Numerical simulation method for vibration response of blasting excavation of deep-buried rock mass

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Abstract. In order to solve the safety problems caused by in-situ stress unloading and blasting impact in blasting excavation of deep-buried rock mass, the initial stress field and dynamic response of excavation unloading of deep-buried rock mass are calculated by ANSYS implicit and explicit solver. The results show that the stress wave induced by in-situ stress unloading diffracts at the foot of the wall and produces stress wave superposition in the surrounding rock above the wall. The vibration of surrounding rock caused by excavation of buried rock mass consists of blasting shock and ground stress unloading. With the increase of excavation depth, the vibration of surrounding rock caused by ground stress unloading exceeds blasting effect and gradually dominates the measured vibration.

1. Introduction
At present, the drilling and blasting method has still been the main excavation method for deep underground excavation. During the excavation process, the blasting load will cause vibration of the wall rock and endanger the safety of the excavation project. According to the engineering survey and calculation research, in the deep buried rock excavation project, the wall rock vibration after blasting excavation will be affected by in-situ stress unloading and blast loading. Moreover, the higher the primary rock stress before excavation is, the greater the induced vibration of the rock mass after excavation will be[1-3]. Therefore, when controlling and evaluating the vibration of wall rock in the deep buried rock excavation project, the disturbance caused by the unloading of the in-situ stress on the excavation surface is one of the factors that cannot be ignored. As early as the 1970s, foreign scholars have systematically studied the vibration of rock mass induced by in-situ stress unloading. For example, N.G.W. Cook[4] studied the microseismic and deformation mechanism of rock mass caused by excavation unloading, proposing that the size of microseismic is related to the release rate of in-situ stress energy; In recent years, domestic scholars have carried out in-depth research on the problem of in-situ stress unloading, and have achieved fruitful results. For example, Lu Wenbo et al. [5] have found that the level of stress at the far field of the blasting area has a decisive influence on the vibration magnitude excited by the dynamic unloading under the same excavation surface; Zhang Zhicheng et al. [6] found through experiments that rock mass excavation disturbance will lead to redistribution of stress, forming a new stress field, and the value of blasting vibration in the direction of principal stress is much larger than the theoretical prediction value.

This paper takes the rock mass excavation of the Pubugou underground powerhouse as the research background, uses implicit solver in finite element software to static solution of in-situ stress field, and...
utilize dynamic relaxation method to perform stress initialization in the excavation area, followed by explicit dynamic solution. It also successively analyze in-situ stress unloading, blasting impact and the wall rock vibration of deep buried powerhouse under the effect of in-situ stress and blasting coupling, in order to provide a reference for optimizing the design of deep burial rock blasting and ensuring construction safety.

2. Establishment of a calculation model

2.1. Calculation model

The Pubugou Hydropower Station is a downstream controlling reservoir project for hydropower cascade development in the Dadu River Basin, which is one of the key projects for the development of cascade hydroelectric plants in the Dadu River Basin. The underground powerhouse of the hydropower station is huge in scale, with a depth of 220-360 meters and an excavation size of 294.1 meters times 30.7 meters times 70.2 meters (length times width times height)\(^7\); The first and third principal stress directions in the underground powerhouse area are basically close to horizontal, and the first principal stress has an angle of 20~30° with the longitudinal axis of the main building. The first and third principal stresses are respectively 21.1~27.3MPa and 10.2~12.3MPa; the second principal stress direction is close to vertical, and its size is 15.5~23.3MPa. The underground powerhouse is under more than middle ground stress conditions\(^8\).

![Figure 1. The excavation calculation model of Layer IV](image)

In this paper, the excavation of rock mass in III~VII layer is selected as the research object. The width of the broached groove is 18.8 m and the excavation progress is 8 m. The protective layers on both sides are excavated by 20 m in the middle trough area, and the thickness of the protective layer is 4 m. The excavation calculation model of the factory workshop is shown in Figure 1. The calculation uses a three-dimensional model with an overall size of 200m times 200m times 60m. Before the excavation of the rock mass, the model grid is divided into 322320 units, and the Solid185 unit is implicitly used. The Solid164 unit is explicitly used.

2.2. Calculating loads and parameters

According to the tectonic stress level and distribution of the underground powerhouse of Pubugou Hydropower Station, this paper takes \(\sigma_y=20\text{MPa}\) as the vertical far-field ground stress, and \(\sigma_x=10\text{MPa}\) as the horizontal transverse far-field stress. Due to the existence of the free surface of the excavation step, the ground stress in the longitudinal direction of the plant is not considered in the excavation unloading calculation. The rock material parameters are: density \(\rho=2840\text{ kg/m}^3\), elastic modulus \(E=18\text{ GPa}\), Poisson ratio \(\mu=0.2\). In the numerical calculation, the load uses equivalent processing. According to the research results of the equivalent application method of the blasting load in the finite element
analysis of the medium and far field vibration [9,10], the blasting load and the in-situ stress load can be equivalently applied to the excavation boundary. The equivalent blasting load of single hole boundary is “$P_e=8.07$MPa”, the rising time of explosive load is “$t_r=1$ms”, and the duration of blasting load is “$t_d=10$ms”.

2.3. Calculation method

Since the calculation model needs to perform dynamic stress unloading under the condition of static stress state before rock excavation, it can be seen that the calculation is a process in which static force and dynamic load work together. The process above can be solved by the finite element software ANSYS/LS-DYNA. Firstly, use the ANSYS implicit solver to calculate the original rock stress field by static calculation, and extract the node stress on the equivalent boundary of the area to be excavated under the original rock static field, then the APDL language programming is used to output the extracted node stress according to the LS-DYNA loading format. The output node stress is applied to the excavation equivalent boundary before the dynamic calculation, and the stress release on the equivalent boundary after excavation; Secondly, when using the explicit solver for the blasting excavation equivalent solution, due to the existence of the initial stress field and the node reaction force on the equivalent boundary before excavation, stress initialization must be performed before the solution. The explicit solver in DYNA usually uses dynamic relaxation method to perform stress initialization.

3. Analysis of calculation results

3.1. Coupled vibration separation contrast

In order to analyze the vibration response of surrounding rock after blasting excavation of deep buried rock mass, the load is separated and coupled: one is the vibration of surrounding rock caused by blasting impact load, and the other is the vibration of surrounding rock caused by dynamic unloading of in-situ stress. The third is the vibration of surrounding rock caused by the coupling of blasting impact load and in-situ stress. In the study of the surrounding rock vibration caused by the blasting load, the in-situ stress is not considered, hereinafter referred to as the blasting effect; the blasting impact load is not considered in the study of the surrounding rock vibration caused by the dynamic unloading of the in-situ stress, hereinafter referred to as direct unloading; when studying the surrounding rock vibration caused by the coupling of blasting impact load and in-situ stress, it is necessary to consider both the blasting load and the in-situ stress, and the two are superimposed on the excavation equivalent surface. Hereinafter, the coupling effect is the vibration of the surrounding rock under the coupling action, which is the actual surrounding rock vibration after the blasting of the deep buried rock mass.

In the numerical simulation of load separation and coupling, the vibration effects of surrounding rock under blasting, direct unloading and coupling are considered respectively. The load acts on the equivalent surface of the MS1 explosion zone, and the 8’ measuring point shown in Figure 1 is selected as the monitoring point of vibration velocity. The vibration velocity of the surrounding rock of the powerhouse under the action of load separation and coupling is obtained by dynamic calculation. The time history curve of the vibration velocity of the surrounding rock is shown in Figure 2. Through the numerical simulation results and the measured surrounding rock vibration curves of the powerhouse, it can be seen that the peak vibration velocity of surrounding rock caused by direct unloading is equivalent to that caused by blasting after the blasting excavation in the MS1 explosion zone; the vibration velocity of surrounding rock under coupling action is superimposed on time domain by blasting action and subsequent direct unloading action, and it can be seen from the curve that the superposition is not a simple linear superposition.
3.2. Vibration attenuation law of arch ring induced by blasting excavation

In order to reveal the vibration law induced by the stress unloading in the excavation of the factory, the peak velocity of each point of the arch ring after excavation of the MS1 section of the rock mass in the middle section of the IV layer is selected, and seven points are selected from the arch to the vault. The vibration speed monitoring point is shown in Figure 3. The peak vibration velocity of each point of the monitoring point of the top arch induced by excavation unloading is shown in Figure 4. The results show that the peak velocity of the horizontal and vertical particles is the largest at the 1# point near the excavation area, and the peak vibration velocity is rapidly attenuated from the arch to the vault, and the horizontal vibration velocity is larger at the arch. The vertical vibration speed is large.

It can be seen from the static analysis that the rock mass in the excavation area is mainly horizontal to geostress, so the horizontal stress wave excited by the rock after direct unloading is stronger than the vertical direction, and the stress wave excited by the horizontal stress is along the x direction. Rapid attenuation, the velocity of the particle at the edge of the near-field is mainly horizontal vibration velocity; then the stress wave is diffracted at the side leg, and the surface wave propagates upward along the sidewall. As the distance increases, the particle vibrates. The peak decays rapidly. The vibration law of the arch circle induced by the ground stress unloading is affected by its structural shape, and the vibration velocity perpendicular to the direction of the air surface is larger. During the blasting, the load is mainly applied to the vertical equivalent excavation boundary, and the explosion excitation stress wave is rapidly attenuated outward. Therefore, as the distance increases, the particle vibration peak also rapidly decays. After the fourth blast, the direct unloading in the actual vibration of the arch ring dominates.
3.3. Vibration attenuation law of side wall induced by blasting excavation

The research shows that the geostress level and the height of the side wall are both proportional to the excavation depth, and the vibration induced by the dynamic unloading of the geostress is more intense. In this section, the vibration velocity of each particle on the side wall induced by the trough excavation in the middle of the VII layer is analyzed. In the calculation, 8#~16# nine vibration speed monitoring points are selected in the upward direction along the side wall. As shown in Figure 3, the peak speed of each monitoring point is shown in Figure 5. The calculation results show that the peak velocity of the horizontal to the mass point is the largest at the side of the foot (8# measuring point), and then decays rapidly upward; the peak velocity of the vertical to the mass point is the largest at the 9# measuring point above the edge of the excavation area, and the peak of the mass point The vibration speed is increased by the side of the foot and then decreased. This is because the stress wave of the rock mass excavation in the high stress area is diffracted at the side legs, and then the stress wave is superimposed near the top of the side foot, and the vertical vibration velocity will also be enlarged. Therefore, the vertical peak velocity of the particle is firstly increased and then decreased along the sidewall, and the law is verified during the excavation of the III~VI layer; the excavation is excavated as the excavation depth increases. The stress level of the rock mass in the area also increases, and the superposition effect is more significant after the unloading stress wave is diffracted at the side legs. Blasting, direct unloading, and coupling have diffraction phenomena at the corners, which are most noticeable when directly unloaded.

4. Conclusion

In this paper, the dynamic finite element software is combined with the implicit and explicit solution method, and the dynamic relaxation stress method is used to initialize. The vibration response law of
surrounding rock in the stratified blasting excavation of deep underground powerhouse is studied, and the following conclusions are obtained:

1. The vibration law of the arch circle induced by the geostress unloading of the rock mass in the excavation area is affected by the distance and gradually attenuates along the arch.

2. The stress wave induced by the unloading of the rock mass in the excavation area is diffracted at the side legs, and then the stress wave is superimposed near the top of the side foot, and the vertical vibration velocity will also be enlarged. Therefore, the peak velocity of the vertical to the particle point increases upward and then decreases along the side wall. As the excavation depth increases, the stress level of the rock mass in the excavation area also increases, and the unloading stress wave is wound around the side leg. The post-shot superposition effect is more pronounced.

3. Stress relaxation using dynamic relaxation method for explicit dynamic calculation can be well applied to numerical simulation of dynamic and static multiple load fields.

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