Field Static load Effect on Performance of Hollow Section Girder Bridge Subjected to Fire (Part A)

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ABSTRACT

Hollow Bridge section inspection was carried out in this study and different reasons may cause major failure of bridge. The field inspection of bridge structural elements has been paying more attention of engineering academic researchers. The bridge has been exposed to fire accident in additional to the excessive load and environmental factors effects. This study dedicated for inspection the White River Bridge elements (Bai xi da Qiao/ China) including the essential damage in main girder , concrete spalling, deformation due to deflection and excessive stress and strain, deck slab and concrete cover, steel corrosion…..etc. The analysis of field test evaluates the performance of whole structure of bridge element under static load test. The investigation results shows that the bridge has minor defects through the substructures such as there is no major corrosion of reinforcement and the concrete in a good condition. The upper structure depending on analysis field test of deflection and strain at the critical section, that the main girder has no enough capacity and need to be strengthened.

Keywords: Field investigation; Concrete Hollow section girder, Bridge performance.

تأثير الحمل الساكن الميداني على اداء جسر ذات مقطع مجوف معرض لحادث حريق (الجزء الاول)

الخلاصة

في هذا البحث أجريت تحريات على جسر ذات مقطع مجوف والتي اظهرت ان هناك اسباب متعددة لحصول الفشل في هذا الجسر. الاختبارات الموقعية والميدانية لاجزاء هيكل الجسر اعطيت اهتمام كبير من قبل الباحثين والاكاديميين . تعرض الجسر لحادث حريق بالإضافة إلى الاحمال العالية وتأثير العوامل البيئية بشكل مفرط. خصصت هذه الدراسة لفحص وتدقيق اجزاء ومكونات جسر النهر الأبيض (باي سي داو تشياو/ الصين) بما في ذلك الأضرار الاساسية في عتبات الجسر الرئيسية ، تساقط وتشظي الخرسانة ، التشوهات بسبب الهطول واجهادات الانفعال المفرطة ، سطح البلاطة والغطاء الخرساني ، تآكل الحديد ......الخ. تحليل نتائج الاختبارات الميدانية التي اجريت هي لتقيم اداء جميع اجزاء ومكونات الجسر تحت تأثير الحمل الساكن . حيث اظهرت نتائج الاختبارات ان هناك عيوب طفيفة في مكونات الجسر السفلية (الاساسات) مثل عدم وجود تآكل كبير في حديد التسليح والخرسانة في حالة جيدة. اما الهيكل العلوي ومن خلال الاعتماد على الاختبار الميداني وتحليل نتائج الانحرافات (الهطول) والانفعال في المقاطع الحرجة للعتبات الرئيسية تبين ان تلك العتبات ليس لديها مقاومة كافية وتحتاج الى تقوية وتدعيم.

INTRODUCTION

One of the most important factors in developing the countries is the economic which depend strongly on using effective public transportation systems. World Bridges are one of the major lifeline structures which facilitate mobility. Bridges are supposed to be maintained properly to keep in safe, where any accident could be disaster on the functionality of transportation. Therefore it’s important to maintain and upgrade bridges integrity to keep the use of bridge. One of the factors effects on performance and degradation of bridges is the higher or increasing the traffic loads.

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In order to accomplish the demands stated in the standards, the alternatives for these bridges are either demolition followed by reconstructs a new bridge, or strengthening of the existing structures. It is preferable in many aspects, to choose strengthening rather than demolition, due to environmental and economic reasons. In last decades there are great uncertainties about which strengthening methods are suitable and when to use them. Beam bridges are much more accessible for strengthening, since they can be strengthened externally on each side of the beam while the slabs deck does not have that accessibility [1].

The strengthening materials have found wide use in civil constructions [2], especially for strengthening and rehabilitation of deteriorated structures, because of their high strength and stiffness, lightweight, resistance to chemicals, good fatigue strength, and simplicity of the field application. Given the savings in construction time and the potential long-term benefits, material of strengthening reinforced concrete bridges can be cost-effective, notwithstanding their high initial costs [3].

Worldwide research and use of strengthening systems have led to the development of standards (ACI Committee 4402R, 2002) to effectively upgrade the strength of systems both in buildings and bridges. In addition to strength increase, FRP strips have been used to repair and retrofit concrete structures (Emmons et al, 1998a & 1998b) [4, 5]. Epoxy Bonded FRP methods also called EB-FRP, have been used in a number of full scale bridge strengthening projects (Alkhrdaji et al, 2000; Stallings et al, 2000; Hag-Elsafi et al, 2000) [6,7,8]. The in-field application of the bonded system however requires time-consuming 3 and often difficult preparation of the concrete surface to provide adequate bond strength between the FRP strip and the concrete substrate. The substrate typically needs to be sand blasted, cleaned and ground smooth prior to the application of the strips, which delays the immediate availability of the strengthening.

Sanaa and Farah in 2014 were studied the characteristic of reinforced concrete exposed to harsh environments specially the deterioration of reinforced concrete on life time. They used different type of additives added to reduce water and two types of mineral additives that include silica fumes and steel fiber. The result of the specimens partially submerged in a solution of chlorides and sulfates were evaluated through the properties investigated included ultrasonic plus velocity, compressive strength electrochemical potential for various types of mixes. Concrete mixed with 10% of silica shown development all properties of concrete, while these properties decease for sample coated with natural rubber or steel fiber [9].

The assessment process of any structure has ultimate essential priority in rehabilitation procedures and evaluation of different structural members. Recently the academic researchers developed several scientific methods to strengthening the deteriorated structures element due to many reasons. Sabih Z. Al-Sarraf et al [10] studied the externally strengthening of continuous concrete beam with CFRP laminates (carbon fiber reinforced polymers) in upgrading or rehabilitation techniques. The results show that the use of external CFRP laminate glued to the beams could enhance the ultimate flexural load capacity up to 102.88%.

Bridge Description

The bridge is located in Ningbo city, Zhejiang province highway road, the total length is 367 m. The upper structure of bridge : 16 span with span length = 20 m , span width of 11.75m, arranged: 0.5m (side-wall) +2.5 m (hard shoulder) +2 × 3.75m (motor vehicle lane) +0.75 m (hard shoulder) +0.5 m (side-wall): This bridge is a consist of four-lane, divided in two direction, hollow slab height 0.85m. Fig. 1 shows the cross section view of the bridge

The substructure consists of U-shaped abutment, expanding base cap and pier pile foundation for the double column. The bridge main technical criteria as follows:

a) Design load rating vehicle- 20, and -120 level 2.
b) Road classified as Highway Road.

The original design of the bridge execution was according to the "Highway Bridge Design General Specification", "Highway Reinforced Concrete and Prestressed Concrete Bridge Design Specifications" [11, 12, and 13]

The end of second span of bridge exposed to fire accident, resulting spalling in the bottom concrete slab, exposed tendons; and spalling of cap beam concrete. The right hand of third span

Through the test program stress and deflection was measured for the bridge span structure under static test loads of control section and compare with theoretical calculations, the actual structure of test stress and deflection control section meets design standard requirement [11].

Through the field loading test, the comparative analyses of experimental were carried out on the span-2 and span-3 of the bridge after the fire accident to assess the carrying capacity of the structure, and then determine the extent of damage and according to the results the maintenance recommendations were made.

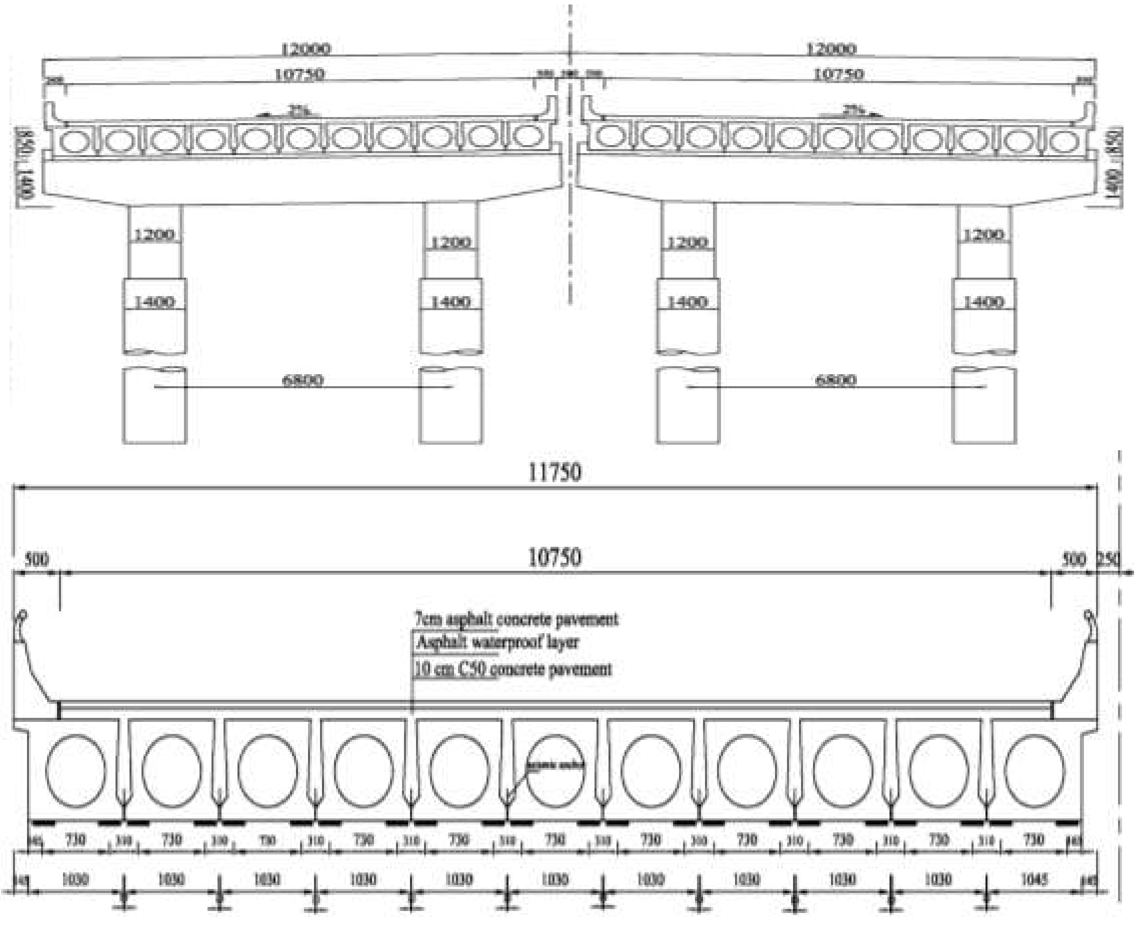


Figure. 1. Bridge layout and section details

Static load test was carried out to verify the design loads action, the bridge structure work status and job performance, and the reliability. Through the static load test of the structure bridge, the measurement test includes: loads, stress and deflection of control section and other parts indicators, compare with the theoretical calculations and related specifications limits, verify that the actual strength and stiffness of the bridge structure meets the design and specifications requirements. The field test was done by Ningbo traffic construction engineering test center company, LTD. Theoretical results was obtained using the finite element method software analysis.

Test section and measuring points Static load test section in Fig. 2, section A, B, C, and the lower edge of the test section for deflection and tensile strain measuring points.

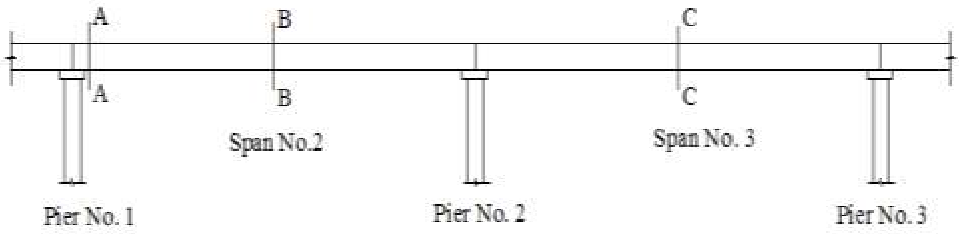


Figure. 2. Control section

Bridge Expose to Fire

On January 28, 2012, the bridge has been exposed to fire accident coming from vehicle crashes continue for one hour. It became obvious that for highway bridges constructed from steel and concrete on major routes the most common events causing severe damage were truck fires due to collision Fig. 3, 4, 5 and 6 showing the spalling of concrete due to fire action for different parts and girders indicates in these figures.

Figure. 3, span 2-Girder 1, concrete spalling, exposed tendons due to exposing fire.

a-Girder 2 **b- Girder 5.**

Figure. 4. Span 2-Girder 5 concrete spalling, exposed tendons due to exposing fire.

Figure. 5. Cover of right hand side a beam bearing after fire.

Figure. 6. Span 2-Girder-2 Pier concrete spalling due to exposing to fire.

Test Load Cases

The loading cases was chosen as according to the critical section

Static load applied basically close to the design load of the bridge to predict the stress state, deformation of the bridge and the main reaction force member. General requirements for the test load are corresponding effect of the closeness of load efficiency coefficient generated by the effect of the design load of the structure on the main control section, as in the following formula [14]:

$$\eta_q = \frac{S_S}{S(1+\mu)}$$

η_q : Static load efficiency coefficient;

S_S : calculated internal force values under Static load of tested section (or deformation);

S : Internal Design force values (or deformation) under static loads of the control cross-section (excluding the impact factor);

μ : The impact coefficient used according to the specifications.

According to the requirements of the highway bridge carrying capacity testing assessment procedures [15] η_q should meet from 0.8 to 1.05. The four cases of the test load, as shown in Table 1.

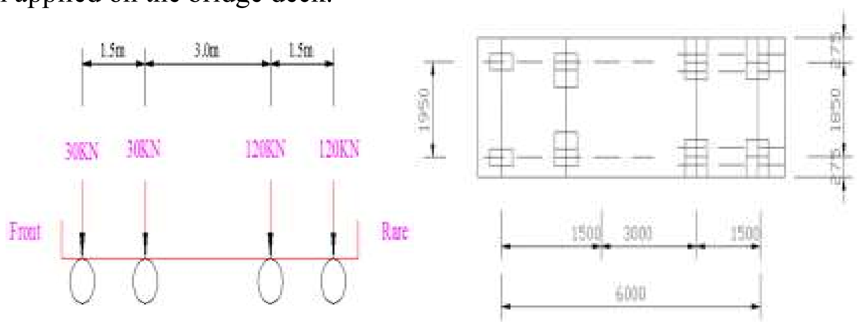
In order to adopting the performance loading test of the control members, will consider a classification method of loading and the efficiency coefficient η_q = 0.86. Figure 7 showing the layout of vehicle load [11].

Table 1. Loading case of static load

Case No.	Load Level	Loading Detail	Test content

Case-1	1,2,3	Span 3 , girder 4 for the maximum positive bending moment and Deflection	Mid span Deflection and Strain
Case-2	1,2,3	Span 3 , girder 8 for the maximum positive bending moment and Deflection	
Case-3	1,2,3	Span 2 , girder 4 for the maximum positive bending moment and Deflection	
Case-4	1,2,3	Span 2 , girder 8 for the maximum positive bending moment and Deflection	
Case-5	1,2	Span 2 , girder 4 for the maximum shear at control section	Observing end shear crack
Case-6	1,2	Span 2 , girder 8 for the maximum shear at control section	

Fig. 7 (a & b) show the layout of the vehicle load applied on the bridge lane. Fig. 8 shows the location of strain gauge sensor at the critical girder section of bridge and fig 9 showing the location of deflection sensor at the critical girder section. Fig. 10 showing the static loading cases which applied on the bridge deck.



a) Axel Load

b) Plan view

Figure. 7.Vehicle load layout (mm) [11]

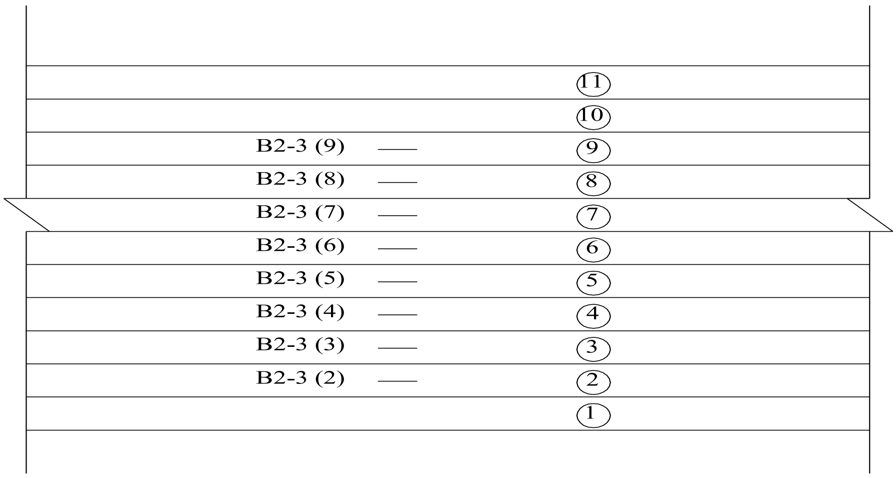


Figure. 8 location of strain gauge sensor at the critical girder section

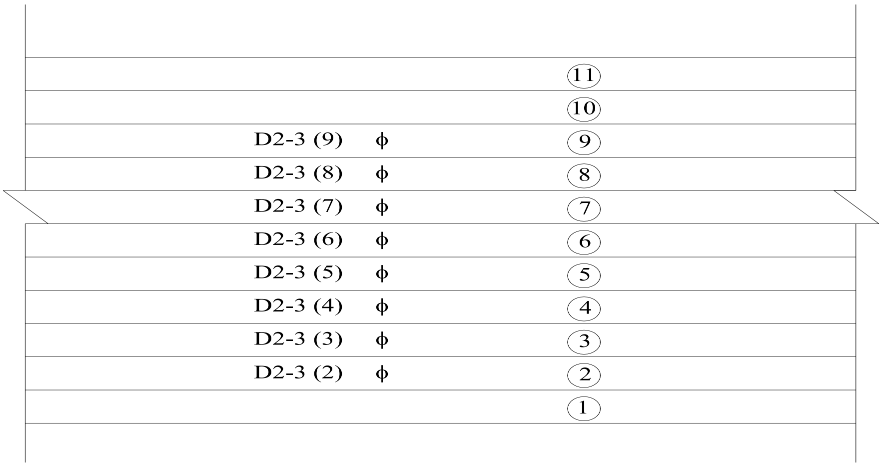
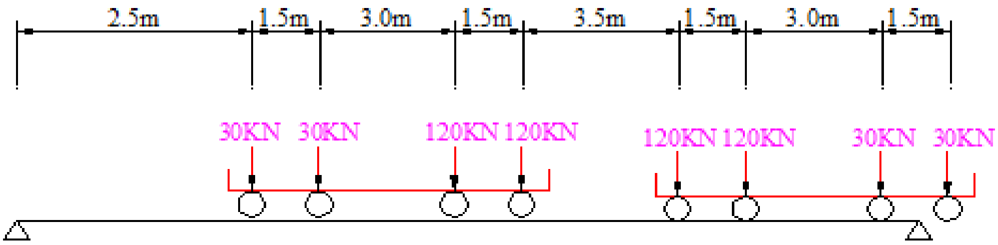
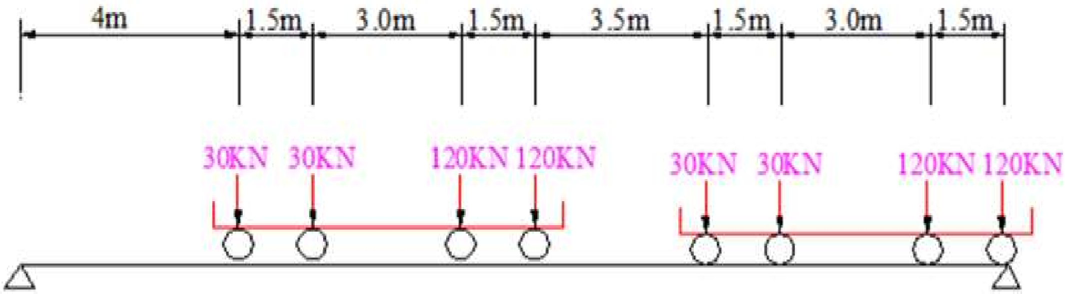


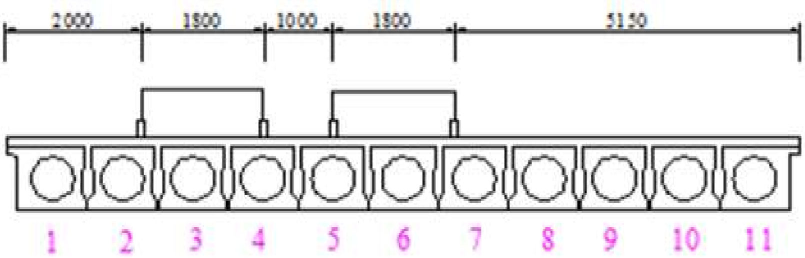
Figure. 9 location of Deflection sensor at the critical girder section



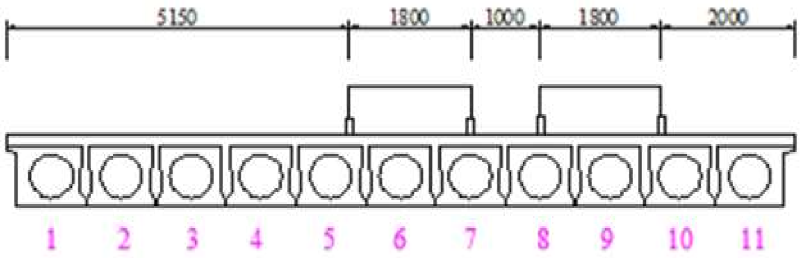
a) case 1,2, 3，4 load vehicle longitudinal layout



(b) Case-5, 6 load vehicle longitudinal layout.



(c) Case-1, 3, 5 load vehicle lateral layout.



(d) Case-2, 4, 6 load vehicle lateral layout (mm)

Figure. 10. Static loading cases layout [11].

Test Equipment and Methods

Strain measurement sensors, static strain signal directly were connected to the computer processing reading data. At specific deflection measurement points of the bridge, measurement of displacement meter were installed, the measurement data collected through the data acquisition instrument [15].

Static Load Test Results and Analysis.

Static Load Test Conditions a Result.

A static load test conditions of case 3 girder-4 for control cross-section maximum bending moment and maximum deflection for loading arrangement, the measured slab girder span section normal strain measurement and calibration coefficients are shown in Table 2, the mid-span deflection measurement and calibration coefficients are shown in Table 3.

Table 2. Case-1, span 3 mid span positive strain and calibration coefficient values (strain unit：$\varepsilon\times 10^{-6}$)

Girder No.	Points	Load Level-3			Unloaded	
		Test Value	Theoretical value	Calibration Coefficient	Test Value	Relative residual deformation
Girder -2	B3-2	62.1	84.6	0.71	1.8	2.9%
Girder -3	B3-3	62.9	85.4	0.72	1.7	2.7%
Girder -4	B3-4	70.1	86.2	0.79	1.6	2.3%
Girder -5	B3-5	62.1	83.4	0.72	1.9	3.0%
Girder -6	B3-6	55.8	77.5	0.70	1.4	2.4%
Girder -7	B3-7	41.2	70.8	0.56	1.5	3.5%
Girder -8	B3-8	39	62.6	0.60	1.3	3.2%
Girder -9	B3-9	26.1	55.1	0.44	2.1	8.0%

Table 3. Case-1, span 3 mid span deflection and calibration coefficient values (deflection unit：mm)

Girder No.	Points	Load Level-3			Unloaded	
		Test Value	Theoretical value	Calibration Coefficient	Test Value	Relative residual deformation

Girder -2	D3-2	5.27	7.25	0.72	0.08	1.5%
Girder -3	D3-3	5.84	7.31	0.79	0.03	0.5%
Girder -4	D3-4	5.31	7.38	0.72	-0.13	/
Girder -5	D3-5	5.35	7.14	0.73	0.11	2.1%
Girder -6	D3-6	4.76	6.64	0.71	0.03	0.6%
Girder -7	D3-7	4.44	6.07	0.73	0.09	/
Girder -8	D3-8	3.56	5.36	0.64	0.13	3.7%
Girder -9	D3-9	3.11	4.72	0.66	0.00	0.0%

Fig. 11 shows the theoretical and experimental strain of indicated girder at specific point loading case-1. Fig. 12 show the theoretical and experimental deflection of girder of loading case-1

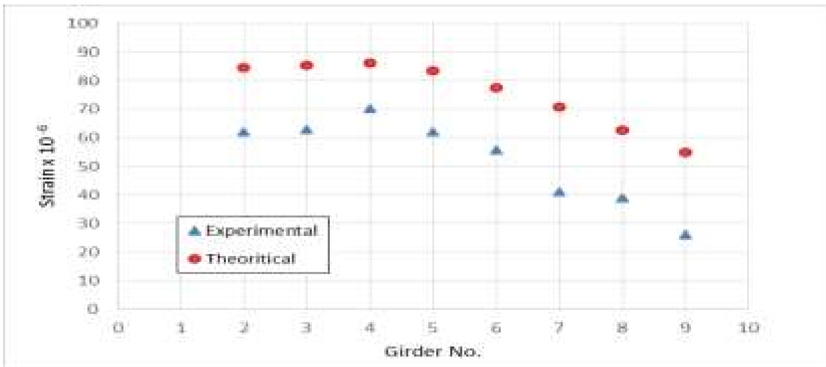


Figure. 11. Theoretical and experimental strain value of loading case-1 (after exposing to fire).

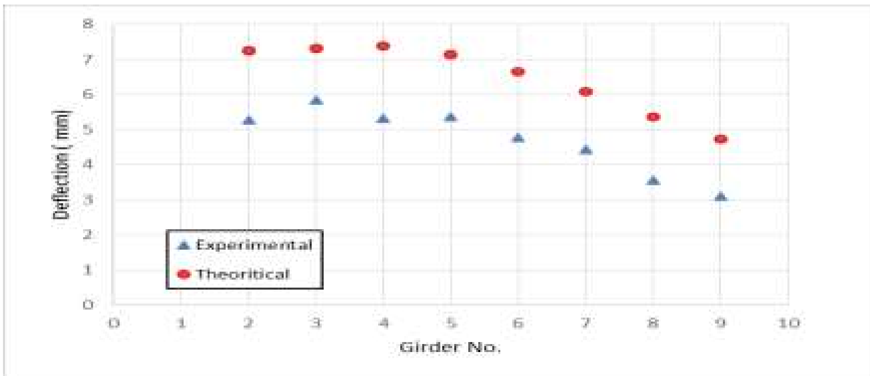


Figure. 12. Theoretical and experimental deflection value of loading case-1 (after exposing to fire).

Table 4. Case-2, span 3 mid span positive strain and calibration coefficient values (strain unit：$\varepsilon \times 10^{-6}$)

Girder No.	Points	Load Level-3			Unloaded	
		Test Value	Theoretical value	Calibration Coefficient	Test Value	Relative residual deformation
Girder -2	B3-2	35.0	50.4	0.66	1.9	5.3%
Girder -3	B3-3	44.3	55.1	0.77	2.1	4.6%

Girder -4	B3-4	51.0	62.6	0.79	1.8	3.5%
Girder -5	B3-5	51.8	70.8	0.70	1.9	3.7%
Girder -6	B3-6	60.4	77.5	0.76	1.5	2.4%
Girder -7	B3-7	60.0	83.4	0.71	0.9	1.5%
Girder -8	B3-8	65.5	86.2	0.75	1.2	1.8%
Girder -9	B3-9	58.4	85.4	0.67	1.5	2.5%

Table 5. Case-2, span 3 mid span deflection and calibration coefficient values (deflection unit：mm)

Girder No.	Points	Load Level-3			Unloaded	
		Test Value	Theoretical value	Calibration Coefficient	Test Value	Relative Residual Deformation
Girder -2	D3-2	3.26	4.31	0.75	0.01	0.3%
Girder -3	D3-3	3.58	4.72	0.76	0	0.0%
Girder -4	D3-4	3.91	5.36	0.73	-0.08	/
Girder -5	D3-5	4.25	6.07	0.70	-0.01	/
Girder -6	D3-6	4.77	6.64	0.71	0.07	1.5%
Girder -7	D3-7	5.27	7.14	0.71	0.21	4.0%
Girder -8	D3-8	5.03	7.38	0.68	0	0.0%
Girder -9	D3-9	4.59	7.31	0.62	0.03	0.7%

Results of static load test of case-2

Static load test case-2 of span 3 girder no.8 of mid-span section for maximum bending moment and maximum deflection, the measured value of normal strain and calibration coefficients are shown in Table 4. The mid-span deflection measurement and calibration coefficients are shown in Table 5. Fig. 13 and 14 shows the strain and deflection with girder number respectively of loading case-2.

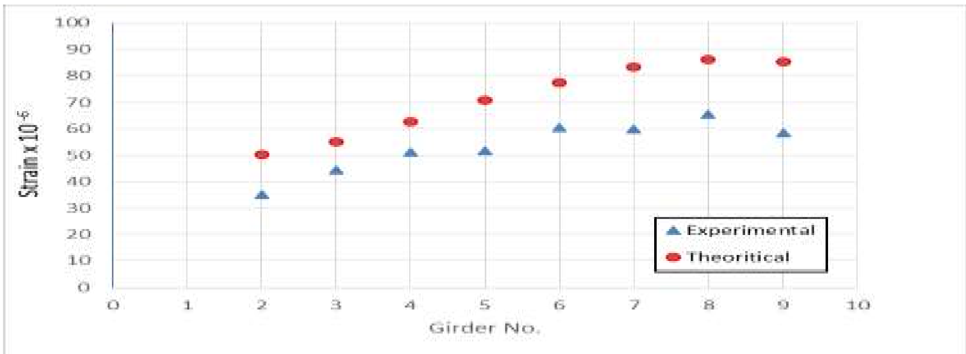


Figure. 13. Theoretical and experimental strain value of loading case-2 (after exposing to fire).

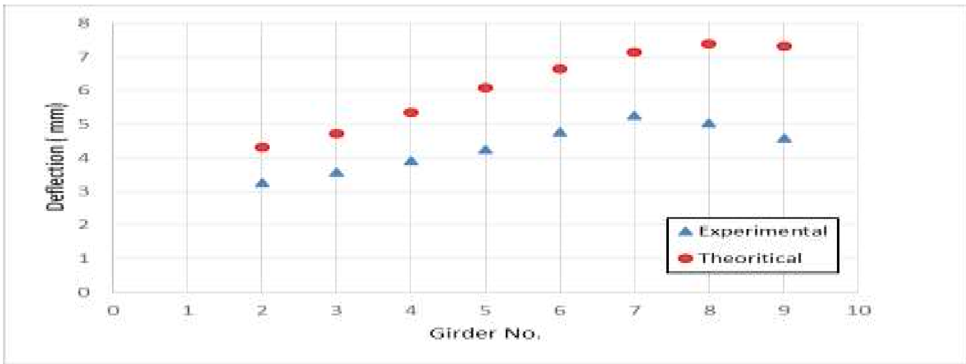


Figure. 14. Theoretical and experimental deflection value of loading case-2 (after exposing to fire).

Static load test case-3 results

Static load test case-3 of span 2, girder 4 for maximum bending moment and maximum deflection of the control cross-section girder span, the measured value of normal strain and calibration coefficients are shown in Table 6. The midspan deflection measurement and calibration coefficients are shown in Table 7.

Table 6. Case-3, span 2 mid span strain and calibration coefficient values (strain unit: $\varepsilon\times 10^{-6}$)

Girder No.	Points	Load Level-3			Unloaded	
		Test Value	Theoretical value	Calibration Coefficient	Test Value	Relative residual deformation
Girder -2	B3-2	78.6	84.6	0.90	2.3	3.0%
Girder -3	B3-3	47.5	85.4	0.52	2.7	5.7%
Girder -4	B3-4	61.9	86.2	0.69	2.4	3.8%
Girder -5	B3-5	82.8	83.4	0.96	2.5	3.1%
Girder -6	B3-6	71.2	77.5	0.89	2.4	3.4%
Girder -7	B3-7	42.1	70.8	0.56	2.5	6.0%
Girder -8	B3-8	28.3	62.6	0.43	1.3	4.6%
Girder -9	B3-9	26.6	55.1	0.46	1.4	5.1%

Table 7. Case-3, span 2 mid span deflection and calibration coefficient values (deflection unit：mm)

Girder No.	Points	Load Level-3			Unloaded	
		Test Value	Theoretical value	Calibration Coefficient	Test Value	Relative Residual Deformation
Girder -2	D3-2	5.64	7.25	0.77	0.08	1.4%
Girder -3	D3-3	6.33	7.31	0.85	0.09	1.4%
Girder -4	D3-4	5.60	7.38	0.75	0.06	1.1%
Girder -5	D3-5	5.86	7.14	0.82	-0.02	/
Girder -6	D3-6	5.46	6.64	0.82	0.00	0.0%
Girder -7	D3-7	4.86	6.07	0.80	0.00	0.0%
Girder -8	D3-8	4.25	5.36	0.79	0.00	0.0%
Girder -9	D3-9	3.38	4.72	0.72	-0.05	/

Fig. 15 and 16 shows the strain and deflection with girder number respectively of loading case-3

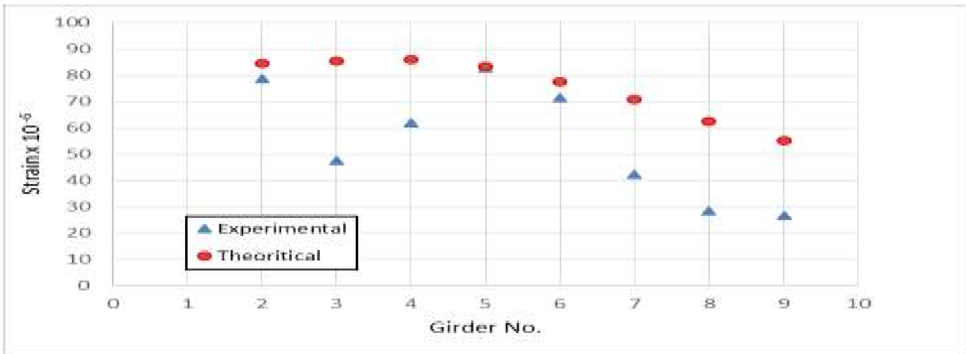


Figure. 15. Theoretical and experimental strain value of loading case-3 (after exposing to fire).

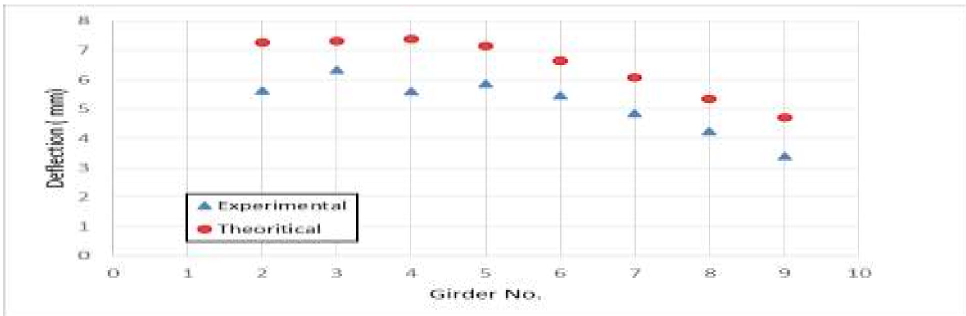


Figure. 16. Theoretical and experimental deflection value of loading case-3 (after exposing to fire).

The theoretical and experimental result after exposed to fire for both strain and deflection shows compatibility trend of curve with a slight difference. Fig. 13 showed that the strain of girders 2, 5 and was abnormal.

Static load test case-4 results

A static load test case-4 of span 2, girder no. 8 of maximum bending moment and maximum deflection at the control cross-section, the results of normal strain and calibration coefficients are shown in Table 8, the mid-span deflection measurement and calibration coefficients are shown in Table 9.

Table 8. Case-4, span 2 mid span positive strain and calibration coefficient value measurement values (*strain unit：με)

Girder No.	Points	Load Level-3			Unloaded	
		Test Value	Theoretical value	Calibration Coefficient	Test Value	Relative residual deformation
Girder -2	B3-2	49.7	50.4	0.95	1.7	3.3%
Girder -3	B3-3	33.7	55.1	0.57	2.5	7.3%
Girder -4	B3-4	52.8	62.6	0.80	2.9	5.5%
Girder -5	B3-5	53	70.8	0.70	3.3	6.1%
Girder -6	B3-6	77.1	77.5	0.96	2.9	3.7%
Girder -7	B3-7	61.4	83.4	0.69	3.7	6.0%
Girder -8	B3-8	64.4	86.2	0.70	4.0	6.1%

Girder -9	B3-9	60.7	85.4	0.69	2.2	3.6%

Table 9. Case-4, span 2 mid span deflection and calibration coefficient values (deflection unit： mm)

Girder No.	Points	Load Level-3			Unloaded	
		Test Value	Theoretical value	Calibration Coefficient	Test Value	Relative Residual Deformation
Girder -2	D3-2	3.64	4.72	0.77	-0.05	/
Girder -3	D3-3	3.78	5.36	0.71	-0.12	/
Girder -4	D3-4	4.29	6.07	0.71	-0.17	/
Girder -5	D3-5	4.76	6.64	0.72	0.00	0.0%
Girder -6	D3-6	5.71	7.14	0.80	0.01	0.2%
Girder -7	D3-7	5.89	7.38	0.80	0.00	0.0%
Girder -8	D3-8	6.06	7.31	0.81	0.11	1.8%
Girder -9	D3-9	5.65	7.25	0.77	0.09	1.6%

Fig. 17 and 18 shows the strain and deflection with girder number respectively of loading case-4.

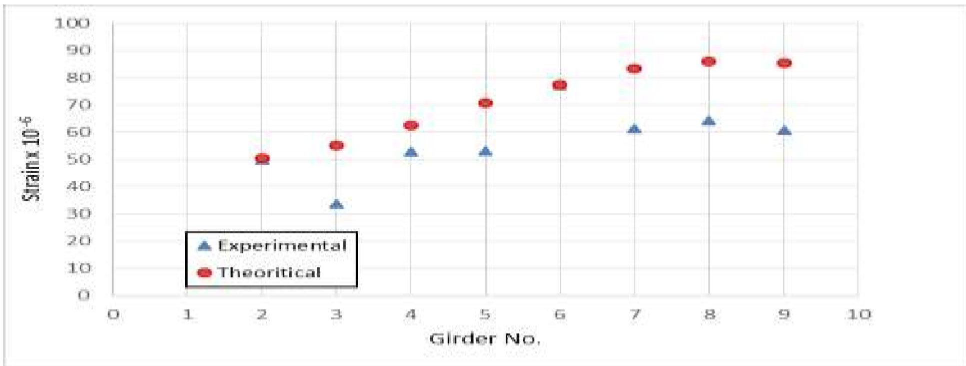


Figure 17. Theoretical and experimental strain value of loading case-4 (after exposing to fire).

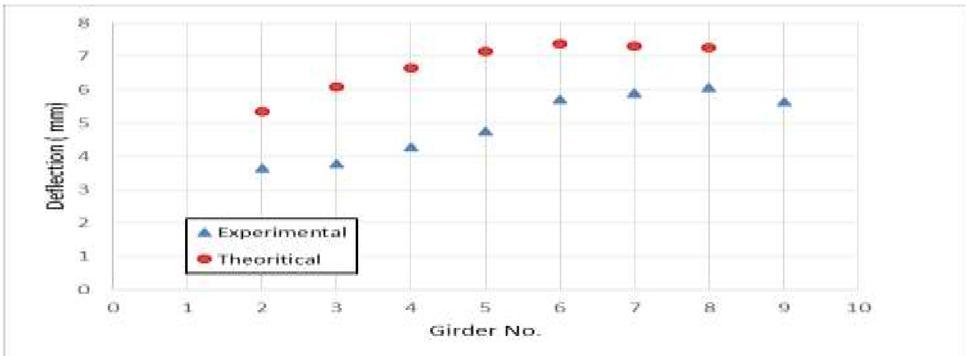


Figure. 18. Theoretical and experimental deflection value of loading case-4 (after exposing to fire).

Static load test results of Case-5 & 6

Static load test for case-5 & 6, of the span 2 girders no.-4, and girder no. 8 is used to predict the maximum ends shear, and it’s found no significant increase in cracks and other abnormal.

Effect of bridge load calibration factor

Load calibration factor is used to test the effect of loading test efficiency, the main effect of the measured values and corresponding to calculated value differences are listed in Table 2 to Table 9, which shows that the cross-sectional girder span no. 2 and 3 calibration factor for the strain is 0.43 to 0.96 and 0.44 to 0.79 respectively, average 0.72 and 0.69; while the deflection of control cross sectional span No. 2 and 3, the beam calibration factor was 0.71 to 0.85 and 0.62 to 0.79, with an average 0.78 and 0.71. It clear that the -positive strain and deflection calibration factor of span 2 is greater than the average of the span 3. The average differences ratio of deflection calibration coefficient between the two cases was 1.1 times.

Relative Residual Deflection and Strain Tests

The test of residual relative deflection (or strain) is important indicators to test the ability of the structure elastic recovery, can be calculated through the following expression formula:

$$S'_p = \frac{S_p}{S_t} \times 100\%$$

S'_p : The measured relative residual displacement (or strain);

S_t : The measured total displacement (or strain);

S_p : The measured unloaded residual displacement (or strain). $S_p = S_t - S_e$

S_e : Elastic deformation (or strain) under test loads.

The measuring points are under loading test when the residual deformation (or strain) is smaller, the structure closer to the flexible working state. From Tables 2 to 9 shows that each measuring point of the mid span strain of cross-section bridge girder, the relative residual deformation value is less than 10.6%, while the deflection relative residual deformation values less than 5%; each measuring point relative residual deformation strain approximately zero; bridge basically is in a good condition and the fire did not affect the bridge structure element too much indication that there is no highly risk.

CONCLUSION

1- For Span 2, positive strain and deflection calibration factor is greater than the average of the span 3, the carrying load capacity of the bridge after the fire effect was decreased. The standards calibration factor should be not greater than 1, the calibration factor values of specification are shown in Table 10, and the second cross-sectional plate girder span calibration factor is the maximum strain of 0.96, more than the specified calibration coefficient constant maximum value, indicating that there are some risks.

Table 10 calibration coefficients constant.

Specification	Strain calibration factor	Deflection calibration factor
Old Highway Bridge carrying capacity identification methods.	0.6-0.9	0.7-1.00
Highway bridges carrying capacity assessment testing procedures	0.5-0.9	0.6-1.0

2- considering the large burned area, the thickness of the concrete spalling was deep causes major effect on the durability of the bridge, beside the effect of the heavy traffic, overloaded vehicles, it is suggested that for the right second girder span should be strengthening or replace. The right hand girder #1 also should be replaced.
3- Repair chiseled cap beam and column excesses surface of concrete.

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