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Field Investigation of Damages and Performance Evaluation of Longtan Truss-Arch Concrete Bridge in China

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Abstract

Longtan truss-arch concrete bridge is located near the mountain of Longtan in the east of Jilin City in the east north of China. This bridge crosses the Songhua River. The damages inspection of the bridge structure must be taken each member to evaluate the structural performance. The main objectives of this study are to inspect and classify the damages of Longtan truss-arch concrete bridge structural members, to determine the compressive strength of concrete, corrosion of steel reinforcement, to check the leveling of deck, and to evaluate the structural performance of the bridge structure members. Ansys ver. 10 software was used to analysis the internal forces. The field tests adopted in this study are: (a) compressive strength of concrete test, (b) corrosion of steel test, and (c) static load test. These tests are used to evaluate the state of a bridge structure. The results of the appearance investigation and field tests show that the bridge structure state is in good, but piers and arch rings suffer from cracks, reinforcement steel corrosion, and spalling of concrete. The results of static load test show that the deflection, strain, and cracks development meet the requirements under test loads. Therefore, this study recommended the repair and strengthening of damaged members of Longtan truss-arch concrete bridge.

Key words: Longtan Bridge, Damages Investigation, Corrosion, Deflection, Strain

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1. Introduction

The objectives of damages field inspection of the bridge structure are to evaluate the structural performance, to identify the actual and potential sources of damage at the earliest possible stage, to explain the member state whether is in safe or unsafe, to classify the damaged parts in bridge members, and to identify any maintenance, repair, and strengthening that needs to be carried out. (AASHTO 1986; Robert 2005).

The deterioration of a bridge structure often appears in visible signs of damage. A detailed investigation provides information about the damages. Various test may be used to complement of the results of the visual investigation. Testing techniques and equipments should be determined relative to the amount and type of the deterioration and the importance of structure. (Raina 1996). The purpose of evaluating the bridge structure damage is not only to determine the effect of damage to its remaining service life and load-carrying capacity, but also to determine the causes of defects. Generally, the damages occur in concrete bridges under unacceptable loads can be classified into cracks beneath the beam and slab, additional settlement of bridge slab, extra vibration under passing loads, corrosion of steel reinforcement, and spalling of concrete. (Sadeghi and Fathali 2007).

In the present study, Longtan truss-arch concrete bridge is inspected by the team of inspection in School of Transportation Science and Engineering/ Bridge and Tunnel Engineering/ Harbin Institute of Technology (HIT). The objectives of this study are to investigate and classify the damages of Longtan truss-arch concrete bridge structure and to evaluate the structural performance of bridge structural members by adopting static load test.

2. Description of Longtan Truss-Arch Concrete Bridge

Longtan truss-arch concrete bridge is located near the mountain of Longtan in the east of Jilin City in the east north of China. This bridge across the Songhua River and it is the main channel of link between the south and the north of Jilin City. The whole length of Longtan bridge is 455m, the total width is 23m, the roadway width is 22.5m, the deck width is 18m, and the width of sidewalk for two sides is 4.5 m. Longtan bridge is a type of truss-arch bridge, and it has 13 spans. The length of each span is 34.95m. The main reinforcement is equivalent to I-grade smooth steel. The original design load is the car-20 grade and lifting car-100 grade. Figure 1 shows the schematic diagrams of the Longtan truss-arch concrete bridge structure.

3. DAMAGES INVESTIGATION PROCESS

The damages inspection process includes the examination and classification of damages for all parts of the bridge structure from the span No. one to the span No.13.

3.1. Damages investigation of the main arch ring

3.1.1. Arch ribs

The overall state of arch ribs is in good, without serious cracks, but there are small numbers of surface cracks and there is spalling of concrete. Most of edge ribs suffer from serious water erosion due to deck seepage. Figure 2 shows the cracks along arch ribs and water erosion of arch ribs.

3.1.2. Horizontal beams between arch ribs

Horizontal beams suffer from severe lateral bending cracks within arch rib No. four and No. six of the first span, and also there are cracks near the arch section of horizontal beams between the arch ribs No. eight and No. nine in the span No. 13. The cracks widths range between 2 mm to 5 mm and the lengths of cracks range from 5cm to 10cm. For others arch ribs, there are not cracks. The horizontal beams undergo serious water erosion due to the deck seepage. Figure 3 illustrates the severe lateral cracks and water erosion of horizontal beams.

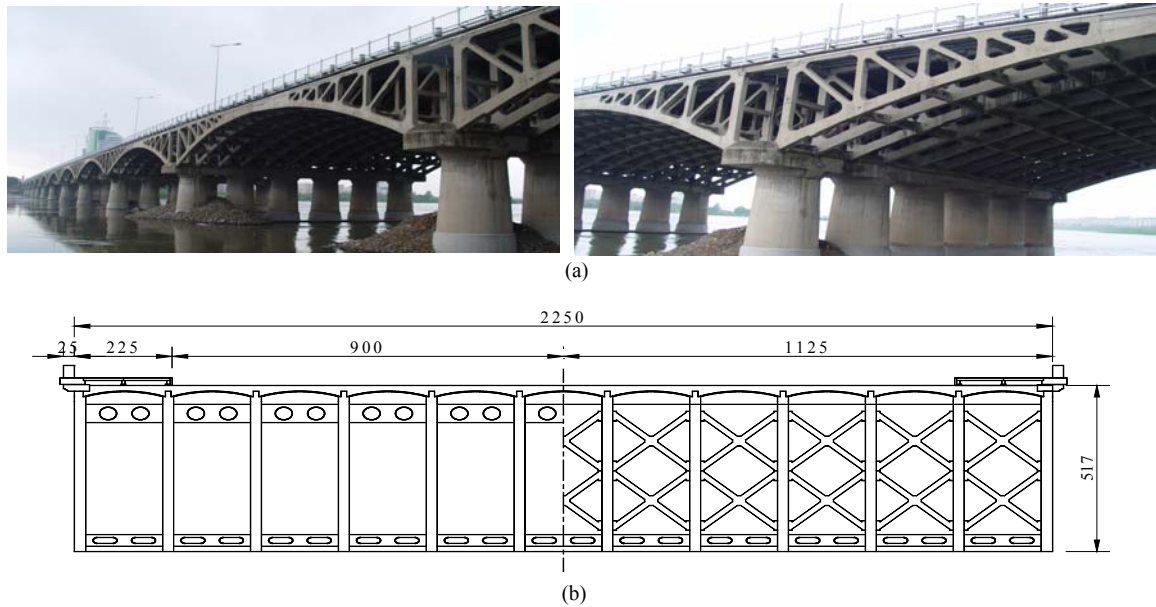


Figure 1: Longtan truss-arch concrete bridge structure : (a) general view, (b) cross-section of bridge



Figure 2: Cracks and water erosion of arch ribs

3.1.3. Arch plate

The overall situation of arch plate is good. There is only local bending cracks occurred in the arch plate within ribs No. three and No. four in the span No. five. In addition, there some seepage of water between parts of arch plate. Figure 4 shows the cracks and seepage of water in the arch plate.

3.1.4. *Truss bars*

The condition of truss bars is good, but there are vertical cracks occur within oblique truss bar of rib No. nine in the first span. Figure 5 shows the vertical cracks of the oblique truss bar.

3.1.5. *Truss bars joints:*

There are cracks through the truss bars joints in the ribs No. five and No. six of the span No. five and ribs No. three and No. four of the span No. six. The width of cracks range between 0.15mm and 0.5mm, and the length of cracks is about 40cm. Fig. 6 shows the oblique cracks of truss bar joint in the spans No. five and No. six.



Figure 3: The damages of horizontal beam: (a) water seepage, (b) and (c) the cracks



Figure 4: The damaged of arch plate



Figure 5: The cracks of the oblique truss bar



Figure 6: The oblique cracks of truss bar joint in the spans No. 5 and No.6.

3.2. *Damages investigation of bridge deck*

The deck pavement condition is good and there is not serious damage for sidewalk and expansion joints. Parts of drainages system are blocked by dust. Therefore, the water is collected on the deck and penetrates from the deck to the edge ribs, resulting in rain water erosion of some edges ribs. Parts of railing columns appear cracks and fracture. Fig. 7 shows the water on the bridge deck and cracks of railing columns.

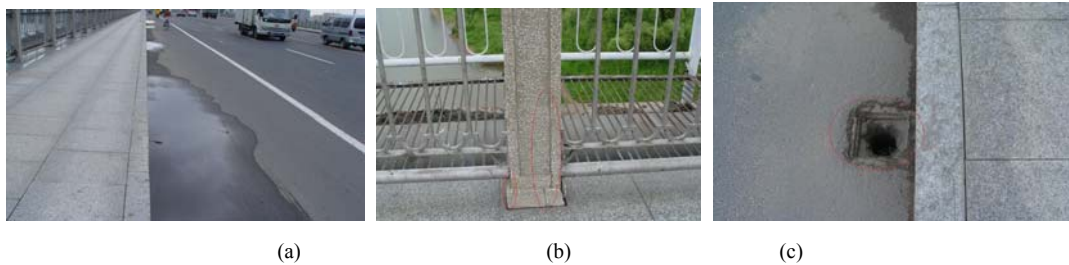


Figure 7: The damage deck system: (a) the water on the bridge deck, (b) cracks of railing columns, (c) drainage system blocked by dust

3.3. Damage investigation of piers

The conditions of bridge piers are good, but there are only some temperature and shrinkage cracks on the surface of concrete without large serious cracks. There are serious spalling of concrete surface in the bottom of the bridge piers and cap beams due to the flow of water erosion.

4. INTERNAL FORCES ANALYSIS

In this analysis, Ansys ver. 10 Software is used to determine the internal forces of bridge structure by adopting the allowable stress method under dead and live load. The load combinations consist of two types. The first type includes dead load+car-20 grade+ crowded load 3.5kN/m^2 , and the second type includes dead load +lifting car-100 grade. Figure 8 shows bridge model for the internal forces calculation. Direct method is used to determine the truss arch bridge transverse distribution coefficient. The results of transverse distribution coefficient of car in arch section are shown in figure 9. The internal forces in arch section and arch bottom under dead and live loads are calculated. Figures 10, 11, and 12 show the results of the internal forces.

5. FIELD TESTS

5.1. Compressive strength of concrete test

The test of concrete compressive strength can be directly reflected the quality of concrete structure. Rebound method is used to examine the concrete as sampling inspection by batch. The Rebound method is applied to the main components of the bridge structure. The equipment of Rebound method is Rebound hammer (ZC3-A). Table 1 shows the test results of compressive strength of concrete test. From this table it can be noted that the oblique truss bars have the higher value of compressive strength. The elastic modulus of concrete for arch rings, straight truss bars, oblique truss bars, and truss bars joints are: 2.98×10^4 Mpa, 3.01×10^4 Mpa, 2.99×10^4 , and 2.78×10^4 Mpa respectively.

5.2. Steel reinforcement corrosion test

The evaluation of steel bars corrosion is followed the instant detection technique which is established by the Highway Scientific Institute of Communications Ministry in People's Republic of China. The test adopts the scribe digital reinforcement rust instrument. In this test, 12 test areas are selected from rib No. one to rib No. 12 from upstream. According to the test results, the corrosion possibility of steel

reinforcement is high in rib No. four and rib No. six of the first span, Rib No. eight and rib No. nine of the span No.13, and rib No. one of the span No. four. The higher possibility corrosion areas occur within seepage, concrete cracking, and spalling of concrete areas.

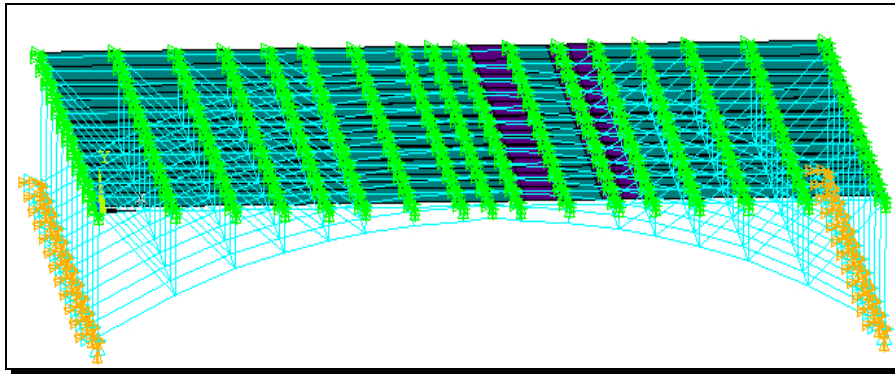


Figure 8: Bridge model of internal forces calculations

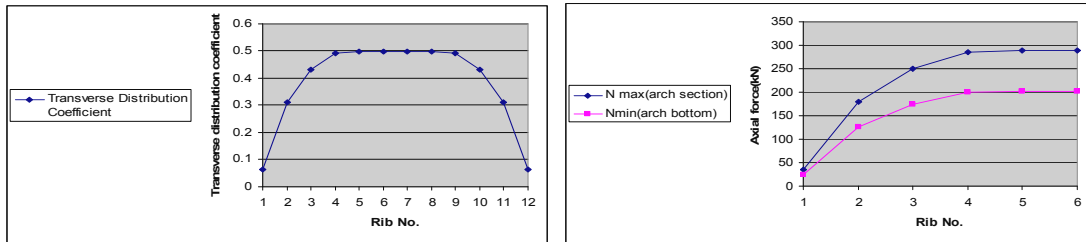


Figure 9: Transverse distribution coefficient Figure 10: Results of theoretical axial forces

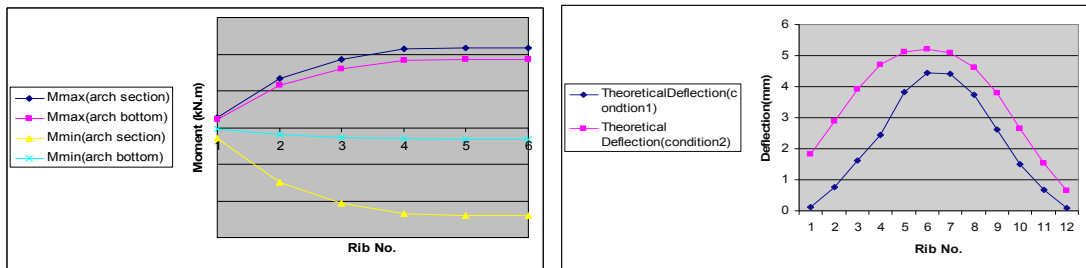


Figure 11: Results of theoretical moments Figure 12: Results of theoretical deflections

5.3. Static load test

The aim of static load test is to determine the deflections, stresses, strains, and cracks developments, and comparing with theoretical values to determine the existing working state and carrying capacity of the bridge structure. According to the damage investigation of the bridge structure appearance, the first span of truss arch bridge is selected to test as experiment span. The arch section and arch bottom section are

selected in the first span to test. The static load test consists of strain test, deflection test, and cracks development observation.

Table 1: Results of compressive strength of concrete test

Members	Arch ring	Straight truss bar	oblique truss bars	Truss bars joints
Average value(MPa)	36.2	34.8	38.3	32.0

5.3.1. Loading of vehicles

In this test, six FAW liberation-bucket cars are used. These cars are produced in Chinese Changchun heavy vehicle factory. The weight of car is 300kN. Table 2 shows the vehicle characteristics parameters. According to chine's requirement (old highway bridge carrying capacity test evaluation code), the efficiency coefficient of test load (η) should meet $1.05 > \eta > 0.85$.

5.3.2. Layout of the measuring Points

Static load test is divided into two different conditions. The first condition includes the selection of arch top and the second condition is selected arch bottom. According to the analysis of the arch ribs transverse distribution coefficient, arch rib No. 6 is selected as the horizontal arrangement basis under maximum load. Arch rib No. 5 is selected as the second location of the horizontal arrangement. Figure 13 shows the layout of measuring points, figure 14 shows the horizontal layout of vehicles loads. The actual load is grading load, and the loads of two cars are recorded for each time and each condition twice. The final test point values are taken as the average value.

5.3.3. Equipments and test references

The equipments that is used in the static load test include 12 of vibrating wire strain sensor, 12 of dial indicators, one of vibrating wire strain sensor acquisition system, one of precision digital level, one of Cracks reader 25 times, one of non-metallic ultrasonic detector, one of hammer of strength of concrete, one of concrete resistivity meter, and one of 100W hair dryer. The references which are adopted for static load test include: JTG D60-2004, JTG D62-2004, MCS, 1998, SRIHCM, 2003, Jilin City Archives, 1976, and CJJ99-2003.

5.3.4. Static load test results

According to the test conditions and load test, the maximum values of test load moment is 108.1 kN.m in rib No. six and five within load condition one, and the maximum theoretical moment is 97.5 kN.m in rib No. six within load condition one. The values of test load efficiency factor (η) range from 0.871 to 0.944. These values meet the requirements ($1.05 > \eta > 0.85$). Therefore, the bridge structure is in good flexible working state. Figures 15 and 16 show the values of field load test and theoretical deflections for test condition one and two. Each measured arch rib deflection values are less than the truss bridge vertical deflection limits which can be shown in equation (1):

$$f \leq \frac{L}{800} \quad (1)$$

where: f = deflection limit, and L = span length

Therefore, the bridge structure working performance is in good state. Figure 1 shows the values of theoretical and test load strain for arch section in ribs No. five, six, seven, eight, nine, and 10. from this fig. it can be noted that the values of strain for condition two are higher than the values in condition one and for two test conditions, the theoretical values higher than test load values. The calibration coefficient ranges from 0.58 to 1.02. Therefore, the structural strength of bridge structure meets the requirement and the bridge structure is in good working conditions. Under test load, the original cracks do not develop and there are not new cracks occur. Therefore, the bridge structure is in good condition and flexible working state.

Table 2: Vehicle characteristics parameters of FAW model

Axial load (kN)			Total weight (kN)	Wheel base (cm)	
Front axle load	Middle axle load	Rear axle load		Between front and middle axles	Between middle and rear axle
60	120	120	300	325	125

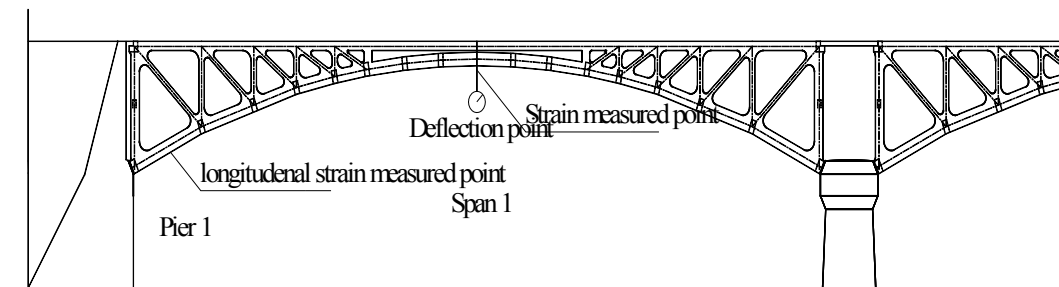


Figure 13: Layout of measuring points

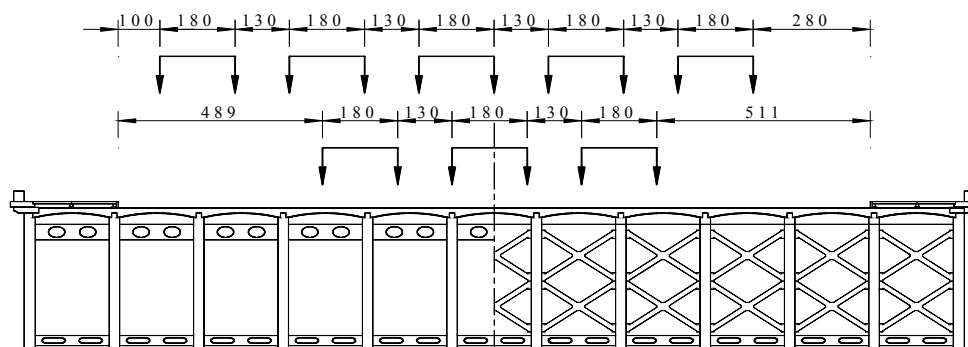


Figure 14: Horizontal layout of vehicles loads

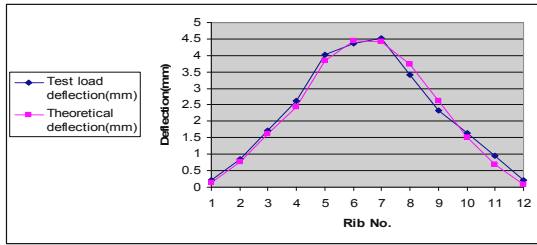


Figure 15: Deflection diagram for condition 1

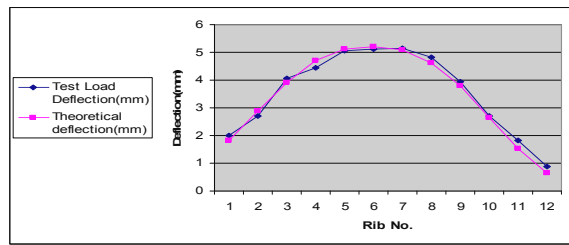
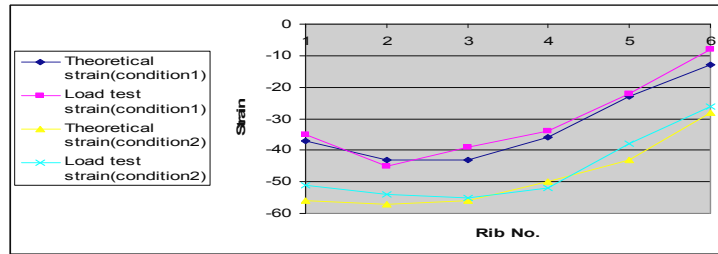


Figure 16: Deflection diagram for condition 2



. Figure 17: Theoretical and test load strain values of the arch section for conditions one and two

6. CONCLUSIONS

According to damage inspection process and static load test, The overall conditions of Longtan truss-arch concrete bridge are in good and carrying capacity meet the usage requirements under the dead load and live load of traffic, but there are some varying degree of damages in local components such as cracks, spalling of concrete, and corrosion of steel reinforcement. The deflection, strain, and cracks development meet the requirements of standard under equivalent loads. Also the bridge structure don't repair for long time. These damages affect the normal using of bridge, durability, and carrying capacity. Therefore, this bridge needs to strengthen and repair the damage components of bridge structure to improve durability and carrying capacity.

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