Research Journal of Applied Sciences, Engineering and Technology 5(7): 2354-2359, 2013
DOI:10.19026/rjaset.5.4664
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: July 09, 2012 Accepted: July 31, 2012 Published: March 11, 2013

Research Article

Study of Concrete Strain for T-Beams Retrofitting by Poly-Urethane-Cement Material (PUC)

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Abstract: Based on the use of Poly-Urethane-Cement composite material to strengthen the concrete structure element, this study concern of the strain induced in concrete and steel bar of control beam and retrofitted beams with PUC. This is a new technique of externally strengthen the Concrete girder beams, control beam (RC) were constructed same in all cases and tested under four-point bending load. The objectives of this study are to examine the flexural bending strain of retrofitted beam with Poly-Urethane-Cement material (PUC). Experimental results show the PUC have highly deformation and improving the stiffness of beams. The retrofitting beams with PUC have highly deformed comparing with control beam.

Keywords: Bending flexural strength, concrete strain, Poly-Urethane-Cement (PUC), T-beam section

INTRODUCTION

Most of the experimental studies concern to FRP strengthening, reinforced concrete beams or structural element, which the concrete surfaces prepared under ideal conditions to install the FRP material. In field, usually concrete is deteriorated usually occurs that the concrete is deteriorated, and the reinforcement is corroded, its important effectiveness of strengthening method and the material type according to field conditions that there are a several failure mechanisms in Reinforced Concrete (RC) or Polymer Concrete (PC) beams (Arduini and Nanni, 1997).

In a recently researches (Aram *et al.*, 2008), focus on the strengthening beam with FRP or CFRP, prestressed and non prestressed laminates to predict the different types of deboning failure modes of unstressed, and existing international codes and guide lines from organizations such as ACI, ISIS and SIA were compared to the experimental results and calculations. These code and guide lines were predicting difference of debonding load about 250% and this problem still needs to solve.

The Reinforced Polymer (FRP) composites have advantages such as light weight, high tensile strength, good durability, etc., which makes using these materials proper to rehabilitation of existing reinforced concrete structures (Taljsten, 1996; Hollaway and Leeming, 1999; Oded, 2008).

The techniques of steel plate have been used widely for repairing cracked in structures element. This method have major problem when used to strengthening the existing concrete structure is high shear interfacial stresses, which may occur near the end of plates. Many researches try to investigate or finding possible ways to reduce these stresses (Deng and Marcus, 2007; Tsai and Morton, 1995; Al-Emrani *et al.*, 2007).

Earlier failures can be limit the enhancement of ultimate flexural capacity of the strengthening beams. Many researches were carried out to find out methods of preventing premature failure and improving the beam capacity and ductility reinforced beams. Studies use end anchorage techniques, such as U-straps, L-shape jackets, and steel plates for preventing early failure of reinforced concrete beams retrofitted with (Ceroni, 2010; Jumaat and Alam, 2010; Wang and Hsu, 2009).

This study is a accomplishing of previous research (Haleem *et al*., 2013), which concern about the improving the loading capacity and reducing induced cracks under normal static load. This study presents strain values of concrete for different loading case of beams, and comparing with strain of beam strengthening with Poly-Urethane-Cement (PUC) material.

MATERIALS

The material used were concrete, steel and the poly urethane-cement, the parameter of these material was already obtain from previous experimental works obtain

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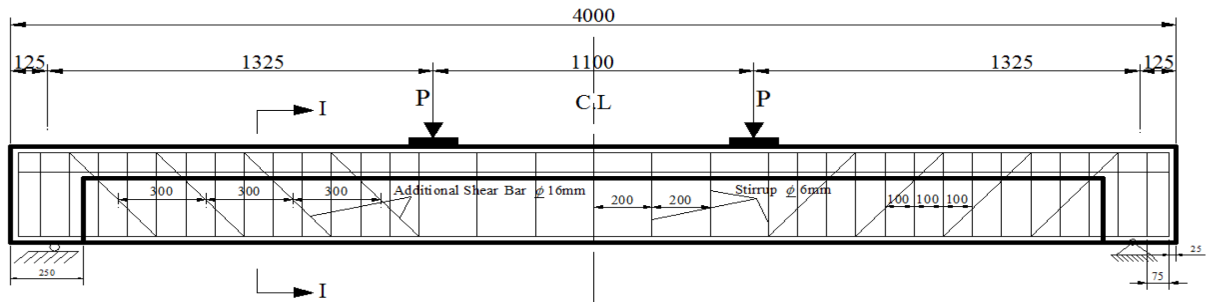
Table 1: Properties of used material (Haleem *et al*., 2013)

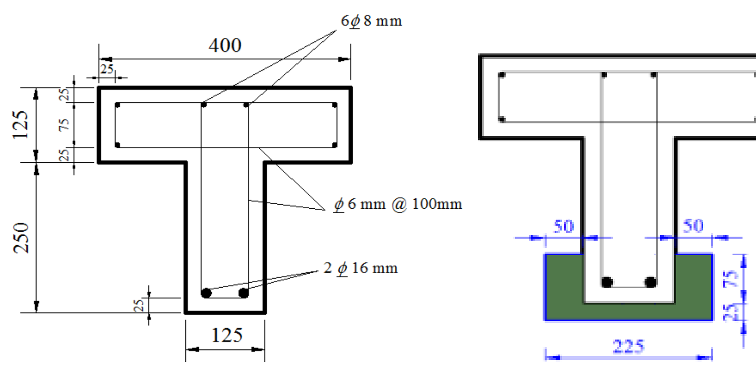
Material	Concrete	Steel	PUC
f_y (MPa)	/	420	/
Modulus of elasticity (MPa)	$E_c = 4700\sqrt{f_c} = 25742$	206000	4540
$\acute{f}_c$ (MPa)	30.70	/	60.61
Density (Kg/m^3)	2350	7800	1648
f_{bt} (MPa)	2.52	-	42.70
Poison ratio (υ)	0.20	0.3	0.27

Table 2: (PUC) material components (Haleem *et al*., 2013)

Chemical components		PU percentage (%)	PUC component (%)
Polyol	Polyether	49	20
	Silicon oil	1	
	Water	0-1	
Polyisocyanate		50-51	20
Cement		-	60



(a) Longitudinal beam section



(b) Detail section with PUC material

Fig. 1: Geometry and section details

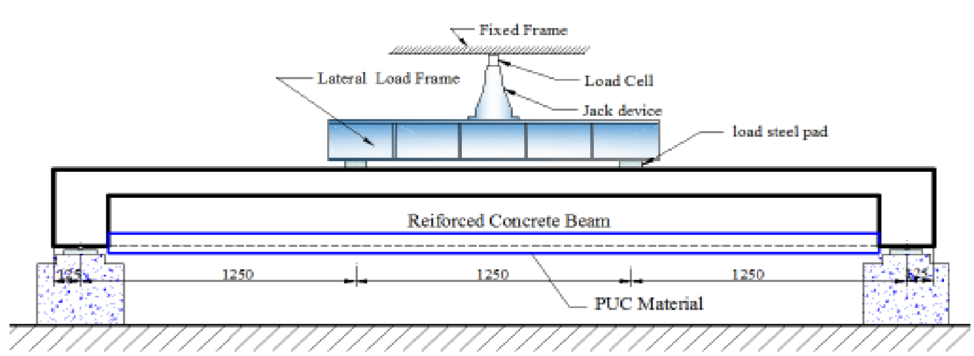


Fig. 2: Loading set up details (Haleem *et al*., 2013)

Table 3: Loading cases

Case No.	Beam group name	Beam type	No. beams	Load case
Set I	RC	Control T beam	2	From 0 --to—failure
Set II	RC + PU	Retrofitting beam	2	From 0 --to—failure
Set III	RC + PU - A	Retrofitting beam	3	1- Preload (0 --50 KN) 2- Retrofitting and tested up to failure

from (Haleem *et al*., 2013) properties of material are listed in Table 1.

If The PUC (Poly-Urethane-Cement) is a high performance polymer elastic material, contains the isocyanate and urethane compounds. These two materials as the main can developed a different series of polyurethane-cement composite with variable densities values. Table 2 lists the chemical component of PUC.

EXPERIMENTS PROCESS

The experimental study consists of pouring of four set sets of Reinforced Concrete (RC) beams. All beams were cast in same geometry and reinforced details. Set I represent control beam, set II represent the retrofitted beam with PUC material, set III devoted for preloaded control beam with (50 kN) and cracks occur with maximum width 0.2 mm then load release and finally reload up to failure (Haleem *et al*., 2013).

Beams are identical and cross sectional dimensions of all set of beams as shown in Fig. 1 and 2 show the loading set up details.

Testing of beams: Loading cases are listed in Table 2 and 3 list the considered cases and loading tests state. Figure 3 shows the beam setup for testing procedures.

The strain was predicted by using strain gauge fixed at five positions (control beam) and six sensors for retrofitted beam. The values of each point are taken the mean of two reading on both side of beam as shown in Fig. 4.

Theoretical analysis model: To simulate the control beam and retrofitting beam, FEM Abaqus software v.10.6 was used to predict the theoretical analysis of the beams and the result showing good agreement.

Constitutive curve of materials:

Concrete: The constitutive curve of concrete was used in this research represent the linear and (elastic) and nonlinear (plastic range) as shown Fig. 5.

The stress strain curve for concrete in tension behavior was assuming linear elastic up to the maximum tensile strength. After this point, the concrete cracks then decreases gradually. The others important parameters of concrete were listed Table 1.

For: $\varepsilon_c \le \varepsilon_o$

$$\sigma_c = \acute{f}_c \left[1 - \left(1 - \frac{\varepsilon_c}{\varepsilon_o}\right)^2\right]$$

For: $\varepsilon_o \le \varepsilon_c \le \varepsilon_{cu}$

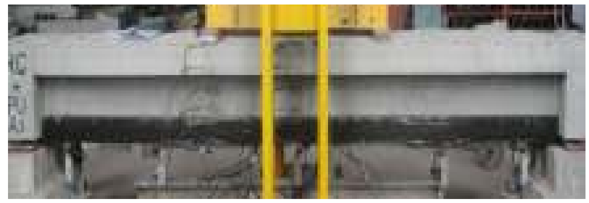


Fig. 3: Beam and devices set up

Fig. 4: Strain sensor gauges location

$$\sigma_c = \acute{f}_c \left[1 - 0.15\left(1 - \frac{\varepsilon_c - \varepsilon_o}{\varepsilon_{cu} - \varepsilon_o}\right)\right]$$

where,

ε_o : Maximum compressive strain

ε_{cu} : Ultimate compressive strain = 0.0033

σ_c : Compressive stress

$\acute{f}_c$: Concrete compressive strength (National Standards of People Republic of China GB50010, 2002)

Figure 5 Show typical tensile stress-strain curve for concrete. The formula is (ABAQUS, 2010):

$$\sigma_t = E_c \varepsilon_t \qquad 0 < \varepsilon_t \le \varepsilon_o$$
$$\sigma_t = \sigma_{to}\, e^{-\beta(\varepsilon_t - \varepsilon_0)} \qquad \varepsilon_t > \varepsilon_o$$
$$\varepsilon_0 = \frac{\sigma_{t0}}{E_c}$$

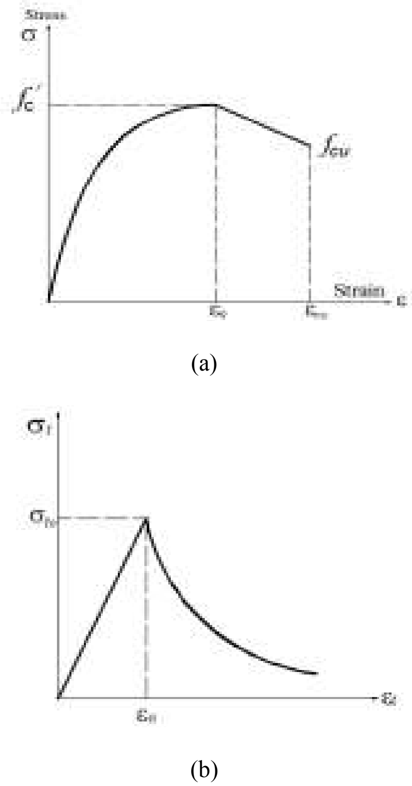


Fig. 5: Stress-strain relation for concrete (tension and compression)

where,

β : The control of descending softening coefficient of concrete fracture is related to the general range of 1-2×10^4

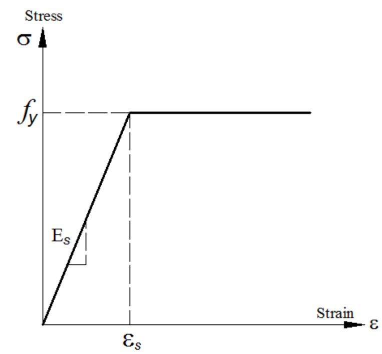


Fig. 6: Stress-strain relation of steel

E_c : The tangent modulus of concrete compressive stress-strain relationship

σ_{to} : Tensile strength of concrete

ε_0 : Concrete cracking strain at maximum tensile stress

Steel: The stress-strain curve of steel was assumed as elastic perfectly plastic model. Properties which used to define this model are elastic are listed in Table 1. Figure 6 shows the relationship between stress and strain of steel.

According to the experimental study of PUC material, the parameter of PUC material were listed in Table 1 which be obtained from ref. Haleem *et al*. (2013) Solid element type C3DR8 was adopted to represent the concrete material and PUC material, while steel bar was represented by using truss Three Dimensional element (T3D2) s shown in Fig. 7.

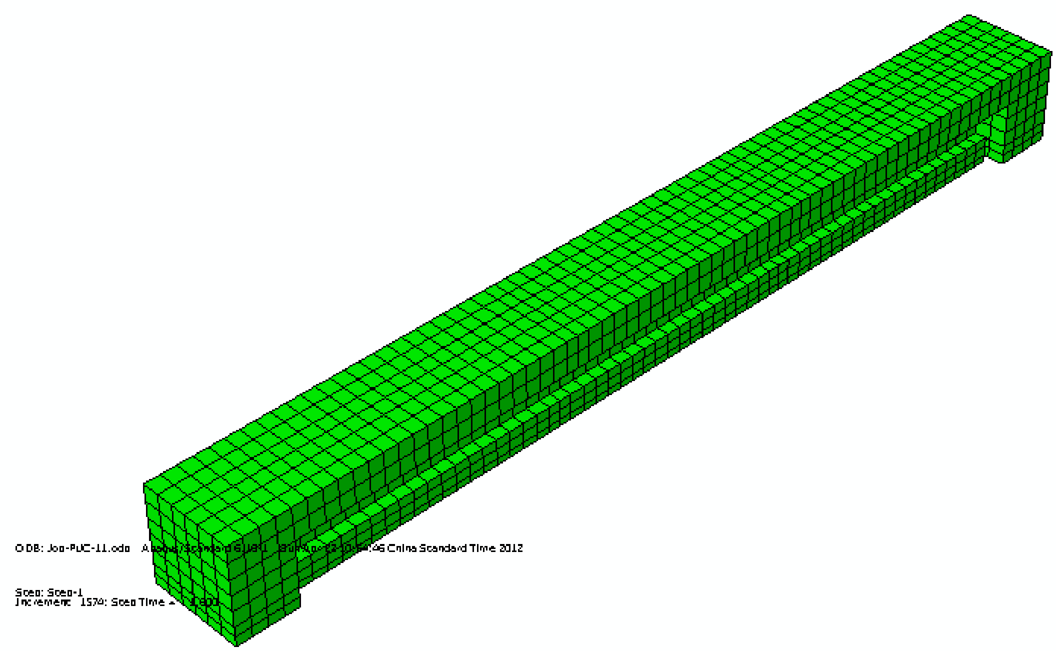


Fig. 7: The FEM model of retrofitted beam with PUC material

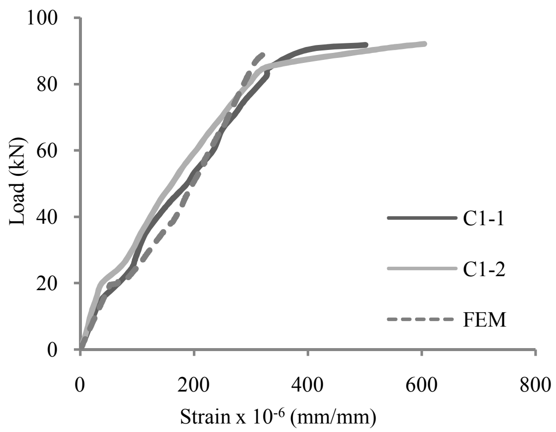


Fig. 8: Load-strain curve of top fiber (compression) of control beam (set I)

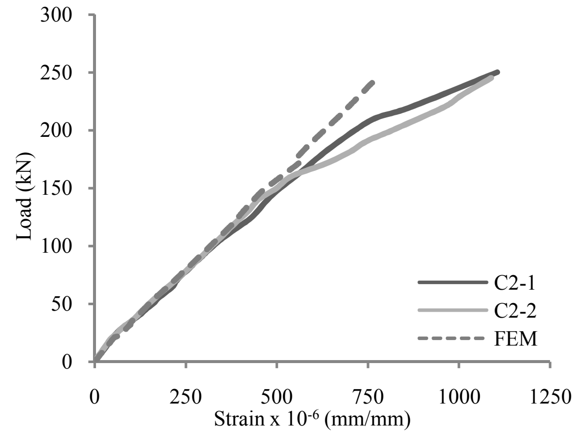


Fig. 9: Load-strain curve of top fiber (compression) of retrofitted beam (set II)

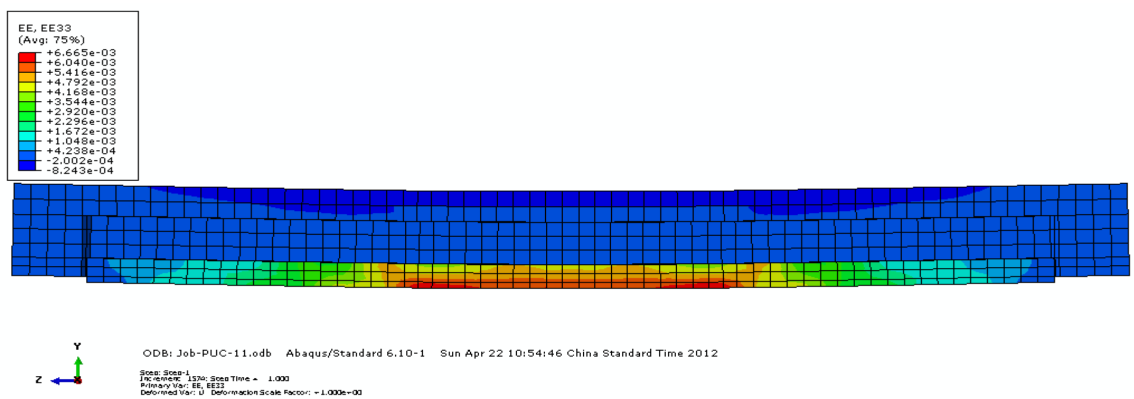


Fig. 10: FEM elastic strain counter values of retrofitting beam (set II)

EXPERIMENTAL RESULTS

Strain of concrete and PUC: Figure 8 shows the relation between the load and the strain of concrete at the top fiber of flange for control beam (set I). The value of maximum strain was around (550×10^{-6}) at the maximum failure load 92.01 kN. Control beam while the maximum strain at top concrete fiber of set II (retrofitted beam with PUC) was around 1100×10^{-6} (mm/mm) with maximum applied load 250 kN as shown in Fig. 9, which mean the retrofitting have increase the capacity of beam or restrict the beam from earlier failure at compressive region. The FEM analysis was shown well agreement between theoretical and experimental results.

For the set III, where the beam have beam pre-loaded up to 50 kN and cracks was appeared, then load release, beams were retrofitting and reload the beam again up to failure. In this case the beams have been already losing some stiffness, it's clearly notes the maximum strain is around 1200×10^{-6} with maximum applied load 241.7 kN The counter FEM results of elastic strain of concrete and PUC material of set II are shown in Fig. 10. The experimental strain values of concrete at the compression zone are shown in Fig. 11 with load step.

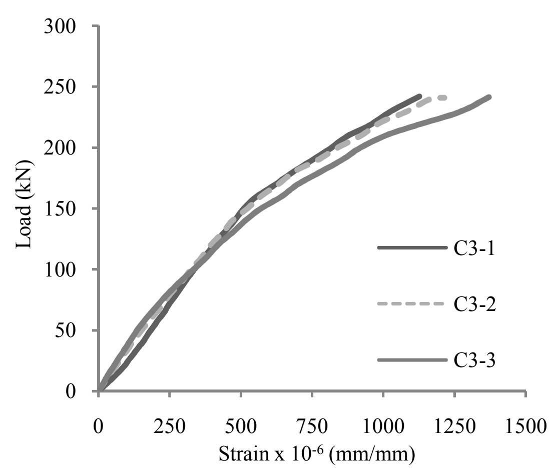


Fig. 11: Experimental strain of top fiber concrete versus applied load (set III)

It's noted that the strain of retrofitted beams of set II and set III have no big differences at failure load stage, while the maximum loading of set II was higher than set III due to losing stiffness during preload of set III.

CONCLUSION

The results can be summarized as follow:

- The strain of concrete at the top fiber was increased for the retrofitted beams
- The maximum top strain at failure load of control beam was less than retrofitted beam by 83%
- The preloaded beams with 50 kN have loading capacity less than the retrofitted beams without pre-loading, this due to the losing stiffness during pre-load process
- The FEM results show good agreements with experimental results

ACKNOWLEDGMENT

The authors wish to thank The Department of Bridge and Tunnel Engineering/School of Transportation Science and Engineering/Harbin Institute of Technology (HIT) for providing the authors the financial and techniques supports.

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