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Application of external prestressing combined with enlarged section method to reinforce T-beam of approach bridge to reduce seawater corrosion

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ABSTRACT

Based on the analysis of the causes of corrosion and damage on the superstructure of the port T-beam bridge, the measures of chiseling out the damaged concrete at the bottom of the beam and removing the failed reinforcement in the lower layer are taken for the most seriously damaged D-level T-beam, so as to achieve the ideal repairing effect. However, the reduction of the beam height and reinforcement will reduce the bending capacity of the T-beam, while the unbonded steel strand body is used the external prestressing reinforcement method can solve the safety and stability problem of the long-span T-beam during the reinforcement construction period. The reinforcement method with enlarged section can improve the bearing capacity of the T-beam during the operation period to meet the functional requirements, and the joint application of the two reinforcement methods complement each other. The engineering practice shows that the combined reinforcement method is reasonable and effective. It can provide a new way for similar projects.

Keywords: External prestressing method; Enlarged section method; Reinforcement; T-beam of approach bridge

1. Introduction

The reinforced concrete structure T-beam bridge is a commonly used type of bridge structure. Because of its strong structural spanning ability, it is widely used in the superstructure of the approach bridge in port engineering. Most of the large ports are seaports, their hydraulic structures are often corroded and damaged by the chloride ions and other media in the seawater, which seriously affects the use and safe operation of the structures. Repairing and strengthening structures is an effective way to extend the service life and improve the capacity. It has the characteristics of short cycle, saving money and convenient construction [1,2].

At present, the reinforcement methods for reinforced concrete beams of port hydraulic structures are divided into passive reinforcement technology and active reinforcement technology [3]. The passive reinforcement technology mainly includes enlarged section reinforcement method, pasted steel plate reinforcement method and pasted carbon fiber reinforcement method et al. The active reinforcement technology mainly includes unbonded steel strand external prestressed reinforcement method and prestressed carbon fiber board reinforcement method et al. The traditional enlarged section reinforcement method can improve its bearing capacity and stiffness by increasing the cross-sectional area of the original component or adding reinforcement bars. It is a mature technology that is widely adopted and effective. However, since the reinforcement will increase the weight of the component, directly using it to reinforce the severely damaged long-span T-beam will have adverse effects. First of all, the safety problem of bearing capacity during construction period should be solved, so the single use of enlarged cross-section reinforcement method often cannot achieve the reinforcement goal well. In contrast, the reinforced components of the external prestressed reinforcement method can not only withstand

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the added dead load and live load, but also withstand the dead load of the original structure. It can even change the internal force distribution and force system of the original structure as required [4,5]. Therefore, the external prestressing reinforcement method can be used to make up for the shortcomings of the enlarged section reinforcement method.

This paper takes the quay approach bridge of Ningbo Port Phase II as the research object. According to the site investigation of the damage of the T-beam of the upper structure of the approach bridge, the causes of the damage are analyzed, and the method of external prestressing combined with enlarged section method is proposed for the most seriously damaged D-level T-beam. The engineering practice shows the rationality and effectiveness of the combined reinforcement method.

2. Project overview

The project is located on the south bank of Jintang Waterway outside Ningbo Yongjiang Estuary, on the east side of Beilun Mountain. It was built from 1989 to 1992. The dock platform is connected to the rear land area through five approach bridges, and the elevation of the approach bridge deck is 7.00 m (Wusong elevation, the same below). The approach bridge structures are all high-pile beam slab structures, each with a length of more than 400 m and a width of 14 m. Each approach bridge has 18–20 bents, and the prestressed concrete square piles of 600 mm × 600 mm are used in the pile foundation under the bent frame. The approach bridge piers are cast-in-place inverted T-beams, on which 6 T-beams are placed. The height of the precast prestressed concrete core rod T-beam is 2.2 m and the width is 1.5 m. The maximum span of the beam is 28 m and the wear layer of cast-in-place concrete deck on T-beam is 100 mm thick. The section of approach bridge as shown in Fig. 1 (The unit of dimension is mm and the unit of elevation is m).

3. Damaged condition of T-beam

According to Li [6], the on-site investigation of the approach bridge found that the T-beams were seriously damaged, and the main types of damage to the core rod were concrete hollowing, cracking, rusting and exposed rebars etc. In terms of core rod position, the hollowing mostly occurred on its bottom surface, the cracking occurred on the lower edge and bottom of its side, which was mainly caused by rebar corrosion along the tendon cracking, the rusting occurred at the cracks on the bottom of both ends, the partially exposed rebars generally occurred on the underside and the area was mostly 0.1 m × 0.1 m to 0.2 m × 0.2 m. Typical damage types of T-beams are shown in Figs. 2 and 3.

In order to evaluate the damage degree of the T-beams of the approach bridge and provide a basis for repair and

Fig. 2. Exposed T-beams.

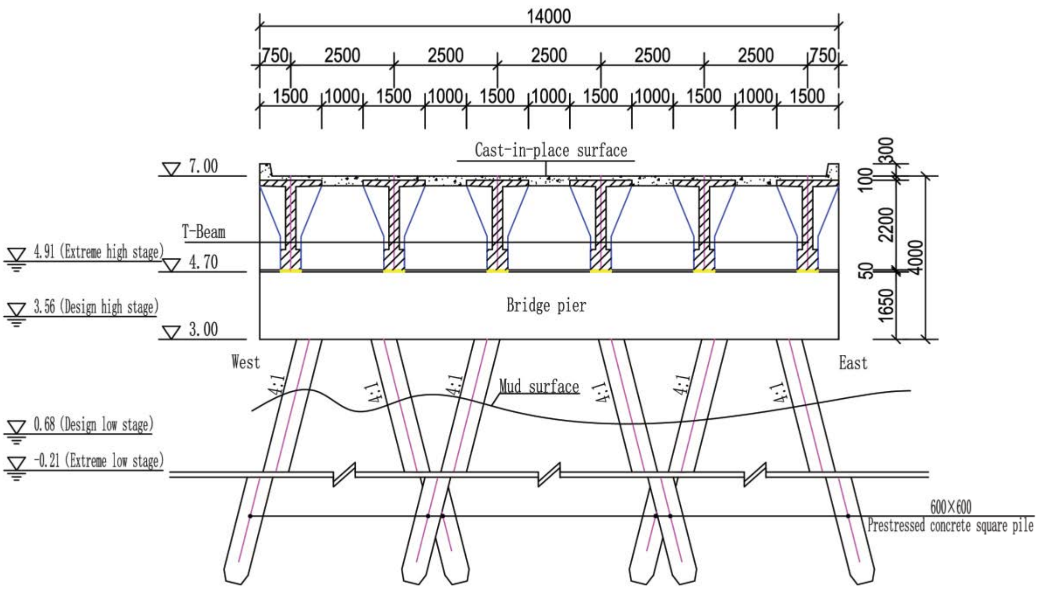

Fig. 1. Cross-section view of approach bridge structure.

reinforcement, based on relevant research and regulations, as well as the appearance of damage, the appearance deterioration degree of T-beams is evaluated as four levels (Level A, B, C, D) [7,8]. Among the T-beams of B-level accounts for 12%, C-level accounts for 78% and D-level accounts for 10%.

4. Causes of T-beam damage

In order to analyze the reasons for the damage of the T-beam, further tests were carried out on parameters such as concrete strength, protective layer thickness, chloride ion content, carbonization depth and rebar corrosion potential [6]. The results showed that the concrete strength of the T-beam was between 50.0 and 54.0 MPa, which met the strength requirements of designed 400# concrete. The average carbonization depth was 2.5–4.5 mm, which was far less than the thickness of the rebar protection layer. The thickness of the side protective layer met the specification requirements, however, the average value of thickness of the bottom protective layer was lower than the design value, which did not meet the design and specification requirements. The chloride ion concentration around the rebars at most measuring points exceeded 0.059%–0.107% (in percentage of concrete mass), the rebars were more likely to be corroded. The loss rate of the main rebar section at the damaged place was 13.1%–51.2%, the corrosion shrinkage of rebar was obvious. Considering that the corrosion damage of T-beams was mainly caused by the thin rebar protection layer and chloride ion corrosion, and the loss of local rebar section of some T-beams had exceeded 10%, which would cause prestress loss. According to the different severity of T-beam damage, in order to ensure the safety and durability of approach bridge operation, corresponding repair and reinforcement measures were proposed. For the B-level and C-level T beams, a repair scheme using local and sacrificial anodes combined protection was proposed, so as to improve its structural durability. The following focuses on the analysis of the D-level T-beam and the corresponding repair and reinforcement scheme is proposed.

Fig. 3. Hollowing and cracking of T-beams.

5. Repair and reinforcement technology of D-level T-beam

5.1. Overview of the original design of the core rod at the bottom of the T-beam

The prestressed concrete core rod at the bottom of the T-beam is the main force-bearing part of the large-span simply supported structure. According to the completion data of the approach bridge and on-site inspection results, the core rod is made of 400# concrete, the longitudinally stressed rebars are made of 12C^{1}25 prestressed rebars and 3Φ25 + 2Φ28 ordinary rebars. It is arranged in four layers and the cross-sectional area of the lowermost layer of the core rod accounts for about 40% of the total area. The section of prestressed concrete core rod of T-beam is shown in the shaded part in Fig. 4.

5.2. Reinforcement plan for core rod at the bottom of the T-beam

In order to achieve a better repair effect, it is necessary to remove the damaged concrete caused by environmental corrosion at the bottom of the beam and remove the failed lower rebar. The section of the bottom of the T-beam after 120 mm is partially cut off is shown in Fig. 5, and the shaded part is the remaining section of the core rod.

As the effective height of the T-beam section and the section area of the longitudinal rebar in the tension zone were reduced, the bearing capacity was decreased. In addition, the repair also required a construction platform. Due to the limitation of site conditions, the construction platform could only be installed on the T-beam by the reverse lifting method and its load is borne by the remaining section of the T-beam. Through the review calculation, the maximum bending moment of normal section of is designed to be 3,672 kN·m, and the flexural bearing capacity of normal section is designed to be 3,960 kN·m. There is not much surplus in the flexural bearing capacity of normal section of the T-beam at this time.

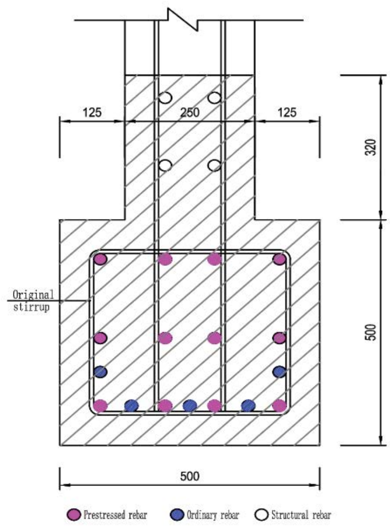

Fig. 4. Cross-section view of prestressed concrete core rod of T-beam (mm).

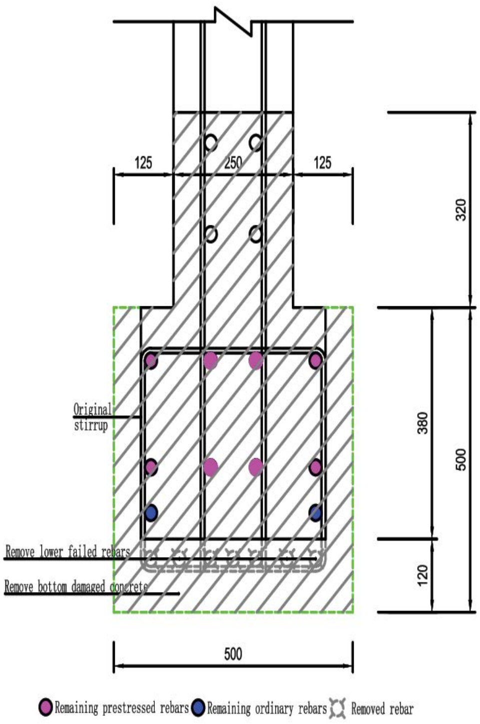

Fig. 5. Residual cross-sectional view of the T-beam after removing the damaged concrete (mm).

Since most of the rebars removed from the lower layer were prestressed rebars, the rebars added for repair and reinforcement were ordinary rebars. Therefore, the amount of rebars increased and the cross-section needed to be enlarged. Before the newly added rebars reached the design strength, it did not form the whole of common forces with the original section, instead of becoming the additional load borne by the remaining section of the T-beam. By rechecking and calculating, the results showed that the T-beam with reduced beam height and rebars could not meet the bearing capacity requirements when the cross section was enlarged during the construction period. In order to solve the safety problem of the bearing capacity of the T-beam during the construction period, firstly, the T-beam was reinforced by external prestressing of unbonded steel strands, then the concrete under the beam and the rebar were removed. The external unbonded steel strand adopted a straight line and was arranged in the range of 16.5 m in the middle of the T-beam. There were 4 single-layer unbonded epoxy sprayed steel strands (UPS15.20) on both sides of the core rod, and adopted anchor block and the supporting block node of reinforced concrete to connect and fix with the core rod. In order to shorten the construction period, in addition to the small amount of anchor blocks and supporting blocks, the concrete was reinforced with high-strength structure grouting material. The site was stretched while the joint concrete strength reached the design strength, reached the standard value of tensile strength of the steel strand f_{ptk} = 1,860 MPa, and the tension control stress σ_{con} = 930 MPa (0.5 f_{ptk}). The external prestressed steel strand layout of the T-beam is shown in Fig. 6.

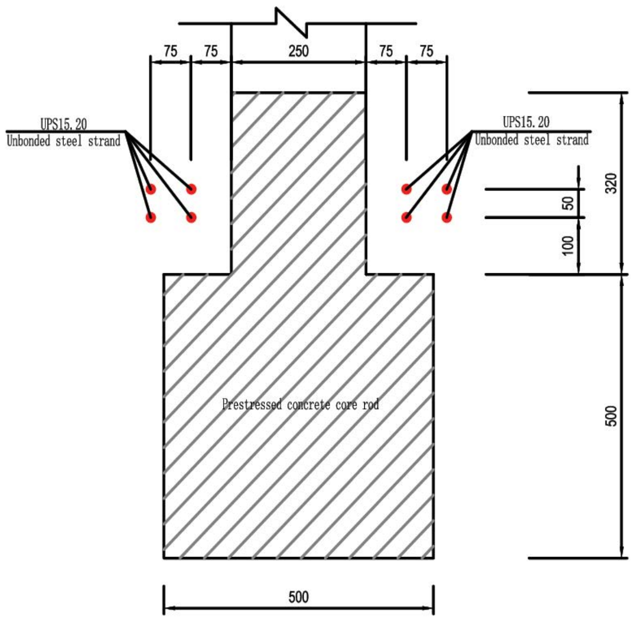

Fig. 6. External prestressed steel strand layout drawing of T-beam (mm).

The design value of the maximum bending moment during the construction of T-beam is 4,913 kN·m, the design value of flexural bearing capacity of the normal section before external prestressing reinforcement is 3,960 kN·m, and that of the normal section after external prestressing reinforcement is 6,450 kN·m. The bearing capacity and safety during the construction period reinforced by external prestressing meet the requirements of the specification.

Since the unbonded steel strand is outside the T-beam, prestress was applied to the original beam concrete only through the anchor block. The steel strands between the supporting blocks were not constrained and could produce deformation and vibration independent of the beam, which was easy to cause prestress loss [9]. The frequent passage of vehicles on the approach bridge could also adversely affect the safe use of the external prestressing system. The external load during the use period of the approach bridge in this project was mainly TR-60 container trailer load. In order to ensure the safety of the approach bridge, it was considered that the remaining tension zone and the enlarged cross-section of the T-beam bore the vehicle load, and the increased bearing capacity of the external prestress as a safety reserve. The reinforced section is shown in Fig. 7. The rectangular section of the T-beam core rod was increased from the original 500 mm × 500 mm to 800 mm × 850 mm (The beam height was increased by 100 mm). To ensure construction quality and structural durability, the concrete of the enlarged section adopted self-compacting and high-performance C45 concrete, and added 22Φ25 longitudinal stressed rebars. The new and old concrete were connected by planting bars. The maximum bending moment of normal section of the T-beam reinforced by the enlarged section method is designed to be 10,116 kN·m, and the flexural bearing capacity of normal section is designed to be 15,130 kN·m.

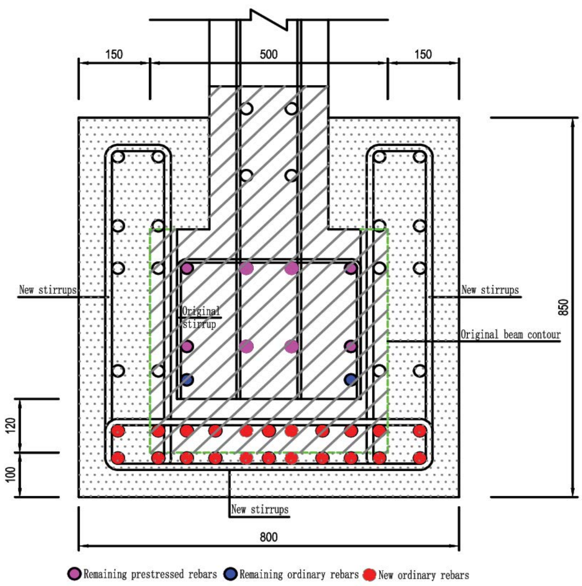

Fig. 7. Sectional view of T-beam after enlarged section reinforcement.

At present, the repair and reinforcement of two of the approach bridges have been completed and are in operation.

The Ningbo Port Phase II Wharf has repaired and reinforced 5 shore approach bridges. The first to be completed was 1# approach bridge, which adopted the scheme to update the upper beam and slab structure. The project cost was about 25 million yuan and the construction period was about 6 months. The 2#~5# approach bridge adopted the scheme of repairing and reinforcing the damaged structure after the scheme was demonstrated. The project cost was about 20 million yuan and the total construction period was about 9 months. In comparison, demolition and reconstruction requires a large investment and a long construction period, while the opposite for repair and reinforcement. Therefore, through repair and reinforcement, limited investment can be exchanged for safe operation of the approach bridge and significant economic benefits.

6. Conclusion

This paper analyzes the causes of corrosion and damage to the T-beams of the superstructure of the approach bridge in Ningbo Port Phase II. On the basis of existing repair and reinforcement methods, for the most severely damaged D-level T-beam, a method of external prestressing combined with enlarged section reinforcement is proposed from different working conditions in the construction and process. The implementation effect proves the rationality and effectiveness of the joint reinforcement method. The main conclusions are as follows.

- The corrosion damage of T-beams is mainly caused by the thin rebar protection layer and chloride ion corrosion, and the loss of local rebar section of some T-beams has exceeded 10%. In addition, the corrosion of rebars will also cause loss of prestress and aggravate the development of cracks, which is not conducive to the safe use of T-beams.
- The T-beam is seriously damaged and the damage types of the core rod mainly include concrete hollowing, cracking, rusting, and exposed rebars et al. It mostly occurs on the lower edge and bottom surface of the core rod side of the main force-bearing part, which has affected the use and safe operation of the approach bridge. Repair and reinforcement measures should be taken as soon as possible.
- In order to achieve ideal restoration effect, it is necessary to remove the damaged concrete caused by environmental corrosion at the bottom of the beam and remove the failed lower rebar. However, the T-beam with reduced beam height and rebar has been unable to meet the requirements for bearing capacity when the cross-section is enlarged during construction, the use of external prestressed reinforcement method of unbonded steel strand can effectively solve this problem.
- To ensure the safety of the approach bridge, in view of the engineering characteristics, it is considered that the remaining tension zone and the enlarged cross-section of the T-beam bear the vehicle load, and the increased bearing capacity of the external prestress as a safety reserve. So that the functional requirements are met and the reinforcement goal is well achieved. At present, the repair and reinforcement of two of the approach bridges have been completed and are in operation.
- Through the repair and reinforcement of 5 shore connecting approach bridges in Ningbo Port Phase II, the safe operation of the approach bridge is ensured and the economic benefits are remarkable.

Acknowledgments

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