Determination of the Velocity and Direction of Groundwater Seepage in Monitoring Wells around Three-Gorges of the Yangtze River Using Isotope Tracing Method

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***Abstract*-In order to investigate whether the groundwater moving state is affected after Three Gorges Reservoir impoundment, this study tested the velocity and direction of the groundwater seepage in the monitoring wells around Three Gorges Dam using the method of isotope tracing, and gained good results. Test results showed that the groundwater seepage directions in Gaojiaxi well (W1) and Hanjiawan well (W4) are respectively 25°east by south and 2° south by east, according with the previous hydro-geological inference. These indicated that the groundwater seepage directions around the Three Gorges Dam are not affected significantly after reservoir impoundment. The groundwater seepage velocities in W1 and W4 wells are respectively 0.72m/d and 1.29m/d. There is small difference between them and this may be related to the tectonic setting of the two wells.**

Keywords- Isotope Tracing; Seepage Velocity; Seepage Direction; The Three-Gorges of the Yangtze River

I. INTRODUCTION

Three Gorges Project(TGP) is the largest hydraulic key project in the world today, including flood control, power generation, shipping and water supply. It is of great promoting significance for the stable development of social economy. Recently, the continuous drought in the middle and lower reaches of the Yangtze River and the extreme weather events such as sharp turn from drought to flood in part countries occur, and these raise again the debate of the advantages and disadvantages of TGP. So TGP exert economic benefits, meanwhile how to make overall plans and take all factors into consideration about social and ecological benefits are constantly exploring scientific problems especially during TGP operation process. Especially after the impoundment of the Three Gorges reservoir, whether reservoir load and reservoir water osmosis will affect groundwater movement state, and thus trigger the ecological environment deterioration of Three-Gorges Dam? These problems are related to environmental protection evaluation and earthquake disaster prevention in the reservoir area.

The physical parameters describing groundwater movement is mainly seepage velocity and seepage direction. Traditional method measuring seepage velocity and seepage direction is water pumping test, On the basis of knowing about the seepage velocity can be determined by arranging the boreholes along the general seepage direction. The method has larger workload, long duration and trivial process [1, 2]. In the 1950s, the foreign scholars put forward the single-hole radioactive isotope tracing method for determining the seepage velocity and seepage direction. After the systematic experimental work by Drost and Klotz, the theoretical foundation of this technology was preliminarily established and the technology was gradually put into production practice [3]. The technology has economic, accurate and efficient advantages, so currently it is widely applied in tunnels, mines, dams and other important engineering fields [4, 5]

This study applied the method to the testing of seepage velocity and seepage direction of groundwater in monitoring wells of the Three Gorges Dam, and explored the influence of reservoir impoundment on groundwater motion state in the dam area.

II. THE PRINCIPLE OF ISOTOPE TRACING METHOD MEASURING THE SEEPAGE VELOCITY AND SEEPAGE DIRECTION

A. The Measurement of Seepage Velocity of Groundwater

The basic principle of single-hole tracing method measuring groundwater seepage velocity is, the radioactive tracer putting into in the well, such as 131I、82Br will decrease with the seepage dilution of groundwater, and the dilution rate is closely related to the groundwater seepage velocity. Therefore, Moser and Drost derived the calculation formula of groundwater seepage velocity [6]:

$$V_f = \frac{\pi r}{2\alpha t} \ln \frac{N_0}{N} \tag{1}$$

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Here, Vf is the groundwater seepage velocity of aquifer; r is the diameter of filter pipe in the bare hole or hole; t is the time interval of twice measurement; N0 is the count of radioactive tracer ([131] I) when t = 0; N is radioactive tracer count at t time; is the correction coefficient of seepage field distortion.

The equation (2) can be concluded by (1):

$$t=\frac{3.14r}{2aV_f}\ln\frac{N_0}{N}=\frac{3.14r}{2aV_f}\ln N_0-\frac{3.14r}{2aV_f}\ln N \quad (2)$$

The t-lnN curve can be plotted. When the measuring data distributes straightly at t-lnN coordinates, the measurement data can be considered to be reliable. Assuming the straight slope is m,

$$m=-\frac{3.14r}{2aV_f} \quad (3)$$

The groundwater seepage velocity is：

$$V_f=-\frac{3.14r}{2am} \quad (4)$$

B. The Measurement of Groundwater Seepage Direction

The basic principle of single-hole tracing method measuring groundwater seepage direction is, because the radioactive isotope has weak adsorption, when it is put into the well, the tracer concentration will show different in different directions with the natural seepage of groundwater. And then the corresponding radioactive intensity from all directions can be measured by probe. The groundwater seepage direction can be calculated by radioactive intensity vector.

III. THE LOGGING TEST BY ISOTOPE TRACE METHOD

A. Test Area

Three Gorges Dam is located in San Douping-Tai Pingxi area in Yichang city of Hubei Province. The rock is relatively complete and uniform diorite pluton, and there are small faults such as Changmutuo, Gaojiachong, Taipingxi and so on. The structural fracture has not developed enough. To monitor reservoir induced earthquake, in 2000, the groundwater monitoring network is built in Three Gorges Dam, and there are 8 monitoring wells distributing in reservoir head area and dam area. Among them, 4 monitoring wells are located on dam area. This study selected two monitoring wells of GaoJiaxi (W1) and Hanjiawan (W4). The specific distribution is shown in Fig. 1.

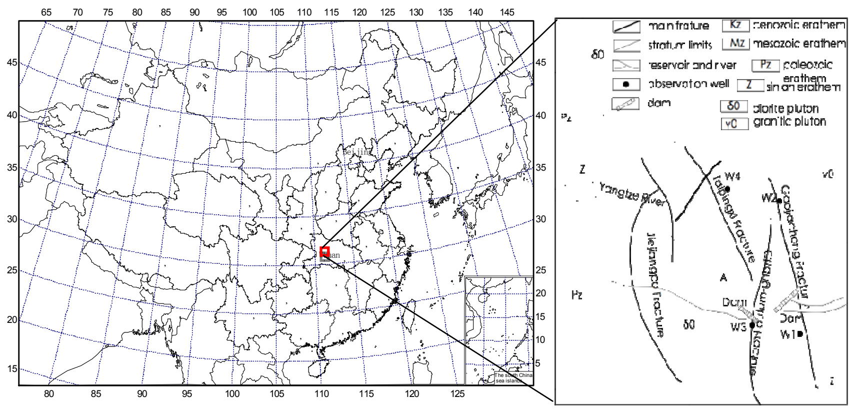

Fig. 1 The map of geology and wells layout of the Three Gorges[7]

1) Hydrogeological Condition of the Three Gorges Dam

The aquifer formation of the Three Gorges Dam in western Hubei (Sandouping-Taipingxi) belongs to the pre-siniansystem crystalline system, and the lithology is mainly igneous intrusion of granite, quartz diorite, diorite, schist and gneiss. The groundwater type is fissure water, the water abundance is 0.01-0.1 liters per second and the maximum spring flow is 0.5 liters per second. The groundwater salinity is 0.1g/l and the chemical type is HCO3-Ca-Mg. Except the fissure water is widely distributed; the confined fracture water also circulates in dense cleavage banding. The specific hydrological geological map is shown in Fig. 2.

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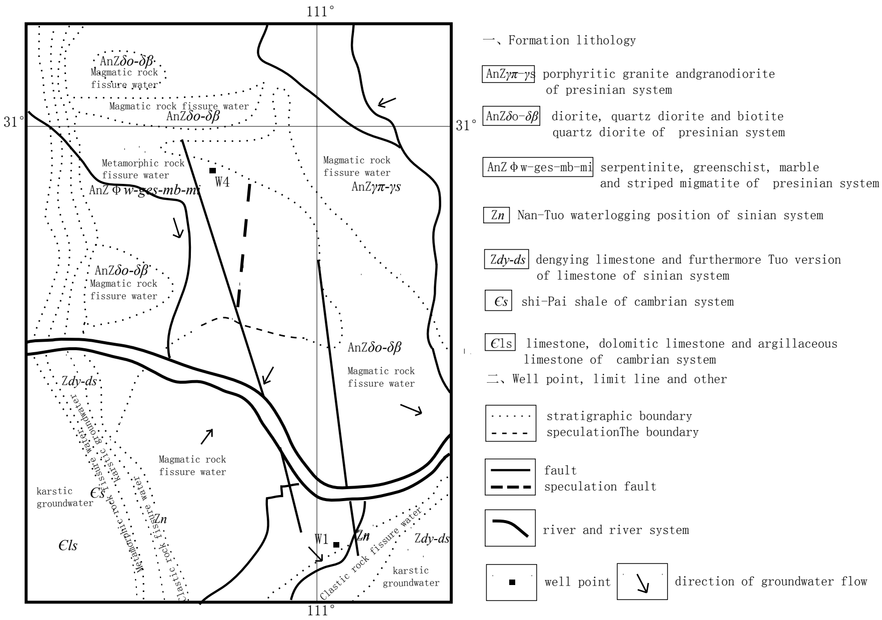

Fig. 2 The hydrogeological map around the Three Gorges Dam

(According to 1:200000 geologic map （1959）of Three Gorges area)

2) The Geological Conditions of W1 Well and W4 Well

W1 well is located on the first grade terrace of Yangtze River. The north is Yangtze River, the east is GaoJiachong River and the west is bedrock hills. The biotite quartz diorite intrusion develops in this area and GaoJiachong fracture zone develops with north-south trending in this area. The horizontal distance from the well point to the fault is about 350m. The specific geological map is shown in Fig. 3 and the typical geological profile around W1 well is shown in Fig. 4. After dam built and reservoir impoundment to 175m, the groundwater seepage direction and hydraulic slope around W1 well remain basically unchanged.

The relevant information about W1 well and W4 well is listed in Table 1.

TABLE1 THE BASIC SITUATION OF MONITORING WELLS OF W1 AND W4 IN THE THREEGORGES OF THE YANGTZE RIVER [7]

well	place	fault	distance between reservoir and well /km	well elevation/m	buried depth of water level /m	well depth /m	hole diameter /mm	observation layer			
								depth （m）	lithology	ground water type	osmotic coefficient （m/d）
W1	Gaojiaxi	hanging side of Gaojiachong fault	2.5	103	8.9	150	114	69-75	δ_0^2 biotite and quartz diorite	crystalline rock fissure mixed water	0.075
W4	Hanjiawan	heading side of Taipingxi fault	0.5	232	9.85	100.5	114	69-72	δ_0^1 quartz diorite	crystalline rock fracture water	0.04

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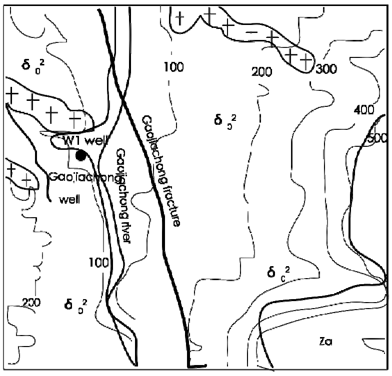

Fig. 3 The geological map of Gaojiaxi well (W1)

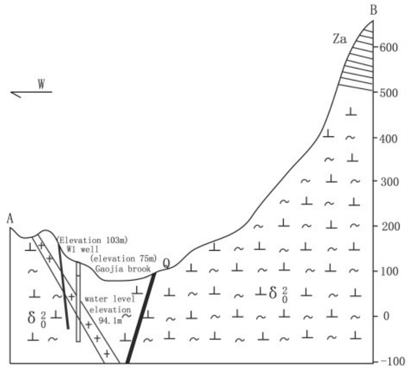

Fig. 4 The geological profile map around Gaojiaxi well (W1)

W4 well is located on the west side of a gully of bedrock hills in the north of Yangtze River, and 500 m far from the west of well point is Baishui brook valley. In this area, quartz diorite intrusion and Taipingxi fracture with SSE-NNW trending developed. The horizontal distance from the well point to fault zone is about 60m. The specific geological map is shown in Fig. 5 and the typical geological profile is shown in Fig. 6. After dam built and reservoir impoundment to 175m, the groundwater seepage direction and hydraulic slope around W4 well remain basically unchanged.

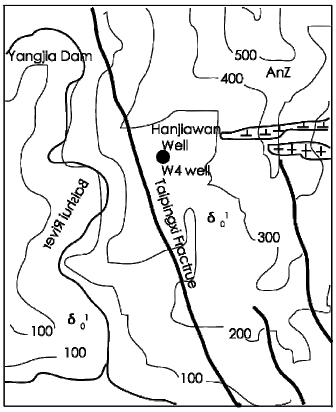

Fig. 5 The geological map of Hanjiawan well (W4)

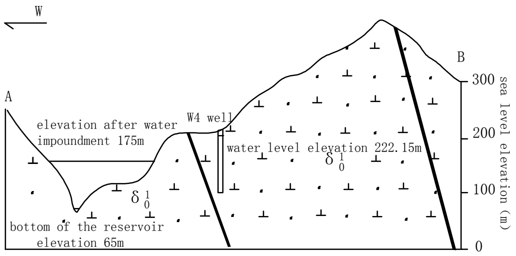

Fig. 6 The geological profile map around Hanjiawan well (W1)

B. The Velocity Seepage Measurement and Calculation

The isotope tracer used in the single well tracing method is radioactive isotope (131 I) based on sodium iodide (NaI) as the carrier, its half-life is 8.07 d and it can release gamma and beta rays. The monitoring instrument is intelligent groundwater dynamic parameter tester, which can be used in the hole with diameter>40 mm. it is a kind of new type measurement device of groundwater seepage velocity and direction, with high measuring precision, automation, safety and reliability.

Given the containing water section of W1 well is 69~75 m and W4 well is 69~72 m, so we choose the test section in W1 well （Gaojiaxi well）is 69.3 m and 71 m in W4 well （Hanjiawan well）.

1) Velocity Test and Results Calculation

Firstly, by sampling needle inject 1~2mci sodium iodide solution to the probe, and then inject about 40ml water for dilution; secondly, put the probe down to the test section, and then track and measure the change of radioactive tracer count N with time t; thirdly, by plotting the t-lnN curve, we found the good linear fitting degree of test data (Fig. 7a, 7 b). This indicated that the test data is reliable; at last, calculate m value of the fitting line slope, select alpha value influenced by the seepage field distortion and known borehole radius r, substitute into the formula (4) and work out Vf value.

According to calculation, the groundwater seepage velocity of W1 well was 0.72 m/d, and W4 well was 1.29 m/d. The specific data fitting results (slope m) and the velocity are shown in Fig. 7 and Tab.2

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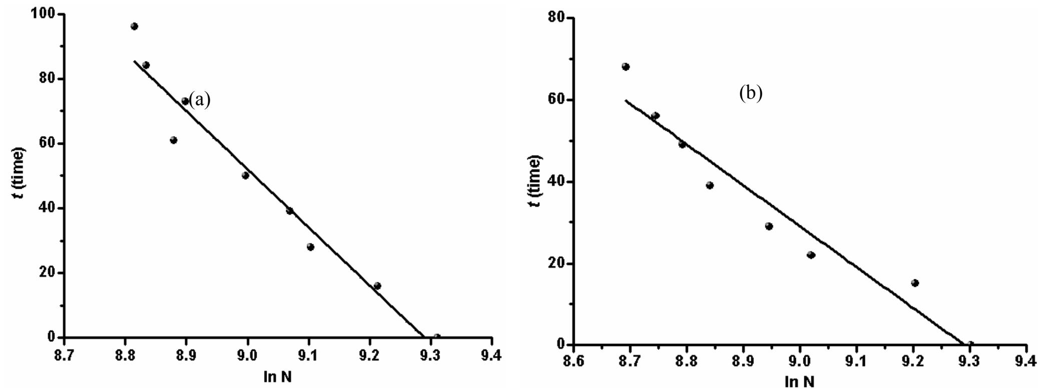

Fig. 7 The fitting line of radioactive intensity N with time t (t-lnN)

Gaojiaxi well (W1) (b) Hanjiawan well (W4)

TABLE2 THE RESULTS TABLE OF GROUNDWATER SEEPAGE VELOCITY TEST

well point	**W1 well (Gaojiaxi well)**	**W4 well (Hanjiawan well)**
test depth (m)	69.3	71
slope value m	-179.39	-99.87
groundwater velocity (m/d)	0.72	1.29

Notice：r=0.114m, α=2

2) Seepage Direction Test and Calculation Results

According to the tracer radioactivity count of each direction of probe (NO.1, NO.2, NO.3... NO.6), the vector addition of each direction can be worked out and the groundwater seepage direction can be determined. According to the angle between NO.1 detector and geographic North Pole recorded by the three-axis air orientation ， the real groundwater seepage direction can be obtained，namely the angel between seepage direction and the geographic North Pole.

After a period time of throwing source, radioactive isotope count of each direction will show obvious difference. The specific test results as well as the angle between NO.1 detector and the geographic North Pole recorded by system are shown in Tab.3. If the count of each direction is made by rose diagram with the same proportion, the vector addition of each direction is the groundwater seepage direction (Fig. 8a, 9a). Considering the deviation angle of NO.1 detector and the geographic North Pole, the groundwater seepage direction should be corrected. The seepage direction of W1 well is 25 degree east by south and W4 well is 2 degree south by east (Fig. 8b, 9b).

TABLE3 THE RESULTS TABLE OF GROUNDWATER SEEPAGE DIRECTION TEST

	0° (1)	60° (2)	120° (3）	180° (4)	240° (5)	300° (6)	the Angle of No. 1 detector deviating from of the arctic
W1	897	960	1112	900	808	626	349°
W4	1467	1091	981	951	1063	1356	200°

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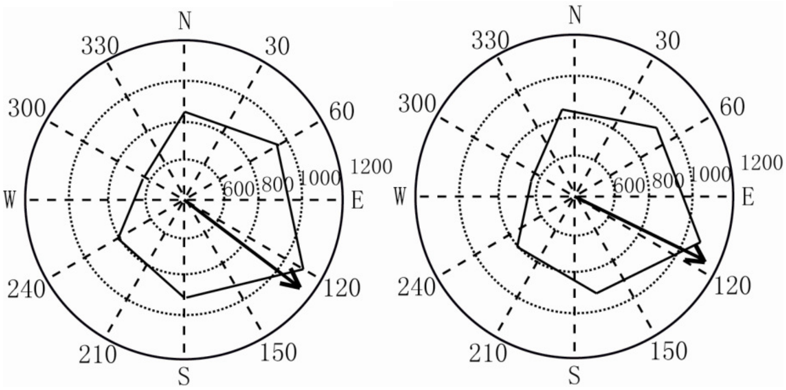

(a) (b)

Fig. 8 The rose diagram of groundwater seepage direction of W1 well (arrow direction is the groundwater seepage direction)

(a)The groundwater flow direction before correction (b) The groundwater flow direction after correction

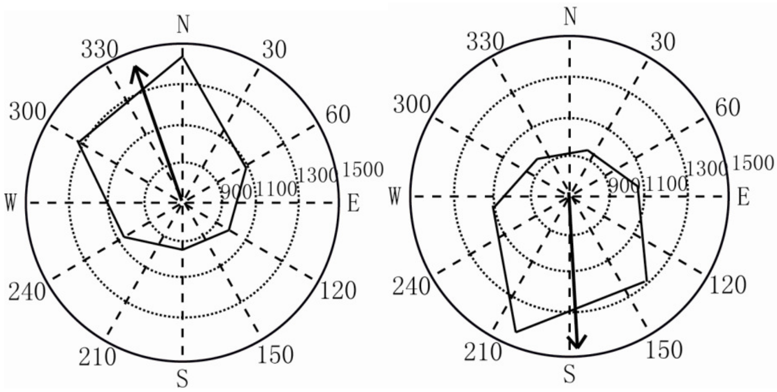

Fig. 9 The rose diagram of groundwater seepage direction of W4 well (arrow direction is the groundwater seepage direction)

(a) The groundwater seepage direction before correction (b) The groundwater seepage direction after correction

IV. CONCLUSIONS AND DISCUSSION

A. The Groundwater Seepage Velocity of Diorite Pluton in Three Gorges Dam

The groundwater seepage velocities of W1 well and W4 well measured by isotope tracing method are respectively 0.72 m/d and 1.29 m/d, and the average seepage velocity is 1.0±0.3 m/d. This result shows the actual groundwater seepage velocity in part aquifer section.

There has a certain difference of seepage velocity between two wells, which reflects the crushing strength is different between the two wells. The distance from W1 well to Gaojiachong fracture is farther (350m), while the distance from W4 well to Taipingxi fracture is closer (60 m), and there are small fractures around W4 well. Therefore, the rock fissure around W4 well is more developed than that around W1 well. Because of large fissure rate and strong permeability, the groundwater seepage velocity of W4 well is relative large. In addition, the difference of the borehole elevation as well as the distance from borehole to river shore may lead to the difference of hydraulic gradient of groundwater, causing the gap of groundwater seepage velocity between of W1 well and W4 well.

B. The Groundwater Seepage Direction of Diorite Pluton in Three Gorges Dam

The groundwater seepage direction of W1 well is 25° east by south, nearly east-west trending, according with the understanding of hydrogeological conditions analysis when the well was built. The well is located on the south side of the left bank of Gaojia brook gully, and the atmospheric precipitation infiltrated from diorite pluton of the left bank of Gaojia brook will flow from west to east in the underground, discharging in Gaojia brook. Because Gaojia brook protrudes partially left (west), the groundwater flow will slightly deviate from south. Therefore, the reservoir impoundment did not change the basic groundwater seepage direction of dam downstream.

The groundwater seepage direction of W4 well is 2 ° south by east, nearly north-south trending. This may be associated with the hydrogeological conditions. From the point of view of landscape, W4 well is located on the right bank (west) of the deep valley nearly north-south trending, and from the point of view of geological structure, W4 well is located on the east side of Taipingxi fracture with NNW-SSE trending. Therefore the groundwater seepage direction is controlled undoubtedly by the

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trending of valley and fracture. The seepage direction showed overall south by east, discharging into reservoir with east-west trending. So there have no obvious effect of reservoirs impoundment on the groundwater seepage direction of the left bank of reservoir.

C. Problems and Suggestions

Some important acknowledge is obtained according to this test. The groundwater seepage direction has not changed obviously after reservoir impoundment in the upstream (W4 well) and downstream (W1 well) of the dam area, and the actual seepage velocity is 1.0±0.3m/d in the aquifer section of diorite pluton. However, there are still some problems. Firstly, due to the test limitation, we have not test all the four wells in the dam area, and the understanding of seepage field characteristics of dam area is not comprehensive. Secondly, due to only once test, accurate description of the groundwater seepage field of reservoir coast area is still inadequate. Therefore, we suggested improving test technology (the radioactive tracer thrown in the probe can be removed as soon as possible, but not stay with the natural decay), expanding the numbers of test well, on this basis selecting the period of larger change of water level, repeatedly measuring and obtaining the synchronous data of the effect of water level change on the groundwater seepage velocity and direction.

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