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STRENGTHENING CONCRETE HOLLOW SECTION GIRDER BRIDGE USING POLYURETHANE-CEMENT MATERIAL (PART B)

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ABSTRACT

This paper presents experimental study to retrofitted reinforced concrete Hollow Section Bridge. The study was carried out on the White River Bridge structure (Bai xi da Qiao / China). The effect of retrofitting on stress and strain of beams at the critical section was studied. Evaluating the bridges girder after strengthening using new material called Polyurethane-Cement material (PUC) as an external material .This study present the strain and deflection before and after strengthening the bridge girders. The results has shown that the overall state of the bridge structural strengthening is in good condition. The enhancement was significant in stiffness of the bridge structure. Regarding to the results of static load test, the experimental values strain and deflection are less than theoretical values, indicating that the stiffness of the structure, overall deformation and integrity satisfy the designed and standard requirements and the working performance are in good condition, and flexure capacity has a certain surplus.

KEYWORDS: Bridge girder strengthening, Polyurethane- cement (PUC); Concrete hollow section girder.

تقوية جسر خرساني ذات مقطع مجوف باستخدام مركب البولي يورثين والسمنت

(الجزء ب)

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جامعة البصرة، كلية الهندسة، قسم الهندسة المدنية

الخلاصة:

الدراسة تعرض نتائج عملية لتقوية احد الجسور الخرسانية ذات المقطع الخرساني المجوف . اجريت هذا الدراسة على هيكل جسر النهر الابيض (باي سي داو تشياو/ الصين) . تم دراسة تاثير التقوية على الاجهاد والانفعال للعتبات في المقاطع الحرجة منها. تقييم روافد الجسر بعد عملية التقوية باستخدام مادة مركبة من البولي يورثين والسمنت كاستخدام خارجي . يعرض هذا البحث نتائج الانحراف والانفعال قبل وبعد عملية التقوية لروافد الجسر. اظهرت النتائج ان الحالة العامة للجسر الذي تم تقويته هو في حالة جيدة. التحسين كان بشكل ممتاز في تقوية صلادة هيكل المنشأ . بالاشارة الى نتائج فحوصات الحمل الثابت , حيث ان نتائج الفحوصات العملية للانفعال والانحراف كانت اقل من تلك النتائج المحسوبة نظريا حيث ان صلاة الجسر والتشوهات الكلية وكذلك سلامة الجسر تحقق متطلبات التصميم الاساسية ومتطلبات المواصفات العامة بالاضافة الى الاداء التشغيلي هو في حالة جيدة وكذلك هناك هامش زيادة مناسب في مقاومة الانثناء.

1. INTRODUCTION

Strengthening of Bridges have been taken into account since several last decades. Many analytical models have been developed (Ahmed and Gemert, 1999; Jansze, 1997; Raoof and Zhang, 1997; Saadatmanesh and Malek, 1998; Varastehpour and Hamelin, 1997) which can be use different method to predict the load carrying capacity using different material such as FRP (Fiber Reinforced Polymer) to strengthen the reinforced concrete structures (beams, columns, piers, ….). FRP composites is used as the confining material of the concrete columns, piers, and beams. The results indicate that the FRP wraps could increase the compressive strength, axial strain at ultimate stress, ductility and deformation capacity of the concrete columns significantly (Matthys et al., 2006; Sheikh, 2007).

Recently Polymer composites are considered of wide use as construction material (Van Gemert et al., 2004; Ohama, 2011). These composite can be obtained by partially replacing the cement hydrate binders with polymeric modifiers such as water soluble polymers polymer, powders dispersion, monomers, and liquid resin (Chandra and Ohama, 1994). The obtained composite mixes compared to the conventional cement pastes, cement polymer composites enhances tensile strength, compressive strength, flexural strength, adhesive properties, good workability and increasing the flexibility of composites (Ohama, 1995; Cota, 2012; Razl, 2012).

The aim of the assessment is in particular to establish the safe load carrying capacity of a bridge. In the last decades, the traffic loads and speeds drastically increased. As a consequence, many existing bridges are now subjected to loads and speeds higher than those for which they have been designed for. Moreover, due to insufficient maintenance, many of them have severely deteriorated over their years of service thus considerably reducing their capacity. The analyzing the increase of the transport capacity and service life of existing bridges must be considerable. In order to demonstrate new and refined methods developed within this paper, field tests of existing bridges were carried out before and after strengthen the bridges.

In this study using new material polyurethane-cement (PUC), have been developed by Haleem et al. (2013) can be used in construction and maintenance structures. PUC has excellent mechanical properties, bonding and adhesive properties with concrete surface. This material can be made simply preparing method and cast in site without extra technical requirement. Haleem et al. (2013) applied PUC to strengthen reinforced concrete bridge T-beams in full scale and the results was could effectively improve the flexural strength capacity for retrofitted beams. Moreover the PUC material have ability to control the crack propagation. In addition, this material improved the stiffness of the beam where cracks propagation was confined.

Furthermore, this material can make the repair or retrofitting of bridge elements more effective, easy to handle and cheaper.

2. BRIDGE DESCRIPTION

The upper structure of bridge : The bridge consist of 16 span each span had 20 m length, 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.

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

1) Design load rating vehicle- 20, and -120 level 2, and highway rating: motor way. 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" (Highway regulation (JTG D60), 2004; Highway regulation (JTG D62), 2004; Highway regulation (JTG / T J22), 2008; Haleem, 2016).

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

Through the test program, stress and deflection was measured for the bridge span structure under static load for control section and compare with theoretical calculations, the actual structure of tested stress and deflection of control section meets design specifications (Highway regulation (JTG D60), 2004).

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 (Haleem, 2016). Fig. 1 shows the cross section view of the bridge

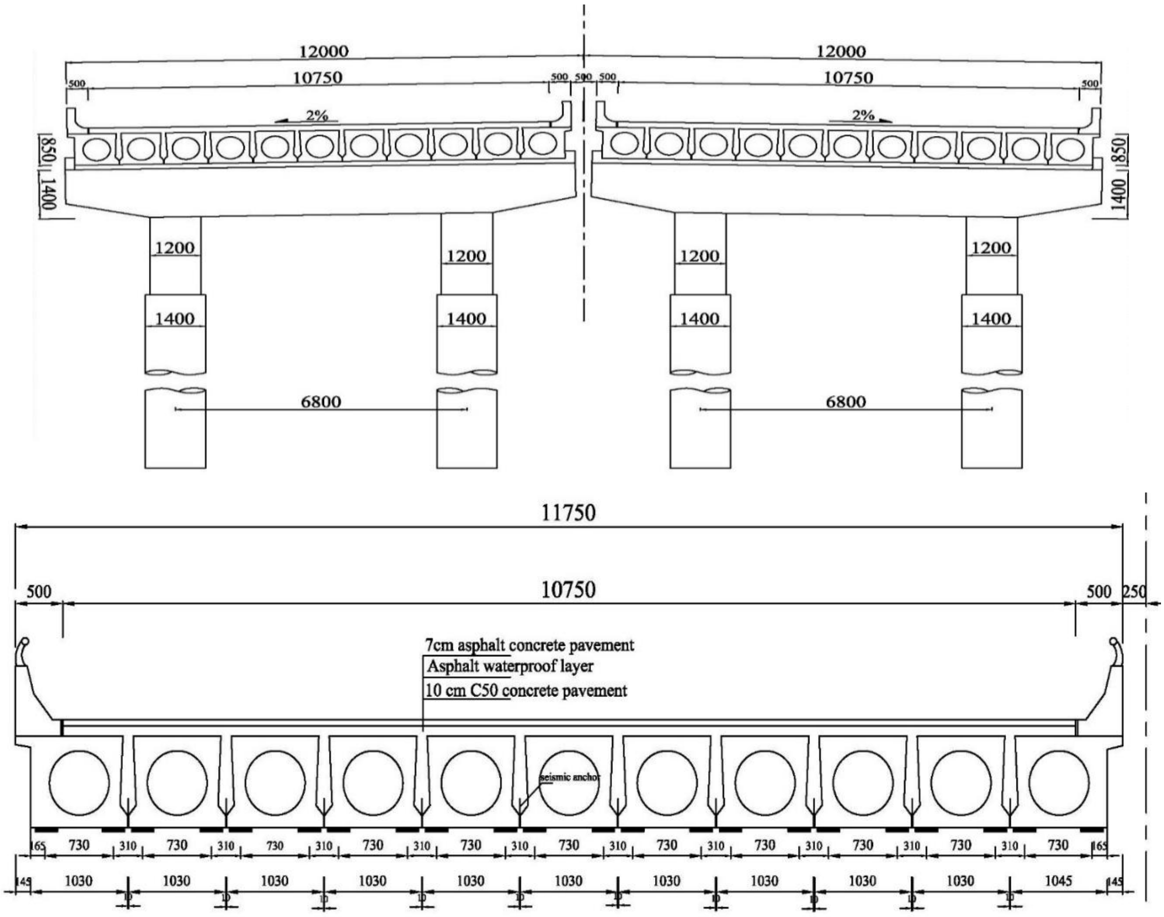


Fig. 1. Bridge layout and section details (unit: mm)

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.

This bridge have been investigated at field under static load by Haleem, (2016) (Field Static load Effect of Hollow Section Bridge Span (Part A). Analyzed results of the bridge showing that the second span at middle section need to be strengthen to provide enough capacity to carry out the applied traffic load.

This study will considering strengthening the bridge using PUC material to enhance the capacity of damaged span , and making comparison the result before and after strengthen.

3. MATERIAL AND EXPERIMENTAL

3.1. Cement

The most widely used of the construction cements is Portland cement. The cement type used in this research was Portland cement Type I. Table 1 present the cement components used in this study (Haleem et al., 2013).

Table 1. Chemical components of cement.

Chemical Constituent	Weight Ratio (%)
SiO_2	50-62
Al_2O_3	18-33
Fe_2O_3	2.0-7.5
CaO	2.4-5.7
MgO	0.4-2.1

3.2. Polyurethane

The main components of the PUC is polyurethane (PU), which is an excellent polymer elastic material, mainly based on the chemical compounds of isocyanate and a strong chain of oligomeric polyols.

The hardness range of this material is 10–100 (IRHD) (International Rubber Hardness Degrees test).A measure of the indentation resistance of elastomeric or rubber materials based on the depth of penetration of a ball indenter. An IRHD value of 0 represents a material with a Young's Modulus of zero and an IRHD value of 100 represents a material with an infinite Young's Modulus [ASTM/ D1415]. Polyurethane has a good wear resistance, chemical resistance, flexibility, adhesion, and film-forming properties of PU material components. Polyol and polyisocyanate were the main raw materials in the mix design, which was used to develop a series of polyurethane filler composites by measuring the density of the new material (PUC). Table 2 shows the components materials ratio mixing of polyurethane which has used in the study (Haleem et al., 2013).

Table 2. Main Chemical Components of Polyurethane (Haleem et al., 2013).

	Chemical Components	Percentage (%)
Polyol	Polyether	49
	Silicon Oil	1
	Water	0-1
Polyisocyanate		50-51

While the component mixing ratio of the PUC materials was (polyo l: polyisocyanate: cement) was 1:1:3 by weight. These proportion material are listed in Table 3.

Table 3. (PUC) material components (Haleem et al., 2013).

PU Components	Component Ratio (%)
Polyether	20.0%
Polyisocyanate	20.0%
Cement	60.0%

The compositions of PUC material have variety to produce the different series of PUC according to the mixing ratio of Polyurethane component ratios. The densities of PUC were chosen for and around (800 Kg/m^3, 1200 Kg/m^3, 1400 Kg/m^3, 1650 Kg/m^3) the mechanical properties will varies according to the deducted density of PUC (Haleem et al., 2014). This study considered the density of the PUC material to be around 1650 kg/m^3, Elastic modulus: 4200 MPa, bonding strength, 3.0 MPa (non slip on interface surface between concrete and PUC will be occurred).

3.3. Mixing of PUC

The mould was clean and slight oil of interior faces; the material components of polyurethane put it together then cement was added in clean pan and finally mixed together according to the design ratio. Mix process was done using electrical mixer machine for 2-4 minutes to obtain homogenous mixture and then poured in the mould. Some special additive were added to mixes to enhance the reaction of the material.

4. STRENGTHENING BRIDGE PROGRAM.

4.1. Critical span

The Span No. 2 and span No. 3 was tested before strengthening and measuring point was appointed at sections A, B, C, and for deflection and tensile strain as shown in Fig. 2 (Haleem, 2016).

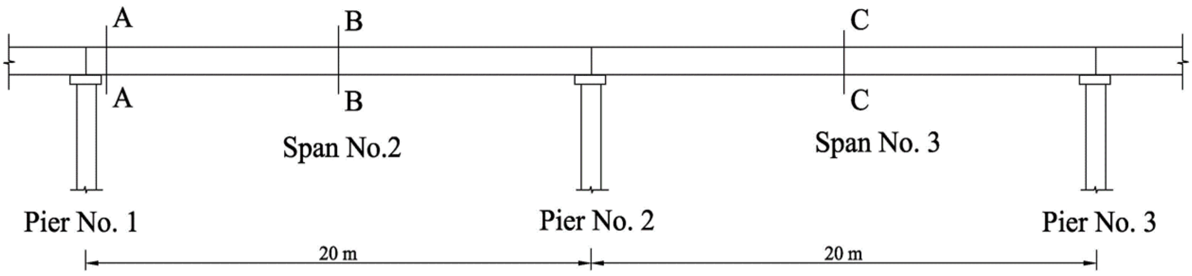


Fig. 2. Control section

The load test conclusion before reinforcement the test deflection and strain coefficient of span No. 3 was 0.79. The coefficient of deflection and strain of span No.2 was 0.90, in other word, the whole stiffness of the prestressed reinforcement concrete hollow slab beam bridge of span No. 2 was decreased to 14% because of the fire action.

4.2. Design strengthening Detail

The Fig. 3 showing the dimension of substrate PUC layer to strengthen the critical section. The data of design are listed in Table 4.

Table 4. Properties of used PUC material (Haleem et al., 2013) [14].

Density (Kg/m^3)	Compressive Strength (MPa)	Modulus of Elasticity (MPa)	Flexural Bending Strength (MPa)	Poisson's Ratio
1600	62.0	4300	39.2	0.27

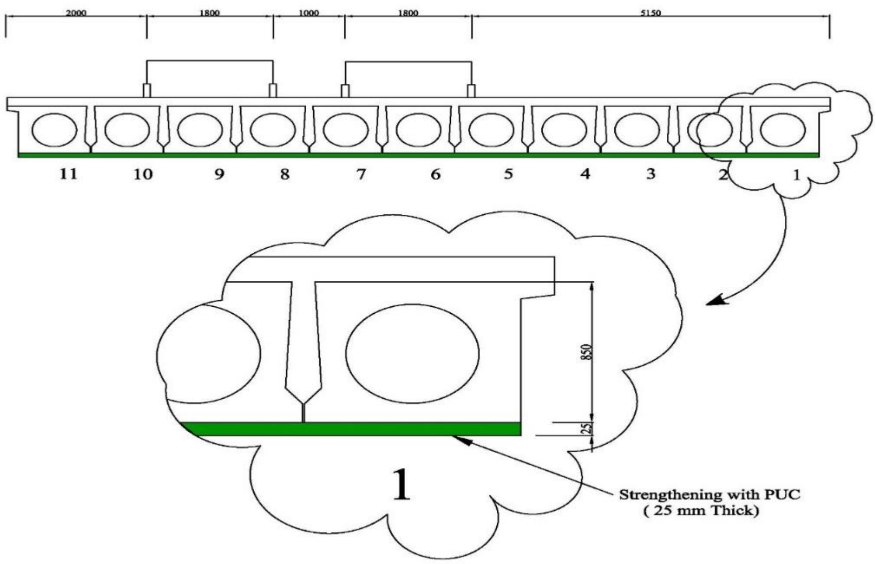


Fig. 3. The strengthening details with PUC.

4.3. Repairing bridge Procedures.

The substrate surface of critical and damaged area of slab girders were cleaning and removing all the rusty reinforcement beside the loose concrete (spalling concrete) using hand tools as shown in Fig. 4. Initial repairing have been made before strengthening the bottom surface with PUC material.

The bottom concrete surface of girders was prepared by cleaning the bottom contact surface with to PUC materials to provide well bonding between concrete and PUC. The mould have was setup and fix properly at the lower surface of girders which need to strengthen. All the joint of mold was closed properly to avoid any leakage of PUC material during the pouring process, where this material has enough flow ability to be leak from the small holes. The components of polyurethane and cement were mix together according to the mix design proportion). Fig. 5 showing the frame of pouring process. During the strengthen procedures, the joint between girder should be keep clean after completion pouring. The completing pouring process after removing the frame are shown in Fig.6.

Fig. 4. Cleaning the substrate surface of girder (loose concrete and rusty steel bars).

Fig. 5. Fixing Frame and pouring of PUC material.

Fig. 6. Strengthen work completion.

5. 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 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 (Highway regulation (JTG/T J23), 2008):

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

η_q : Static load efficiency coefficient;

S_s : calculated internal force values under Static load of control sectional (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.

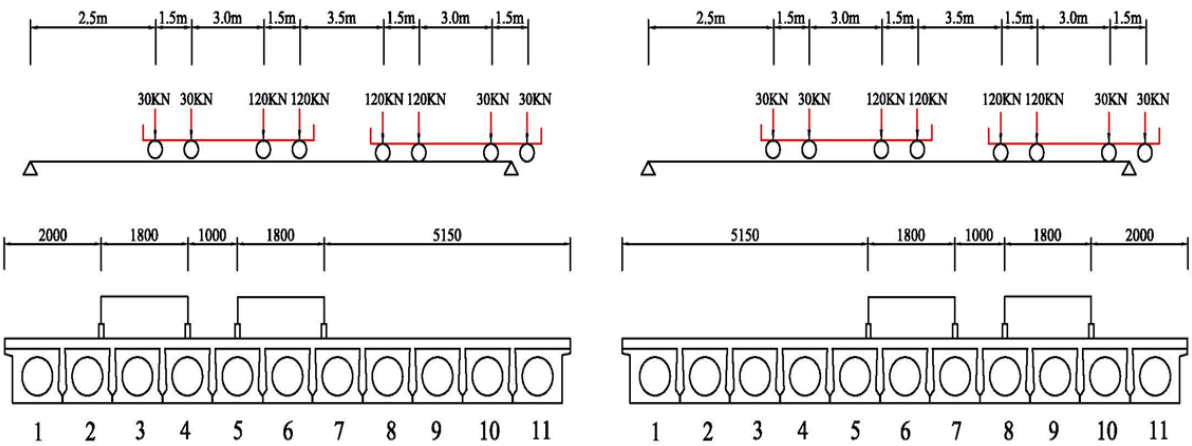
According to the requirements of the highway bridge carrying capacity testing assessment procedures η_q should meet from 0.8 to 1.05. The four cases of the test load, as shown in Table 5.

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.

Table 5. 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	Mid span Deflection and Strain
Case-2	1,2,3	Span 3 , girder 8 for the maximum positive bending moment and	
Case-3	1,2,3	Span 2 , girder 4 for the maximum positive bending moment and	
Case-4	1,2,3	Span 2 , girder 8 for the maximum positive bending moment and	

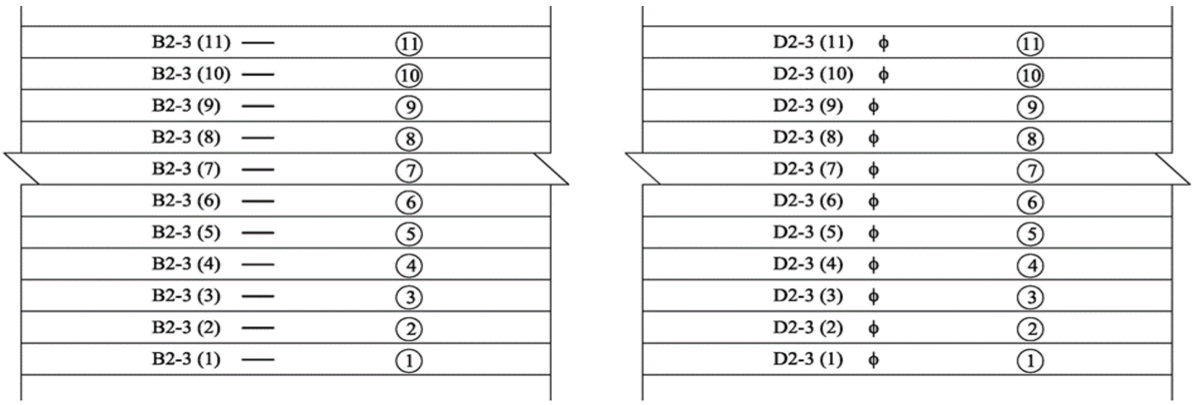
Fig. 7 a and b showing the layout of the applied vehicle load on the bridge lane of loading case 1, 2, 3 and 4. Fig. 8 shows the location of strain and deflection gauge sensor at the critical girder section of bridge (Mid-span).



a) Load vehicle layout of Case 1 and 3

b) Load vehicle layout of Case 2 and 4

Fig.7. loading Vehicle layout.



a) Strain gauge sensor position

b) Deflection sensor position

Fig. 8. Location of strain and deflection sensor gauge span 2.

5.1. Load Test Results and Analysis after Strengthening

Loading case 1 of middle span No. 2 results at maximum bending moment of critical section, the strain and the deflection are listed in Table 6 and Table 7 respectively. The efficiency was measured through the calibration factors (or efficiency factor) and also listed in Table 6 and Table 7.

The relation between the strain at the middle span section and the girder number are shown in Fig. 9 and Fig. 10 shows the relation between the deflections of mid span section versus the girder number.

Table 6. Case-1, strain and calibration coefficient measured values of span -2 at mid-span (strain unit：ε×10-6).

Girder No.	Point	Load Level-3			Unload	
		Experimental	Theoretical	Calibration coefficient	Measured	Residual deformation
Girder - 1	B2-1	85	102	0.83	2	0.024
Girder - 2	B2-2	85	105	0.81	1	0.012
Girder - 3	B2-3	78	106	0.74	0	0
Girder - 4	B2-4	55	107	0.51	-1	/
Girder -5	B2-5	69	103	0.67	3	0.043
Girder -6	B2-6	78	96	0.81	4	0.051
Girder -7	B2-7	64	88	0.73	0	0
Girder -8	B2-8	54	77	0.70	-2	/
Girder - 9	B2-9	43	68	0.63	-1	/
Girder - 10	B2-10	50	62	0.81	1	0.02
Girder - 11	B2-11	48	59	0.81	3	0.063

Table 7. Case-1, deflection and calibration coefficient measured values of span-2 at mid span (deflection unit: mm).

Girder No.	Point	Load Level-3			Unload	
		Experimental	Theoretical	Calibration coefficients	Measured	Residual deformation
Girder - 1	D2-1	5.53	8.48	0.65	0.01	0.002
Girder -2	D2-2	5.62	8.69	0.65	0	0
Girder - 3	D2-3	5.59	8.77	0.64	0.02	0.004
Girder - 4	D2-4	5.59	8.85	0.63	-0.01	/
Girder -5	D2-5	5.57	8.56	0.65	-0.01	/
Girder - 6	D2-6	5.30	7.96	0.67	0	0
Girder -7	D2-7	5.16	7.27	0.71	0.02	0.004
Girder -8	D2-8	4.31	6.42	0.67	0	0
Girder - 9	D2-9	4.29	5.66	0.76	-0.03	/
Girder - 10	D2-10	3.91	5.17	0.76	-0.01	/
Girder - 11	D2-11	43.54	4.93	0.72	0.01	0.003

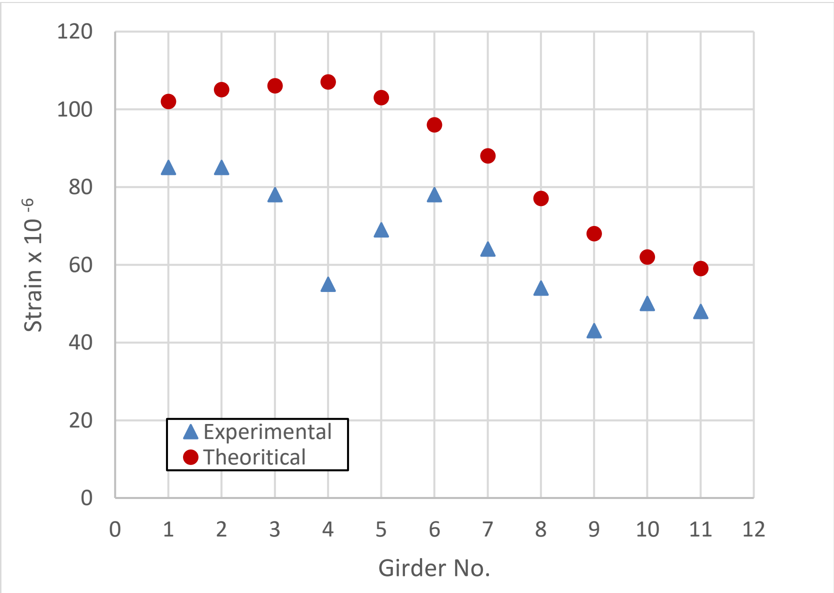


Fig. 9. Theoretical and experimental strain value of loading (Case-1).

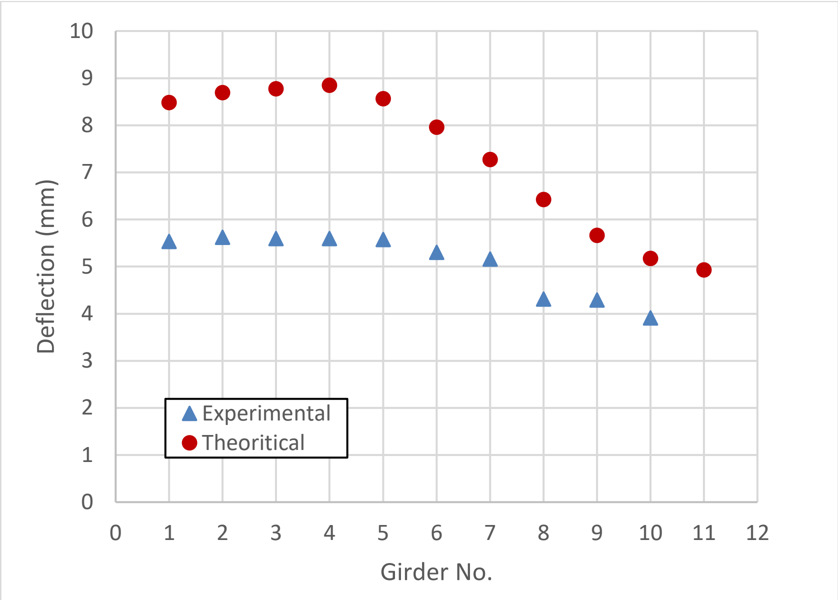


Fig. 10. Theoretical and experimental deflection value of loading (Case-1).

The loading case -2 have been applied on the bridge lane to deduct the maximum bending moment and maximum deflection at the control cross-section, Table 8 showing the normal strain and calibration coefficients. Table 9 presents the measured mid-span deflection and calibration coefficients of the control section.

The strain at the middle span section and the girder number are relationship shown in Fig. 11 and Fig. 12 shows the relation between the deflections of mid span section versus the girder number.

6. DISCUSSION

6.1. The result after strengthening the structure

Loading Case 1 and Case 2 for second span, the deflection calibration coefficients were 0.63 to 0.76 and 0.54 to 0.82, respectively. The values for both cases according to standard "highway bridges carrying capacity assessment procedures (Highway regulation (JTG/T J21), 2011), specified that the common value of deflection calibration coefficients of reinforced concrete girder bridge within the range of 0.5 - 0.9, shows that the stiffness of structure after strengthening can meet the requirements of the design class I of road design loads.

Furthermore, measured deflection of middle span 2 indicating that after the lateral strengthening the structure has been significantly improved.

Table 8. Case-2, strain and calibration coefficient measured values of span -2 at mid-span (strain unit : ε×10-6).

Girder No	Point	Load Level-3			Unloading	
		Experimental	Theoretical	Calibration coefficient	Measured	Residual deformation
Girder - 1	B2-1	54	59	0.92	1	0.019
Girder -2	B2-2	52	62	0.84	2	0.038
Girder - 3	B2-3	61	68	0.9	3	0
Girder - 4	B2-4	45	77	0.58	0	/
Girder -5	B2-5	62	88	0.7	-1	/
Girder - 6	B2-6	87	96	0.91	-2	0.046
Girder -7	B2-7	81	103	0.79	4	0.025
Girder -8	B2-8	79	107	0.74	2	0.013
Girder - 9	B2-9	66	106	0.62	1	0
Girder - 10	B2-10	78	105	0.74	0	/
Girder - 11	B2-11	94	102	0.92	-2	0

*Note: $\mu=1\times10^{-6}$

6.2. Comparing the result before and after strengthening.

For load condition case-1 of girder no. 2 at the middle span, the deflection calibration coefficient were between 0.63-0.85 with an average 0.79. After strengthening of the girder no. 2, the deflection calibration coefficients were 0.63 to 0.76 with an average 0.68, indicating that the overall stiffness of the structure after the strengthening has increased by 16%.

Before strengthening, under loading case-2 of girder no. 2, the deflection calibration coefficients were 0.7 to 0.81 with an average 0.76. After strengthening of the girder no. 2, the deflection calibration coefficients were 0.54 to 0.82 with an average 0.66, indicating that the overall stiffness of the structure after the strengthening has increased by 15%.

The deducted results show that after strengthening bridge girders, the vertical stiffness of the structure has been significantly improved and restored the requirements specified in the original design.

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

Girder No.		Load level Three			Unload	
		Experimental	Theoretical	Calibration coefficients	Measured	Residual deformation
Girder -1	D2-1	4.00	4.93	0.81	0	0
Girder -2	D2-2	4.23	5.17	0.82	0.03	0.007
Girder -3	D2-3	4.38	5.66	0.77	-.01	/
Girder -4	D2-4	4.60	6.42	0.72	0.02	0.004
Girder -5	D2-5	4.90	7.27	0.67	-.01	/
Girder - 6	D2-6	5.13	7.96	0.64	-0.01	/
Girder -7	D2-7	5.26	8.56	0.61	0	0
Girder -8	D2-8	4.77	8.85	0.54	0	0
Girder -9	D2-9	4.98	8.77	0.57	0.01	0.002
Girder -10	D2-10	4.84	8.69	0.56	0	0
Girder -11	D2-11	4.63	8.48	0.55	0	0

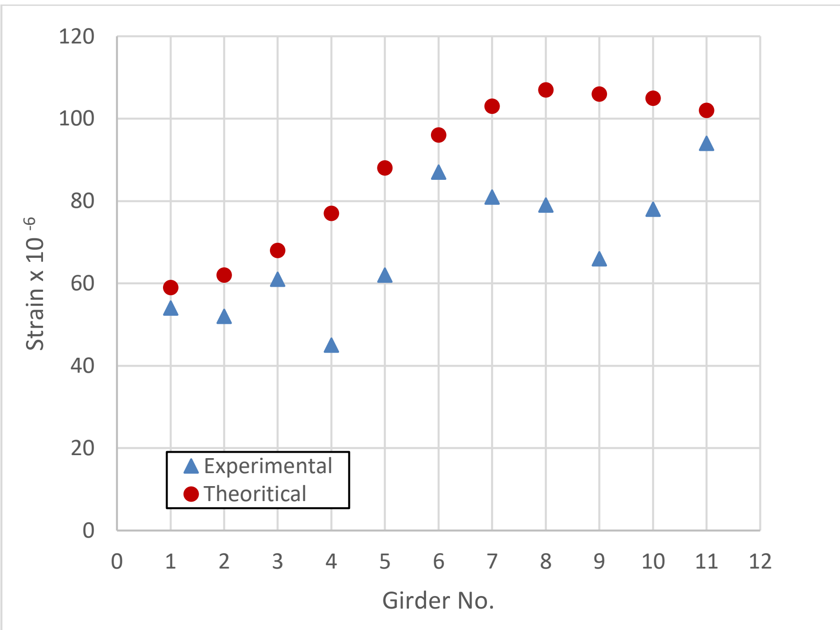


Fig. 11. Theoretical and experimental strain value of loading (Case-2).

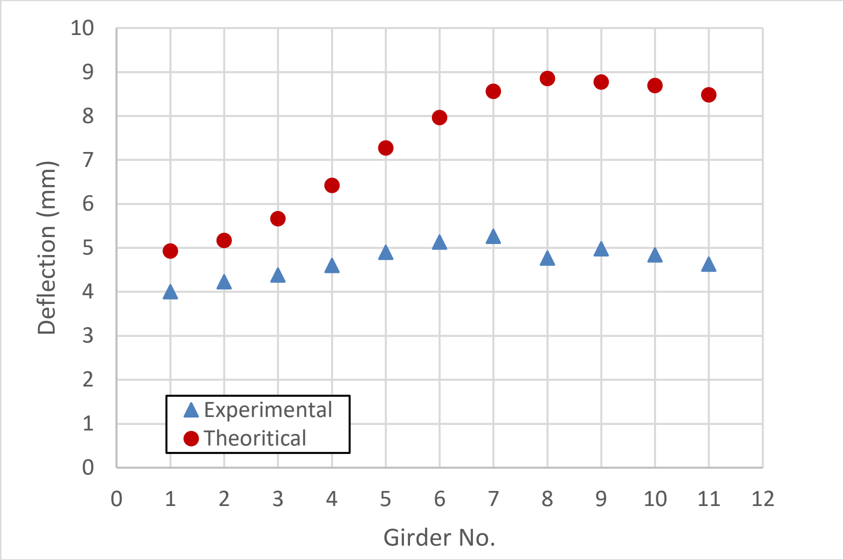


Fig. 12. Theoretical and experimental deflection value of loading (Case-2).

7. CONCLUSIONS

The main conclusions of analysis of load test results of White River Bridge (Bai Xi da Qiao) before and after the strengthening process can be summarized as follows: this research has use of special PUC composite materials, within a relatively short period of time the maintenance and strengthening process was done without interrupting of road traffic, and achieved the expected design effect. This is a new scientific and quick repairs method of strengthening old bridge. The research results had applied on certain bridge model. Because it is a new material, new technologies, new processes, therefore, after strengthening the bridge should be monitoring in early plan observations to identify problems in time to ensure smooth flow of traffic and keep safe.

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