A Fast Construction Technique for High RCC Dam

-- Guangzhao RCC Dam of 200m as an Example

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Abstract: this essay introduces a fast construction technique used in the construction of 200.5m Guizhou Guangzhao Gravity Dam. A series of fast construction technique such as Adjustable Cantilever Turn-over Steel Formworks, continuous concreting realized by cancelling discharging gaps, concreting by Box-type Tubes, continuous cant rolling in layers, and simultaneous concreting normal concrete for spillway and RCC dam were adopted. For the advantages of them, the dam was successfully placed till the top in mere 2 years, setting a new record of fast construction, and thus, is valuable for similar projects.

Key words: Guangzhao Dam, Fast Construction Technique

1 Introduction

Guangzhao Hydropower Station is located in the midstream of Beipang River where Guanlin county borders Qingrong county. It is the backbone power station of the main stream of the said river. With the overflow dam section for the river bed and retaining dams at banks, the dam top is 410m long with the level of 750.50m. The maximum dam height is 200.5m. The access for construction is hard due to its some 45°shore slope angle and the typical V-shape river valley.

The total volume of the concrete is about 2.8 million m$^3$, out of which Roller Compacted Concrete is about 2.4 million m$^3$, normal concrete is about 400,000 million m$^3$, and the highest graduation is Grading 3. The concrete is produced by 4 Concrete Mixing Plants (2 forced concrete mixing plants with the capacity of 2×4.5 m$^3$ and 1 Concrete Mixing Plant at the left bank and 1 Gravity Type Concrete Plant at the right bank). In accordance with Construction Progress, the peak concreting volume is 240,000 m$^3$/m of which 210,000 m$^3$/m is RCC while 30,000 m$^3$/m is normal concrete.

2 The application of Adjustable Cantilever Turn-over Steel Formworks as a convenient condition for continuous construction of RCC

2.1 Types of Adjustable Cantilever Turn-over Steel Formworks

In the construction of Guangzhao RCC Gravity Dam, Adjustable Cantilever Turn-over Steel
Formworks was used in all those places such as vertical surfaces at the upstream, slant surfaces at the downstream, spillway, gate piers, stilling basins. And the result is desirable, since the concrete surface is smooth and flat and free from visible holes. In addition, it allows fast removal of templates and make continuously turning over achievable, and thus is desirable for fast construction of RCC as well as for continuously lifting.

2.1.1 Adjustable Cantilever Turn-over Steel Formworks for Vertical Surfaces
With 2 cold rolled steel plates (3000×1500×5mm) as its panel, each template is 3×3m with the weight of 1210 kg and fixed with 6 anchor bars (φ25). The transverse purlin, also used as the transverse rib, is consisted of 4φ10 box ribs. The vertical purlin and the rear truss are consisted of 2 □ 10 and 2∠50×5. In addition, ∠30×5 was used around the plates so as to address the insufficient precision produced during processing and the mismatching of joints. (Refer to Diagram 1 for the format).

2.1.2 Adjustable Cantilever Turn-over Steel Formworks for Slant Surfaces
With one 3000×1875×5mm cold rolled steel plate as the panel, each template is with the weight of 720 kg and fixed with 4 anchor bars (φ25). The transverse purlin, also used as transverse rib, is consisted of twoφ10 box ribs. The vertical purlin and the rear truss are consisted of 2 □ 10 and 2∠50×5. In addition, ∠30×3 was used around the plates so as to address the insufficient precision produced during processing and the mismatching of joints. (Refer to Drawing 2 for the format).

2.1.3 Adjustable Cantilever Turn-over Formworks for Overflow Surface Arc Sections
This type of template has been developed from Adjustable Cantilever Turn-over Formworks. The panels are made to the required dimensions whose supporting systems are all cant templates. The advantages are obvious: on the one hand, it is helpful for the mass production and maintaining accuracy, and on the other hand, cost saving can be realized since its supporting system is exchangeable with cant template system.

2.1.4 Adjustable Cantilever Turn-over Formworks for the arc sections at Gate Pier End
This type of template has been developed from Adjustable Cantilever Turn-over Formworks. The height remains 3m while its width is subject to the dimensions of the pier end. The transforming is easily realized by remolding the panels, the horizontal ribs of horizontal ribs after the panels and
the supporting platform subject to dimensions of the pier end. The remaining structure is kept unchanged.

Diagram 1: Sketch Map of Adjustable Cantilever Turn-over Steel Formworks for Vertical Surfaces

Diagram 2: Sketch Map of Adjustable Cantilever Turn-over Steel Formworks for Slant Surfaces
Diagram 3: Sketch Map of Adjustable Cantilever Turn-over Formworks for Overflow Surface Arc Sections

2. Technical Characteristics of Adjustable Cantilever Turn-over Formworks

(I) It is adjustable. In addition, each of them is with desirable weight and hardness.

(II) It appears elegant since the minor faulting of slab ends between formworks has been offset owing to the trim strips attached make the dam surface grid-like pattern.

(III) Bolts are used for rear trusses and panels for the convenience of removal and transportation and thus can be easily and repeatedly used in different projects.

(IV) It is equipped with Attachment Safety Rails through which the safety of operation is improved.

(V) Heat preservation plates are allowed to be attached to the panel system to keep the temperature of concrete of dam surface.

(VI) This means adopts Adjustable Cantilever Turn-over Formworks for both arc sections of Gate Pier and curvature of spillways (the rear support trusses are interchangeable with the flat formworks since it can be transformed to Adjustable Turn-over Steel Formworks for vertical surfaces and cant surfaces through panels transformation) and then, together with Adjustable Turn-over Steel Formworks for vertical surfaces and cant surfaces, forms vertical surfaces, slant surfaces, arc surfaces, chambered surfaces, etc. Besides, it further expands the application of Cantilever Turn-over Formworks because RCC and normal concrete are exchangeable, and the formworks for vertical surfaces and cant surfaces are exchangeable.
3 Continuous concreting through removal of discharging gaps

The foundation of the original dam had been designed with the assumption of ten years return period. Period of low flow is 6 months plus 10 days, starting from Nov.6 to May.15 of the next year. The cofferdam is Earth-rock Overflow Cofferdam and the elevation of the upstream cofferdam is 596.5m. The 1120m³/s of designed water retaining capacity is not so desirable for the frequent flooding, and thus was likely delay the construction progress.

In our original plan, flood discharging was realized by simultaneously using diversion tunnels and reserved gaps. However, the elevation of gaps (EL 578m) was lower than that of the banks (EL 594). Therefore, under the condition of frequent flooding, it was unfavorable for the construction progress and quality.

After having hydraulic model tests, the Contractor increased the water retaining capacity of the cofferdam at the upstream to 2220m³/s through heightening it by 6m. The result has been proved by its holding flood for 7 times during mere 1 year. At the same time, the continuous placing and safely discharging flood have been realized by removal of the flood discharge gaps, contributing to the accelerated construction progress and effectively cost saving.

4 Application of Box-type Tubes as an effective means of fast concrete feeding

4.1 Technology of concrete feeding by Box-type Tubes

(I) Background

In this project, the majority of concrete must be placed in an up-to-down mode except for concrete for some places at the bottom that can be fed through auto. There are two appropriate ways to feed concrete: by tower belts or negative pressure chutes. However, the cost of the former is expensive while up till now, the later has not been successfully employed to feed as large as 2 million m³ of concrete worldwide. In addition, there is little room for negative pressure chutes to be used for larger cross sections judging from the structure and design principles of it. The negative pressure is produced by the close connection of flexible adhesive tapes at the top and the arc lining plate. The limitation of performance of the flexible tape material left little room for the improvement of the maximum feeding capacity. So, to improve feeding quantity, the only choice is to use more chutes.

In this project, the V-shape valley and the slope banks at both sides greatly affect concrete feeding. At very beginning, the concrete was fed by using dumpers, the access for which was filled by
ballast from the downstream. Though fast feeding was guaranteed, the quantity of filling and removal has been increased, affecting the downstream aprons, lengthening construction period and increasing costs. Therefore, it has been replaced by using box-type tubes installed at slopes to vertical delivering concrete, which is transferred within bins.

(II) Know-how of Box-type Tubes

The process is as follows: concrete mixing plant → high speed belt → Box-Type Tubes → concrete transferred within bins. Concrete produced at the mixing plants at the left bank are delivered to Box-type Tubes through feeding hoppers at the top of Box-type Tubes #1 and #2 at the left dam shoulder by 2 belts (EL680m and EL750.5m respectively). And then, the concrete was sent out through arc door at the bottom and transferred within the bins. The same means is also used for the concrete produced at the right bank. Refer to Diagram 1 for detailed parameters.

<table>
<thead>
<tr>
<th>Diagram 1</th>
<th>Main Parameters of Box-type Tubes System</th>
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<tr>
<td>Items</td>
<td>Parameters</td>
</tr>
<tr>
<td>Capacity of feeding hopper</td>
<td>20m³</td>
</tr>
<tr>
<td>Cross section of Box-type Tube</td>
<td>Square tube 800×800mm, Circular tubeφ800mm</td>
</tr>
<tr>
<td>Standard section length of box-type tubes</td>
<td>Square tube 1.5m, Circular tube 3-6m</td>
</tr>
<tr>
<td>Dip angle</td>
<td>≥45°</td>
</tr>
<tr>
<td>Elevation difference for concrete feeding</td>
<td>≤90m</td>
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<tr>
<td>Average gliding speed of concrete</td>
<td>&lt;5m/s</td>
</tr>
<tr>
<td>Dimension of feeding open of hydraulic arc outlet</td>
<td>1000×1000mm</td>
</tr>
<tr>
<td>Feeding efficiency</td>
<td>≥500m³/h</td>
</tr>
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4.2 Location & Structure of Box-type tubes

(I) Location of Box-type tubes

3 sets of tubes are supplied for the RCC placed at the dam section between EL622.5~EL748.5, among which Box-type Tube #1 is for sections between EL680~EL750.5 at the left bank, #2 for EL622.5~EL680 at the left bank, and #3 for EL674~EL750.5 at the right bank. For convenient maintaining and repair, the feeding system at the left bank is consisted of 2 chutes while 1 set of Box-type Tube for the right bank, each of which is with 500m³/h.
(II) Structure of Box-type Tubes

The structure of feeding system is crucial. It includes feeding hoppers, control elements of feeding (arc discharging outlets), chute body and the supporting structure. Among them, the first 3 are important. Attention should be paid to issues such as the shape of chutes and hoppers, dimension of cross section, control models and seal of the system and so on.

Structure of feeding hoppers:

To guarantee the effect of continuous feeding and to make sure that the tube is full of concrete, large hoppers with capacity of 20m$^3$ has been adopted. The dimension of the upper door is 3400×3400mm and that of the lower door is 800×800mm, with a height of 3150mm. The thickness of steel of feeding hopper can body is 6mm. 4 supporting poles are used for connecting foundation bolts and the foundation.

Hydraulic pressure arc outlets:

The total height of the outlets is 1200mm, with 1000×1000mm for the upper outlet and 1000×1000mm for the lower one. The two outlets are manipulated through 2 oil pumps (34BM-B10H-T) respectively and are driven by a motor (YML2-4) which is placed on the bin top.

Structure of Box-type tube body:

It is consisted of 1.5m of 45°standard elbows and 0.55m un-standard elbows, with 800mm×800mm as cross section. And the outlet is 0.7m gradually expanded elbows, with cross section of 800mm×1000mm. The body structure is either 3m-6m (standard) or 1.5m (un-standard), with the cross section of ø800mm, and the outlet is 0.7m gradually expanded with the cross section of 800mm×1000mm and 45°elbow. The gradually-expanded elbows are installed at places between the elbows and arc outlet so as to avoid blocking during feeding. Sections of the body are all connected through flange blots so are easy to install and remove.

Layout of Box-type Tubes is present on Diagram 1, the cross section of supporting on Diagram 2, standard cross section of Square Pipe on Diagram 3, Plan on Diagram 4 and Circular Pipes on Diagram 5.
Diagram 4: Layout of Box-type Tube System

Diagram 6: Cross section of body of Square Box-type tubes

Diagram 5: Cross section of supports of Box-type tubes (A-A)
4.3 Application of the usage of Box-type Tubes in Guangzhao Hydropower Station

(I) Conveying capacity

Guanzhao Dam was first placed on Feb.11, 2006. Till Feb.6, 2008, RCC had been placed till the top of the right bank and on Feb.16, 2008, till the top of the left bank, with the total amount of 2.8 million m³ for the dam body. Concrete for sections below EL622.5 was placed by dumps, the maximum monthly concreting volume was 212677 m³ while those exceeding EL622.5 was placed by the combination of belt conveyors, Box-type Tube and auto transference within bins, with the maximum daily concrete of 11161 m³ and the maximum monthly concrete of 15m. As a result, over 1.5 m³ concrete had been carrying into the bins “vertically” by Box-type Tubes which shows
that Box-type Tubes are with equal capacity with feeding by dumpers.

(II) Quality

To test the quality of RCC placed in this way, coring tests were carried out. The details is as follows: the accumulative driving of the first test was 549.02m, among which 300.55m was for Ф150mm and 248.47m was for Ф200mm. 99.50% out of 99.76% coring rate was obtained and 95.19% of which was good. The percentage of pass for those cores was 98.72%. 6 core samples were over 10m, accounting for 13.5%. Among them, the longest Ф150mm core sample was 15.33m, which was of the best worldwide.

1209 cores of those with 90 days of age were with fissures, 20 out of which broke (Joint Broken Rate is 1.65%); 119 cores were with fissures, 1 of which broke (Rate of Joint Broken is 0.84%); 1090 cores were with layers, 19 of which broke (Rate of Layer Broken is 1.74%). The connection of layers and joints were desirable.

The appearance of core samples: the appearance is smooth, tight, and well structured with well distributed aggregates. The quality in general is good.

106 water pressure tests were carried out for Gagnzhao RCC dam. All trail sections was less than 1Lu; 93.4% was less than 0.1Lu; 12.3% less than 0.01Lu. The maximum value is 0.22Lu and the minimum is 0.00Lu. The general impervious performance was good.

To sum up, RCC placed by using Box-type Tubes (vertically delivering concrete) possesses high quality with aggregates well distributed with scare separation.

4.4 Creation & characteristics of vertical delivery by Box-type Tubes

In current China, RCC vertically-fed is usually made by negative pressure chutes, large discharging chutes and small steel pipes, which is, to some extent, undesirable. Taking into consideration of the characteristics of RCC of this project, large volume and its requirement of large amount of concreting, vertically-delivering RCC by large size of Box-type Tubes, which had been the first time in China, was adopted. The advantages and creation are as follows:

(I) The tubes function as both large size pipes for conveying concrete and large storage, and thus possess the two advantages.

(II) To continuous high efficiency of concreting, Box-type Tubes are able to convey no less than 500m3 of concrete per hour, much higher than average vertical conveying system.

(III) Large volume of conveying can be realized without changing Box-type Tubes (in the case
of this project, the total volume of conveying is over 1.5 m$^3$), much higher than usual vertical conveying system, and thus, not only saved cost, but also was able to avoid delay of construction progress caused by frequent accessories changing.

(IV) Low costs of processing, installation, and maintaining. No need to use special wear-resistant materials; the tube body can be made of Steel A3 or 16Mn. Since a whole tube is made of same material, if the bottom, where is easy to wear out, goes wrong, the tube is still usable (just to turn the side or top side to the bottom). Places with slight wearing can be easily fixed up through welding with steel plates.

(V) Using Box-type Tubes, which are to be fully covered by concrete, is able to effectively reduce falling height of concrete. Meanwhile, concrete at the bottom of the tubes also serves buffering to the concrete above. So, separation produced in delivering process can be effectively avoided and guarantee the quality of the RCC.

(VI) The large arc outlet of a Box-type Tube guarantees the fast and smooth feeding of the concrete (Averagely, a Dumper T20 is fully loaded in 10s), and thus, lays the foundation for continuous high efficient construction.

(VII) The combination of vertical delivering and deep groove fast-speed belt conveyors, dumpers, especially when used with deep groove fast-speed belt conveyors, provides convenience to the high efficiency of delivery of the belt conveyors so as to effectively avoid troubles occurred to the belt and reduce the duration of delivering RCC from the mixing plant to the bin and guarantee the quality.

(VIII) It can be used for RCC delivery as well as normal concrete delivery.

(IX) It can be used anywhere with slope ≥45°. The study of the case of this project shows that it can be used even when the slope is vertical, and is desirable for RCC concreting at places with V-shape valley shoulder and dam gaps.

4.5 Prospect Analysis
The Box-type Tube plays an important role in concreting. By the use of it, fast delivery of RCC can be realized without loss of $V_C$ value and entirely overcome the problem of concrete delivery. In the practice, its performance is stable and satisfactory: daily volume of concreting reached 11161 m$^3$, monthly volume of concreting 221831 m$^3$, and over 1.5 m$^3$ of concrete were delivered through this means. Furthermore, it can be used together with horizontally-delivered belt
conveyors or dumpers to meet requirements of construction sites with different slopes. It has already been popularized and promoted for major projects as a replacement of negative pressure chutes.

5 Fast construction progress through continuously compacting slant layers

The compaction of RCC for this project was from left to right and then, vice versa. Slopes were controlled at degrees between 1: 10~1: 15, with each compaction layer of 30cm. Abnormal concrete were used at both rock surfaces of banks. The concrete was sent from the left bank to the right bank, with each layer being 3m, and the next construction layer started from the opposite direction, alternatively proceeding with consolidation grouting, by which continuous and fast construction had been realized.

Diagram 9 Sketch map of Slant layer compaction

6 Accelerating construction progress by simultaneous concreting normal concrete and RCC

After concreting till a given height, normal concrete for spillway turned out to be a key in controlling construction progress. To fasten the construction progress, normal concrete was simultaneously concreted with RCC. Inside the dam, C15 RCC with Graduation 3 was used, and for spillway surfaces, normal Concrete C40 was used. While simultaneous placing was carried out, two different types of concrete were transformed by RCC with Graduation 2 (C20) and its abnormal concrete.
For adopting a series of techniques in Guanzhao Dam Project, Adjustable Cantilever Steel Formworks, continuous placing by removal of discharging gaps, concreting by box-type tubes, continuous cant concrete compaction, simultaneous placing normal concrete for spillways and RCC for dam body, etc., the 200m high dam had been placed till the top in only 2 years. It not only contributed to another new record, but also made the project won the Gold Cup for China’s Best Project and thus is worth promoting in similar projects.