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STUDY ON PIER-BEAM COUPLING STRUCTURE OF STEEL TRUSS-CONCRETE CONTINUOUS RIGID FRAME COMBINED BRIDGE

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Abstract: Three pier-beam coupling schemes applicable to the steel truss-concrete composite continuous rigid-frame bridge with super large-span, large-span, and middle-span have been introduced in this article respectively. These three pier-beam coupling structures have been analyzed in two aspects of transmitting force performance and construction technology. The results show that it can be a reference extended to design other bridges with the same type.

Keywords: continuous rigid frame combined bridge, pier-beam coupling structure, transmission force performance, construction.

I. INTRODUCTION

Composite structure is defined by two or more components made of different materials. The different materials work with each other by shear connectors. The goal of combination is to cost saving, reliable performances and construction convenience. Steel truss-concrete continuous rigid frame combined bridge combines steel truss-concrete composite continuous beam bridge with traditional prestressed concrete continuous rigid frame bridge. It is a new type of bridge structure.

II. THE CHARACTERISTIC OF STEEL TRUSS-CONCRETE CONTINUOUS RIGID FRAME COMBINED BRIDGE

The steel truss-concrete continuous rigid frame combined bridge can make full use of steel and concrete compared with traditional prestressed concrete continuous rigid frame bridge. It significantly reduce the weight superstructure and detrimental impact of earthquake. Truss grider can reduce member section dimensions. Both carriageway slab and substructure are made of concrete, the combined bridge reduces the amount of steel and construction costs compared with steel structure, which benefit to strengthen the fire prevention and durability. On the other hand, the combined bridge own high stability in the absence of support. But the key issue of design and construction is how to ensure the deck loads can transfer to bridge pier effectively. One of the main differences between the steel truss-concrete continuous rigid frame combined bridge and traditional prestressed concrete continuous rigid frame bridge construction process and techniques of pier-beam coupling structure. It must be required to the destroy of pier-beam coupling structure lag behind the main grider and bridge pier for guaranteeing safe. So the pier-beam coupling structure must be strong, and it own good durability and ductility for resisting effects of temperature changing and earthquake. It is easy to transmit axial forces and shearing forces for the pier-beam coupling structure, while the key question is how to ensure the moment transfer to bridge pier.

III. THE SCHEMES OF PIER-BEAM COUPLING STRUCTURE

A. *The channel steel anchorage*

The channel steel anchorage is designed for super large-span steel truss-concrete continuous rigid frame combined bridge, as shown in Fig.1. It is mainly made up of two channels of back-to-back web, which are welded to the pier top perpendicular to the bottom chord bar and allow 5cm gap. The end of pre-stressing tendon is embedded in the top of bridge pier, the other end thread puts on from the reservation crevices between the channel. Reinforcing welded wire mesh was set in the bridge at the bottom of pre-stressing tendon. The top of pre-stressing tendon will be bolted to the top of channel via anchoring part after imposed on the steel truss of prestress. The channel, pre-stressing tendon and the upper anchord end are buried in the concrete completely. Post-pouring concrete at the top of bridge pier play a dual role of resisting the loads and protecting coupling structure.

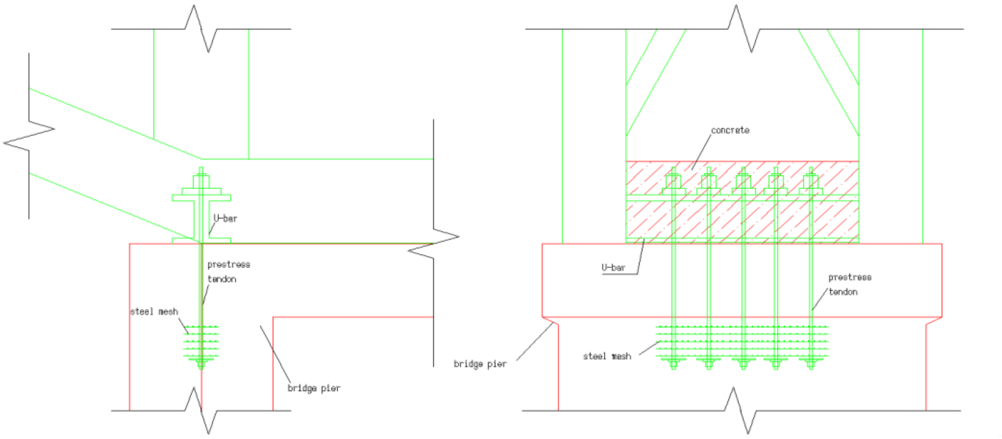

Figure 1: the structural diagram of the channel steel anchorage

B. The embedded corbel anchorage

The embedded corbel anchorage is designed for large-span steel truss-concrete continuous rigid frame combined bridge, as shown in Fig.2. The pier-beam coupling structure in the embedded corbel anchorage is reduced to the node of bottom chord bar at the top of pier. Each node of anchorage assigns two vertical pre-stressing bars. The lower end and reinforcing welded wire mesh are embedded in inside of pier. Slotted on the top of pier act as embedding positions of the corbel anchorage, the corbel is inserted into slotted on the top of pier to make the elevation of bottom chord and the top of prier consistent when the steel truss is building. The prestressing tendon thread puts on from the reservation hole at the corbel and is anchored after making precise positioning for transferring the vertical force. Pouring the concrete to the provided groove after applying epoxy resin for anticorrosion treatment on the anchor end.

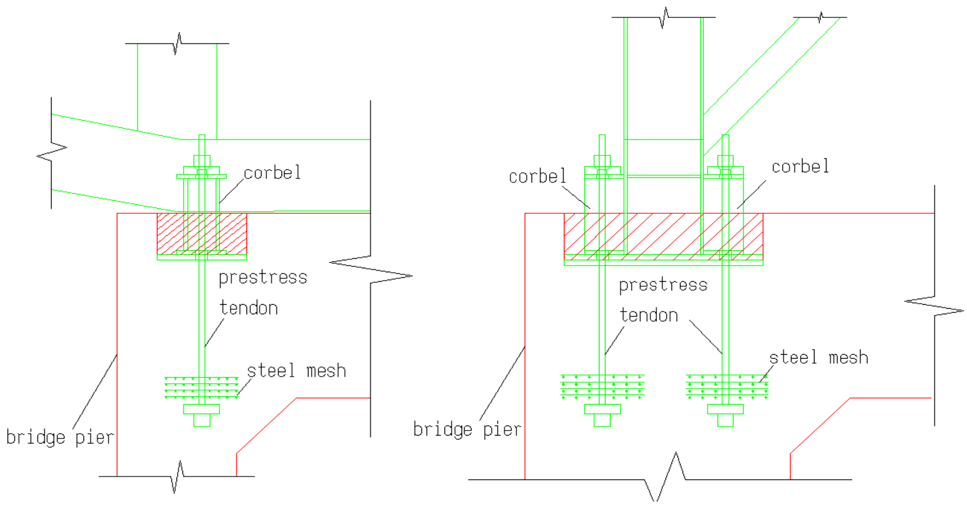

Figure 2: the structural diagram of the embedded corbel anchorage

C. The preserved embedded anchorage

The preserved embedded anchorage is designed for large-span steel truss-concrete continuous rigid frame combined bridge, as shown in Fig.3.

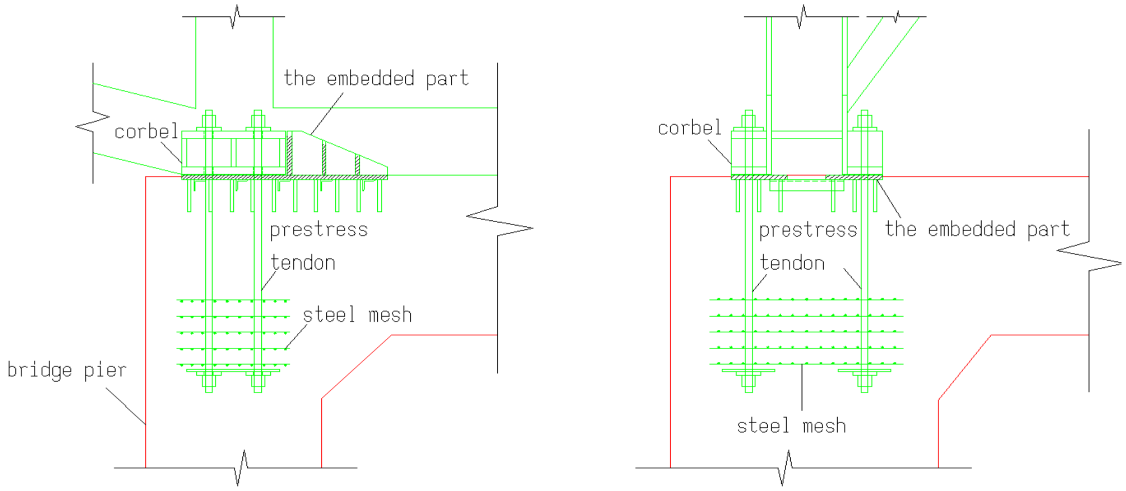

Figure 3: the structural diagram of the preserved embedded anchorage

It is improves from the embedded corbel anchorage.The design of the level of power transmission components is the most important difference between the preserved embedded anchorage and the embedded corbel anchorage. The new design reduce the height of corbel and make the elevation of bottom corbel and the bottom chord bar, which avoid assign reserved notch at the top of pier. The design of prestressing tendon has no change. The preserved embedded anchorage add buried parts in advance ,which can resist vertical and horizontal force. The buried parts in advance is the main stress components in the preserved embedded anchorage.The structure of the buried parts in advance as shown in Fig.4.

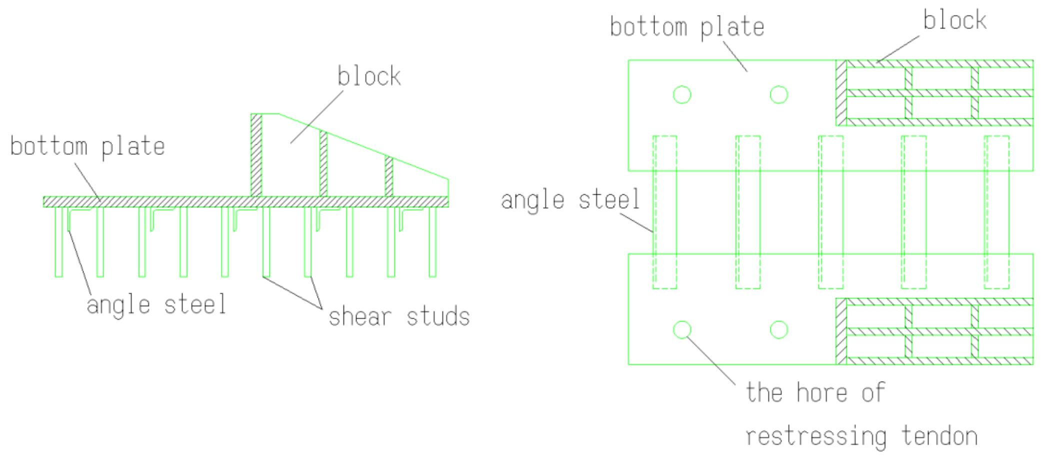

Figure 4: the structural diagram of the buried parts in advance

The buried parts in advance is a global stress component which is welded with some parts . It includes block of bearing horizontal force immediately, group of shear studs which deliver the horizontal force to bridge pier, angle steel and bottom.

IV. THE COMPARISON OF FORCE TRANSMISSION PERFORMANCE

A. The force transmission performance of the channel steel anchorage

The two piece of main truss via welded steel connection thanks to the spacing is large in the channel steel anchorage. The bearing capacity of transferring vertical force component is increased owe to more pre-stressing tendon. From construction property perspective, the channel steel anchorage connect steel truss to the pier through prestressing force of pre-stressing tendon to bear vertical force. The horizontal force is transferred to pier by the post-pouring concrete at the top of pier.

As can be seen from force transmission line, the channel steel plays a key role in transfer vertical force and horizontal force. But its slenderness ratio is large in terms of single channel steel. It is easy to make the channel steel deformation. So it is necessary to increase some vertical ribs with a certain space for resolving the defect.

B. The force transmission performance of the embedded corbel anchorage

The strained condition of the embedded corbel anchorage has been greatly simplified by simplifying the anchorage position into two nodes in each side of the bottom chord bar. The bottom boom is imbedded in pier by welding extended anchor bracket. The level of force transfer to the pier through the welding extended anchor bracket and the vertical force is to rely on the pre- embedded anchor. From the point of view of the characteristics of the joint structure, the welding extended anchor bracket provide anchor point of the vertical prestressing tendon and bear the horizontal force. As a vertical stress component, the prestressed tendons directly connect the truss and the pier. The path of force transfer is very simple and clear. Prestressing tendon which located inside the pier is covered by the corrugated pipe.it apart from the pier concrete to prevent the damage caused by the failure of the pier top concrete caused by the change of the surrounding rock bolts.

C. The force transmission performance of the preserved embedded anchorage

The embedded anchor is the optimization design of the anchorage scheme of embedded corbel. It design the component of the horizontal force separately. This scheme further simplifies the structure of the pier beam joint force form, it designed respectively component to transfer the horizontal force and vertical force. Block directly contact with the bottom chord and steel anchor bracket to deliver horizontal force. The horizontal force distribute to the shear pin group by the bottom plate,and further spread to the pier follow. As connecting component between two pieces of force transmission member, the angle steels play a role of location. After the installation of embedded parts is completed, the angle steels are still in the pier to transfer partial bridge to horizontal force partly. Its function is equivalent to the shear connector.

The comparison of the load-bearing performance of these three schemes is shown in table1.

Table 1: the comparison of the load-bearing performance of these three schemes

Scheme	Force transmission path	Applicable span	Remarks
Scheme of channel steel anchorage	Relatively complex	Super large-span	Due to relatively large slenderness ratio of channel steel , this scheme is suitable for the super large-span with several pre-stressing tendon can be anchored. The vertical force transmission path is from the channel steel to pre-stressing tendon, then to the pier. The transmission path of bi-directional horizontal force is from the channel steel to the post-cast concrete bottom board, and then to the thin-wall piers.
Scheme of embedded corbel anchorage	Relatively clear	Large-span and middle-span	Because of the anchorage location is simplified to two anchorage points on either side of the pier top bottom chord, the number of the pre-stressing tendon has been reduced and the loading capacity of the vertical load-bearing element reduces. The transmission path of bi-directional horizontal force is from the post-cast concrete to the piers. The size of the provided groove is small so its bearing capacity of the bi-directional horizontal force is low. This scheme suits the large-span and middle-span.

Scheme of the preserved embedded anchorage	Clear	Middle-span	In comparison with the embedded corbel anchorage scheme, the embedded anchorage is applicable to the middle-span for the height of corbel and the force transmission capacity has reduced. The vertical force transmission path is from steel corbel anchorages to the piers. The transmission path of bi-directional horizontal force is from the steel corbel anchorages to the embedment, and then from the studs to the thin-wall piers.

V. COMPARISON OF THESE THREE SCHEMES CONSTRUCTION TECHNIQUES

The construction steps of channel steel anchorage are: Firstly, embedding the pre-stressing tendons, local reinforcement steel meshes and corrugated pipes in the design position; Secondly, after the trusses of zero block have been set up, threading the pre-stressing tendons through the reserved pores in the channel steel and tensioning to the design value by torque force and then anchoring; Finally, pouring the floor slab concrete between the bottom chord bar to completely wrap the channel steels and pre-stressing tendons. This completes the pier-beam coupling structure construction.

The emphasis of this scheme is the accurate installation of the pre-stressing tendons. If not, the pre-stressing tendons would be unable to be threaded, tensioned and anchored， thereupon it would adverse to pass the unbalanced bending moment. Due to the pre-stressing tendons would be wrapped to unable to be repaired, maintained and replaced after pouring the floor slab concrete, it is necessary to research its property and failure models in design phase in order to insure the connection structure safety reliability.

When adopting the scheme of embedded corbel anchorage, it is also need to embed the pre-stressing tendons in design position in the pier, and install steel mesh in the area around the end of the anchor bar. It reserve slot to anchoring steel bracket at the top of pier. When setting up the pier top zero section truss, the steel anchor bracket of pier beam connecting part is inserted into the slot, the prestressing tendon is anchored on the top of bracket through the steel anchor bracket after accurate positioning. The post pouring concrete and pier top at the same height after the completion of anchor, and complete the construction of pier and beam combination structure

The advantages of this scheme are: the number of anchor points has reduced for its only need to set anchorage structures in the bottom chord bar; The transmission of horizontal thrust force is more efficient as the steel corbel anchorages embed in the pier top; The reserved open slots have played the role of limiting the displacement of the truss segment on pier top.

The scheme of embedded anchorage is an improvement on the basis of the embedded corbel anchorage scheme. The major construction technology between these two schemes has no big difference, while the principal difference is that each anti-thrust structure should be embedded separately in embedded anchorage scheme. The horizontal thrust forces transmit from the steel corbel anchorages to the anti-thrust structures, and then from the studs at the bottom face of the anti-thrust structure to the thin-wall piers. The zero blocks play an important effect in positioning. Threading the steel corbel anchorages though the reserved anchor rod (no need of pre-tightening force), then anchoring, finally completing the pier-beam coupling structure construction.

This scheme has the advantages of convenient construction, simple constructional details and relatively low precision of construction positioning due to the gap between the bottom chord bar and the anti-thrust structures embedded in advance. And the horizontal pier top is beneficial to the truss stability during the construction.

The construction difficulty degree comparison of these three pier-beam coupling schemes is shown in table2.

Table 2-2: The construction difficulty degree comparison of these three schemes

Scheme	Construction technology	Characteristic	Remarks
Scheme of channel steel anchorage	Complex	The pre-stressing tendons could not be repaired, maintained and replaced because of having been completely wrapped by concrete.	The construction difficulty is ensuring the accurate installation of the pre-stressing tendons. Otherwise, it would adverse to pass the unbalanced bending moment. The construction of post pouring concrete is difficulty due to the limitation of the pier top space.
Scheme of embedded corbel anchorage	Relatively simple	The reserved notches are needed to embed the steel corbel anchorages in the design position of pier top.	The size of anchorage structures is small. The reserved open slots help the steel truss positioning. After anchoring, it's also need to pour concrete into the notches, and the construction is difficult.
Scheme of the preserved embedded anchorage	Simple	Each anti-thrust structure should be embedded separately.	The embedment is beneficial to the truss stability. Due to the gap between the bottom chord bar and the anti-thrust structures embedded in advance, the precision of construction positioning is relatively low. The construction is simple for no need to pour concrete after the anchoring.

VI. CONCLUSION

To sum up, the channel steel anchorage scheme is suitable for the super large-span steel truss-concrete composite continuous rigid frame bridge, the embedded corbel anchorage is suitable for the large-span and middle-span steel truss-concrete composite continuous rigid frame bridge, the preserved embedded anchorage is applicable to the middle and small span steel truss-concrete composite continuous rigid frame bridge.

In terms of the construction technology, it is not complex. The major sequence of these three pier-beam coupling schemes is embedding the vertical load-bearing element firstly, anchoring the main truss after installed secondly, finally completing the pier-beam consolidation. In terms of the construction simplicity, the third scheme is most simple, the second is next, and the first scheme is the most complex. Due to the limitation of the construction machinery and personnel activity space in the pier top, it's better to avoid carrying out complex and long period construction. The construction process of the third scheme is obviously simple for only need the corrosion prevention and positioning anchor, while the other two schemes need to pour concrete after anchoring.

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