Analysis of anchor bolt stress characteristics in arch ring support of super-large underground powerhouse

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Abstract. Taking the surrounding rock deformation and bolt stress response characteristics during arch excavation of the left bank underground powerhouse of baihetan hydropower station as the research object, On the basis of the monitoring data of anchor stress, anchor rod stress response characteristics summarized as three types including "stepped", "one pull one press" and "load drop " , and preliminary discussed the mechanism of bolt stress. The research results can provide important technical support for the reinforcement design of cavern in the following similar projects and have guiding significance for engineering practice.

1. Introduction
Anchor is an "internal support" of the "anchor-surround rock" interaction system to improve the mechanical properties and stress conditions of the surrounding rock, so that the passively deformed rock mass becomes active bearing structure. According to the anchoring method, it can be divided into three types: mechanical, adhesive and friction. According to the position and length of the anchor, it can be divided into two types: end anchoring and full length anchoring, and the later are widely used in large underground caverns, mines and tunnels. A large number of experimental studies and numerical analysis calculations of the reinforcement mechanism of full-length anchors at home and abroad have been conducted. Ge Xiurun[1], Zhang Zhiqiang[2], etc. explored the effects of anchors on the strength of jointed rock masses through experiments. Ferrero[3] carried out a shear test and proposed that the strength of the anchored rock mass includes anchor material, rod size, and rock type. Li Shucai, You Chunan[4] obtained a series of laws of anchoring effect through theoretical numerical calculations.

In this paper, the characteristics of surrounding rock and the stress response of anchor bolts during the excavation of the arch ring of the underground caverns on the left bank of the Baihetan Hydropower Station are taken as research objects. Based on the monitoring data of the anchor stress instruments, the representative time-process lines are selected for analysis. Based on the results of previous experiments and theoretical calculations, this article summarizes the stress changes of anchor during the construction of large underground cavern, and explores the mechanism of anchor stresses.
2. Engineering background

2.1. Engineering Overview and Geological Conditions
The main underground powerhouse of the Baihetan Hydropower Station are arranged in a "line" shape, and the auxiliary plant, auxiliary installation site, unit section, installation site and air-conditioning room are arranged in order from south to north. The section size is: 438m long, 88.7m high, and 31m~34m wide. The installation height of the unit is 570.00m, the elevation of the top arch of the cavern is 624.60m, and the elevation of the bottom plate of the draft tube is 535.90m.

The distance between the left underground cavern and the water inlet is about 280m, and the vertical burial depth is about 260m~330m. The stratum is a monoclinic structure. The overall formation of the rock stratum is N40°~45°E, SE∠15°~20°. The stratum strikes at a small angle with the plant axis, and the intersection angle is 20°~25°. The lithology is mainly P2β31 oblique porphyry basalt, almond-shaped basalt, breccia, cryptocrystalline basalt, and the third type of columnar jointed basalt is locally developed. The surrounding rocks are mainly III1 type, with a small amount of IV type distributed locally.

Figure 1 shows the spatial distribution of the main geological structural planes. Three small faults (f717, f720, and f721) are developed, and they are rock debris-type steep dip angle structural planes. T720 and T721 are long fractures, which are steep dip structural planes. Interlayer shift zone C2 obliquely passes through the middle and lower part of the side wall of the cavern, and develops along the middle of the P2β24 layer of tuff. The thickness is 10cm~30cm. The perturbation zone in the gently dipping angle layer and the same group of cracks extend about 150m from the south end wall of the powerhouse to the north fault. The area is most affected by excavation and the surrounding rock deformation and failure phenomena are most obvious (measured top arch and arch shoulder, arch The cumulative maximum deformation of the feet is distributed in this range), which is also the main area studied in this article.

![Figure 1. Layout of spatial distribution of main geologic structures.](image)

2.2. Monitoring arrangement
As shown in Figure 2, underground powerhouse of left bank is divided into 8 monitoring sections, with a total of 96 multi-point displacement gauges, 100 sets of anchor stress gauges (except for rock wall crane beams) and other. A typical section monitoring arrangement is shown in Figure 3.
3. Deformation and failure of surrounding rock and response characteristics of supporting bolts

3.1. Deformation and failure characteristics of surrounding rock

Excavation of the surrounding rock in the arched area at the top of the super-large underground powerhouse will cause the surrounding rock to unload radially along the section of the cave, and the circumferential tangential stress of the cave will increase accordingly. Due to the stress deflection process and the loose zone of the surrounding rock and the control of the structural plane, the arch ring is often accompanied by the failure of the surrounding rock such as slide falling, block collapse and even rock burst. There are three main forms.
3.1.1. Stress controlled failure. Stress-controlled failures are mainly manifested as slide falling and burst damage, which occur on the surface of the excavation contour surface and belong to the shallow surface failure of the surrounding rock. During the excavation of the arch ring, the surrounding rock of the powerhouse's top arch and the upstream side of the arch shoulder formed a pit due to the slide falling. The pit generally formed a platform ridge in the direction of the vertical axis of the powerhouse. When the rock mass has been (partially) supported, burst damage occurs under the influence of high stress, and the damage surface is nearly parallel to the excavation empty surface. The inner layer perturbation zone LS3152 affects the slide falling depth, which is generally 10cm ~ 30cm, and locally can reach 50cm.

3.1.2. Structural plane controlled destruction. The main manifestations of structural-surface controlled surrounding rock failure are the slumping and falling of blocks along the structural surface with a gentle inclination angle, which are controlled by misaligned zones and steep-inclined fracture combinations. The left bank powerhouse's top inclination drift zone LS3152 was revealed. When the distance between the shift zone and free faces is close, it is easy to form local block loss and large-scale unstable rock block collapse.

3.1.3. Compound controlled destruction. The underground powerhouse has a superlarge span of 34m. The cross-section span is large, and the entire cross-section cannot be excavated in one time. Sequential expansion excavation causes the surrounding rock to be unloaded in steps along the radial direction of the cavern, the stress of the surrounding rock of the arch ring is repeatedly adjusted, and stress concentration occurs in a local area. The failure surface of the surrounding rock is nearly parallel to the direction of the cave axis, and the occurrence location is mainly concentrated on the upstream arch shoulder (foot). The failure mechanism is affected by structural planes and stress concentration.

3.2. Stress response of supporting bolts
The surrounding rock support of the underground powerhouse is mainly anchored by shotcrete system, supplemented by local reinforced support, and combined with random support. Combining with the above deformation characteristics of the surrounding rock of the arch ring, as an active support method, the anchor bolt has a restraining effect on the unstable blocks formed after cutting the perturbation zone and the dominant fissure structural surface in the layer. A statistic was made on the distribution of rock bolt stress in the hole affected by in-layer stagger belt, stress values less than 50MPa and 50MPa~150MPa account for 43.33% and 31.67%. The anchor stress in large parts is in a low stress or low-medium stress state. The proportions of stress values between 250MPa and 400MPa and over range (400MPa) were 8.33% and 5.00%. The bolt in high stress state is mainly located in the position where the deformation magnitude of surrounding rock is large or the measured value of multi-point displacement meter appears "negative growth". The proportions of the stress value between 105MPa and 250MPa is 11.67%.

The mechanical characteristics of the anchoring system composed of anchor bolt body, grouting body after grouting and fractured rock mass are more complicated. Through in-depth analysis of the stress monitoring data of the supporting anchor during the excavation of the arch ring, this paper summarizes several types of rock bolt stress variation in the affected section of stagger belt in underground powerhouse, as shown in Figs. 4, 5, and 6.

3.2.1. "Stepped" Type. As shown in Figure 7, the stress increase of the anchor on the downstream side of the powerhouse 0+018 section is mainly affected by the unloading in the powerhouse 0+10~0+30 area in the I4 layer. Due to the deformation of free faces, the stress development process has obvious stages. When the excavation face is gradually shifted to the upstream side, the stress increase of the anchor bolt is low, but it still has a certain timeliness. When the excavation of the section is completed, the stress changes of the anchor tend to converge quickly.
From the perspective of spatial distribution, the monitoring value of ASzc0+018-2 decreases from shallow to deep, which is consistent with the law that the monitoring value of the multi-point displacement measurement at this part gradually decreases along the depth of the hole.

![Figure 4. Rock-bolt stress curve of ASzc0+018-2.](image4)

3.2.2. "One Pull One Press" Type. As shown in Figure 8, the arched anchor at the upstream side of the underpower house 0+076 section shows a stress state of shallow tension and deep compression, and this phenomenon also occurs in underground caves of Xiangjiaba Hydropower Station and Xiluodu Hydropower Station. Chen Zhongxian believe that the cause of this phenomenon is due to the complexity of rock stress at the arch site. Some analyses also think that it is affected by the temperature change of grouting concrete, and the temperature stress causes the axial pressure of the bolt.

![Figure 5. Rock-bolt stress curve of ASzc0+077-1.](image5)

3.2.3. "Load Drop" Type. Figure 9 shows the historical process line of the shoulder anchor bolt on the upstream side of the underground 0-012 section. According to the figure, rock bolt stress gauge ASzc0-012-1 measuring point (6.5m) stress dropped by 93.3MPa during the blasting of III\textsubscript{2,3} layer on the upstream side on December 24, 2015. Meanwhile, the stress at the measuring point (3.5m) of the shallow bolt also decreased from 248.9MPa to 176.3MPa. Combined with the monitoring data of the multi-point displacement gauges at the corresponding position, there is no abnormal situation in the deformation of the surrounding rock, indicating that the shallow anchor bolts still play an anchoring role.
4. Analysis of anchor stress response mechanism

Based on the statistical analysis of the stress distribution pattern of the anchor bolts in the left bank powerhouse layer staggered zone LS3152 and the joint fractures in the same group (K0-71~K0 +76 segments), it is found that the stress of the "stepped" anchor accounted for 62%. It is mainly distributed in the upstream and downstream side walls and downstream side abutments, the deformation of the surrounding rock in this part is mainly "stress-controlled", and the load change has a good corresponding relationship with the monitoring results of the multi-point displacement gauges at the corresponding position. The "One Pull One Press" and "Load Drop" phenomenon of abnormal anchor stress mainly occurred on the upper arch foot, arch shoulder under the control of the structural surface, or there were shear deformation sites. The distribution of the stress response of the anchor bolt is closely related to the deformation characteristics of the surrounding rock. The correlation between the two is based on the coordinated deformation relationship of the "anchor-grouting body-surround rock" system. In an ideal state, the "anchor-grouting body-surrounding rock" is consolidated into a whole, and the deformation is coordinated. However, restricted by the quality of on-site support construction, grouting property, surrounding construction disturbance and surrounding rock characteristics, "bolt-grouting and surrounding rock" shows the characteristics of non-coordinated deformation.

5. Conclusion

In this paper, the stress response characteristics of the bolt are divided into three categories: the stress change of the "Stepped" bolt is in step with the corresponding "stress-controlled" surrounding rock, and gradually declines along the depth of hole; The stress of "One Pull One Press" type bolt is mainly controlled by the structural plane. The stress of "Load Drop" bolt appears with the non-coordinated deformation between the medium interface of the anchorage system.

Acknowledgments

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