Study on Difference of Permeability Coefficient Obtained by Hydrogeological Test in Ground Fissure Zone

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Abstract. In order to study the reason of different permeability coefficient obtained by pumping test and water injection test, based on the field test of ground fissures in Xi’an City, this paper analyzed the reasons that affect the results of the two tests by means of chart analysis and curve fitting. At the same time, the reasons for the different permeability coefficients of the upper and lower walls of ground fissures are analyzed. The results show that the permeability coefficient has a linear relationship with flow rate and drawdown. The permeability coefficient increases with the increase of discharge and decreases with the increase of drawdown. This phenomenon is related to the changes of capillary water and bound water. The difference of permeability coefficient between the upper and lower walls of ground fissures is also related to the content difference of bound water and capillary water.

Keywords. Ground fissure, pumping test, water injection test, permeability coefficient.

1. Introduction
Ground fissure is a kind of special urban geological disaster. Since the first ground fissure was discovered in goose, Texas, USA from 1918 to 1926 since the discovery of the green oil field [1-2], scholars have studied ground fissures for more than 100 years. The activity of ground fissures in Xi’an is closely related to urban pumping activities, which has been studied and demonstrated by predecessors [3-7]. Pumping groundwater makes the aquifer produce uneven settlement on the surface under the action of water releasing pressure, and aggravates the activity of ground fissures. Therefore, it is particularly important to study the hydrogeological characteristics of ground fissures. In order to ensure the safety of construction in the area across ground fissures, it is necessary to master the hydrogeological characteristics of the ground fissure area, so as to provide reasonable parameters for the design of foundation pit dewatering.

The permeability coefficient can be measured by laboratory tests and in-situ tests. During the tests, some scholars discovered that the permeability coefficient obtained by different test methods in the same site will be different [8-10]. For the reason of this phenomenon, James J. Butler Jr. et al. [11] considered that the difference of permeability coefficient obtained by pumping test and slug test is due to the well wall conditions and observation wells. Ju Xiaoming et al. [12] carried out in-situ pumping test and slug test on a site, and considered that the difference between the two tests was due to the size of the site affected by the test. Pumping activities will have a certain impact on the properties of the site rock and soil, especially in the ground fissure area. Helm [13] pointed out that the seepage force generated by groundwater under pumping conditions affects the stress-strain distribution and
deformation of aquifer. Wang Qingliang [14] and Liu Hongyun [15] discussed the influence of pumping on ground fissures. Zhao Xi et al. [16] and Xu et al. [17] think that the permeability coefficient will also change when the pore properties of site rock and soil change due to pumping and other reasons. Therefore, it is necessary to explore the reasons for the differences in the results of different hydrogeological tests.

The purpose of this paper is to study the difference of permeability coefficient obtained from different in-situ hydrogeological tests at sites across ground fissures and the reasons for this phenomenon. In this paper, based on the relevant data of in-situ test results of a site near the F3 ground fissure in Xi’an city as the research background, various factors in the test are analyzed based on the test data, and the reasons for the difference of permeability coefficient obtained by different test methods are studied, and the differences of these data are explained theoretically. Discussion on the difference of permeability coefficient between the upper and lower walls of ground fissures is of great significance for obtaining the permeability coefficient through hydrogeological test and studying the hydrogeological characteristics of ground fissures in Xi’an.

2. Overview of Test Site
In this paper, based on the results of water injection test and water pumping test in Laodong South Road Primary School of Xi’an City, which is 300 m away from Metro Line 1 in the north of Xi’an City [18], the data are processed and analyzed. The site strata are mainly loess, paleosol and silty clay. The phreatic water level in the site is between 9.20 m and 9.70 m. The recharge mainly comes from atmospheric precipitation and underground runoff, and is subject to natural evaporation, artificial development and groundwater seepage discharge. Nine boreholes are arranged in the test, with three pumping holes (D1~D3) respectively arranged on the fracture zone, the footwall and the hanging wall of the ground fissure, and the arrangement direction is roughly vertical to the direction of the ground fissure. And 6 observation boreholes (G1~ G6) are arranged in two directions parallel to and perpendicular to the strike of ground fissures. See figure 1 for details.

![Figure 1. Plan of pumping wells and boreholes.](image)

3. Test Method
The main test methods are pumping test and water injection test. Pumping test is a kind of field in-situ test to identify some hydrogeological conditions. According to The Specification for Water Conservancy and Hydropower Engineering Drilling Pumping Test [19], three times of drawdown should be set for steady flow pumping test, so as to correctly select the pumping test characteristic curve, correct the permeability coefficient parameters, and infer the size of borehole water inflow. Xue Yuqun et al [20] have studied the principle of calculation.

Water injection test is to inject water into the well at a constant flow rate to raise the water level in the well. After the water level is stable and lasts for a period of time, the water injection can be stopped. The relationship between water level and time can be observed and the permeability...
coefficient of soil layer can be calculated. According to the change of water head, it can be divided into constant head water injection test and variable head water injection test [21].

4. Results

4.1. Water Injection Test Results
The results of in-situ borehole water injection test are shown in table 1. The permeability coefficient K measured by borehole G1-G5 is between 0.245-0.806 M / D, and that of borehole G6 is 4.853 M / D. It is speculated that there are other drainage channels around the location of borehole G6, which makes the calculated permeability coefficient value far greater than that of other boreholes. Therefore, the data of borehole G6 is omitted in the analysis.

Table 1. Drilling water injection test results.

| #  | s/m | t/min | Q/(L/min) | k/(m/d) |
|----|-----|-------|-----------|---------|
| G1 | 5.07| 100   | 0.67      | 0.259   |
| G2 | 5.21| 149   | 5.30      | 0.302   |
| G3 | 4.70| 30    | 23.85     | 0.806   |
| G4 | 4.65| 150   | 1.30      | 0.403   |
| G5 | 7.85| 170   | 2.60      | 0.245   |
| G6 | 5.60| 89    | 4.26      | 4.853   |

4.2. Draining Test Results
The test results grouped by pumping wells and their observation wells have been listed in detail by Wang pengpeng [18]. The permeability coefficient values of observation wells D1 and D2 are between 0.49-1.16m/d, and most of the data are greater than 0.6m/d, while the results of pumping hole D3 are 0.17-0.35m/d, which is quite different from the data of the first two pumping wells. It is speculated that the reason may be that the data of pumping hole D3 is out of order due to the use of G6 as observation hole in D3.

5. Analysis

5.1. Influence of Flow Rate on Permeability Coefficient
According to the data in table 1 and other referenced datas, it can be seen that most of the permeability coefficient values obtained from the pumping test are greater than those of the water injection test. The average permeability coefficient of the pumping test is 0.78 m/d, and that of the water injection test is 0.40 m/d, the statistical average permeability coefficient of the pumping test is 1.95 times of the average value of the drilling water injection test; The average flow rate of water injection test is 6.75 L/min and 109.63 L/min, which is 16.2 times of that of water injection test. Figure 2 shows the relationship between permeability coefficient and flow rate of borehole water injection test, and its expression is as follows:

\[ K = 0.02Q + 0.25 \]
It can be seen that there is an obvious linear relationship between the permeability coefficient and the flow rate in the process of water injection test. Figure 3 shows the combination diagram of permeability coefficient value and flow rate (observation well number is marked in brackets), broken line reflects permeability coefficient change, and histogram reflects flow change. It can be seen that in the water injection test part, the permeability coefficient and flow rate are kept at a low level, while in the pumping test part, the permeability coefficient and flow rate are higher than those in the water injection test part. The results show that the permeability coefficient and flow rate have a good corresponding relationship. The scatter plot is drawn by taking the multiple of the pumping test flow of each observation hole to the water injection test flow as the abscissa, and the corresponding multiple of the permeability coefficient as the ordinate, as shown in figure 4. These data can be expressed as:

$$\frac{K_d}{K_g} = 0.007 \frac{Q_d}{Q_g} + 1.500$$  \hfill (2)

Among them, $K_d$ and $K_g$ are the permeability coefficient values measured by pumping test and borehole water injection test respectively. $Q_d$ and $Q_g$ are the flow rates in the process of pumping test and borehole water injection test respectively. The results show that the larger the difference between

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**Figure 2.** Permeability coefficient changes with flow rate in water injection test.

**Figure 3.** Combination diagram of discharge and permeability coefficient of pumping and water injection test.

**Figure 4.** The relationship between $K$ and $Q$ magnification.
pumping test and borehole water injection test is, the greater the difference between the test results will be, and there is a relatively obvious linear relationship between them.

5.2. Influence of Drawdown on Permeability Coefficient
Drawdown reflects the change of water level during the test. For borehole pumping test, it is the difference between the initial water level of borehole and the water level at the end of pumping. For water injection test, it is the difference between the water level when the well water reaches the set value after the test and the final water level at the end of the test. Figure 5 shows the combination of drawdown and permeability coefficient of each pumping test. The broken line shows the change of permeability coefficient, and the histogram shows the change of discharge. The results show that the permeability coefficient decreases with the increase of drawdown in each group of pumping tests. The corresponding relationship between drawdown and permeability coefficient in pumping test is plotted as a scatter diagram, as shown in figure 6. It can be expressed as:

$$K = -0.02S + 1.04$$  \( (3) \)

![Figure 5. Combination diagram of discharge and permeability coefficient of each group of pumping test.](image)

![Figure 6. Relationship between drawdown and permeability coefficient.](image)

It can be seen that with the increase of drawdown, the permeability coefficient generally shows a decreasing trend. The reason why the same drawdown corresponds to different values of permeability coefficient is that in pumping test and borehole water injection test, drawdown is often taken as a fixed value, and multiple groups of experiments are carried out under the same drawdown. Under the condition of different drawdown, the permeability coefficient decreases with the increase of drawdown, which also accords with the variation trend of permeability coefficient in figure 5.

5.3. Theoretical Explanation and Discussion
As mentioned above, the permeability coefficient obtained from pumping test and water injection test is mainly affected by discharge and drawdown. In this paper, homogeneous cohesive soil model is taken as an example to analyze it.

According to the Stokes pore flow permeability coefficient equation [22]:

$$k = \frac{\gamma_{wz} R^2}{8\eta} n$$  \( (4) \)

where k is the permeability coefficient, R is the radius of capillary, n is the porosity of soil, \( \gamma_{wz} \) is the gravity of free water, and \( \eta \) is the dynamic viscosity coefficient of free water. Some of the pores occupied by bound water and capillary water are not allowed to pass through under certain conditions, which are invalid pores. However, the pores occupied by free water allow free water to move freely, which are effective pores. The Stokes formula with effective porosity can be expressed as:
For the bound water in the soil, the strong bound water will not participate in the seepage, while the weak bound water will transform into free water to participate in the seepage when the hydraulic gradient reaches a certain value [23]. For the capillary water in saturated soil, it is subjected to capillary force due to the existence of bubbles in the soil, so it has been fixed at the edge of the contact between soil particles. Under certain conditions, when the force produced by seepage is greater than capillary force, capillary water will also move. This shows that the effective porosity is not invariable in the process of seepage, but is changed by the transformation of water in soil. The essence of seepage process is that capillary water, weakly bound water and gravity water in pores change into free water under certain conditions.

According to Darcy formula [24]: 
\[ Q = K_i A \]
the seepage area a can be regarded as a constant. With the increase of discharge Q, the hydraulic gradient \( i \) will increase. When the hydraulic gradient increases to a certain value, the capillary water in the soil overcomes the capillary force and transforms into free water to participate in the seepage movement, and part of the weakly bound water also transforms into free water to participate in the seepage, which makes part of the invalid pores turn into effective pores, thus increasing the permeability coefficient.

In addition, soil particles will be affected by seepage force, which is the product of soil particle buoyancy and hydraulic gradient. When the hydraulic gradient increases, the permeability of soil particles increases, and some fine particles move, thus changing the connectivity of soil pores. From this point of view, the increase of flow leads to the increase of hydraulic gradient and the increase of effective porosity, thus increasing the permeability coefficient.

The results show that drawdown also affects the permeability coefficient, and the permeability coefficient decreases with the increase of drawdown. The drawdown measured in a pumping well is the superposition of head loss caused by various reasons, including: the loss when the water flows through the filter; the head loss caused by the change of the movement direction when the water flows close to the horizontal movement to the vertical movement in the well; and; This also means that the greater the drawdown, the greater the head loss. The head loss will lead to the smaller hydraulic gradient in the calculation process, which will make the calculated permeability coefficient smaller.

6. Discussion on the Permeability Coefficient Between Two Sides of Ground Fissures

According to the test results, there are differences in permeability coefficient between the two sides of ground fissures. The permeability coefficient of hanging wall is the smallest, the permeability coefficient of footwall is higher than that of hanging wall, and the permeability coefficient of ground fissure zone is higher than that of upper and lower walls [6]. When pumping test is carried out in borehole D1 and D2 in footwall, the reaction between borehole D3 and G6 is very small, which indicates that the hydraulic connection between hanging wall and fracture zone is weak. In the process of the change of groundwater level caused by rainfall infiltration, natural evaporation and various factors in historical time, there is more hydraulic exchange and connection between the footwall and the ground fissure, and the hydraulic exchange between the hanging wall and the ground fissure zone may be less than that of the footwall.

According to Li Xinsheng, et al. [25], the water content of the south side (i.e. the hanging wall) of the ground fissure is higher than that of the north side (footwall); According to the research done by Li Yanlong [26], the higher the water content in the soil is, the lower the chemical potential energy is, and the energy in the soil body must transfer from the area with high chemical potential energy to the area with low chemical potential energy, and the soil has a higher matrix gradient potential, so that the water migration amount in the soil increases with the increase of the bound water content. Wang Pingquan [27] also concluded in his research that the content of bound water increases with the increase of humidity. The higher the water content in the hanging wall of ground fissures also means that the higher the content of bound water, and in general, the bound water is relatively stable,
occupying the volume of pores and hindering the seepage flow. On the macro level, the permeability coefficient of the hanging wall of ground fissures is smaller than that of the footwall. In addition, the more stable hydraulic connection and better hydraulic exchange between the footwall and the ground fissure zone may also make the fine particles and soluble substances in the footwall soil drain through the fracture zone, so that the footwall has better permeability.

7. Conclusion
In this paper, based on the relevant data of in-situ test results of a site near the F3 ground fissure in Xi’an city as the research background, the factors in the test are analyzed based on the test data, and the differences between the permeability coefficient obtained by different test methods and the permeability coefficient between the upper and lower walls of the ground fissure are comprehensively studied:

(1) Based on the research background of the results of borehole pumping test and borehole water injection test in Xi’an, the difference of permeability coefficient between the two tests is compared and analyzed, and the conclusion is drawn that the average permeability coefficient measured by the borehole pumping test is 1.95 times of the water injection test, and the average flow rate is 16.2 times of the water injection test. There is a linear relationship between the permeability coefficient and the flow rate.

(2) The reason for the difference of permeability coefficient between borehole pumping test and borehole water injection test is that under the action of seepage, when the hydraulic gradient increases due to the increase of flow rate, the weakly bound water and capillary water in the pores are transformed into free water to participate in the seepage, and some small particles in the soil migrate, which leads to the increase of effective porosity and the increase of permeability coefficient.

(3) In the pumping test, the permeability coefficient decreases with the increase of drawdown. The reason is that the increase of drawdown intensifies the head loss and makes the calculated value of permeability coefficient smaller.

(4) The difference of permeability coefficient between the upper and lower walls of ground fissures is related to the hydraulic connection of the fracture zone. The hydraulic connection between the hanging wall and the fracture zone is poor, and the permeability coefficient is the smallest; The better hydraulic connection between the footwall of ground fissure and the fracture zone makes more dissolved matter in soil drain through the fracture zone, so it has better permeability.

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