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Static load test and evaluation of a separated interchange bridge

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Abstract: The separated interchange bridge described in this paper has a large bevel angel and its superstructure is combined steel and concrete girder. The bridge shakes significantly when heavy-loaded vehicles travel on it. Moreover, the box girder has warped upwardly and the bearing has disengaged with the girder body. Therefore, a static load test on the bridge has been performed. By the test, corresponding results have obtained, damage conditions and bearing capacity have been analyzed and evaluated, and measures to prevent bridge defects have been proposed. Finally, a maintenance and reinforcement scheme has been formulated, which has a reference significance for overall inspection and evaluation of the similar old bridge.

1. Introduction

The separated interchange bridge has a span combination consisting of 25m, 38m and 25m and its southern and northern half sections are separated from each other. The bridge crosses over the road below it at a skew angle of 32°. Its superstructure is combined steel and concrete girder including open type steel box (with top flange slab) and prestressed concrete deck slab. Its understructures are ribbed abutment and column pier and the foundations for the abutment and pier are all bored pile type. The horizontal plane of this bridge is located on the straight segment and its longitudinal section is located on a convex vertical curve of R=23000m and the longitudinal slopes are 1.02% and -0.94%. The design load criteria are super 20 class for automobiles and 120 class for trailers. The bridge deck width is 28m consisting of 0.5m crash barrier, 12m carriageway and 1m corrugated guardrail at one side, 2x0.5 m median divider at the center, and 1m corrugated guardrail, 12m carriageway and 0.5m crash barrier at the other side. The 2% two-way cross-slope of the bridge deck is adjusted by the unequal height of the web and is formed by the slope created by top surface of the box girder.

With rapid development of society, economy and transportation, the number of vehicles traveling across this, especially heavy-loaded vehicles, is increasingly growing, which has aggravated the damage to this bridge. After inspection, it is found that 1# side box girder of the third span on the southern half roadway shakes significantly when heavy-loaded vehicles are travelling across it and that this box girder warps upwardly and the bearing disengagement arises after such vehicle travelling, while corresponding 4# side steel box girder at 3# abutment of northern half roadway does not disengage from the bearing but has the tendency to deform and disengage from the bearing.

In engineering practices, the load test of a bridge is generally used for overall evaluation of load-bearing capacity and operation performance of in-service bridges [1-5]. The static load test of a bridge structure is to test bending moment, strain and deflection at the specified points on the bridge



structure in a bid to determine working status of the bridge structure under test load, examine bridge load-bearing capacity, decide whether the requirements of serviceability limit state are met and identify the reasons for bucking deformation. The test results can provide basis for bridge reinforcement design so that the reinforcement design scheme can be optimized.

2. Static load test

2.1 Items and cross sections tested

According to stipulations for load test items [6] as well as main test purpose of this bridge, the static load test items for southern half bridge include: (i) maximum positive bending moment effect and maximum vertical deflection effect of cross sections of middle segments of two side spans; (ii) maximum vertical deflection effect of cross sections of middle segments of the midspan; and (iii) analysis of effect of side span upwarping. The locations of cross sections tested are shown in figure 1. In consideration of different test items, three different loading conditions are arranged. The first loading condition (loading condition 1) refers to the symmetrical loading test for obtaining maximum positive bending moment of the box girder near the center point of the segment between #0 abutment and #1 pier. The second loading condition (loading condition 2) means the symmetrical loading test for obtaining maximum positive bending moment of the box girder at the center point of the segment between #1 and #2 abutments. The third loading condition (loading condition 3) is the symmetrical loading test for obtaining maximum positive bending moment of the box girder near the center point of the segment between #2 pier and #3 abutment.

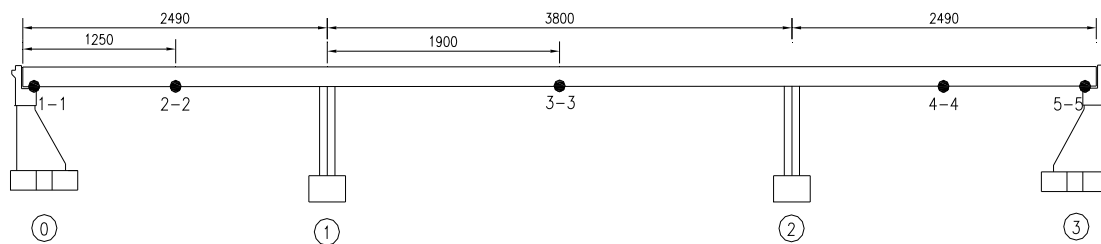


Figure 1. Layout of test section (unit: cm)

2.2 Arrangement of test points

(1) Stress test points

A vibrating wire strain gauge (HY65 type), which has a good stability and high precision and is suitable for field environment, is used for measuring concrete surface of each cross section of the box girder in order to mainly test stress distribution law and stress performance of controlling cross sections. Strain test points for bottom slabs were arranged on the surface beneath the center of bottom slabs of the first and third span box girders (#1 and 2 test points located on the bottom of the two box girders).

(2) Deflection test points

A HY 65 type wireless digital displacement meter, which has a high precision and is suitable for field environment, is used for measuring deflection of each cross section of the box girder. Deflection test points for 2-2 and 4-4 cross sections are arranged on the surface beneath the center of bottom slabs of the box girder (#1 and 2 test points located on the bottom of the two box girders). The deflection of 3-3 cross section is measured on the bridge deck by a high-precision level gauge due to large traffic volume under the bridge, fast vehicle speed and difficulty in maintaining uninterrupted traffic.

(3) Girder end displacement test points

A HY 65 type wireless digital displacement meter, which has a high and reliability and precision and is suitable for field environment, is used for measuring lateral displacement of the box girder. Displacement test points for 1-1 and 5-5 cross sections are shown in figure 2.

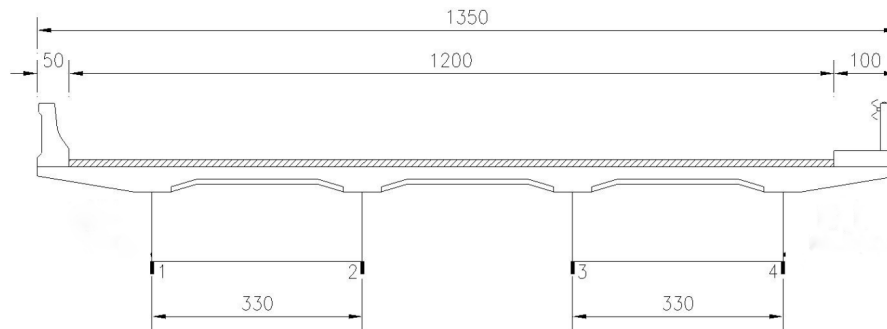


Figure 2. Layout of displacement measuring points(unit:cm)

2.3 Test results

2.3.1 Deflection of midspan. Measured and theoretical deflection values and check coefficients for the three loading conditions above are shown in table 1.

Table 1. A list of deflection data under various loading conditions of south bridge

loading condition	measure point	measured value (unit:mm)	calculated value (unit:mm)	Testing coefficient
loading condition 1	1	-6.114	-3.641	/
	2	-5.373	-4.993	/
loading condition 2	1	-6.62	-9.178	0.72
	2	-6.62	-9.178	0.72
loading condition 3	1	-3.895	-4.993	0.78
	2	-2.512	-3.641	0.69

Note: Because of the upwarp for the first span, The measured value is inconsistent with the calculated value, so the deflection is not judged.

It is shown that: (i) measured deflection under design load conditions is not evaluated, because measured data for midspan deflection of the first spanned girder is inconsistent with theoretical deflection values under normal service condition after the first spanned girder end warps upwardly; (ii) maximum measured deflection values for the second and third spanned girders are less than the specified values set out in the Specification[7]; and (iii) the deflection check coefficients for the two girders are between 0.69 and 0.78, which conforms to the evaluation stipulation that the deflection check coefficient should be less than 1 and demonstrates that rigidity of the second and third spanned girders meets traffic requirements under design load.

2.3.2 Residual deflection of midspan. Table 2 shows that measured residual deflection values for midspan of the three spanned girders of the southern half bridge under the above three loading conditions. It can be seen from table 2 that relative residual deflection is between 1.8% and 8.62%, conforming to the evaluation stipulation that relative residual deflection should be not more than 20%. The foregoing demonstrates that the southern half bridge can basically recover to its previous condition after forces act on it and that it is in elastic working status.

Table 2. A list of residual deflection data under various loading conditions of south bridge

loading condition	measure point	residual deflection (unit:mm)	measured value (unit:mm)	Relative residual deflection(%)
loading condition 1	1	-0.320	-6.114	/
	2	-0.088	-5.373	/
loading	1	-0.119	-6.62	1.8

condition 2	2	-0.480	-6.62	7.3
loading	1	-0.336	-3.895	8.6
condition 3	2	-0.120	-2.512	4.8

Note: Because of the upwarp for the first span, the inelastic deformation exist in measured value, so the inelastic is not judged.

2.3.3 Strain analysis. Strain of the first and third spanned girders bottom under the first and third loading conditions is shown in table 3. It can be seen from table 3 that: (i) measured strain values of the first and third spanned girders bottom under design load conditions are not more than theoretical strain values; and (ii) strain check coefficient is between 0.334 and 0.721, conforming to the evaluation stipulation that strain check coefficient should be less than.

Table 3. A list of strain data under various loading conditions of south bridge

loading condition	measure point	measured value (unit: $\mu\epsilon$)	calculated value (unit: $\mu\epsilon$)	Testing coefficient
loading condition 1	1	31.2	93.4	0.33
	2	75.4	115.6	0.65
loading condition 3	1	83.3	115.6	0.72
	2	36.1	93.4	0.39

2.3.4 Residual strain analysis. Residual strain test for the southern half bridge under above loading conditions 1 and 3 is shown in table 4. It can be seen from table 4 that relative residual deflection is between 7.1% and 10.3%, conforming to the evaluation stipulation that relative residual deflection should be not more than 20%. The foregoing demonstrates that the southern half bridge can basically recover to its previous condition after loading is completed and that it is in elastic working status.

Table 4. A list of residual strain data under various loading conditions of south bridge

loading condition	measure point	residual deflection (unit: mm)	measured value (unit: mm)	Relative residual strain(%)
loading condition 1	1	2.2	31.2	7.1
	2	7.8	75.4	10.3
loading condition 3	1	7.0	83.3	8.4
	2	3.3	36.1	9.1

2.3.5 Girder end displacement analysis. Loading conditions and values for vertical displacement of the box girder at the bearings of #0 and #3 abutments of the southern half bridge are shown in tables 5 and 6. It can be seen from the two tables that: (i) under the above loading condition 1, the minimum vertical displacement for the girder end of #0 abutment is -9.754mm and the maximum settlement for the bearing at #3 abutment is 0.294mm and (ii) under the above loading condition 2, the girder ends at #0 and #3 abutments warp upwardly with a maximum upwarp height of 2.883mm. Girder end upwarping and bearing disengagement have deviated from the original design conditions and should be controlled by taking measures.

Table 5. A list of measured vertical displacement values in support of 0# abutment (unit: mm)

measure point	loading condition 1	loading condition 2	loading condition 3
1	-9.754	3.318	-0.437
2	-8.647	4.553	-0.344
3	-5.177	2.286	-0.156

4	0.409	-0.232	0.012
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Table 6.A list of measured vertical displacement values in support of 3# abutment(unit:mm)

measure point	loading condition 1	loading condition 2	loading condition 3
1	-0.018	-0.214	-0.019
2	0.077	0.786	-1.252
3	0.016	1.554	-1.084
4	-0.175	2.883	-1.862

3. Bridge defect conditions and analysis and evaluation of load-bearing capacity

In addition to the static load test, routine inspection, nondestructive test and linear measurement were performed on this bridge to comprehensively diagnose the distribution and severity of bridge defects and evaluate this bridge's load-bearing capacity. The conclusions are shown as follows:

(1) It is obviously observed that under normal traffic, 1# side box girder of the third span of the southern half bridge shakes significantly and its bearing disengages from it when heavy-loaded vehicles are travelling across it. It is found after test and calculation that the box girder warps upwardly and its bearing fully disengages from it after heavy-loaded vehicles have travelled across it.

(2) The static load test shows that: (i) the overall bridge rigidity is inadequate; (ii) the side girder body can not meet the requirements under serviceability limit state; (iii) the bearing disengagement arises; and (iv) the ordinary pressure bearing in the original design can not meet requirements for load transmission and deformation.

(3) The steel plate at the acute angle of the box girder has corroded. The precast concrete at the lateral diaphragm has been damaged, causing exposure of the steel bar. As for main spanned girders on the side, corrosion and damage varies depending on girder number and location. Debris from construction has accumulated in the box girder, the zinc-aluminum coating at the bottom of the girder has stripped and the steel plated has corroded. Diagonal, longitudinal and lateral cracks with different widths exists on the top precast slab.

(4) The bearing at the acute angle of side span of the southern half bridge has disengaged completely from the box girder and the girder end has warped upwardly due to uneven stress. The bearing for the northern half bridge tends to disengaged from the girder and the girder end has warped slightly, maybe because the heavy traffic on the northern half bridge is relatively small.

(5) Concrete of abutments of the southern half bridge has been damaged and all the pier columns are in a good condition. The steel plate at the toe of pier column has corroded. Moreover, the wing walls at the two abutments of the northern half bridge have been damaged, and pitting and damage on the middle segment of the protection slope of the northern half bridge are evident.

(6) The concrete in the anchorage area at the driveway of all expansion joints has been seriously damaged, and the girder height on both sides of the expansion joint has a significant height difference from back wall of the abutment.

(7) According to *Technical Specifications for Highway Maintenance* (JTJ073-96), a current standard, which is issued by the Ministry of Transport of China, this bridge's evaluation results in terms of technical grade are shown in table 7. Based on the test results above and evaluation results for each component, the score for overall technical conditions of this bridge is 56.5 and the technical condition is classified as class 4.

Table 7. Bridge overall technical condition assessment

Sequence umber	Part	Weight	Score
1	Upper load-bearing member	0.70	40.00
2	Upper common member	0.18	72.50
3	Support	0.12	40.00
5	Wing wall and ear wall	0.03	72.50

6	Cone slope and slope protection	0.02	85.00
7	Bridge pier	0.47	72.40
8	Bridge abutment	0.47	72.50
9	Bridge deck pavement	0.53	33.03
10	Expansion clearance device	0.33	63.79
11	Guardrail	0.13	72.37
The score of bridge		56.5	

4. Defect prevention and maintenance and reinforcement scheme

(1) Before this bridge is repaired and reinforced, only vehicles with a limited load and at a limited speed can travel on this bridge and no overloaded vehicle is allowed. The allowable traffic load of this bridge should be reduced to class 20 for automobile and class 100 for trailers.

(2) Steel shot concrete will be poured between two lateral diaphragms at the steel box girder end near the supporting point of the abutment so as to increase weight of side girder, solve the problem of girder end upwarping and improve stress performance of the whole bridge.

(3) Two additional lateral connections along the longitudinal direction of this bridge are provided between two side box girders to increase overall lateral rigidity and strengthen overall performance of the bridge structure.

(4) Steel strips is welded at the bottom of midspan of 1# and #4 steel box girders and at some locations of side girders to increase the bending strength of the bridge structure.

(5) The rubber bearings that have disengaged from the girder and are subjected to uneven pressure are replaced with the tensile bearings that can withstand more load. The purpose of replacing rubber bearing with tensile bearing is to ensure that the tensile bearing can be compatible with the negative reaction force arising at the acute angle of the bridge and that the requirements for load transmission and deformation properties.

(6) Concrete in the anchorage area of expansion joint of southern half of #0 abutment should be removed to replace expansion joint. New expansion joint should be smoothly connected with the original road surface so as to restore normal use of the bridge and ensure a comfortable driving.

(7) As for the steel plate inside the box girder, if no anti-rust coating is applied on it, its coating falls off or its surface corrodes, decaling and surface roughening should be carried out for anti-rust treatment to ensure the bridge durability.

(8) Diagonal and longitudinal cracks arise on the same location of the precast slab of the box girder. The cracks in the precast slab of 1# box girder of the third span of the southern half bridge are more significant than those in the precast slab of other spans and are beyond specification requirements and should be repaired by grouting and sealing.

(9) It is a common phenomenon that the concrete of top slab of the box girder is damaged and steel bars are exposed. Damaged slab should be repaired by epoxy mortar.

(10) All the defects and cracks existing on the concrete surface should be repaired by different measures. In case of a crack with a width of more than 0.2mm, it should be repaired by injecting a kind of special glue. In case of a crack with a width of more than 0.5mm, it should be repaired by sealing its surface.

(11) Where obvious ruts exist on the driveway surface, the original asphalt concrete pavement of the bridge deck should be removed. New asphalt concrete will be placed after the main girder has been reinforce so as to avoid possible secondary stress.

(12) The alignment of the southern half bridge has been measured during this test. It is recommended that the measurement results should be taken as reference data to perform regular observation and observe the long-term variation trend of bridge alignment.

(13) Main components of this bridge should be regularly checked to identify any defects. Expansion joints and bearings should be checked for any abnormality. Any problems should be solved immediately once found.

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