Construction Control Method and Application of Hydropower Project Based on Permanent and Temporary Monitoring

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Abstract. According to the permanent and temporary monitoring results, the warning boundary method and the mathematical physical model method are used for early warning and forecasting, and the construction measures are dynamically adjusted to form a construction control method based on safety monitoring technology. The application of the method which combines permanent monitoring with temporary monitoring on the front slope of the tail water outlet of the left bank, the upstream side wall of the 7#-8# machine on the right bank, and the downstream abutment of the 9#-10# unit section of Wudongde Hydropower Station, shows that it can fully grasp the stability of surrounding rock during construction period of slope and underground caverns. Through the early warning and forecasting, the mechanism of deformation is analyzed, the construction measures are adjusted in time, and the effect of the measures is evaluated, which plays an important role in ensuring the safety of the construction period.

1. Introduction

With the comprehensive acceleration of hydropower construction[1], the cascaded Xiluodu and Xiangjiaba hydropower stations in the lower reaches of the Jinsha River have been completed, and the Baihetan and Wudongde hydropower stations are in full swing. At present, large-scale hydropower projects are located in the western alpine valleys and high-intensity seismic zones[2]. And there are many difficulties and challenges in the construction period. For example, the scale of the project is huge, the geological conditions are complex, the construction technology is difficult, and the safety risks are high[3]. In order to ensure the safety of hydropower projects during construction, monitoring techniques are often used for understanding the safety status of geotechnical structures or buildings to analyze abnormal conditions and take targeted construction measures. Due to the low investment in temporary monitoring during the construction period, the observation accuracy and the quality of the buried often fail to meet the safety evaluation requirements. Permanent monitoring is only for the project operation period, and it is impossible to fully grasp the safety status of rock and soil or buildings during construction. In view of this, this paper proposes a method of combining temporary monitoring with permanent monitoring, establishes monitoring results analysis and early warning forecasting methods, and forms a construction control method based on safety monitoring technology, which effectively ensures the safety of hydropower projects during construction.
2. Analysis of advantages and disadvantages of permanent monitoring and temporary monitoring methods

Hydropower engineering safety monitoring is generally divided into temporary monitoring and permanent monitoring. The contract management structure is shown in Figure 1. Temporary monitoring is to guide the construction. It is generally included in the civil construction contract and implemented by the civil construction company. It has the characteristics of short monitoring time, simple monitoring method and low cost. Permanent monitoring is mainly for the operation period, generally in a separate contract section, and the professional monitoring company is responsible for the construction. It has the features long monitoring time, high installation quality, and systematic layout.

During the construction of large-scale hydropower projects, the complicated geological conditions and technical difficulties make the construction especially the excavation of large underground caverns face severe situations, the safety risk during the construction period is high. Temporary monitoring in civil construction contracts generally has lower investment. Simpler monitoring methods such as temporary convergence monitoring and crack meter are used in this condition. Measuring point arrangement is more limited. Monitoring instrument buried quality and observation accuracy are poor. Monitoring results are not reliable. Because of this, only the qualitative judgment of the safety status during the construction period can be made and can not meet the safety evaluation requirements during the construction period.

Permanent monitoring generally includes monitoring items such as deformation, seepage, stress and strain, and temperature. The project settings are shown in Figure 2. Compared with the temporary monitoring during the construction period, the monitoring methods are more diverse and comprehensive, and can be verified against each other. The accuracy of the monitoring instruments and the quality of the embedded installations are high, and the information provided is more reliable. Together with the application of automated monitoring technology, it has greater advantages in data collection timeliness and analysis and early warning. However, there are certain limitations in the application of permanent monitoring during the construction period. Because the monitoring instruments generally adopt system layout, there is no targeted arrangement for the parts with poor local geological conditions or poor stability, and it is impossible to fully perceive the security status of the various engineering parts during the construction period.
3. Monitoring and arrangement method of permanent monitoring combined with temporary monitoring

In order to ensure the safety of large-scale hydropower projects during the construction period, to overcome the shortcomings of temporary monitoring and permanent monitoring and give full play to the advantages of the two monitoring methods, people can adopt the way of "mainly permanent monitoring, supplemented by temporary monitoring, combined with system layout and random arrangement". It's a way to combine temporary monitoring with permanent monitoring to fully capture security risks during construction.

"Mainly permanent monitoring, supplemented by temporary monitoring", the advantages such as high accuracy and reliable monitoring results of permanent monitoring can be fully utilized. Safety analysis and evaluation based on permanent monitoring results, supplemented by temporary monitoring and mutual verification.

“Combined with system layout and random arrangement” can fully combine the advantages of temporary monitoring and permanent monitoring. The monitoring instruments are arranged according to the safety level and the local regional geological conditions. The permanent monitoring is systematically arranged to meet the needs of permanent operation. For the important engineering parts or parts with poor local geological conditions, permanent monitoring instruments can be randomly arranged; for general engineering parts or better geological conditions, only temporary monitoring instruments can be arranged.

4. Introduction to monitoring data analysis and early warning forecasting methods

4.1. Normal method

The conventional methods of monitoring data analysis can be divided into four categories: comparison method, drawing method, eigenvalue statistical method and measurement factor analysis method.
4.1.1. Comparison method
The comparative method is a method of comparative analysis to verify whether the physical quantity and its changes are reasonable, or whether the state of the object is stable. During the construction of large-scale hydropower projects, the results of temporary monitoring and permanent monitoring are compared with each other. The results of deformation monitoring and stress-strain monitoring are compared with each other, and the measured values and technical warning values are compared with each other.

4.1.2. Drawing method
By drawing the process line diagram, correlation diagram, distribution map and comprehensive process line diagram of temporary monitoring and permanent monitoring, the magnitude and regularity of the observed values are visually reflected, and the influencing factors are analysed.

4.1.3. Eigenvalue statistical method
The eigenvalue statistical method is to count the characteristic points (such as the maximum value, the minimum value, the change range, the change trend, etc.) during the change of the measured value, and compare and recognize the change law of the monitored physical quantity.

4.1.4. Measurement factor analysis method
In the construction process of large-scale hydropower projects, important influencing factors such as blasting excavation, grouting, drilling, support, lining, unfavorable geological conditions and groundwater will be collected, and the influence characteristics and laws of these influencing factors on the measured values will be analysed.

4.2. Early warning method
During the construction of large-scale hydropower projects, in view of the obvious changes in the results of temporary monitoring and permanent monitoring, it should be analyzed in time, and determine whether warning information needs to be released, which is also the key to safety monitoring. The usual methods of early warning and forecasting include the warning line method and the mathematical physical model method.

4.2.1. Warning line method
The application of the warning line method in the construction of large-scale hydropower projects is based on the geological factor analysis method, the engineering analogy method and the rock mass structure analysis method. The monitoring results are used for comprehensive analysis to determine the critical values such as deformation or strain. Safety warning line for monitoring and forecasting.

4.2.2. Mathematical physics model method
Mathematical physics model method is to establish relationship between monitoring physical quantities (such as displacement, strain, osmotic pressure) and other causes (such as time, water pressure, initial ground stress, etc.) by mathematical tools and physical mechanics, and quantitative analysis of monitored physical quantities. The mathematical physics model method mainly explains and analyzes the monitoring data based on the principle that the measured effect quantity and the model prediction effect quantity are basically consistent, judges the working state and stability of the geotechnical engineering, and predicts the change trend of the effect quantity. There are mainly three types of statistical models, deterministic models and mixed models.

5. Construction control method based on safety monitoring technology
The permanent monitoring and temporary monitoring results analysis method is combined with the PDCA cycle management method to dynamically adjust the construction method. The control flow is shown in the Figure3. During the construction process, the permanent monitoring and temporary
monitoring results are analyzed, and predictions are made to judge the safety status of buildings or structures. For the existing warning situation, people should take corresponding construction control measures, and dynamically adjust the frequency of encrypted observations, track the change process in time, evaluate the effect of the control measures, and realize the timely and rapid dynamic adjustment of the construction plan.

![Construction control method flow](image)

**Figure 3. Process flow of safety monitoring technology combined with construction control**

6. **Cases in Wudongde Hydropower Station Application**

6.1. **Brief introduction of Wudongde Hydropower Station**

Wudongde Hydropower Station is the highest level of the four cascade hydropower stations in the lower reaches of the Jinsha River – Wudongde, Baihetan, Xiluodu and Xiangjiaba, belonging to the mountain valley. The slope of Wudongde Hydropower Station is characterized by high, steep and dangerous features. The underground project has the characteristics of large scale, large caverns and complicated layout. The length of the high slope of the dam site is about 2.0km, and the natural slopes of the left and right banks are as high as 1036m and 830m, respectively, which are mostly steep slopes[4]. The maximum excavation size of the main powerhouse of the underground power station is 333.00m×30.50m (32.50m)×89.80m (length×width×height). The scale of digging is the forefront of similar projects in the world[5]. The engineering geological problems in the dam site area mainly include high slope stability problems, stability of surrounding rock of caverns, and groundwater corrosion problems. There are many safety risks during construction, and unproven geological problems in the local area. It is necessary to make timely adjustments to the design and construction measures.

6.2. **Application case statistics**

The safety monitoring project of Wudongde Hydropower Station adopts the method of “mainly permanent monitoring, supplemented by temporary monitoring, combined with system layout and random arrangement” to arrange the measuring points, analyze the monitoring results, form rapid warning and feedback mechanism, adjust the construction measures timely, ensured the safety of the hydropower station effectively during the construction period. During the construction of the front slope of the left bank tail water outlet, the upstream side wall of the 7#–8# machine on the right bank, and the
downstream arch of the 9#–10# unit section, major deformations were monitored in time. The results were timely forecasted and forecasted, the deformation mechanism were analyzed, the corresponding engineering measures were taken, and the engineering measures were evaluated based on the monitoring results. The specifics are shown in the table1, which effectively guarantees the safety of the Wudongde Hydropower Station during construction period and plays an important role.

| Engineering site | Deformation | Early warning method | Reason | Engineering measures | Effect of measures |
|------------------|-------------|----------------------|--------|----------------------|-------------------|
| Left bank tail water outlet front slope | Daily deformation > 2mm/d | Cordon method | Excavation has cutting feet, overall unloading deformation | Reinforce the front slope of the exit and the transition section of the tunnel exit, and pour the middle pier | Slow deformation, stable slope |
| The right side wall of the main building of the right bank 7#–8# | Daily deformation > 3mm/d | Cordon method | The side wall is a steeply inclined and small angled layered structure, excavating the cutting feet, and the support is not timely | Reserved rock piers, interval excavation, controlled blasting | Slow deformation, stable surrounding rock |
| Downstream abutment of the 9#–10# unit section of the main building on the right bank | Daily deformation > 5mm/d | Cordon method | Located in the core of the fold, excavation unloading leads to stress concentration | "Rolling steel fiber concrete + coarse steel mesh" forms a joint anchor cable group reinforcement | Slow deformation, stable surrounding rock |
| Flood discharge hole plunge pool slope | Monthly sedimentation rate > 5mm/month | Mathematical physics model | The quality of the slope rock mass is poor, the excavation unloading is slack, and the slope foot restraint is released. | Start the elevation support below 835m as soon as possible, and strictly control the blasting | Slow deformation, stable slope |

7. Conclusion

(1) In the arrangement of measuring points, the method of “mainly permanent monitoring, supplemented by temporary monitoring, combined with system layout and random arrangement” can take full advantage of the benefits of temporary and permanent monitoring.

(2) According to the results of permanent and temporary monitoring, the warning boundary method and the mathematical physical model method are used for early warning and forecasting, the deformation mechanism is analyzed, the construction measures are adjusted in time, and the effect of the measures is evaluated to form an effective construction control method.

(3) After the application in the Wudongde Hydropower Project, the construction control method based on permanent and temporary monitoring can fully grasp the stability of the surrounding rock during the construction period of the slope and underground caverns, and the method plays an important role in ensuring the safety of the construction period.

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Table 1. Application of typical case of Wudongde Hydropower Station
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