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Research Paper

Calculation of head difference at two sides of a cut-off barrier during excavation dewatering

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ABSTRACT

This paper proposed a series of simple equations to calculate the head difference at the two sides of waterproof curtain. The barrier effect of waterproof curtain is considered from two situations with respect to without barrier case: (i) groundwater head difference below the barrier and (ii) groundwater head difference by convergence into the opening. The solution for the first situation can be derived from hydraulic analyses and the second situation can be obtained using a numerical analysis. The final groundwater head difference is the sum of these two situation according to the superposition principal. In the proposed equations, the head difference is expressed as a function of the inserted depth of the barrier into confined aquifer, the ratio of the hydraulic conductivity of the aquifer, the thickness of the aquifer, and hydraulic gradient under normal conditions. Finally, the proposed equation was applied to a field case to verify the validity of the proposed approach. Compared with the field data, the results show that the proposed method is reasonable.

1. Introduction

In recent years many deep excavations are being constructed in coastal regions of China. These regions are typically characterized by soft deposits comprising marine and estuarine sediments with alternating, sub-horizontal strata of permeable coarse-grained (mostly sand with some silt and clay fractions) strata constituting the aquifers and soft (relatively more compressible), low-permeability fine-grained (predominately clay and silt) strata constituting the aquitards [1–9]. These deposits often have a high groundwater head [10,11]. Since the excavation depth in many construction projects is large, withdrawal of groundwater in the confined aquifer should be conducted to keep safety during construction execution.

In general, waterproof curtains, e.g. deep-mixed piles [12], jet-grouted piles [13–16], and diaphragm walls [17,18] are used to not only retain structures, but also block groundwater seepage [17,19]. Inappropriate dewatering activities during excavation would lead to rapid ground subsidence accompanied by damages to adjacent superstructures, particularly in heavily congested urban areas [18]. For dewatering in the confined aquifer, there are typically three dewatering-retaining patterns on the basis of the insertion depth of the waterproof curtain [20,21]: (i) Pattern 1: the waterproof curtain extends into the first aquitard or enters only a little into the upper part of the first confined aquifer, and pumping wells are placed outside the excavation pit; (ii) Pattern 2: the insertion depth of the waterproof curtain is large, and pumping wells are placed within the excavation pit; and (iii) Pattern 3: the waterproof curtain cuts off the confined aquifer completely, and pumping wells are placed within the excavation pit. Among the three patterns, Pattern 2 is used the most to lower the confined water head for deep excavation purposes [22,23].

For Pattern 2, when groundwater pumping is conducted in the excavating pit, the barrier effect of the waterproof curtain reduces the groundwater head in the pit quickly, and that outside the pit slowly, generating a difference in groundwater heads across the two sides of the waterproof curtain. For instance, in the remediation project for Metro Line 4 in Shanghai, the depth of the waterproof curtain is 65 m, which penetrated 37 m into the confined aquifer; the waterproof curtain successfully blocked groundwater flowing from the surrounding strata into the foundation pit, and the groundwater head was decreased by 34 m in the foundation pit and by 3 m outside it [24]. Another documented case is an excavation project for Metro Line No. 9 in Shanghai, the waterproof cur-

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tain went 9 m into the confined aquifer; the maximum drawdown in the pit was 17.6 m whereas the maximum drawdown outside it was only 1 m during excavation [25]. These two cases had monitoring wells both inside and outside the excavation pit so that variations in groundwater head can be observed. However, because of the limitations of access or damage to the monitoring wells, there are no monitoring wells outside the excavation in many field projects so that groundwater heads cannot be obtained. Therefore, in designing the insertion depth of the waterproof curtain in the aquifer, it is required to calculate groundwater heads outside the pit when groundwater heads inside the pit are known. It is noted that waterproof curtains as well as other types of hydraulic barriers including soil-cement-bentonite vertical cutoff walls are also extensively used in geoenvironmental applications [26–28]. These vertical barriers can control migration of contaminants in groundwater. The barrier effect of vertical walls on contaminants has relationship with the hydraulic conductivity and the depth of the vertical walls as well as head difference between two sides of the barrier [26]. If groundwater head inside the barrier is higher than the head outside the barrier, then contaminants transportation are easy to occur, and vice versa.

Numerical method is usually adopted to calculate the head variations during dewatering [25,29–32]. However, numerical calculation is complex and cannot be used directly in the field. Currently there is no direct method of calculating the insertion depth of each waterproof curtain. Pujades et al. [33] proposed an empirical analytical approach for calculation of the groundwater head difference across the two sides of elongated blocking structures (such as tunnels) in a confined aquifer under natural conditions. However, Pujades' approach requires that there are no sink or source terms, and the structure completely cut off the confined aquifer in the horizontal or vertical direction. Under such conditions, groundwater can only flow from one direction to the other side of the structure. Pujades' approach cannot cater for situations in which groundwater seepage from different directions into the excavation pit. Thus, it is worth developing a generalised approach to calculating the head difference across two sides of a cut-off barrier. The objectives of this study are to: (i) investigate the relationship between head difference across two sides of a barrier and its insertion depth into a confined aquifer, the ratio of the horizontal hydraulic conductivity over the vertical conductivity of the aquifer, the thickness of the aquifer, and the hydraulic gradient without a barrier; (ii) to propose a generalised simple approach to calculating the head difference across the two sides of a cut-off barrier during excavation dewatering.

2. Hydraulic analysis of a barrier

Fig. 1 shows a well in the centre of a circular excavation pit used to lower the water head. A circular waterproof curtain is used to block groundwater seepage into the pit from the surrounding strata. As seen in Fig. 1, r_0 is the inner radius of the pit, L_b is the thickness of the waterproof curtain, and Q_w is the pumping rate at which water is extracted from the pumping well. The barrier effect on groundwater seepage includes three aspects: (i) to change the direction of seepage, (ii) to change the seepage path, and (iii) to change the seepage area.

2.1. Seepage direction

Fig. 2 shows a cross-sectional view of the groundwater head in the confined aquifer without and with a barrier under conditions involving pumping with a fully-penetrated well. The insertion depth (b_b) of the waterproof curtain into confined aquifer for the case without barrier is zero, that is, $b_b = 0$. For the case with barrier,

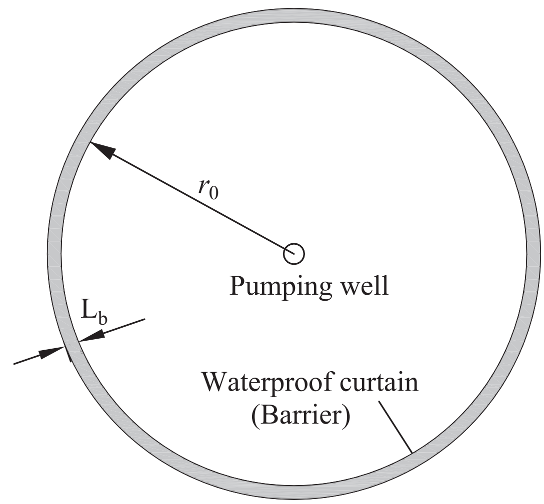

Fig. 1. Plan view of a circular pit.

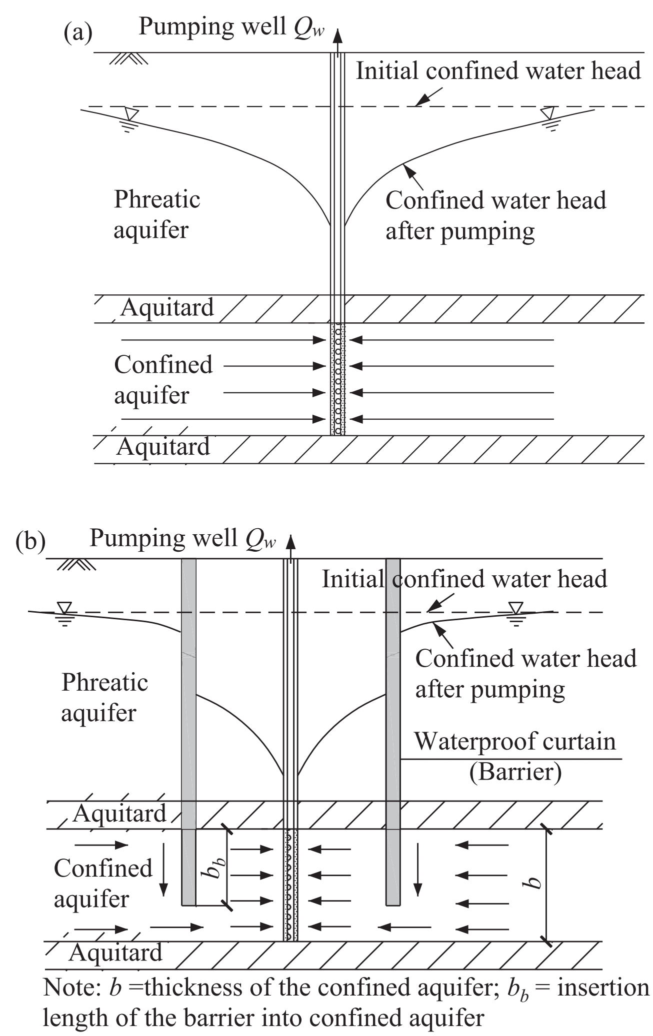

Fig. 2. Cross-section view of groundwater head and fully penetrated pumping well in confined aquifer: (a) without barrier, (b) with barrier.

b_b is larger than 0, however, b_b is less than the thickness (b) of the confined aquifer, that is, $0 < b_b < b$. It can be seen from Fig. 2(a) that, groundwater flows into well screen perpendicularly in case with-