Application of the Centralized Charge Chamber Technique in Directional Blasting Demolition of the RCC Cofferdam in the Third Phase of the Three Gorges Project

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Abstract: The upstream roller-compacted concrete cofferdam in the third phase of the Three Gorges Project on the Yangtze River was demolished using a scheme featuring a combination of directional tip-over blasting by setting up centralized charge chambers (holes) at 380m on the middle section of the cofferdam and deep-hole blasting on both ends. This paper primarily elaborates on the directional tip-over blasting model test with preset centralized charge chambers, blasting parameters, priming circuit design, and execution results.

Keywords: Three Gorges Project, RCC Cofferdam, Centralized Charge Chambers, Cofferdam Demolition, Design of Blasting Parameters

1.Project Overview

The upstream roller-compacted concrete cofferdam in the third phase of the Three Gorges Project on the Yangtze River is arranged in parallel to the dam; its transverse cofferdam axis is located 114m upstream from the dam axis, with its right side connected to the mountain on the right bank and its left side linked to the longitudinal cofferdam axis. The transverse cofferdam axis stretches 546.5m, comprising, from right to left, the right-bank slope section (Cofferdam Blocks No. 2~5, 106.5m long), the riverbed section (Cofferdam Blocks No. 6~15, 380m long), and the left junction section (60m long).

The third-phase roller-compacted concrete cofferdam is of a gravity structure. The cofferdam crest is 8m wide, and the cofferdam rises 121m at its highest point. The part of the upstream slope of the cofferdam above EL70m is the vertical slope, while the part below EL70m is the 1:0.3 side slope. The part of the downstream slope of the cofferdam above EL130m is the vertical slope, the part from EL130m to EL50m is the 1:0.75 terraced side slope, and the remaining part is a platform.

According to the results of hydraulic model tests, Cofferdam Blocks No. 2~4 of the upstream cofferdam do not affect the river water passage of the right-bank powerhouse, and therefore is not demolished. Actually demolished parts include Cofferdam Block No. 5 on the right bank, Cofferdam Blocks 6~15 on the riverbed section, and the left junction section. Specifically, the extent of demolition is as follows: Cofferdam Block No. 5 on the right bank, 40m long, demolished by 30m from

EL140m to EL110m; Cofferdam Blocks 6~15 on the riverbed section, 380m long, demolished by 30m from EL140m to EL110m; and the left junction section, 60m long, demolished from EL140m to EL110m, with its boundary with the longitudinal cofferdam demolished to the inner slope face of the longitudinal cofferdam.

The total length of the part of the cofferdam demolished by blasting is 480m, involving a total work quantity of 186,000m^3.

2 Overall Blasting Scheme for Cofferdam Demolition

Concrete work for the right-bank powerhouse section of the dam was performed ahead of schedule, and the dam was ready to resistant water during the flood season; thus, the period of the cofferdam blocking water for power generation could be ended ahead of schedule, shifting to the initial operational period. As such, the third-phase upstream roller-compacted concrete cofferdam was scheduled for demolition on June 6, 2006.

As all of the 14 generating units in the left-bank powerhouse had become operational, the entire length of the dam was blocking water, and the right-bank powerhouse was under intense construction, it was required that the demolition blasting operation should not interfere with the safety of the dam, the powerhouses and other key facilities.

On the basis of earlier research, tests and dedicated designs, the scheme featuring "a combination of directional tip-over blasting by setting up centralized charge chambers at 380m on the middle section of the cofferdam and deep-hole blasting on both ends" was adopted.

This paper primarily elaborates on the directional tip-over blasting model tests with preset centralized charge chambers, blasting parameters, priming circuit design, and execution results.

3 Directional Tip-over Model Test with Centralized Charge Chambers

The centralized charge chamber blasting technique is typically used in massive excavations of caverns in mountains, and there was no precedent of this particular technique being applied to cofferdam demolition. In order to investigate the reliability of directional tip-over demolition of the cofferdam with the centralized charge chamber blasting technique, a blasting model test was performed.

The 1:10 model tip-over blasting test for the transverse cofferdam was carried out at the Testing Facility. In light of the structural characteristics of the cofferdam, two pieces of concrete (C30), one 5m high and 6m long (1.5 cofferdam blocks) and the other 5m high and 8m long (2 cofferdam blocks), were made in the testing pond to simulate the cofferdam above EL90m which was to be demolished.

All charge chambers were preset according to the blasting design scheme. PP-R tubing materials were used for 1#, 2# and 3# preset charge chambers and fracture holes.

2# Charge Chambers were set up at an interval of 0.5m when the concrete pouring for the cofferdam reached EL101.5m from EL90m. 3#

Charge Chambers were set up at an interval of 0.4m when the concrete pouring reached EL106.4m. Prefabricated gallery were set up when concrete pouring reached EL107.5m. 1# charge chambers were set up at an interval of 0.22m when the concrete pouring reached EL108.7m. Fracture holes were set up at an interval of 0.10m when the concrete pouring reached EL109.7m. As it was unlikely to load charges from inside the prefabricated culverts, 1#, 2# and 3# Charge Chambers all had their horizontal connecting tubes arranged on the façade of the cofferdam, and charges were loaded into the chambers via the horizontal connecting tubes. The openings of the fracture holes were located on the back of the cofferdam in a horizontal pattern.

Figs. 3.1 and 3.2 are respectively the sectional view and plan view of the arrangement of the charge chambers in the model test. Fig. 3.3 shows the actually fabricated cofferdam model.

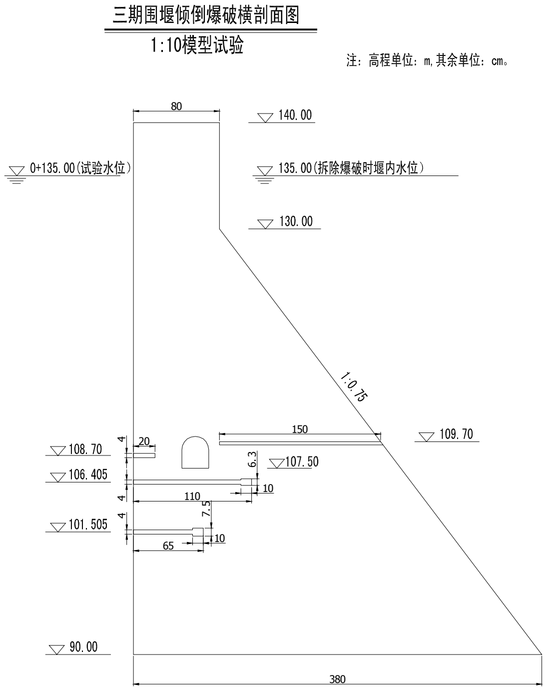

Fig. 3.1 Sectional View of the Arrangement of the Charge Chambers of the 1/10 Cofferdam Model

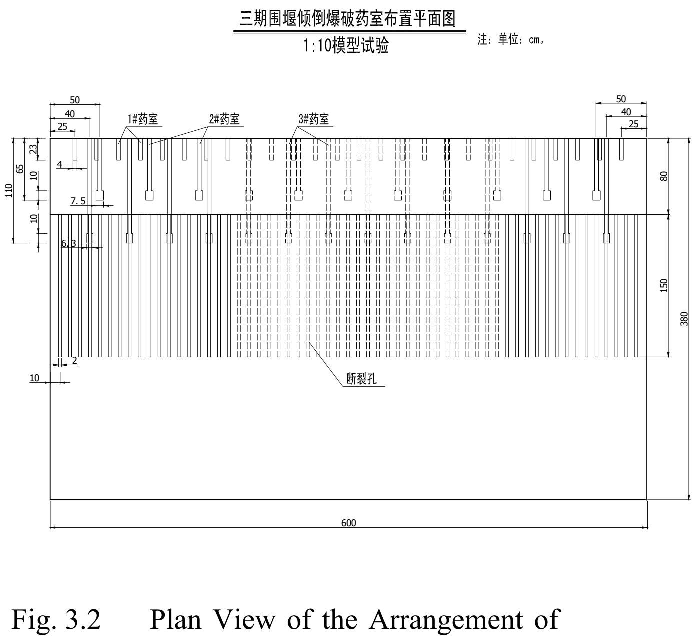

Fig. 3.2 Plan View of the Arrangement of the Charge Chambers of the 1/10 Cofferdam Model

Fig. 3.3 Actual 1/10 Cofferdam Model

Immediately after the loading of charge into the preset chambers and circuit connection, water was filled into the pond to a depth of 4.5m in simulation of the water level at EL135m both in and outside the cofferdam for demolition by blasting.

The blasting test showed favorable overall tip-over results, with the tip-over process and the form after tip-over largely consistent with what had been expected in the design, indicating that centralized charge chambers could create a gap to topple the cofferdam with ease.

4 Design of Blasting Parameters for Tip-over Location Design Conditions for Tip-over Blasting

4.1.1 Tip-over Space

Actual underwater terrain showed that within 70m of the upstream cofferdam axis, the underwater terrain facing the upstream surface of Cofferdam Block No. 15 had an elevation ranging from 62m to 73m, the underwater terrain facing the upstream surface of Cofferdam block No. 14~7 had an elevation ranging from 62m to 64m, and the underwater terrain facing the upstream surface of Cofferdam Block No. 6 had an elevation ranging from 64m to 95m.

Counting from EL110m at which demolition was to be performed, Cofferdam Block No. 15, Cofferdam Blocks No. 14~7 and Cofferdam Block No. 6 had an upstream tip-over space (height) of 37m, 46m and 15m, respectively, the maximum height required by a cofferdam after tip-over was 30m. Thus, there was adequate space for the tip-over of Cofferdam Blocks No. 15~7, but not so for Cofferdam Block No. 6. As such, Cofferdam Blocks No. 15~7 were meant to be blasted for complete tip-over, while Cofferdam Block was intended to be blasted for tip-over by preset charge chambers and fragmentation with boreholes.

4.1.2 Gravity center of the Tipped-over Part of the Cofferdam

The transverse cofferdam was to be demolished by 30m from EL140m to EL110m. The cross section of the cofferdam had a bottom width of 23m at EL110m, and the cross section area of the tipped-over part of the cofferdam had a size of 390m^2. The center of gravity was located 7.5m from the upstream surface and at EL121.8m.

4.1.3 Arrangement of Charge Chambers (Holes)

During cofferdam construction, the demolition scheme was integrated into the construction work, and #1, #2 and #3 Charge Chambers and fracture holes were set up in accordance with design requirements. 1# Charge Chambers were located at EL108.7m and 2.2m from the upstream surface, with an interval of 2.2m between the chambers; #2 Charge Chambers were located at EL101.5m and 6.0m from the upstream surface, with an interval of 5.0m between the chambers; 3# Charge Chambers were located at EL106.4m and 10.5m from the upstream surface, with an interval of 4.0m between the chambers; and a row of fracture holes was set up at EL109.7m in the cofferdam on the downstream side of the charge loaded gallery, with an interval of 1.0m between the holes. Fig. 4.1 shows the sectional view of the arrangement of the preset charge chambers and fracture holes.

The actual number of preset charge chambers is the same as the design. A total of 354 charge chambers were set up, including 178 #1 Charge Chambers, 78 #2 Charge Chambers, and 98 #3 Charge Chambers, as well as 376 fracture holes.

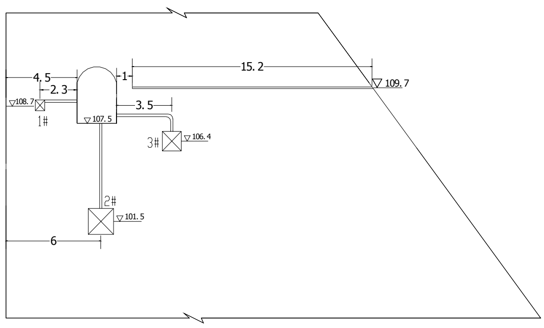

Fig. 4.1 Sectional View of the Arrangement of the Preset Charge Chambers and Fracture Holes

4.1.4 Water Level Conditions

Before the cofferdam demolition, the water level outside the cofferdam should be lowered to EL135m, while the water level inside the cofferdam should be impounded to EL139m, so that a water head differential could be created between the inside and outside of the cofferdam in order to form a tip-over moment to the upstream and enhance the reliability of the cofferdam tipping over to the upstream.

4.2 Design of Blasting Parameters

4.2.1 Design of Blasting Parameters for Preset Charge Chambers

The computational formula for the standard throw-blasting in unit volume is:

$$K = 0.4 + (\gamma/2450)^2$$

where γ is the volumetric weight of the blasting medium, kg/m^3.

The computational formula for chamber charge is:

$$Q = eK_d(K + HC_a)W^3 f(n)$$

where e is the charge conversion coefficient; K_d is the bidirectional action coefficient; K is the standard throw-blasting in unit volume over water, kg/m^3; H is the water depth, m; C_a is the water depth influence coefficient; W is the minimum resistance line, m; f(n) is the blasting action index function; n is the blasting action index. Table 4.1 shows the results of the computation of charges in the charge chambers.

In light of the characteristics of the arrangement of the charge chambers, all chambers were filled with mixed charges using charge loaders. The horizontal charged holes of #1 Charge Chambers had a plug length of 2.2m, the vertical charged holes of #2 Charge Chambers had a plug length

No.	Computational Parameters	Unit	#1 Charge Chambers	#2 Charge Chambers	#3 Charge Chambers
1	Design chamber interval	m	2.2	5.0	4.0
2	Charge conversion coefficient		1	1	1
3	Bidirectional action coefficient K_d		1.2	1.2	1
4	Standard per unit consumption of projection over water K	kg/m^3	1.36	1.36	1.36
5	Water depth H	m	26.3	33.5	28.6
6	Influence coefficient of water depth C_a		0.01	0.01	0.01
7	Minimum resistance line W	m	2.2	6.0	3.6
8	Blasting action index n		1.5	1.25	1.4
9	Chamber charge Q	kg	50	690	160

Table 4.1 Computation of Charges in the charge Chambers

of 5.5m, and the horizontal charged holes of #3 Charge Chambers had a plug length of 3.3m.

4.2.2 Design of Blasting Parameters for Cut Holes

According to the results of the model test, Cofferdam Blocks No. 6~15 must be divided into single blocks and tipped over in turn in order to avoid the impact of whole blocks hitting the ground.

A row of holes for cutting-off was arranged at 0.5m to the left of each traverse joint face between Cofferdam Blocks No. 6~14. On each row, 23 holes were arranged, and there were 184 holes on 8 rows in total.

The cut holes had an aperture of 91mm and a pitch of 0.85~0.9m.

The cut hole bottoms were 1m from the normal charged section, i.e., the cut hole bottom at the particular location had an elevation of 110.7m, and the cut hole bottom at other locations had an elevation of 111.5m. The cut holes were filled with ready-made cartridges, and the normal charged section had a linear charge density qline ＝1.0kg/m, and φ35mm ready-made cartridges were used. The cut hole bottom reinforcement was 4.2kg/m, and φ37mm ready-made cartridges were used. Depending on the depth of the hole, the reinforced section ranged from 1.6m to 3.2m in length. Each cut hole was filled with one digital primer, with a plug length of 1.5~2.0m, and the linear charge density was partially reduced to 0.5kg/m on the part of the plugged section below 2m.

4.2.3 Design of Blasting Parameters for Fracture Holes

The fracture holes were charged at four times the regular charge density for presplitting blasting in order to ensure that the tipped-over upper part of the cofferdam is completely severed from the lower part. Calculations showed that the fracture holes had a linear charge density of 1.5kg/m. Charge was increased at 3m on the bottom of the fracture holes to a linear charge density of 6.0kg/m (using φ80mm ready-made cartridges) to ensure concrete at this location would be completely fragmented. In the meantime, to prevent sympathetic detonation on adjacent sections, the linear charge density on the bottom of fracture holes on these sections was changed to 2.0kg/m (using φ35mm ready-made cartridges).

5.Priming Circuit Design

5.1 Overall Conception for Circuit Design

The blasting circuit in the entire blasting zone consisted of three sub-circuits: □ the deep-hole blasting circuit on the left connection section; □ the tip-over blasting circuit for Cofferdam Blocks No. 15~6; and □ the deep-hole blasting circuit for Cofferdam Blocks No. 6~5.

The overall detonating sequence for the Cofferdam Blocks No. 15~6 was as follows: Cofferdam Blocks No. 15~6 are detonated in turn, with Block No. 15 being the first and Block No. 6 being the last.

On the vertical axis, the cofferdam blocks were detonated in the following sequence: #1 Charge Chambers → #2 Charge Chambers → Upstream and Downstream Discharge Holes → #3 Charge Chambers → Downstream Horizontal Fracture Holes → Cut Holes between Units

Four to six #1 Charge Chambers constitute one section, one #2 Charge Chamber makes one section, and two #3 Charge Chambers form one section. The maximum single section priming charge for tip-over blasting reached 690kg.

Cofferdam blocks were detonated in turn from No. 15 to No. 6 as single tip-over units while Cofferdam Blocks No. 15 and 14 being a single tip-over unit).

5.2 Selection of Detonators

The world’s most advanced digital detonators were used for all blasting holes and preset charge chambers. The delay of the digital detonators could be set from 0 to 15000ms. Two such detonators were loaded into each #1, #2 and # 3 Charge Chambers and deep holes, and one such detonator was loaded into other holes.

5.3 Selection of Time Differentials

Adjacent #1 Charge Chamber sections, adjacent #2 Charge Chamber sections, and adjacent #1 Charge Chamber sections, as well as fracture hole sections and cut hole sections, all had a time differential of 68ms.

#2 Charge Chambers had a time differential of 765ms later than adjacent #1 Charge Chambers, #3 Charge Chambers had a time differential of 357ms later than adjacent #2 Charge Chambers, and fracture holes had a time differential of 17ms later than adjacent #3 Charge Chambers. Auxiliary charge for discharge holes were detonated 9ms after adjacent #2 Charge Chambers.

The entire blasting circuit had a total delay of 12,888ms and comprised 961 sections.

5.4 Circuit Connection

When the charge chambers (holes) were loaded, the leg wire ends of the digital detonators were labeled. The labels were marked with the serial numbers of the chambers (holes) and their corresponding design delays. The identity numbers (ID codes) of the digital numbers were recorded one to one.

Digital detonators within the range of five #2 Charge Chambers were bunched together as a cluster and laid down from the discharge holes in the gallery to the cofferdam crest; digital detonators inside the cut holes and fracture holes were also bunched together on the cofferdam crest.

Each 120~180 digital detonators were made one set and used a LOGGER digital detonator controller. The address numbers and their corresponding delays of the digital detonators could be entered one by one into the LOGGER controller. After the delays of the digital detonators were set, the LOGGER controller was used to check the address numbers, ID codes and delays of the digital detonators on the priming circuit.

Each LOGGER digital detonator controller was then connected via a conductor to the dedicated digital detonator primer, and the overall conductivity of the circuit was inspected and tested.

6.Implementation of the Blasting Scheme

Loading officially began on May 27, 2006 and was completed on June 2, with 191.3 tons of charge loaded, including 152.7 tons of spot-mixed high-strength emulsion charge. A total of 2,506 digital detonators were used.

Charge for the charge chambers and blast openings in the discharge holes in the gallery was transferred over the distance by the loading truck via a 30-plus meter loading tube on the cofferdam crest, and loaded by the loader after re-pressuring. Charge for other deep holes was directly loaded by the loading truck on the cofferdam crest. Cartridges were directly loaded into the blasting holes manually.

Charge for the fracture holes and cut holes were delivered into the blasting holes by lashing cartridges and primacords to bamboo sheets. All primacords were produced by manufacturers meeting the length specifications of the design and their both ends were subjected to strict waterproofing treatment; severance of the primacords during construction was strictly forbidden. Charge chambers and blasting holes were plugged using brand-new special-purpose slightly expansive plugging material.

After the charge was loaded, water inside the cofferdam was filled to EL139.5m, 4.5m higher than the water level of 135.0m outside the cofferdam.

After the charge was loaded for the left junction section, the cofferdam crest was covered with two layers of sand bags for protection, and Cofferdam Blocks No. 5 and 6 were covered with sand bags, steel meshes and rubber bands for multiple protections, in order to prevent debris from flying about.

7.Blasting Results

At 4 PM, June 6, 2006, the RCC cofferdam in the third phase of the Three Gorges Project was detonated as scheduled. At the instant of detonation, it could be seen that the blasting opening of the shattered part of the left junction section was the first to detonate, creating a massive water column, and then, three seconds after the detonation, in front of the cofferdam, a wave spread rapidly from Cofferdam Block No. 15 towards Cofferdam Block No. 6, which was the trace of the propagated blast on the water surface as the result of the #1 Charge Chambers inside all cofferdam blocks exploding in sequence as designed. In addition, on the cofferdam crest, a row of water columns were also seen bursting out in sequence from the left bank to the right bank, which was the result of the high-pressure air created by the sequential blasting of #1 Charge Chambers in all cofferdam blocks squeezing water inside the gallery out of the discharge holes. When the cut holes arranged between two cofferdam blocks were detonated at an interval of 0.9s, the cut cofferdam blocks were also tipped over in the design sequence of detonation in an upstream direction, causing surges in the water. When Cofferdam Block #5 was undergoing a reverse propagated blast from the right bank to the left bank, the shattered part of the right bank created an enormous water column, and for a moment, the water column and waves resulting from tip-over spread both up and downstream.

Results of monitoring in key locations such as the dam, the foundation curtain grouting and the central control room in the left-bank powerhouse showed that all actually measured vibration values arising from the blasting were below the permissible control standard, and in particular, vibrations caused by cofferdam blocks hitting the ground were less than the predicted value. Although the surge wave actually detected in front of the gate was slightly higher than the predicted value, the dynamic strain measured on the date was far below the control standard, and the surge wave had a highest actually measured ascent of 3.8m, largely consistent with the predicted value prior to blasting.

A survey of the terrain after underwater blasting showed that the blasting had created a favorable gap in consistence with design intents, all cofferdam blocks tipped over in front of the cofferdam in an upstream direction and sank into the mud before the cofferdam, and that, the cofferdam was largely smooth and straight at EL110m after blasting, with residual concrete blocks in some locations. The protective measures had effectively reduced flying debris.

8.Conclusions

The third-phase RCC latitudinal cofferdam had a demolition length of 480m and a demolition height of 30m; the highest water depth at the charge burial location was 35m, and the amount of demolition reached 186,000 cubic meters. Considering the enormity of the work quantity and technical difficulty of the blasting demolition, the cofferdam for the Three Gorges Project is currently the No. 1 in the world's history of cofferdam demolition. With 961 detonation sections in a single blasting operation and a detonation length of 12.888s, this cofferdam holds the domestic and international records in the number of detonation sections in a single blasting operation. Demotion was considered while cofferdam was under construction, and the future cofferdam blasting demolition scheme was integrated into cofferdam construction, with charge chambers and blasting openings required for the blasting set up in advance. This reduced the operational difficulty and work quantity of the cofferdam blasting demolition, constituting an innovation of cofferdam demolition practices. Previously, most cofferdam demolitions used borehole blasting shattering. The third-phase RCC cofferdam took full advantage of the clearance in front and employed preset centralized charge chambers for tip-over blasting, constituting a major innovation in cofferdam demolition works.

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