Reinforcement Design and Physical Testing of New and Old Cushion Cap of Existing Bridge

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Abstract. As an important part of bridge structure, pile cap plays an important role in its operation. There is a lack of sufficient research in the design and construction of the existing bridges, especially in the operation process of the river crossing bridge, there will be more security risks, so it is urgent to strengthen the bearing platform. Combined with the general design theory of bridge cap, considering the feasibility of construction and the difficulty of operation, the new and old caps are planted with steel bars to make them bear the common force. Aiming at the problem of insufficient bearing capacity, the cap reinforcement method is proposed, so as to improve the stability of the bridge. The research results can provide reference for similar bridge reinforcement projects in the future.

Keywords: Bridge cap, Design reinforcement, Planting steel bar.

1. Introduction
In the construction of bridge, when the river bed water and groundwater rich environment are encountered, the construction progress of pile cap is usually hindered, especially the construction of pile cap in water is a more difficult link in bridge construction, which affects the progress and quality of the project [1]. As an important part of the bridge, the bearing platform should be studied and analyzed in the design and construction. Based on the engineering example of Dongming Yellow River Highway Bridge, this paper analyzes the construction difficulties of the bearing platform of the bridge, formulates a reasonable construction scheme, puts forward a relatively perfect construction process and reinforcement technology, adds a new bearing platform on the basis of the old bearing platform, and plants steel bars on its contact surface, so that the new and old bearing platforms can bear the force together. Therefore, through the research and analysis of the reinforcement technology, a set of theoretical results that can be applied in practical engineering are put forward.

2. Project overview
Dongming Yellow River Highway Bridge is located on the Yellow River between Dongming County of Shandong Province and Puyang City of Henan Province. The main bridge adopts prestressed concrete continuous rigid frame continuous beam composite structure. The four main piers adopt...
double thin-walled pier body, the pier beam is consolidated, and the other piers are thin-walled hollow piers. The width of the bottom plate of the variable section box girder of the main bridge is 9m, the height of the beam at the fulcrum is 6.5m, and the height of the middle span is 2.6m. A total of 16 new caps are added to the project, including 8 new and old caps.

![Figure 1. Bridge structure in its original state.](image1)

3. **Organization of the Text**

**Design of steel sheet pile cofferdam**

3.1. **Determination of steel sheet pile length**

The use of steel sheet pile cofferdam is conducive to the excavation of foundation pit and the safety and quality of the project. However, due to the influence of geological conditions, groundwater level and other factors, the selection and use of steel sheet pile need certain research and analysis, which is very important for the preparation of steel sheet pile. According to the environmental conditions of the site, through calculation and analysis, the length of steel sheet pile used in this project is 18m.

3.2. **Construction method of steel sheet pile cofferdam**

(1) Construction preparation

When the drilling rig is evacuated after the construction of bored pile of main pier, the existing steel casing can be used as the working platform of steel sheet pile [2-3]; At the same time, the materials should be processed according to the design of supporting facilities. The supporting system materials of main pier cap cofferdam include double leg hm500, hm700 steel, 630mm × 10mm steel pipe pile, steel plate, etc.

![Figure 2. Vertical layout of cofferdam.](image2)
(2) Measurement and positioning
Firstly, the section steel to be welded is installed on the steel casing. According to the side line of the pile cap set out and positioned, it is used as the control line for the construction of steel sheet pile, so that the steel sheet pile can be kept vertical and driven one by one.

(3) Steel sheet pile construction
During the construction of steel sheet pile, the pile driver and driving method should be selected to ensure that the steel sheet pile has sufficient stability and waterproof performance, so as to meet the requirements of foundation construction to the greatest extent.

(4) Construction of closure section
When the steel sheet pile cofferdam is closed, the steel sheet pile on one side of the corner should be inserted first, and the requirements of welding at the right angle should be met. During the construction of the closure section on the other side, a certain space should be reserved, and the subsequent steel sheet piles should be inserted first and then driven, and the construction of the closure section should be completed after reaching the design depth.

4. Power frequency monitoring of foundation pit excavation and visual construction

4.1. Foundation pit excavation
According to the geological map and site geological conditions, the excavation method of the foundation pit is proposed to adopt dry excavation method, and the soil below the riverbed surface needs to be pumped out from the cofferdam by mud pump [4].

(1) After the completion of Larsen pile cofferdam, the water will be pumped. When the water level in the cofferdam is about 50cm below the bottom elevation of purlin, the purlin and support will be installed. The thickness of concrete cushion and bottom sealing concrete is 1.0m (the thickness can be adjusted according to the geological conditions of the base), and two supports are arranged.

(2) Fabrication and installation of purlin: according to the design, the welding construction of purlin bracket is carried out at the specified position of steel sheet pile, and then the 500 × 300 double H-beam is reinforced. The support adopts 630mm diameter and 10mm wall thickness steel pipe, and the support is set at one side of the original pier body and bearing platform.

During the construction of foundation pit, the excavation of soil should be carried out in layers, and the installation of support should be closely combined. When the support system has enough stiffness, the foundation pit can maintain relative stability. In order to ensure the safety of construction, over excavation is strictly prohibited.

4.2. Construction monitoring of steel sheet pile cofferdam
During the construction monitoring, it is mainly through the monitoring to sort out and analyze the stress, deformation and other indicators of the enclosure structure, and then compare with the results of theoretical calculation [5]:

(1) By comparing the measured data with the theoretical values, the results are evaluated scientifically;
(2) The reliability of the structure is evaluated by analyzing the relative difference between the measured data and the theoretical value;
(3) According to the monitoring results, the corresponding early warning mechanism can be established, so as to ensure the stability of sufficient strength in the process of foundation pit excavation and meet the safety of construction.

4.3. Quality control of steel sheet pile cofferdam
In order to ensure the quality of steel sheet pile cofferdam, it is necessary to calculate the structure of steel sheet pile cofferdam. The main parameters are as follows.

(1) Steel sheet pile cofferdam size: 35.2m × 17.2m;
(2) The technical parameters of Larsen IV steel sheet pile are as follows:
Table 1. Technical parameters of steel sheet pile.

| Width | Thickness | Unit weight | Bending modulus |
|-------|-----------|-------------|-----------------|
| 400mm | 155mm     | 77kg/m      | 2037cm³         |

(3) According to the geological exploration data, the physical characteristics of the soil are as follows: \( \gamma_1 = 19.9\text{kn/m}^3 \), \( \varphi = 40.4^\circ \), \( c = 29.8\text{kpa} \). Coefficient of active earth pressure:

\[
K_{al} = \tan^2\left(45^\circ - \varphi/2\right) = 0.21
\]

Coefficient of passive earth pressure:

\[
K_{pl} = \tan^2\left(45^\circ + \varphi/2\right) = 4.68
\]

According to \( \varphi = 40.4^\circ \), the correction coefficient of passive earth pressure is 2.0 [6].

4.4. Checking calculation of steel sheet pile cofferdam

The steel sheet pile is checked and calculated (according to the actual working conditions), and the foundation pit is excavated after the cofferdam construction adopts the installation support.

Case 1: when the foundation pit is lowered to 50cm below the second support, the first support is the most unfavorable stress state

Calculate the position of the reverse bending point: (the force on the steel sheet pile is 0, and the force on the periphery of the steel sheet pile is equal to the passive earth pressure).

External force:

\[
P_2 = P_1 + P_2 = 15.2 + 44.5 = 59.7\text{kpa}
\]

\[
P_1 = K \times H \times V \times B \gamma / 2g
\]

Where, \( P \) denotes Total hydrodynamic pressure per linear meter of plate wall, KN; \( H \) denotes The water depth (m) is 63.61 - 57 = 6.61m during construction; \( V \) denotes The average velocity of water flow (M / s) is 1.5m/s; \( g \) denotes Acceleration of gravity(9.8m/s²); \( B \) denotes Width of sheet pile (Take 1 meter); \( \gamma \) denotes Bulk density of water (KN/m³); \( K \) denotes coefficient (1.8 - 2.0); \( P_1 = 2 \times 6.61 \times 1.52 \times 1 \times 10 / 2 \times 9.8 = 15.2\text{KN} \).

Hydrodynamic pressure can be assumed as the concentrated force acting on 1 / 3 of the water depth below the water surface [7].
Hydrostatic pressure:

\[ P_2 = 10 \times 4.45 = 44.5 \text{kpa}; \gamma = \frac{P_0}{\gamma(KK_p - K_a)} = \frac{59.7}{19.9 \times (2.0 \times 4.68 - 0.21)} = 0.33m \]  

Case 2: when the excavation reaches the bottom of the foundation pit, the stress of the second support is in the most unfavorable state

Calculate the position of the reverse bending point: (the force on the steel sheet pile is 0, and the force on the periphery of the steel sheet pile is equal to the passive earth pressure).

External force:

\[ P_0 = P_1 + P_2 + E = 15.2 + 72 + 1.3 = 88.5 \text{kpa} \]  

Hydrostatic pressure:

\[ P_2 = 10 \times 7.2 = 72 \text{kpa} \]  

Active earth pressure:

\[ E = \gamma \frac{t}{2} (45 - \phi / 2) - 2ctg(45 - \phi / 2) = 19.9 \times 0.212 \times 0.5 + 2 \times 2 \times 0.21 = 1.3 \text{kpa} \]  

(2) Determination of penetration depth of steel sheet pile below zero point:

According to the principle of equivalent beam method, the support reaction and earth pressure can be established

\[ x = \sqrt{6P_0 / \gamma(KK_p - K_a)} = \sqrt{6 \times 88.99 / 19.9 \times (2.0 \times 4.68 - 0.21)} = 1.71 \text{m} \]  

Penetration depth \( h \) of steel sheet pile:

\[ L = 1.1 \times (x + 1.71) = 2.42 \text{m} \]  

The actual penetration depth of steel sheet pile is 2.42M. According to the calculation, the required penetration depth is 9.48m, which meets the requirements.

Strength calculation of steel sheet pile: it can be seen from the above calculation

\[ M_{\text{max}} = 66.6 \text{KN} \cdot \text{m}; \]

\[ \sigma = \frac{M_{\text{max}}}{W} = \frac{66.6 \times 10^3}{2037 \times 10^6} = 32.7 \text{N/mm}^2 < 310 \text{N/mm}^2 \]  

Through the above calculation, the strength of steel sheet pile can meet the requirements.
5. Pile cap construction

5.1. Foundation pit excavation of pile cap (construction of pile cap on land)
(1) In the excavation of foundation pit, we should pay attention to the relationship between the depth of water level and the elevation of pit bottom. When the construction water level of the bearing platform is high, certain drainage measures should be taken. After the excavation of the foundation pit, a certain thickness of underwater bottom sealing concrete can be laid, and a large well or sump can be set around the foundation pit, and it can be discharged out of the designated drainage outlet outside the construction scope of the foundation pit by a pump.

(2) In order to prevent the recharge of surface water, a certain slope can be set on the ground around the foundation pit, and a drainage ditch can be excavated at a certain distance from the pit wall.

(3) The depth of foundation pit is usually determined by the pile cap. In this project, the buried depth of the bearing platform is shallow, but the soil condition is relatively general. In order to ensure the safety of foundation pit construction, I-beam support method should be adopted in slope construction. For the section with good soil quality, the slope excavation can be carried out directly according to a certain slope.

5.2. Pile head treatment
After the pouring of the bottom sealing concrete of the main pier bearing platform (the land bearing platform is the cushion), its strength shall reach 90%, and then the concrete at the pile head shall be chiseled out, and the redundant reinforcement shall be cut off. However, during the construction, it is necessary to ensure the safety of the pile body concrete and the main reinforcement, so that the pile foundation and the bearing platform have a good connection, so as to meet the stability of the overall structure.

5.3. Concrete pouring
When pouring the bearing platform, steel pipe and steel formwork shall be used for reinforcement and support. The first concrete pouring is 1.5m to connect with the old bearing platform. The pouring is divided into five times, with the thickness of 0.3m each time; Second new small cap is poured, and 20cm thick foam board is attached to the side formwork of the old pile cap for post cast steel bar reinforcement. It should be noted that the pressure relief hole should be set in the bearing platform during the first pouring to prevent the cracking caused by concrete shrinkage and creep, so as to effectively ensure the connection performance of the new and old bearing platforms.

5.4. Cofferdam Demolition
After the construction of the bearing platform is completed, certain maintenance shall be carried out. The gap between the steel sheet pile and the bearing platform shall be filled with permeable materials, and the height of the original riverbed shall be ensured. After that, the construction of pier body and other superstructure shall be continued. When the pier body is out of the water, it shall be demolished at the same time of backwater until the backwater is level with the water level outside the cofferdam.

(1) When the steel sheet pile is removed, it is easy to pull out the adjacent sheet pile at the same time. In order to effectively avoid this situation, the steel purlin and steel sheet pile used for support can be removed one by one.

(2) When the steel sheet pile is difficult to be removed, it can be driven again by vibrating hammer, which can overcome the soil adhesion to a certain extent.

(3) The soil and sand shall be removed immediately for the steel sheet pile pulled out. The sheet pile with large deformation needs to be straightened and transported to the ground outside the site after treatment.
6. Main risks and Countermeasures of pile cap construction

At present, the pile cap is mainly reinforced by increasing the prestress and the cross-sectional area in China [8]. As the main component of the bridge substructure, the bearing platform usually causes structural diseases under the impact of huge traffic flow. In this case, it is necessary to take reinforcement measures for the bridge bearing platform [9-10].

Taking the reinforcement of Dongming Yellow River Bridge as an example, this paper analyzes the design and construction key technologies of the bearing platform, and puts forward some solutions for the construction difficulties of the bearing platform: when the pouring of the new and old bearing platform is completed, the temporary support will not be removed temporarily, the new bearing platform on both sides and the thickened 1.5m concrete at the bottom of the old bearing platform will be constructed first, and then the 1m wide post pouring belt will be left at the joint of the new and old bearing platform. After the pile foundation reinforcement is completed, it will be connected with the old pile cap. In order to ensure the connection between the thickened part and the old bearing platform, a grouting pipe is reserved at the top of the new part for post grouting to fill the gap. Because the new bearing platform needs to be connected with the old one to bear the force together, the design and construction optimization of the new and old bearing platform has become the research focus.

![Figure 4. Connection of new and old pile caps.](image)

7. Conclusions

At present, there is a lack of norms on the reinforcement and maintenance of the bearing platform in China, and the research on the reinforcement method of the river crossing bridge is less, which is difficult to meet the needs of the actual project, and the bearing platform plays a connecting role in the bridge structure. Therefore, this paper studies the reinforcement method of the bridge bearing platform combined with the actual project case, and obtains the following conclusions:

1. This paper elaborates the process of foundation pit excavation and pile cap pouring, and puts forward corresponding countermeasures for the difficulties of pile cap reinforcement.
2. Based on the calculation of the mechanical characteristics of the steel cofferdam structure, it shows that the support strength of the steel cofferdam can ensure the safety and stability of the pile cap to a certain extent.
3. By planting steel bars on the old bearing platform, pouring 1.5m thick concrete under the old bearing platform and setting circumferential prestressed steel tendons, the new and old bearing platforms are effectively connected and stressed together, and the feasibility of reinforcement design and construction technology is verified.
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