

## Application of Bonding Steel Plate with Ballast to Reinforce Composite Box Girder Bridge

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**Abstract.** In order to change the shortcoming of bonding steel plate method, which can't improve the stress state of the original structure, this paper analyzed the causes of diseases of the composite box girder bridge at Yancheng east interchange bridge, compared and analyzed the difference between the bonding steel plate method with or without ballast at adjacent span, and bonding steel plate method with ballast at adjacent span is selected as the reinforcement method., which can both improve the bearing capacity and stress state of the girder. The result provides reasonable recommendations of the reinforcement of similar disease composite box girder bridge.

### Introduction

With the rapid development of transportation, new challenges and new problems are appeared in the work of management and maintenance of highway. Composite box girder bridge is widespread used in the construction of highway bridges. Some of the composite box girder bridges, which were constructed at the end of the last century, appeared different degrees of disease. The reinforcements of bridge [1, 2] can classify by two categories. One class is the passive reinforcement method, such as increase cross-section method, bonding steel plate method [3] and bonding fiber composite method. The second class is the active reinforcement method, such as prestressing method [4] and change of structural system method.

Bonding steel plate reinforcement is the method to reinforce concrete structure by bonding the steel plate to the weak position with epoxy resin binder to form monolithic structure to bear loads. The method can enhance the flexural, shear capacity and stiffness of the structure, and restricted the development of crack, finally improve the bearing capacity and durability of the bridge [5].

The method needs less space, does not reduce the headroom of the structure, the position and degree of reinforcement can be set flexible, short construction period and have little effect to the traffic. But it can't improve the original stress state of the structure, thus limits the application in the reinforcement of structure.

This paper compared and analyzed the difference between the bonding steel plate method with or without ballast at adjacent span, and select bonding steel plate method with ballast at adjacent span as the method to reinforce Yancheng east interchange bridge. The result provides reasonable recommendations of the reinforcement of composite box girder bridge which have similar disease.

### Background of the Yancheng East Interchange Bridge

**Summary of the Bridge.** Yancheng east interchange bridge (pile No. K997+544.1), stride across S331 and Chaoyang river, is an important part of G15 in China. This bridge has a length of 605.355m, and is composed of (3\*20+4\*20)m reinforced concrete continuous box beam+(25+32+25)m prestressed concrete continuous box girder+3\*(5\*25)m composite box girder. The design load is Truck-Load over 20 and Trailer-100. The bridge has two separate framing, with the width of 17m each. Fig.1 is the Yancheng east interchange bridge, and Fig. 2 shows the typical

cross section of the bridge.



Fig. 1 Yancheng east interchange bridge.

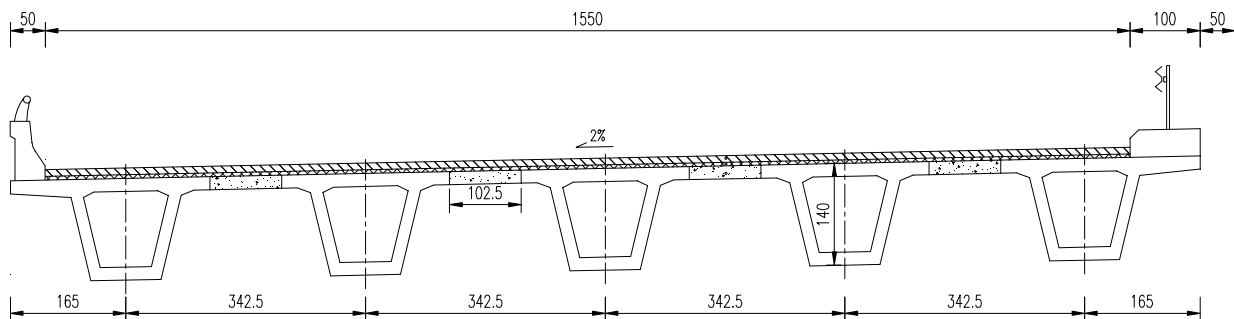


Fig. 2 Typical cross section of composite box girder (unit: cm).

The pavement is composed of 6cm cement concrete and 10cm asphalt concrete. The height of the girder is 1.4m, thickness of top plate is 18cm. Both the thickness of bottom plate and web is 18cm at the middle span sections and 25cm at support section. The prestressed tendons of each girder in side span are 4\*15-5 and 2\*15-4, while 4\*15-4 and 2\*15-3 in each girder in midspan. The prestressed tendons in each girder at continuous pier are 3\*15-5 and 2\*15-4. Fig. 3 is the cross section of girder.

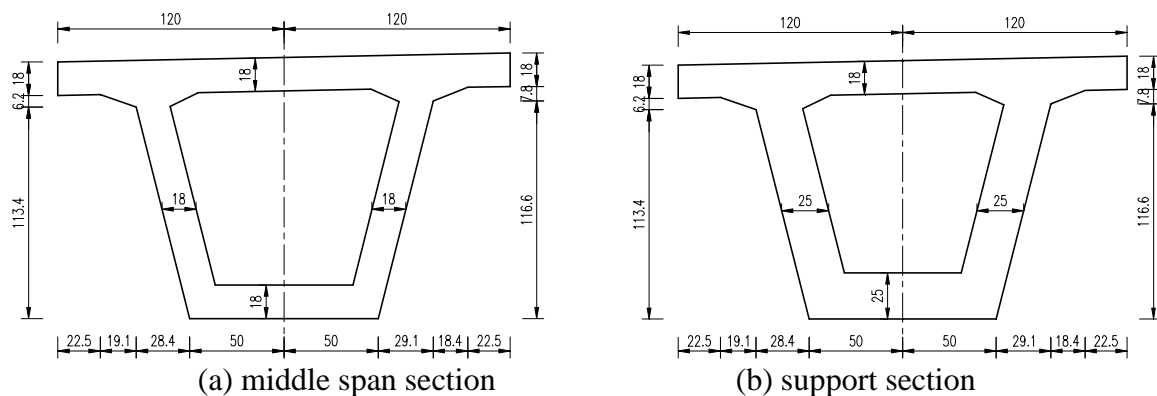


Fig. 3 Cross section of composite box girder (unit: cm).

**Status of Diseases.** Periodic inspection of the composite box girder(No.4~6 bridge) of Yancheng east interchange bridge is taken by Jiangsu Province Communications Planning and Design Institute Limited Company in 2010, 2012 and 2014. And special examination is done in 2014.12. The development of the disease is shown in Fig. 4.

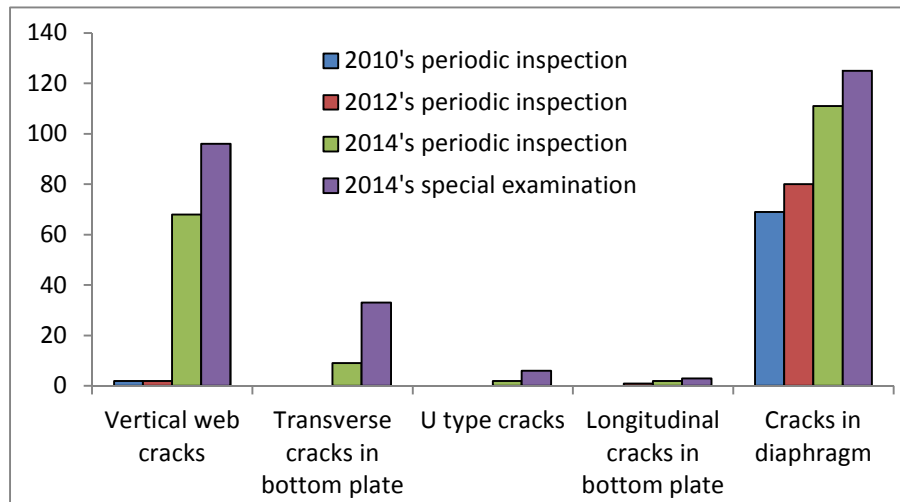
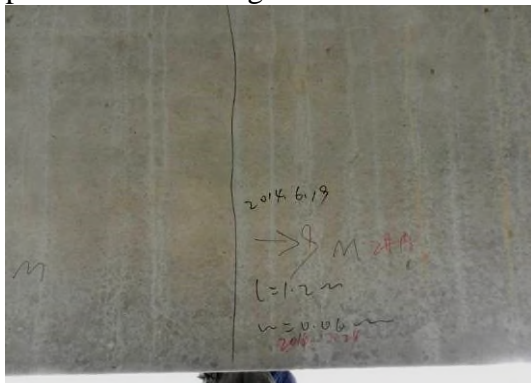
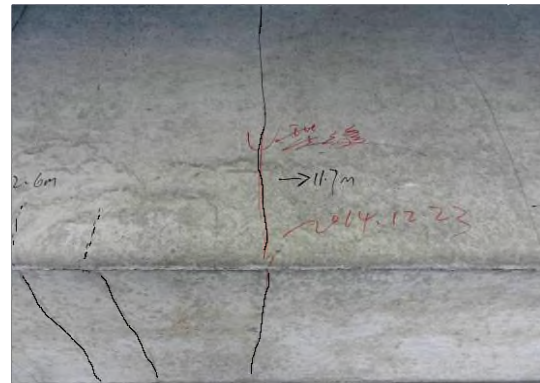


Fig. 4 Development of the disease

Typical cracks of the girder are shown as follows:



(a) Vertical web crack



(b) U type crack



(c) Transverse cracks in bottom plate



(d) Cracks in diaphragm

Fig. 5 Typical crack of the girder.

### Analysis of the Causes of Disease

The design load of G15 is Truck-Load over 20 and Trailer-100, but practical load is bigger than this. Refer to the research of “Practical Load of Beijing Shanghai Expressway (G2) and the Influence to the Concrete Composite Box Girder Bridge”, operating load is considered as 1.3 times of Truck-Load over 20.

According to “Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts”( referred as “85 standard”) [6], operating load is considered as 1.3 times of design load [7], the bending strength of the girder under combination I&II is studied. Fig. 6-9 shows the bending moment and bearing capacity [8, 9] of the middle beam and side beam under operating load.

## Middle Beam.

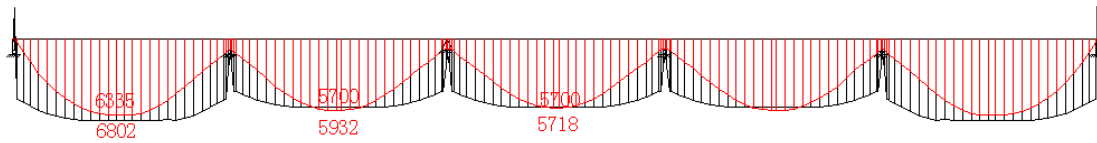


Fig. 6 Maximum bending moment and bearing capacity under combination I(unit: kN·m).

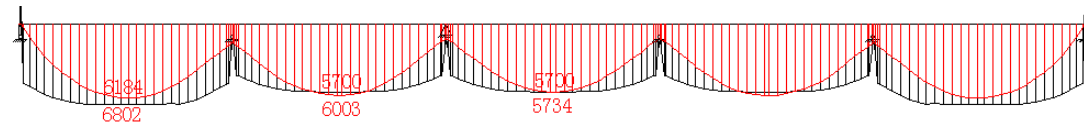


Fig. 7 Maximum bending moment and bearing capacity under combination II(unit: kN·m).

## Side Beam.

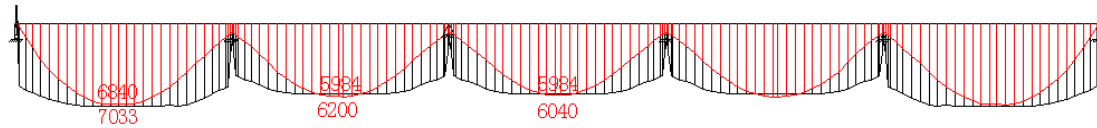


Fig. 8 Maximum bending moment and bearing capacity under combination I(unit: kN·m).

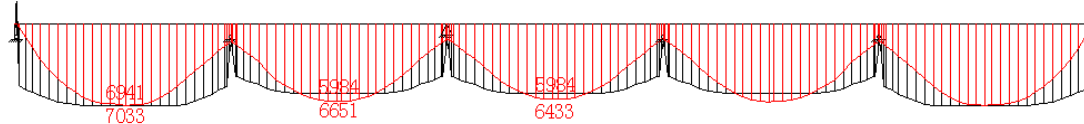


Fig. 9 Maximum bending moment and bearing capacity under combination II(unit: kN·m).

According to analysis:

- (1) Under the operating load, the bearing capacity of the girder in side span of the bridge meet the requirement of the “85 standard”, but the rest of the girder can’t.
- (2) The shear capacity and shear’s size to meet the “85 standard” requirements.
- (3) Stress and principal stress can meet the requirements of “85 standards”.

There is a variety of reasons leads to the cracks of composite box girder. According to the disease situation, the main reasons are shown in Table 1.

Table 1. Analysis of the cause of disease.

	Disease description	Structure shape and reinforcement ratio	Lack or loss of prestress	Construction	Over load
1	Vertical web cracks (shrinks)	√	√	√	
2	Vertical web cracks (bending)	√	√	√	√
3	Transverse cracks in bottom plate	√	√	√	√
4	Cracks in diaphragm	√		√	√

## Bonding Steel Plate Reinforcement

The original bonding steel plate reinforcement is the reinforcement method, and can’t improve the original stress state of the structure. Bonding steel plate method with ballast at adjacent span is semi passive semi active reinforcement method, and can improve the strength of the box girder, improve the original stress state of the girder, and limit the concrete crack. Fig. 10 shows the comparison between bonding steel plate method with or without ballast.

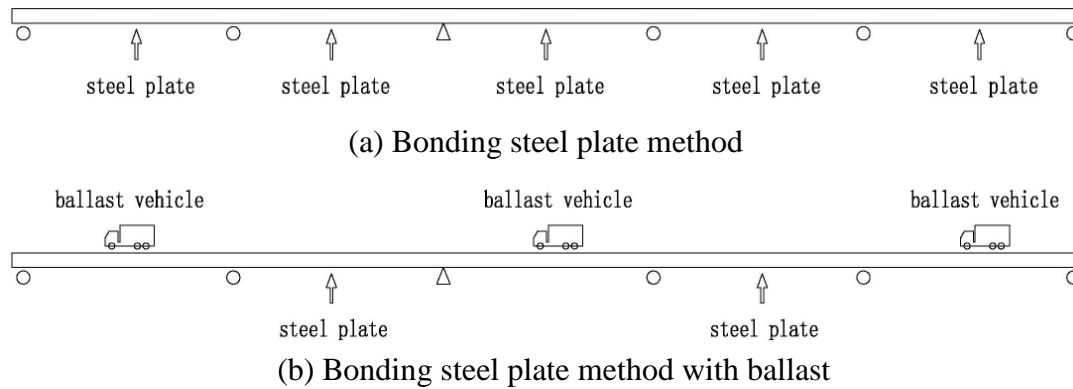


Fig. 10 Comparison between bonding steel plate method with or without ballast.

Two strips of steel plate(250\*5mm) are bonded to the bottom plate, and two strips(200\*5mm) are bonded to each web of the girder. Fig. 11 shows the arrangement of the steel plates.

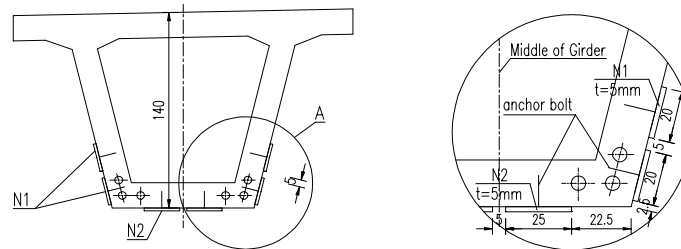


Fig. 11 Arrangement of steel plates.

The weight of ballast vehicle is 300kN, the load of front axle(P1) is 60kN and both of the two rear axle(P2 & P3) is 120kN. The size and axle load of the vehicle is shown in Fig. 12.

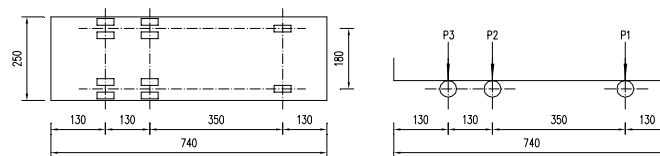


Fig. 12 Size of the vehicle (unit: cm).

Bonding steel plate method with ballast at adjacent span is selected as the reinforcement method of the composite box girder bridge. The vehicles were located at span 1, 3 & 5, when the steel plates were bonded to the girder of span 2 & 4. Fig. 13 only shows the location of the vehicles at one span.

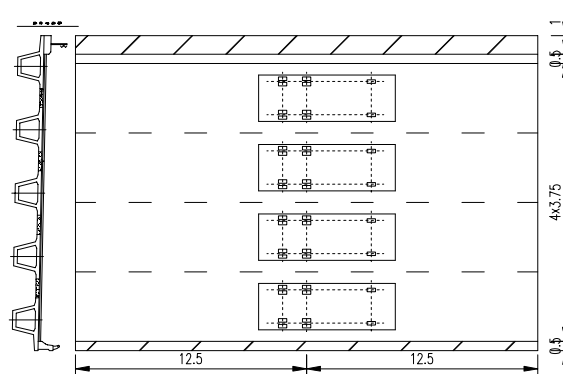


Fig. 13 Location of vehicles (unit: m).

The construction steps are as follows:

(1) Drilling and planting anchor bolts at the web and bottom plate of the girder.

- (2) The vehicles are located at span 1, 3 & 5, when the deformation of the girder don't change , the steel plates should be bonded to the girder of span 2 & 4.
- (3) Revoke the ballast at span 1, 3 & 5 after the binder cured.
- (4) Then vehicles are located at span 2 & 4, when the deformation of the girder don't change , the steel plates should be bonded to the girder of span 1, 3 & 5.
- (5) Revoke the ballast at span 2 & 4 after the binder cured.
- (6) Preservative treatment must be done to the steel plates after the construction of the bonding.

### Analysis of the Bonding Steel Plate Method with or without Ballast

**Analysis of Bearing Capacity.** Due to the difference of the two methods, bonding steel plate method with ballast can apply prestress to the steel plate, thus reduce the internal forces under combination I&II. The method has more advantageous to internal forces. “*Normal*” in Table 2 means bonding steel plate method without ballast while “*Ballast*” means bonding steel plate method with ballast. “ $M_{jmax}$ ” means “resistance to positive moment”, “ $M_{jmin}$ ” means “resistance to negative moment”, “ $M_{maxI}$ ” means “maximum internal force of combination I”, “ $M_{maxII}$ ” means “maximum internal force of combination II”, “ $M_{minI}$ ” means “minimum internal force of combination I”, “ $M_{minII}$ ” means “minimum internal force of combination II”.

Table 2. Comparison of bearing capacity (unit: kN·m).

	Internal forces	Side span		Secondary span		Mid-span	
		<i>Normal</i>	<i>Ballast</i>	<i>Normal</i>	<i>Ballast</i>	<i>Normal</i>	<i>Ballast</i>
Middle Beam	$M_{jmax}$	7918	7918	6610	6610	6610	6610
	$M_{maxI}$	6435	6440	6020	6029	5817	5819
	$M_{maxII}$	6640	6645	6398	6405	6134	6142
	$M_{jmin}$	-5406	-5406	-5406	-5406		
	$M_{minI}$	-2315	-2307	-2725	-2716		
	$M_{minII}$	-2625	-3071	-3093	-3285		
Side Beam	$M_{jmax}$	7860	8127	6861	6885	6861	6885
	$M_{maxI}$	6967	6974	6309	6309	6165	6163
	$M_{maxII}$	7066	7019	6758	6768	6563	6564
	$M_{jmin}$	-5503	-5503	-5503	-5503		
	$M_{minI}$	-2683	-2668	-3171	-2966		
	$M_{minII}$	-3618	-3606	-3728	-3525		

**Analysis of Stress.** Table 3 shows the minimum stress results at the cross section of the girder. Bonding steel plate method with ballast can reduce the minimum stress by 0.15MPa. And the method has certain advantages to the resistant of crack at the cross section.

Table 3. Comparison of minimum stress (unit: MPa).

		Side span		Secondary span		Mid-span	
		<i>Normal</i>	<i>Ballast</i>	<i>Normal</i>	<i>Ballast</i>	<i>Normal</i>	<i>Ballast</i>
Middle Beam	Combination I	-0.21	-0.18	-0.47	-0.39	-0.47	-0.43
	Combination II	-0.46	-0.42	-1.44	-1.37	-1.36	-1.22
Side Beam	Combination I	-1.46	-1.31	-1.35	-1.25	-1.46	-1.39
	Combination II	-1.69	-1.59	-2.35	-2.24	-2.24	-2.13

**Comparison of Principal Stress.** The maximum principal compressive stress of the girder under the operating load are far less than the allowable value of codes, thus only the maximum principal

tensile stress results are compared. The results are shown in Table 4. Bonding steel plate method with ballast can reduce the maximum principal tensile stress by 0.1MPa.

Table 4. Comparison of principal stress (unit: MPa).

		Side span		Secondary span		Mid-span	
		<i>Normal</i>	<i>Ballast</i>	<i>Normal</i>	<i>Ballast</i>	<i>Normal</i>	<i>Ballast</i>
Middle Beam	Combination I	-0.43	-0.43	-0.51	-0.51	-0.5	-0.5
	Combination II	-0.48	-0.45	-1.44	-1.4	-1.24	-1.22
Side Beam	Combination I	-1.46	-1.37	-1.39	-1.3	-1.49	-1.39
	Combination II	-1.69	-1.59	-2.32	-2.24	-2.24	-2.13

## Conclusion

Bonding steel plate method with ballast can reduce the stress and principal stress of the bridge. Though the comparison and analysis of different method, the following conclusion is got:

(1) Bonding steel plate method with ballast can apply prestress to the steel plate, and thus reduce the internal forces under combination I&II. The method has more advantageous to internal forces of the girder.

(2) Bonding steel plate method with ballast can reduce the minimum stress by 0.15MPa. And the method has certain advantages to the resistant of crack at the cross section.

(3) Bonding steel plate method with ballast can reduce the maximum principal tensile stress by 0.1MPa.

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