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Cause Analysis of Transverse Cracks and Reinforcement Mea sures for Midspan of Assembled Box Girder Bridge

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Cause Analysis of Transverse Cracks and Reinforcement Measures for Midspan of Assembled Box Girder Bridge

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Abstract. Taking a prestressed concrete box girder bridge as the research object, this paper analysis the causes of transverse cracks in the middle span of small box girder and adopts external prestressed bars for reinforcement. Two years of monitoring data showed that the strengthening effect was good, which accumulated experience for the treatment of similar bridge structures.

1. Introduction

Simple supported continuous prestressed concrete composite box girders were adopted in the 1st to 7th and 9th to 16th couplings of the bridge's superstructure. The bridge span combination is 3 x 30m, the beam height is 1.6m, the roof thickness is 18cm, the web thickness gradually changes from 25cm near the support to 18cm in the middle span, and the floor thickness gradually changes from 25cm near the support to 18cm in the middle span. The bridge piers of the lower structure adopt rectangular piers and cast-in-place pile foundations. See Fig.1 for the profile of the bridge and Fig.2 for the standard cross section layout of the bridge.
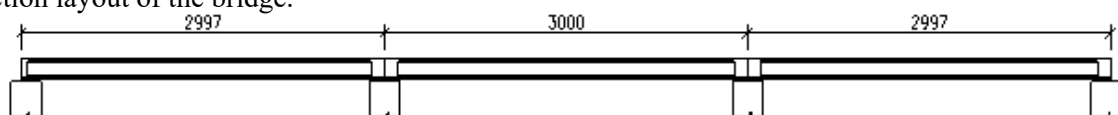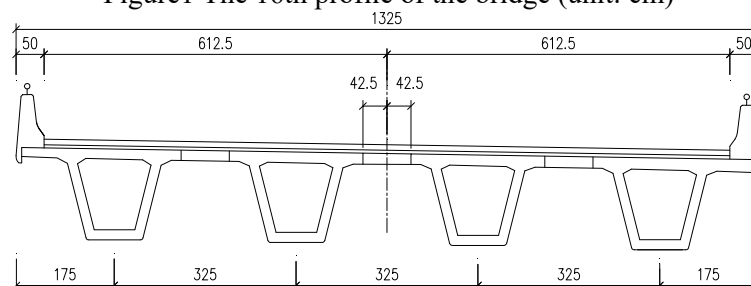

Figure1 The 16th profile of the bridge (unit: cm)

Figure2 Standard cross-section of the bridge (unit:cm)

2.Current situation and cause analysis of the cracks

2.1.Current situation of the cracks

In February 2014, it was first discovered that small box girders had transverse cracks in the floor near the mid-span and vertical cracks in the webs. In June 2015, the number of cracked box girders showed a growing trend. From August to December 2015, the cracked box girders were strengthened with external prestress. In 2016 and 2017, it was found that the unreinforced small box girder continued to crack. The statistics of cracked box girders are shown in Table 1. Typical fracture schematic diagram is shown in Fig. 3.

Table 1 Statistics of cracked box girder

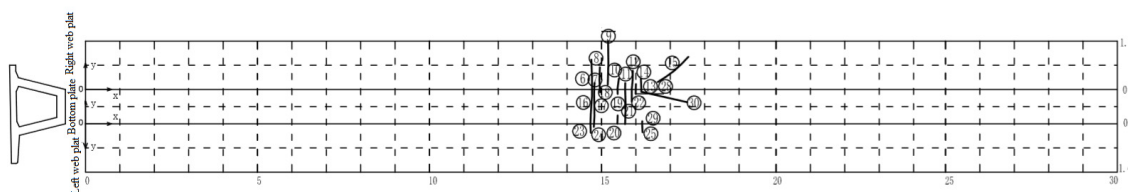| Examine time	Number of cracks	
2014.02	Cracked bridge span (span)	3
	Cracked box girder (piece)	6
2015.06	Cracked bridge span (span)	12
	Cracked box girder (piece)	18
2016.06	Cracked bridge span (span)	8
	Cracked box girder (piece)	14
2017.06	Cracked bridge span (span)	16
	Cracked box girder (piece)	25

Figure3 Typical fracture schematic diagram

From the cracking situation, the characteristics are as follows:

(1) For every four pieces of box girder across the transverse, transverse cracks occur in the middle girder or side girder without certain regularity; the new cracks are mostly distributed around the mid-span. (2) The cracks are mainly vertical in the abdomen and transverse in the floor, some of which are in the shape of "U" or "L", and the width of the cracks is less than 0.15mm. (3) Transverse cracks in the bottom plate of composite box girder and vertical cracks in the web plate are shallow in depth, which crack in the protective layer until the end of the reinforcement surface. (4) The cracked beam has slight downwards, and the non-cracked beam has certain upper arch.

2.2.Cause analysis of the cracks

Comparisons to the general table Compared with the General Table of Highway and Bridge in the Transportation Industry of the People's Republic of China*, the number of steel beams in the middle span is slightly less than that in the general table. The comparison results are shown in Table 2.*

Table 2 Comparison results of prestressed beam of the compared bridge and the general table

Comparison subject	Side span	Difference ratio（%）	Mids pan	Difference ratio（%）	Pier top	Difference ratio (%)
The compared bridge	36	——	28	——	25	——
85 specification general table	36	0.0%	30	-7.1%	25	0.0%
04 specification general table	36	0.0%	32	-14.3%	26	-4%

2.3.Structural calculation results

(1) The ultimate bearing capacity state of the original design meets the requirements of the specifications. Under normal use, both normal tensile stress and normal stress of the side beam meet the requirements of the code for prestressed class A members, but there is little reserved safety in the midspan.

(2) Based on the test results, the normal tensile stress of each key section of the beam body under the condition of the most unfavorable combination of side beam and middle beam is shown in Table 3.

Table 3 Normal tensile stress of side beam based on test results

Position	Normal stress （MPa）		Specified limited value （MPa）	Comply to the requirements or not
side span of side beam	Combination Ⅱ	0.47	2.7	yes
midspan of side beam	Combination Ⅱ	2.82	2.7	no
side span of center sill	Combination Ⅱ	0.76	2.7	yes
midspan of center sill	Combination Ⅱ	3.08	2.7	no

Based on the calculation of the test results, it can be seen that under ultimate state in normal use, the maximum normal tensile stress of the lower edges of the midspan of side beam and the midspan of center sill is 2.82MPa and 3.08MPa respectively, both exceeding the specified value 2.7mpa for the limit value of prestressed class A member the specifications.

2.4.Static load test results before reinforcement

The results of static load test show that: (1) Under the test load of corresponding working conditions, the strain and deflection check coefficients of individual measuring points of mid-span section of 53 span (side span) and most measuring points of mid-span section of 52 span (middle span) are greater than 1, which do not comply to the requirements in the specifications. (2) Under the test load of each working condition, the relative residual strain and deflection values of each measuring point of each test section are less than 20%. At present, the test sections are basically in the elastic working state.

2.5.Actual operational load survey

Based on the investigation of vehicle traffic from June 1, 2015 to May 31, 2016, a total of 6 exits were counted, and 40 vehicles exceeding 100 tons were found, among which the heaviest vehicle was 114.32 tons.

Based on the above analysis, the main reasons for transverse cracks in the mid-span area of the small prestressed box girder of this bridge are the small prestressed box girder with less prestressed beam distribution, increased traffic volume and more overweight vehicles on the bridge.

3.Maintenance and reinforcement

3.1.Reinforcement

The original small box girder structure was strengthened by external prestress, and only the external prestress was tensioned in the middle span. Two 3φs15.2 steel cables are used for each piece of box girder in the middle span, and the tension control stress is 0.65×1860 = 1209MPa. The longitudinal and cross-sectional arrangements of externally prestressed steel beams are shown in Fig. 4 and Fig. 5.
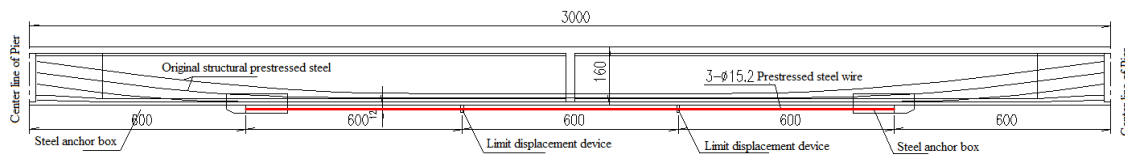
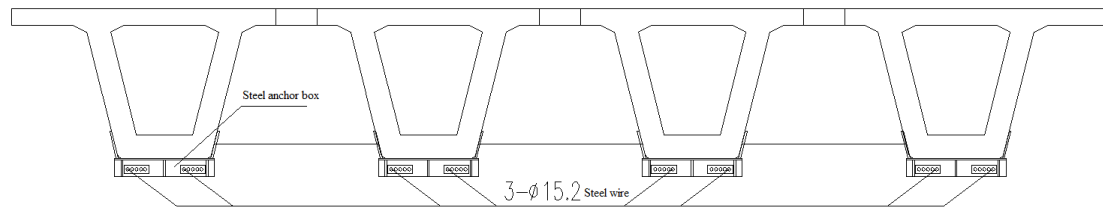Figure 4 Longitudinal arrangement of externally prestressed steel beam

Figure 5 Cross-sectional arrangement of externally prestressed steel beam

3.2.Analysis of reinforcement effects
See Table 4 for the comparisons of tensile stress of key sections of the main girder strengthened by the original design, detection results and recommended schemes.

Table 4 Comparison of tensile stress of key sections of main girder

subject	Tensile stress of each key section （MPa）					
	Side beam			Middle beam		
	side span	midspan	pivot	side span	midspan	pivot
Original design	0.71	2.12	0.7	1.04	2.4	0.7
Based on detection results	0.47	2.82	0.21	0.76	3.08	0.21
After strengthening	0.78	0.95	0.82	1.12	1.18	0.82

As can be seen from Table 4, based on the test results, the mid-span tensile stress of the side beam and the midspan of the middle beam was calculated as 2.82MPa and 3.08MPa, respectively. The tensile stress of the two sections after reinforcement was 0.95mpa and 1.18mpa, and the midspan tensile stress of the side beam was close to the original design value, and the reinforcement effect was relatively ideal.

4. Assessments of after-reinforcement effect monitoring

(1) For the bridge span strengthened by external prestress, the early-warning level of the monitoring point under the action of operating load is safe. The deflection data of the same months of consecutive two years are basically the same, and the daily mean change of the deflection measurement point is relatively small, as shown in Fig. 6.

(2) For the bridge span that cracks and are only closed for treatment, the early-warning level of the monitoring point under the action of operating load is highly risky. The deflection data of the same months of consecutive two years across the bridge has an increasing trend, and the beam body downwards. At the same time, new structural cracks are generated in the mid-span region of the bridge, as shown in Fig. 7.
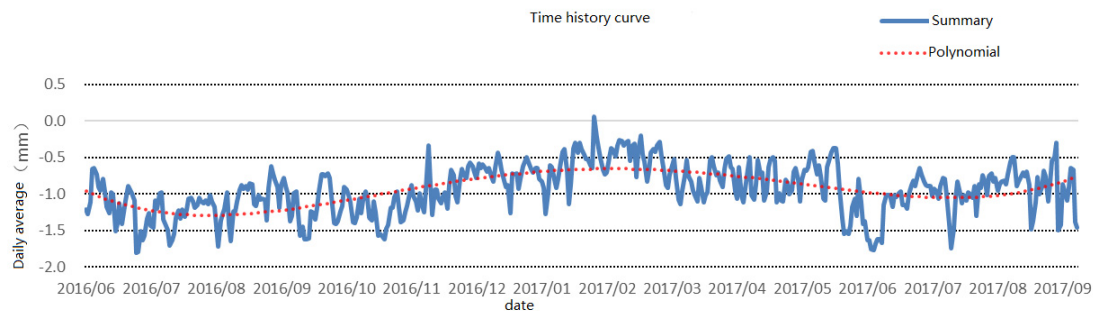
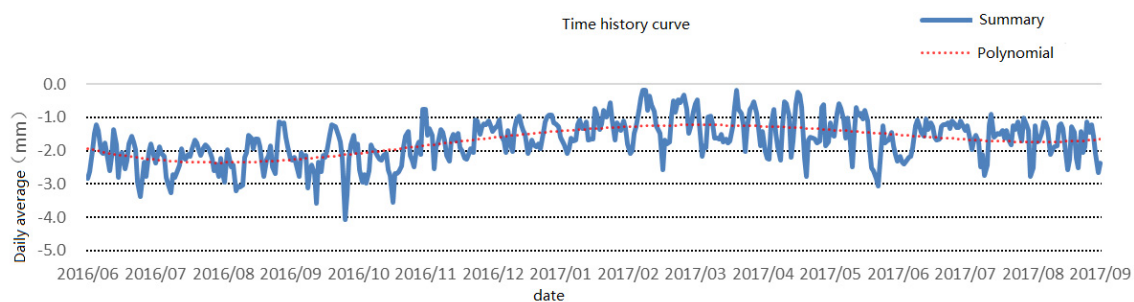Figure 6 The time curve of daily average deflection of midspan for the bridge span by external prestress

Figure 7 The time curve of daily average deflection of midspan for the bridge without reinforcement

The monitoring results show that no new cracks are found in the small box girder after external prestressed reinforcement, and the bridge is in a safe state under operating load, indicating that the reinforcement measures are practical and effective.

5. Conclusion

Aiming at the transverse cracks in the floor near the midspan and vertical cracks in the webs of the small box girder, the reinforcement measures of external prestress were adopted to improve the bearing capacity of the box girder and increase the reserved safety. The bridge has been in operation for more than two years after reinforcement, and no other cracks have been discovered. Therefore, the reinforcement method proposed in this paper can provide reference for the maintenance and reinforcement of similar bridges.

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