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Research on Rapid Construction Technology of Deep Water Rock-socketed Bridge Foundation

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Abstract: - The construction of deep water rock-socketed bridge foundation is pretty difficult and people routinely use the method of combining underwater blasting and double-wall steel box cofferdam support for construction. Combined with the site construction conditions and analysis of FEM software, through schemes comparison and technical research, the paper puts forward the construction scheme of rotary drilling pilot hole, high-pressure rotary jet grouting pile for grouting and water stopping, and cofferdam support for locking steel pipe pile, which completes the foundation construction smoothly and rapidly. By adopting the technology, the construction period is greatly shortened, the material utilization rate is improved, the construction cost is reduced, and the scheme has reference significance for foundation construction under similar environments.

Keywords: Deep Water Foundation, Rock-socketed, Cofferdam, Locking Steel Pipe Pile, Rapid Construction, FEM

I. INTRODUCTION

With the continuous development of bridge construction, the number of river-crossing and sea-crossing bridges is increasing. Most of such bridge foundations are large-size deep water foundations, with complex construction environment and difficult construction. For deep water foundation construction, the main supporting structures are steel sheet pile cofferdam, locking steel pipe pile cofferdam and double-wall steel box cofferdam. At present, there are a number of studies on the design and construction of deep water foundation of bridges at home and abroad[1-6], among which the construction mainly focuses on steel plate and steel pipe pile supporting forms[7-11], and a small number of studies on double-wall steel box supporting forms[12-13].

For the construction of deep water rock-socketed foundation, there are relatively few studies at home and abroad. Dai Yuchen et al. [14] combined AHP, Entropy Method, GRA, TOPSIS method and BIM technology to build a deep-water cofferdam model based on BIM technology and provide a method for the selection of deep-water foundation cofferdam. Taking the project as an example, Zhang Yanhe [15] studied the construction of double-wall steel box cofferdam for deep water shallow overburden and partial bare rock foundation. Taking the project as an example, Zhang Xiong [16] studied the construction of double-wall steel box cofferdam for deep water rock-socketed foundation. In specific, the blasting excavation and leveling were adopted for the construction, and then the cofferdam was lowered as a whole for bottom sealing. Tatsuya Komazawa [17] et al. adopted the method of steel sheet pile and steel pipe pile pilot hole excavation and vibration sinking in the bearing layer including rock and boulder as well as soft rock layer, which provides reference for the construction of rock stratum geological hole pilot hole + locking steel pipe pile cofferdam. Taking the project as an example, Jiang Haitao [18] and Zhang Hongwu [19] analyzed the form of locking steel pipe pile support for deep water rock-socketed foundation, and studied the construction technology of percussive drilling pilot hole + concrete water stop. Tu Xianxing [20] and Zeng Hongjun [21] conducted in-depth research on deep water rock-socketed foundation support and introduced the construction technology of percussive drilling pilot hole + concrete anchor pile locking steel pipe pile. At present, for the deep water rock-socketed foundation, the double-wall steel box cofferdam construction after underwater blasting excavation and leveling is mainly adopted at home and abroad, or the construction of the percussive drilling pilot hole + concrete water stop locking steel pipe pile cofferdam is adopted, which is with slow construction progress, and large influence on the environment during the construction process.

With the aim of addressing the challenges associated with complex construction environments and slow progress in constructing deep water rock-socketed foundations, this study focuses on the construction of such a foundation for a bridge. Through extensive research, engineering tests, and comparative analysis, the paper thoroughly explores the

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supporting structure form and corresponding construction technical points. Ultimately, the study advocates for the adoption of a locking steel pipe pile cofferdam with a pilot hole as the preferred supporting form, enabling rapid construction of the foundation through efficient and rational pilot hole and water stop modes. Furthermore, the findings provide valuable insights for expediting the construction of similar foundations under comparable conditions.

II. Project Background

A cross-river super-large highway and railway dual-purpose cable-stayed bridge has a total length of 706m, the bridge span is arranged 49+144+320+144+49m, and the main girder adopts steel box plate truss composite girder. The two main towers are located in the middle of Ganjiang River, with embedded rectangular pile cap foundation. The size of the pile cap is 46.0×24.4×5.0m, the bottom elevation of the pile cap is-2.954m, and the pile cap is connected with 32Φ2.5m drilling hole pile below.

The maximum water level at the bridge site in recent ten years is +21.07m, and the maximum flow velocity is +2.53m/s.

The overburden at the bridge site consists primarily of fine sand and gravelly sand, with calcareous sandstone serving as the underlying bedrock. The saturated compressive strength of the rock formation is recorded at 30.0MPa, with the maximum depth of the rock layer embedded at the bottom of the main tower cap measuring 2.55m. The geological parameters of the soil layer at the main tower are detailed in Table 1.

Table 1: Geological parameters of soil layer at main tower (riverbed elevation +2.60m)

Names of soil layers	Layer thickness m	Saturated gravity density γ	Angle of Internal friction φ	Soil cohesion c	Saturated compressive strength (MPa)
Fine sand	1.6	19.0	32	1	
Gravelly sand	1.4	19.5	38	1	
Strongly weathered calcareous sandstone	1.1	20.0	23	34	
Weakly weathered calcareous sandstone	——	24.5	——	——	30.0

III. Study on Key Construction Schemes

A. Cofferdam Scheme Study

This bridge project won the bid in October 2022. According to the construction period plan, the pile cap construction is required to be completed before the flood season in May 23. The bridge is located in the Ganyuan Nature Reserve, where fish species are abundant, and there are a variety of freshwater rare species activities, which have high requirements for environmental protection. According to the actual situation on site, the schemes of foundation pit supporting cofferdam are compared and analyzed. See Table 2 for details.

Through comparative analysis, in terms of construction equipment, construction period, environmental protection and economy, the construction scheme of the pilot hole locking steel pipe pile cofferdam has obvious advantages compared with the double-wall steel casing scheme, which is more suitable for the characteristics of the project. The foundation construction of the bridge finally adopted the pilot hole locking steel pipe pile cofferdam scheme.

B. Cofferdam Bottom Embedding and Water Stop Scheme Research

Due to the reason of the pilot hole, there is a gap between the locking steel pipe and the rock wall of the pilot hole within the rock-socketed range at the bottom of the cofferdam, and measures shall be taken to block the gap to realize the stable embedding and water stopping at the cofferdam bottom. According to the relevant literature [18-21], there is pilot hole locking steel pipe pile cofferdam existing, and the cofferdam bottom rock-socket water stop measures are mainly to set concrete anchor piles at the bottom of the steel pipe, or to suck the soil in the gap and then pour concrete in the gap. The concrete anchor pile measures are arranged at the bottom of the steel pipe, namely, after the locking steel pipe pile cofferdam is inserted and molded and the pilot hole is completed, a section of concrete anchor pile will be poured in the hole to realize the connection of the cofferdam locking steel pipe pile and the concrete anchor pile and embed and water stop. The measure of pouring concrete after soil absorption in the cofferdam is to use the suction equipment to remove the mud and sand in the gap between the steel pipe pile and the rock wall of the pilot hole in the cofferdam after the pilot hole of the cofferdam of the locking steel pipe pile is completed and inserted and formed, and then the underwater concrete is poured in the gap to realize the embedding and water stopping at the bottom of the cofferdam. Regardless of which of the above embedded and water-stopping methods is used in the cofferdam of this project, it is necessary to wait for the completion of all the pilot holes of the locking steel pipe pile cofferdam before the embedding and water-stopping are carried out. These processes are time-consuming and labor-intensive, and it is difficult to meet the deadlines of construction period.

Table 2: Comparison of Cofferdam Schemes

Items	Locking steel pipe pile with pilot hole	Double-wall steel casing
Main construction technology	The drilling rig shall make the pilot hole, insert and drive the locking steel pipe pile, cast the anchor pile for water stop after the cofferdam is formed, suck the soil from the inner gap, pour concrete to stop the water	Underwater blasting excavation and leveling of riverbed at pier position, assembly of cofferdam in blocks, integral lowering, and inner bottom sealing of cofferdam
Advantages	This method adopts conventional construction equipment, with short construction period, small impact of construction on the environment, small water pollution, and high economic efficiency due to turnover of materials	Good structural integrity and water stopping property, which can save pile cap formwork
Disadvantages	There is a risk of water leakage in the locker gap, which requires sealing and plugging.	Blasting has a great impact on the environment and pollution to the water area. At the same time, the blasting risk is high, the cofferdam processing and manufacturing cost is high, the construction equipment cost is high, the construction period is long, and the materials cannot be reused, which brings poor economic efficiency.

In order to solve the problem of construction period, this project has conducted in-depth research on the measures of embedding and water stop at the bottom of the locking steel pipe pile cofferdam with pilot hole, and put forward the construction scheme of fine sand backfilling + grouting embedding and water stop. After the locking steel pipe piles are inserted and driven to a certain amount, a high-pressure rotary drilling machine is inserted into the fine sand inside and outside the locking steel pipe cofferdam, and the sand layer between the inner and outer sides of the pilot hole of the cofferdam is subjected to grouting compaction treatment so as to achieve the water stopping effect.

In order to further prove the feasibility of the grouting water stop scheme, determine the grouting water stop effect, the reasonable spacing and quantity of the grouting holes, an on-site grouting simulation experiment is carried out by the construction unit. First it simulates the construction conditions of the locking steel pipe pile cofferdam construction on the cement ground, fabricates three arc steel plates with a diameter of 1.6m and a circle center spacing of 1.24m to simulate the pilot hole foundation trench; then replaces the locking steel pipe pile with three ø1.02m steel casings and I20 steel, simulating the condition that the locking steel pipe pile deviates from the center line in the inserting and driving process. In specific, the 1st locking steel pile is deviated by 161mm (the steel pile is 77mm away from the hole wall), the 2nd locking steel pipe pile is in a normal state, and the 3rd locking steel pipe pile is deviated by 90mm (the steel pile is 150mm away from the hole wall); Finally, 6 grouting holes are arranged circumferentially around the 1st locking steel pile at a spacing of not more than 60cm. And 4 grouting holes are arranged circumferentially at a spacing of not more than 80cm around the second and third locking steel pipe piles, and the grouting effect is tested. The plane layout of grouting holes is shown in Figure 1.

The grouting test results indicate that the compressive strength of grouted compacted sandy soil can reach 7.5MPa after 3 days, with an effective radius of grouting compaction exceeding 0.4m and a crossing of effective grouting range between adjacent holes of more than 0.1m. The on-site grouting construction by the construction unit is illustrated in Figure 2.

Based on the grouting test results, it is demonstrated that high-pressure rotary jet grouting is utilized in the space between the locking steel pipe and the rock wall of the pilot hole. This approach ensures effective compaction of the sand within the gap and successfully achieves the objective of embedding and water stoppage at the base of the cofferdam. In accordance with the test outcomes, the construction unit on-site has finalized the plan for high-pressure rotary jet grouting and water stoppage, with the distance between adjacent high-pressure rotary jet pipes not exceeding 80cm.

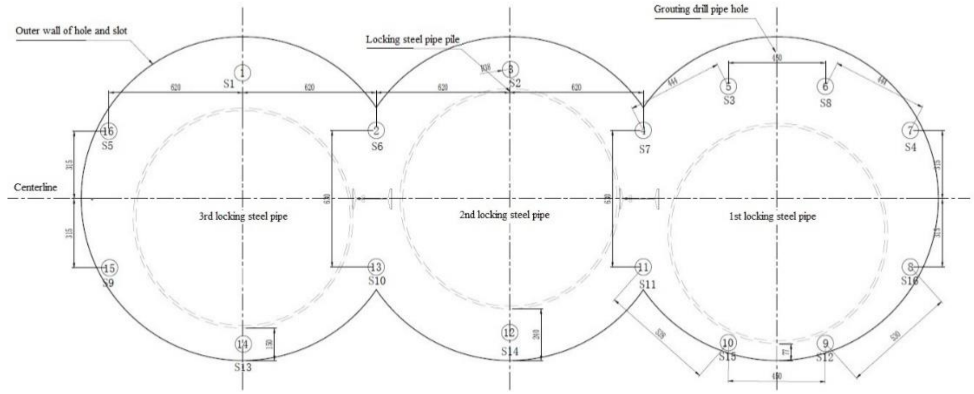


Figure 1: Layout Plan of Grouting Hole

(a) Cross effect of grouting range of adjacent holes (b) Photo of grouting compaction specimen

Figure 2: Photos of On-site Grouting Construction

After the embedded and fixed water stop scheme is adopted, the water stop work does not need to be carried out after all the steel pipes are inserted and punched, and the soil suction in the gap is not needed either, so that the construction process is simplified, and the construction efficiency is improved.

C. Cofferdam Structure Design

The plane size of the locking steel pipe pile cofferdam is 54.56m×28.52m. The waterproof level is +21.07m. The top elevation of the cofferdam is +21.5m, and the bottom elevation is -6.5m. The cofferdam bottom is embedded in the moderately weathered rock stratum of not less than 3.0m. The locking steel pipe pile adopts φ1020×14mm steel pipe with length of 28.0m and locker type of C-T [2]. The cofferdam incorporates four layers of interior supports: 3HN900×300 steel is employed for the assembly and welding of the intermediate purlin and diagonal bracing in the first and fourth layers of interior supports, with φ1020×20mm steel pipe utilized for the straight support. For the second and third layers interior support purlins, 3HN1000×300 steel is utilized, along with 3HN900×300 steel for welding the diagonal bracing, and φ1020×20mm steel pipe for the straight support. The cofferdam locking steel pipe is constructed from Q355B steel, while the interior support is composed of Q235B steel. The configuration of the locking steel pipe pile cofferdam is depicted in Figure 3.

According to the cofferdam construction period, structural stress change during the construction procedure and process, five typical construction stages are selected to analyze the strength and rigidity of the cofferdam structure:

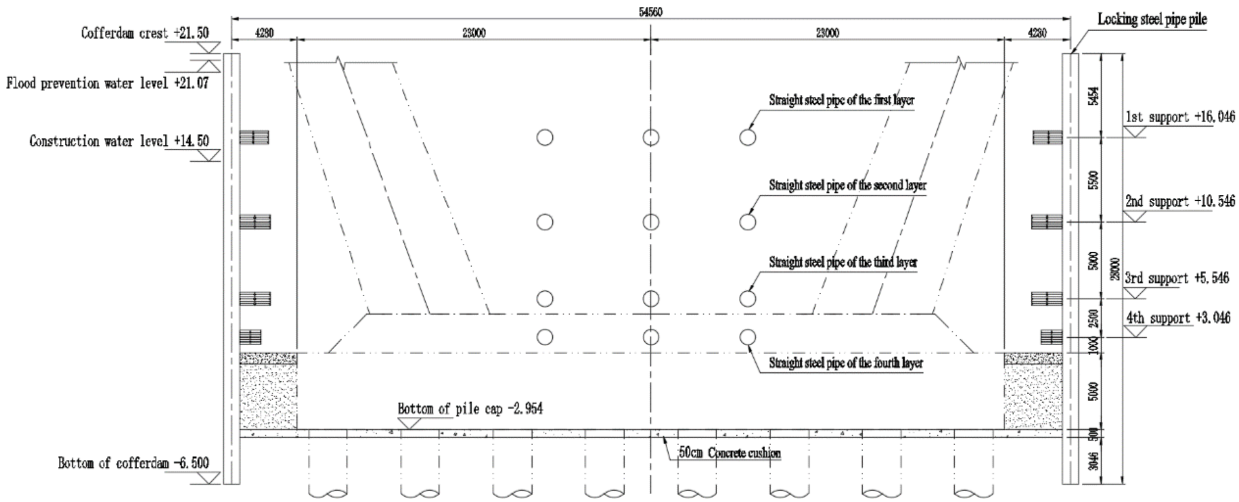
Construction stage I: install the first layer interior support below the construction water level of+14.50m, and pump water in the cofferdam to the position of 1m below the second layer interior support;

Construction stage II: after installing the interior support for second layer, pump water and take soil from the cofferdam to the position of 1m below the third layer interior support;

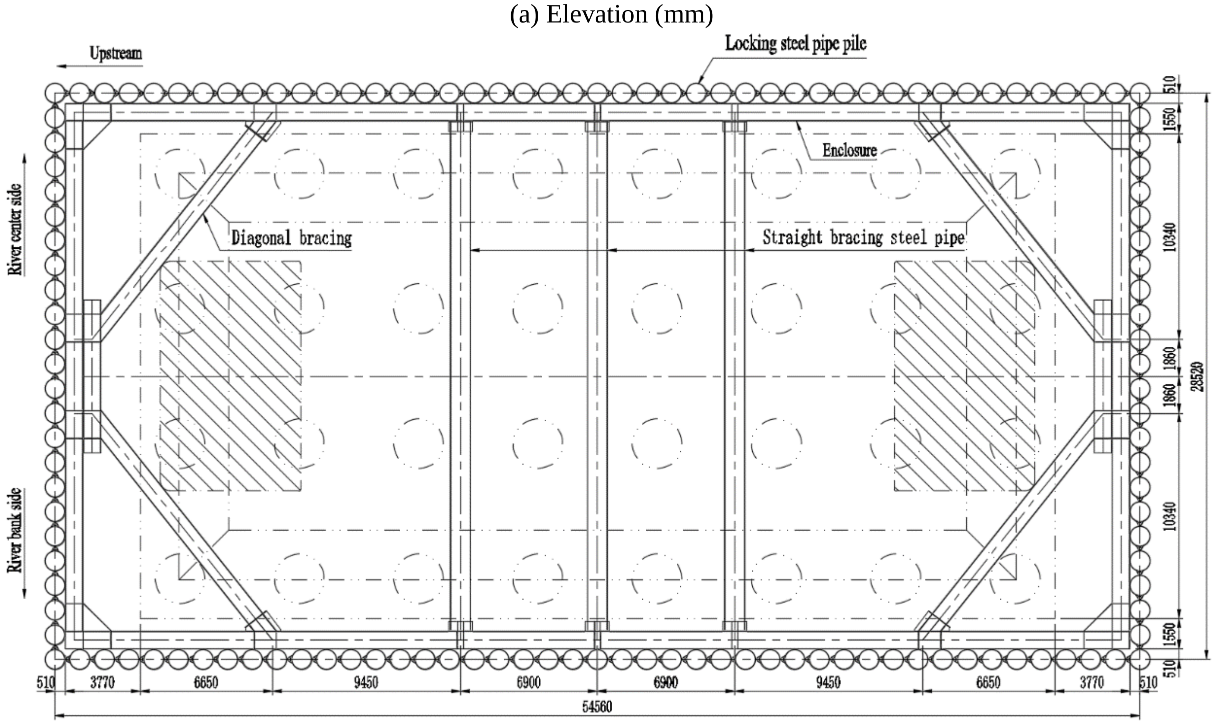
Construction stage III: after installing the third layer interior support, pump water and take soil from the cofferdam to the position of 1m below the fourth layer interior support;

Construction stage IV: after installing four layers of interior supports, pump water from the cofferdam and excavate to the design elevation;

Construction stage V: the concrete cushion is poured, and the water rises to the flood prevention elevation+21.07 during the construction of the pile cap.



(a) Elevation (mm)



(b) Plan (mm)

Figure 3: Layout of Cofferdam with Locking Steel Pipe Pile

In this paper, MIDAS CIVIL FEM software is used to establish the integral model of cofferdam structure, and the allowable stress method is used to analyze the main structure.

In the model, the earth pressure load on the inner and outer sides of the cofferdam is calculated according to the "Technical Specification for Retaining and Protection of Building Foundation Excavations" (JGJ120-2012) by calculating the earth pressure and water pressure separately. The water pressure is calculated according to the hydrostatic pressure, taking into account the action of the water flow force. The calculation of earth pressure is illustrated in Figure 4.

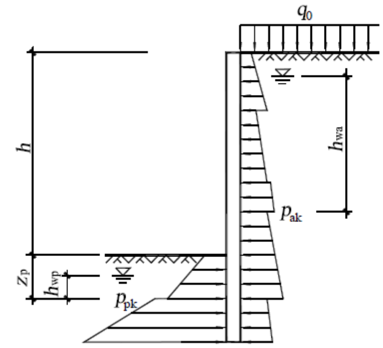


Figure 4: Diagram of Earth Pressure Calculation

Active earth pressure outside cofferdam and passive earth pressure inside cofferdam:

$$p_{ak} = \gamma_f H K_a - 2c\sqrt{K_a} + u_a \tag{1}$$

$$p_{pk} = \gamma_f H K_p + 2c\sqrt{K_p} + u_a \tag{2}$$

Hydrostatic pressure strength inside and outside cofferdam:

$$u_a = \gamma_w h_{wa} \tag{3}$$

$$u_p = \gamma_w h_{wp}. \tag{4}$$

The soil reaction force inside cofferdam is calculated by elastic fulcrum method:

$$p_s = k_s v + p_{s0} \tag{5}$$

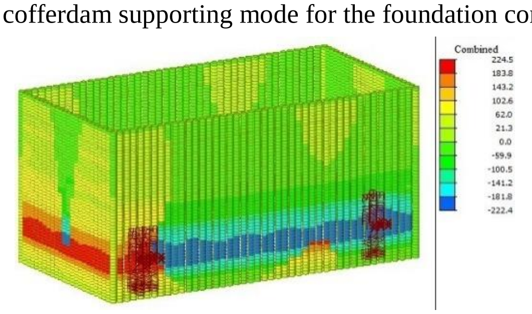
The flow force is calculated according to the Port Engineering Load Code (JTS 144-1-2010):

$$F_w = C_w \frac{\rho}{2} V^2 A \tag{6}$$

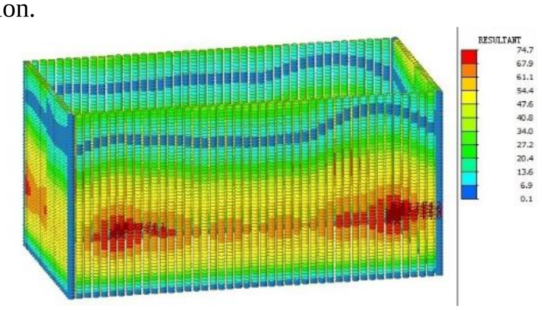
The construction stage analysis is conducted for five typical construction stages. The maximum combined stress and deformation of each main structure in the construction stage are shown in Figure 5.

The maximum combined stress of the locking steel pipe is 225MPa<240MPa, and the maximum horizontal displacement is 75mm<0.8%h=197mm; the maximum combined stress of the first, second (third) and fourth interior supports is 131MPa, 156MPa and 166MPa respectively, all less than 170MPa.

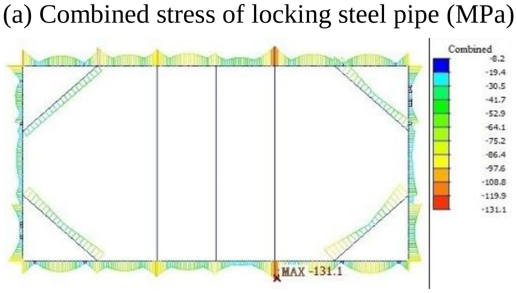
The calculation of the finite element model shows that the stress and deformation of the main structures of the cofferdam meet the requirements of the specification, and it is reasonable and feasible to adopt the locking steel pipe pile cofferdam supporting mode for the foundation construction.



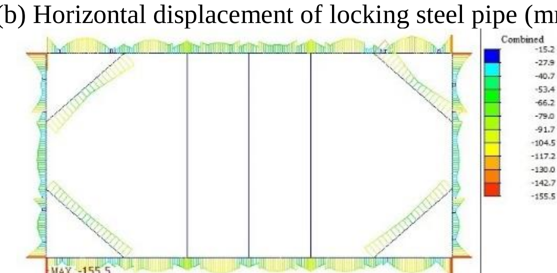
(a) Combined stress of locking steel pipe (MPa)



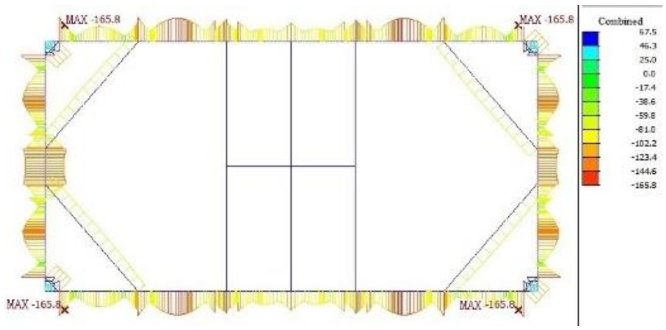
(b) Horizontal displacement of locking steel pipe (mm)



(c) Combined stress of first layer interior support (MPa)



(d) Combined stress of second and third layer interior support (mm)



(e) Combined stress of the fourth layer interior support (MPa)
Figure 5: Calculation Results of Locking Steel Pipe Pile Cofferdam

IV. KEY CONSTRUCTION TECHNIQUES OF COFFERDAM

A. Pilot Hole for Locking Steel Pipe Pile

According to the cofferdam structure design, the maximum depth of the locking steel pipe entering the stratum is 9.1m, and the maximum embedding depth is 5.0m in the moderately weathered rock stratum. The riverbed covering layer at the cofferdam position is fine sand and gravelly sand, and the lower part of the covering layer is strongly and weakly weathered calcareous sandstone, and the saturated compressive strength of the rock stratum is 30MPa.. Combined with the depth of the borehole and the condition of the soil layer, the on-site unit used a rotary drill to carry out the construction of pilot hole of the locked steel pipe pile, which greatly improves the efficiency of pilot hole making while ensuring smooth pilot hole.

The pilot hole of the locking steel pipe pile adopts the A-B hole classification jumping hole overlapping pilot hole method. That is, the steel casing at hole position A (the steel casing is concentric with the design position of the locking steel pipe) shall be inserted into the hole at first, and the pilot hole at hole position A shall be completed by using the rotary drilling drill, the tank sand in hole A shall be backfilled, and the steel casing at hole position A shall be pulled out; The next step is to place the steel casing into hole position B, which is situated between the hole position A and must be concentric with the design position of the locking steel pipe. The pilot hole work for hole B shall be completed in a similar manner to that of hole A, and one round of hole jumping and interlocking pilot hole construction should be accomplished. All cofferdam locking steel pipe piles, along with their respective pilot hole constructions, must be completed consecutively from upstream to downstream. The number of hole positions A-B constructed in each round should be based on the efficiency of the Rotary Drilling Pilot Hole, with 7-10 steel casings serving as a cycle. For further details regarding the plane layout and on-site construction of the A-B hole position classification, jumping hole overlapping pilot hole, please refer to Figures 6 and 7.

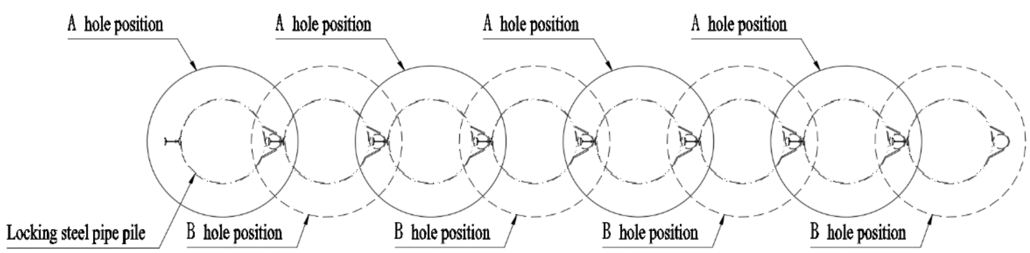


Figure 6: Plan Layout of Hole Position A-B Classification and Jumping Hole Occlusion Pilot Hole

The diameter of the pilot hole will be determined based on the diameter of the locking steel pipe, taking into account the effective action range and economic considerations of high-pressure rotary jet grouting. After conducting research and analysis, the pilot hole diameter is set at 1.8m to ensure that the minimum area of the pilot hole (the dimension of engagement position A-B along the thickness direction of the cofferdam) is larger than the diameter of the locking steel pipe. This approach prevents scenarios where deviations against the rock surface might prevent the locking steel pipe from being inserted and driven to the design elevation.

Figure 7: Photos of On-site Rotary Drilling Pilot Hole Construction

After the pilot hole is completed and before the steel pile casing is pulled out, the hole shall be backfilled with fine sand, so as to prevent the collapse of the hole and prevent the riverbed sludge from entering the hole, thus affecting the follow-up grouting effect.

B. Locking Steel Pipe Inserting and Driving and Water Stoppage

After completing 2-3 rounds of pilot holes for the locking steel pipe pile, proceed to insert and drive the locking steel pipe pile using a vibration pile hammer. Once the locking steel pipe pile has been inserted and driven for 3 rounds, grouting should be carried out in the gap between the inner and outer pilot holes of the cofferdam with the inserted locking steel pipe pile. The detailed procedure can be found in Section 3.2. It is important to note that the pilot hole clearance grouting process should lag behind the procedure of inserting and driving the locking steel pipe pile by 3 rounds. This ensures that the sand at the grouting hole position is undisturbed during the process of inserting and driving the steel pipe, thereby preventing any adverse effects on the water-stopping effectiveness.

After the locking steel pipe pile cofferdam is inserted and driven, and the pilot hole clearance grouting is completed and the strength is reached, the cofferdam locking steel pipe with C-T locker water stop shall be carried out. The C-T locker shall be filled with a mixture of impervious clay and sawdust wrapped with geotextile, and plugged and pounded densely with steel bars. C-T locker water stop filling is shown in Figure 8.

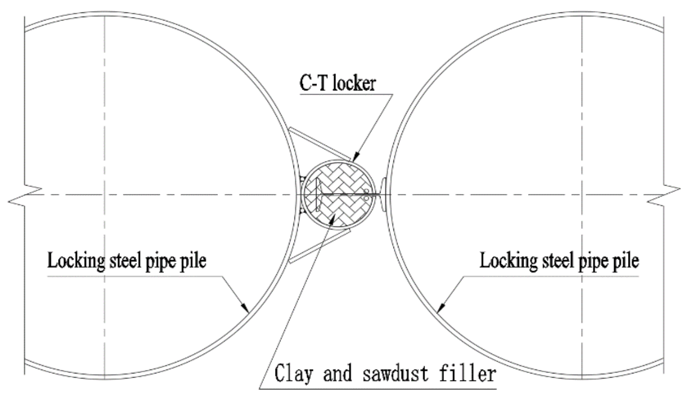


Figure 8: C-T Locker Water Stop Filling Schematic Diagram

C. Installation of Interior Support and Excavation of Foundation Pit

After the completion of cofferdam water stop process, the triangular bracket shall be welded on the locking steel pipe, and the first layer interior support shall be installed.

The water inside the cofferdam shall be pumped out until it reaches a level 1m below the interior supports of the second and third layers, and then the installation of the second and third layer interior supports shall be carried out accordingly. The pumped water is directed from the cofferdam to the riverbed surface, and the excavation of the foundation pit is performed using an excavator equipped with a long arm grab bucket. Soil is removed from the cofferdam until it reaches a level 1.0m below the fourth layer interior support, at which point the fourth layer interior support is installed. The excavation process within the cofferdam continues using the excavator and hydraulic hammer to excavate through the rock stratum. The on-site excavation of the foundation pit is illustrated in Figure 9 below.

Figure 9: Photos of On-site Foundation Pit Excavation

According to the design calculation of the cofferdam, the stress of the second and third layer interior supports of the cofferdam is large, and the locking steel pipe has local instability risk under the action of the water level. During the construction of the second and third layer interior support, the method of filling concrete between the interior support purlin and the locking steel pipe pile is employed. This effectively transforms the line contact between the interior supporting surrounding purlin and the locking steel pipe pile into surface contact, thereby reducing the local stress on the locking steel pipe and resolving issues related to its local instability. The process of concrete filling between the locking steel pipe pile and the surrounding purlin is demonstrated in Figure 10.

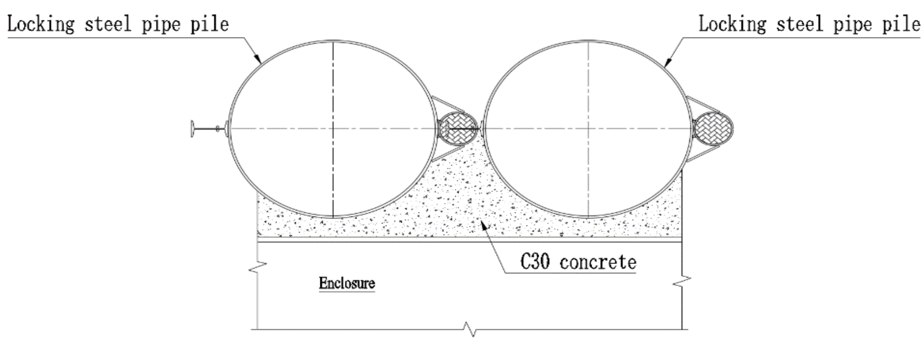


Figure 10: Schematic Diagram of Concrete Filling between Locking steel pipe pile and Purlin

Excavate from the foundation pit in the cofferdam to the design of the foundation pit bottom elevation and pour 50cm cushion concrete for subsequent pile cap construction.

V. Construction efficiency Analyses

The construction period of the cofferdam structure of the bridge is reviewed, and the ergonomics of the key processes of the cofferdam construction are as follows:

(1) The rotary drill is used for pilot hole construction, and the efficiency is about 7 holes/day;

(2) Locking steel pipe pile inserting and driving is restricted by the efficiency of pilot hole, and the efficiency is about 7 holes/ day;

(3) High-pressure rotary grouting with efficiency of 6.0h/hole.

The structure of the cofferdam, the locking steel pipe pile insertion and the pilot hole gap grouting and water stop can be operated in a continuous sequence, so that the working efficiency is greatly improved. Based on the construction records, it was observed that the construction of the locking steel pipe pile cofferdam structure, from pilot hole to grouting water stop, took a total of 36 days. Additionally, the entire foundation construction process, starting from the cofferdam pilot hole and concluding with the pouring of the pile cap, required approximately 2 months. To illustrate this, a comparison and analysis of the construction schemes for the double-wall steel box cofferdam, traditional percussive drilling pilot hole locking steel pipe pile cofferdam, and the locking steel pipe pile cofferdam implemented in this Project are presented. Please refer to Table 3 below for further details.

Table 3: Comparison of Work Efficiency of Three Cofferdam Construction Schemes (Unit: days)

<table>
<tr><th>Items</th><th>Double-wall steel box</th><th>Percussive drill locking steel pipe pile with pilot hole + concrete water stop</th><th>Rotary Drilling Pilot Hole locking steel pipe pile +grouting water stop</th></tr>
<tr><td>Blasting excavation</td><td>90</td><td>——</td><td>——</td></tr>
<tr><td>Drilling hole</td><td>——</td><td rowspan="2">45</td><td rowspan="3">36</td></tr>
<tr><td>Drive in of Locking steel pipe</td><td>——</td></tr>
<tr><td>Water stop</td><td>——</td><td>30</td></tr>
<tr><td>Cofferdam assembling and lowering</td><td>45</td><td>——</td><td>——</td></tr>
<tr><td>Interior support installation and soil borrowing</td><td>——</td><td>12</td><td>12</td></tr>
<tr><td>Back Cover/Bottom</td><td>7</td><td>3</td><td>3</td></tr>
<tr><td>Total</td><td>142</td><td>90</td><td>51</td></tr>
</table>

Note: 1. Consolidated statistics shall be adopted for the construction periods and process could be operated in a continuous sequence in the table; 2. The same process in the two locking steel pipe pile schemes shall be considered according to the same work efficiency; 3. The construction period of general process and non-control line process of the three schemes is not calculated.

By conducting a comparative analysis of the work efficiency among the three schemes, it becomes evident that the construction scheme proposed in this paper offers the shortest construction period for foundation construction. Furthermore, the implementation of this scheme leads to a substantial improvement in construction efficiency when compared to the traditional construction approach.

VI. Conclusions

Aiming at the deep water rock-socketed bridge foundation with saturated compressive strength less than 30MPa, this paper adopts rotary drilling pilot hole and high-pressure rotary jet grouting water stop locking steel pipe pile cofferdam construction, realizes the multi-process operated in a continuous sequence of pilot hole works, inserting and driving and water stopping, shortens the construction period of the locking pipe pile cofferdam, greatly improves the foundation construction efficiency, improves the material utilization rate, effectively reduces the construction cost, and provides a set of economic and efficient technical scheme for the construction of the deep water rock-socketed bridge foundation. Due to the limitation of on-site construction conditions, the pilot hole mode and efficiency of rock stratum with saturated compressive strength above 30MPa need to be further studied and demonstrated.

The construction technology presented in this paper is capable of meeting the demands of an increasingly complex construction environment and efficient, rapid construction needs within the bridge industry. Furthermore, it boasts a promising application prospect with a wide range of potential use cases.

References

[1] Stipanić, Bratislav; Pavić, Lazar; Taktak, Mehmet; Eksi, Ugur Gokhan; Yazkac, Ercan Kemal; Tandogan, Eren. Highway Bridge over the Sava River at Sremska Raca–Construction. IABSE Symposium Istanbul 2023: Long Span Bridges-Proceeding Book, Pages 521-528, 2023.

[2] Löhning, Thomas; Ravn, Uffe Graaskov; Pedersen, Flemming; Christoffersen, Louis Westh Moe. THE 1915 ÇANAKKALE BRIDGE – DESIGN AND CONSTRUCTION OF SUBSTRUCTURE. IABSE Symposium Istanbul 2023: Long Span Bridges - Proceeding Book, p 575-582, 2023.

[3] Firth, Ian; Walker, Chris; Archer-Jones, Cameron; Mountjoy, Andrew. Challenges of a Multiple Super-long Span Suspension Bridge Crossing of the Irish Sea. IABSE Symposium Istanbul 2023: Long Span Bridges - Proceeding Book, p 811-819, 2023

[4] Quang, T.N., Anh, B.T., Cong, T.V., Cao, T.M. (2022). Combination of Cement Deep Mixing (CDM) and Steel Sheet Piles for the Cofferdam Used in Construction of Deep Foundation Pit in Soft Ground in the Mekong Delta Coast. CIGOS 2021, Emerging Technologies and Applications for Green Infrastructure. Lecture Notes in Civil Engineering, vol 203. Springer, Singapore.

[5] Verstov, V.V., Yudina, A.F. & Gaido, A.N. Improving Efficiency of Arranging Offshore Cofferdams. Soil Mech Found Eng 57, 73–76 (2020).

[6] Sulovska, M., Stacho, J., Kopecky, M.; The Stability Analysis of a Cofferdam using the Numerical Modelling. IOP Conference Series: Materials Science and Engineering, v 960,p 022068(10 pp.),2020.
[7] Zhou Xinya, Liu Changjian, Qian Youwei. Design of Very Long Steel Sheet Pile Cofferdam for Deep Water Foundation and Key Construction Techniques. World Bridges, 2020, 48(2): 20-24.
[8] Raja Rajan, K., Nagarajan, D., Vijayakumar, T. (2023). Overview of Enabling Works for Waterfront Structures—Design and Construction. Deep Foundations for Infrastructure Development in India. DFIIndia 2021. Lecture Notes in Civil Engineering, vol 315. Springer, Singapore.
[9] Komazawa, T., Harada, O., Inazumi, K. (2020). Installation of steel pipe piles and steel pipe sheet pile for bridge foundation using vibratory inner-excavation method (NB SYSTEM). Geotechnics for Sustainable Infrastructure Development. Lecture Notes in Civil Engineering, vol 62. Springer, Singapore.
[10] Nazarova, E.V.; Kaloshina, S.V.; Zolotozubov, D.G.; The choice of a metal sheet piling for the construction of the foundation pit. Journal of Physics: Conference Series, v 1928, n 1, 2021.
[11] Sobala,D.; Rybak,J.; Steel Sheet Piles – Applications and Elementary Design Issues. IOP Conference Series: Materials Science and Engineering, v245, p022072 (10 pp.), 2017.
[12] Junhu Shao, Zihao Fan, Yuanyuan Huang, Yulin Zhan, Qinhao Cai. Multi-objective optimization of double-walled steel cofferdams based on response surface methodology and particle swarm optimization algorithm .Structures, 2023, 49: 256－266.
[13] Xuesong Zhang, Wenying Li, Baoshan Zeng. Design and Construction of Double-wall Steel Cofferdam in Deep Water Foundations. IOP Conference Series: Earth and Environmental Science.2021.
[14] Dai Yuchen, Tuo Yu, Liu Quan, Wang Hao. Multi-attribute Decision-making Method of Deep-water Cofferdam Schemes in Reservoirs Based on BIM. Water Resources and Power, 2022, 40(05): 96-100.
[15] Zhang Yanhe. Construction Techniques for Steel Cofferdam in Deep Water and Shallow Overburden Area. World Bridges, 2019, 47(2): 28-32.
[16] Zhang Xiong. Research on Deep Water Foundation Construction Technology of the 5# Main Tower Pier in Menghua Railway Bridge over Dongting Lake. Lanzhou: Lanzhou University, 2015: 14-15.
[17] Komazawa, T., Harada, O., Inazumi, K. (2020). Installation of steel pipe piles and steel pipe sheet pile for bridge foundation using vibratory inner-excavation method (NB SYSTEM). Geotechnics for Sustainable Infrastructure Development. Lecture Notes in Civil Engineering, vol 62. Springer, Singapore.
[18] Jiang Haitao. Study on the application of bridge cofferdam in deep water and shallow overburden bed conditions. Journal of Railway Science and Engineering, 2020, Vol 17, 1778-1784.
[19] Zhang Hongwu, Mu Qingjun, Chen Zhuoyi, Yang Wu. Key Technology and Application of Locking Steel Pipe Pile Cofferdam in Deep Waters with Shallow Overburden. China Harbour Engineering, 2023, 43(7): 55-60.
[20] Tu Xianxing. Design and Application of Cofferdam for Riverbed with Inclined Rock Surface in Deep Water and Shallow Overburden. Railway Construction Technology, 2021, 03, 49-52.
[21] Zeng Hongjun. Technical Application of CT Type Locking Steel Pipe Pile Cofferdam in Hard Rock. China Water Transport, 2022, 22(7), 156-160.