Study on Dynamic Control of Underground Powerhouse Construction Process of Hydropower Station

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Abstract. Dynamic control of underground powerhouse construction can ensures the construction progress and quality of hydropower station. Based on the comprehensive management and control of underground powerhouse construction, the intelligent monitoring, comprehensive analysis, dynamic management and control technology of the excavation, support and monitoring were studied to realize the perception, analysis and control of the construction process of underground powerhouse. Furthermore, the reliability of dynamic control was verified according to the excavation of an underground powerhouse of hydropower station. The research results shows that the loose circle after the excavation is less than 20 cm, the over excavation were less than 6.5 cm, the evenness is less than 4.6 cm, and the half hole rate is more than 98.4% under the interaction of dynamic control. The research results can provide reference for promoting the information and intelligent development of hydropower project construction.

Keywords: Dynamic Control, Underground Powerhouse, Hydropower Station, Excavation.

1 Introduction

China has a vast territory and complex topographic features. The Qinghai-Tibet Plateau, Yunnan-Guizhou Plateau, the central mountainous areas and the eastern offshore plain constitute the characteristics of the three-level platform with sudden drop in topography from west to east in Chinese mainland, and the complex geological conditions are rare in the world. At the same time, most of the water resources are distributed in the western mountains, deep valleys and great rivers, such as Jinsha River, Yalong River, Dadu River, Nujiang River, Lancang River, Wujiang River, Hongshui River and the upper reaches of the Yellow River. Typical topography, geology, environment and hydraulic conditions in western China make underground caverns become the best choice for the layout of hydropower projects in most cases. With the development of hydropower in western China, the number, scale, geological conditions and technical difficulty of underground powerhouses will continue to surpass, and underground caverns are developing towards the direction of large capacity of single machine, large span of caverns, large-scale construction and high safety requirements. In view of the complex geological conditions and high requirements of excavation forming on the left

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bank of Baihetan Hydropower Station, a set of technically feasible construction schemes and blasting parameters were selected by comparing and analyzing various construction schemes and blasting parameters by scientific means, and the quality control objectives of rock wall beam excavation were set, and the special construction quality management methods of rock wall beam excavation were formulated [1]. He et al. [2] put forward new ideas and methods of intelligent analysis and evaluation and time-space prediction system of rock engineering safety under complex conditions by using artificial intelligence, system science, rock mechanics and engineering geology, which have been successfully applied in slopes and underground powerhouses of many large-scale projects such as Longtan, Bachimen, Shuibuya and Laxiwa. Fan et al. [3-4] put forward the whole process construction technology of time-space deformation control of surrounding rock of basalt caverns group, which is "advanced pre-control, vertical thin stratification, plane subdivision, short footage, fine and strict blasting, rapid and strong support, full-time diligent measurement, fast data feedback and dynamic inversion optimization". Combined with the large scale and complex geological conditions of the underground powerhouse of Xiangjiaba Hydropower Station on Jinsha River, the construction procedures and supporting parameters of the underground caverns, especially the main powerhouse, are determined through a large number of scientific research designs. In the construction process, fine management is adopted to strictly control the construction, and a real-time monitoring dynamic analysis feedback system integrating design, scientific research and construction is established. Qi et al. [5] By analyzing the engineering geological conditions of underground powerhouse of CCS Hydropower Station, the geological generalized model is established by selecting the unit profile, and the numerical analysis model is established by using the finite element program Phase 2. Based on the elastic-plastic constitutive relation, the construction excavation and support are numerically simulated, and the distribution and change characteristics of deformation field, stress field and plastic zone of surrounding rock during excavation are studied. Hong et al. [6] analyzed the airflow structure and dust migration law in the underground main powerhouse of a hydropower station by using a three-dimensional unsteady Euler two-phase flow turbulence model, and revealed the dust distribution changes at different times. Based on the advanced geological exploration and deformation monitoring results of underground powerhouse in Pakistan, Chen et al. [7] introduced and summarized the excavation construction technology and technical points of underground powerhouse under large deformation conditions in detail from the perspectives of excavation construction procedures, methods and permanent support design adjustment and optimization. Xie et al. [8] According to the structural characteristics, geological conditions and construction influencing factors of the underground powerhouse system of Dagangshan Hydropower Station, the excavation quality of the underground powerhouse is effectively guaranteed and the deformation of the high side wall is effectively controlled by scientifically arranging the excavation sequence before excavation, rationally arranging the construction channel, and adopting technical measures such as controlled blasting influence, safety monitoring, timely support and strong support during excavation. Yan et al. [9] In view of the excavation construction of underground powerhouse of Pubugou Hydropower Station, measures such as reasonably determining excavation stratification, optimizing construction channel, actively responding to unfavorable geological conditions, carefully drawing up excavation procedures and methods, strengthening monitoring and control, etc., ensured that the excavation of underground powerhouse was completed on schedule, with high quality and in an orderly manner. Xiao et al. [10] combined with the excavation construction of underground powerhouse of Pubugou Hydropower Station, the deformation status of surrounding rock can be grasped at any time through loose circle detection, and the construction is carried out in strict accordance with the excavation blasting test parameters during the construction process, strengthening safety monitoring analysis and feedback, ensuring the construction quality of the project and speeding up the construction progress.

According to the control requirements of quality, schedule and cost in hydropower industry, this paper builds a dynamic control platform of construction resources, studies the basic theory and practical application of intelligent monitoring, comprehensive evaluation and dynamic scheduling of construction resources, and establishes a complete comprehensive control theory of the whole process of underground powerhouse construction, so as to realize intelligent scheduling of construction resources.

2 Underground Powerhouse Construction Process Control

2.1 Review of Excavation Measures Plan

(1) Excavation sequence of caverns. The underground cavern group of hydropower station is super-large, and the construction sequence of main and auxiliary powerhouse, main transformer room and tail water surge chamber affects the stability of surrounding rock of the whole underground cavern group. The excavation sequence of caverns examined and approved by the supervision organization is as follows: the main powerhouse is constructed first, the tail water surge chamber is delayed, and the main transformer chamber is delayed [11].

(2) Relationship between high side wall and construction of penetrating cavern. In order to reduce the deformation of plastic zone of high side wall and surrounding rock, the construction sequence of tunnel and side wall crossing high side wall of powerhouse is arranged according to the principle of "first tunnel and then wall". Diversion tunnels, draft tubes, bus tunnels and other traffic passages shall enter the workshop in advance before the side wall of the workshop is excavated to the corresponding elevation (generally controlled according to the height of 1 ~ 2 floors), and the locks shall be made.

(3) Construction relationship between drainage tunnel on floor I of underground powerhouse and pilot tunnel on floor I of powerhouse. There are a large number of observation instruments in the drainage tunnel on the I floor of underground powerhouse. In order to obtain the original data of stress and deformation, the drainage tunnel is arranged to penetrate before the excavation of the pilot tunnel on the I floor of the powerhouse, and the instruments are buried.

(4) The excavation of the workshop is layered. Excavation of underground powerhouse is carried out in multiple layers. The excavation of the top floor adopts the middle pilot tunnel and the smooth blasting expansion excavation on both sides [12].

2.2 Review of Construction Channel Layout and Ventilation Scheme

(1) Construction channel layout. The workshop should be excavated in three parts: upper, middle and lower, and the excavation channel should be arranged in three floors: upper, middle and lower. Two construction passages are arranged on the upper part (I ~ III floors) of the main and auxiliary powerhouses. The main passages used in the middle (IV ~ VI) are: factory transportation tunnel, bus tunnel, main transformer transportation tunnel and traffic tunnel. The upper section of the lower part of the main and auxiliary powerhouse (VII ~ X layer) uses a flat tunnel under water diversion, and the lower section uses draft tube as the excavation channel.

(2) Review of ventilation scheme. According to the construction schedule, the construction ventilation scheme approved by the supervision organization is as follows: during the construction period above the third floor of the main workshop, because the permanent ventilation shaft has not yet been formed, the external ventilation channels during the construction period are the downstream tailrace gate transportation tunnel and the upstream No.3 construction branch tunnel, which is constructed with double working faces, and the ventilation system fans are arranged at the entrance of No.3 construction branch tunnel, which undertakes the construction exhaust of the upper part of the main workshop and the permanent ventilation system in the early stage and the underground caverns in the later stage. The downstream side mainly uses tailrace gate fan ventilation system. During the construction below Floor IV of the main workshop, the construction of permanent exhaust shaft is completed, and the construction air intake is mainly based on the fan system at the entrance of the transportation tunnel of the main workshop, and the exhaust air is mainly based on the permanent exhaust system, supplemented by the water diversion channel.

2.3 Configuration of Main Excavation and Support Equipment

According to the construction bidding documents and project progress requirements of the contractor, the supervision organization puts forward requirements on the quantity and equipment performance of important construction machinery and equipment such as rock drilling jumbo, concrete spraying truck, mortar anchor grouting machine and anti-well drilling rig. Usually, the main construction machinery and equipment are shown in Table 1.

Table 1. Main construction machinery and equipment.

Equipment	Numbers
BOOMER353E Three-arm rock drilling rig	3
BOOMER282 Two-arm rock drilling rig	2
ROCD7Crawler-type drilling rig	4

ROC442PC Crawler-type drilling rig	2
RH400Raise-boring machine	2
LM-200Raise-boring machine	3
Deguna 20TEV Anchor rod grouting machine	6
UH4.8 Anchor rod grouting machine	8
Meyco Concrete sprayer truck	3
Sika-PM 500PC Concrete sprayer truck	1

2.4 Site Construction Process Control

(1) Drilling and blasting test. In order to ensure the blasting effect, the supervision organization organized the construction unit to carry out drilling and blasting tests on the excavation of roof arch protective layer, presplitting of side wall, excavation of rock wall beam area and excavation of ladder section, and determined and optimized the drilling and blasting parameters. Through drilling and blasting test, the blasting particle vibration velocity affecting the stability of surrounding rock is determined.

(2) Drilling and blasting quality control. Supervisors focus on checking the preparatory work before blasting, such as construction preparation, measurement, drilling, charging and blockage, blasting network and monitoring. When measuring the placement point of smooth blasting hole and presplitting hole, the supervisor shall stand by and retest to ensure the accurate position of blast hole. In pre-splitting and smooth blasting hole-making of rock wall beam, supervisors check the position of drilling sample rack, hole spacing, inclination angle, azimuth angle and hole depth to ensure that the drilling quality meets the requirements. After the hole is formed, the supervisor shall recheck and accept the blast hole. Before blasting, the supervisor shall check the length and quality of blast hole blockage and initiation network, and sign the quasi-blasting certificate before allowing initiation.

(3) Quality control of bolting and shotcreting support. The supervision organization requires that rock drilling jumbo must be used for bolt hole making, high-power mortar grouting machine must be used for bolt grouting, and concrete shotcrete truck must be used for shotcrete. The input of construction resources provides a guarantee for the support quality. The supervision organization puts forward surface requirements for the maximum distance between cavern support and excavation face of different surrounding rock types. Weak surrounding cave section and cross volley face require support to keep up with excavation face. When the tunnel penetrates into the high side wall and other parts, it is required to lock the mouth in advance. The anchor grouting and shotcrete construction shall be managed by quasi-installation and quasi-shotcrete system. Only after the supervision personnel check the hole-making quality and the quality of shotcrete rock surface is qualified can the anchor grouting and shotcrete operation be started. Supervisors shall supervise the construction of anchor cables and important anchor rods on the side, and supervise the whole process of the quality of anchor rods, anchor cable grouting and anchor cable tension (including prestressed anchor rods). Relying on the owner's geophysical prospecting center and based on the self-inspection of the construction unit, the supervision organization inspected the length of mortar anchor rod and grouting compactness according to the proportion of not less than 15%

of the self-inspection quantity of the construction unit. The thickness of shotcrete is checked by marking method and core drilling method, which ensures that the thickness of shotcrete meets the design requirements.

2.5 Special Area Construction Control

The key points of excavation control are the rock wall beam, the part between the downstream side wall bus tunnel and draft tube, the rock pier reserved in the machine pit of the workshop, and the upside down suspension at the top of draft tube. The supervision organization has carried out detailed examination on the construction bills of the above parts, and strengthened the monitoring of the construction process.

(1) Rock wall beam. It mainly controls the pre-splitting of excavation, smooth blasting partition, hole-making method of smooth blasting hole on rock wall, bolt installation method and construction quality.

(2) Downstream side wall of powerhouse between bus tunnel and draft tube. Follow the excavation sequence of "first hole and then wall", and make a good lock. Anchor cable is required to follow the excavation face. Some anchor cables adopt steel anchor piers, which accelerates the construction progress.

(3) Rock piers are reserved in the machine pit of the workshop. The rock pier is constructed by the method of "pulling the middle groove", that is, the construction scheme of the middle groove first and the smooth blasting of the pit wall is adopted. Before the excavation of the pit, the top of the pit should be supported with anchor bars in advance, and prestressed anchor rods and small opposite anchor cables should be added to the pier wall.

(4) Upside down suspension at the top of draft tube. The excavation of the first layer of draft tube must enter the workshop before the pit excavation, and complete the top support. It is required to reinforce the draft tube and its top upside down part with prestressed anchor rod, which ensures the safety and stability of rock column [13].

3 Research on Comprehensive Evaluation Model of Construction Resources

Comprehensive evaluation of construction resources takes the whole process of excavation, support and monitoring in underground powerhouse construction as the research object. According to the control requirements of quality, schedule and cost, combined with the analysis results of historical information of monitoring in the whole process, the comprehensive evaluation index system of construction resources is determined, and the comprehensive evaluation model of construction resources and key factor positioning is constructed [14].

3.1 Construction of Evaluation Index System

According to the standard construction efficiency of construction equipment, combined with the analysis of on-site monitoring information, considering the influencing factors such as construction personnel and time, the evaluation index calculation model is constructed.

Benchmark value = (standard efficiency × a + historical efficiency × b + efficiency in recent March × c) × x

(X is the influence coefficient of comprehensive factors, $1=a+b+c$)

Early warning value = benchmark value × b (b is early warning coefficient)

3.2 Single Link Efficiency Evaluation

According to the monitoring data of excavation system, analyze the productivity of excavation production system; According to the monitoring data of transport vehicles, analyze the synthesis and single efficiency of transport vehicles; Based on the monitoring data of support, the working efficiency of support equipment is analyzed.

3.3 Multi-Link Comprehensive Evaluation

According to the eigenvalue of historical data, combined with the theoretical efficiency analysis of equipment operation, the evaluation index system and evaluation model of each link are studied. According to the evaluation of each link, combined with the site construction constraints, a comprehensive evaluation model is constructed, that is, according to the barrel law multiplied by the influence coefficient of other factors.

3.4 Positioning Analysis of Key Factors

According to the data link of the whole process of excavation, support and monitoring, trace the data source exceeding the standard, analyze the time-consuming ratio of each link, and compare it with the index of each link to accurately locate the abnormal link. Combined with the field construction situation, comprehensive analysis and reasonable improvement scheme are put forward.

4 Research on Dynamic Scheduling Model of Construction Resources

Based on the construction progress and cost control, combined with the needs of multi-part construction, the idle situation of various equipment in the construction process is dynamically analyzed, and the dynamic scheduling model of multi-part construction resources is constructed, so as to improve the utilization rate of construction resources and reduce the comprehensive cost of construction resources. See Figure 1 for the dynamic scheduling model.

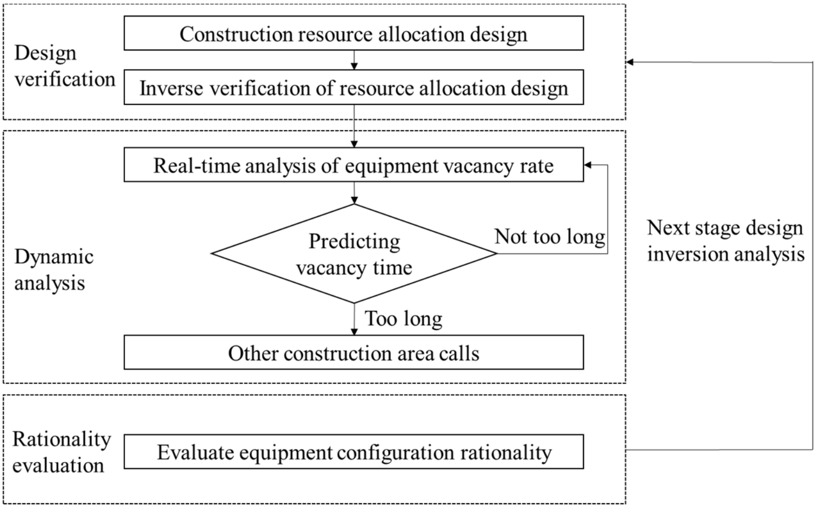

Fig. 1. Dynamic scheduling model for construction resources.

4.1 Process Gap Scheduling

Comprehensive historical monitoring data and construction technology time interval requirements, predict the idle time of construction equipment, and flexibly dispatch equipment in combination with other construction requirements.

4.2 Link Anomaly Scheduling

According to the abnormal situation in the field link, the time-consuming of abnormal handling is comprehensively judged, and idle equipment in other links is flexibly dispatched.

5 Research on Dynamic Management and Control Platform of Construction Resources

In view of the diversity and quantity of underground powerhouse construction equipment and the demand for multi-platform display, SOA service framework technology is adopted to break through the timeliness and integrity of big data processing and meet the requirements of multi-platform application. SOA architecture supports the integration of various devices. The architecture separates data collection and data processing. Data collection and data processing transmit data through message queue to improve data timeliness and accuracy. Data processing end, computer client and mobile phone client programs read and write data through a unified Web Api. See Figure 2 for the framework of dynamic management and control platform for construction resources.

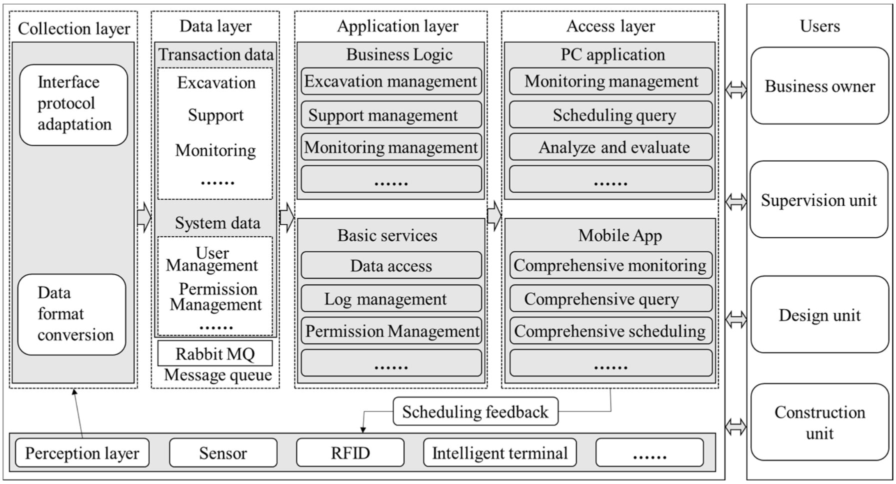

Fig. 2. Construction resource dynamic control platform framework.

Taking the construction progress and cost control as the goal, and based on the fine process control, the dynamic management and control platform of construction resources is constructed. See Figure 3 for the functions of construction resource evaluation optimization, dynamic scheduling and dynamic management and control platform. The main functions are as follows:

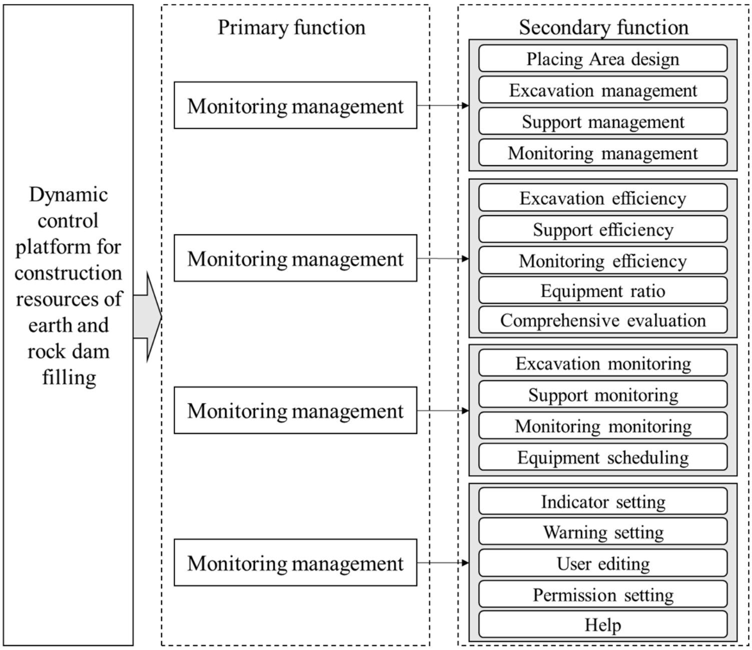

Fig. 3. Construction resource dynamic control platform.

(1) Monitoring and management: Configure the basic monitoring information, mainly including warehouse design information and production and transportation equipment information configuration.

(2) Analysis and evaluation: Statistical analysis of equipment efficiency, mainly including statistical analysis of each link efficiency of excavation and support, analysis of construction equipment configuration ratio, and comprehensive evaluation of single warehouse construction efficiency, so as to realize the whole process control of overall evaluation, link analysis, abnormal positioning and construction suggestion.

(3) Scheduling query: Real-time monitoring and dynamic scheduling of the whole construction process, mainly including real-time monitoring of equipment in each link of excavation and support, comprehensive construction of various parts, dynamic scheduling of equipment, and real-time monitoring of the whole construction process and scheduling of construction equipment.

(4) System management: Set up basic system information such as index users, mainly including index system and early warning model, users and authority.

6 Construction Control of Underground Powerhouse

6.1 Project Overview

The rock wall beam on the left bank of a hydropower station measures 384.02 m in length, while the one on the right bank spans 387.62 m. The excavation section from the rock anchor beam above to the chamber crown spans 31.9 m in width, and the section from the rock anchor beam below to the bottom of the powerhouse spans 28.4 m. The top width of the rock anchor beam is 265 cm, and its height is 325 cm. The design elevation of the upper inflection point on the rock platform stands at 390.345 m, while the lower inflection point has an elevation of 387.75 m. The rock face of the rock anchor beam spans 175 cm in width and 259.5 cm in height, with the slope of the rock platform extending 312 cm. Figure 4 shows the excavation section of the rock anchor beam for the powerhouse on both banks. The design documents stipulate that the excavation of the powerhouse's rock anchor beam must adhere to the following standards:

(1) Under-excavation and over-excavation of the rock wall must not exceed 20cm. The angle between the inclined plane of the rock wall and the horizontal plane should not deviate from the design value by more than 3°.

(2) Rock wall excavation ensure that the measured loosening range after blasting is less than 20cm.

(3) Residual blast holes from smooth blasting should be evenly distributed on the excavation contour surface. For intact rock, the residual porosity should exceed 80%, for relatively intact and less intact rocks, it should not be less than 50%, and for relatively fragmented and fragmented rocks, it should not be less than 20%. The rock surface between two adjacent holes should be flat, with no evident blasting cracks on the hole walls.

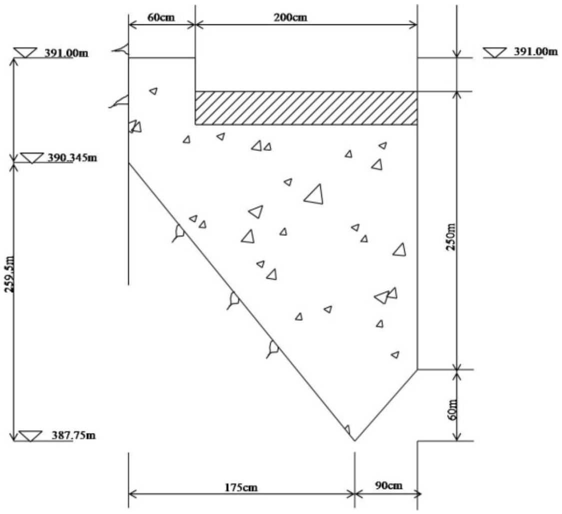

Fig. 4. Excavation section

6.2 Construction Sequence

The left and right bank power houses were originally planned to be excavated in 11 layers. After optimization, they were excavated in 10 layers from top to bottom, with each layer being 7~12 m high. The rock anchor beam is located in the third layer of the excavation construction group, and the excavation height of this layer is 9 m. According to the construction plan, 4m protective layer shall be reserved outside the excavation design line of the upstream and downstream side walls. The middle part of the plant between the upstream and downstream protective layers shall be excavated by slotted bench blasting. After the working face is expanded, the reserved protective layer and rock abutment shall be excavated. Before excavation, holes shall be made and presplitting blasting shall be conducted according to the reserved 4m protective layer outer boundary line to reduce the impact damage of subsequent middle excavation to the upstream and downstream side walls, and then the bench blasting in the middle of the plant shall be conducted. The excavation of the ladder shaped groove in the middle of the powerhouse is divided into two layers, the first layer is 4m deep and the second layer is 5m deep. The reserved protective layer shall be excavated after the layout of presplitting in front and large bench blasting excavation in the middle is formed. The excavation of the protective layer is divided into three sequences for smooth blasting, and the depth of each sequence is 3 m.

6.3 Construction Process Control

The 1:1 excavation model blasting test was carried out for the powerhouse on both banks before the excavation of the protective layer and the rock abutment. The excavation procedure and blasting technology were strictly implemented in accordance with the excavation construction of the rock anchor beam. The left bank is 15 m long and the right bank is 5 m long. During excavation, sonic velocity measurement and particle velocity monitoring shall be carried out for excavation blasting, and the disturbance of blasting to surrounding rock and system support shall be analyzed. Meanwhile, the excavation forming quality under different initiation parameters shall be analyzed, and the over and under excavation, flatness and half hole rate shall be recorded and counted. Finally, the drilling and charging parameters of basalt with different surrounding rock types under the optimal flatness and half porosity are determined, as shown in Table 2. In addition to the excavation operation space implied in the specification requirements and excavation quota, technical overbreak hole making is adopted in the protective layer and rock bench hole making. The vertical hole and inclined hole of rock bench are offset to the outside of the design excavation line, and the hole bottom is not too deep.

Table 2. Bore making and charging parameters

Type	Bore diameter (mm)	Bore depth (cm)	Bore distance (cm)	Power diameter (mm)	Single charge (kg)	Linear density (g/m)	Stemming length (cm)	Mode
Vertical bore	40	217.5	35	25	0.3	70	30	Interval charge
Auxiliary bore	40	252.4	70	25	0.8	80	90	Continuous charge
Incline bore	40	325.7	35	25	0.3	90	40	Interval charge

Table 3 shows the inspection data of excavation. The measured blasting loose circle after the excavation of the rock anchor beam on the left bank is less than 20 cm, the average overbreak is 5.95 cm, the unevenness is 4.40 cm, and the half hole rate is 98.85%; After excavation of rock anchor beam on the right bank, the measured blasting loose circle is less than 20 cm, the average overbreak is 6.35 cm, the unevenness is 4.10 cm, and the half hole rate is 99.15%.

Table 3. Excavation inspection

Part	Over excavation (cm)		Evenness (cm)		Half porosity (%)		Rock platform	Inflection point
	Upstream <10	Downstream <10	Upstream <10	Downstream <10	Upstream >90	Downstream >90	Angle deviation (°) 2	Fluctuation (cm) 10
Left bank	5.5	6.4	4.2	4.6	99.3	98.4	0.15	7

Right bank	6.2	6.5	4.5	3.7	99.0	99.3	0.25	6

7 Conclusion

(1) Based on the comprehensive management and control of underground powerhouse construction, the intelligent monitoring, comprehensive analysis, dynamic management and control technology of the excavation, support and monitoring were studied to construct the dynamic control platform.

(2) The loose circle after the excavation is less than 20 cm, the over excavation were less than 6.5 cm, the evenness is less than 4.6 cm, and the half hole rate is more than 98.4%, which verified the reliability of dynamic control.

(3) Through real-time monitoring, the refined management level of hydropower construction will be improved, and practical engineering applications will be carried out in the future, so as to continuously improve the system framework and integrated analysis functions, providing reference for promoting the information and intelligent development of hydropower engineering construction.

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