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Research Paper

Evaluation of hydraulic parameters from pumping tests in multi-aquifers with vertical leakage in Tianjin

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ABSTRACT

This paper presents a case history of behaviour during a series of pumping tests in an alternated multi-aquifer-aquitard system in a foundation pit in Tianjin, China. The test site is located at Tianjin Railway Station, which is in the downtown area and is surrounded by many buildings. The groundwater system at the test site is composed of a phreatic aquifer and three confined aquifers. Four groups of single well pumping tests were conducted in each aquifer to obtain the hydrogeological parameters of the aquifers and investigate the hydraulic connection among the aquifers. Test results show that there is hydraulic connection among the upper 3 aquifers. Moreover, both analytical and numerical methods were employed to analyse the hydrogeological parameters. The analytical solution was obtained for the phreatic aquifer using the Dupuit equation, and the Cooper–Jacob method was conducted for the confined aquifers. The numerical simulation was performed using a finite element method (FEM). The results illustrate that the numerical method gives more reliable results than the analytical method does. The numerical simulation considers the anisotropic characteristic of soils, and the hydrogeological parameters of all of the soils can be calculated. The analytical solution, however, may be influenced by wellbore storage or by the leakage effect of the aquitards, and it only gives the parameters of the aquifer where the pumping tests were performed.

1. Introduction

Soft Quaternary deposits of large thickness are distributed in the coastal regions of China under different palaeoclimatic and sedimentary (marine or terrestrial) environments, forming an alternated multi-aquifer aquitard system (MAAS) with the characteristic of a very high groundwater head [4,47,50]. When excavation pits are located in this type of soft deposit, dewatering is conducted to ensure excavation safety [34,38,45]. In general, dewatering may last for months or even more than one year, which may cause ground settlement [5–7,35,40,42]. In the analysis of excavation dewatering, understanding the hydrogeological parameters, such as the hydraulic conductivity (k), transmissivity (T), and storage coefficient (S), is helpful in reducing the settlement caused by dewatering.

There are three common ways to ascertain the hydrogeological characteristics of soils: predicting methods [10,12,28], laboratory tests [8,25,26] and field tests [11,16,32]. Among these, field tests, such as pumping tests and slug tests, are the most widely used. Slug tests are primarily used in weak aquifers, where it is difficult to draw groundwater continuously, and pumping tests are commonly used in aquifers, where groundwater can be drawn easily. Generally, an analytical method for non-steady flow has been used to obtain hydrogeological parameters by matching observed drawdown data [3,13,14,18,19,37,43]. In recent years, back calculation through a numerical method has become more widely used, particularly in complicated geological environments [20,22–24,27,46].

This paper presents a field case study of pumping tests conducted in Tianjin, China. Both analytical and numerical methods are employed to obtain the hydrogeological parameters, and the results from the two methods are compared.

2. Site conditions

The Tianjin transportation hub project is located in the Hedong district of Tianjin and includes the traffic square behind Tianjin

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Railway Station, the landscaped square in front of Tianjin Station, and the related municipal works. The traffic square is the transfer hub for metro lines 2, 3, and 9, Jinjing Intercity Railway and China Railway. Metro line 2 is parallel to metro line 9 from east to west and crosses metro line 3 below the traffic square. The construction site is 400 m from the Haihe River. Fig. 1 presents the site plan of the transfer hub project. There are many buildings around the excavation pit. The excavation pit consists of three sections (sections I, II, and III). It is one of the largest and deepest excavations ever constructed in Tianjin. The depth of the excavation varies from 23.0 m to 32.5 m. To investigate the groundwater conditions at the project site, several single-well pumping tests were performed in the planning square. The test site was approximately 315 m from the excavation (see Fig. 1).

3. Engineering geology and hydrogeology

3.1. Geological conditions

The elevation at the test site is 2.3–2.4 m above sea level. Fig. 2 shows the soil profile and properties at the construction site. As observed in Fig. 2, the investigation area is characterised as a marine–terrestrial zone with silty sand, silt and silty clay. The first layer is uncontrolled fill (artificial layer) in the upper 2.6 m below the ground surface, followed by silty clay and silt to a depth of 12.6 m. The next layer is silty clay extending to a depth of 20.5 m, which is underlain by silt and silty sand to a depth of 32.1 m. These layers are underlain by silty clay with some silt to a depth of 44.4 m. The subjacent layer is silt to a depth of 47.2 m. Under the silt, silty clay is present at the site, to a depth of 64.0 m. The following layer is silty sand to a depth of 68.0 m. Beneath this layer is a layer of silty clay until the termination depth of 80 m.

The soil properties along the depth were established through a series of laboratory tests. The grain size distribution indicates that the silt content of the silty clay and silt is relatively high, at approximately 78%. The initial void ratio, e_0, was determined based on the soil's physical properties from the laboratory tests. The water contents are generally close to the liquid limit, apart from that of silty clay, whereas the plasticity index of the silty clay is approximately 19%. The compression index, C_c, was obtained from laboratory oedometer tests. For the layers from the ground surface to 15 m deep, the compression index, C_c, ranges from 0.2 to 0.4, and for the soil layers at depths of more than 20 m, C_c, ranges from 0.1 to 0.2.

3.2. Hydrogeology

The types of groundwater are phreatic water and confined water. There are one phreatic aquifer (referred to as Aq0) and three confined aquifers (referred to as AqI, AqII, and AqIII). The aquifers are separated by three aquitards (referred to as AdI, AdII, and AdIII). The values of hydraulic conductivity k_h and k_v that are plotted in Fig. 2 were obtained from laboratory oedometer tests using soil samples extracted in both horizontal and vertical directions, respectively. Table 1 lists the measured values of k_h, k_v, and k_h/k_v, which shows that k_h/k_v varied from 1.5 to 5.8.

Aq0 is primarily composed of silt with a thickness of 7.3 m. In this article, the ground surface is taken as the reference datum; the water level of the phreatic aquifer is −1.90 to −1.97 m. AqI is mainly composed of silt and silty sand. The average thickness of the sand is 5.0 m. The water level of AqI is −2.79 to −2.84 m. AqII is mainly composed of silt with an average thickness of 2.0 m. The continuity of this layer is not good in the horizontal direction. The water level of AqII is −3.07 to −3.38 m. AqIII is mainly composed of silty sand with an average thickness of 4.0 m. The water level of AqIII is −12.25 to −12.35 m.

4. Pumping tests

4.1. Well installation

Pumping tests were performed between March 16, 2006, and April 4, 2006 [51]. Fig. 3 shows a plan layout of the wells. There are four pumping wells (labelled W1–W4) and ten monitoring wells. The monitoring wells for pumping well W1 were P1-1 and P1-2, for pumping well W2 were P2-1 to P2-3, for pumping well W3 were P3-1 to P3-3, and for pumping well W4 were P4-1 and P4-2. The distance between wells W1 and P1-1 and P1-2 was 3.35 m and 7.90 m, that between wells W2 and P2-1, P2-2 and P2-3 was 3.85 m, 8.95 m and 19.75 m, that between wells W3 and P3-1, P3-2 and P3-3 was 4.00 m, 9.10 m and 19.90 m, and that between wells W4 and P4-1 and P4-2 was 7.91 m and 12.31 m, respectively. Fig. 4 plots the structure of the wells. The pumping wells W1–W4 were installed in Aq0 to AqIII at depths of 18 m, 35 m, 50 m and 71 m, respectively. The four wells were fully penetrating wells with an internal radius of 300 mm and an external radius of 610 mm. The screens of the pumping wells were 11 m long in Aq0, 9 m long in AqI, 4 m long in AqII, and 7 m long in AqIII. The monitoring wells had an internal radius of 219 mm

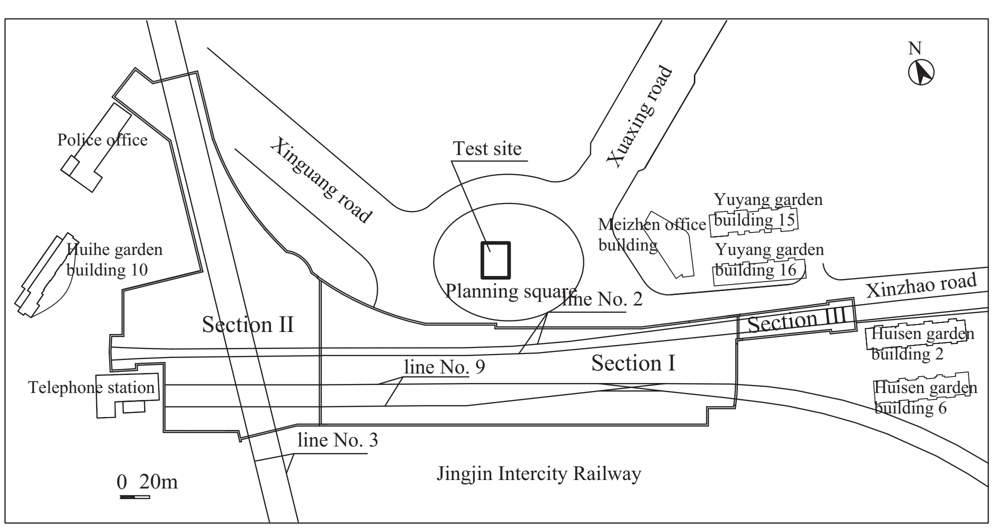

Fig. 1. Plan view of the construction site.