

Influence of the Faults in Foundation on the Response of arch dam

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Keyword: Dam-foundation-storage; Arch dam; The opening of contraction joints; Faults in foundation

Abstract. Safety evaluation of the dam subjected to the design earthquake is a crucial factor for the project. The dynamic behavior, the dynamic reaction of the gravity arch dam including of dam-foundation- storage capacity of water system, have been studied and analyzed for the 269m high Baihetan arch dam under construction in China. By applying the seismic load method, the three dimensional finite element method and nonlinear wave analysis technique, that the overall influence of real geological and topographical condition of dam site and the earthquake input and faults in foundation are taken into consideration. The study result shows that the existence of faults would generate an influence on seismic response in different extents, and cause the redistribution of earthquake stresses, even stresses to be concentrated partially and the change of opening of contraction joints. So the effect of the presence of faults should be more taken into consideration.

1.Introduction

Concrete arch dams play important roles in current society life and national economy such as their safeguard from floods, electric supplying, and so on. Since the dam failures due to strong earthquakes will cause catastrophic consequences, the importance of seismic safety evaluation of high dams is well recognized. Although some sophisticated numerical methods have been developed for seismic analysis of high dams, it is still immature in studying realistic earthquake behavior of a complete dam-foundation-reservoir system especially involving nonlinearities. Many researchers are working on the influence of faults in foundation on seismic response of dam. Clarence and Lloyd [1] pointed out faults in dam foundations play important role in foundation displacements of dam. Guan et al.[2] simulated faults in foundation of Baihetan arch dam to analyze whose stability and reinforcement of faults in foundation. Yan et al. [3]studied the influences caused by the factors of fault dip, thickness, elastic modulus, Poisson's ratio and relative position to dam in order to explore the influences of the faults in rock foundation on the seismic response of concrete gravity dam. Wieland et al.[4] discussed the vulnerability of concrete dams due to differential faults in rock foundation and illustrated that faults in dam foundations are an important issue in dam safety assessments. Li et al.[5] analyzed the influences of faults in foundation on the earthquake response of Longyangxia gravity arch dam, which is a key project for hydropower development at upper reaches of Yellow River in China.

In this paper, the seismic response analyses of the 269m high Baihetan arch dam in China are analyzed. The main purpose is to analyze and compare the influence of the faults in foundation on seismic response of dam-foundation- storage capacity of water system for Baihetan arch dam. Four cases of seismic load including static loads are respectively used foundation without and with faults input model. Moreover, the constitutive model of Drucker-Prager is used for faults in foundation. Hydrodynamic pressure effects are considered using additional mass elements according to Westergaard expression to simulate incompressible reservoir fluid. The analyses show that significant influence on dam response is observed when using different types of foundation. Finally, some conclusions are given.

2.Viscous-spring Artificial Boundary Condition Input Model

In the viscous-spring boundary input model, pairs of dashpots and springs are installed in all nodes

of artificial boundaries. Each node on the artificial boundary contains three pairs of dashpots and springs, i.e. one in the normal direction of the boundary plane and the other two in the tangential directions. The parameters of springs and dashpots of node m on the artificial boundary are given as the following:

$$K_n = \frac{\lambda + 2G}{(1+a)r}, C_n = b\rho c_p \quad (1)$$

$$K_s = \frac{G}{(1+a)r}, C_s = b\rho c_s \quad (2)$$

Where n and s refer to the normal and tangential direction of the boundary plane, K is the elastic stiffness of the spring, C is the viscous damping, λ and G are the Lamé's constants, c_p is the propagation velocity of P-wave, c_s is the S-wave velocity, ρ is the mass density, r is the distance from the wave source, which takes the approximate value of the perpendicular distance from the center of the structure to the nodes of artificial boundary, and a and b are modification coefficients, which may be determined from parameter analysis.

To satisfy the force equilibrium conditions at the artificial boundary, the equivalent stress exerted on the node m can be expressed as

$$f_m(t) = K_m u_0(x_m, y_m, z_m, t) + C_m \dot{u}_0(x_m, y_m, z_m, t) + \sigma_0(x_m, y_m, z_m, t) \quad (3)$$

3. Modeling of Contraction Joints

As shown in Fig. 1, the contact boundary is comprised of master and slave surfaces. For an arbitrary node N on the slave surface, it has a corresponding anchor point N on the master surface to determine the touching point without tangential sliding when contact occurs.

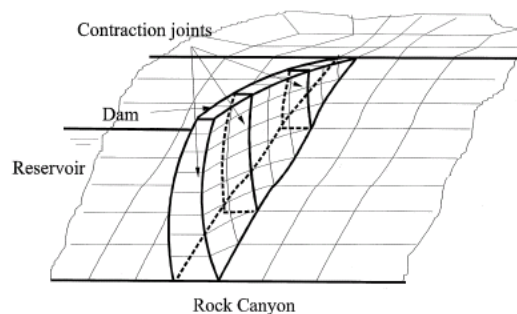


Fig 1. Schematic layout of dam canyon system with contraction joints

4. Comparison Study on the Response of the System of Dam and Foundation with and without Fault Rocks

The Baihetan arch dam with 269m in height and 715.3m in the arc length of the dam crest is analyzed. The thicknesses at crest and base (maximum) of the dam are 14m and 60m, respectively. The total number of contraction joints in the dam is 11. The normal depth of reservoir water is 260m. The dam is located in an extremely strong earthquake region with the design peak ground acceleration in time domain (PGA), $PGA=0.325g$. The static loads include the uplift of base of arch dam, hydrostatic pressure and gravity. Safety evaluation of the dam subjected to the design earthquake is a crucial factor for the project. The types of rock foundation are adopted according to rock foundation with faults and rock foundation without faults. The tensile and compressive strengths of concrete of arch dam are 2.8MPa and 30MPa. The upper acceptable bounds of opening of contraction joints of arch dam are 2cm. The main assumptions of the analysis is that the constitutive models of arch dam and rock foundation are always linear elastic and the constitutive

model of faults in foundation is elastic-plastic. The basic material parameters of model are given in Tab.1. The time courses of earthquake are shown in Fig.2. The model of Baihetan arch dam and the faults of foundation are shown in Fig.3.

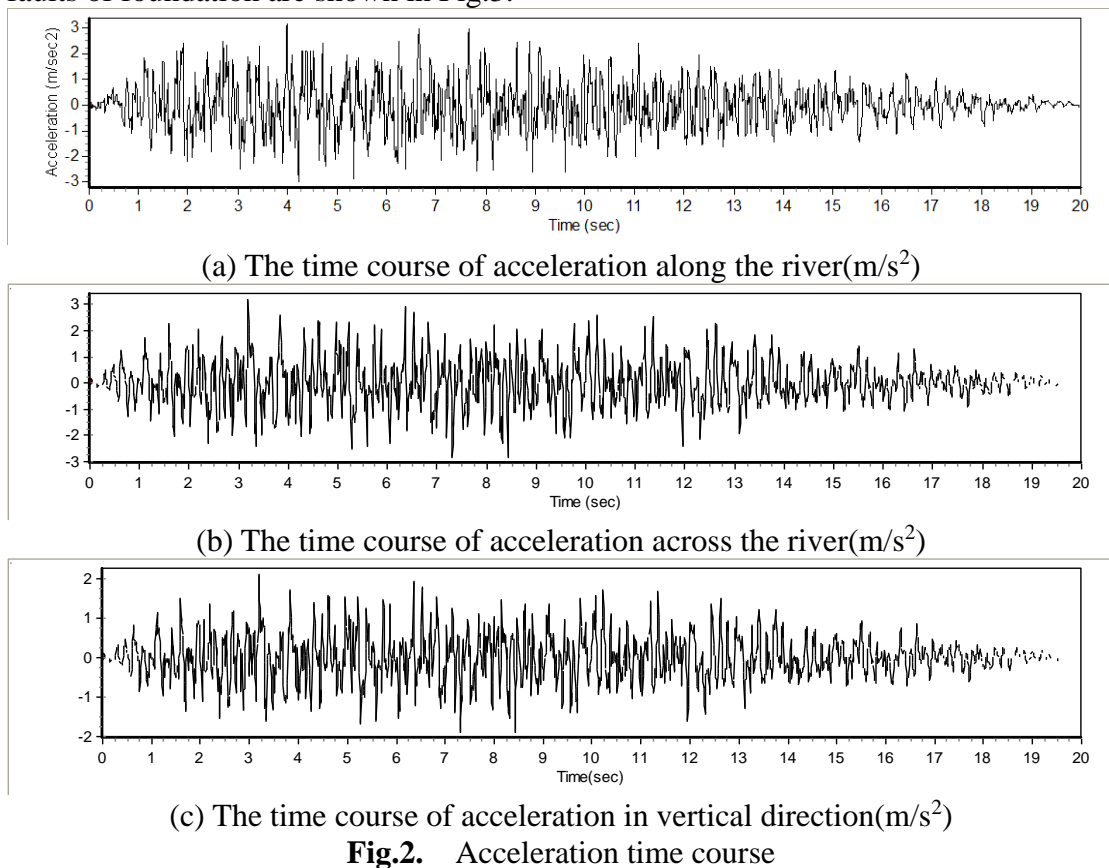


Fig.2. Acceleration time course

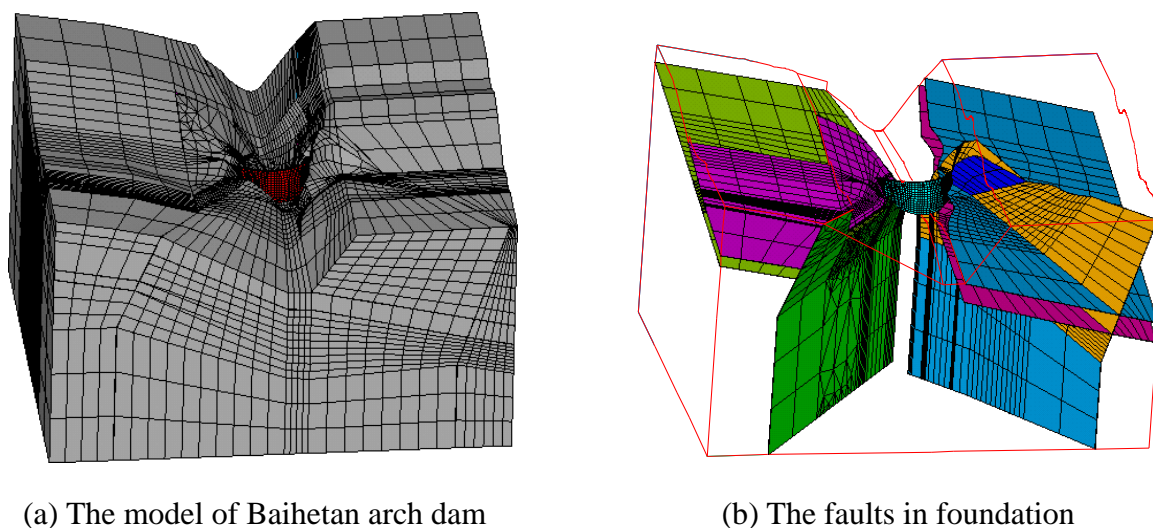


Fig.3. The model of Baihetan arch dam and the faults of foundation

Tab.1. The basic material parameters of model

Material	Density(kg/m^3)	Elastic modulus (GPa)	Poisson's ratio	Angle of friction $\varphi(^{\circ})$	Cohesion $c(\text{MPa})$
Concrete	2400	24	0.167	/	/
Rock mass	2800	20	0.24	/	/
The faults(FS)	2800	3	0.24	49	1.15

The principal tensile and compressive stress of upstream and downstream surface under the condition of foundation without faults using viscous-spring artificial boundary condition is shown as Fig.4 and Fig.5. And the maximum contraction joint opening distribution in selected contraction joints is shown in Fig.6. From the above analysis, it shows that the faults of rock foundation cause the redistribution of stresses of arch dam, even stresses to be concentrated partially. According to the analysis of Fig.6, the maximum opening of contraction joints of arch dam using foundation with faults is approximately 80% larger than that without faults. These results shows the faults of rock foundation have larger influence than earthquake input models on the contraction joint opening.



Fig.4. The maximum principal tensile stress of arch dam(Pa)

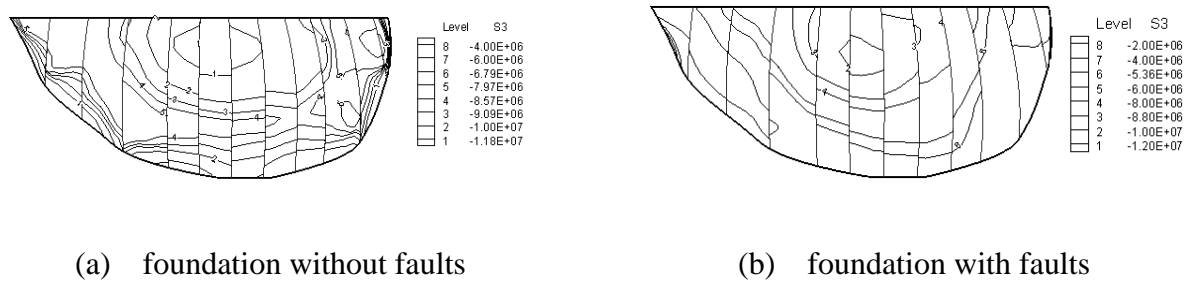


Fig.5. The maximum principal compressive stress of arch dam(Pa)

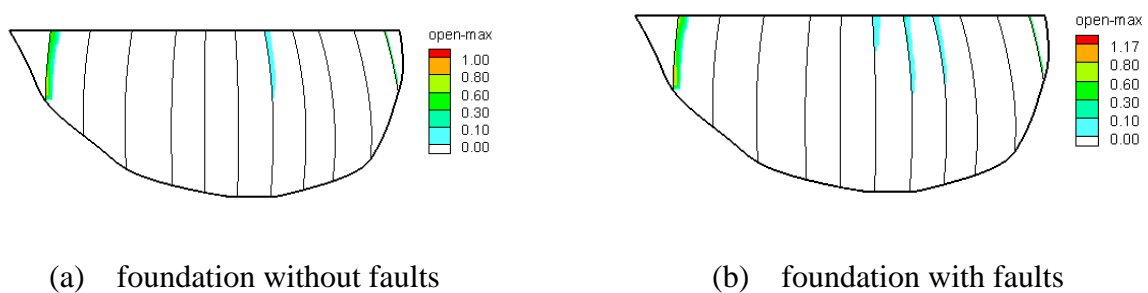


Fig.6. The maximum opening of contraction joints of arch dam

5.Conclusion

The faults of rock foundation cause the redistribution of stresses of arch dam, and the faults can increase stresses of arch dam. And the faults in rock foundation not only have large influences on the opening of contraction joints of arch dam but also can cause larger openings.

Acknowledgements

This study was supported by Educational Commission of Liaoning Province of China(No.LZ2015022), the State Key Development Program for Basic Research of China

(No.2013CB035905).

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