A new method for measuring the flow velocity and direction of groundwater

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Abstract: In this paper, in a karst fissure well with a large water depth, the flow velocity and flow direction of the monitoring wells at different depths (239m, 157m) were measured using the AquaVISION Colloidal Borescope produced by Geotech, USA. The results showed that, the flow direction of 239m deep karst water was 322.73° (37.27° North West), the flow velocity was 1496.60 μm/s. The flow direction of 157m deep karst water was 309.18° (50.82° North West), the flow velocity was 1032.0 μm/s, the flow direction of groundwater was Northwest, and the flow velocity gradually decreased from deep to shallow.

1. Introduction

The commonly used methods for groundwater flow velocity and flow direction are conventional methods such as hydro-geophysical prospecting, tracer method, charging method or a combination of two methods. When the flow velocity and direction are measured by the tracer method, the tracer needs to be placed in the well, which is poor in safety and controllability, especially when it is measured for drinking water wells, it is easy to cause groundwater pollution. Charging method is susceptible to external magnetic field interference and has limited in test depth[4]. The AquaVISION Colloidal Borescope adopts an advanced detection process, and the test probe is used to measure the colloidal particles in the groundwater (the neutral suspension in the water), and the groundwater flow velocity and the flow direction value can be accurately measured. This technology has been used in the shallow water of the North Canal section of Beijing Subway Line 6[5]. In addition, the American Chamber of Commerce in the Desert Research Institute in Boulder, Nevada, used a colloidal hole detector to measure the laboratory laminar velocity at 0.10 cm/s, and the tracer test measured at a speed of 0.11 cm/s. The safety and accuracy of the instrument have been experimentally verified[6].

2. Instrument Related Description

2.1. Instrument Introduction

The AquaVISION Colloidal Borescope mainly consists of high resolution video camera, precise flux valve electronic compass component, an optical magnifier, a high intensity backlight and a steel shell. It can be sealed at 1000 feet water depth. The device is approximately 89cm long and 44mm in diameter for easy insertion into monitoring wells larger than 5.8cm in diameter. It is connected to the camera controller with a high-strength cable. Software AQUALITE is mainly used to control camera shooting, parameter adjustment and calculation of related data. Instrument connection as shown in Figure 1.
2.2. Measuring Principle
The Colloidal Borescope calculate the flow velocity and flow direction of groundwater by observing the migration of colloidal particles in groundwater. The video camera takes photos, magnifies and digitizes the observed colloidal particles in a preset time frame, and transmits them to the instrument observation interface through a high-strength cable. The computer compares the first digitized image with the next image, and a vector line connects the two locations of the same particle, thereby obtaining the corresponding particle motion direction and velocity. The compass is used to determine the actual running track of the colloidal particles by capturing the magnetic direction of the image, and finally determine the flow rate and flow direction of each colloidal particle. The software AQUALITE uses the parallelogram rule to vectorize the direction and velocity of each particle to determine the direction and velocity of the water flow finally. The number of captures of colloidal particles is critical to the test results of the flow direction and velocity. If the number is too large, it will affect the operation of the computer. It is easy to make mistakes. If the quantity is too small, the representativeness is not strong. Generally choose to capture 60-100 colloidal particles in 1 minute. Parameters affecting the number of colloidal particles captured are Capture Delay-millisecond, Particle Sensitivity, Minimum Particle Size. In the field test, we need to use AQUALITE to combine the three, so that the number of particles captured per minute is 60-100.

2.3. Determination of Priority Water Flow Zone
Priority water flow zone dominates groundwater flow including homologous water layers. For reliability, the colloidal borescope must be measured in these priority water flow zones. The so-called dominant water flow zone means that the velocity and direction of the water flow are relatively stable, and it is the most representative flow velocity and direction of the water layer. According to the hydrogeological histogram and data of groundwater drilling, the colloidal borescope should be placed in the center of the water flow area to start measurement. In order to further determine the priority water flow zone, the colloidal borescope is tested from the center position of the water flow area to the top and bottom plate positions of the water flow zone, and the priority water flow zone is determined by comparison.

3. Application
The Dawu water source belongs to oversize groundwater source in the north, and the aquifer thickness is 200-300m. It is a relatively independent hydrogeological unit. There are two major aquifer in the unit. The upper part is the Quaternary pore water aquifer, and the lower part is the Ordovician fractured karst water aquifer. The Ordovician fractured karst aquifer is the main mining layer for drinking water and industrial water in the area. Pore water is replenished by atmospheric precipitation, and water abundance is poor. The karst water is mainly supplied by the atmospheric precipitation infiltration in the southern mountainous area and the leakage of the river. Its water abundance is strong.

According to the historical data of the water source and the water level elevation of the observation well, it is determined that the general direction of groundwater flow in the monitoring well area is northwest. Locations of observation well and monitoring well are shown in Figure 2.
3.1. Drilling Information and Location of The Water Flow Zone
The measuring well is 365 m deep and the water level is measured at 65.84 m. From the top to the bottom, the stratigraphic chronology are the Quaternary, Ordovician, and Cambrian.(see Table 1) According to the drilling information, there are two water flow zones: 156.3-158.7 m, 236.3-242.6 m. The water flow zone is thinner and the test position is first selected in the middle of the aquifer. That is 157, 239 m. Until the priority water flow zone is detected.

| stratigraphic chronology | Top buried depth (m) | Bottom buried depth (m) | Stratigraphic lithology | karst development |
|--------------------------|----------------------|-------------------------|-------------------------|------------------|
| Quaternary               | 0                    | 40                      | The surface layer is planting soil, and the following is clay gravel layer |
| Ordovician               | 40                   | 285.8                   | Limestone and cloud limestone | There are minor fractures and small dissolved holes in the local part of 156.3-158.7 m and 236.3-242.6 m. |
| Cambrian                 | 285.8                | 365                     | Thick limestone and argillaceous limestone |

3.2. Field Test

3.2.1. Preparation before Monitoring. In order to make the data measured by the colloidal borescope accurate and reliable, the equipment must be used in high quality monitoring wells. The monitoring well filter screen should consist of mechanical slotted screen pipe with three rows of slits at least or line filter. Before measurement, monitoring wells should be fully washed by sprinklers or mechanical spray.
Because a low-permeability obstacle can make water bypass the sampling well or cause a swirling flow. Finally, the equipment in the monitoring well (such as a dedicated water pump) should be removed from the well 24 hours before the start of the measurement, which will ensure that the environment in the well is in a natural state, and the turbidity of the water flowing from the well can also subside.

3.2.2. Field Practical Monitoring Process. Before the colloidal borescope going down the well, firstly open the camera to detect the working state of the test controller. After everything is normal, the colloidal borescope should be slowly placed into the well to prevent the water flow state from being destroyed. When the camera is lowered to the proper position, adjust the backlight to get the best image contrast so that more particles can be observed. If the groundwater flow can maintain a steady flow for more than 30 minutes, the instrument should be in the dominant flow zone of the groundwater flow. If unstable water flow continues, the instrument should be placed at another depth. Experience has shown that when the colloidal borescope changes position in the well, the surrounding groundwater flow will be affected. The instrument directs groundwater flow from the well into a nearby water layer to affect the measurement of water flow[7]. This effect lasts for about 10 to 30 minutes. Therefore, after the colloidal borescope adjusts the measurement position, it needs to be allowed to stand for 10-30 minutes before the next measurement.

In order to reduce the disturbance of the instrument to the water body and save time, adopt the method of measuring from bottom to top. The two water flow zones are named as the first and second water flow zones from deep to shallow.

3.3. First and Second Dominant Water Flow Zone Test
Firstly, the colloidal borescope was placed down to 239m and allowed to stand for 20 minutes. The signal transmitted to the computer through the underwater high-resolution camera was used to observe the flow velocity and direction of the colloidal particles. No major change occurred in the flow direction for 40 minutes, and it was determined that the 239 m was the dominant water flow zone. Then the parameters were debugged, and after comparison, the relevant parameters were determined. Capture Delay-millisecond was 15 μs, Particle Sensitivity was 4000, Minimum Particle Size was 2 μm. 9:37:24-9:48:13 Am, the colloidal borescope started to capture, the number of colloidal particles captured was 807 in the time period of 10 min 49 s. Direction was expressed in degrees. 0° (360°) is north, 90° is east, 180° is south, 270° is west.

The test directions of 807 colloidal particles were all dispersed between 83.2° northwest and 13.24° northeast, of which 83.7% of the particles (671) were concentrated between 300°-340°. The velocity was between 463.35 and 4977.55μm/s, and the arithmetic average velocity was 1570.76μm/s. Using the parallelogram rule on the AQUALITE software, 807 points were vectorized, and the vector direction was 322.73° (37.27°North West). In this direction, the vector velocity was 1496.60 μm/s.

After the 239m test was completed, slowly increased to 157m, standed still, adjusted the parameters and determined it. 10:48:55-11:04:18 Am, the colloidal borescope started to capture, the number of colloidal particles captured was 713 in the time period of 15 min 23s. The test directions of 713 colloidal particles were all dispersed between 88.3° northwest and 27.25° northeast, of which 86.4% of the particles (616) were concentrated between 290°-330°. The velocity was between 355.85 and 3777.33μm/s, and the arithmetic average velocity was 1093.37μm/s. Using the parallelogram rule on the AQUALITE software, 713 points were vectorized, and the vector direction was 309.18° (50.82°North West). In this direction, the vector velocity was 1032.0 μm/s.(see Figure 3)
4. Conclusion and Analysis

239 m: direction: 322.73° (37.27° North West), velocity: 1496.60 μm/s.
157 m: direction: 309.18° (50.82° North West), velocity: 1032.0 μm/s.

The industrial area and water plant in the northwest of the monitoring well are the main exploitation areas for groundwater. Combined with the water level elevation, the direction of the monitoring well flow was determined to be northwest. The directions of 239 and 157m were also in the northwest direction, which verified the reliability of the data. The velocity gradually decreased from deep to shallow, indicating that the monitoring well karst development is deeper than shallow.

Compared with other methods (isotopes, charging methods, etc.), the colloidal borescope is small in size, light in weight, and easy to move and carry. Combined with battery, it can operate in various field environments. The whole process of measurement is monitored by computer, and the operability is strong. The single dominant water flow zone is measured for about 1 hour, and the measurement time is short. This type of measurement does not cause secondary pollution to groundwater, and can accurately measure the flow velocity and flow direction at a specific location. This is an effective prospecting means for the flow velocity and direction of groundwater. The disadvantage is that the requirements for the observation well are high. In wells with inadequate washing or sludge siltation, the expected measurement results are often not achieved.

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