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A Research on Seepage Detection Technology of Water Storage Dam in Secondary Disaster Prevention of Water Resources

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ABSTRACT

Dam leakage is an important aspect of secondary disaster of water resources. The heat transfer theory is used for the quantitative analysis of the abstract linear heat source model, which determines the flow rate of water leakage. Based on the abstract model of dam seepage, we use the thermal fluid knowledge to analyze and solve the key parameters. Based on the measured data, the model quantitatively calculates the water velocity and radius of seepage channel. Compared with the measured flow velocity of drill channel, the two conclusions basically proves the accuracy and validity of the method.

INTRODUCTION

Water resources have brought the inexhaustible motive force for the survival and development of mankind. Meanwhile, In order to protect the water resources, the construction of large reservoirs and dams is a great hidden danger to human life and property. China has about three hundred thousand kilometers of flood control dam, in which ninety thousand dams on the river. There are a series of security problems in dam break. Seepage is one of the important factors leading to dam collapse. The domestic and international statistics on dam show that seepage on the bottom and the damage of dam foundation causes the most of the dam break and safety accidents accounted for 16% of the total number of dam engineering accidents [1-2]. Therefore, it is of great practical significance to study the seepage model and parameters. The whole damage degree of the dam cannot be mastered in time [2].

The dam seepage detection methods in domestic and international include point detection method, integral detection method and distributed detection method. The

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Point detection method [3][4] has the advantages of simple operation, low cost, short detection time. But it is vulnerable to electromagnetic interference and external environment, and the greater the detection depth, the lower the accuracy. Integral detection method [5][6][7] increases the detection accuracy and can control the internal structure of the whole dam, but it is easy to be affected by topography and geology. The accuracy will be greatly affected by the complicated terrain and topography. Distributed detection method[8][9][10] has the advantages of fast construction, anti-interference, low cost, safety and reliability, but the sensitivity is not enough, especially in the case of small seepage flow.

This study is based on the dam seepage model of heat transfer theory. It analyzes the heat transfer process in the channel and deduces the accurate velocity of water flow in seepage channel.

PRELIMINARIES

Parameterization of Linear Heat Source of Water Flow

Under normal conditions, the seepage water of the dam which is constructed along the river can be regarded as a linear heat source model. Because the seepage model of dam is based on the quantitative analysis of the linear heat source of water flow, parameter of flowing water and study of temperature variation are the technical preparation for measuring water flow velocity in seepage channel of dam.

Linear heat source of water flow is shown in Fig. 1. Assuming infinite heat conduction medium around the water, the water temperature is uniform and the initial temperature is T0， In the three-dimensional coordinate system, the intersection point with xoy is (x0, y0).

If the heat released from water on two-dimensional space around the section is unsteady, it instantaneously releases the heat Q1. The excess temperature at any point in time t in the coordinate system can be expressed as:

$$\theta_{(x,y,t)} = \frac{G}{4\pi at} \exp\left[-\frac{(x-x_0)^2 + (y-y_0)^2}{4at} \right] \tag{1}$$

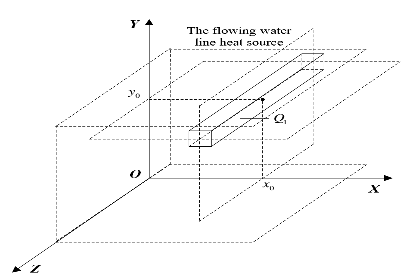

Figure 1. Linear heat source of water flow.

Among them, $\theta = T - T_0$ represents the magnitude of temperature change. The equation $G=1$ represents the temperature change caused by the instantaneous release of heat which is from linear heat source of unit strength's water flow. The parameter a represents the coefficient of heat conduction.

The linear heat source of actual water flow is continuous heat source. Make $R^2 = (x-x_0)^2 + (y-y_0)^2$, $\Phi_1(t) = q_1(t)/\rho c$ as the intensity of linear heat source of continuous water flow, c as the specific heat capacity of seepage, ρ as the density of seepage. We define $t^{'}$ as an instantaneous time interval which belongs to t. So during the time 0~t, the integral of excess temperature is：

$$\theta_{(R,t)} = \frac{1}{4\pi a}\int_0^t \frac{\Phi_1(t^{'})}{t-t^{'}} \exp\left[-\frac{R^2}{4a(t-t^{'})}\right] dt^{'} \tag{2}$$

Analysis of Dam Seepage Model

If the dam medium is homogeneous and specific heat capacity is relatively stable, only a single seepage channel exists in stratum. The initial temperature is t1 and the crossover point in xoy surface can be defined as (x0, y0). The seepage channel is parallel to the axis Z. We release heat from the time $t=0$. The abstract model of dam is shown in Fig. 2.

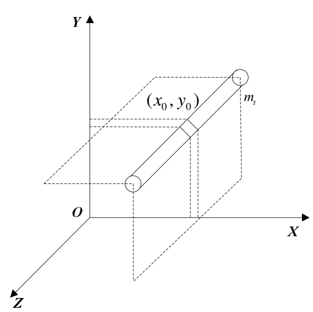

Figure 2. Abstract model of dam.

We consider that the parameter Φ_1 and the power q_1 of the released heat that from the linear heat source of seepage water is constant. The relationship can be calculated as the equation $\mu = R^2 / \left[4a(t-t^{'})\right]$. The parameter λ is the thermal conductivity of the dam. Then we put it into the formula (2). When the parameter t is larger, it can approximate be deduced to:

$$\theta(R,t)=\frac{q_1}{2\pi\mu}\left(\ln\frac{1}{R}+0.5\ln(4at)-0.5\mu\right) \tag{3}$$

Among them, Euler coefficient can be shown as $\mu = 0.5772......$.

Assuming that the initial water temperature of the dam is T_1 and the inside wall temperature of seepage channel is T_W. The water radius of seepage channel is r_1. The initial temperature is T_2. The radius of underground rock in dam bottom is r_2. The temperature change in the length direction can be ignored.

Because the temperature of seepage water in the direction of the length has no change. Therefore, thermodynamic equation is $\frac{\partial}{\partial r}(r\frac{\partial T}{\partial r})=0$. Then integrate r on both sides. If $r=r_1$, $T=T_W$. If $r=r_2$, $T=T_2$. From Newton's law of cooling, we know that the density of heat flow of seepage channel wall is $q=a(T_W-T_1)$. The density of heat flow of channel wall is identical. The following formula can be deduced:

$$T_W=\frac{T_2+\beta T_1\ln(r_2/r_1)}{\beta\ln(r_2/r_1)+1} \tag{4}$$

Among the formula, we assume that $\beta = ar_1/\mu$. Then plug formula (3) into (4), the velocity of water in the seepage channel is obtained as:

$$v=\frac{\theta(R,t)\ln(r_2/r_1)}{T_2-T_1}\left[1+\frac{1}{\beta\ln(r_2/r_1)}\right]\left(\ln\frac{1}{R}+0.5\ln(4at)-0.5\mu\right)^{-1} \tag{5}$$

DETERMINATION OF PARAMETERS IN DAM MODEL

Because of the water flowing in the seepage channel, there exists the heat exchange between the pipe and the pipe wall and the water. Assume the channel radius is r_1. The temperature of the junction between the channel and the wall is T_W. The central velocity of the pipe is v_0. The velocity distribution of water in the pipeline can be obtained by using the flow mechanics.

The temperature distribution of flowing water in pipeline can be obtained:

$$T=\frac{1}{a_r}\cdot\frac{\partial T}{\partial x}v_0\left(\frac{r^2}{4}-\frac{r^4}{16r_1^2}\right)+c_1\ln r+c_2 \tag{6}$$

The parameter c_1 and c_2 is undetermined integral constant. We put $r=0$ into formula（6）that $c_1=0$, when $r=0$,$T=T_1$. Then make it plug into formula （6）. So the average volume temperature T_b can be expressed as:

$$T_b=\frac{\int_0^{r_1}\rho\cdot 2\pi rdr\cdot vc_rT}{\int_0^{r_1}\rho\cdot 2\pi rdr\cdot vc_r}=T_1+\frac{7}{96}\cdot\frac{v_0r_1^2}{a_r}\frac{\partial T}{\partial x} \tag{7}$$

The temperature of the inner wall of the pipe can be expressed as :

$$T_w=T_1+\frac{3}{16}\cdot\frac{v_0r_1^2}{a_r}\frac{\partial T}{\partial x} \tag{8}$$

Plug formula (6)、(7)、(8) into heat exchange coefficient. Then we can obtain the equation $\beta=\frac{24}{11}\cdot\frac{\mu_r}{\mu}=2.1818\frac{\mu_r}{\mu}$.

ENGINEERING APPLICATION FOR THE DETECTION MODEL

General Situation of Engineering

The Hydropower Station Dam in the middle and lower reaches of the Yellow River has occurred serious seepage and canal gush in the history, which is a serious threat to people's safety of production and life.

During 1993-1998，Imposed a sediment grouting treatment on the 7.6km riverbank of the hydropower station, the depth of reinforcement is 2.1m. But in the 1998 flood disaster which is not occur even in a hundred years, it appeared serious piping and sand eruption phenomenon in the downstream, which caused a great loss to the life and property of people. The main cause of the disaster is the formation of seepage channel in the underground bedrock.

The holes in the dam is evenly distributed belong the terrain. The temperature information of the dam can be collected to reflect the temperature variation characteristics before and after the seepage. Using the centerline of the dam as the axis, the distance distribution of each borehole from the dam is shown in TABLEI.

TABLE I. THE DISTANCE OF EACH BOREHOLE FROM THE DAM.

Number	Distance	Number	Distance	Number	Distance
1	18.9	9	15.9	17	0.1
2	15.4	10	19.3	18	1.2
3	17.5	11	9.0	19	0.3
4	9.0	12	3.9	20	1.5
5	12.3	13	15.1	21	0.4
6	11.6	14	14.5	22	1.2
7	5.1	15	1.0	23	1.6
8	2.6	16	0.2	24	0.4

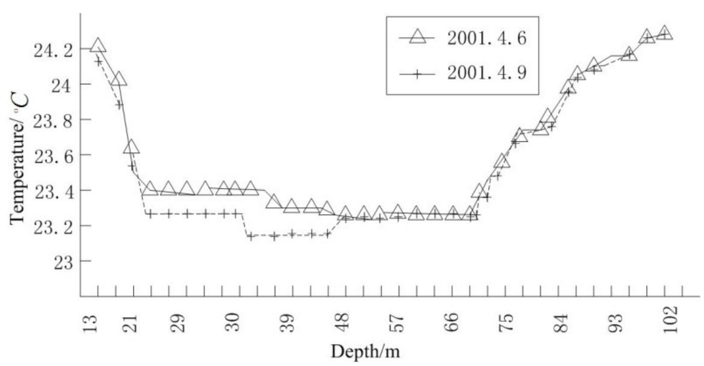

Figure 3. Schematic diagram of dam seepage in.

Using this characteristic to observe and compare each borehole, the depth is 25m, 50m, 75m respectively. When the depth is 50m, the temperature of the hole which is numbered 16 has not changed at different time. Therefore, we can choose the hole which is numbered 16 and dam seepage model to analysis the seepage.

From the statistical study of temperature change on the No.16 hole, we can find a phenomenon that the hole near seepage channels have obvious low temperature. The water influx into the channels is the mainly reason. The diagram is shown in Fig. 3.

Method for Measuring and Controlling Flow Velocity

As is seen from the dam seepage diagram in Figure 3, the time is April 9, 2001 and April 6, 2001 respectively in the two temperature measurement which is in No. 16 hole. When the depth is 48-68m, temperature remained unchanged, while the other depth of the temperature changed greatly. It can be judged that there are many seepage channels in this range of depth. The central position of the channel is at 58m and the radius of seepage channel is $r_1 = 10m$, $T_1 = 24.53^{\circ}C$. We can consider that the seepage channel of the dam is a stable continuous line heat source approximately. Because the upper and lower rock has the different specific heat capacity, the temperature curve of the upper and lower parts of the seepage channels are not strictly symmetrical.

The temperature curves of the two measurements at 98m are overlapping, because they are unaffected by the seepage channels. Therefore, it can be used as the original temperature collection point. Using the measured temperature in 22-49m at different time can solve the water flow velocity in the seepage channel. The results are shown in TABLEII.

TABLE II. FLOW VELOCITY MEASUREMENT OF DAM SEEPAGE CHANNEL.

Depth (m)	Temperature 2001.4.6	Temperature 2001.4.9	Flow velocity v (m/d)	Average value of velocity 48-68m (m/d)	Measured value of velocity 48-68m (m/d)
22	24.6	24.4	4.39	6.7313	6.67
26	24.5	24.4	4.49		
30	24.5	24.4	4.71		
34	24.5	24.4	9.68		
38	24.4	24.3	8.21		
42	24.4	24.3	8.69		
46	24.4	24.3	6.59		
50	24.4	24.3	6.99		

CONCLUSIONS

(1) We use the theory of heat conduction to quantitatively analysis the dam seepage model and calculate the data which is closely related to the water velocity in the seepage channel.

(2) Based on the collection of the temperature of different depths in the seepage channels, we use critical data and this scheme to calculate the velocity of the seepage channel.

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