RADIOACTIVE OR NATURAL TRACER TECHNIQUES FOR LEAK DETERMINING OF DAM ABUTMENT*

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ABSTRACT

Infiltration and localization of preferential infiltration zones at the dam abutment are measured using radioactive tracer tests of flow in boreholes, meanwhile interconnection between boreholes and the energing water points is analysed. The theory and practice of radioactive tracer synthetic detective method are described to give methods and calculation formulae used under the condition of stable flow in single well to measure permeability coefficient and hydrostatic heads. Major single hole techniques including measurement for seepage line, velocity, rate of seepage flow and relationship of recharge of groundwater in aquifers are introduced briefly. The possibilities offered by natural tracers are analysed, including electric-conduct, pH-value and temperature of water as well as stable isotopes (D, ^{18}O) and tritium. Furthermore, the sensibilities of this theory and methods were confirmed by detecting seepage flow field of Xinanjiang Dam.

Keywords Isotope tracers, Natural tracers, Single hole techniques, Seepage flow field, Hydrostatic heads

1 THEOREM OF PERMEABILITY AND LEAKAGE MEASUREMENT IN DAM BASE

In most cases it is unable to find out the leaks in dam base without using tracer techniques. To detect permeated leakage of reservoir accurately, one must know as more as possible of the geological structure relationship beforehand, parameters related to underground flow in some areas, so some detective methods should be used. Routine hydrological methods such as water pressure test, geophysical investigation and water injection test are frequently not sufficient. Many repair works only using these methods are known to have failed.

1.1 Introduction to measurement of the leaks in dam base and abutment

Some main measurement methods for getting the leaks in the aquifers and crevices in dam base and abutment are measuring water level variations in observing holes, detecting seepage flow passage by natural or artificial tracers, measuring flow direction

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and velocity in single boreholes, measuring the recharge or outcharge in each aquifer, measuring permeability coefficient and hydrostatic head under the condition of water injection. For knowing more about the water sources of each aquifer in observing holes and relationship between the sources and the reservoir water, it is necessary to measure the temperature, electric conductivity, pH-value of every aquifers in all holes, sometimes sampling and analysing environmental isotopes including ^{2}H, ^{18}O, ^{3}H, ^{14}C are also necessary. This is an advanced method developed in previous decade. It is useful to enhance utilization scope of observing and reduce measurement cost. There is no routine procedure to detect seepage and leakage in dam base and abutment, we can only make the optimum programme according to the feature of each dam.

1.2 Measurement of direction and velocity of groundwater in single borehole

Point dilution method may be used to measure flow direction and velocity of underground water, if there is no vertical flow or less than 1 m/h in filter case or no case[1]. Underground water is labelled by micro-radioactive isotope and mixed evenly by a stirrer in a well. Underground water takes the isotope tracer into aquifer. It can be demonstrated that the relation between reduction C in isotope concentration in the hole and velocity V_f of permeated flow satisfies Dilution Theorem, if the underground water is laminar flow,

$$V_f = [\pi(r_1^2 - r_0^2)]/(2\alpha r_1 t) \ln C_0/C \quad (1)$$

where C_0 is primary concentration, t measurement time, r_1 radius of detector, α the correction coefficient.

The maximum velocity that can be measured using point dilution method is the critical velocity of turbulence flow occurring which relating to structure of the hole and so on, it is about 50~300 m/d in general; the minimum velocity is mainly influenced by concentration reduction caused by molecular diffusing, it is about 0.005~ 0.01 m/d in general[2].

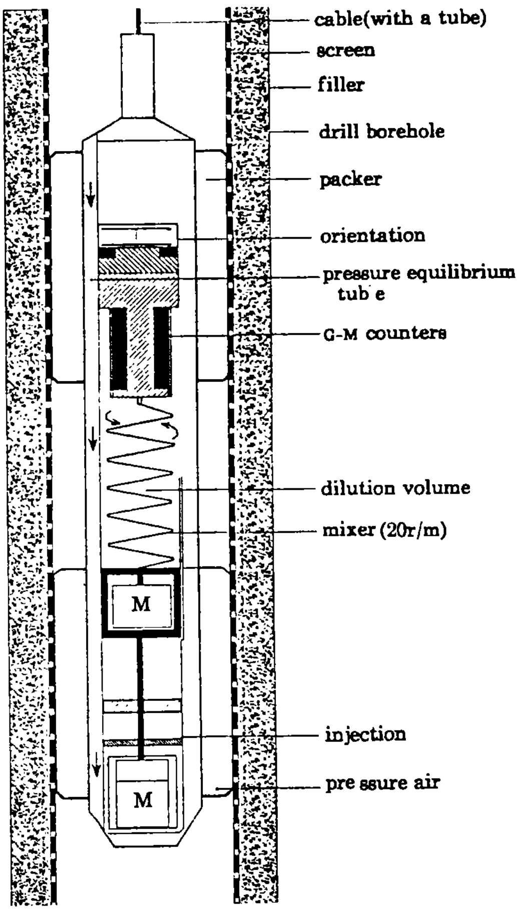

Fig.1 Direction and velocity tracer equipment

The radioactive tracer equipment used to measure direction and velocity of flow has many functions, such as injecting tracer, mixing, choking vertical flow in a part of hole, measuring radioactive tracer concentration, etc (see Fig.1). It can measure not only horizontal flow direction and velocity, but also vertical flow ones. It is a very useful measurement meter in measuring seepage flow field in dam base, abutment and measuring other hydrogeological parameters in holes.

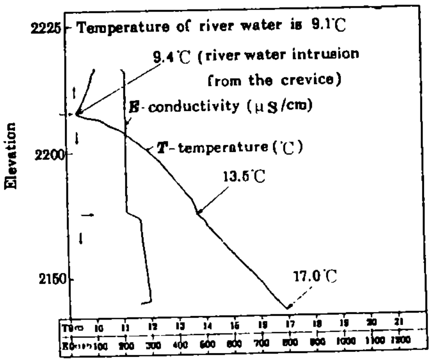

Fig.2 To find crevice by temperature profile in hole of Laxiwa

1.3 Natural tracers being used to detect leaks in dam base

1.3.1 Temperature fields in geosphere and under water

The change of surface temperature of a reservoir water depends on the seasonal variations, but the smaller the variation is, the more remote from water surface is. Temperatures of water in a reservoir, seepage water coming from hillside and underground water are different in each layer, the formation water where temperature is abnormal is always considered as a permeable layer. By measuring temperatures in every hole, reservoir, river, uplift pressure holes and weep holes in grouting gallery, emerging water points and spring in different altitudes, we can determine variation of the temperature field in each layer. That is to say the temperature is a good natural tracer which can be used to detect seepage flow passage in dam base. If there is a leak in dam base, an abnormal lower temperature will appear. If the seepage water came from hillside, the temperature is always changeable. Fig.2 shows the temperature of the holes in crevices of Laxiwa dam abutment.

1.3.2 Electrical conductivity of water

Electrical conductivity of water can be used as a good tracer to detect seepage flow passage. It is helpful to divide what kind of souces coming from. It is important for being used to check the result of isotopic tracer. Water in a reservoir came mainly from precipitation. It has a low mineralization and a lower conductivity in general. Hillside permeated water is recharged by precipitation directly. It stays in geosphere for a short time, it has a lower conductivity. The conductivity of the water in the underground rock formation is very high as the water can stay and flow for years. By measuring the conductivities in whole hole, reservoir, river, emerging water and spring under condition of natural flow, we can determine variation of mineralization of water in each layer, each position of a dam block, thereby determine the relationship between recharge of reservoir water, seepage water from hillside and underground water in aquifers. Fig.3 shows the conductivity variation that the leaks come from dam base (a), and the leaks come from abutment or precipitation (b).

1.3.3 pH-value in water

In a borehole the water coming from different formation maybe has different pH-values, that is due to the chemical composition is different in each aquifer. pH-value is related to precipitation, composition of rocks, retention period, etc. In acid rain area the pH-value in reservoir water is below 7, in fissure aquifer composed of silicious limestone the pH-value is always smaller, but in some metal mineral rock fissure the pH-value is bigger than 7. The seepage water can come from dam abutment, dam base, precipitation or underground aquifer, their backgrounds and passages are more different, and the pH-values maybe are also different. If the pH-value is unchangeable yearly the seepage water can come from reservoir by passed the dam or from groundwater. If the pH-value is changeable daily or weekly in rainy season the seepage water can come from precipitation of hillside.

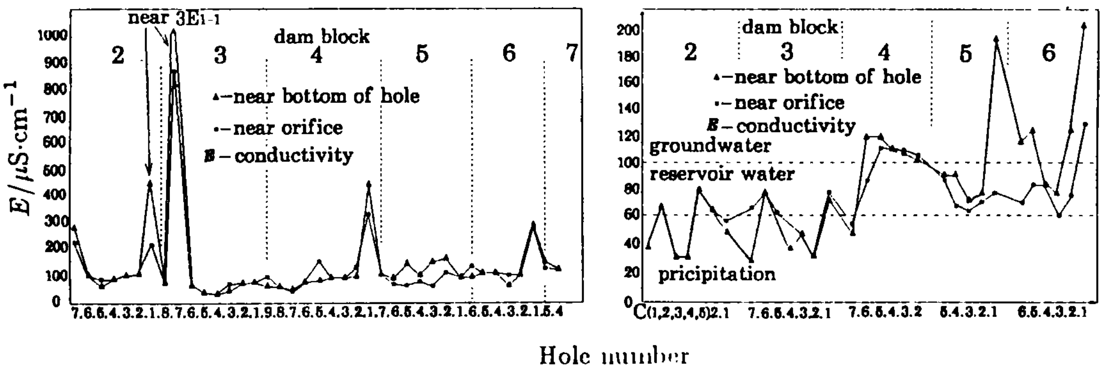

Fig.3 Conductivity in drain holes of grouting gallery (a) and conductivity in drain holes of drainage gallery (b)

1.3.4 Environmental isotopes in water

Environmental isotopes such as ^{2}H, ^{18}O, ^{3}H, ^{14}C in water have close relation to the origin of water[3]. By measuring the ratio of environmental isotopes ^{2}H, ^{18}O in water, we can distinguish disturbance of chemical reaction between water and minerals in aquifers, find out the real recharge source of each aquifer. Determining permeated flow water component in mixture water is an absolutely necessary method for determining a large range and long distance circumference of even several km to several hundreds km distribution of underground water seepage flow field.

2 AQUIFER SEEPAGE FLOW FIELD IN BLENDED BOREHOLE

Before determining the permeated flow field and its distribution, one should determine aquifer one in single hole in the dam area, should also detect real aquifer distribution in dam area, relationship and rate of recharge between one aquifer and another, static head of each aquifer, permeability coefficient, seepage line and velocity of permeated underground water, vertical flow, etc under natural condition.

2.1 Aquifer distribution in blended borehole

While two or more aquifers are unmasked by a boring hole, vertical flow will be found because of the difference of hydraulic heads and recharge sources between the two aquifers, the aquifer with high static head will recharge low static head aquifer. The water level we detected in blended borehole is the blending water level, this level has relation to permeability coefficient, thickness and hydrostatic heads of the aquifers. The distribution of aquifer flow is shown in Fig.4(a). Aquifers divided depend on the structure and recharge source according to the traditional method, there must be an isolation between each two aquifers, sometimes one aquifer may be very thick the permeability coefficients may be various in identical aquifer.

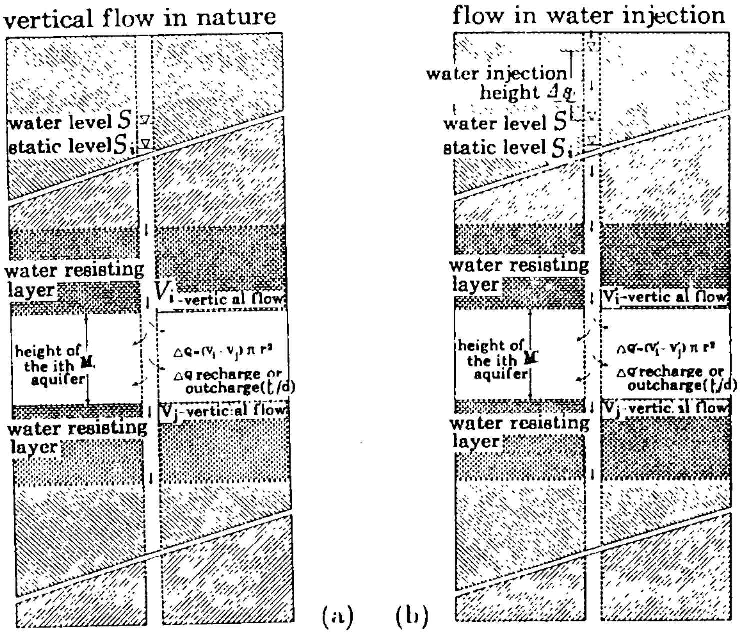

Fig.4 Hydrostatic level and permeability coefficient measured in blended borehole

This simple division is not good enough, if one wants to investigate the aquifers and its nature in greater detail and deeply, one must divide the thick aquifer further.

2.2 Permeability coefficient and calculating hydrostatic head of each aquifer

Who wants to determine the distribution of permeated flow field, he must know that the parameters of aquifers in boreholes and their dynamic flow field, such as permeability coefficient, seepage line and velocity of groundwater flow, relationship of recharge, hydrostatic head, etc, of each aquifer. Choking vertical flow method is often used to measure these parameters. Engineers always use packers at two ends of water-resisting layers to choke recharging vertical flow, to get geological parameters by measuring water level and pumping water or water injection. This is a difficult method and not a good one[4]. It can not be used to study all the aquifers divided man-madely. We may make a model as in Fig.1 and make a systematic study on flow field of one or some that we are interested in. We propose a principle and a method by which we can measure all parts of every aquifer. This principle is based on measurement theory of blended borehole. Using isotope tracer to log well, under condition of not choking vertical flow, no matter it is a natural flow field and a man-make flow field (see Fig.4(b)), we can measure the lowest vertical flow[3] (0.20 m/d), can measure the velocity of vertical flow on all boundary. We can measure the recharge water ΔQ (natural flow field), $\Delta Q'$ (man-made). It is supposed that the ith aquifer is satisfied to Darcy's Law, put ΔQ, $\Delta Q'$, blended water level S_0 and the height of water injection ΔS into the Dupuit discharge formula:

$$\begin{cases} K_i = & \Delta Q_i/[2\pi M_i(S_0 - S_i)]\ln(R_i/r_i) \\ K_i = & \Delta Q_i'/[2\pi M_i(S_0 + \Delta S - S_i)]\ln(R_i/r_i) \end{cases} \tag{2}$$

Solving equation group (2) one can obtain formulae (3)

$$\begin{cases} K_i = & [(\Delta Q_i' - \Delta Q_i)/(2\pi M_i \Delta S)]\ln(R_i/r_i) \\ S = & S_0 - [\Delta Q_i/(\Delta Q_i' - \Delta Q_i)]\Delta S \end{cases} \tag{3}$$

Phreatic aquifer formula can also be obtained

$$\begin{cases} K_i = & \frac{\Delta Q}{\pi[H^2 - \Delta Q' S_0^2 - \Delta Q(S_0 - \Delta S)^2]/(\Delta Q_i - \Delta Q)} \ln\frac{R}{r} \\ S = & \pm\sqrt{\frac{\Delta Q' S_0^2 - \Delta Q(S_0 + \Delta S)^2}{\Delta Q' - \Delta Q}} \end{cases} \tag{4}$$

where R_i is the influence radius of the ith aquifer and r_i is the hole radius of the ith aquifer.

2.3 Division of aquifers in blended borehole

Aquifers are always divided by geological logging of drill-hole. Ge Liangtao said this method was not a scientific conclusion for these aquifers and water-resisting layer was not got by measuring recharge or discharge flow[4]. Man-made division can not tell the truth. Now we can divide aquifers in great detail for the improvement on measurement technology, the thickness could be 0.5 m or less. By measuring and calculating we can divide aquifers according to permeability coefficient K value of each thin layer, then a total aquifer distribution can be obtained. Water conductivity is greatly various in karst and crevice developed area, water even can not flow in some crevices. Dimensions of some little crevices are just about several cm. It is important to divide aquifers into layers for knowing the real distribution of seepage flow field.

2.4 Flow field distribution in bearing water layer (crevice network) in blended borehole

Ground water flow in aquifer will vary under the influence of the vertical flow coming from upper or underneath aquifer, water in this part of the hole and its surrounding aquifer will finally be occupied by the vertical flow water coming from upper aquifer or underneath aquifer or injecting water. Whether the underground water in the ith aquifer can flow into the hole through the screen that is depending on the difference of the vertical flow rates between the two edges of the ith aquifer. Underground water in the ith aquifer around the hole perhaps can not flow into the hole if the vertical flow recharges in. In this time the chemical composition of water in this part of the hole may be the similar to the upper or underneath aquifer. The flow field in pervious bed will vary under the vertical flow recharge or discharge. The two pervious beds will be supplied by each other. So the conductivity and temperature have not only relation to upper aquifer, but also to underneath one it makes us difficult to analyse. For this reason we must make a concrete analysis to every holes under various circumstances.

3 IN SITU EXPERIMENTS

By using isotope tracer synthetic detective method to measure about 100 observative holes, drainage holes and uplift pressure holes at different temperature for years in right dam base and abutment of Xinanjiang, the seepage flow fields in right dam were basiclly determined. It is a valuable method for finding reason for pressure and passage of permeated reservoir water, the place where seepage flow occured and dividing permeated crevices. This passage was proved by a tracer connection test from 21#→12#→3#→5# and the stable isotope D, ^{18}O and tritium analysis. The time reservoir water takes for travelling to back of dam through crevice is about 3~7 d. It depends on crevice construction. Main sources of seepage water in drainage gallery belong to reservoir water, hillside precipitation and by-pass seepage through dam base. In the season the more precipitation is the more drainage is. The seepage flow passage was labled in Fig.5.

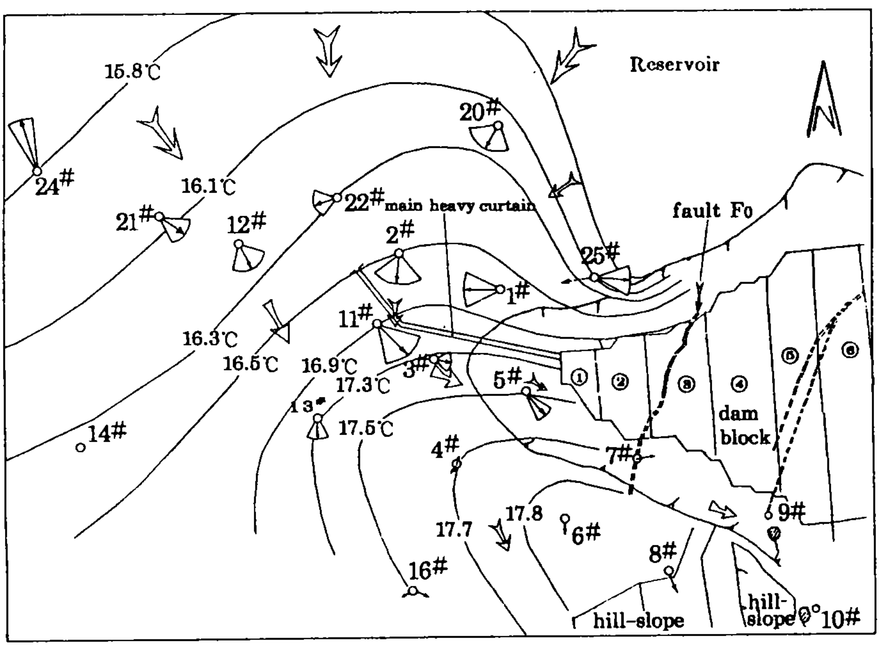

Fig.5 Seepage line, velocity and temperature curve in deep crivice in dam abutment of Xinanjang

4 CONCLUSIONS

Radioactive and natural tracers are important tools for the investigation of leakage of dam base and abutment. On the other hand this investigation is absolutely necessary before taking any repair work. Many failures are known of repair works executed without an appropriate previous investigation. Furthermore, investigation costs are usually negligible in comparison with repair works.

Stable isotopes may allow the identification of water coming from the reservoir and from local precipitation. The use of natural tracers at an early stage is strongly recommended. Chemical composition, pH-value of water can give information on the connection with the reservoir of the sampling point. In some cases, relative value of the transit time can be obtained.

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Prof. Chen Jiansheng, born in 1955, graduated from physics department, Nanjing University in 1982. He has worked in nuclear technological and groundwater field for more than 10 a. He won the first prize of Jiangsu Province Science and Technology Progress Award in 1988 for his inventing Direction and Velocity Meter in Groundwater, the Second National Youth Science and Technology Prize in 1990, National Youth Science and Technology Building Prize in 1994, the Second Prize of Jiangsu Province Science and Technology Progress Award in 1995 for his work in tracer and seepage flow field, respectively. He has proposed a theory and method of measuring parameters in groundwater without pumping test. He has made a multi-layers aquifers stable flow nondisturbed wells group model.