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Evaluation Behavior of Qing Shan Concrete Bridge under Static Load Test

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Abstract: This study describes and evaluates the state of Qing Shang Bridge. The deterioration of bridge can be summarized due to increased internal forces may be a result of higher loading or due to the sever climatic and environmental weathers changes, bridges need reinforcement because damage due to external factors which reduced the cross-sectional resistance to external loads. The assessment of traffic loading on bridges is subject to large levels of uncertainty. While some allowance is provided in design codes for variable traffic conditions, they are conservative to allow for generalization at a safe level. Also this article identify the design demands of Qing Shan bridge which is located in China/ Heilongjiang Province, He gang - Nen Jiang Road 303 provincial highway, Wu Da Lian Chi area, is an important bridge in the urban areas. The investigation program was include the observation and evaluate the damage in T-section concrete beams , box girder bridges section in additional evaluate the whole state of bridges under static load test, the use of Finite Element Analysis was preferred method to study the behavior of concrete. Furthermore the load test program includes the main beams of bridge. The test results show that the bridge in general structural condition is good. T beam girder of the span No. 10 was tested for static load and need to be strengthening. The concrete box girder shows good state of condition, and no seriously damage effects.

Key words: Finite element analysis, live load effect, pre-stressed concrete box girder, static analysis

INTRODUCTION

The right evaluation of the behavior of highway bridges under heavy loading is extremely important both in the enhancing of design techniques, and also in the assessment of existing infrastructure. It is widely accepted that shortfalls exist in design codes due to inadequate consideration of the static dynamic interaction between the bridge structure and the heavy vehicles crossing it (Gonzalez *et al*., 2003).

Increasing degradation of bridge structures and inevitable increase in requirements posed on bridges during their service-life leads to spending huge financial resources. For this purpose bridge management systems are developed, based on database comprising all relevant data on bridge design and construction, performed inspections and testing, as well as identified damage. Gathered results serve as a basis for prioritization of repair works and calculation of associated costs. Data collection is largely based on hands-on visual inspection by trained inspection personnel, supplemented by mainly the laboratories and on-site testing. In all countries, the existing bridge management systems are in process of constant revaluation and modification (Radić *et al*., 2008).

Highway structures need to cater for an increasing demand in transport capacity while in many cases deteriorating through, for example, corrosion and excessive deformation. As a result, in-service structures require assessment and a prioritization of the measures necessary to ensure their structural integrity and safety. It is generally accepted that the use of design standards for assessment is over conservative and can lead to unnecessary replacement or strengthening of existing structures with all the attendant costs of traffic delays. In the design phase, loading conditions may be overestimated and structural strength underestimated to cater for the inherent uncertainties associated with in-service conditions. While the cost of providing this enhanced level of safety is marginal at the design stage, the same cannot be said for assessment, where over-conservatism can lead to considerable unnecessary expenditure (O rien *et al*., 2005).

BRIDGE DESCRIPTION

Qing Shan Bridge shown in Fig. 1 is located in Hegang - Nenjiang 303 provincial highway lane, Heilongjiang Province; an important bridge in the urban areas of Wu Dalian Chi, the bridge has been operating for more 29 years since August 1982.

Bridge length is 314.0 m, including 13 spans; the bridge consists of the left approach, right approach and the main bridge. among them, the left approach abutment have two span, 20 m of reinforced concrete simply

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Fig. 1: General view of bridge

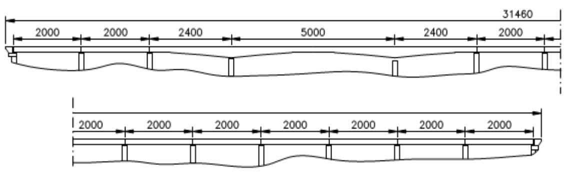


Fig. 2a: General layout of bridge (Unit cm)

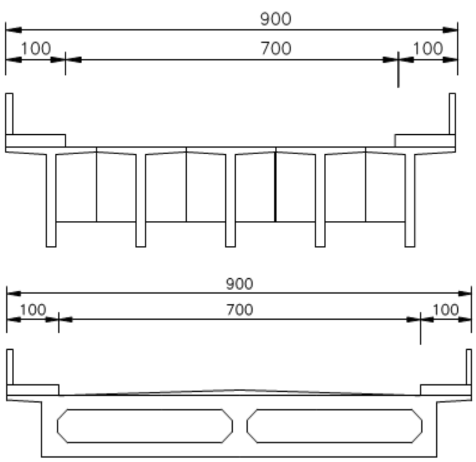


Fig. 2b: Bridge superstructure (simply supported T beam) and prestressed continuous box girder (Unit cm)

supported T beam; the main continuous box girder with three-spans, overall prestressed concrete box girder, spans arrangement are (30 m + 50 m + 30 m); the right side approach has eight spans, 20 m of reinforced concrete simply supported T beam.

Structure elements: The bridge deck of two lanes was paved with 9 cm thick concrete pavement. Upper structure: simply supported T beam prefabricated installation, prestressed Continuous box girder constructed with cantilever casting method. Fig. 2a and b shows the main parts of bridges (dimensions in cm).

Continuous span bridge (static analysis): The continuous beam span bridge structure is shown in Fig. 3

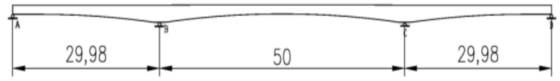


Fig. 3: Continuous beam structure (Unit m)

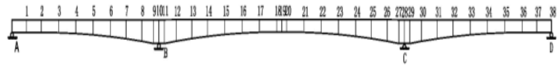


Fig. 4: Finite element models

and 4 using the Doctor Bridge V3.0 software to analyze finite element model, full-bridge divided into 38 beam element, 39 nodes.

Select control section: According to the structural characteristics of a continuous beam and environmental conditions in which the bridge site, select the following location as the cross-section controls of calculation and testing: (1) Side span at mid span section; (2) The support (pier) section (3) Cross span section.

Effect of live load:

Influence line of the internal force control section: The computer software was using to calculate the influence line of the control section of structure, as shown in Fig. 5.

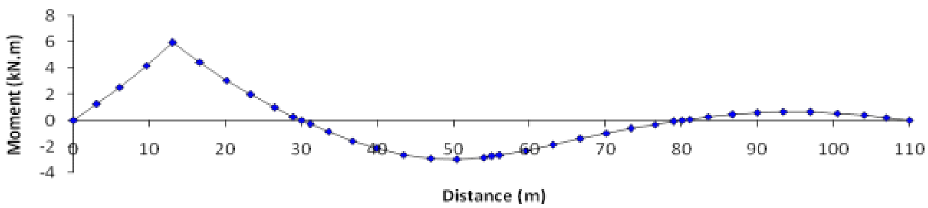
Influence line load: The bridge design load level of the of vehicle is truck No. 15 and trailer No.80, as the standard loading which the result shown in Fig. 5, the influence line loading consider a horizontal arranging of two lanes, to predict impact and the unbalanced live load effect, control section internal force and test load are listed in Table 1 contains internal force.

Simple beam bridge spans (static analysis): The bridge approach spans of 20 m of reinforced concrete simply supported T beam, five horizontal beams hinged together. Design load level is truck No.15, and truck No.80. Table 2 shows the largest forces values in the beam.

Influence line load: The bridge design load level is the truck No. 15 and trailer No. 80 as a standard load to calculate the influence line of live load on the control section, as showed in Fig. 6 and Table 3.

Prestressed concrete continuous beam bridge (static load test): The main bridge of variable cross-section of prestressed concrete box girder has span arrangement of (30 m +50 m +30 m). Perform the static load test In order to test the carrying capacity of cross-bridge.

The purpose and test result types: The load test is designed to evaluate the carrying capacity of bridge and structural properties, include the following:



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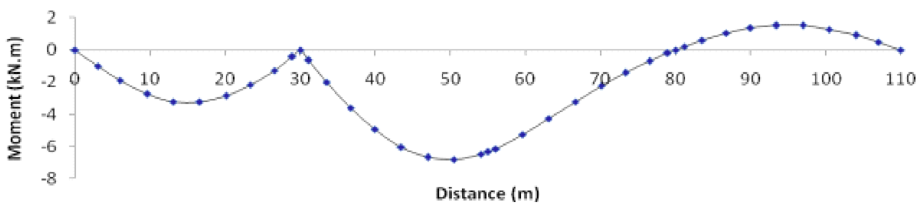

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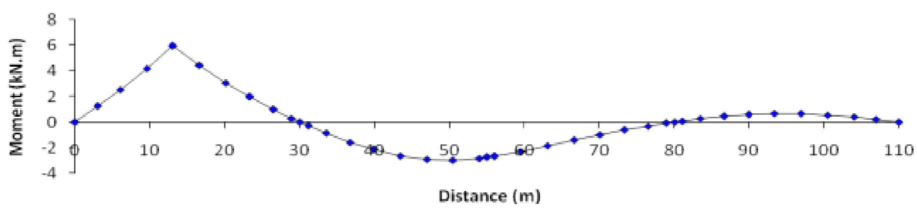

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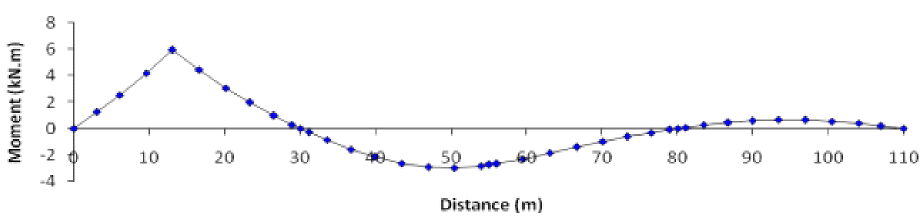


(d)

Fig. 5: Influence line of displacement in control section (a) Influence line of bending moment side- span section at mid span, (b) Influence line of bending moment at the support section, (c) Influence line of moment of cross-section at span section, (d) Influence line of vertical displacement at span section

- Concrete strain: live load effect on longitudinal of control concrete section.
- Deformation: live load effect on vertical deflection of control concrete section.

The selected control section and the measuring points: According to the structural characteristics of continuous beam and environmental conditions of bridge site, following locations and control sections for test were selected: (1) Side span mid span section, (2) Support section (pier), and (3) cross-span section. As shown in Fig. 7.

Measuring points: The strain measuring points position for side span across, support section, and mid span cross section, total of eight measurement points for each beam section, as shown in Fig. 8 (a, b, and c).

The main beam deflection test point arrangement shown in Fig. 9, all 6 measuring points were arranged downstream of the bridge, using precise leveling deck method.

Vehicle loading: Tri axial loading dump trucks used as vehicle loading characteristics are shown in Table 4.

Table 1: Design Moment of Live Load of the continuous beam cross-section (Unit: kN.m)

No.	Section	Design Moment
1	Side span section	3860
2	Support section	- 6080
3	mid span section	4020

Table 2: Lateral distribution coefficient

No.	Truck No 15	Trailer No. 80	Factor
1	0.413	0.206	0.432
2	0.507	0.388	0.06
3	0.511	0.394	0.007
4	0.507	0.388	0.059
5	0.411	0.206	0.417

Table 3: The internal forces of live load of beam (unit: kN.m)

No.	Section	Design of internal forces kN.m
1	Mid span bending moment	736.4
2	support section shear	164.6

Loading condition: According to the designed live load used and the actual loading condition, the vehicles, loaded with the equivalent load method. According to the principle of equivalent load, the control section, the experimental effects of load and design load effect should be equivalent, the efficiency of the test load shall meet the η>0.85 (η = calculated value/ measured value) requirement, considering that the bridge has been in use nearly 29 years, carrying capacity of the bridge had varying degrees of degradation, for safety reasons, the efficiency of this test load factor is 0.8, and loading the lanes according to this control ratio.

According to the procedures of the test, influence line of the control section and the actual parameters used in experimental vehicles, the most unfavorable position can be calculated in different conditions. The test results are shown in Table 5. Internal design forces are shown in Table 6, the average testing load effect is 0.81.

Vehicles load layout: The layout of vehicles arrangement is shown in Fig. 10.

Laboratory test equipment: The instrument and equipments which used in this test investigation was: (1) Concrete strain gauge; (2) Precision electronic level instrument, (3) DH Intelligent Dynamic Signal Acquisition and Analysis System; (4) DH static signals intelligence collection system, (5) Crack measurements apparatus; (6) Concrete strength hammer test apparatus; (7) Servo sensor (vibration device) type 941B. The Experimental references used in this research were listed in references list (Chinese Code JIG H11-2004; Chinese Code JTJ021-85, 1985; Chinese Code JTJ023-85, 1985).

Load pattern and test results: The actual load was applied on bridge a twice, the final value of the test points deformation represent the average of repeated loading. A total of 6 times full-bridge loaded. Before applied the vehicle load, initial reading of test point was taken then completed applying loads according to design layout requirements, after 15 min loading period, reading the values of measurements and finally completely unloading the main bridge, and waiting 15 min to read final test values. Table 7 shows the measured longitudinal strain of the concrete sections.

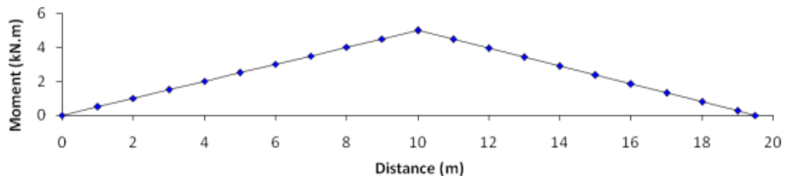
Strain values are shown in Table 7. According to section deformation of the plane section assumption, the upper and lower sections can be calculated by the stress of the edge, stress test values of the bridge versus height of beam distribution along the cross section shown in Fig. 11.

Figure 11 shows measurement of the strain test distributed along girder section. It can be seen from Fig. 11, each point of the linear distribution along the beam depth, basically meet the plane section assumption, according to the linear equation, strain and stress was calculated for the upper and lower sections, as shown in Table 8.

Table 7 and 8 and Fig. 11, shows the tested strain generated in the longitudinal cross section compared with theoretical values with strain ratio of (0.724-0.896) with an average of (0.814), in the "span test methods for concrete bridges, "the requirements of range 0.70 to 0.90, the measured values are less than the theoretical value, the test section measuring the strain distribution along the section height is well, indicating good performance of continuous beam structure. Stress test upper and lower sections calculated values are small, less than the theoretical value, which was not observed crack in box girder, indicating that the carrying capacity of the bridge still in good state and have a certain safety margin.

Deflection test results: Measurement points are located in the mid span of the continuous beam section in both side of span section, a total of six deflection measurement points, the deflection measured by precise leveling. Figure 12 shows the deformation of the three experimental conditions of the bridge compared with the theoretical calculation. Table 9 shows the deflection measurements of specific comparison with the calculated values. In the calculation of deflection, the elastic modulus of concrete is taken as the result based on the rebound hammer test results.

Figure 12 shows the experimental measuring deflection points along the longitudinal bridge with calculated values, it clear that the variation beam shape deflection both the calculated and measured so smoothly same of the bending trend line, indicating that the stiffness, the overall deformation and integrity in good working condition, and its performance is good. When the entire test load drops, the deformed of the control section recovered to the initial state before the test, the residual deformation is small, indicating that the structure is always flexible working state.



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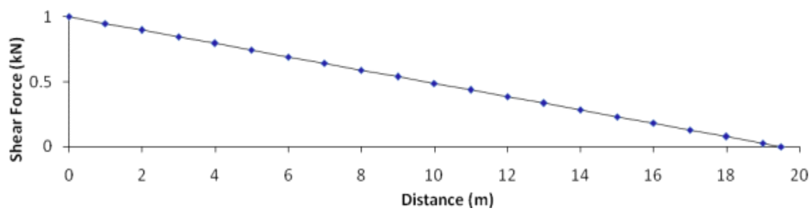


(b)

Fig. 6: Influence line of beam at control cross-section, (a) Influence line of moment in span cross-section, (b) Influence line of shear at support cross-section

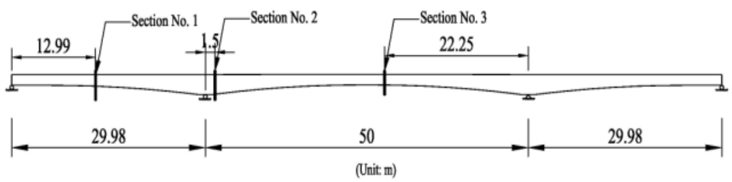
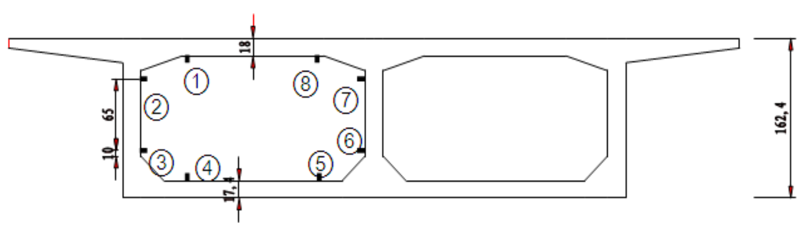


Fig. 7: Test sections position (Unit : m)



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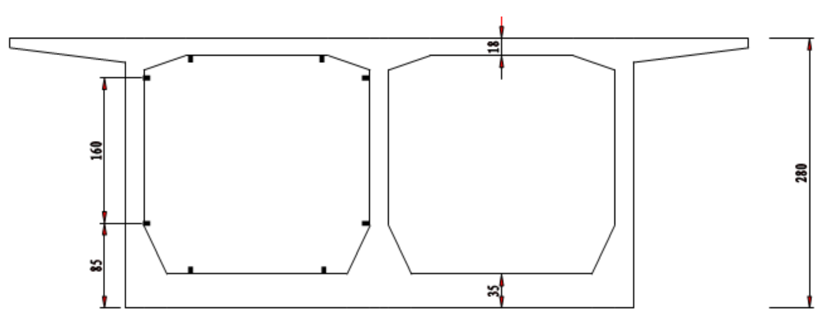

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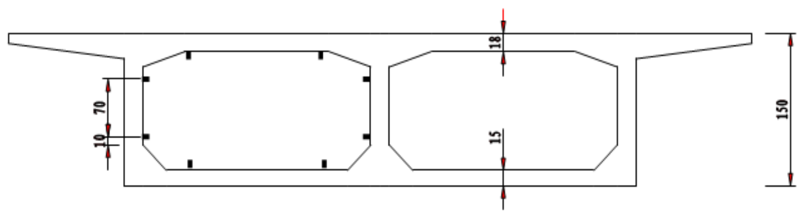


(c)

Fig. 8: Strain measuring points position of Side Span, Pier section, and mid span cross- section (unit : cm)

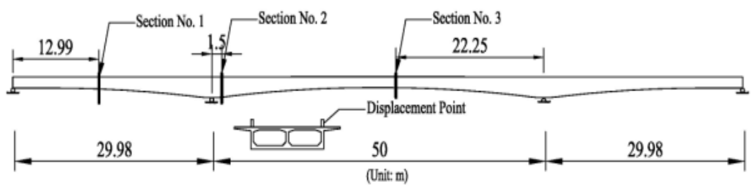


Fig. 9: Position of main beam deflection measurement points (Unit : m)

Table 4: Loading the vehicle parameters

	Axle load kN			Wheel distance cm		
Models	Front axle load	Middle Axle load	Rear Axle load	Total Weight	Front- middle	Axle Middle – rear Axle
Truck 1	49.8	98.4	98.4	246.6	400	135
Truck 2	43.2	98.8	98.8	240.8	400	135
Truck 3	46.6	99.2	99.2	245.0	400	135
Truck 4	55.4	97.5	97.5	250.4	400	135

Table 5: Load conditions and test content

No.	Conditions	Test condition
1 (symmetric)	Maximum positive moment load cross- section of mid span	Concrete strain Main beams
2 (symmetric)	Support (pier) section of maximum negative moment load	Concrete strain Main beams
3 (symmetric)	The maximum positive moment load at cross-section of side span	Concrete strain Main beams

Table 6: Experimental design internal forces and internal forces compared

No.	Position test	Design moment kN.m	Calculated moment kN.m	Test efficiency
1: symmetric	Maximum positive moment at mid span	4020	3211	0.79
2: symmetric	Maximum negative at support	- 6080	- 4932	0.81
3: symmetric	Maximum positive Moment at side span	3860	3212	0.83

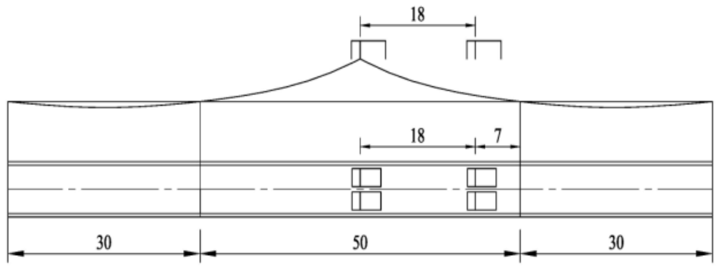
Under loading case 1, the measured middle span deflection and the theoretical value with ratio (experimental/theoretical coefficient) were 0.82; the measured value is less than the calculated value, representing that the stiffness has a certain safety margin. In the load case 3, the side span deflection of mid span section validation coefficient 0.785, the measured value is less than the calculated value, indicating that the stiffness has a certain safety margin

Simply supported beam under static load test: The static load test was designed to test cross-beams carrying capacity and structural performance. Program includes the following tests:

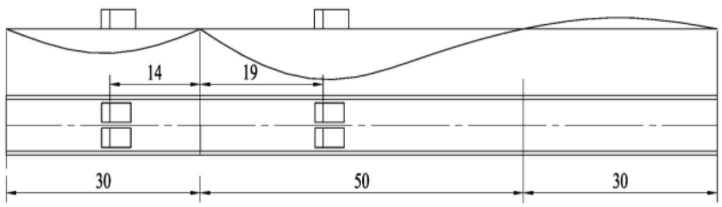
- Concrete strain and longitudinal stress
- The deformation of the beams
- The principal concrete tensile stress and diagonal crack conditions of beams near the support under live load.

Select the control section: The test program of T beam section includes the following test cases:

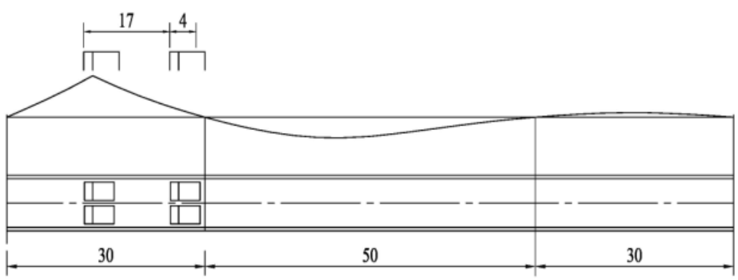
- The maximum positive moment of beam cross-section under load (flexural strength)
- The maximum deflection of beam under load
- Maximum principal stress of the support section along the beam height (diagonal shear)
- Symmetric transverse load of the main beam



Case 1: Maximum positive moment in cross section of mid span



Case 2: The maximum negative moment at support section



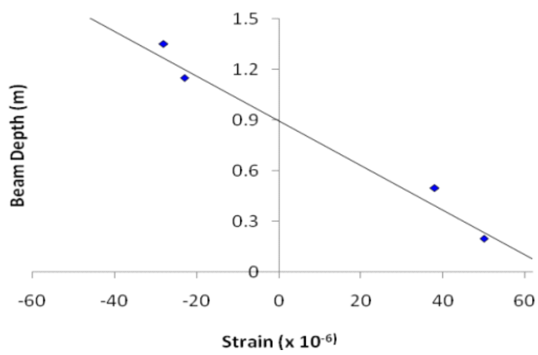
Case 3: The maximum positive moment at cross-section of side span
Fig. 10: Show the vehicles loads layout (Unit: m)

Table 7: The main longitudinal strain of concrete continuous beam bridge results

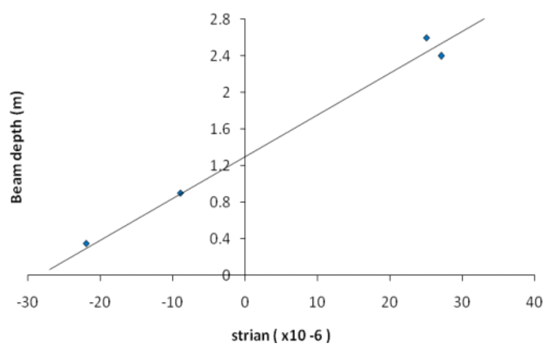
Test section	Measuring point number	value of strain $\mu\epsilon$	Theoretical value ($\mu\epsilon$)	Calibration coefficient
Mid span section (case 1)	1	- 33	- 41	0.801
	2	- 23	- 30	0.762
	3	28	34	0.827
	4	53	66	0.803
	5	49	66	0.750
	6	24	34	0.724
	7	- 26	- 30	0.850
	8	- 34	- 41	0.830
Support section (case 2)	1	28	32	0.855
	2	25	28	0.896
	3	- 9	- 11	0.751
	4	- 20	- 24	0.842
	5	- 19	- 24	0.799
	6	- 9	- 11	0.811
	7	24	28	0.869
	8	27	32	0.821
Side span section (case 3)	1	- 33	- 38	0.859
	2	- 15	- 19	0.790
	3	23	28	0.840
	4	43	53	0.801
	5	41	53	0.774
	6	23	28	0.823
	7	- 16	- 19	0.841
	8	- 31	- 38	0.807

Table 8: Strain and stress conditions of the upper and lower cross section

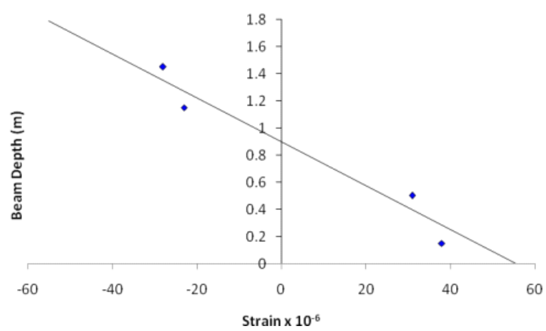
Test section	Point	Estimated value of the strain (με)	Estimated value of stress (Mpa)	Theoretical (με)	Calibration coefficient
Mid Span	Section at edge	- 46	- 1.454	- 58	0.793
	lower edge of section	63	1.991	80	0.788
support	Section at edge	29	0.916	37	0.784
	lower edge of section	- 27	- 0.853	- 33	0.818
Side Span	Section at edge	- 44	- 1.390	- 52	0.846
	lower edge of section	57	1.801	66	0.864



(a) Mid-span Cross section



(b) Cross section at the support



(c) Side span mid-span section

Fig. 11: The measured strain with beam depth

Section measuring points: The main beam section strain measuring points are shown in Fig. 13. Beam strain measurement points #1, #2, #3 are arranged in beam web as strain measurement points for beam #2 and #3 to test the performance of T beams, total measuring points were12.

Displacement measuring points in the beam girder cross section (maximum deflection measurement points), two support (bearing settlement), as in Fig. 14, each piece measuring beam have 3 points, a total of 15 measuring points, located on the deck layout center line of the corresponding main beam, used to test the main beam deflection, a bridge bearing lateral settlement and distribution test case.

Principal tensile stress test of the support girder section: Stress test points are located near the central axis between the section of girder #3 at supporting point and far one girder height from the supporting point as shown in Fig. 15.

Vehicle loading: Tri axial loading dump trucks used and the vehicle characteristics as shown above in Table 4. The loading pattern and standard requirement was illustrated above in paragraph (3.5 loading condition).

Simply supported beam under the loading conditions and tests requirement are all shown in Table 10.

According to the test program, and the actual loading of vehicles used, The calculation shows that the 4 vehicles are needed to verify the loading test, but because the bridge is narrow, two barely covered the bridge deck, to improve the experimental efficiency, each of two vehicle merged into a single line. A comparison of the experimental and calculation of internal forces under design load are shown in Table 11. Average test load calibration coefficient is about 0.844, the lateral distance between the vehicles is 1.3 m, and layouts of the vehicles are shown in Fig. 16.

Analysis of load test results:

Concrete strain test: The comparison between measured the maximum strain of beam section under the test load and calculated values are shown in Table 12, the measuring points of beam #2, and # 3 of which have the high strain test values are shown in Table 13.

From Table 12, 13 and Fig. 17, the main girders #1 to #3 shows that the measured and calculated values of longitudinal strain are agree relatively well, some measuring point slightly larger than the calculated value

Table 9: deflection test results (Unit: mm)

Condition No.	Location	Theoretical value of deflection	Measured deflection	Experimental/Theoretical
Case 1: Maximum positive moment (Span Section)	Cross-Span 1	3.380	2.647	0.783
	Cross-Span 2	- 12.000	- 9.840	0.820
	Cross-Span 3	4.300	4.306	0.999
Case 2: Maximum negative moment (support)	Cross-Span 1	0.670	0.657	0.980
	Cross-Span 2	- 5.500	- 4.400	0.800
	Cross-Span 3	1.500	1.305	0.870
Case 3: Maximum positive moment side span	Cross-Span 1	- 5.000	- 3.925	0.785
	Cross-Span 2	3.800	3.048	0.802
	Cross-Span 3	- 0.900	- 0.829	0.921

Table 10: Load conditions and test content

No.	Condition	Test content
1. Partial load	Beam span#3 The maximum positive moment	1) strain in longitudinal Cross-section of 2) deflection 3) The lateral distribution
2. Partial load	Support # 2 maximum shear beam	1) strain in longitudinal Cross-section of 2) deflection 3) The lateral distribution
3. symmetry	Deflection Span of the main beam	1) strain in longitudinal Cross-section of 2) deflection 3) The lateral distribution

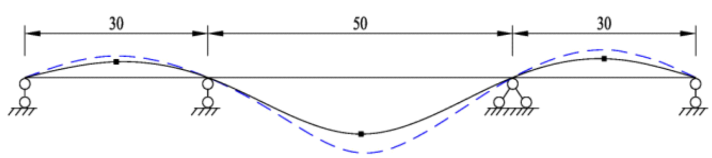
Table 11: Effect of test load compare with the design load

		(Unit: kN, kN.m)		
No.	Section	Test internal force	Calculated internal force	Experimental/calculated
1	Beam no 3 under bending	586.47	736.4	0.796
2	Beam no 3 under shear	146.83	164.6	0.892

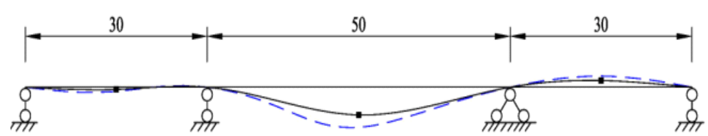
Table 12: The test and calculated strain section #1and #3 of the main beam under the lower edge

No.	Measured strain ($\mu\varepsilon$)	Calculation of strain $\mu\epsilon$	Measured / calculated
1	109	116	0.94
2	211	203	1.08
3	227	212	1.07

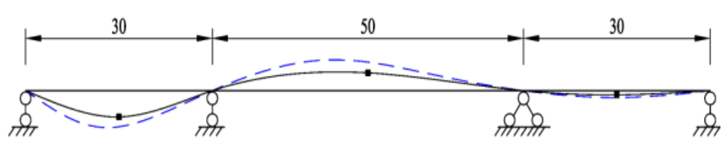
Note: $\mu = 10^{-6}$



(A) Case 1: Max symmetrical load deflection of positive bending moment at mid-span. (Unit m)



(B) Case 2: Max symmetrical load deflection of negative bending moment at supporting point section



(C) Case 3: Max symmetrical load deflection of negative bending moment at mid-side span section

Fig. 12: Comparison of measured value with calculated values of various loading case (dashed line is the calculated values, solid line is measured) (Unit: m)

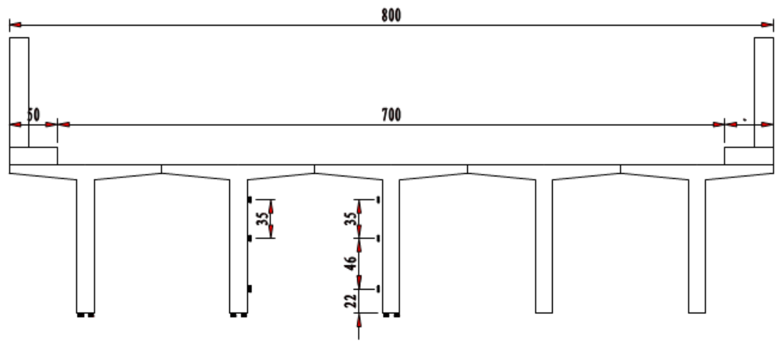


Fig. 13: Strain measuring point's position (Unit : cm)

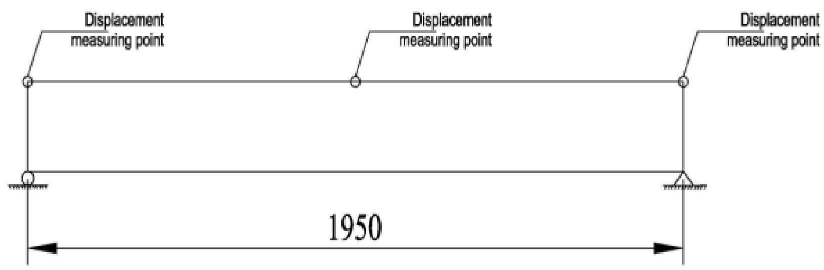


Fig. 14: Main beam displacement measuring points (Unit : cm)

Table 13: The maximum strain at measuring point of the main beam #2, and #3 along sections

No.	Measuring point number	The Distance from the lower edge of beam (Cm)	Strain (με)
#2	4	103	- 21
	5	68	55
	6	22	156
	7	0	211
#3	9	103	- 23
	10	68	61
	11	22	168
	12	0	227

Table 14: Crack width (Unit: mm)

No.	Before loading	After loading	Unload
#2	0.18	0.28	0.21
#3	0.22	0.31	0.25

Table 15: Deflection test results under test loads of main beam section

Beam No.	Measured (mm)	Calculated (mm)	Measured/calculated
1	5.6	5.9	0.95
2	11.2	10.3	1.09
3	12.3	10.7	1.15
4	10.9	10.3	1.06
5	6.2	5.9	1.05

of strain. Each value of strain point of beam #2 and # 3 can basically meet the high linear variation. Table 13 shows that, during the experiment, there is an increasing trend crack, crack width about 0.31, more than crack limit 0.25mm and during unloading case; the crack has not been completely restored to the initially state. The bridge carrying capacity has decreased and has some plastic deformation, which indicates that the main beams has small safety margin, the margin carrying capacity insufficient and need reinforcement. The cracks width measurements are shown in Table 14.

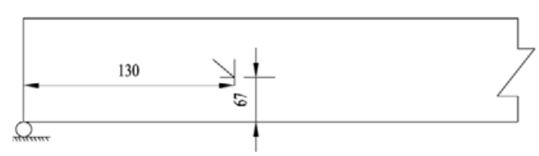


Fig. 15: Support section strain measuring points (Unit : cm)

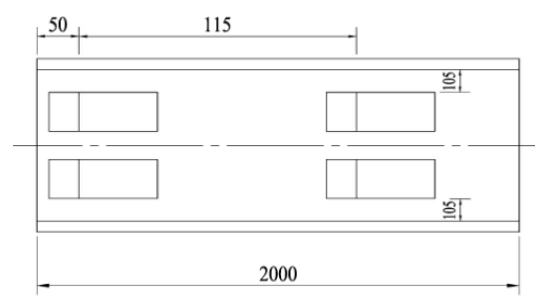
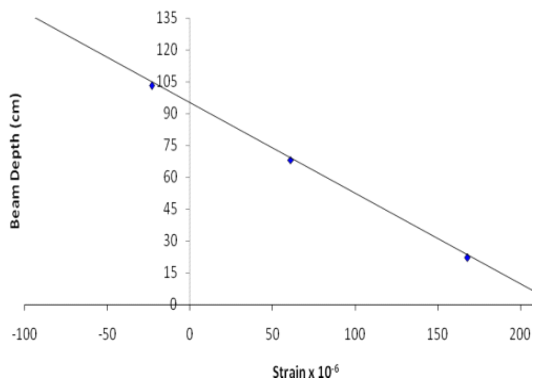
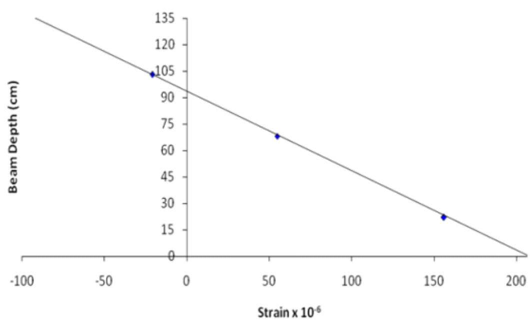


Fig. 16: Vehicles load layout (Unit : cm)

T Beam deflection test: The comparisons of the measured and calculated deflection test of the beam were shown in Table 15. It clearly from Fig. 18, the measured deflection was close to calculated values, at some



(a) Beam # 2



(b) Beam #3

Fig. 17: The measured strain along cross section of the beam #2, and #3

measurement points it's greater than the calculated deflection. Indicating that the large cracks mean the stiffness of main beam losing seriously, carrying capacity decreases. It can be seen, under the experimental loads, the beams integrity of the deformation performance well, indicating that the horizontal linkages of beam are well.

Tensile stress of the main beam at support cross-section: The measured principal tensile stress at the measured point was 0.7 MPa, calculated value is 0.79 MPa, ratios between them is 0.88, almost so close. In the experiment, measuring the inclined cracks before the experiment it was 0.1 mm, after loading it was 0.17 mm, and after unloading it was 0.12 mm, meet regulatory requirements, indicating that the shear capacity of the bridge basically meet the specifications, but the reserve is not much enough.

CONCLUSION

The continuous bridge span beam: Prestressed concrete box girder under static load test and structural analysis of the test, we can find the following conclusions:

- Under the test load, longitudinal theoretical strain generated by the loads along the cross section with the range of 0.724-0.896, an average 0.814, in the (long span bridge test) the strain range requirements is 0.70 to 0.90, the measured values are less than the theoretical value, indicating that the measuring strain distribution along the section height is well, also indicating good performance of continuous beam structure. Calculated stress values test at upper and lower sections are all less than the theoretical values, doesn't observed crack in box girder, indicating that the carrying capacity of the bridge has good condition and have a certain safety margin.
- Under the test load ,vertical deflection of the measuring point along the bridge show the same variation for experimental and theoretical results which shows the deflected smooth shape line almost same bent, indicating that the stiffness, the overall deformation and integrity are in good working condition, and its performance is good. When entire test load drops, the control section of the deformed

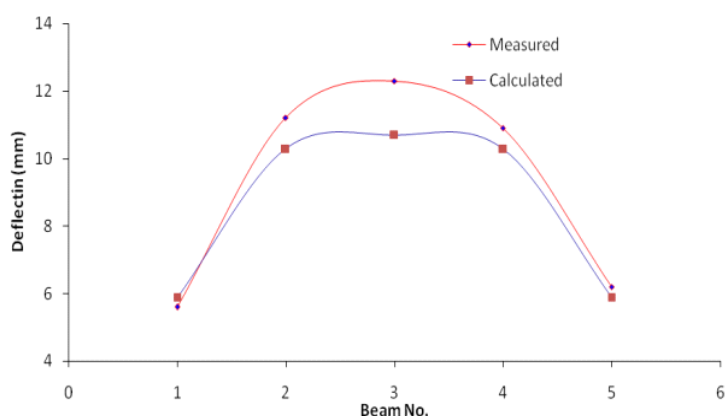


Fig. 18: Experimental load deflection of the main beam of the film distribution

recovered to the initial state before the test; the residual deformation is small, indicating that the structure in the experiment is always in flexible working state.

- During testing process, the pier cracks was check, and found no cracks expansion and in good work conditions. In summary, continuous beam bridge carrying capacity and stiffness all meet the truck No.15 level and trailer No.80 level design requirements.

Side span beam: Beams behavior through the static load test and structural analysis, we can conclude the following:

- The calculated and measured strain values of the main beam agree relatively well. Most of the measuring point calculation of strain is greater than the theoretical strain, indicating that the carrying capacity of the main beam down to a certain extent, carrying capacity is not enough.
- The cross beams beyond the limit of crack width, after unloading; cracks cannot be fully restored, residual deformation very small, indicating that the main beam has a certain extent the development of plastic deformation.
- Each point of deflection measured value of main beam is greater than the calculated values, indicating that main beam stiffness decreased to a certain extent.
- The measured principal tensile stress at support section are in a good agreement comparing with the calculated values, diagonal crack width meet the specifications, indicating the bridge strength meet the requirements.
- Under the test load, deformation of the main beams linkage, there were no single stressed beams, indicating that horizontal linkages of the bridge are safe and reliable.
- In the experiment, the bearing of bridge piers hasn't observed abnormal deformation.

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