American Journal of Water Science and Engineering
2023; 9(1): 8-16
http://www.sciencepublishinggroup.com/j/ajwse
doi: 10.11648/j.ajwse.20230901.12
ISSN: 2575-1867 (Print); ISSN: 2575-1875 (Online)

Research on Installation Technology of Super Large Radial Gate of Dam in Complex Environment

Zhou Ruoyu*, Gou Meichun

Manufacturing and Installation Branch, Sinohydro Engineering Bureau 3 Co., Ltd., Xi'an, China

Email address:
Dzry1983110@163.com (Zhou Ruoyu)

*Corresponding author

To cite this article:
Zhou Ruoyu, Gou Meichun. Research on Installation Technology of Super Large Radial Gate of Dam in Complex Environment. *American Journal of Water Science and Engineering*. Vol. 9, No. 1, 2023, pp. 8-16. doi: 10.11648/j.ajwse.20230901.12

Received: October 9, 2022; **Accepted**: October 26, 2022; **Published**: March 20, 2023

Abstract: Taking the installation construction of super large radial gates of Nam theun1 hydropower station in Laos as an example, due to the lag of civil construction period and the dam structure, it is not convenient for large lifting equipment to enter the installation face directly. This paper introduces the application of "Bailey beam + Gantry crane" lifting radial gate technology under the conditions of large construction interference, heavy construction task and tight construction period, The installation of super large multi hole radial gate was successfully and quickly realized, which ensured the water storage and power generation schedule of the power station. According to the normal construction sequence, the radial gate of the spillway should be installed normally with large lifting equipment in the open hole state after the civil construction junction, and the upper concrete construction should be carried out after the radial gate is installed. During the construction of the dam and the arc gate, the civil engineering is in the process of sluice construction, the concrete of the dam body is rising, the multi-process and multi-professional construction is intensive, and there are multi-directional intersecting operations, which causes great construction interference. Combined with relevant cases, this paper focuses on the installation technology of super large radial gate in the high temperature and Rainy Zone and the complex environment with limited construction site conditions, so as to provide reference for the implementation of similar projects and actively explore new advanced technology for the industry.

Keywords: Nam Theun1 Hydropower Station, Super Large Radial Gate, Bailey Beam + Gantry Crane, Complex Environment, Installation Technology

1. Introduction

The overflow of the Nam theun1 Hydropower Station in Laos is mainly undertaken by the 6-hole overflow gate, which is arranged in the 14#~20# dam section of the dam. The working gate adopts a super-large exposed-top radial gate with an orifice size of 17.3m×20m (W×H), in which the single-hole radial gates have a total weight of 333.8t and is divided into seven gate leaves. The maximum single-piece hoisting weight is 54.726t. The radial gates are arranged in a curved surface along the axis of the dam. The elevation of the radial gate trunnion is 182m, and the radius of the radial gate is 20m. The radial gate is composed of a trunnion, an arc gate slot, a gate leaf, a strut arm, a hinge, accessories and a hydraulic hoist. Among them, the gate leaf has seven horizontal structures, the weight of the gate leaf structure is 189.394t, and the weight of a single piece is about 54.726t. The whole strut arm is composed of left and right upper and lower strut arms and hinge support. The vertical support is welded between the upper and lower strut arms and between the strut arm and the gate leaf. The radial gate adopts the operation mode of double hanging points and inclined arms, which can be opened and closed by moving water. The main technical parameters are shown in Table 1.

Table 1. *Main technical parameters of the spillway arc gate of Nam theun1 Hydropower Station.*

Orifice size: 17.3*22m,	Hinge form: cylindrical hinge
Gate form: Curved door	Hanging point form: double hanging point

Bottom sill elevation: ▽272.00m	Operating conditions: open and close by moving water, can be opened by bureau
Design head: 145.35m,	Number of orifices: 6 holes
Orifice type: Roof type,	Gate number: 6 holes
Operating equipment: Hydraulic hoist,	Single weight of gate: 331t
Support hinge height: 9.63m,	Radial gate radius: 19.94m
Orifice size: 17.3*22m,	Hinge form: cylindrical hinge

There are two types of climate in Laos, the dry season and the rainy season: dry season and rainy season. The dry season is from November to April of the following year, with an average temperature of around 28°C and an extreme high temperature of 45°C; the rainy season lasts from May to October, with an average temperature of 45°C. around 20°C. The rain and rain are fleeting and the rainfall is abundant, and the effective construction time is only 6 months every year. Because the weight and structural size of the radial gates are too large, the radial gate is transported to the construction site for assembly. The conventional hoisting method is to use a cable crane or a crane at the top of the dam. The width cannot be arranged by crane on the top of the dam [1, 15]. In order to ensure the construction schedule and power generation goals, a complete and feasible installation scheme is required for the installation of super-large radial gates in high temperature and rainy areas and complex environments with limited construction site conditions. Combined with the actual situation on the site, the "Bailey beam + Gantry crane" hoisting radial gate technology was used for construction, which realized the rapid installation of the porous super-large radial gate, and ensured the scheduled water storage and power generation construction period of the power station.

2. Construction Preparation and Construction Process

2.1. Construction Facilities

During the civil works for the spillway, there are 3 tower cranes (32T/16T/8T) installed at the downstream of the dam block 14#-20 which could be used for the lifting of the embedded parts in preliminary stage of the spillway radial gate installation (Reference to Figure 1).

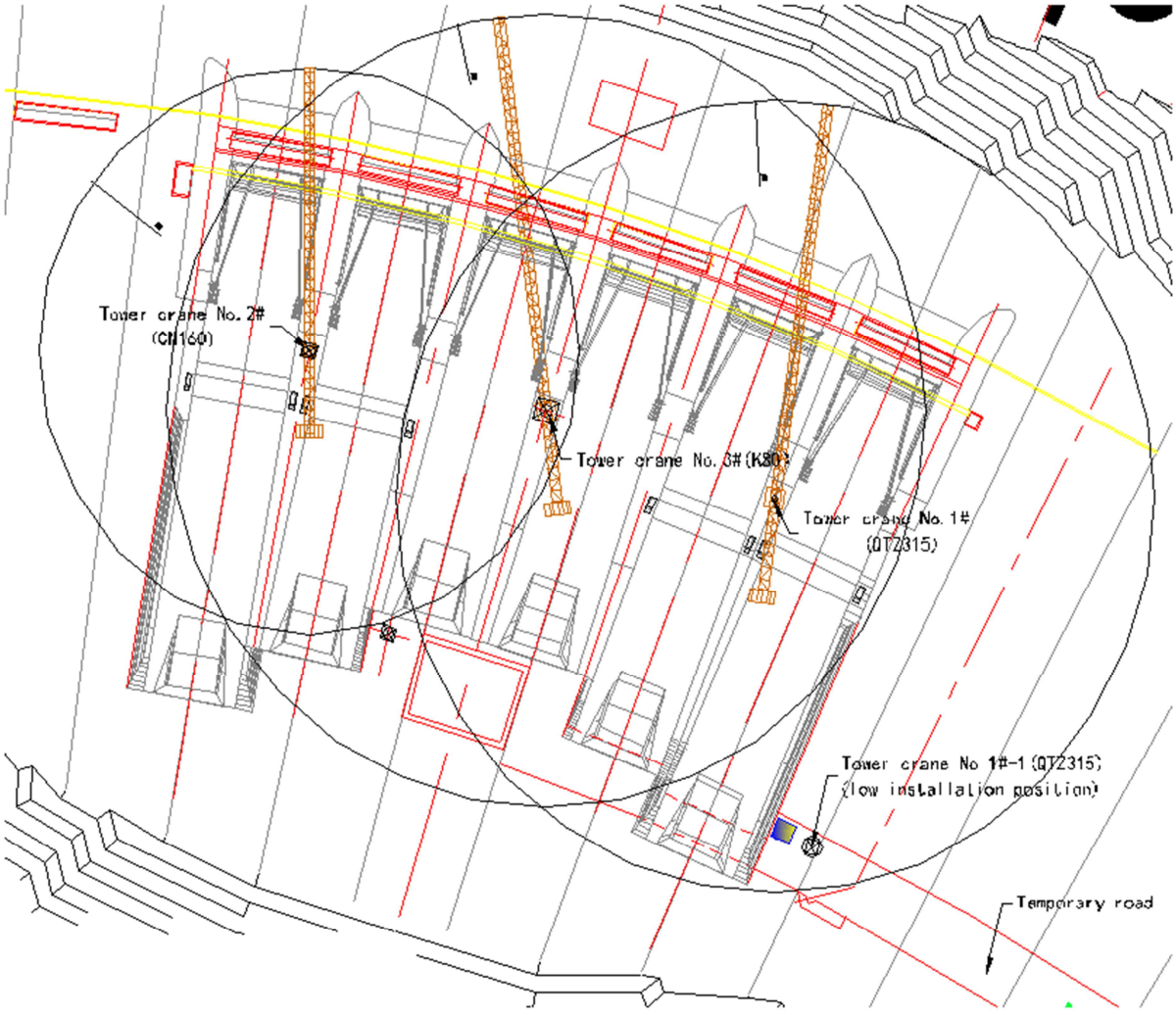

Figure 1. *Spillway tower crane layout.*

A bridge crane 65t with span of 27m will be placed along the dam axis direction from the block 1# to block 6#. The girder for the bridge crane will be assembled by the girder of the bailey bridge with the weight of 250t. The bailey bridge 18m (clear span of 17m and weight of 40t) will be erected at the block 1# by utilizing the existing bailey bridge constructed at the downstream cofferdam (span of 33m, the dump truck 50t and flat trailer 100t can pass on the bridge) and the column of the bridge will adopt the steel pipe φ400 for the transportation, loading and installation of the equipment for the spillway. It is not essential to complete the traffic bridge. This proposal could make it possible to install the radial gate in various blocks, the stoplog, the girder of the bridge crane on dam crest and the T girder of the traffic bridge at the same time. The layout of bridge crane and the bailey bridge refers to Figure 2 and Figure 3.

All equipment for the radial gate and the stoplog for the spillway will be loaded at the storage yard and delivered to the construction site. The embedded parts will be lifted in place by the tower cranes (30t & 16t) on dam. The downloading point will be at EL170.0m in the downstream of the dam block 18. The radial gate members will be delivered from the left dam section to the bailey bridge erected at the Block 1# on the dam block 20 for the downloading and lifting.

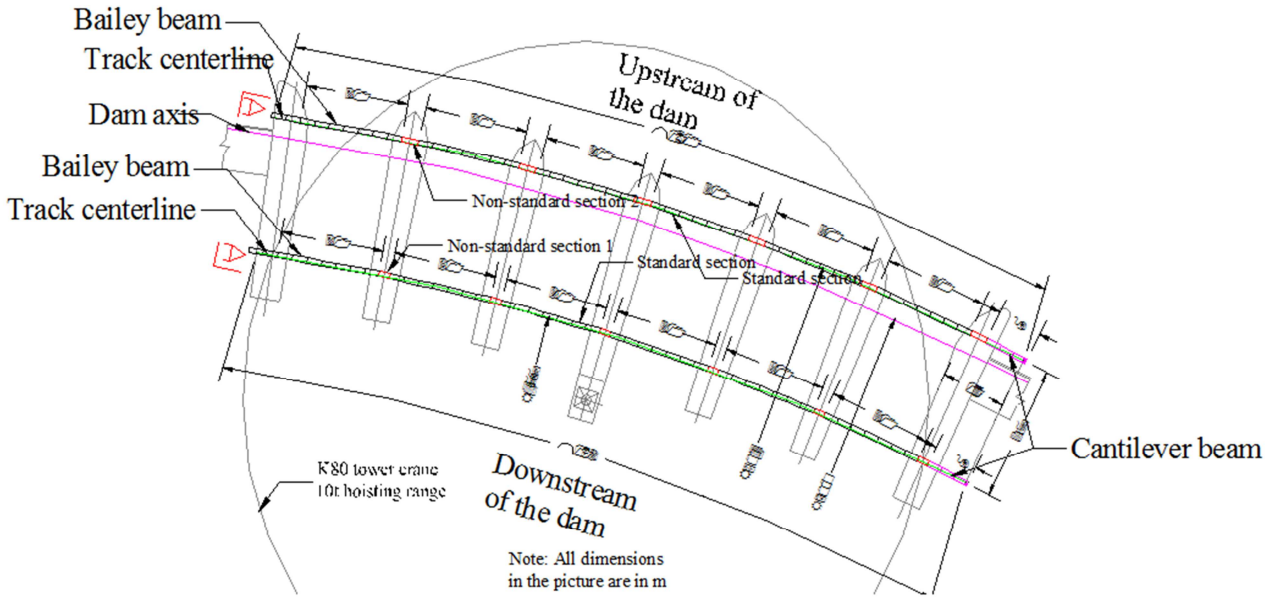

Figure 2. *Layout of Bailey Bridge.*

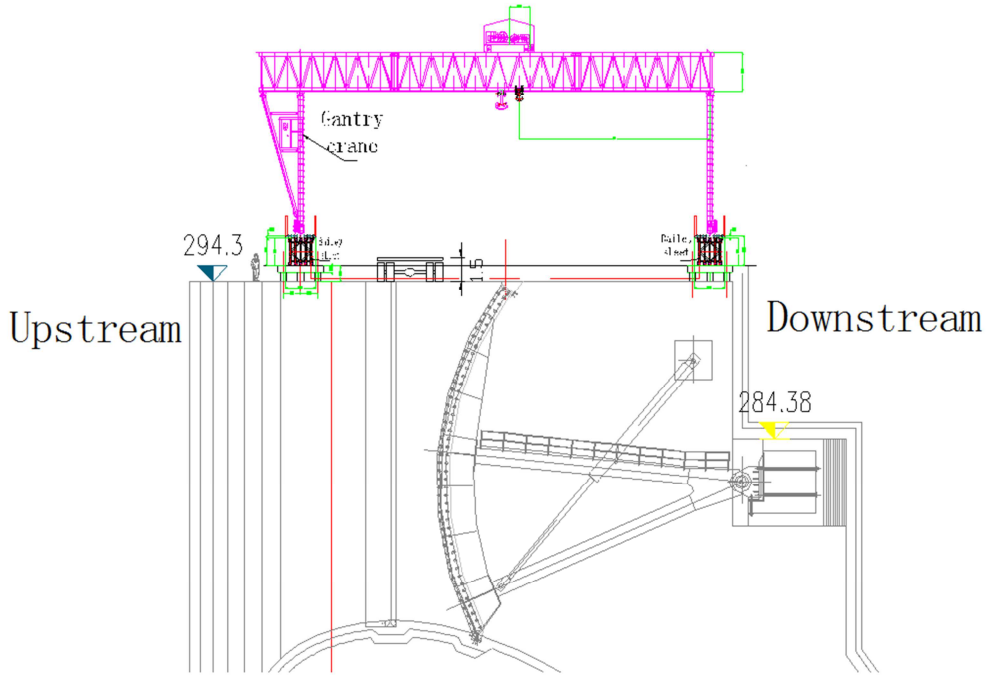

Figure 3. *Layout of Bailey Crane.*

2.2. Construction Access Road

The embedded parts for the radial gate and the stoplog required for the preliminary stage will be transported through the access road along the powerhouse to the downstream downloading platform at EL170.0m of the dam block 18#. The radial gate and the stoplog will be delivered from the access road EW-1 to the left dam abutment along the left dam crest EL297.0m to the platform placed on the bailey bridge on the block 1# at the dam block 20# for the downloading and lifting.

2.3. Construction Procedure

The working procedure for the installation of the radial gate refers to Figure 4.

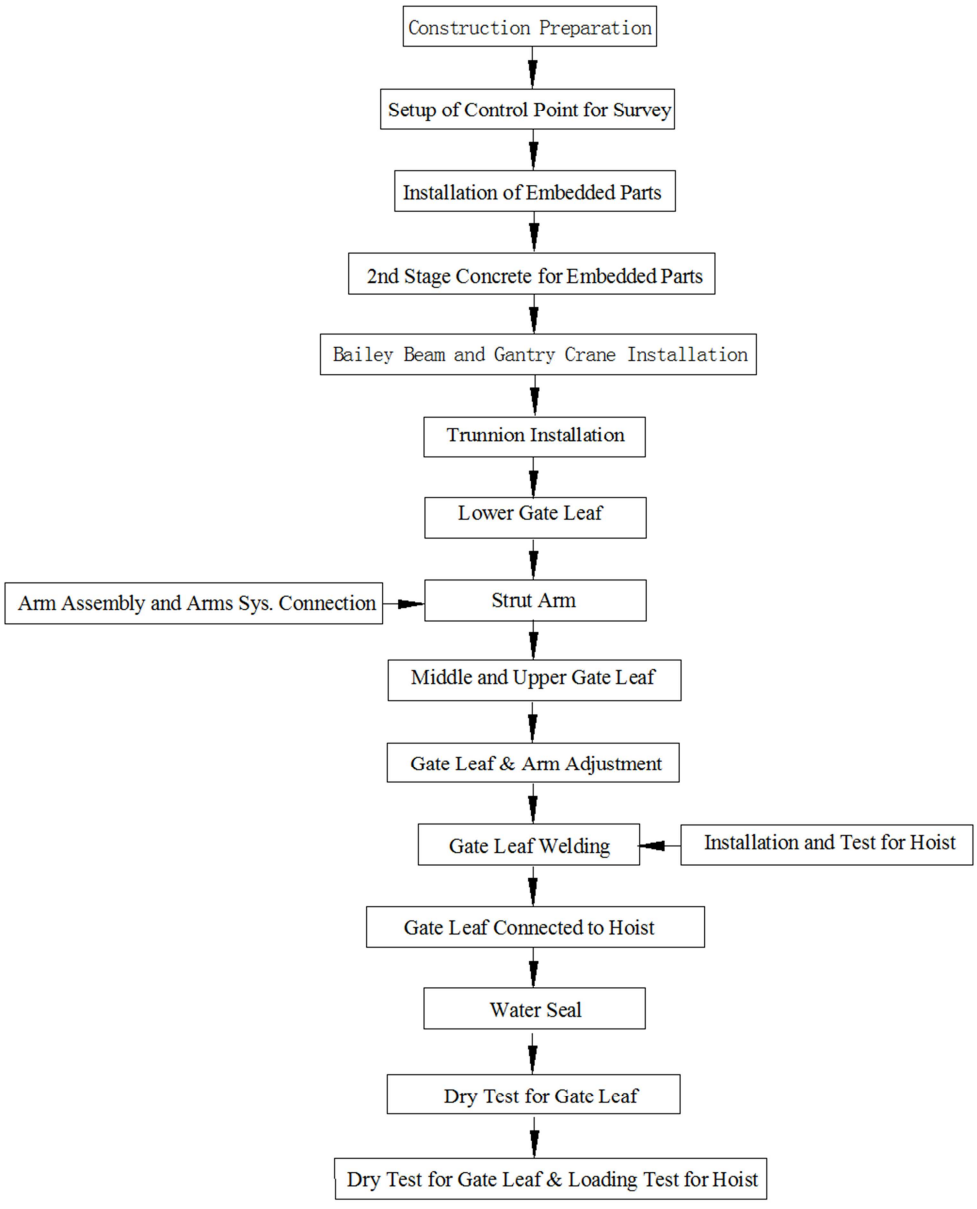

Figure 4. *Working Procedure of Radial Gate Installation for Spillway.*

3. Difficulties in Installation and Construction of Radial Gate

3.1. High Temperature, Rainy and Construction Disturbance

The power station is located in the subtropical zone of Southeast Asia, with two climatic patterns of dry season and rainy season throughout the year. The average temperature is around 28°C, and the extreme high temperature is above 45°C. The whole year is hot and rainy, with abundant precipitation in the areas along the route. The climate changes vertically and the rainy season is long throughout the year. Up to 6 months, and the maximum precipitation can reach 440mm ~ 520mm, which has a great impact on the

construction of the arc gate, and the effective construction time is short, which directly affects the construction progress. According to the normal construction sequence, the radial gate of the spillway should be installed normally with large lifting equipment in the open hole state after the civil construction junction, and the upper concrete construction should be carried out after the radial gate is installed. During the construction of the dam and the radial gate, the civil engineering is in the process of sluice construction, the concrete of the dam body is rising, the multi-process and multi-professional construction is intensive, and there are multi-directional intersecting operations, which causes great construction interference.

3.2. The Size and Weight of a Single Piece Are Large and the Lifting Is Difficult

The size of the opening of the spillway radial gate is 17.3m×20m (W×H), the maximum single-piece hoisting weight of the radial gate is 54.726t, and the size is 17.22m×3.44m×3.14m, which belongs to the super-large radial gate. According to the dam design of Nam theun1 Hydropower Station, the width of a single dam section of the 14#~20# dam section is 8m, and the width of each surface hole is 17.3m. The radial gate components are transported from the storage site through the right bank to the 20th dam section of the dam at an elevation of EL294.3m. Unloading and hoisting are carried out by tower crane or 65t gantry crane. The vertical height of hoisting is more than 20 meters, which is difficult to hoist. When the gate is transported and assembled, the support arm needs to be suspended at a high altitude, which requires high safety [1].

3.3. High Precision Requirements

The working gates of the spillway of Nam theun1 Hydropower Station is a deep-hole curved radial gate, which has a huge bearing capacity; the installation accuracy of the hinge seat and gate leaf is high, and the installation quality acceptance is carried out by the American Society for Testing and Materials (ASTM) and the American Society for Steel Construction (AISC). and other European and American standards, which are higher than the requirements in Chinese current <<Technical Conditions for Eccentric Hinged Arc Gates>> (SL37-91) and <<Code for Manufacture, Installation and Acceptance of Steel Gates for "Water Resources and Hydropower Engineering">> (GB 14173-2008-T) [2].

4. Survey of Benchmark Line & Point for Installation

In accordance with the survey benchmark given in civil works, the center line of the gate shall be setting out and firmly marked on the fixed position. The L/2 will be surveyed on the both sides from the center line of the gate. L shall be the distance between the center line of the support hinge on the left and the right. Then the center line of the hinge support along the water flow direction will be obtained. Subject to the dam axis, the milage between two hinge supports on the left and the right perpendicular to the water flow direction shall be measured.

The center elevation of the hinge support shall be surveyed. The intersection between the elevation line and the milage line of the hinge support shall be the center point. The connection between the center points of the two hinge supports shall be the connected center line which shall be marked on the left and right gate piers after its' extension [3, 5-8].

The two hinge support center shall be moved to the sill beam and the center of the sill shall be properly divided in accordance with the two points to check whether the center line is aligned with the center line of the gate hole surveyed in previous stage. The installation elevation of the sill shall be surveyed and the distance from the center of the hinge support to the center of the sill will be measured. The marks shall be made on the sill.

The arch benchmark for the hinge support center and survey at the same elevation shall be placed on the gate wall and the center control line of the side rail shall be marked and determined with the steel tape. The various points and lines shall be placed on the sample frame for the survey. After checking in correct status, the survey works is completed.

During the setting out and survey, all the distance between the embedded parts and tolerances regarding the installation elevation shall be in the allowable value specified in the drawings. Meanwhile, the control point for the hoist installation shall be properly fixed after the benchmark line of the embedded parts is surveyed.

When the survey is made for the embedded parts installation, the survey shall also be executed to the sill, the hinge support center to ensure the distance between the sill center to the center line of the hinge support. The center line of the hinge support shall be parallel to the sill center line [4].

5. Method Statement

5.1. Installation of Embedded Parts in Gate Slot

5.1.1. Installation of the Sill Beam

After the sill is hoisted to the installation position, the first thing to do is to mount it with adjusting bolt, and then to adjust the water-stop centre of the sill into the criteria that are specified in the TS (Technical Specification), in terms of its elevation, its distance, levelness. To check the distance between the water-stop centre to the trunnion centre again and again while the adjustment. After it is well checked and all is correct then to be reinforced. The second stage concrete will be cast after it is inspected.

5.1.2. Side Guides Installation

After the sill is cast with the second stage concrete, construction scaffolding shall be erected for the guides installations in the gate slot. When the second stage concrete on the sill achieved 70% of its concrete strength, the side guides shall be hoisted and installed. After it is in placed and

initially adjusted, the adjusting bolts shall be properly welded.

In the process of side guides adjustment, it is required to carefully measure and control various indicators such as the working surface of the side rail and the middle span of the hole, the center elevation and mileage of each seat plate, the flatness of the working surface, and the twist value.

The reinforcement welding of the embedded parts shall be carried out according to the requirements of the design drawings. The connection of each installation unit of the door slot member, the reinforcement materials used, the quantity and the lap length should be strictly implemented in accordance with the design drawings and the requirements of the tender to ensure that the embedded parts will not be deformed or displaced during the second-stage concrete pouring process. It is strictly forbidden to directly weld the reinforcement material on the working surface of the side guides.

After the completion of the reinforcement welding, all indicators shall be rechecked in accordance with the above-mentioned requirements.

The welding of all joints of the embedded parts should be completed before the second stage concreting. Stainless steel joints must be welded with a suited stainless steel electrode.

Upon the completion of the embedded parts installation, a re-survey shall be made to the embedded parts for its final installation accuracy. Only after that can the second stage concreting be proceeded.

5.1.3. Installation of Trunnion Anchor Bolt Bracket

The trunnion anchor bolt bracket and the fixed trunnion are pre-assembled in the assembly yard, and the screw is spot welded on the the fixed trunnion. After the acceptance is qualified, it is disassembled, and the trunnion anchor bolt bracket is transported to the site for installation.

When the anchor bolt bracket for the trunnion is being installed, its installation accuracy shall be strictly controlled in accordance with the construction drawings, and be reinforced reliably in accordance with the requirements that specified in drawings.

After the first stage concrete is cast and fully achieved its concrete strength, the anchor bolt shall be re-surveyed. If the size is out of the tolerance, it shall be corrected.

5.1.4. Cleaning and Re-survey of the Radial Gate Embedded Parts

After the second stage concreting completed and the formwork are removed, all the working fronts (e.g. the sill working front, the stainless steel surface of the side guides, the trunnion etc.) shall be cleaned from cement slurry and other debris.

A comprehensive re-survey shall be carried out for the embedded parts and it shall be recorded. Meanwhile, the concrete surface shall be checked in terms of the size, the rebars that been left and other debris shall be cleaned, and all exposures within the gate slot and will interfere the safe operation of the gate shall be removed.

After the installations of the radial gate sill, side guides, and trunnion anchor bolt brackets are completed and all be re-surveyed, as well as be inspected and qualified, some of the scaffolding that interfere the gate body hoisting shall be removed.

5.2. Radial Gate & Trunnion Installation

5.2.1. Installation of Mounting Assembly

Before the installation, the trunnion anchor bolt bracket shall be cleared.

To hoist the mounting assembly with a tower crane to the installation position, and then, a screw bar will be used for initially connecting the mounting assembly with the anchor bolt bracket. Pulling the steel strand of the mounting assembly (which is the connection wire of centre of the left and the right hinge supports) via the axle hole of the mounting assembly, to adjust the mounting assembly, and make the steel strand locates at the centre of the mounting assembly's axle hole, which means to ensure the concentricity of the left and the right mounting assemblies, in the meantime, the inclination of the axle hole shall be controlled. After an inspection and everything is correct, the fixing screw rod of the mounting assembly shall be firmly connected with the anchor bolt bracket. Then the concentricity of the mounting assemblies shall be rechecked, and the bolts shall be securely tightened up after everything is ensured be correct. Re-survey each deviations and when all of them are correct could the Epoxy resin be grouted. And during the process of the grouting, attentions shall be taken on the protection of the axle holes.

5.2.2. Installation of Radial Gate

After the second-phase concrete age of the trunnion anchor bolt brackets are reached, use the construction tower crane arranged by the dam to hang the fixed hinges, After the fixed hinge seat is hung in place, adjust the control dimensions such as the concentricity (The fixed hinges and the trunnion anchor bolt brackets are pre-assembled in advance), and the bolts are tightened after meeting the requirements. The installation accuracy of the fixed hinges shall be strictly in accordance with the requirements of the design drawings, and shall also be checked with the embedded parts of the sill beam.

The components of radial gate will take use of a 70t mobile crane, 60t trailer will be used for heavy cargo transportation, and 8t trucks will be used for delivering small pieces. The route of radial gate and stoplog transportation will through the construction access EW-1 to the dam left abutment, and then through the left bank dam crest (EL.297m) to the Gate#1of the dam block #20, where a bailey bridge unloading platform is set to unload and hoist the components. The lower arm, hinge support, and trunnion will be assembled into one piece at the fabricating yard, and be hoisted and installed by 65t overhead crane. After the shaft-pull-through of the trunnion completed, the lower arm will be temporarily braced on a supporting bracket installed. The hoisting and installation of the lower arm refer to Figure 5.

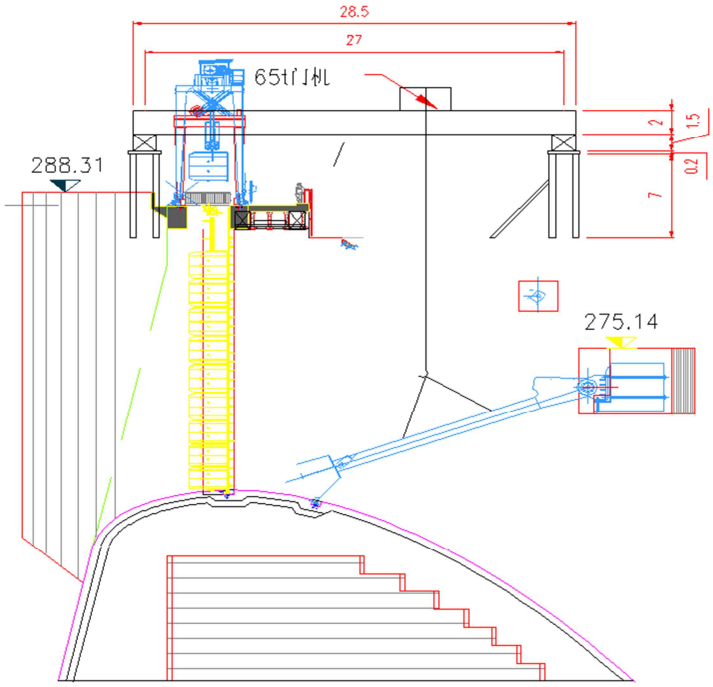

Figure 5. *Sketch of Lower Arm Installation.*

Hoisting and installing the lower gate leaf, and to precisely adjust the position of the lower gate leaf, and make it 5cm higher than the designed elevation, then to survey the intervals on the lower gate leaf's left and right side, and the interval in the gate body's lower side. These intervals shall be uniform, and meet the requirements that specified in drawings. Meanwhile, radius of curvature of the 4 points (top, bottom, left, and right) in the gate leaf shall be measured and shall be satisfied with the requirements that specified in TS. The strut arm and the lower gate leaf will be temporarily spot welded and reinforced by steel plate. Hoisting and installation of the lower gate leaf refer to Figure 6.

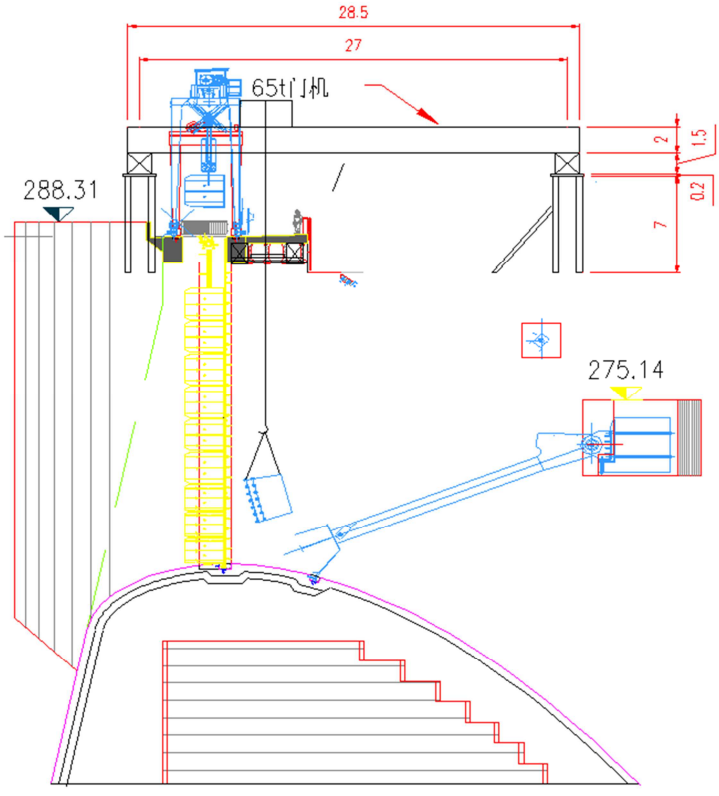

Figure 6. *Sketch of Lower Gate Leaf Installation.*

Hoisting and Installing the 2nd, 3rd, and the 4th Gate Leaves, and to survey their elevations, intervals on the left and right, radius of curvature etc. After it's qualified, the connection leaves shall be connected and bolted, and firmly reinforced.

Radius of curvature of the 4th gate leaf shall be 10mm larger than the design to ensure the safety hoisting of the upper arm.

2 Nos. of chain blocks, in corporation with the overhead crane will be used for gently hoisting the upper arm to the upward side of the 4th gate leaf and the installation position of the trunnion, and then to slightly adjust the angle and elevation of the upper arm by using the chain block. To connect and fix the upper arm and the trunnion, including the gate body. Then to re-survey all the data until it is qualified.

Hoisting and installation of the 3 remained gate leaves will observe the same procedures that mentioned above, and to monitor all technical data to satisfy requirements of the design.

After the strut arm and the gate leaf main girder is firmly bolted in accordance with the requirements, intervals and contacting area of the connection end plate shall be carefully measured, and their values shall conform to the relevant provisions of the design drawings and the TS [9-12].

The assembling quality of the gate body shall be in conformance with the relevant provisions of the design drawings and the TS. Welding of the gate body can only be proceed when the assembling is inspected and qualified.

Staggered joints in the assembling joints shall be eliminated by seam welding machine and jack.

5.2.3. Welding of the Radial Gate

(i). Welding Techniques

Wind speed and relative humidity shall be in line with the welding regulations during the process of welding. If they exceeds the standard that specified in the regulations, welding is strictly prohibited. It is strictly prohibited to weld under the situation when welding surface is wet, or under a rain, snow, windy weather, or welders and weldments are free of protection measures.

Radial gates on the Spillway has 6 field joints, which mainly includes: butt weld on side beam web flange plate and panels, fillet weld on vertical baffles, butt weld on the main girders of the strut arm, butt weld and fillet weld on connection rods of the strut arm and etc. Welding of the radial gates requires welders with rich experience and mature skills involved to take responsibility of radial gates welding. Electric-arc welding method shall be taken for the welding [13, 14].

The welding construction would arrange 8 welders welding simultaneously, and the principle is to weld the strut arm first and then the gate leaves. Welding of the gate leaves will follow the sequence as: side column web, butt joint → fillet welds between baffles and main beam flange plate, as well as fillet welds between panels → butt joint between panels and others. The electrode is tentatively adopts E5015 low hydrogen sodium electrode supplied by ATLANTIC.

(ii). Inspections on Welding Joints

All welds shall be inspected for appearance defects such as cracks, surface slag inclusion, undercut and surface porosity.

Nondestructive inspection shall be carried out for weld joint of Class I and ii. Nondestructive testing can be performed on ordinary carbon steel only after the weld joint is cooled to the working environment temperature and the low alloy steel is welded for 24h.

In case of any intolerant defects in the weld is inspected, causes shall be found out and analyzed, repair measures shall be made to deal with them. After it is repaired, defect detecting test shall be carried out as required.

5.2.4. Installation of Accessories

Accessories of the radial gates include side rollers, water seals etc.

During the process of water seals installation, rubbers shall be bonded to the required length, and then together with the water-seal pressing plate, to drill bolting holes. Special hollow bit is used and with rotary drilling method. The diameter of the water seal shall be 1mm smaller than that of the bolt. Installation deviation and quality requirements of water seals shall meet the requirements of bidding documents and construction drawings.

5.2.5. Sandblasting & Painting

The welding parts of the gate, strut arm and other components and the parts damaged by transportation shall be sandblasted & painted. The initial treatment of anti-corrosion on the surfaces shall adopt manual grinding wheel with bowl brushes for the sandblasting & painting. The sandblasting & painting shall conform to the construction drawings.

5.2.6. Testing of Radial Gates

Upon the completion of hydraulic system installation, hoisting test for the radial gates shall be proceed, and it shall satisfies requirements that specified in the drawings.

6. Conclusion

In this paper, taking the installation and construction of the super-large radial gates on the spillway of Laos Nam Theun 1 Hydropower as an example, through the analysis of the layout, specifications and dimensions of the spillway radial gates, the on-site operating environment, construction schedule and other factors, as well as the construction of the super-large radial gates in the hydropower station in the complex. The construction difficulties in the environment, the design and arrangement of temporary lifting facilities, installation measures and processes are analyzed in detail. Adopting the installation method of split hoisting, on-site assembly and overall welding after assembling, and controlling deformation, in the installation process of the dam spillway radial gates, the problem of radial gates hoisting

and quality control has been successfully solved [15].

Through the analysis and research on the complex factors of the on-site installation of the radial gates on the Spillway, the large radial gates are installed using the "Bailey beam + Gantry crane" technology, which provides a guarantee for the power station's flood control and flood control and the goal of commissioning and power generation, and provides a new technology application in the industry new ideas.

References

[1] Wang Xiaohai, Luo Gang, Huang Jicun, Zhao Helai, Wang Bo. (2020). Key technologies for installation of radial gates at the entrance of the spillway of Baihetan Hydropower Station [J]. Water Power, v. 46; No. 557 (09): 109-113.

[2] Zhang Jinlong, Yin Haidong. (2019). Application of quick installation technology for radial gates in the spillway of Huangjinping Hydropower Station [J]. Yangtze River.

[3] Ma Jianrong, Yu Haijun. (2017). Analysis on the progress of rapid installation of radial gates in Tongzilin Hydropower Station [J]. Water Resources and Hydropower Engineering.

[4] Zhao Hailin, Wang Zhanyun. (2005). Installation of large radial gate and hoist in Nierji project. Water Power, 31 (11).

[5] Hu Honglang. (2015). A Installation of radial gate and hydraulic hoist of Tingzikou Water Conservancy Project [J]. Design of hydro power station, 000 (003): 47-48.

[6] Li Qixiang, Liu Jianchuan, Ma Qiang. (2015). Application practice of gantry crane in hoisting large radial gate. Science & Technology Information.

[7] Ling Guangda, Li Chungui. (2012). Example of quick installation of embedded parts of radial gate support hinge [J]. Water Resources and Hydropower Engineering, 043 (005): 27-28.

[8] Lu Ping, Chen Yong. (2009). Installation technology of arc-shaped working gate of sand radial gate on the left bank of the San Xia [J], Yangtze River,: 88-90.

[9] Liu Jianquan. (2007). Research on quick installation of super-large radial gate by highway bridge erecting machine [C]. National Water Conservancy and Hydropower Metal Structure Professional Information Network Conference.

[10] Xiao Tianpeng. (2016). Brief Discussion on the Installation Technology of Super Large radial gate in Nuozhadu Hydropower Station [J]. Low Carbon World,: 2.

[11] Li Guiji. (2016). Installation technology of down-the-hole radial gates for large-scale flood discharge tunnels in Huangjinping Hydropower Station [J], Water Power, 42 (3): 4.

[12] Liao Min. (2013). The hoisting process of the arc-shaped working gate of the flood discharge gate of the NamNgum5 hydropower station in Laos [J]. Construction Science and Technology,: 2.

[13] Huang Wei, Yang Yonggang. (2014). Reverse-order installation of super-large radial gates on the surface of the spillway in Nuozhadu Hydropower Station [J]. Yunnan Water Power, 30 (2): 4.

[14] Yuan Li. (2014). Analysis on the key technology of installation of radial gate at the entrance of flood discharge tunnel of hydropower station [J]. Jushe Zazhi: 57-58.

[15] Miao Yanfa, Peng Yanglin. (2019). Rapid construction technology of radial-shaped working gate with large overflow meter hole in Lidi Hydropower Station [J]. Mechanical & Electrical Technique of Hydropower Station: 29-31.