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Inversion analysis of elastic modulus of Shankouyan arch dam before and after crack grouting

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Abstract

In the early stage of water storage of Shankouyan arch dam, many cracks appeared in the dam body. After the crack occurred, the construction company carried out grouting treatment. How to scientifically and effectively evaluate the grouting effect is a practical problem encountered in many water conservancy and hydropower projects. In this paper, the hybrid model is used to invert the dam comprehensive elastic modulus and bedrock deformation modulus before and after crack grouting, the research results can provide accurate parameters for the overall safety analysis before and after crack grouting.

Keywords

Shankouyan arch dam, crack grouting, elastic modulus, inversion analysis.

1. Introduction

The Shankouyan Water Conservancy Project is located in Shangbu Town, Luxi County, Pingxiang City, Jiangxi Province. It is a large (2) water conservancy project that focuses on water supply and flood control, taking into account the comprehensive utilization of power generation and irrigation. The dam is a roller compacted double-curved arch dam with dam crest elevation of 247.6m and maximum dam height of 99.1m.

After Phase I impoundment, the dam has been running for more than a year, and many cracks have been found in the upstream and downstream dam surfaces. After the cracks appeared, the construction company treated the cracks by chemical grouting. How to scientifically and effectively evaluate the grouting effect is a very important topic [1-2]. In this paper, the hybrid model is used to invert the dam comprehensive elastic modulus and bedrock deformation modulus before and after crack grouting [3].

2. Inversion method

The mechanical parameters of RCC dams are diverse and complex，there is a very complicated nonlinear relationship between the mechanical parameters and the dam displacement. If all the parameters are inverted, the amount of calculation is huge, and it is difficult to meet the real-time requirements of data analysis. In order to simplify the calculation and meet the engineering requirements, the more sensitive parameter elastic modulus is generally selected for inversion calculation [4]. In this paper, the hybrid model inversion method is used [5].

Under the action of reservoir hydraulic force, when the ratio of concrete elastic modulus to bedrock deformation modulus is a certain value, the displacement $\{\delta_H\}$ of the dam caused by the reservoir water pressure is inversely proportional to the concrete elastic modulus E_c.

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The elastic model inversion first needs to find the true water pressure component from the analysis of the prototype observation data. Then, assuming the dam elastic modulus E_{c0} and bedrock deformation modulus E_{r0}, the water pressure component $\{\delta'_H\}$ is calculated and statistically calculated by the finite element structural analysis method.

The formula for calculating the true average modulus of dam or bedrock is:

$$E_c = E_{c0}\delta'_H / \delta_H \qquad E_r = E_{r0}\delta'_H / \delta_H \tag{1}$$

The adjustment parameters X of the water pressure component in the hybrid model are directly used in the specific calculation. Because $X = \delta_H / \delta'_H$, therefore, the inversion calculation can be performed according to the following formula:

$$E_c = E_{c0} / X \quad E_r = E_{r0} / X \tag{2}$$

The horizontal displacement hybrid model is taken as:

$$\delta = \delta_H + \delta_T + \delta_\theta \tag{3}$$

Where: δ_H is the water pressure component, δ_T is the temperature component, δ_θ is the aging component, and δ is the horizontal displacement cumulative value.

The water pressure component δ_H uses the finite element calculation value, considering that the value of the dam body and the bedrock modulus is not very accurate, the adjustment is made with X, namely:

$$\delta_H = X\delta_{iH} \tag{4}$$

Where: X is the adjustment factor ($X = E_{c0} / E_c$, E_{c0} is the average elastic modulus of the dam concrete assumed for the calculation, E_c is the actual average elastic modulus of the dam concrete).

3. Calculation data

3.1 Basic situation of cracks

After Phase I impoundment, the dam has been running for more than a year, and many cracks have been found in the upstream and downstream dam surfaces. Before the grouting, the crack width is checked by photoelectric automatic crack detector, and the crack depth is detected by simple water pressure method. The concrete cracks on the upstream and downstream dam surfaces are shown in Figure 1 and Figure 2.

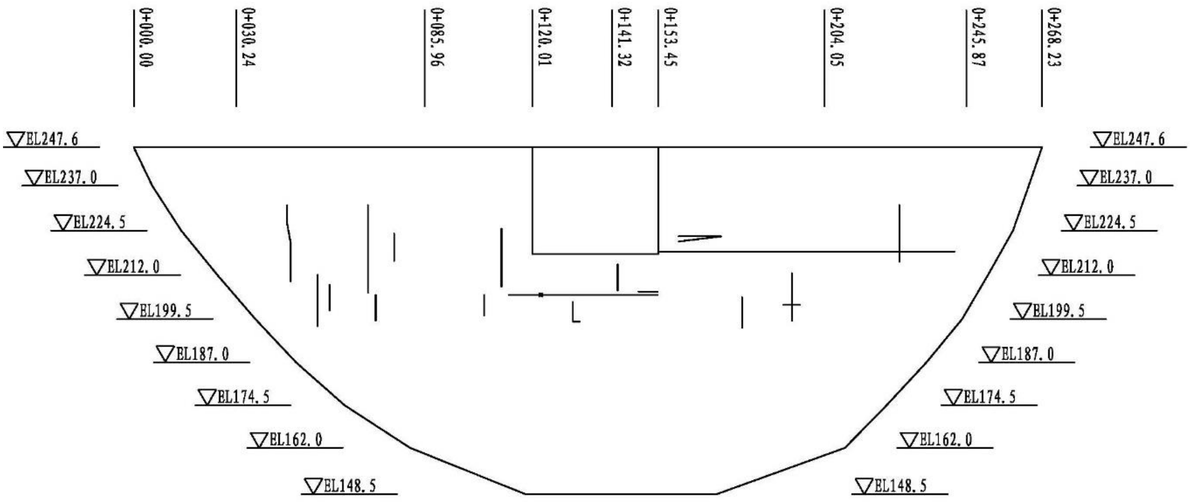

Figure 1 Cracks distribution map on the upstream dam surface

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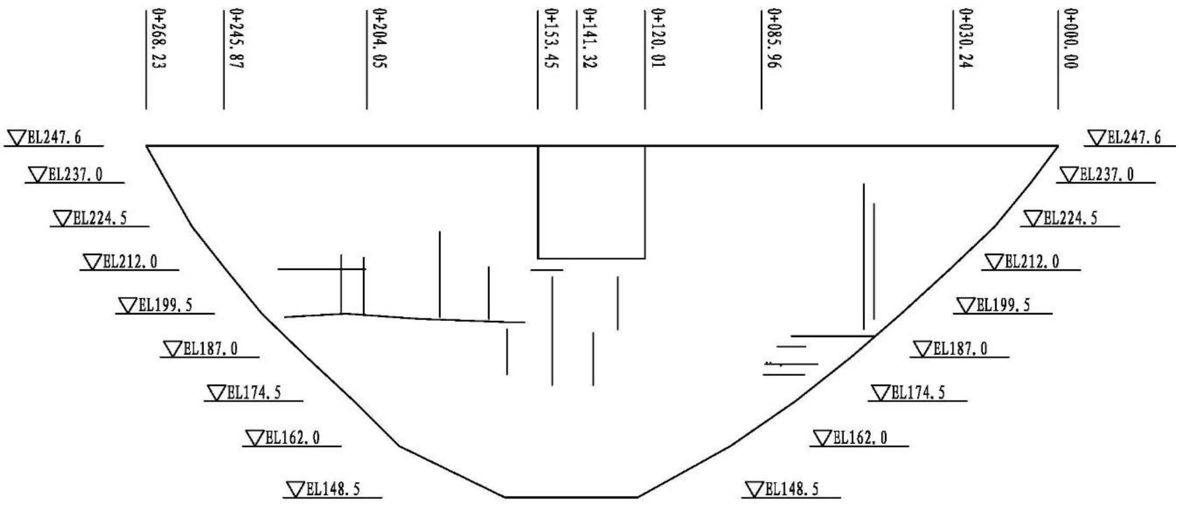

Figure 2 Cracks distribution map on the downstream dam surface

3.2 Calculation plan

The horizontal displacement along the river at the 195m elevation observation point of Shankouyan arch dam is analyzed by establishing a hybrid model. The water pressure component of the model is calculated by finite element method and its regression equation is obtained, the other two components use expressions in the statistical model.

3.3 Material parameters

The material parameters of the concrete and bedrock are shown in Table 1 and Table 2.

Table 1 concrete material parameter

name	density $/(kg/m^3)$	Elastic Modulus $/GPa$	Poisson's ratio
concrete	2400	25	0.167

Table 2 bedrock material parameter

name	density $/(kg/m^3)$	Deformation Modulus $/GPa$	Poisson's ratio	Coefficient of friction $/f'$	Cohesion c' $/MPa$
bedrock	2700	11	0.25	1.00	0.95

4. Parameter inversion results

4.1 Before crack grouting

The parameter inversion time before crack grouting is taken from December 5, 2012 to January 30, 2013.

In the finite element calculation, the concrete average elastic modulus is 25GPa, the bedrock average deformation modulus is 11GPa.Taking different subsamples of water level (H=221m～246.2m), the finite element is used to calculate the water level-displacement relationship under different water levels. The calculation results are shown in Table 3.

Table 3 water level to displacement relationship at different water levels before crack grouting

water level (m)	221	223	225	227	229	231	233
displacement (mm)	5.78	6.26	6.76	7.28	7.81	8.36	8.91
water level (m)	235	237	239	241	243	245	246.2

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displacement（mm）	9.48	10.06	10.64	11.24	11.84	12.46	12.83

Using the above calculation results, taking the primary, secondary and cubic of the upstream water depth as the factor, using the stepwise regression method, when the significance level α=0.01, the expression of the horizontal displacement of the observation point IPA2 along the river is as follows:

$$\delta_{iH} = 3.1678 + 0.0916(H-206) + 0.0072(H-206)^2 - 0.0001(H-206)^3$$

The complex correlation coefficient is 92.99%, which indicates that the calculated displacement regression effect is good under different water levels. Use this as the water pressure component in the hybrid model.

The statistical model uses data measured in actual engineering, while the water pressure component of the hybrid model takes into account the effects of stress. According to the actual situation of the dam, the mechanical parameters of the dam and bedrock are inverted, and the ratio of the elastic modulus of the dam and the bedrock is assumed to be a fixed value. The hybrid model regression equation can be obtained by using the IPA2 horizontal displacement of the 195m elevation observation point:

$$\delta = -43.69+1.57[3.1678+0.0916(H-206)+0.0072(H-206)^2-0.0001(H-206)^3]-0.97T_1+3.47T_2+0.12T_3+0.123\theta-0.275\ln\theta$$

The complex correlation coefficient of the hybrid model is 96.1%, indicating that the regression effect is better.

The water pressure component adjustment coefficient X=1.57, then the average elastic modulus of the dam concrete in the reverse performance: $E_c = 25/1.57 = 15.9$GPa, the average deformation modulus of bedrock: $E_r = 11/1.57 = 7.0$GPa.

4.2 After crack grouting

The parameter inversion time after crack grouting is taken from November 5, 2013 to December 30, 2013.

Taking different subsamples of water level (H=221m～246.2m), the finite element is used to calculate the water level-displacement relationship under different water levels. The calculation results are shown in Table 4.

Table 4 water level to displacement relationship at different water levels after crack grouting

water levels（m）	221	223	225	227	229	231	233
displacement（mm）	5.78	6.26	6.76	7.28	7.81	8.36	8.91
water levels（m）	235	237	239	241	243	245	246.2
displacement（mm）	9.48	10.06	10.64	11.24	11.84	12.46	12.83

The expression of the horizontal displacement of the observation point IPA2 along the river is as follows:

$$\delta_{iH} = 3.1678 + 0.0916(H-206) + 0.0072(H-206)^2 - 0.0001(H-206)^3$$

The complex correlation coefficient is 93.86%, which indicates that the calculated displacement regression effect is good under different water levels.

The hybrid model regression equation is:

$$\delta = -8.38+1.34[3.1678+0.0916(H-206)+0.0072(H-206)^2-0.0001(H-206)^3]+0.05T_1-0.09T_2+0.94T_3+0.065\theta-0.063\ln\theta$$

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The complex correlation coefficient of the hybrid model is 97.2%, indicating that the regression effect is better.

The water pressure component adjustment coefficient X=1.34, then the average elastic modulus of the dam concrete in the reverse performance: $E_c = 25/1.34$ = 18.7GPa, the average deformation modulus of bedrock: $E_r = 11/1.34$=8.2GPa.

5. Conclusion

The mixed model method is used to analyze the IPA2 displacement along the river at the 195m elevation observation point. The conclusions are as follows:

(1) The water pressure component adjustment coefficient before crack grouting is 1.57. The average elastic modulus of the dam concrete in the reverse performance is 15.9GPa; the average deformation modulus of bedrock is 7.0GPa.

(2) The water pressure component adjustment coefficient after crack grouting is 1.34. The average elastic modulus of the dam concrete in the reverse performance is 18.7GPa, the average deformation modulus of bedrock is 8.2GPa.

(3) The average elastic modulus of the concrete and the average deformation modulus of the bedrock after crack grouting have a certain degree of increase before the grouting.

Acknowledgements

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