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Steel-Concrete Combination Structure Strengthening Method On Bridge Maintenance

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Abstract. Taking west quay No.15 bridge reinforcement in Beijing as an example, the application of the steel-concrete composite structure in T girder bridge reinforcement engineering is analyzed in this paper, which focuses on the performance comparison before and after reinforcement such as the bearing capacity of the bridge (bending, shear), the dynamic characteristics (natural frequencies and natural period). Data analysis results show that Bridge bending and shear carrying capacity greatly increased and so as the dynamic characteristics by steel structure and mixed reinforcement method, which meets the requirements of the specification and provides an important basis for the same type of bridge reinforcement.

1. Introduction

Transport infrastructure is the basic of national economic and social development. Reinforced bridge is the important part of transportation infrastructure, and play key role in transport system. With the urbanization of city, traffic volume is increasing, the type of vehicle is tending to be larger, and the load of bridge is also getting larger. Due to many old worn and damaged bridges and be, or the limit of old design standards, the carrying capacities of many bridges are insufficient, which cannot meet the requirement of modern traffic. In order to avoid the loss of function of the substandard bridges, it is necessary to reinforce the aged bridges. Now there are many bridge reinforced methods, for example, large section reinforcement, prestressed reinforcement, steel-bonded reinforcement method, FRP bonded reinforcement, changing structure force distribution method, and steel-concrete combined structure reinforcement. Among those methods, steel-concrete combined structure reinforcement is a very effective method.

The paper takes the Beijing dewaixi river bridge as example, studies the application of steel-concrete combined structure reinforcement on T beamed bridge, compare the status of the bridge before and after reinforcement from dynamic characteristics and carrying capacity. The results show that the rigidity and carrying capacity of the bridge enhances remarkably, life-span of structure is prolonged, and usability of structure is enhanced, so the enforcement method is promising.

Steel-concrete combined structure reinforcement is a new structure based on steel structure and steel reinforced concrete which concrete on the top, around or inside the profile steel, combine steel and concrete which work together [1]. Steel-concrete combined structure shows each advantages of steel and concrete with high carrying capacity, high rigidity, good stretch ability and earthquake-resistance, low cost, and easy construction. Thus the steel-concrete combined structure is widely used. In Japan, composite structure, traditional timber structure, masonry structure, steel structure, and steel reinforced concrete structure are five popular structure systems. There are five common composite structures, that is, profiled steel sheet and concrete composite slab, steel and concrete composite beam,



steel reinforced concrete composite structure, encased structure, and steel encased concrete structure. At present, steel encased concrete structure and externally bonded fiber reinforced concrete structure are commonly applied in concrete structure projects [2-6].

2. Overview

DewaixiRiver Bridge lies at the north of jishuitan flyover, crosses over palace moat with three spans (see Fig.1). The first span and the third span are reinforced concrete hollow slabs. The second span has 36 beams whose cross section is 6 T-beam+3 I beams+18 wide abdominal T beams+3 I beams+ 6 T-beam. The design load class is truck-20, and trailer-100.

In September 2005, construction engineering quality test institution make a periodic test for the bridge. Bridge condition index (BCI) is 78.88, therefore, the test result shows that the class of the bridge is C. In 2014, the class of the bridge is D based on the result of new test.

In 2015, march, field investigation is carried on. The main bridge diseases are:



Figure 1. Dewaixi River Bridge

①the L and U shaped fissure of wide abdominal T beam and slant fissure exist and are beyond the limit. The L and U shaped fissure at the middle of span is bending fissure for act of long term load. The tensile stress at the bottom of beam increase, and exceed the ultimate tensile strength, which lead to the existence of vertical fissure on web and further flexural fissure. The fissure of the range of fixed pivot is typical shear cracks. Those cracks which are structural crack affect the carrying capacity. The case of the cracks is shown in Fig.2.

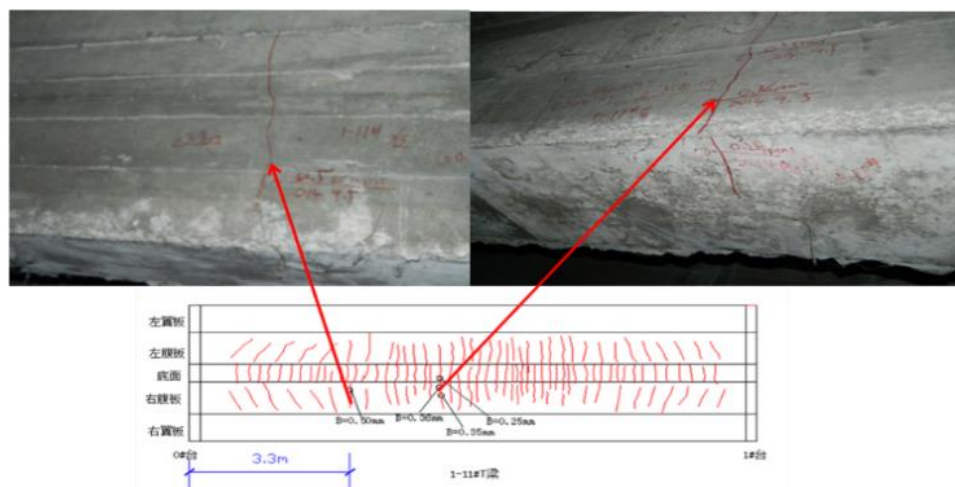


Figure 2. beam body cracks

②there usually exist longitudinal crack on bridge deck pavement, because there is no reliable horizontal linkage between wide abdominal T beams and the pavement is repeatedly acted by dynamical load.

③Concrete expansion crack, peeling, exposed reinforcing bar, aggregate exposure exists at the beam of the middle because the high water level affects the beam and leads to the concrete degradation, steel corrosion expansion, and concrete peeling and exposure.

3. The Bridge Reinforcement Scheme

3.1. The Design Principle of Reinforcement

①Based on the bridge test and field investigation information and the main diseases which affect its safety, usability and durability of the bridge, a reinforcement scheme is presented.

②The reinforcement design scheme should consider the workload and convenience of later maintenance stage, and the safety and durability of structure.

③Safe operation of bridge should be guaranteed after reinforcement.

④The bridge reinforcement scheme should be easy to implement.

3.2. Crack Treatment

The diseases of Dewaixi River Bridge, for example, cracks of superstructure, concrete damage, steel exposure, reduce the rigidity, safety and durability of original structure. If those diseases cannot be repaired timely, the carrying capacity and normal use will be affected. The repair method is as follows: for the crack great than or equal to 0.15mm, it is coated by polymer mortar; for the crack less than 0.15mm, it is filled by polymer mortar.

3.3. Beam Reinforcement

Under act of long-term load encased steel structure, the damage of beam exists, and affect the safety and durability of bridge. Thus, the reinforcement scheme of encased steel structure increases the size of structure cross-section, optimize the structure stress, and enhance the carrying capacity of beam. The reinforcement scheme is show in Fig.3.

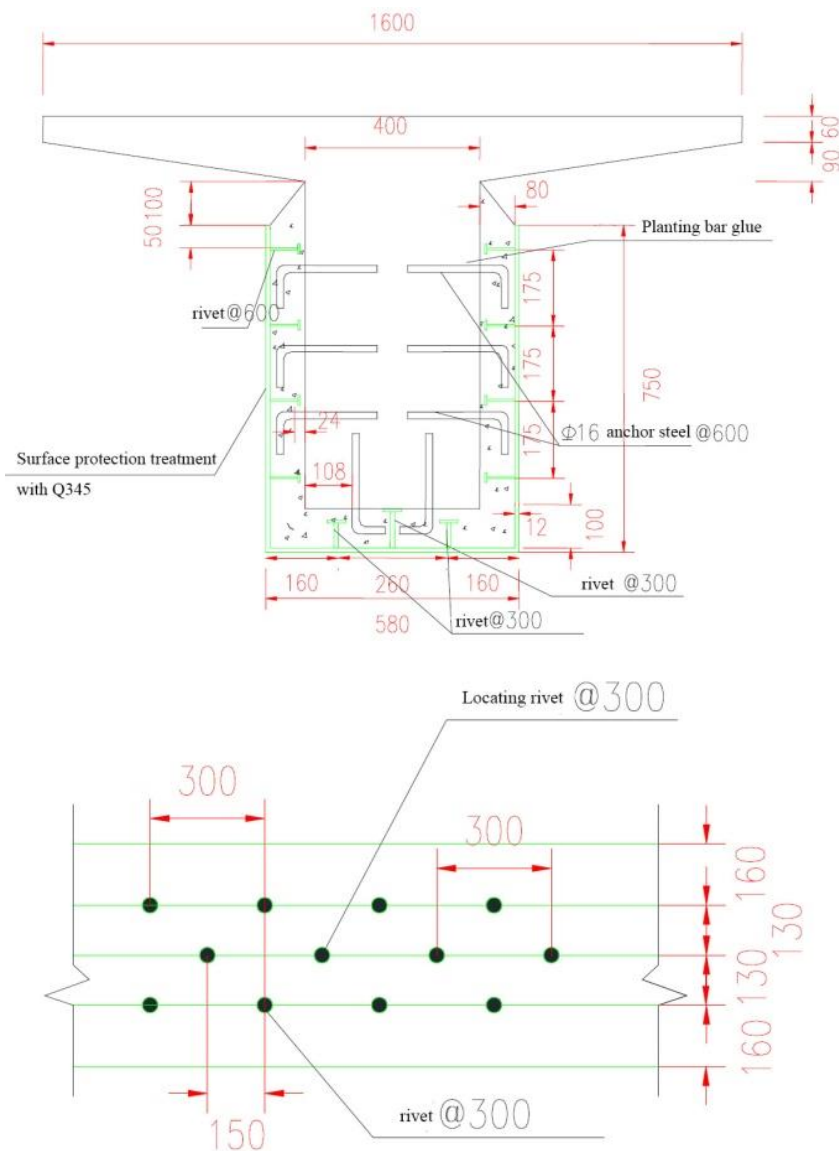


Figure 3. Beam reinforcement figure

4. Structure Analysis after Bridge Reinforcement

4.1. Carrying Capacity Calculation

4.1.1. *Check Calculation of Ultimate Bearing Capacity of Bending.* The ultimate bearing capacity of bending of composite beam after steel plate reinforcement is computed as:

$$\gamma_0 M_d \leq f_{cd1} b x (h_0 - \frac{x}{2}) + f_{sd}' A_s' (h_0 - a_s') + E_{sp} \epsilon_{sp} A_{sp} a_s \quad (1)$$

Concrete compression height is:

$$f_{cd1} b x = f_{sd} A_s + E_{sp} \epsilon_{sp} A_{sp} - f_{sd}' A_s' \quad (2)$$

Under ultimate capacity state, tension strain of steel plate is calculated as:

$$\varepsilon_{sp} = \frac{\varepsilon_{cu}(\beta h - x)}{x} - \frac{\varepsilon_{c1}(h - x_1)}{x_1} \quad (3)$$

ε_{c1} is the compression stress of concrete edge of compression zone, and the equation of ε_{c1} is given in Eq.(4).

$$\varepsilon_{c1} = \frac{M_{d1}x_1}{E_c I_{cr}} \quad (4)$$

The scheme of reinforcement is modelled by Bridge Doctor software. The envelope diagram of the bending resistance capacity of the original bridge is shown in Fig.4. From Fig.4, the safety factor is $K = 1026.95/961.24 = 1.06$. Safety margin of the bending resistance capacity is not enough. The bending resistance capacity of encased steel structure computed by Eq.(1) is 1591kN.m. The bending resistance capacity of encased steel structure calculated by Bridge Doctor software is 1574 kN.m. the error between the two methods is within permissible range.

Because the origin structure damaged seriously, and the effect of linkage of new and original concrete is unclear, 20% discount is given to the calculated result based on previous experiences. The bending resistance coefficient is $K1 = 1574 \times 80\% / 961.24 = 1.31$, and the bending resistance coefficient increase by 24%.

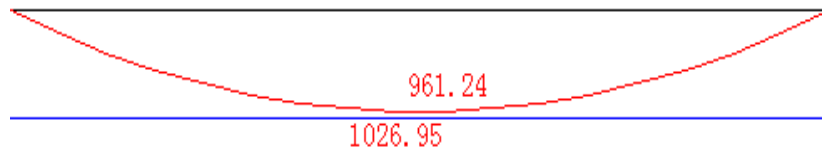


Figure 4. The bending bearing capacity Envelope diagram

4.1.2. Check calculation of ultimate shear capacity. The ultimate shear capacity of steel concrete composite beam is calculated as:

$$V = V_c + V_g \quad (5)$$

where V_c is the ultimate shear capacity of the concrete flange plate which is calculated in Eq.(6):

$$V_c = d \left(\frac{0.2}{l + 1.5} f_c + r_p f_p \right) b_{ce} h_{ce} \quad (6)$$

where V_g is the ultimate shear capacity of steel beam which is calculated in Eq.(7):

$$V_g = 0.9 h_w t_w f_v \quad (7)$$

where, ρ_π is the stirrup reinforcement ratio of concrete frange plate; f_π is the design value of shear capacity; δ is the coefficient which reflects the degree of the effect of concrete frange plate on the shear capacity of composite beam; b_{ce} is the effective width of frange plate; h_{ce} is the effective height of frange plate;

The shear capacity is 377kN by Eq. (5), and the design value of the shear capacity is 197kN, which indicates that the shear capacity meets the design requirement. The shear capacity of the original bridge is 248Kkn and the safe coefficient of shear capacity is $K2 = 377 \times 80\% / 197 = 1.53$. The shear capacity of increase by 22% after reinforcement

4.1.3. The check calculation of limit states of serviceability. The crack width under the states of serviceability by Bridge Dr. software is calculated. The maximum width of crack at the middle span is 0.3mm, and the required value of crack with by standard is less than 0.2mm, so the crack value under the states of serviceability cannot meet the standard requirement. After bridge reinforcement, the crack value computed by equivalent cross-section method is 0.1mm which indicates that it meets the requirement of the states of serviceability.

In conclusion, the carrying capacity of the bridge structure after reinforcement compared with the original bridge increase greatly, and the structure is more safe and durable after reinforcement.

4.2. The Analysis of Dynamic Characteristics of Structure

4.2.1. The method of dynamic characteristic theory. In dynamic characteristic theory, the basic dynamic characteristics are inherent frequency and mode of vibration. It is necessary to analyze the characteristic of inherent frequency before the analysis of the dynamic response of bridge structure. because the dynamic response of the structure under forced vibration is closely related to the dynamic characteristic of the structure. The dynamic balance method based on d'Alembert's principle is used to directly establish the undamped free vibration equation, by ignoring the influence of damping, the nonzero solution of the vibration equation (see Eq.8) can be obtained under non-zero initial condition

$$M \ddot{u} + Ku = 0 \quad (8)$$

Assuming that harmonic vibration exists in the structure, the displacement of harmonic vibration is given in Eq.9.

$$u(t) = \phi \sin(\omega t + \theta) \quad (9)$$

where, ω is the frequency of vibration; ϕ is a time-independent vector ; θ is the initial phase angle; t is time.

substitute $u(t)$ and its second derivative into Eq.(8), the Eq.(10) is obtained:

$$K\phi = \lambda M\phi \quad (10)$$

where, ϕ is modal vector; $\lambda = \omega^2$ is the eigenvalues; ω is the Free vibration frequency.

From the point of view of mathematics, there are many methods to solve the eigenvalue of matrix, and most of them have been programmed by computer numerical simulation. From the perspective of engineering application, we usually use Jacobi method in case there are not many degrees of freedom in the structure and it does not take too much time to solve all frequencies and modes of vibration [7]. However, in practical engineering structures, after being discretized by finite element method, it often contains thousands or even tens of thousands of dynamic degrees of freedom. In this case, it will take a lot of time for engineers to solve all the frequencies and modes of vibration. The dynamic action of civil engineering structures under external loads (such as earthquake, wind, etc.) mainly stimulates a small number of low-order vibration modes of the structure, while vibration modes higher than a certain frequency value do not contribute much to the dynamic response of the structure [8-10], so they can be ignored. In this way, only a few low order modes need to be solved in practical numerical analysis. Theoretically, the solution of the characteristic value has been obtained from the mathematical perspective, among which the most used method should be the subspace iteration method [11]. The subspace iteration method adopted in this paper can effectively overcome the difficulty of the slow convergence speed of numerical calculation when several frequencies are very close, which includes the advantages of high accuracy and reliability compared with other methods.

4.2.2. *Simulation analysis of dynamic characteristic.* In the finite element model by Midas (given in Fig.5), the T-beam structure before reinforcement is viewed as link elements, and the section adopts design section. For the T-beam structure after reinforcement, the calculation model is the steel-concrete composite beam structure, the section adopts the joint section. As the steel beam and T beam are connected by a bolt, the shear slip between the steel beam and concrete is ignored in the calculation.

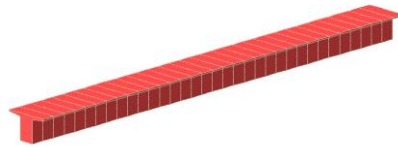
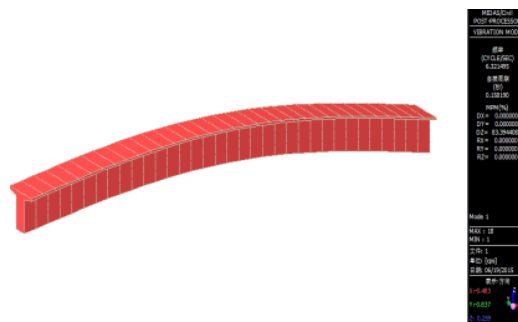
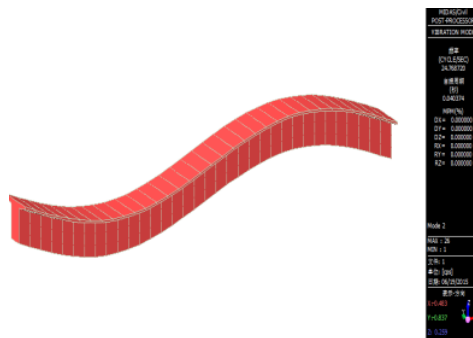


Figure 5. Midas calculation model

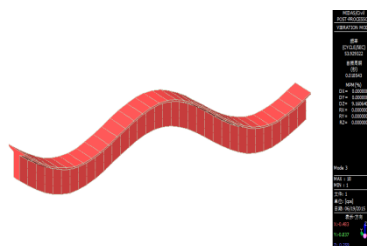
the previous third-order mode before and after reinforcement is shown in Fig.6.



vibration mode 1 after reinforcement



vibration mode 2 after reinforcement



vibration mode 3 after reinforcement

Figure 6. Modal analysis after reinforcement

The values of dynamic characteristic of the structure of the previous third-order mode before and after reinforcement is listed in table 1.

Table 1. the values of dynamic characteristic of the structure

Modes	1	2	3
Frequency before reinforcement	5.84	22.8	49.8
Frequency after reinforcement	6.32	24.8	53.9
Period before reinforcement(s)	0.17	0.04	0.02
Period after reinforcement (s)	0.16	0.04	0.02

From Table 1, the frequency of the previous third-order mode increases greatly, and the period reduces, which shows that the rigidity of structure increases, accordingly dynamic performance enhances, and the method of reinforcement satisfied the requirement of structure.

5. Conclusion

The paper based on the reinforcement of Beijing west quay No.15 bridge introduces the calculation method of steel encased T-beam in engineering application, compares structural carrying capacity and structural dynamic characteristics of main beam before and after reinforcement. The results show that the rigidity and carrying capacity of bridge after steel-concrete composite structure reinforcement is increased remarkably, the service life of the structure is effectively lengthened, and the performance of structure is also increased. the reinforcement method satisfies the requirement of the development of sustainability and has great prospect.

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