Dynamic response of rock-soil dam to blasting-induced vibration with different distances

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Abstract. In order to assess the dynamic performance of a rock-soil dam Zhejiang, Eastern China and suggest a proper blasting scheme for the adjacent tunnel excavation, a three-dimensional finite difference model was established, and dynamic simulation analyses were carried out. Results show that close blasting will have severe impact on the stability of the dam. The different part of the dam has different response to the blasting shock. The velocity response at the side close to the blasting is far larger than that of the other side. Local damage may occur in the dam body near the blasting point. The vibration amplitude of the dam due to the blasting decreases with the distance of blasting point to the dam. The peak vibration velocity reduces to less than 0.4 cm/s and the maximum permanent displacement of the dam decreases to no more than 0.1 cm when the distance between the blasting point and the dam reaches to 180m. It indicates that the blasting at this distance has little influence on the stability of the dam. So, a safe blasting distance of 180m is suggested in the project.

Key words: Blasting-induced vibration; dam stability; dynamic analysis; tunnel excavation; permanent deformation.

1. Introduction

Large cross-sectional hydraulic tunnel is the common way for long distance water delivery. The conventional method of tunnel excavation in hard rock is drilling and blasting, in which the excavated rock mass was broken and removed. However, the shock wave caused by the explosive blasting may influence the stability of adjacent buildings, even lead to failure of structures. Thus, the seismic response of adjacent buildings during tunnel blasting should be studied beforehand. It is of significant in assuring the safety of the engineering and preventing engineering disasters.

With the development of underground engineering, many researchers have focused on the seismic response of buildings to adjacent underground blasting. Cheng et al. monitored the velocity of explosive wave in the rock mass during the excavation of rock slope. The accumulated damage of the rock during blasting was investigated through introducing damage factor [1]. Yang and Zhang presented a technology to control the vibration of blasting in a tunnel project [2]. Shi et al. found a cavity effect on the ground vibration through field monitoring and numerical modeling on a shallow buried tunnel.
excavation [3]. Liu studied the influence of underground blasting on the adjacent structures by finite element method [4]. Li et al. provided the maximum frequency of the blasting wave which may cause dam failure and obtained the threshold of blasting wave velocity [5]. Deng et al. investigated the response of an arch dam to underground blasting [6]. Chen et al. simulated the violation of grout curtain during blasting in different rock types [7]. Nguyen et al. presented a new computing model in estimating and controlling of blast-produced ground vibration [8]. Guan et al. provided a structure vibration reduction method by blasting control technology [9]. Park et al. studied the effects of blasting-induced vibration on adjacent dam and pore water pressure fluctuation by numerical methods [10]. Zhou et al. presented a mechanical model to derive vibration response to a cylindrical explosion source [11]. Xue et al. used the subtractive clustering algorithm and fuzzy c-mean clustering method to predict the blast-induced ground vibration[12]. Silva-Castro presented a methodology to control and predict ground vibrations from blasting based on a semi-empirical approach [13].

The present publications mainly focus on the methodological analysis. The hydraulic dam is a linear structure. Different parts of the dam may have different responses to the blasting at different locations. Research on vibration response of hydraulic dam to adjacent blasting with different distance and dam vibration stability is not enough. On the basis of a tunnel excavation engineering near an existing rock soil mixture hydraulic dam, the vibration of different parts of the dam to the blasting with different distances was studied in this paper. The permanent deformation and the stability of the dam were also presented.

2. Project settings
Tangpu reservoir, located about 23km upstream Shaoxing City of Zhejiang Province, has a normal storage capacity of 185 million m$^3$. The reservoir has a comprehensive function of water supply, flood control and irrigation. The water retaining dam has a shape of a triangle. The dam, with a maximum height of 29.6m, is made of gravels and rock blocks. The top width of the dam is 6.0m and the bottom is about 90m. Gravels filling of 9.2m high and 30m width was placed at the downstream toe of the dam. The normal dammed water level is about 4.6 m to the dam crest. The upstream face of the dam is covered by a concrete panel of 0.4m thick to prevent seepage. The foundation of the dam consists of quaternary alluvial silty clay layer, silty clay with gravel and Jurassic welded tuff. The cross section of the dam is given in Figure.1.

With the development of economy and the rise of population, the existing water delivery tunnel can’t meet the requirement of water supply. A new water transfer route was proposed to connect Tangpu reservoir and Daguo reservoir. The design tunnel is in welded tuff layer with a diameter of 3.8m. The entrance of the tunnel is near the Tangpu dam and the closest distance is about 16m. The relative location of the dam and the tunnel is illustrated in Figure 2. The influence of the tunnel excavation on dam stability should be investigated. Especially the vibration response of dam to tunnel blasting attracts more interesting of designers and administrators.

Figure 1. The cross section of dam.
3. Modeling and parameters
The detailed vibration response of Tangpu reservoir dam was simulated using software Flac$^3$D. A three-dimensional model of the dam was established based on the topographic and geological maps. The X axis of the model was set along the longitudinal direction of dam, Y axis was set along the river, and the Z axis was set opposite to the direction of gravity. The model was discretized by tetrahedron element. The model comprises 20481 nodes and 100866 elements. The 3D grid of the numerical model as well as the simulated locations of blasting points is shown in Figure 3. The elastic-perfectly plastic model was used for in the modeling and the failure criterion of the Mohr-Coulomb model was selected. The parameters obtained laboratory tests are shown in Table 1.
The analysis was conducted in two steps. First, the static analysis was carried out. In the static analysis, the vertical and horizontal displacements were fixed for the bottom boundary, and the horizontal displacement was fixed for lateral boundaries. In the second step, the dynamic response of the dam to the blasting was presented. The vibration wave obtained from the field blasting wave monitoring was applied at the blasting point and the viscous boundary was applied to the lateral boundaries. The simulated blasting points were shown in Figure 3. The corresponding distances of A, B, C and D in Figure 3 are 30m, 80m, 130m, and 180m, respectively.

### Table 1. Parameters used in the modeling.

| Soil                        | Elastic modulus (MPa) | Possion’s ratio | Cohesion (kPa) | Friction angle (º) |
|-----------------------------|-----------------------|-----------------|----------------|--------------------|
| Dam fillings                | 2000                  | 0.3             | 120            | 31                 |
| Silty soil                  | 40                    | 0.35            | 36             | 14.2               |
| Silty soil with gravel      | 80                    | 0.35            | 30             | 15                 |
| Moderately weathered        | 30000                 | 0.2             | 500            | 40                 |
| welded tuff                 | 40000                 | 0.2             | 1500           | 46                 |

4. Result of the Analyses

4.1. Displacement response

The displacement in Y and Z direction has a large effect on the stability of the dam. So, we mainly focus on the displacement response in Y and Z direction. The permanent Y displacement contours of dam after blasting are shown in Figure 4. When the blasting point is about 30m and 80m to the dam, the blasting point is near the left toe of the downstream part. A large displacement develops at the left downstream toe of the dam due to the blasting. The maximum displacement in Y direction is nearly 1.34cm and 0.34cm when the blasting distance to the toe is 30m and 80 respectively. The blasting may cause the loose of gravel at the left downstream toe of the dam. Most part of the dam has the deformation trend to the upstream except the left abutment where the deformation is towards to the downstream. When the blasting distance to the dam reaches to 130m, the blasting point is located at the left of the dam. The blasting has a large impact on the left part of the dam. The whole dam has a displacement towards upstream. The maximum displacements corresponding to the distances of 130m and 180m are 0.098cm and 0.083cm, respectively. The blasting vibration wave has little influence on the stability of dam.
Figure 4. Horizontal displacement response of dam to blasting at a distance of (a) 30m, (b) 80m, (c) 130m and (d) 180m.

The permanent vertical displacement of the dam at different blasting distance is shown in Figure 5. It indicates that large upward displacement occurs at the toe of the downstream gravel filling. The displacement at the left toe of the downstream reaches 3.9cm when the blasting point is 30m to the toe, which may lead to local fractures during the blasting. The dam body excepting the left toe and abutment illustrates a deformation of settlement. The displacement of the dam decreases quickly with the blasting distance. When the blasting point is about 80m to the dam, the maximum upward displacement decreases to 0.3cm. The whole dam shows a deformation of settlement when the distance of blasting point to dam reaches 130m. The maximum settlement under the influence of blasting is 0.085cm. The maximum vertical displacement of the dam reduces to 0.048cm when the blasting distance is 180m. The deformation has little influence on the stability of the dam.
4.2. Velocity response

Figures 6-8 show the velocity response of dam to the blasting vibration at the left abutment of the dam. It can be seen that there is large velocity when the blasting point is near the left toe. The dynamic velocity decreases with the distance of blasting point to the dam. The X directional velocity reaches its peak value at about 0.3s. Then the velocity decreases with the attenuation of energy of blasting wave. The peak X directional velocity is about 0.049 m/s when the blasting point is 30m to the left toe of the downstream part. It reduces to 0.0025 m/s when the blasting point is 180m away. The peak Y directional velocity at the left abutment of the dam is 0.032 m/s, which occurs at about 0.7s of the vibration. The maximum vibration velocity of the dam decreases with the distance of the blasting point to the dam. The peak velocity in Y direction of the dam corresponding to a blasting distance of 80m, 130m and 180 m is 0.18 m/s, 0.004m/s and 0.002m/s, respectively. The Z directional vibration time-velocity curves are similar to those of the X and Y direction. The peak velocity appears at about 0.2s and attenuates gradually to zero at the end of the vibration. The peak velocity at the left abutment is about 0.46m/s with blasting distance of 30m and reduces to 0.004 m/s when the blasting distance is 180m.
Figure 6. X velocity at the left abutment of dam with blasting distance of (a) 30m, (b) 80m, (c) 130m and (d) 180m.

Figure 7. Y velocity at the left abutment of dam with blasting distance of (a) 30m, (b) 80m, (c) 130m and (d) 180m.
In order to study the vibration response of different parts of dam to different blasting distances, the variations of peak vibration velocity at the left abutment, top center and right abutment with blasting distance are shown in Fig.9. It indicates that the vibration velocity of the left abutment is far larger than other parts when the blasting distance is within 130m. The reason is that the blasting point is near the left side of the dam. The underground blasting has large influence on the stability of the left part of the dam. The peak velocity in the three directions at the right abutment is only 0.0025m/s, 0.0012m/s and 0.0016m/s corresponding to that of 0.49m/s, 0.32m/s and 0.46m/s. But the velocity of at the left abutment decreases rapidly with the blasting distance. When the blasting distance extends to 180m, the velocities at different locations are close. The peak velocity is no more than 0.004m/s. It indicates that the underground blasting has little influence on the stability of the dam. According to the Chinese standard of safety regulations for blasting, the velocity response of dam with a 180m blasting distance satisfies the blasting safety requirement of hydropower station facilities. So, a safety blasting distance of 180m is suggested.

Figure 8. Z velocity at the left abutment of dam with blasting distance of (a)30m, (b)80m, (c) 130m and (d) 180m.
5. Conclusion
Underground blasting may cause the damage of the adjacent earth-soil dam. Tangpu Reservoir is the most important water conservancy facility in Shaoxing, Zhejiang Province. The drill and blasting working adjacent to the water retaining dam has drawn great concerns. In order to thoroughly understand the vibration performance of the dam with respect to the adjacent blasting engineering, three-dimensional finite difference technique was adopted in this paper. Some conclusions were obtained as following:

The blasting may cause local damage when the blasting point is close to the dam. The maximum horizontal displacement is about 1.3cm and vertical displacement reaches 3.9cm when the blasting point is 30m to the dam. The influence of blasting on dam deformation degrades with distance. When the distance of blasting point to the dam reaches 180m, both the horizontal and vertical deformations of the dam are smaller than 1.0mm.

The underground blasting has a large impact on the left part of the dam. The maximum vibration velocity at the left abutment is nearly 5.0 cm/s when the blasting distance is 30m, while the maximum velocity at the right abutment is only 0.25 cm/s in the same condition. The velocity decreases with the distance of blasting point to the dam. The maximum velocity at different points is almost the same when the blasting distance is more than 180m. The maximum velocity is smaller than 0.4 cm/s, which satisfies the requirement of the standard for hydropower station facilities. So a blasting distance of 180m is suggested for the stability of the dam in this project.
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