Research on the Dynamic Response of Gravity Dam under Blasting Vibration

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Abstract. With the continuous development of blasting technology, it has been widely used in various construction projects. While bringing convenience to construction, it also has a series of negative effects on surrounding buildings (structures), especially the negative effects of blasting vibration on buildings (structures), which has been paid close attention by scholars at home and abroad. For blasting vibration on the dynamic response of the gravity dam to produce, this article adopts the method of numerical simulation, the finite element software ANSYS is applied, the numerical calculation model of concrete gravity dam is established and the dynamic time-history analysis is calculated, in the different blasting conditions, the blasting vibration on the dynamic response of gravity dam is obtained, the calculation and analysis results as basis is supplied for the selection of the blasting vibration monitoring part of the gravity dam.

1. Introduction
With the development of hydroelectric power generation and dam construction technology, a large number of large-scale hydropower stations, led by the Three Gorges Hydroelectric Power Station, have been built and played an important role in the development of China's national economy[1]. Sometimes, due to the need of engineering, blasting construction is carried out near the gravity dam which has already been built, thus affecting the original dam body. The safety problems involved in the dynamic response of the hydraulic engineering structure have gradually attracted the attention of scholars. Taking the Longyangxia Gravity Arch Dam as an example, De-Fa LI [2] used the dynamic test load method and the elastic finite element method to calculate, and obtained that the radiation damping of the foundation had a significant effect on the dynamic response of the dam body, the compressive strength of the dam body met the requirements of the code, but the main tensile stress of the upper and lower reaches of the dam body exceeded the limit state. Taking the Dongjiang Hydropower Station as the engineering background, Cheng WANG [3] set up a three-dimensional model with Arch Dam as the center. After he determining the damping coefficient, the time-history curve of the vibration velocity had been calculated, the result accords with the standard of "Safety regulations for blasting ". In the study of blasting vibration in the near zone, Wei-Jun YANG [4] found that the stress of the dam body and the stability of the dam slope were the most important factors, the allowable particle vibration velocity was calculated by the horizontal vibration velocity curve and compared with the field blasting test, and a reasonable blasting control zoning method was worked out. Xiao-Jun CAO[5] based on the theory of structural dynamics, the relationship between the damage of buildings under blasting earthquake and the natural vibration frequency of structures was revealed.
Shi-Rong ZHANG [6] studied the destructive effect of the dam under the impact load, such as penetration explosion, water explosion and air explosion, and put forward that the development of the dam crack could be limited by adopting proper reinforcement and anti-explosion measures. The failure characteristics of gravity dam under impact load are simulated by Pei-Ying GU [7], and the results showed that the middle part of the dam body was the location of the maximum dynamic strain, and the head of the dam was the weak location to resist the impact. Shan-Shan Wang [8] studies the damage of gravity dam under impact load by means of model test. It was found that the acceleration response or strain response of every part of the structure decreases before the damage.

The dynamic response of gravity dam under blasting vibration is related to gravity dam and the safe operation of hydropower equipment, so it is very necessary to study the dynamic response of gravity dam under blasting vibration. In this paper, the actual measurement curve of the ground motion data-acceleration time history is used to input into the numerical calculation model of the gravity dam, and the vibration velocity of the dam body is extracted from the calculated results, the dynamic response of blasting vibration to gravity dam is analyzed.

2. Establishment of Finite Element Model

When studying the influence of blasting vibration on gravity dam, it is difficult to make accurate analysis of gravity dam because of the uncertainty of blasting seismic wave and blasting dynamic process. At present, computer numerical simulation and field test are mostly used to analyze. Explosive explosives propagate through the rocks to the ground, generating seismic waves, which are transmitted to the dam body on the surface through the surrounding rock and foundation, and have a dynamic impact on the dam body.

In order to analyze the dynamic response of the blasting point to the dam body, the ANSYS finite element numerical calculation software is used to establish a numerical calculation model. According to the material and mechanical characteristics of the concrete gravity dam, the plane42 element is selected as the element division, and the solid65 element is selected for the reinforced concrete of the dam. The solid45 unit is selected for the bedrock. The isotropic linear elastic constitutive model of gravity dam and bedrock is adopted. The mechanical parameters of Dam Body and bedrock are shown in Table 1:

| Name of material | ρ/(kg/m³) | ν  | E/Pa          |
|------------------|-----------|----|---------------|
| Dam Body         | 2500      | 0.167 | 2.85×10¹⁰  |
| Bedrock          | 2630      | 0.25 | 3×10¹⁰        |

According to the geometric dimensions of the dam body of an actual project, the model is simplified into two parts: the above-ground dam body and the underground rock. The dam foundation is 71m wide and 150m long. The dam head is 36m wide, 150m long, and 94m high. The upper part of the dam head is rectangular. The downstream dam face extends to the dam foundation at a slope of 74m, as shown in Fig. 1. Taking into account the contact between the bedrock and the dam body and the boundary effect of the bedrock size on the dam body, the size of the bedrock is increased to a certain ratio to reduce the boundary constraint effect: the size of the surrounding rock on the dam side is 2.5 times the height of the dam body, the lower bedrock is 5 times the height of the dam body. The surrounding rock on both sides of the dam has a width of 521m, a length of 200m, and a height of 94m the same as that of the dam. The base rock of the dam is 521m wide, 550m long, and 500m high. The mesh of the dam model is divided by hexahedral elements, and the elements are sparse in linear proportion from the position close to the dam to the boundary surface elements. The overall model of the dam and bedrock is divided into units as shown in Fig. 2. The three directions of X, Y, and Z constraints are imposed on the bottom surface of the bedrock at the bottom of the dam, and all sides of the bedrock are free surfaces without reflection.
A surface load is applied to the connection part between the bottom of the dam body and the bedrock to simplify the loading; When the blasting source is located on the side of the dam body, a surface load is applied to the connection part of the bedrock and the side of the dam body. The transient calculation is carried out in the form of acceleration time history curve. The acceleration in the three directions of X (width), Y (height) and Z (length) are loaded at the same time. Linear interpolation is used to calculate between each step to analyze the dynamic response of the dam. Before time history analysis and calculation, monitoring points are set at different positions of the dam to extract the vibration response of different parts of the dam. The layout of monitoring points on the dam is shown in Fig.3.

3. Influence of Blasting Vibration on Gravity Dam Downstream
When the blasting construction is carried out downstream of the gravity dam, the blasting vibration generated by the blasting construction will adversely affect the gravity dam. Before calculating the dynamic response of the gravity dam, the dynamic characteristics of the dam itself are determined, and the main frequency of the gravity dam is 6.457 Hz through modal analysis of the dam model.

3.1. Distribution Law Along Dam Height
In the "Safety regulations for blasting" (GB6722-2014)\cite{9}, the vibration velocity of the building particles is taken as the judging index, and the blasting seismic waves are input into a certain working condition to carry out numerical time-history analysis and calculation, the time-history curves of particle vibration velocity in X, Y and Z directions of each monitoring point on the cross-section of the dam are shown in Fig. 4 ~ Fig. 9.
As can be seen from Fig. 4 ~ Fig. 9, when the blasting vibration wave is introduced into the gravity dam, the vibration velocity of every particle in the dam body will fluctuate up and down, and the peak vibration velocity in the same direction is different at different monitoring points. Now extract the three-direction peak vibration velocities of the particles at each monitoring point in the middle section, and analyze the change law of the vibration speed along the height, as shown in Fig. 10, the trend graph of the peak vibration velocity in the X, Y, and Z directions at the monitoring points of the middle section.
Figure 10. The peak trend of vibration velocity at the monitoring points in the middle section of the dam in X, Y and Z directions

It can be seen from Fig.10 that the peak vibration velocity in the three directions of the dam crest particle monitoring points is greater than the vibration velocity peaks of the other height monitoring points, and the bottom monitoring point peak vibration velocity is the smallest. Basically, the vibration velocity gradually increases from low to high dam mass points. Mainly due to the amplification effect of the dam on the blasting vibration, the vibration velocity increases with the height of the monitoring point.

3.2. Distribution Law Along the Length of Dam
In order to obtain the vibration velocity distribution law of the blasting seismic wave on each particle along the longitudinal direction of the dam, the peak vibration velocity time history curves in the X, Y, and Z directions at different monitoring points at the same level are respectively extracted, as shown in Fig. 11~ Fig. 13.

Figure 11. The peak vibration velocity trend of the monitoring point in the X direction at the same height

Figure 12. The peak vibration velocity trend of the monitoring point in the Y direction at the same height
Figure 13. The peak vibration velocity trend of the monitoring point in the Z direction at the same height

From Fig. 11 to Fig. 13, it can be seen that the particle distribution law in the X, Y and Z directions at the same level of the gravity dam is that the vibration velocity of the middle section of the dam is the largest, and then decreases gradually to the two sides of the dam body, and the side of the dam is the smallest. This is mainly due to the restriction of the rock mass on both sides of the gravity dam. From the analysis of the peak vibration velocity, it can be concluded that the peak vibration velocity in the middle of the dam head is maximum when the blasting vibration is input from the downstream surface of the dam.

4. Effect of Side Blasting Vibration on Gravity Dam

Due to the need of blasting engineering, the blasting engineering project may be located on the side of the gravity dam. When the blasting source is located on the side of the dam, the blasting vibration wave is transmitted to the gravity dam through the bedrock on the side of the dam. In order to study the influence of the side vibration of the dam on the gravity dam, the measured blasting seismic wave is input from the left side of the gravity dam, and the time-history analysis is carried out, so as to obtain the influence law of the side blasting vibration of the dam on the gravity dam.

4.1. Distribution Law Along Dam Height

By numerical calculation, the peak vibration velocity in three directions of each monitoring point on the downstream of the dam body is extracted, and the peak velocity is extracted as shown in Table 2 ~ 4.

| Table 2. The peak vibration velocity in X direction of monitoring points in the dam |
|------------------------------------------|-----------------|-----------------|-------------|-------------|
| location                                  | Peak vibration velocity of each part (cm/s) |
|                                          | 94m              | 74m              | 39m         | 4m          |
| Downstream face dam                       | 0.1304           | 0.0483           | 0.0716      | 0.0345      |
| 38m to the left of the downstream face dam | 0.0849           | 0.0377           | 0.0333      | 0.0205      |
| Downstream face dam left                  | 0.0537           | 0.0166           | 0.0225      | 0.0157      |
| 38m to the right of the downstream face dam | 0.0901          | 0.0563           | 0.1302      | 0.0392      |
| Downstream face dam right                 | 0.0748           | 0.0399           | 0.0870      | 0.0220      |

| Table 3. The peak vibration velocity in Y direction of monitoring points in the dam |
|------------------------------------------|-----------------|-----------------|-------------|-------------|
| location                                  | Peak vibration velocity of each part (cm/s) |
|                                          | 94m              | 74m              | 39m         | 4m          |
| Downstream face dam                       | 0.2510           | 0.2038           | 0.1695      | 0.0929      |
| 38m to the left of the downstream face dam | 0.3184           | 0.2345           | 0.1959      | 0.0828      |
| Downstream face dam left                  | 0.2174           | 0.2260           | 0.1914      | 0.1228      |
| 38m to the right of the downstream face dam | 0.2516          | 0.1652           | 0.1376      | 0.0869      |
| Downstream face dam right                 | 0.1860           | 0.0663           | 0.0517      | 0.0500      |
Table 4. The peak vibration velocity in Z direction of monitoring points in the dam

| location                              | Peak vibration velocity of each part (cm/s) |
|---------------------------------------|--------------------------------------------|
|                                       | 94m | 74m | 39m | 4m  |
| Downstream face dam                   | 0.2391 | 0.1156 | 0.0736 | 0.0412 |
| 38m to the left of the downstream face dam | 0.2611 | 0.1215 | 0.1251 | 0.0340 |
| Downstream face dam left              | 0.0431 | 0.0492 | 0.0525 | 0.0366 |
| 38m to the right of the downstream face dam | 0.2132 | 0.1184 | 0.0791 | 0.0396 |
| Downstream face dam right             | 0.1138 | 0.0643 | 0.0581 | 0.0312 |

From table 2 to table 4, it can be seen from the vibration velocity values of monitoring points extracted that the peak vibration velocity of the detection points at the dam crest in X, Y and Z directions are greater than those of other detection points, which is basically the same as the vibration velocity distribution law when the blasting point is located on the downstream surface.

4.2. Distribution Law Along the Length of Dam Body

From table 2 to table 4, it can be seen that the vibration velocity in the Y direction of the dam is larger than that in the X and Z directions, and the peak vibration velocity at the dam head is greater than that at other parts of the dam body. At the same time, it can be seen that the peak vibration velocity in the X direction appears at the monitoring point of the mid-section position along the length of the dam crest, and the peak vibration velocity in the Y Z direction appears at about 1/4 of the dam crest along the length direction.

5. Conclusions

When the blasting source is located on the downstream surface of the dam, the peak vibration velocity in the middle of the dam head is the largest, and the peak vibration velocity at the bottom of the dam is the smallest. Along the length of the dam, the peak vibration velocity at the center position is greater than the peak vibration velocity at the dam side. The top position is the key monitoring point to control the safe vibration speed; When the blasting source is located in the bedrock at the side of the dam, the middle part of the dam head and 1/4 of the length of the dam body are greatly affected by the blasting vibration and should be used as the key monitoring point.

6. References

[1] Ji-Feng WANG. The Present Situation and Development of Rock Blasting Technology[J]. Journal of Coal Mine Blasting, 2005, (3):25~28.
[2] De-Yu LI, Shun-Zai HOU, Yan-Hong ZHANG, et al. Dynamic behavior and aseismic safety evaluation of longyangxia gravity arch dam[J]. Journal of China Civil Engineering Journal, 2003,36(10):41~46.
[3] Chen WANG, Zhang-Hua HONG. Numerical Simulation of the Dynamic Response of Dongjiang Arch Dam under Blasting Vibration[J]. Journal of Hydropower and New Energy, 2015,129(3):34~39.
[4] Wei-Jun YANG. Impact analysis of blasting nearby on safety of earth-rock dam[J]. Journal of Water Resources and Architectural Engineering, 2012,10(3):178~182.
[5] Xiao-Jun CAO, Ji-Chun ZHANG, He-Lin LU. Effect of Frequency on the Dynamic Response of Structure Resulting from Blasting Seism[J]. Journal of Blasting, 2006,23(2):14~19.
[6] She-Rong ZHANG, Gao-Hui WANG. Study on the antiknock performance and measures of concrete gravity dam[J]. Journal of Hydraulic Engineering, 2012,43(10):1202~1213.
[7] Pei-Ying GU, Shi-Yan XIAO, Chang DENG, et al. Damage Characteristics of Concrete Gravity Dam under Impact Load[J]. Journal of Yangtze River Scientific Research Institute: 2016,33(5):48~52.
[8] Shan-Shan WANG, Qing-Wen REN. Experimental study of the gravity dam damage caused by impact load[J]. Journal of hydroelectric engineering, 2010,29(5):11~14.
[9] GB6722-2014. Safety regulations for blasting[S]. Beijing, Standards Press of China.