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Study on strengthening effect of prestressed cfrp sheet on steel box girder

Xiaodong Liu[1,*], Dongxiang Liu[2], Hanxiao Wang[1]

[1]*College of School of Architecture and Engineering, Chongqing University of Science and Technology, Chongqing, China*
[2]*College of Chemical Science and Engineering, Yunnan University, Yunan, China*
[*]*Corresponding author*

Abstract: *The finite element software Abaqus is used to simulate the reinforcement of the steel box girder with CFRP sheets. The wave anchor anchorage system clamps the carbon fiber (CFRP) sheets and anchors them in the tensile zone at the bottom of the steel box girder. The temperature method is used to simulate the prestress applied to the steel box girder in the actual project, and the stress of the steel box girder in the project example is compared to analyze the mid span deflection of the steel box girder; With the change of stress and strain, the mid span deflection of prestressed CFRP sheet to steel box girder is analyzed; Stress; The improvement of strain sum shows that prestressed CFRP has good reinforcement effect for flexural members.*

Keywords: *Prestress, CFRP, Steel box girder, Abaqus, Reinforcement effect*

1. Introduction

As a common component, steel box girder is mostly used in continuous girder bridges, cable-stayed bridges and suspension bridges due to its good torsion resistance and bending resistance. The steel members are generally high order statically indeterminate structures. When the steel box girder is used as a bending member, due to the residual stress, residual deformation at the weld position and corrosion of the stressed part, fatigue cracking will occur under the alternating stress of the material yield strength. In the process of putting the steel box girder into use, corrosion and fatigue will occur at the same time to a certain extent, and brittle failure may occur under the effect of stress accumulation [1]. Because of the connection characteristics of the steel box girder components, there are many openings and welding positions in the construction. During the construction process, some original cracks will be generated at these positions. Therefore, there will be stress concentration problems on these original cracks [2]. Therefore, the traditional method of connecting the steel box girder into a whole in the form of assembly has many disadvantages, such as the stress concentration generated by splicing, the splicing part as a whole Excessive deflection in midspan, etc. This paper will use finite element Abaqus to simulate the reinforcement of steel box girder, and analyze the reinforcement effect of carbon fiber composite sheet on steel box girder from the principle and method of prestress.

The strengthening technology of CFRP [3] sheets has various advantages and disadvantages. CFRP has plasticity and can deal with many complex structures when strengthening; And with its super corrosion resistance and fatigue resistance, it can play its advantages in dealing with the actual working conditions; The continuous face to face reinforcement between CFRP sheet and steel can fully form a whole with the steel, can evenly transfer the load on the steel to CFRP sheet, and can deal with the important disadvantage of steel stress concentration. There are also many defects in the reinforcement of steel by CFRP sheets: the thermal expansion coefficient of CFRP materials differs greatly from the thermal expansion coefficient of steel. After reinforcement, the residual stress caused by thermal expansion between CFRP materials and steel will affect the reinforcement effect; The bonding materials between CFRP materials and steel need to have high requirements, and in the actual application process, there will be many factors that make the adhesion between CFRP materials and steel not close enough, and the stress of the two cannot correspond [4].

As a new composite material, CFRP has the characteristics of high strength and corrosion resistance. Its theoretical tensile strength can reach 6000Mpa at most. Moreover, the crack growth rate of steel plate can be significantly reduced by using CFRP reinforcement, which is 6.9 to 1.3 times of that of unreinforced CFRP[5]; Cracked steel plates strengthened with CFRP can prolong the fatigue life by

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97~186% [6]. Because CFRP can effectively control crack propagation, CFRP is commonly used in engineering cases, especially in long-span structures. The bending members are mainly stressed by upper compression and lower tension, while the tensile stress borne by ordinary steel box girders can not meet the needs of long-span bending members. When steel box girders are used as members, in order to compensate for corrosion Cracking under fatigue and damage of member connection, therefore, prestressed CFRP is required to apply a prestress to long-span flexural members to achieve good reinforcement effect.

The wave anchor developed by Zhuo Jing [7] team has realized the anchoring of both ends of CFRP sheet, and the anchoring performance is very superior and applied in engineering practice. In this simulation, CFRP sheets will be tensioned based on the anchoring system of wave anchors, pasted and fixed in the tensile zone at the bottom of the steel box girder, so that the steel box girder and CFRP sheets will bear the force together, and the steel box girder will be simulated to apply prestress, so as to study the reinforcement of the steel box girder by CFRP sheets, as shown in figure 1.

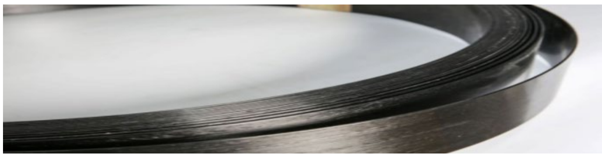

Figure 1: CFRP sheet.

2. Prestressed CFRP strengthening principle

2.1. Material selection

This simulation is based on the waveform anchor developed by Zhuo Jing's team to anchor both ends of CFRP sheet and the end of steel box girder, as shown in Figure 2. The size of 500 mm×500 mm×5000 mm is selected; Q235 hot-rolled steel box girder with a thickness of 150 mm is taken as the research object, and its tensile zone is longitudinally strengthened with 50 mm×2 mm×5000 mm CFRP sheets. The specific reinforcement method is shown in Figure 3. Specification of Steel Box Girder is shown in table 1.

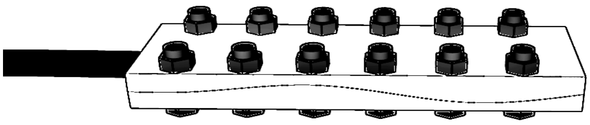

Figure 2: Wave anchor Perspective.

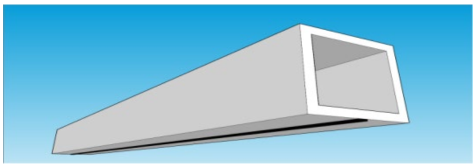

Figure 3: Simulation diagram of sheet strengthening steel box girder.

Table 1: Specification of Steel Box Girder.

Material Science	Steel_beam	CFRP
Length	5000 mm	5000 mm
Width	500 mm	50 mm
Height	500 mm	/
Thickness	15 mm	2 mm

2.2. Basic principles

From the perspective of studying the reinforcement effect of CFRP sheets on steel box girders, this simulation will apply prestress to CFRP sheets based on the principle and method of prestress [8].

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In this paper, the external prestressing direct tensioning method [9] is simulated to strengthen the steel box girder. The direct prestress tensioning method is to anchor CFRP sheets and tension CFRP sheets with a wave anchor anchorage system, anchor the tensioned CFRP sheets and paste the CDRP sheets in the middle of the tensile zone at the bottom of the steel box girder by applying epoxy resin adhesive, and then unload the tensioning force to transfer the pretensioning force to the bottom of the steel box girder, so as to achieve the purpose of strengthening the steel box girder.

3. Abaqus simulation process

3.1. Modeling and Assembly

The specification is 500 mm×500 mm×5000 mm; The Q235 hot-rolled steel box girder model with a thickness of 150mm is assembled with the CFRP sheet model with a specification of 50 mm×2 mm×5000 mm. The component models are stretched by three-dimensional entities. The specific effect is shown in Figure 4.

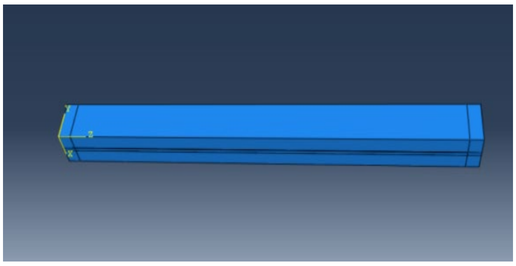

Figure 4: Assembly of steel box girder and CFRP sheet.

150 mm shall be reserved at the bottom anchorage seat as the binding length of the corrugated anchor connecting the steel box girder and CFRP sheet to bind the two parts. Therefore, the parts shall be divided into three sections, with the specific operation of specifying the base point and offset by 150mm, splitting the geometric elements and defining the dividing surface.

3.2. Material parameters and boundary conditions

The material of steel box girder is Q235 hot-rolled-steel, with Young's modulus of 2.06×10^5 and Poisson's ratio of 0.27; The composite materials association has different opinions on the relevant parameters of CFRP sheet. This simulation will use the parameters used by our team. The Young's modulus is 1.7×10^5, Poisson's ratio is 0.307, and the thermal expansion coefficient is 1×10^{-5}. The specific parameters are shown in Table 2.

Table 2: Material Parameters of Steel Box Girder and CFRP Sheet.

Material Science	Steel_beam	CFRP
Elastic modulus	2.06×10^5	0.27
Poisson's ratio	1.7×10^5	0.307
Coefficient of expansion	/	1×10^{-5}

Create constraint conditions on the interaction interface and select the main surface m_ Surf-1 and slave surface s_ surf-1, the specific effect is shown in Figure 5.

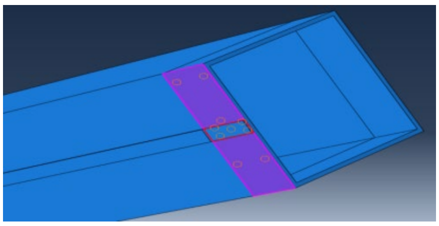

Figure 5: Binding of steel box girder with CFRP sheet.

Create boundary conditions BC-1 and BC-2 in the load interface. The type is displacement/rotation. BC-1 is set at the left end of the assembly, that is, the positive direction of the x-axis. Therefore, the boundary conditions of U1, U2 and UR2 are set to 0; BC-2 is set at the right end of the assembly, that is, the negative direction of the x-axis. Therefore, the boundary conditions of U1, U2, UR1, and UR2 are

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set to 0, as shown in Figure 6, to complete the boundary conditions of the assembly.

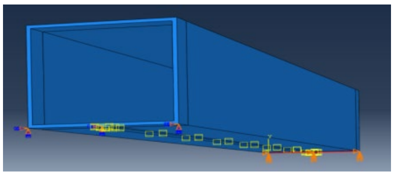

Figure 6: Boundary condition.

3.3. Loads

Abaqus' method of prestress is relatively complex. This simulation will use the temperature method [10] to load CFRP sheet.

$$\sigma = \Delta t E \alpha \tag{1}$$

Where:

σ——Material stress value

Δt——Temperature control value

E——Material elastic modulus

α——Material expansion coefficient

Add a predefined field of type Temperature in Initial, and set the initial value to 0. Create the analysis step-1 and select the load to create a predefined field with the type of temperature. The prestress is applied to 1500 Mpa, calculated according to formula (1.1) Δt is -882.35, that is, the predefined field size in step-1 should be set to -882.35 to complete the application of prestress.

3.4. Cell division

In the finite element Abaqus simulation, the model shall be reasonably divided according to the size of the element and the algorithm, and the three-point one normal method shall be used to divide the cells by drawing corners at the boundary to avoid the calculation failure due to non convergence of the cells or too small cell division [11]. The cell division of this simulation is based on the model size to divide the steel box girder and CFRP components. The cell size of the steel box girder is 0.48, and the cell size of the CFRP sheet is 0.3, which can meet the requirements.

4. Results

4.1. Stress

The stress change can directly feel the stress of the steel box girder, and the specific results are shown in Figure 7.

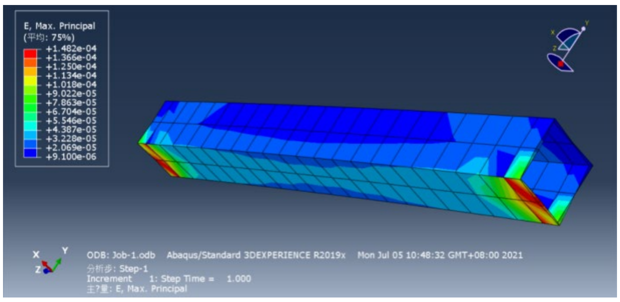

Figure 7: Stress distribution of steel box girde.

The maximum stress borne by the steel box girder is 1.4×10^{-4}Mpa, which is mainly distributed at both ends of the anchorage, specifically at the binding position of the steel box girder and CFRP sheet, while the minimum stress is 9.1×10^{-6}Mpa, which is mainly distributed at both ends of the top of the steel box girder.

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In the actual working condition, when the steel box girder is prestressed, the tensile stress borne by the end anchorage seat is large, while the stress at the top ends of the steel box girder is small. This simulation is consistent with the actual situation.

4.2. Strain

The strain change can reflect the relative change of the steel box girder length, which is a dimensionless ratio, specifically representing the percentage of the deformation amount and the original length of the component. The strain relationship of the simulated steel box girder is shown in Figure 8.

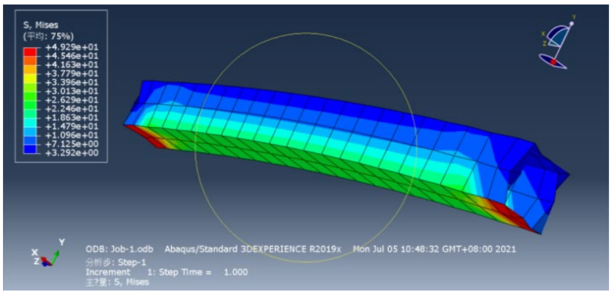

Figure 8: Strain diagram of steel box girder.

It can be seen from the figure that the maximum strain value of the steel box girder is 4.929%, which is mainly distributed in the anchorage seat at the bottom of the steel box girder, specifically the binding position of the steel box girder and CFRP sheets, while the minimum strain is distributed at the top and both ends of the steel box girder. The strain change at the neutral axis is close to 1%, that is, the strain at the neutral axis is consistent with the actual situation.

In the actual working condition, the stress value of the prestressed steel box girder is the largest at the end, and the strain value is the largest there; The stress at both ends of the top of the steel box girder is small, so the strain value at both ends is small. Therefore, this simulation is consistent with the actual situation.

4.3. Displacement

The change of component displacement mainly reflects the mid span deflection of the steel box girder. The distribution of the mid span bending moment can be effectively improved by prestressing the steel box girder, so as to reduce the mid span deflection and achieve the purpose of strengthening the steel box girder.

The simulation effect is shown in Figure 9.

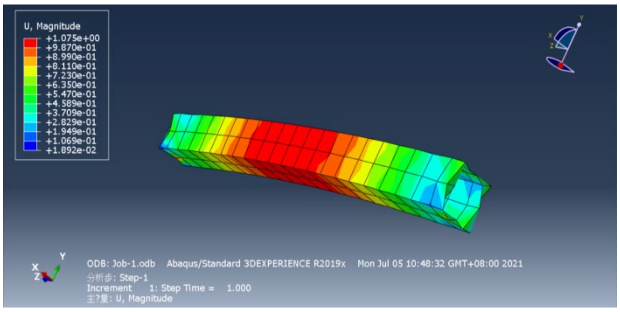

Figure 9: Displacement distribution of steel box girder.

It can be seen from the figure that the deflection changes are mainly distributed in the middle of the span, and the maximum value is 1.075 mm; The minimum deflection value is 1.892×10^{-2} mm, which is mainly distributed at the four corners at the bottom of the steel box girder. The deflection change is relatively small. The reason is analyzed as follows: the steel box girder is slightly shorter, the steel box girder is thicker, the steel box girder is too strong, and the prestress load is too small, resulting in the CFRP reinforcement effect on the steel box girder is not obvious.

In actual working conditions, the maximum deflection of steel box girder is mainly distributed in the mid span position, and the prestress applied to the steel box girder can provide a maximum deflection of

1.075 mm at the mid span position of the steel box girder. For the steel box girder, the reinforcement effect is still very considerable.

5. Conclusion

Assuming that the assembly conforms to the plane section assumption, the prestressed CFRP sheet has a good reinforcement effect on the steel box girder from the perspective of stress, strain and displacement, which is shown as follows:

(1) Prestressed CFRP sheets can provide the steel box girder with a maximum stress of 1.4×10^{-4} Mpa, which can improve the offset of the steel box girder when it is stressed, and play a certain role in strengthening.

(2) Prestressed CFRP sheets provide a maximum strain of 4.929% for the steel box girder, and offset about 5% of the strain for the steel box girder during loading, which has a certain reinforcement effect.

(3) Prestressed CFRP sheets provide the steel box girder with a maximum deflection of 1.075 mm, which has a certain reinforcement effect.

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References

[1] Wang Weidong. Common Diseases of Steel Box Girder Bridge and Their Detection [D]. Housing and Urban Rural Development Bureau of Jishui County, Jiangxi Province, 2014.
[2] Zou Jianbo, Zhang Xiaochen. Research on fatigue damage assessment and experimental method of bridge steel box girder [J]. Engineering technology research, 2021.
[3] Huang Zhen, Miao Xin, etc. Experimental investigation on shear behavior of concrete beams with CFRP grid shear reinforcements [J]. Structures, 2021, 33.
[4] Wang Feng. Study on mechanical performance of CFRP strengthened steel box girder [D]. Fuzhou University. 2016.
[5] Wang Haitao, Zhang Lei, Wu. Gang Study on fatigue performance of steel plate with unilateral crack strengthened by CFRP [J]. Building structure, 2018, 48(S2):750-753.
[6] Yu Q Q, et al. "Fatigue behaviour of CFRP strengthened steel plates with different degrees of damage." Thin-Walled Structures 69.3(2013):10-17.
[7] Zhuo Jing, Li Tangning, Xing Shijian, et al A new external prestressing method for anchoring FRP sheets [J]. Journal of Civil Engineering, 2007, 40(1):15-19, 41.
[8] Liu Yusong. Research on flexural performance of pretensioned prestressed centrifugal concrete steel strand pile [D]. Zhejiang University, 2021.
[9] Chen Yong. Research on the application of external prestressing technology in strengthening concrete continuous box girder [J]. Municipal technology, 2022, 40(4):16-21.
[10] Zhang Wenhao. Experimental Study and Finite Element Analysis of Hollow Slab Bridge Strengthened with Prestressed CFRP [D]. Hebei University of Engineering, 2020.
[11] Duan Zhiyao. Study on the coupling problem between ABAQUS and time-domain boundary element program [D]. Harbin Institute of Technology, 2020.