Hydrogeology Tests Performed in Shazaoyuan Candidate Site for China’s HLW Geodisposal

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Abstract. Rock mass hydraulic conductivity is one of the most important indexes for candidate site quantitative assessment of high-level radioactive waste disposal. 178 hydrogeology tests, mainly constant head injection test and pulse test, were performed in the 4 boreholes drilled in Shazaoyuan candidate site. Reliable hydraulic conductivity was obtained with transient curve matching methods. The result shows that the hydraulic conductivity was high heterogeneous; the maximum hydraulic conductivity was $9.30 \times 10^{-8}$ m/s and 93% of the sections were lower than $10^{-8}$ m/s. Shazaoyuan candidate site can be inferred as one of the most potential sites for the geological disposal of China’s HLW in the view of low permeability.

1. Introduction

High-level radioactive waste (HLW) is a kind of special waste with strong radioactivity, high toxicity, containing long half-life radionuclide, generating heat, its final disposal is extremely difficult [1]. The geological disposal is commonly regarded in the world as the most reasonable and effective way to the safe disposal of high-level radioactive wastes. Transport in groundwater is an important mechanism for the migration of radionuclide to the biosphere [2], rock mass hydraulic conductivity affects groundwater flow, solute migration rates and the long-term safety of underground works, low permeability helps to isolating radionuclide from biosphere [3]. Therefore, rock mass hydraulic conductivity is one of the most important indexes for candidate site quantitative assessment of high-level radioactive waste disposal.

China started research on HLW disposal in 1985, granite has been chosen as the prior host rock, and Beishan area, located in Northwest China’s Gansu Province, is selected as the most potential area for China’s HLW repository [4]. Site characterized works has been performed in Shazaoyuan candidate site to assess its suitability for geological disposal repository of HLW.
Fig. 1 (a) location of Shazaoyuan site and (b) borehole location
2. Location and Geology
Shazaoyuan site, one of the most potential pre-selected sites of Beishan area, is located at north of Jiayuguan city with a distance of 80km. Shazaoyuan site shows a typical gobi-desert view with rare plant cover, baring rocks, hill and low mountains. The mean annual precipitation is 60–120mm, while mean annual evaporation is about 3200 mm. The location of Shazaoyuan site is shown in Fig.1a. The main host rock of Shazaoyuan site is biotite granodiorite, therefore, the main type of groundwater is bedrock fissure water. 4 boreholes with a depth of 600m have been drilled in Shazaoyuan site since 2014 (Fig. 1b), the borehole core shows a RQD of more than 90%, which infers this site a good quality rock mass with few fractures.

3. Hydrogeology Tests

3.1. Instrumentation
Hydrogeology tests were performed in the 4 boreholes with double packer hydrogeology test system (DPHT) to obtain reliable hydraulic conductivity, DPHT was assisted by the International Atomic Energy Agency through its technical cooperation projects, and is an ideal system for borehole test of which the depth is no more than 600m, transmissivity of test section is higher than $10^{-13} \text{m}^2/\text{s}$.

DPHT is composed of surface part and underground part. Underground part is mainly composed of two inflatable packers and three pressure and temperature transducers; surface part plays a role of controlling and monitoring, such as the monitoring of flow rate, pressure controlling of packers. Fig.2 shows some test equipment parts and equipment connection schematic diagram. The borehole was divided into 3 parts, interval (test section), above interval and below interval, after the packers were inflated. Water pressure and temperature of sections could be measured respectively by the transducer installed in sections and transferred directly to the surface monitoring system by electrical cables. Corresponding operations can be adopted instantly according these data, for example, if the water pressure of above interval section keeps rising during the injection period, it means the interval is not efficiently sealed, operators must re-inflat packers with a higher pressure or move the packers to other depths until the test section is efficiently sealed.

![Fig.2](image-url) (a)packers, (b)flow meter and (c)schematic diagram of double packer hydrogeology test system
3.2. Test procedure

Constant head injection tests (CHI tests) and pulse tests were performed in these 4 boreholes. CHI tests are preferred because they allow avoiding wellbore storage effects and are then able to provide most reliable values of the hydraulic conductivity. CHI tests are applicable for hydraulic conductivities ranging between $10^{-6}$ and $10^{-11}$ m/s. Furthermore, pulse tests are used to investigate very low permeability zones ($K<10^{-11}$ m/s) in which the flow-rate for the injection tests cannot be measured properly [5].

The interval length of CHI tests conducted by Swedish Nuclear Fuel and Waste Management Company (SKB) is 100m, 20m and 5m successively, the injection period is followed by a pressure recovery period of approximately the same duration as the injection period [6]. Based on the experience of SKB, the interval length of CHI tests performed in Shazaoyuan site is about 12 m, and injection and recovery period were both conducted. Fig.3a shows the procedure of CHI test performed in borehole BS25.

CHI tests were carried out by applying a constant injection pressure of 30 m water column above the ground surface, and flow rate was measured by flowmeters automatically during the injection period. After injection period, the recovery in this section was measured. Generally, the higher the flow rate was during the injection period, the shorter the recovery period would last. Procedure of CHI tests performed in Shazaoyuan site was the same with tests conducted by SKB: 1) Packer inflation; 2) pressure compliance in the test section; 3) Injection of water and registration of decline of flow rate in test section; 4) Registration of pressure recovery in test section; 5) Stop of recovery period; 6) Packer deflation [7-8].

The main parameters for calculating the hydraulic conductivity are the pressure difference and flow rate of the test section during the CHI tests. In some cases, the permeability of the test section was too low that the flow rate couldn’t be measured by the flowmeters, then pulse tests were conducted in these sections. The procedure of pulse tests was basically the same as CHI tests. Fig.3b shows pulse tests procedure performed in borehole BS20.

4. Data Interpretation

4.1. Data interpretation of CHI tests

Both steady formula methods and transient curve matching methods were used for the data interpretation of CHI tests. A raw hydraulic conductivity could be obtained instantly after the recovery period completed by formula methods, since data interpretation with formula methods is quick and
convenient. A more reliable K could be obtained by transient curve matching methods based on the analysis of flow models and dimensional. The software used for transient curve matching in this paper was AQTESOLV, which contains a series of algorithms (models) applicable to various hydrogeology tests (constant flow, constant pressure, slug and pump) [6], and it has been widely used for hydrogeology tests data interpretation in Sweden and Finland [7-9]. Constant head injection period is most often interpreted with the Jacob and Lohman solution (Fig. 4a) [10], and Agawal solution is commonly used for data interpretation of recovery period (Fig. 4b) [11]. Basically, the K data obtained from injection and recovery period would be the same, as shown in Fig. 4a and Fig. 4b.

![Fig.4](image)

**Fig.4** (a) curve matching result of injection period of section 355.33~367.69m in borehole BS25, (b) curve matching result of recovery period of section 355.33~367.69m in borehole BS25, (c) curve matching result of pulse test of section 484.12~496.57m in borehole BS20.

### 4.2. Interpretation of Pulse test data

Hytool, which was developed by Philippe Renard of Neuchatel University in Switzerland, is an open source Matlab toolbox that provides a library of analytical solutions and a set of routines to pulse tests interpretation [12]. Fig. 4c shows the curve matching result of pulse test performed in the section of 484.12~496.57m in borehole BS20, the transmissivity of this test section is $2.7 \times 10^{-10} \text{m}^2/\text{s}$.

### 5. Result

#### 5.1. Profile of hydraulic conductivity

178 CHI tests and pulse tests, with the interval length was 12.50m ± 0.30m, were performed in the 4 boreholes located in Shazaoyuan site, and a reliable conductivity of every section was obtained by data interpretation procedure introduced in sections 3. Fig. 5a shows the of hydraulic conductivity profile of 4 boreholes.

The hydraulic conductivity of rock mass along 4 boreholes vary between $2.48 \times 10^{-15} \text{m/s}$ and $9.30 \times 10^{-4} \text{m/s}$, of which shows a high heterogeneity in both horizontal and vertical directions. For the
section below the depth of 400m, which would be the repository depth, the hydraulic conductivity is mainly lower than \(10^{-8}\) m/s.

![Fig. 5](image)

**Fig. 5** (a) Profile and (b) cumulative probability distribution of hydraulic conductivity

5.2. **Probability distribution of hydraulic conductivity**

In the quantitative assessment index of site suitability, the higher the probability of rock mass hydraulic conductivity lower than \(10^{-8}\) m/s is, the more suitable of the site be chosen as HLW repository site [3]. The hydraulic conductivity of over 93% of all test sections was lower than \(1 \times 10^{-8}\) m/s, which means Shazaoyuan could be a potential site for HLW repository.

**6. Conclusion**

The hydraulic conductivity of rock mass along 4 boreholes vary between \(2.48 \times 10^{-13}\) m/s and \(9.30 \times 10^{-8}\) m/s, of which shows a high heterogeneity in both horizontal and vertical directions.

The hydraulic conductivity of over 93% of all test sections was lower than \(1 \times 10^{-8}\) m/s, which means Shazaoyuan could be a potential site for HLW repository.

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