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# Reinforcement Efficiency of Carbon Fiber Reinforced Plastics on Concrete T-beam Bridge

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***ABSTRACT:*** *As time goes by, more and more bridges will reach and approach their design reference periods, or need to be repaired, reinforced and reconstructed because of constructional damages for a variety of reasons. Before repair and reinforcement, it is very necessary to conduct reasonable detection and valuation in order to know actual condition and carrying capacity and analyze causes for damages so that effective reinforcement measures can be worked out. Taking Changxiangdong Bridge as an example, this paper introduces the detection methods, detection results and reinforcement measures of reinforcement concrete T-beam bridge and gives a comparison to static and dynamic performance before and after reinforcement. It turns out that the main beam has a greater rigidity and strength after being reinforced, the carrying capacity and impact properties of bridge meet the standard, which proves the reliability of CFRP (Carbon Fiber Reinforced Plastics).*

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## PREFACE

Many small and medium sized bridges built in the 1980s still play an important role in domestic railway network, but as the railway level across the country updates as a whole and constructional damages and lack of carrying capacity occur for various reasons, many of these bridges cannot meet the needs of normal use, it is necessary to detect their actual carrying capacity and reinforce them[1].

Based on the calculation of reinforced bridges and numerical simulation with QLIC , a professional analyzing software for bridge structure[2-3], this paper explains how carbon fiber reinforcement influences the carrying capacity of 16m spanned reinforcement concrete T-beam bridge. In addition, by taking Changxiangdong Bridge as an example, the paper gives an introduction to the characteristics of carbon fiber material, the mechanism of carbon fiber reinforcement, how to choose reinforcement plans as well as the methods of using CFRP strengthening and its construction technology.

## I. BRIEF INTRODUCTION OF BRIDGE

Railway from Huangling to Lizhanghe, about 32km long, is the special line for coal transportation of Mine 1 of Huangling Mining Group in the northwest of China. It has 20 prestressed RC beam and RC beam bridges, with a total length of 2863.4m. This special line was built from 1988 and put into use in 1991. In recent years, the coal transport volume has increased, but the bridge has not been subject to systematic detection for more than twenty years since being used. Thus, part of them, especially Changxiangdong Bridge has had many problems, such as concrete beam cracks, protective layer peeling off and piers corrosion and so on.

Changxiangdong Bridge is a concrete T-beam bridge, 10 holes × 16 meters, has a length of 178.91m. It is found that there are a total of 179 cracks on this bridge, small and large. The width of the largest crack reaches 0.9mm. Many of them have cracks in central part of beams, diagonal shear cracks in quarter point of midspan to supporting seat, and there are defects in beams and exposed bars (see Figures 1 and 2). These were mainly because the beam has no strong resistance to bending and shear-bearing capacity, for the beam will crack if bending normal stress, shear stress and bending stress exceed cracking resistance of concrete.

**Figure 1: Diagonal shear cracks on web near supporting seat**

**Figure 2: Cracks in main beam**

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## II. CALCULATION AND CHECK

*2.1 Calculation parameters*

The "Bridge Doctor" is a Finite Element Program[4], which be used to calculate and analyze the force bearing status of main beams of Changxiangdong Bridge during operation. Calculated beam span is the main beam of 16m, design load is standard railway live load, dynamic coefficient is 1.26; main beam concrete adopts C25, gravity density is $\gamma$ =26KN/$m^3$ ; main reinforcement, stirrup, horizontal strengthened bars, ballast horizontal bar are rebar T20MnSi.

There are 18 units in total, discretization figure is shown as follows:

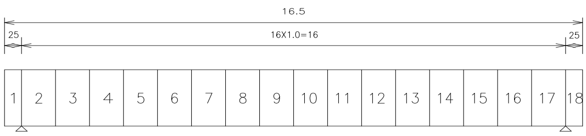



**Figure 3: Structural discretization figure**

*2.2 Section stress checking computation result*

Allowable stress method is used in calculating the intensity of normal section of main beam, allowable stress of concrete C25 takes 8.5MPa, and allowable stress of rebar T20MnSi on 16m span bridge is calculated on a basis of 160MPa[5-6]. The result is shown in Table 1.Calculation result of shear stress of main beam's section is shown in the table 2.

**Table 1: Checking computations on main beam's section normal stress (unit: MPa)**

| Checking item | Section position | | | | |
|---|---|---|---|---|---|
| | Supporting point | 1/8L | 1/4L | 3/8L | 1/2L |
| Concrete stress | 0 | 4.67 | 7.49 | 8.46 | 8.87 |
| Reinforcement stresses | 0 | 50.86 | 77.93 | 85.66 | 89.01 |
| Whether or not meet specification | Y | Y | Y | Y | Y |

**Table 2: Checking computations on shearing strength of main beam's section (unit: MPa)**

| Checking item | Section position | | | | |
|---|---|---|---|---|---|
| | Supporting point | 1/8L | 1/4L | 3/8L | 1/2L |
| Principal tensile stress | -1.7 | -1.3 | -0.86 | -0.45 | -0.29 |
| Whether or not meet specification | Y | Y | Y | Y | Y |

*2.3 Analysis on checking computation results*

It can be seen from the above result that:

1). Concrete stress of 16m main beam's midspan section has exceeded the allowable value of the specification, and fulcrum section's shear stress is very close to the specified limit, main beam's carrying capacity is not in a safe extent.

2). Crack resistance of the bridge's normal section meets the requirement, but the crack width of 16m span is very close to the specified limit, and the result is in line with the phenomenon that a lot of cracks has been detected on 16m main beam.

On the basis of the statistics and analysis on the damages on Changxiangdong Bridge, and the preliminary check according to Railway Bridge Test Specification, it is found that the number and width of cracks on this bridge are beyond the scope of security, with cracks covering in shearing zone of web and bending zone of beam bottom, and other damages are very serious. It also reveals that its carrying capacity is difficult to meet the growing capacity needs, and its main beam needs to be reinforced to increase its carrying capacity.

## III. CHANGXIANGDONG BRIDGE'S MAIN BEAM REINFORCEMENT DESIGN AND TESTING

*3.1 Main beam reinforcement design*

In order not to destroy the main beam and improve its carrying capacity, the reinforcement was completed by sticking CFRP on 16m beam bottom so that the components' flexural bearing capacity and shearing capacity can be improved.

CFRP is a kind of structural reinforcement composite sheet produced from carbon fibers with high strength and elastic modulus that are presoaked by epoxy[7]. It is stuck, with epoxy as binder, on damaged components along the forced direction or the direction perpendicular to cracks[8]. As a shearing force connection media between them, the binder will form a new kind of complex, making the reinforced patches and original rebar carry load jointly, which increases the resistance to tension or to shear and effectively improves the strength, stiffness, ductility and crack resistance and controls the worsening of cracks and deflections[9-10].

The performance indicators of the CFRP used in this reinforcement engineering are as follows: fiber has an weight per unit area of 300g/$m^2$, design thickness is 0.167mm, tensile strength is 3400MPa, modulus of elasticity is 2.3 × 105 MPa.

The reinforcement scope covers: two layers of CFRP need to be stuck at the bottom of 16m main beam, the length is one-third span from midspan to both sides; the wide is equal to the full width of main beam's bottom; in addition, CFRP of 0.25m wide needs to be stuck in 1/4L span in the main beam, with three pieces in each side of webs, 12 pieces of CFPR needs to be stuck in each beam (as shown in Figure 4).

（a）Beam end

（b） Beam bottom

**Figure 4: Beam CRPF reinforcement effect**

*3.2 Beam CRPF reinforcement analysis*

In this reinforcement engineering, three-forth span and one-forth span shearing zone in beam bottom of Changxiangdong Bridge are pasted with transverse and longitudinal carbon fibers, which are flat, have no wrinkles, no hollowing and stuck tightly with underlying concrete structure, no degumming; in the mean time, load testing and calculation was conducted for the reinforced bridge, as follows:

1). Structural analysis model

Dynamic load testing is conducted on the reinforced beam, computing is done with QLJC. The bridge was divided into 38 units longitudinally in total as shown in the following figure:

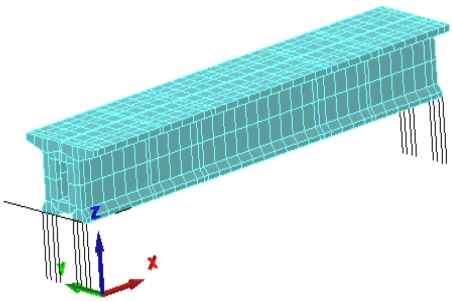
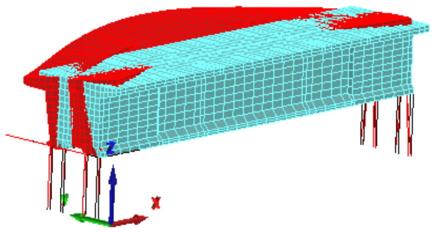


**Figure 5: Beam analysis model**

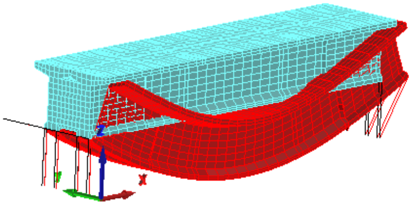
Cast-in-place main beam material is concrete C25, gravity density is based on equation $\gamma$ =26KN/m$^3$. Calculated live load is standard railway live load.

2). Natural frequency and modes of vibration

Software is used to calculate the second-order longitudinal natural frequency and modes of vibration of a single span structure, which is shown in the figure below:



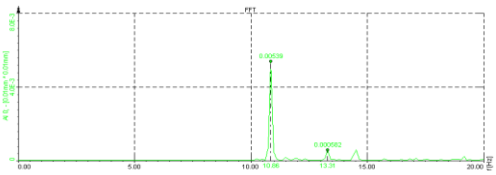
**(a) f1=9.10Hz**



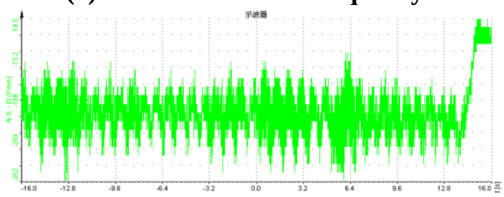
**(b) f2=12.62Hz**

**Figure 6: Calculated vibration mode and natural vibration frequency of the beam**

According to test requirements, a dial indicator is installed under each beam floor as dynamic deflection measurement point, testing the dynamic deflection of bridge structure under load of passing trains. In addition, the natural vibration frequency of the structure is analyzed on the basis of the dynamic deflection testing, as shown in Figure 7.



**(a) Natural vibration frequency**



**(b) Vibration curve**

**Figure 7: Measured natural vibration frequency and vibration curve of Changxiangdong Bridge**

Analyze the structure's dynamic stiffness through comparing measured natural vibration frequency and calculated result. The testing result is shown in Table 3 below:

**Table 3: Comparison between measured value of the second-order natural vibration frequency and calculated result of the bridge**

| Order No. | Calculated value | Measured value | Ratio of calculated value and measured value (calibration coefficient) |
|---|---|---|---|
| 1 | 9.10 | 10.86 | 0.838 |
| 2 | 12.62 | 13.31 | 0.948 |

It can be seen from Table 3 that measured value of the second-order natural vibration frequency is higher than the calculated value under full load, that is, dynamic stiffness of the tested bridge meets requirements of the specification.

3). Live load dynamic coefficient μ

A train’s vertical live load, which contains vertical dynamic effect, is computed by the train’s vertical net live load timing dynamic coefficient $(1+\mu)$ which is calculated based on the following equation:

$$1+\mu=1+\alpha\left(\frac{6}{30+L}\right) \qquad (1)$$

Where in: $\alpha=4(1-h)\leq 2$ ;

1.26 is the dynamic coefficient when calculating 16m span bridge.

Measured midspan dynamic coefficient:

$1+\mu=2\times fmax/(f_{max}+f_{min})$, and $f_{max}$ and $f_{min}$ are the peak and trough value of deflection curve.

The comparison between the bridge’s measured dynamic coefficient and calculated value is shown in Table 4, and measured dynamic deflection curve is shown in Figure 8.

**Table 4: Comparison between the beam’s measured dynamic coefficient and calculated value**

| Dynamic deflection peak value $f_{max}$ (0.01mm) | Dynamic deflection trough value $f_{min}$ (0.01mm) | Calculated value of dynamic coefficient | Measured value of dynamic coefficient | Ratio of measured value and calculated value (calibration coefficient) |
|---|---|---|---|---|
| 254 | 156 | 1.26 | 1.24 | 0.984 |

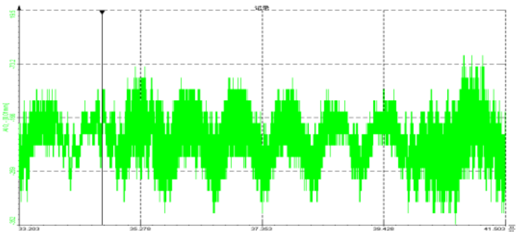


**Figure 8: Changxiangdong Bridge (full capacity) measured dynamic deflection curve**

It can be seen from Table 4 that the actual dynamic coefficient is lower than the midspan impact coefficient’s calculated value that is based on main bridge’s basic frequency: $1+\mu=1.26$, which meets requirements of the specification.

According to dynamic load testing result, the first-order natural vibration frequency is higher than the calculated value after reinforcement, which means that the structure’s dynamic stiffness meets standard requirement and there is a certain dynamic stiffness reserve. In the mean time, the dynamic coefficient of each bridge is less than the calculated value of the actual midspan bridge structure, showing that the structure’s impact property is within the specification limits, meeting requirements.

In short, the reinforcement engineering of Changxiangdong Bridge has achieved significant effect, with its reinforced structural dynamic stiffness, dynamic coefficient and other design indicators in line with requirements.

## IV. CONCLUSION

The reinforcement and repair engineering of Changxiangdong Bridge covers works related to carrying capacity enhancement, damaged concrete, exposed reinforcing bar repair, cracks treatment, main beam transverse bulkhead repair and supporting seats repair and so on.

1) The 16m span Changxiangdong Bridge was reinforced by using the method of CFRP. In the course of reinforcement, the CFPR was stuck well, and no hollowing and degumming was found; the technique is simple, with short construction period and expected effect.

2) The strength testing results show that the strength of reinforced concrete after reinforcement meets the design requirements, and there is a certain safety margin; the bridge’s supporting seats are clean and free from foreign matter stuck and rust, and they were subject to antirust and lubrication treatment and can slide freely.

3) The dynamic stiffness of each reinforced bridge structure is in line with the requirements, and there is a certain reserve, and the impact performance meets requirements of the specification. After reinforcement and repair, the bridge’s work performance was improved much, meeting its capacity requirements.

**CONFLICTS OF INTEREST**
The authors confirm that this article content has no conflicts of interest.

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