Research on the Quality Control Technology of Dam Shoulder Groove Project of Wudongde Hydropower Station

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Abstract. The shoulder groove project of Wudongde dam is a key program of the entire Wudongde Hydropower Project. The slope of the dam project is centered on the dam shoulder groove, where the upstream is the upstream shoulder and the power station intake, and the downstream is the downstream shoulder, plunge pool, second dam and downstream revetment. Therein, the excavation quality of the dam shoulder groove directly affects the long-term safety of the dam operation. The dam shoulder groove excavation elevation is 988m-718m, with the excavation height of about 270m, the excavation width of 18.32-51.42m, and excavation slope ratio of 1:0.21-1:9.2. The slope changes from steepness to slow, and there is no horse track set in the middle. Since the excavation quality directly affects the long-term safety of the dam operation, this paper deeply analyzes the influence factors of the relevant quality control requirements such as over-under-excavation, flatness, half-hole rate and blasting depth of the dam shoulder groove project of Wudongde Hydropower Station through integration and modularization of its key processes. This paper has a certain practical significance for the formation of the theoretical system and practical foundation of quality control technology for abutment trough of high slope dam of large hydropower station.

Keywords: Wudongde Hydropower Station, dam shoulder groove, Quality Control Technology

1. Overview

1.1. Project Introduction
The Wudongde Hydropower Station is the one in the upstream of four hydropower cascades in the lower reaches of the Jinsha River (Panzhihua to Yibin) - Wudongde, Baihetan, Xiluodu and Xiangjiaba. The main building of this Level I large project consists of retaining structures, discharge structures, water diversion buildings and other components. The retaining structure is a concrete double curvature arch dam with a height of 718m, a crest elevation of 988m and a maximum dam height of 270m. The total storage capacity of the power station is 7.408 billion m$^3$ with a total installed capacity of 10200MW.

The side slope of the dam takes abutment slot as the center line, the upper reaches are the upstream abutments, the inlet of the power station, and the down reaches are the downstream abutments, the plunge pool, the second dam and the downstream revetment. Therefore, the excavation quality will directly affect the long-term security of the dam. The excavation height of dam abutment slot is 988m - 718m. The excavation height is about 270m, the excavation width is 18.32 - 51.42m, and the slope ratio of excavation is 1: 0.21 - 1: 9.2, which is affected by the steepness and slowness of the dam.

The dam is located in steep slopes, the rock is mainly thick limestone, thick dolomite, medium
limestone, thick quartzite, with A type breccia and B conglomerate developed locally and rock mass fractured and fragmented in few parts. Most of the abutment slot is composed of level II 1 rock mass, there are some level II 2 rock mass located in the upper part of the two banks, and there’s only a few level III 1 rock mass on the right bank with an elevation of 910 m.

1.2. Excavation Quality Requirements
(1) The quality of drilling
The deviation of hole along the contour line is no more than 5% of the pitch, inclination and direction of deviation is no more than ± 1.5% of hole depth, the elevation deviation of the drill-hole finished is ± 5cm.

(2) Presplit effect detection requirements
1. half-hole rate of the abutment slot: for level II rock mass, it should reach more than 90%; for level III rock mass, it should be in the range of 60%-90%; for level IV rock mass, it should be in the range of 20%-60%. There should be no blasting cracks on the structural plane.
2. Over/Under excavation, unevenness: The over-excavation of structural surface shall be less than 20cm, no under excavation allowed; unevenness should be no greater than 15cm.

(3) Safety monitoring standards
The vibration velocity of blasting particle is less than 10cm / s and the depth of blasting effect is less than 1.0m.

1.3. Construction Difficult
(1) The excavation shape of abutment slot from top to bottom is in fan shaped divergence, it is both a slope and a twist surface; the no berm setting increases the rigging difficulties, making it more difficult to drill holes.

(2) Although the overall rock mass of the abutment slot is in good quality, it is easy to be cracked locally after the blasting, due to the influence of the interlayer and intra-layer misalignment belt cutting, weathering unloading, etc., and it is more difficult to control the quality indicators of evenness, over/under excavation, half-hole rate etc.

(3) The construction projects on the upstream and downstream side of abutment slot are complicated and strong connected, and there are overlapping problems in terms of construction period. If there is no coordinated planning, the projects may become great interferences for each other.

2. Research on Abutment Slot Excavation Technology

2.1. Selection of Blasting Parameters
In order to obtain the reasonable blasting parameters, seven blasting tests were conducted on the base of the left and right abutment trenches, and the blasting effects of 10m, 12m and 15m height were tested respectively. The following statistics were collected from the abutment slot blasting test: over/under excavation, evenness, pre-split half-hole rate, maximum blasting particle vibration velocity, the maximum impact depth of blasting, the specific data were shown in Table 1.
Table 1. Statistics table of dam slot demolition test

| Project Part | Heights (m) | Over/under excavation | Evenness | Pre-split half-hole rate (%) | Max. vibration velocity (cm/s) | Max. influence depth (m) |
|--------------|-------------|------------------------|----------|-----------------------------|------------------------------|-------------------------|
|              |             | Over excavation        | Max. under-exca    | Acceptability (%)          | Mean (cm)                   |                          |
|              |             | Max. value (cm)        | Mean (cm)         |                             |                             |                          |
| Left bank    | EL.975-960m | 15                     | 55.2             | 21.5                        | 12.6                        | 81.3                    | 35                      | 12.6                     | 83.0                     | 55.2                     | 13.5                     | 1.25                    |
|              | EL.976-961m | 15                     | 46.7             | 19.1                        | 7.2                         | 85.5                    | 31.0                    | 8.45                     | 92.3                     | 53.8                     | 11.3                    | 1.30                    |
|              | EL.987-975m | 12                     | 42.0             | 12.4                        | 11.0                        | 93.1                    | 14.0                    | 8.0                      | 100                      | 91.0                     | 11.1                    | 1.13                    |
|              | EL.982-972m | 10                     | 25.0             | 7.22                        | 5.6                         | 89.8                    | 24.0                    | 12.1                     | 85.0                     | 60.9                     | 8.7                     | 0.65                    |
| Right bank   | EL.976-966m | 10                     | 29.0             | 13.8                        | 0                           | 86.0                    | 19.0                    | 8.80                     | 90.0                     | 82.1                     | 7.62                    | 0.77                    |
|              | EL.985-975m | 10                     | 27.7             | 12.3                        | 0                           | 99.7                    | 12.0                    | 5.74                     | 100                      | 92.8                     | 7.98                    | 0.68                    |
|              | EL.975-965m | 10                     | 15.8             | 6.15                        | 10.0                        | 94.4                    | 9.8                     | 5.78                     | 100                      | 90.3                     | 6.23                    | 0.59                    |

It can be seen from the blasting test statistics (see Table 1), the quality of the blasting is the best in the stairs height of 10m, followed by that in the height of 12m, and the quality of the blasting in 15m staircase height is the worst. Considering the relationship between excavation quality and construction progress, the height of the abutment slope is generally determined as 10m, the thickness of blasting is 6.0m - 8.0m, the quantity of blasting is about 4500m³, explosive charge is more than 2t. The blasting parameters of left and right bank abutment slot are as follows:

1. Blasting parameters of the left bank abutment slot
   Pre-split hole: line charge density 294g / m, 147g / m, the bottom charge 1.8kg, single hole charge 3.8kg.
   Buffer hole: row spacing 1.6m × 2m, unit consumption 0.25g / m³, stem length 2.5m, single hole charge 22kg.
   Main blast hole: row spacing 3m × 3m, unit consumption 0.33g / m³, stem length 3m, single hole charge 36kg.

2. Blasting parameters of the right bank abutment slot
   Pre-split hole: line charge density 263g / m, 130g / m, the bottom charge 1.5kg, single hole charge 3.4kg.
   Buffer hole: row spacing 1.6m × 2m, unit consumption 0.3g / m³, stem length 3m, single hole charge 22.4kg.
   The main blast hole: row spacing 4m × 3m, unit consumption 0.4g / m³, stem length 3m, single hole charge 40kg.

2.2. Abutment Slot Layering, Zoning Planning
Abutment slot excavation principle is: top-down stratification; upstream to downstream zoning, in order to ensure the relevance of each part of the process, facilitate the overall coordination of planning and reduce the construction interference between adjacent parts.

2.2.1 Stratification Plan. The excavation height is the same as the height of the blasting bench. The height of the excavation on the left and right bank abutment slot is generally 10m. Considering the left bank elevation of 785m and the right bank elevation of 805m, the slope of the abutment slot is gradually reduced with an adjustments of the excavation height 7.5m - 2.0m, to ensure the quality of excavation. According to the above stratification principle, there are 29 excavation stratifications in the overall planning of left and right bank excavation.
The overall target progress is to excavate a height of 30m for every 40 days, taking abutment slot excavation as a vanguard line, adjust the upstream and downstream slope schedule accordingly. It’s planned to reach a stratified height (10m) every 13 days for the excavation of the abutment slot, a stratified height (15m) every 20 days for the excavation of the upper and the downstream slope (see Fig.1). The side slopes of upstream and downstream projects are supposed to be blasted ahead of abutment slot, so that the excavation of side slope will not affect the excavation of abutment slot.

2.2.2 Zoning planning. The abutment slot slope rom the mountain to the riverfront is divided into the posterior area and the former two sub-areas; the slopes on both sides of the abutment groove from upstream to downstream is divided into four partitions, each partition from the mountain to the river is divided into berm protective layer, the back area and the front area three sub-areas, see Figure 2. In order to create a favorable surface for the abutment slot blasting, both sides slopes of the abutment slot should be preceded blasting ahead of abutment slot, the slope excavation is proceeded in eight processes in turn: 1) Excavation of berm protective layer in district 2 and 3 → 2) Front area blasting of side slopes in district 2 and 3 → 3) Excavation of berm protective layer in district 1 and 4 → 4) Pre-splitting blasting of structural plane in posterior area of side slopes in district 2 and 3 → 5) Front area blasting of abutment slot → 6) Front area blasting of side slopes in district 1 and 4 → 7) Pre-splitting blasting of structural plane in posterior area of the abutment slot → 8) Pre-splitting blasting of structural plane in posterior area of side slopes in district 1 and 4 (see Figure 2).
2.3. Study on Pre-Split Hole 3D Modeling

Taking into account the irregular twist of abutment slot slope (See Figure 3), the accuracy of three-dimensional modeling of abutment slot pre-hole directly affects the quality of the abutment slot excavation. According to the principle of over/under balance, the three-dimensional original coordinate model is established before the excavation by taking the 40cm space of the drilling rig into full consideration, linear interpolation and trigonometric functions are used for calculation, including:

(1) Pre-split orifice coordinates: first blast height (988m) control point coordinates, pre-split hole spacing;

(2) The control point coordinates of hole bottom elevation design: adopt linear interpolation formula for checking:

\[
\begin{align*}
    x_q &= x_d + \left( \frac{z_q - z_d}{z_g - z_d} \right) \times \left( x_g - x_d \right) \\
    y_q &= y_d + \left( \frac{z_q - z_d}{z_g - z_d} \right) \times \left( y_g - y_d \right)
\end{align*}
\]

Where: \(x_q\) is the X coordinate value of a point on demand, m; \(y_q\) is the Y coordinate value of a point on demand, m; \(z_q\) is the height of a point on the Z axis, m; \(x_g, x_d\) are the X coordinate value of known points, m; \(y_g, y_d\) are the Y coordinate value of known points, m; \(z_g, z_d\) are the Z-axis elevation of known points, m;

(3) The actual control point coordinates of the hole bottom elevation: considering QZJ-100B drilling rig requires a certain construction space, equidistant slope is 40cm longer than side slopes, variable slope ratio can be increased accordingly but under 200cm; move the control point coordinates in step (2) to the slope (see Figure 5).

(4) Design pre-split hole bottom coordinates: The actual control point coordinates of the hole bottom elevation and pre-split hole spacing from step (3). In order to ensure the blasting quality, equidistant holes are drilled in the middle area of the spandrel slot, divergent holes on both sides of the spandrel slot (see Figure 4);

(5) Pre-split hole depth, inclination, azimuth: pre-split hole orifice coordinates, the pre-split hole bottom coordinates according to step (4);

(6) The coordinates of the actual control point of the next blasting hole: move the coordinates of the designed control point calculated in accordance with step (2) to the outreach of the slope;

(7) The coordinates of next blasting hole: according to the actual control point coordinates and pre-split hole spacing in step (6); the others shall be recycled based on Step (2) to (6).
2.4. Technological Transformation of QZJ-100B Drilling Rig

(1) Sample transformation

The drawbacks of QZJ-100B drilling rig lead to the drilling rig instability and large swing in drilling process. In order to ensure the stability of the rig, the two sides of the drill were welded with two Ф48 steel pipe and the steel pipe and the sample stand pole were firmly connected to eliminating drilling rig swing and improve the drilling accuracy (see Figure 6).
In the figure: Steel pipe fixing bracket 1, drill rod positioning device 2, rig support 3, pneumatic motor 4, drill-rod lifter 5, drill rod 6, impacter 7, pneumatic motor control integration 8

(2) Increase the number of spacing board
The spacing board of QZJ-100B drilling rig has a 1.0m above distance to the hole, it’s easy to deviate from the hole site in the drilling process, in order to reduce the drill deviation, a spacing board is welded to the bottom of the rig.

(3) Install centralizer
The rigidity of QZJ-100B drilling rig is too low to match the drilling diameter. With the deepening of hole depth and the increase of the number of drill pipe, the swing amplitude of drill pipe increases. A centralizer is added to the drill pipe (an additional centralizer is added to the connection of the first drill pipe and the third drill pipe, then one for every 3m) to avoid the occurrence of “floating drills” caused by geological changes.

2.5. Pre-split Hole Customized Charge
The abnormal conditions are recorded during drilling process, and a column of Drill Hole has been drawn in the pre-split drilling process. In the follow-up blasting charge design, we charge normally to the parts with no abnormality and charge fewer to parts with abnormalities, in order to improve the excavation quality parameters such as over-under-excavation, evenness, half-hole rate through the development of customized blasting parameters.

3. Quality Test Result
At present, the left and right banks of abutment slot have been excavated to the elevation of 805m, the results of excavation quality test are as follows:
(1) Unevenness, over and under excavation, half-hole rate
The maximum, minimum and average unevenness of the abutment slot on the left bank are 34.2cm, 0.2 cm, 5.52cm respectively with an acceptability of 97.6%. The maximum, minimum and average unevenness of the abutment slot on the right bank are 32.5cm, 0cm, 5.93cm respectively with an acceptability of 97.4%.
(2) Half-hole rate
The average half-hole rate of the abutment slot on the left bank is 91.4%, and that on the right bank of the abutment slot is 93.5%.
(3) Over and under excavation
The maximum and average over-excavation of the abutment slot on the left bank are 121.2cm and 11.2cm (including geological defects), with no under excavation; the maximum and average over-excavation of the abutment slot on the right bank are 97.6cm and 10.7cm (including geological defects), with no under excavation.
(4) The maximum blasting vibration velocity
The total number of blasting detection on the left bank abutment slot is 16 times, the maximum vibration velocity exceeds the standard 2 times and the over-proof rate is 12.5%; the total number of blasting detection on the right bank abutment slot is 16 times, the maximum vibration velocity exceeds 3 times, the over-proof rate is 18.8%.
(5) The influence depth of blasting
The influence depth of excavation blasting on the left bank of abutment slot does not exceed the standard, with an over-proof rate of 0.55% and an average depth of 0.63m. The influence depth on the right bank also does not exceed the standard, with an average depth of 0.53m.

4. Conclusion
This paper successfully verified the feasibility of related technology of construction quality control by scientific technology planning, fine management and quality control. Through the scientific field test, technical analysis and planning, and the use of limit blasting scale control of the total charge and the use of high-precision detonator in the abutment slot excavation in Wudongde hydroelectric dam, this
paper studied and analyzed the effect of shaping dam abutment trench to control the excavation quality from the micro-mechanism. Starting from the source, the whole process advanced and went deeply into each key process and succeeded in obtaining the management means and practical data to improve the quality and progress of dam abutment trench, which has provided an important reference in terms of the quality management for the follow-up dam abutment trench projects of subsequent large hydropower stations.

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