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# Research on the Application of Prestressed CFRP in Strengthening Concrete Beams

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***Abstract:*** *CFRP plate is a kind of common bridge reinforcement material, its high tensile strength, shrinkage, environmental corrosion resistance. It is conducive to the bridge reinforcement of CFRP plate, which can not only effectively improve the bearing capacity, stiffness, crack resistance and ductility of the component, but also will not increase the original size and weight of the bridge. It has the advantages of reliable anchorage effect, large tensile stress, simple process, good technology and economy. The reinforcement can give full play to the high strength characteristics of CFRP material, effectively improve the mechanical properties of components in the use stage, prevent spalling damage, reduce strain lag phenomenon, while the construction does not interrupt the traffic, and the material utilization rate is high, light weight, beautiful appearance and so on.*

***Keywords:*** *crestressed CFRP plate; construction process; reinforcement; construction method; composite box girder; surface protection; precautions*

## 1. Introduction

Xinshuhe bridge which goes across Xinshu River is located at fenguan expressway within K813+412. Bridge is orthogonal and the total length of the bridge is 1688m. The upper structure which is 8×(6×35) meter is prefabricated partially prestressed concrete continuous box girder, simply supported to be structurally continuous, while the substructure consists of pile column pier, ribbed slab platform and bored pile foundation. The bridge deck is 33.5m in width consisting 0.5 m outer guardrail, 14.75m carriageway, 1.0 m inner guardrail, 1.0 m separator strip, 1.0 m inner guardrail, 14.75 m carriageway, and 0.50 m outer guardrail. The original design load of the vehicle is over 20, while the trailer is 120. It is built and opened to traffic in 2004.

With the increase of traffic volume and load, some components of the bridge have been damaged, d amaged and cracked because Xinshuhe bridge has been operated safely for 16 years. Through the inspection, it is found that there are vertical cracks in the webs of the main beams of each span, and some transverse cracks run through the beam bottom mainly distributing in 2l / 5 ~ 3L / 5 which is about 0.10 mm in width. Generally, there are often 1-2 webs on one side of one beam, hence, there are vertical cracks in many beams at the same position. When cracks were closed in previous years, such cracks appeared in the vicinity again. In order to prevent the spread of disease and affect the service performance of the bridge, the prestressed CFRP plate of composite box girder bottom plate is finally used for reinforcement[1-2].

## 2. Strengthening design of Prestressed CFRP plate

After comprehensively considering the load of fenguan expressway, it is required that the prestressing increment in the middle of the box girder of Xinshuhe bridge after reinforcement should reach 10% of highway class I standard. The main design conditions are as follows:

(1) Two single-layer CFRP plates are tensioned in the bottom plate of composite box girder along the bridge direction. The design thickness of CFRP plate is 3.0 mm, the width is 50 mm, the tensile strength is more than or equal to 2400 MPa, the elastic modulus is not less than 160 GPA, the elongation at break is not less than 1.7%, the ultimate bearing capacity is 420kN, and the tension control stress is 1277 Mpa. Therefore, the safety performance index of CFRP plate meets the requirements of high strength grade I plate of in“Code for design of highway bridge reinforcement” (JTG/T J22-2008).

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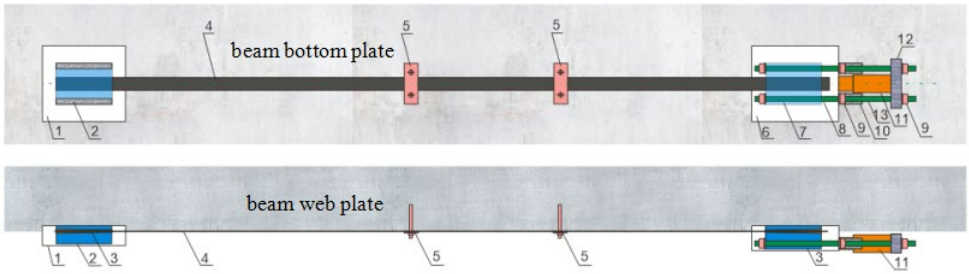
(2) The prestressed CFRP plate is connected with the bottom of composite box girder through the steel members at the fixed end and tension end, whose steel members and concrete beams are connected by high strength bolts. The bolts are made of 8.8 grade galvanized steel (RGM 16×270) belonging to fisher brand. The depth of anchoring is 95 mm, and RSB16mini is utilized as injection glue. In the design process, the local stress of the concrete at the anchorage end and tension end is analyzed to ensure that the concrete will not crack which is illustrated in **Figure 1**.




*(1: stop block in anchor end; 2: anchor block at anchor end; 3: wedge shaped steel clip; 4: CFRP plate; 5: limit card; 6: stop block in tension end; 7: stop block in tension end; 8: Connecting screw; 9: nut; 10: sleeve; 11: lifting jack; 12: reaction steel plate; 13: tensioning screw)*

*Figure 1: Schematic diagram of reinforcement design in CFRP*

(3) The steel plate using steel Q235 with 5mm and 200mm in thickness and width is pasted along the bridge direction at a certain height of the composite box girder web.

(4) After the construction, the outer surface of CFRP Board should be coated with paint as protection.

## 3. Construction process

The construction process of strengthening composite box girder with prestressed CFRP plate is as follows: two single-layer CFRP plates are tensioned on the bottom plate of composite box girder by hydraulic jack along the direction of the bridge, while the prestressed CFRP plate is connected with the bottom of the composite box girder through the anchor blocks of fixed end and tension end, hence, the interface between CFRP plate and beam bottom is bonded with adhesive. The anchor block is made of Q235 steel, the surface of steel components is treated with integral galvanized antirust treatment. M16 high strength anchor bolt is used to connect the fixed and tension end anchor block with the beam body. The anchorage position is about L / 6 of the beam end. After the construction, the outer surface of CFRP Board should be coated with paint as protection. The construction process is shown in Figure 2.

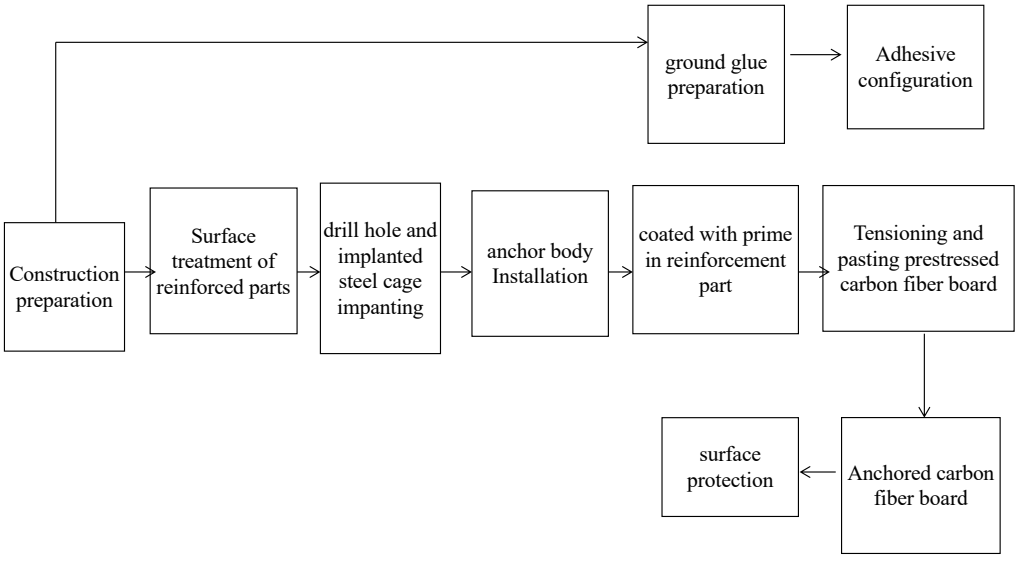



*Figure 2: Construction technology process of concrete composite box-beams with Pre-stressed CFRP Sheet*

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## 4. Construction method

### *4.1 Construction preparation*

Before construction, the surface water content and ambient temperature of the concrete pasted on the reinforced bridge should be measured accurately to ensure the appropriate construction conditions, that is, moisture content of concrete surface is not more than 4%, and the ambient temperature is between 5℃ and 40℃. If the environmental conditions cannot meet the construction requirements, measures should be taken to meet the requirements before construction. Before construction, the reinforcement part of the bridge shall be set out and accurately positioned according to the design drawings to ensure that the anchorage end and the tensioning end are in the same straight line[3-4].

### *4.2 Surface treatment of reinforced parts*

The surface performance of the reinforced bridge concrete was tested, and the loose part of the component surface was removed until the concrete structure layer was exposed. If there are cracks, the concrete cracks should be repaired first using required repair materials in concrete surface to ensure that the thickness of the concrete cover is not less than 20 mm.

If the concrete surface at the position where the prestressed CFRP plate is pasted is solid, the laitance layer, oil stain and other impurities shall be removed and polished until the new surface of aggregate is exposed. If there is segment difference or corner, it needs to be trimmed to a smooth surface, taking into account the flatness. After being polished, the dust on the surface is removed by a strong blower, and then thoroughly cleaned with cleaning agent (acetone).

### *4.3 Hole drilling and steel bar planting*

(1) According to the design drawings to roughly determine position of anchor hole by steel bar detector, if anchorage hole position is in conflict with the steel bar, according to the characteristics of on-site cutting in rigid self-locking prestressed CFRP plate anchorage system, the drilling position will be slightly adjusted as a whole in the longitudinal direction before drilling holes.

(2) When the length of the prestressed CFRP plate is more than 5 m, the planting reinforcement holes of the limit plate are arranged every 5 m.

(3) After cleaning holes, high-strength stainless steel bolts should be implanted with planting reinforcement glue.

### *4.4 Anchorage installation (anchorage end, tension end)*

(1) The anchorage material should be stainless steel whose designed anchorage capacity is 1.5 times more than that of pre-stressed CFRP plate;

(2) Groove is made at the anchorage end and tension end of the beam to make the anchor block embedded into the concrete at a certain depth. Moreover, groove depth shall ensure that the upper edge of wedge-shaped duct of anchor block is just slightly higher than the surface of beam bottom, and the remaining protective layer of reinforcement shall not be less than 15 mm. The installation of anchorage is shown in Figure 3.

(3) The grooved surface should be leveled with structural adhesive, and grease should be applied between the upper surface of anchor block and the grooved surface for lubrication.

(4) After the reinforcement adhesive is cured to the design strength, the anchor is fixed on the pre implanted high strength stainless steel bolt with nuts.

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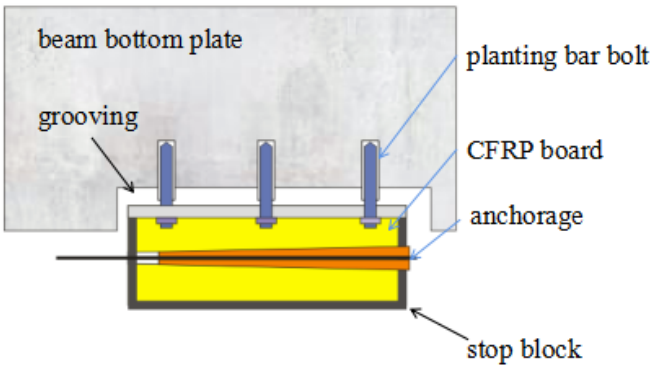


*Figure 3: Elevation plan of tensioning side*

### *4.5 Primer applied on reinforcement part*

Primer is applied on the concrete surface of Prestressed CFRP plate. The primer shall be evenly coated on the fully cleaned concrete surface with roller brush or special brush to avoid bubble appearance. The prepared primer should be used up within the specified time. The next process can be started after the finger touch is dry.

### *4.6 Tensioning and pasting prestressed CFRP plates*

(1) Cut the CFRP Board following the formula according to the size requirements after field adjustment.

$$\text{Cutting length} = \text{working length} + 2 \times \text{anchorage length (clip length} + 3\text{cm)} - \text{calculated elongation.}$$

(2) Clean the side of CFRP Board with acetone (alcohol). Wedge channels and wedge-shaped steel clips shall be cleaned with clean cloth in advance.

(3) Fix one end of the CFRP plate in the anchor block of the anchor end. Firstly, the CFRP plate is put through the wedge-shaped hole of the anchor block to be exposed about 3cm. The upper and lower wedge-shaped steel clips of the anchor block are initially installed. The contact surface between the wedge-shaped steel clip and the wedge-shaped channel needs to be lubricated with grease. Secondly, the upper and lower wedge-shaped steel clips of the anchor block are knocked back and forth with a hammer until the exposed length of the embedded anchor body is no more than 0.5cm so as to complete the fixation of the CFRP plate anchor block. Finally, under the fixed state, the upper and lower wedge-shaped steel clips should be strictly flush, and the wedge-shaped steel clips and CFRP plate should be located in the middle of the wedge-shaped channel. The other end of CFRP plate is fixed in the anchor block of tension end, and the method is the same as above.

(4) Connect the tension screw with the connecting screw with a sleeve to install the reaction steel plate. Lifting jack and pressure sensor are placed between the reaction steel plate and the anchor block.

(5) The strain sensor can be installed on the CFRP plate if necessary to measure the strain change of CFRP plate during the tensioning process. The range of the sensor should meet the requirements of the maximum strain value.

(6) The tension test is carried out to check the working condition of CFRP plate and anchorage system, as well as to reduced loss of prestressing force in gap between the clip and CFRP plate. The CFRP plate is prestressed by the method of step-by-step tensioning, and the tensioning sequence is as follows: 10% tensile force →20% tensile force→50% tensile force→75% tensile force→100% tensile force→Continuous load for 5min. During the tensioning process, the tensile force shall be based to the pressure sensor, and the elongation and strain of CFRP plates at all levels shall be measured to check anchoring system. If there is no abnormality in the anchoring system, lifting jack could be released to complete the trial tension.

(7) The surface of CFRP board is evenly coated with a layer of prepared adhesive. The adhesive layer is thick in the middle and thin on both sides with an average thickness of 2.5-3 mm.

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(8) The tensioning sequence of formal tensioning is: 10% tensile force →20% tensile force→50% tensile force→75% tensile force→100% tensile force→105% tensile force→Continuous load for 5min.

(9) After each stage of tensioning, 2 minutes will remain, while prestressing force reaches 105% for loading 5 min before tightening tension rod nut, the degree of which is closely related to the short-term loss of prestressing. Elongation of CFRP plate, strain and concrete strain in each stage respectively are observed to check whether the anchoring system is abnormal or not. The elongation calculation of CFRP plate is shown in the formula:

$$90\%\,L_{total} = 100\%\ \text{elongation of tension control force} - 10\%\ \text{elongation of tension control force}$$

$$10\%\,L_{total} = 20\%\ \text{elongation of tension control force} - 10\%\ \text{elongation of tension control force}$$

$$L_{total} = 90\%L_{total} + 10\%L_{total}$$

(10) If the anchoring system is normal, the lifting jack can be slowly returned to the cylinder and removed after unloading. The instantaneous prestress loss during tensioning shall not exceed 2%. The tensioning is shown in **Figure 4**.

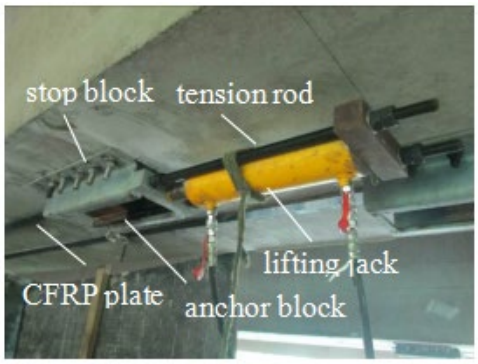


*Figure 4: Tension construction is carried out after installation*

(11) If there are voids and voids between CFRP slab and concrete, the voids and voids should be added with adhesive.

(12) The thickness of bond layer between prestressed CFRP plate and concrete surface should not be greater than 2.0 mm.

(13) Rigid self-locking prestressed CFRP plate anchorage system could set the anchorage tension stress to 1500 MPa safely by 3-50 mm CFRP board because tensile strength of CFRP plate is not less than 2400 MPa, and the tensile control stress is 0.63 times of the tensile strength.

(14) Tensioning and pasting of Prestressed CFRP plate and installation of limit plate should be completed before the initial setting of adhesive.

### *4.7 Surface protection*

After the initial setting of the adhesive, a layer of UV protective adhesive is applied on the surface of CFRP Board to protect the CFRP Board, and the thickness should be ≤ 5mm to ensure the reliable bonding between the protective material and the CFRP Board.

### *4.8 Precautions in construction*

(1) The preparation of adhesive shall be carried out according to the ratio and process requirements provided by the adhesive supplier and special responsible person. In addition, the tool used for glue mixing shall be a low-speed mixer.

(2) The range of the jack shall not be less than 1.5 times of the pre-tensioning force of CFRP plate, the process of which ought to be applied slowly and uniformly.

(3) In the process of tensioning, it is strictly forbidden to stand at the front end of the tensioning end

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to ensure the safety of the whole construction.

(4) In the process of CFRP plate tensioning, the tensile force and elongation of CFRP plate should be monitored to ensure that the CFRP plate tension reaches the design value after installation[5-6].

## 5. Summary

Prestressed CFRP plate reinforced concrete composite box girder has the advantages of reliable anchoring effect, large tensile stress, simple technology and good technical economy. It can give full play to the high-strength characteristics of CFRP materials, effectively improve the mechanical performance of components in service stage, prevent peeling damage, reduce strain lag phenomenon, and can be constructed without interrupting traffic, and has high material utilization rate Light weight, beautiful appearance.

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