Original Research Article

Key Technology for Construction of Steel-concrete Composite Suspending Cofferdam without Bottom Cover for Platform of Coastal Intercommunication Project

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Abstract: Many bridge piers were built in the Coastal Interconnection Project of the Ningbo Section of the Hangzhou-Ningbo Expressway Double Line. Affected by the tides at the bridge site, the high pile caps are constructed using a suspending cofferdam without a bottom cover. Based on the consideration of various factors such as construction difficulty, safety, cost and construction period, etc. A cement structure is generally adopted as the floor of the suspended box cofferdam. The steel-concrete combined hanging box cofferdam without bottom cover adopts the structure of steel wall plate and prefabricated cement floor, and the partition wall plates are connected by bolts. The steel-concrete composite suspending cofferdam adopts the prefabricated bottom plate and wall plate. The construction sequence is listed as follows: First, weld the load-bearing corbel on the steel casing, and then hoist the prefabricated bottom plate to the steel casing corbel in blocks. Pour the wet joint between the prefabricated bottom plate and install the side plate. After that, pour the cushion after welding the shear plate. Finally, carry out the construction of the cap. During the construction of the project, the connection method between the wall plate and the bottom plate was optimized. The connection of the fine-rolled rebar hanger rod was changed to the steel bar pair pulling, which improved the construction efficiency significantly.

Keywords: Tidal area; High pile cap; Steel-concrete composite hanging box cofferdam without bottom cover; Construction optimization.

1. Introduction

In tidal areas of the ocean, suspended box cofferdams have been widely used in the construction of bearing platforms due to their convenience in construction and cost advantages[1-8]. The first phase of the Binhai Interchange project on the Hangzhou Ningbo Expressway's double track Ningbo section has numerous piers, and the construction of bridge piers requires the use of an unsealed steel-concrete composite suspended box cofferdam. This article takes this project as an example to analyze and study the technical issues in the construction of steel-concrete composite suspension box cofferdam, providing reference and inspiration for similar projects in the future.

2. Project Overview

The first phase of the Binhai Interchange of the Ningbo section of the Hangzhou Ningbo Expressway occupies an area of 613.03 acres, making it the largest offshore hub interchange project in Asia. The starting and ending mileage of the S3 contract section of the Ningbo Phase I project of the Hangzhou Ningbo double track is K31+020~K37+920, with a main line length of 6.9 kilometers. The main project content includes Binhai Interchange and Binhai Elevated Bridge, with a single track length of 21.078 kilometers per 16 bridges. Specifically, there are 2.4 double track kilometers per bridge for Binhai Interchange, 1.32 kilometers per bridge for Binhai Interchange No. 1 and No. 2 main bridges on Jintang side, 5.9577 kilometers per A-H ramp bridge for Binhai Interchange, and 4.5 double track kilometers per bridge for Binhai Elevated Bridge. Bridge piers

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mostly use rectangular piers, with a small number of H-shaped piers. High pile piers are used for both main and ramp piers, with a total of 348 piers, including 172 in the coastal interchange area.

Figure 1 Layout plan of Binhai interchange on hangzhou ningbo expressway.

The bridge site area belongs to the North Asian monsoon climate zone, which is warm and humid, with abundant rainfall, strong sunlight, and distinct four seasons. In summer and autumn, it is controlled by the Pacific subtropical high pressure, with sunny and hot weather with little rain. There are often typhoons invading, and disaster weather is frequent. The project area belongs to the non regular semi diurnal shallow sea tidal type and belongs to the strong tidal zone. The tidal level characteristics are shown in Table 1, and the tidal characteristic value standards and cofferdam parameters within the S3 contract section are shown in Table 2. The single low tidal level time refers to the time when the tidal level is lower than the bottom elevation of the suspended box during each ebb and flow tidal cycle, with two ebb and flow tidal cycles per day.

Table 1 Tidal level characteristics of the Hangzhou Ningbo project.

Project		Tidal level characteristics
Tidal level	The highest tide level over the years	5.15m
	The lowest tide level over the years	-0.25
	Average sea level	2.13m
	Average high tide level	3.01m
	Average low tide level	1.12m
Tidal range	Annual average tidal range	1.91m
	Maximum tidal range over the years	3.67m
Duration	Average duration of rising tide	6hr:18min
	Average duration of ebb tide	6hr:07min

Table 2 Standard values of tidal characteristics and cofferdam parameters for contract section S3.

Project	Parameter
Average low tide level	-0.83m
Average tidal level	+0.41m
Bottom elevation of pier cap	+1.2m/+0.2m
Bottom elevation of suspended box	+0.9m/-0.1m
Height difference from the bottom of the suspended box to the low tide level	1.73m/0.73m
Single low tide time	5h（+0.5）

Due to the influence of tides and considering various factors such as construction difficulty, safety, economic benefits, and construction period, this project adopts a high pile cap that is exposed to the water surface while meeting the above requirements and considering aesthetics. During the non tidal period, the construction is carried out using an unsealed hanging box. The time when the tide level is below the bottom of the cofferdam is about 11 hours per day, which is the dry operation time for cofferdam construction.

3. Scheme Comparison and Selection

The bottom elevation of the pier cap in this project is+1.2m, located between the average high tide level and the low tide level. Through a large amount of on-site actual data collection, only 11 hours a day can be used for the construction of the pier cap steel cofferdam, and the construction period is short. Therefore, the selection of the cofferdam construction plan is particularly important. Based on the characteristics of this project and the geological conditions of the bridge site, taking the 8.4m×8.4m bearing platform as an example, a comparison is made between two types of suspension box cofferdam schemes: steel bottom plate and cement prefabricated bottom plate.

3.1 Steel Bottom Plate Suspension Box Cofferdam Scheme

The bottom plate of the steel bottom plate suspension box cofferdam is made of 8mm thick steel plate, and the flange plate is made of 16 × 200mm steel plate, [10 channel steel is used for panel ribs, []25b channel steel is used for purlins, and 11.5m long double spliced 56a section steel is used for the main beam of the bottom plate.

When constructing the steel base plate, first accurately position the steel casing, weld the lower steel cow legs, set two positions for each casing, with cow legs at a height of 40cm and a length of 54.4cm, and then install the hanging distribution beam. The suspension system is the main load-bearing component. All plates with a thickness greater than 12mm need to be beveled and welded using penetration welding. Use 40mm diameter precision rolled threaded steel as a suspension rod, lower the longitudinal beam (double assembly 56a) and level it, then lay the bottom formwork (bottom plate with purlins). The style of the formed steel bottom plate and steel suspension box cofferdam is shown in Figure 2.

Figure 2 Steel bottom plate and steel suspension box cofferdam diagram.

3.2 Cement Bottom Plate Suspension Box Cofferdam Scheme

Cement prefabricated panels mainly consist of steel-concrete prefabricated panels, clamps, wedges, wet joints, and cushion layers. Among them, the hoop is placed on the cow leg of the steel casing; Ring beams are used to reinforce the stress on the bottom plate; Wet joints are used to connect 4 steel reinforced concrete prefabricated panels into a whole; Shear plates are used for the connection between the bottom plate and the steel casing; The stopper is used to reinforce the side formwork. The specific structure of the cement base plate is shown in Figure 3.

During the construction of prefabricated cement slabs, support brackets should be welded at the bottom of the suspension box of the casing, with three positions set for each casing. The bottom plate of the suspended box adopts a prefabricated reinforced concrete structure, with a concrete grade of C50, a thickness of 15cm, and an overall size of 9072 × 9072mm, divided into 4 pieces, with a single block size of 4386 × 4386mm, with a middle sleeve hole diameter of 2.3m (30cm larger than the steel casing); There are reinforcing ribs (bottom plate tie beams) with a width of 30cm and a thickness of 30cm between the casing, which are connected to the bottom formwork as a whole through steel bars; Each steel casing is equipped with 30cm wide and 30cm thick circular reinforcing ribs (circumferential ring beams), and the circumferential main beams on all sides are 50cm wide and 30cm high.

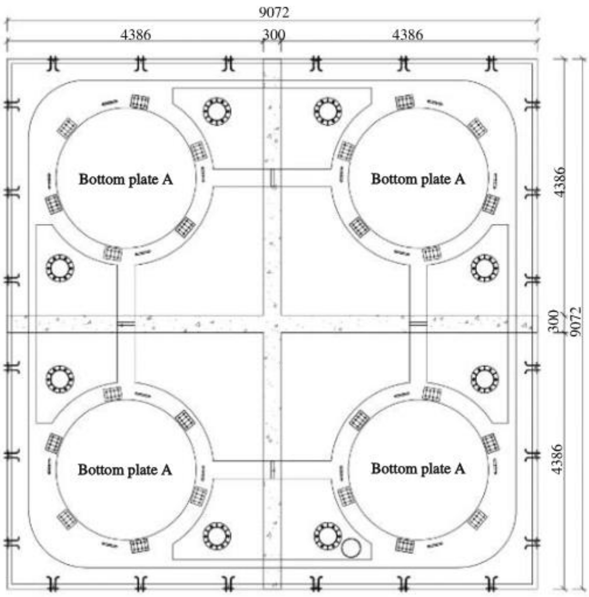


Figure 3 Construction diagram of cement bottom plate.

At low tide, the prefabricated bottom plate is transported to the site in the back yard, installed on the cow legs, and the direction of the four prefabricated plates is adjusted. The bottom plate is fixed to the permanent steel casing column with shear plates, and wet joint steel bars are installed. The formwork is then poured to form a complete cement prefabricated plate. The on-site installation of cement bottom plate is shown in Figure 4.

Figure 4 Installation diagram of cement bottom plate on site.

3.3 Comparison and Selection of Cofferdam Bottom Plate Schemes

The comparison indicators of two schemes for a single suspended box cofferdam are shown in Table 3. After the above multiple comparisons, the suspension box cofferdam using cement prefabricated bottom plate is suitable for the construction environment, with the advantages of simple process, convenient operation, time saving, the ability to form flowing operations, and low risk sources. Therefore, the bearing platform of this project has been determined to adopt the cement prefabricated slab suspended box cofferdam scheme.

Table 3 Comparison and selection of bottom plate schemes for suspended box cofferdam.

Project	**Steel bottom plate suspended box cofferdam**	**Cement bottom suspended box cofferdam**
Material	Steel 90t	Steel 30.7t Concrete: 13m3 Reinforcement 6t
Material costs	￥585,000	￥291,018
Construction period	15 days/piece	10 days/piece
Construction personnel	12	10
Planned construction period	464 days	309 days
Material utilization rate	After construction is completed, the steel bottom plate can be extracted and reused	After the construction is completed, the cement bottom plate will not be removed, only the side plate can be reused
Comprehensive cost	211,200 yuan/piece	172,600 yuan/piece
Construction convenience	The materials are bulky and rely heavily on mechanical installation, making it inconvenient; When dismantling, it is necessary to first remove the fixing of the bottom formwork, drop it into the sea, and then drag the formwork out, which is difficult to operate; The working environment for workers is dangerous, and there is always a high risk of falling into the water.	Backyard prefabrication, convenient transportation and installation, low mechanical occupancy time, no need for dismantling, and can form a streamlined operation.

4. Process Flow

4.1 Hanging Box Structure

There are 7 types of bearing platforms in the Binhai Interchange area, and the construction process is similar. This article takes the bearing platform with a structural size of 8.4×8.4×3m as an example to explain the construction of the hanging box method for the bearing platform. The plan size of the unsealed steel-concrete composite suspension box on the pier is 9.112m×9.112m, with a wall height of 4.0m and a net inner wall size of 8.4m×8.4m. It includes supporting brackets, suspension box bottom plate, suspension box side wall, pedestrian walkway and other components. The bottom plate of the suspension box adopts a C50 prefabricated reinforced concrete structure, with a thickness of 15cm and an overall size of 9072 ×9072mm. It is divided into 4 blocks, with a single block size of 4386 ×4386mm and a middle sleeve hole diameter of 2.3m; A bottom plate tie beam with a width of 30cm and a thickness of 30cm is installed between the casing; Four lifting points are set on each prefabricated slab, using ø28 round steel as lifting rings. The steel bars of the lifting rings are bent into a Ω-shape and firmly tied to the bottom steel bars. The side walls are made in single wall blocks, with a total of two forms. There are 8 side walls with a plane size of 2.995×4m, and the four corner L-shaped side walls have a plane size of 1.546×1.546×4m. Vertical connection flanges are installed between the block hanging boxes, and M20×60mm high-strength bolts are used for connection; The side wall is composed of a steel panel with a thickness of Q=6mm, HN200×100 vertical back ribs, 2×HN350×175 circumferential main beam, and HN100×50 secondary beam. The side wall is connected to the bottom plate using ø15 precision rolled threaded steel. Install ø325×8m steel pipe inner support at the four corners of the upper part of the suspension box. The specific layout of the unsealed steel-concrete composite suspension box cofferdam structure is shown in Figure 5.

4.2 Construction Process Flow

The overall construction process of the steel-concrete composite suspension box bearing platform in the Binhai Interchange area of the Hangzhou Ningbo double track project is as follows: dismantling of the drilling platform → installation of load-bearing brackets → block processing of the wall panel → prefabrication of the concrete bottom plate → processing of other components → installation of the prefabricated bottom plate → installation of wet joint steel bars to help seal and clamp the installation → pouring of wet joint and sealing concrete → installation and reinforcement of the suspension box wall panel → installation of internal support → welding of the cushion layer and shear plate → treatment of the pile head → construction of the bearing platform → steel Dismantle the mixed combination suspension box.

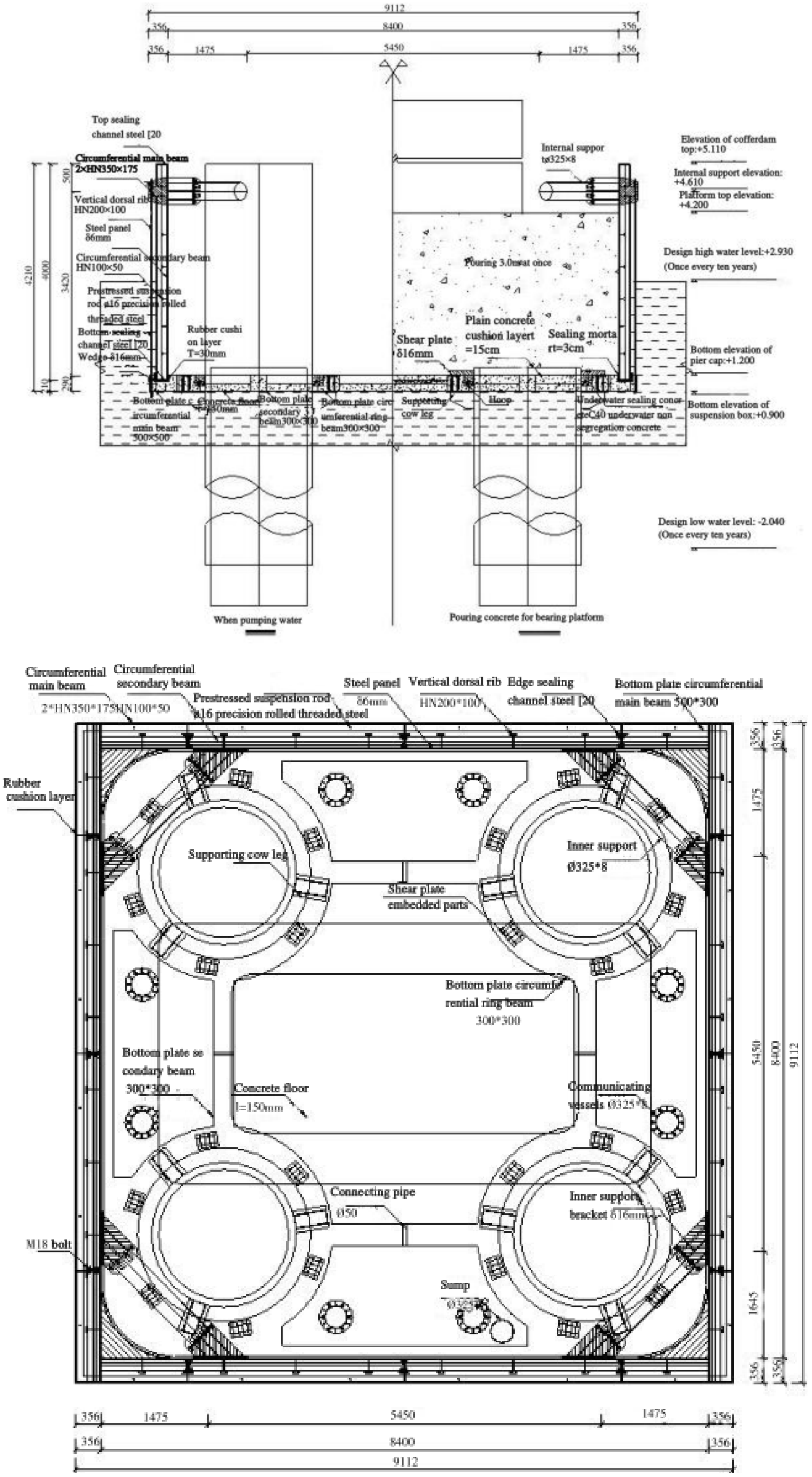


Figure 5 Unsealed steel-concrete composite suspension box structure (Unit: mm).

4.2.1 Installation of Load-Bearing Bracket

During low tide periods, install support brackets at the design elevation on the steel casing. Weld support brackets at the bottom opening of the suspension box of the casing, with three brackets set at each casing, with a height of 31cm and a length of 45cm. The welding between the cow leg and the steel casing adopts manual welding. Before welding, the mud, rust, or oxide film attached to the outer surface of the steel casing should be cleaned up to expose the metallic luster on the surface of the casing, ensuring welding quality; Welding adopts three sided surround welding, and the weld seam must be full, with welding slag removed. After the welding of the cow leg is completed, it can only proceed to the next construction process after passing the acceptance by the technical personnel and quality inspection engineer. (Figure 6)

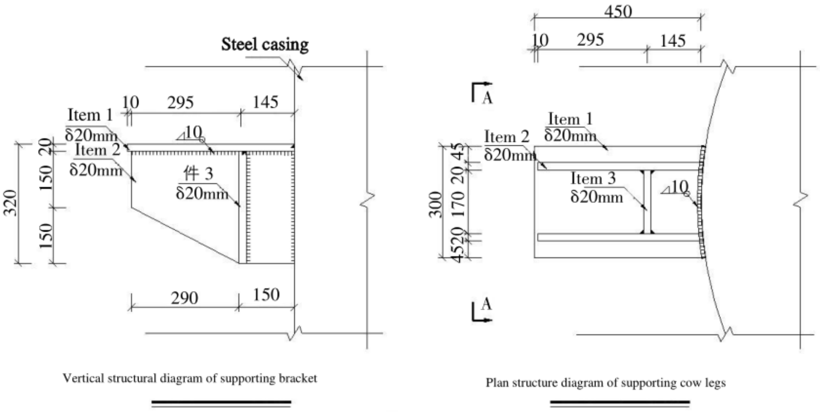


Figure 6 Schematic diagram of supporting bracket structure.

4.2.2 Wall Panel Block Processing

The side walls of the hanging box are made in single wall blocks, consisting of 8 straight wall panels and 4 L-shaped side walls. Before leaving the factory, the components should be tested and assembled in the factory to check the flatness of the formwork and whether the joints are smooth, and whether there are any excessive gaps or misalignment. The wall panel structure is shown in Figure 7.

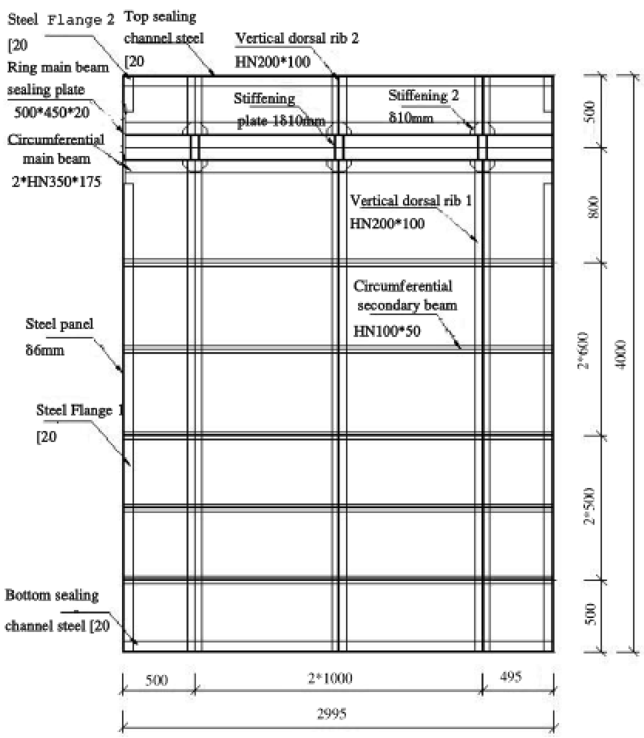


Figure 7 Side wall schematic diagram.

4.2.3 Prefabrication of Concrete Base Plates

The bottom plate of the suspension box adopts a prefabricated reinforced concrete structure, consisting of four 15cm thick C50 concrete slabs. To avoid being stuck by the steel casing when the bottom plate is lowered, the diameter of the reserved sleeve hole on the bottom plate is 30cm larger than the diameter of the steel casing, and its center position is consistent with the pile center. The steel casing is connected to the bottom plate using clamps. Leave a 30cm wet joint between the bottom plates of each suspension box. Set up 4 lifting points on each prefabricated slab, with grooves on the upper side of the main beam facing the bottom plate ring. After the installation of the side walls is completed, wedge-shaped blocks are used for fixation. (Figure 8)

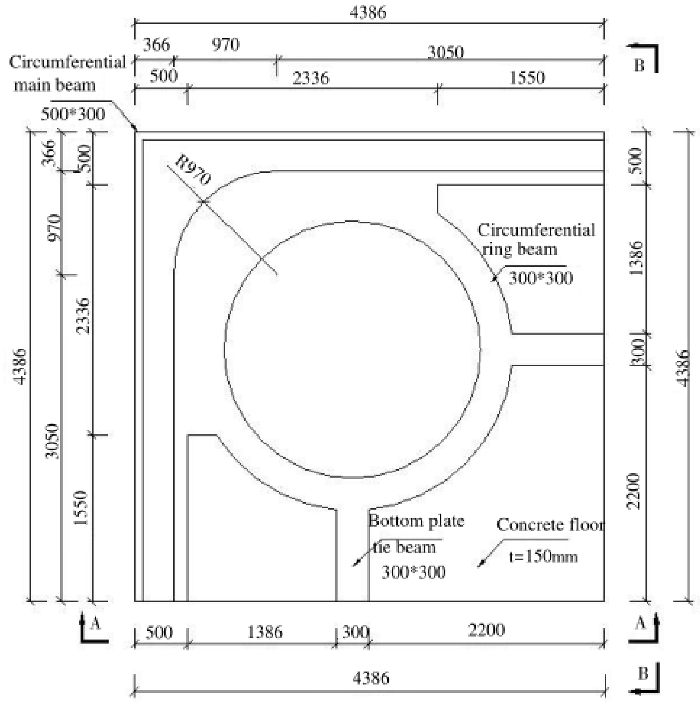


Figure 8 Schematic plan of single prefabricated bottom plate.

4.2.4 Prefabricated Bottom Plate Assembly

The prefabricated bottom plate is lifted to the bracket of the steel casing in blocks, and the relative position of the bottom plate is adjusted after the lifting is completed, so that the net distance between the bottom plate and the main beam is equal to 8.4m. Tie the wet joint steel bars and weld the bottom plate steel bars to the wet joint steel bars before pouring the wet joint concrete. Install sealing clamps around the steel casing and pour sealing concrete between the bottom plate and the steel casing. Install rubber cushion layer on the precast bottom plate circumferential main beam. (Figure 9)

Figure 9 Prefabricated bottom plate assembly site diagram.

4.2.5 Installation and Reinforcement of Suspension Box Sidewalls

The hanging box wall panels are processed in the template factory and transported to the site for installation. Before installation, first measure and lay out, control the inner net size of the bottom plate to be consistent with the bearing platform, and then lay a sealing strip at the bottom of the hanging box wall panel to ensure the sealing between the bottom plate and the hanging box wall panel.

After measuring and positioning, symmetrically lift the side wall, adjust the plane position of the bottom opening of the lifting box according to the slot on the bottom plate. After the inner wall of the wall panel coincides with the edge line of the bearing platform, use temporary support to fix the wall panel, release the crane hook to complete the force conversion of the wall panel, lift the next wall panel, and repeat the above process until the assembly of the lifting box side panel is completed. Rubber skin is used to fill the joints of adjacent wall panels, and after the splicing is completed, glass glue is applied to prevent water leakage. The bottom of the wall panel can be adjusted to the final size of the mold using wedges, and after passing the inspection, the bottom can be sealed with mortar. (Figure 10)

Figure 10 Installation site diagram of side wall.

4.2.6 Welding of Cushion Layer and Shear Plate

After the concrete at the joint of the bottom plate of the suspended box reaches the design strength, the accumulated water inside the box is removed. Six shear plates are welded around each steel casing. One end of the shear plate is welded to the casing, and the other end is welded to the corresponding embedded parts on the prefabricated bottom plate as a whole. The weld seam is in the form of a corner weld, with a height of 10mm. Finally, a 5cm thick coarse sand cushion layer is laid between the beams and slabs of the bottom plate, and the cushion layer is poured with plain concrete once. The elevation of the cushion layer is the bottom elevation of the bearing platform, making the bottom plate flat as a whole. The embedded parts and shear plates of the bottom plate are completely buried in the cushion layer, and the bottom elevation is consistent with the design elevation of the bearing platform bottom.

4.2.7 Pile Head Treatment

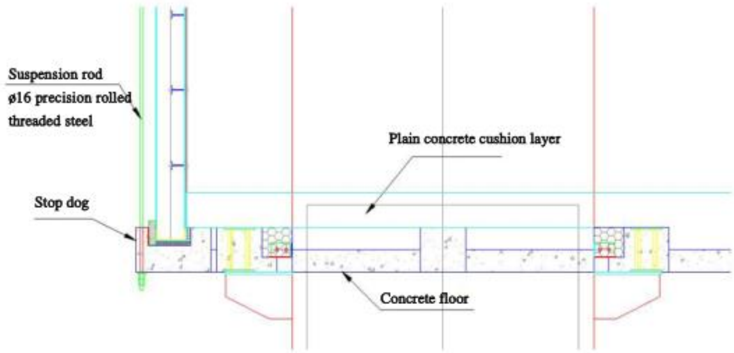
The measurement personnel determine the cutting elevation of the steel casing for the drilled pile, and the operators use an oxyacetylene flame cutting torch to cut off the upper casing according to the elevation line of the casing. The crane, in conjunction with a vibrating hammer, pulls out the casing.

After the casing is cut off, the construction of breaking the pile head is carried out. The measurement personnel mark the elevation of the cut off position at the pile head through measurement, and use manual cutting method to cut the concrete at the pile head. Use a pneumatic pick to chisel off the concrete at the pile head, peel off the main reinforcement and acoustic pipe at the pile head, and during the chiseling process, the pile head must not damage the concrete below the designed height of the pile head. The top part of the pile that extends into the bearing platform should be chiseled and cleaned thoroughly. After the pile head treatment is completed, the steel bars of the pile body that extend into the bearing platform will be cleaned and repaired into the design shape. The elevation of the pile top will be retested, and the steel bars of the pile head will be sorted out and subjected to cold bending treatment. Finally, proceed to the construction of the pier cap.

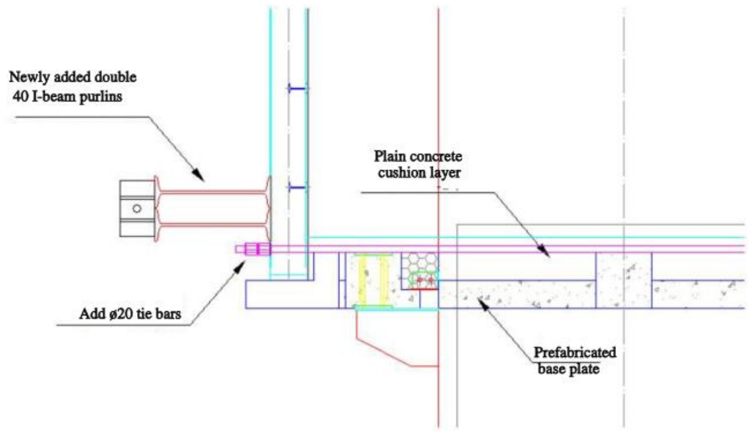
5. Optimization of Wall Panel Reinforcement Plan

In the original plan, the side wall panels were limited by blocks and fixed with vertical precision rolled threaded steel suspension rods. This plan requires high strength of the stopper, and the gap between the stopper and the side wall panel needs to be filled with wedges. When adjusting the suspension box, it is easy to crush the stopper, causing limit failure, and there is no good remedy, so the bottom plate can only be reworked and replaced. The side wall panel is placed in the groove inside the block, but the space is limited, and the relative position accuracy of the four bottom plates is required to be high. When the relative deviation between the four bottom plates is too much 5cm, it will be difficult to fix the side wall panel.

In response to this situation, the project has optimized the wall panel reinforcement plan. The optimization plan adopts a double construction 40a purlin, with a circle set 50cm away from the bottom of the pier, and ⌀20 tie bars (four in each direction) reinforced in the plain concrete cushion layer of the suspension box. At the same time, the stopper and precision rolled threaded steel suspension rod were removed, and the optimization plan is shown in Figure 11 before and after.



Before adjusting the plan (a)



After scheme adjustment (b)

Figure 11 Optimization diagram for adjusting the connection method between wall panels and bottom plates.

The original plan was to fix the side wall panels by limiting them with stop blocks, but now the method of adding diagonal braces with I-beams will not result in fixation failure; After removing the blocking block, the adjustable range of the side wall panel increases, making it easier to adjust the side wall panel; The original plan required the precision rolled threaded steel suspension rod to be fixed on the blocking block. When the blocking block was removed, the suspension rod was also removed. The function of the suspension rod was to fix the side wall panel and the bottom plate. Now, the reinforcement method with tie bars has also played a similar role. This optimization has improved the efficiency of construction.

6. Conclusion

The pier of the Binhai Interchange in the Ningbo Phase I project of the Hangzhou Ningbo double track is located in a strong tidal area. In order to effectively solve the problem of steel suspension box construction in tidal areas and accelerate construction efficiency, the steel concrete composite suspension box adopts the overall process of rear yard prefabrication and on-site assembly. The bottom plate of the steel-concrete composite suspension box adopts a precast concrete bottom plate, which is placed on the cow legs. After the sealing of the cofferdam is completed, the bearing platform construction can be carried out, greatly saving the amount of bottom sealing concrete and steel. To reduce the investment of large-scale water equipment, the bottom plate and wall of the steel-concrete composite suspension box are prefabricated in the back yard and assembled piece by piece on site. To improve the efficiency of assembling and dismantling steel-concrete composite suspension boxes, steel bars are used to reinforce the walls, which is easy to operate. Relying on the construction technology described in the article, the project has reduced construction risks and saved construction costs. Currently, most of the pier cap construction has been successfully completed.

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