separately or simultaneously. This paper presents an innovative technique referred to as 'Dual Function Well' (DFW). In DFW, a valve box is applied to an ordinary mixing well at the depth of the aquitard, and the valve can be opened or shut on an as-needed basis. For deep excavations where it is necessary to lower both shallow and deep groundwater, the use of the DFW technique can save 30% to 50% of the dewatering construction cost. In order to verify the effectiveness of DFW technology, field tests performed in Shanghai are presented and the results are compared with those simulated by numerical method.

2. Methodology

2.1. Composition of DFW technology

DFW technology employs a method to lower shallow groundwater and deep groundwater either separately or simultaneously using one well, which is achieved by shutting or opening a valve. When the valve is closed, groundwater is pumped from the upper screen in the shallow aquifer; and the water level is maintained in the initial state in the deep aquifer. When the valve is open, groundwater is pumped from the screens in both the shallow and deep aquifers. Fig. 2 shows a schematic view of the Dual Function Well. The basic composition of the DFW is as follows:

(1) Screens. The well includes two or more independent screens corresponding to each aquifer. The screen in the shallow aquifer is used to drain shallow groundwater, and the screens in the deep aquifers are used to lower deep groundwater. The number and lengths of the screens are determined based on in situ geotechnical investigation.
(2) Steel pipes. Screens are connected by steel pipes which are located in the aquitards between aquifers. The diameters of the steel pipes are determined according to the dewatering demands, and generally vary from 200 to 500 mm.
(3) Valve. A valve is set between the screens inside the steel pipe. The hydraulic connection between the shallow and the deep groundwater in the well is controlled by opening or shutting the valve. The valve should satisfy the following requirements: (a) it must