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Cyclic performance of concrete beams reinforced with CFRP prestressed prisms

Jiongfeng Liang*[1,2], Yu Deng[3], Minghua Hu[2] and Dilian Tang[2]

[1]*Jiangxi Engineering Research Center of Process and Equipment for New Energy, East China Institute of Technology, Nanchang, P.R.China*
[2]*Faculty of Civil & Architecture Engineering, East China Institute of Technology, Nanchang, P.R.China*
[3]*College of Civil and Architecture Engineering, Guangxi University of Science and Technology, Liuzhou, P.R.China*

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Abstract. This paper describes an experimental study of the cyclic performance of concrete beams reinforced with CFRP prestressed concrete prisms (PCP). The failure modes, hysteretic loops, skeleton curve, ductility, energy dissipation capacity and stiffness degradation of concrete beams reinforced with CFRP prestressed concrete prisms were analyzed. The results show that The CFRP prestressed prisms reinforced concrete beams have good seismic performance. The level of effective prestress and cross section of CFRP prestressed prisms had a little influence on the bearing capacity, the ductility and energy dissipation capacity of CFRP prestressed prisms reinforced concrete beams.

Keywords: CFRP; prism; cyclic; beam; ductility

1. Introduction

Today, use of fibre reinforced polymer (FRP) materials has become a more common practice in construction. FRP materials have unique mechanical properties such as high tensile strength, light weight, corrosion resistance, and magnetic neutrality.

However, most FRP materials have relatively low modulus of elasticity compared to steel. Due to this low modulus and the relatively small cross sectional area of FRP bars, when FRP reinforced concrete flexural members crack, the neutral axis considerably shifts up in the section causing a significant decrease in flexural stiffness. This is accompanied by increased deflections and crack widths under service load condition. To eliminate these problems, use of FRP prestressed concrete prisms (PCP) as an alternative reinforcement for concrete had been studied (Hanson 1969, and Bishara *et al.* 1971, Chen and Nawy 1994, Nawy and Chen 1998, Svecova and Razaqpiir 2000, Banthia *et al.* 2003). And these studies have mainly focused on the flexural and shear performance of FRP prestressed concrete prisms reinforced concrete structures.

A few research has been conducted so far concerning the performance of CFRP prestressed prisms reinforced concrete beams under cyclic loading.

Saiedi *et al.* (2011) investigates the behavior of concrete beams prestressed with carbon fiber-reinforced polymer (CFRP) rods under high-cycle fatigue at low temperature. It was shown that the bond between CFRP rods and concrete could be weakened because of cyclic loading, low temperature during loading, or high prestress level. The premature bond failure at 70 to 90% of the full flexural strength in subsequent monotonic loading. Also, stiffness and camber gradually decreased during cyclic loading. Yet, the mechanical performance of FRP reinforced concrete beams under reverse cyclic loading has rarely been reported. Carneiro and Melo (2011) presented an analytical model to simulate the behavior of prestressed concrete girders strengthened with various carbon fiber-reinforced polymer systems and subjected to static and cyclic loading. Kesavan *et al.* (2013) studied the performance of reinforced concrete beam strengthened with CFRP under cyclic loading using Fiber Bragg Grating (FBG) array. Bae *et al.* (2013) investigated the shear performance of an RC beam strengthened in shear with externally bonded carbon fiber-reinforced polymer (CFRP) strips, subjected to a cyclic loading for 2 million cycles at 1 Hz. The results showed that RC beams strengthened in shear with externally bonded CFRP could survive 2 million cycles of cyclic loading without failure. Furthemore, the residual shear strength of the FRP-strengthened beam appeared to be greater than the static shear strength of the unstrengthened control beam. This study’s results also suggested that limiting the interfacial stress in CFRP strips to less than 1.5 MPa or 25% of its ultimate interfacial strength would increase fatigue life by avoiding debonding of CFRP strips. Sakar *et al.* (2014) evaluate experimentally and numerically the cyclic loading response of reinforced concrete (RC) beams strengthened in shear with Glass Fiber Reinforced Polymer (GFRP) rods using the near surface mounted (NSM) technique. Realfonzo *et al.* (2014) investigated the seismic performance of RC beam-column joints strengthened with FRP systems. Selman *et al.* (2015) studied FRP-strengthened reinforced concrete beam under cyclic load by acoustic emission technique. Faustino and Chastre (2015) studied different external strengthening systems applied to rectangular reinforced concrete columns with rounded

∗Corresponding author, Ph.D.
E-mail: jiongfeng108@126.com

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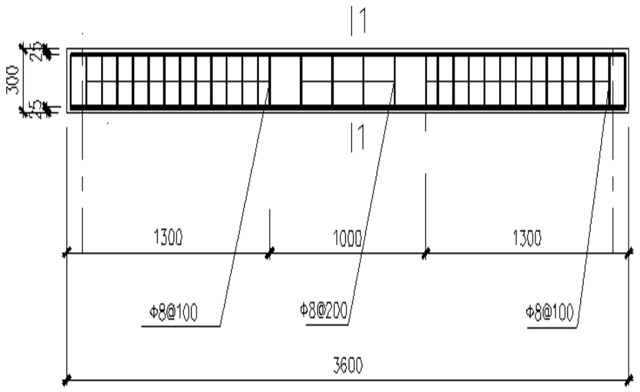
Table 1 Reinforcement details of all tested beams

Beam number	Tension reinforcement	Prestress (kN)	Cross section of PCps (mm)	Compressive reinforcement	Stirrup	
					Mid-span	Shear span
CB1	2∅22	——	——			
PB2	1φ7CFRP+2∅12	35	——			
PB3	1PCPs+2∅12	35	40×40	2∅22	φ8@200	φ8@100
PB4	1PCPs+2∅12	43	40×40			
PB5	1PCPs+2∅12	35	60×40			



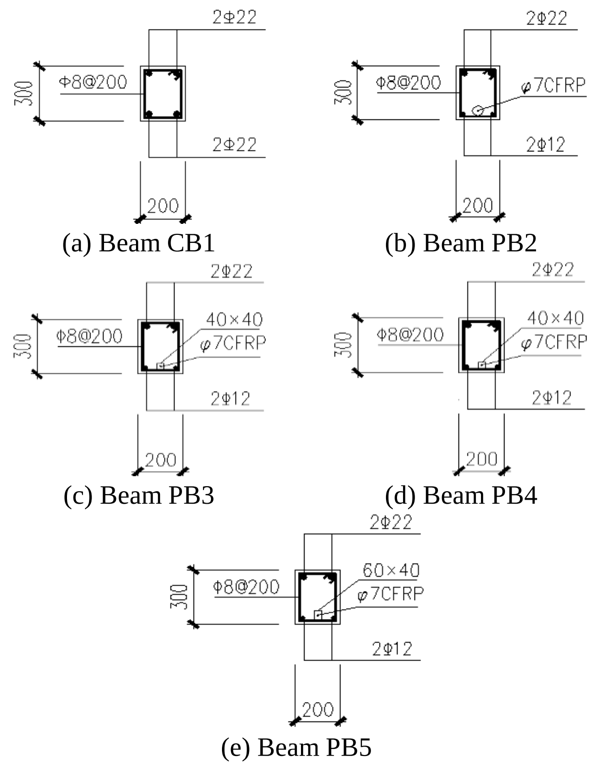


Fig. 1 Typical dimensions and geometry of tested beams

corners. Youssf *et al.* (2016) investigated the possible use of crumb rubber concrete (CRC) for structural columns by evaluating the use of fibre reinforced polymer (FRP) confinement as a means of overcoming the material deficiencies (compressive strength). Liang *et al.* (2016) tested the behaviour of concrete beams reinforced with various reinforcement, including ordinary steel bars, CFRP bars and CFRP prestressed concrete prisms (PCP). Liang *et al.* (2016) tested concrete slabs reinforced with CFRP prestressed concrete prisms (PCP) on the flexural behavior. Liang *et al.* (2016) studied mechanical properties of concrete beams reinforced with CFRP prestressed prisms under reverse cyclic loading.

In this study, experiments are performed to investigate the performance of concrete beams reinforced with CFRP prestressed prisms under reverse cyclic loading. The failure characteristics ,crack patterns, lateral load versus lateral displacement curves, characteristic loads, characteristic displacement, ductility factor, stiffness degradation, energy dissipation capacity of concrete beams reinforced with CFRP prestressed prisms was studied.

2. Experimental programme

2.1 Fabrication of specimens

Five beams were fabricated with 200 mm×300 mm cross sections and spans of 3.6 m. The design parameters of beams were tension reinforcement type, cross section of CFRP prestressed concrete prism, the level of effective prestress, their parameters are presented in detail in Table 1, Fig. 1 shows the typical dimensions for the specimens.

2.2 Materials

Table 2 Mechanical properties of rebars

Reinforcement type	Diameter	Yield strength	Ultimate strength	Elasticity modulus
	d/mm	f_y/MPa	f_u/MPa	E_s/MPa
Steel bar	8	235	370	2.1×10^5
Steel bar	12	360	550	2.0×10^5
Steel bar	22	365	560	2.0×10^5
CFRP bar	7	------	2200	1.5×10^5

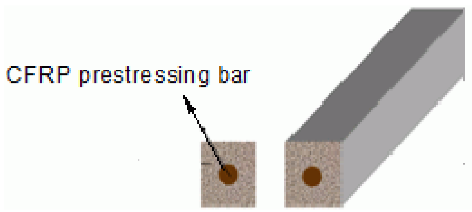


Fig. 2 Typical CFRP prestressed concrete prism(PCP)

In this test, CFRP rebar with diameters of 7 mm was adopted, HPB235 plain rebar with diameters of 8 mm was used for the transverse stirrups, and HRB335 ribbed rebar with diameters of 12 mm and 22 mm were used for the tension reinforcement and compression, respectively. Table 2 lists the mechanical properties of the rebars adopted in the beams.

A typical geometry of the prestressed prism that was used in this experimental investigation is shown in Fig. 2. The prisms were made of reactive powder concrete (RPC) with a compressive strength of 154 MPa and a tensile strength of 17.4 MPa. Prims were concentrically prestressed by a single CFRP rebar. The jacking stresses varied from 880 MPa to 1320 MPa, which are equal to 0.40 to 0.60,

Fig. 3 Test setup

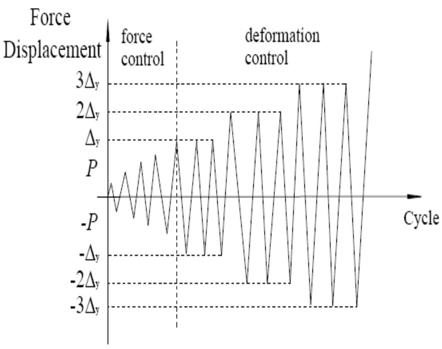


Fig. 4 Loading procedure of test beams

respectively, of the guaranteed tensile strength. All beams were cast with normal-strength concrete with a compressive strength of 48.8 MPa and a tensile strength of 2.8 MPa.

2.3 Test devices of and methods

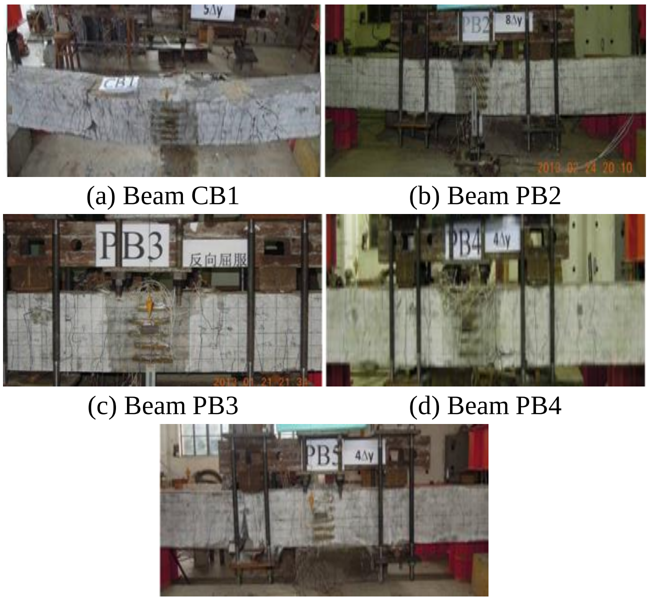
Each beam was loaded under four-point bending with loading points symmetrically placed about the mid-plane of the beam at 1000 mm apart. In the test, vertical loading was applied by an electro-hydraulic servo test machine with a load capacity of 500 kN. The test set-up is shown in Fig. 3. The vertical loading procedure included two main steps, namely, a load-controlled step and a displacement-controlled step, which are illustrated in Fig. 4.

To measure the slab deflection, the linear variable displacement transducers (LVDTs) were placed under the load points and at midspan of beams. In addition, LVDTs were placed at both ends of the slabs to measure the possible of tilting. Electrical resistance strain gauges were used to measure the strain in the transverse stirrups, the tension and compression reinforcement. Strain gauges were also used to monitor strain in concrete.

3. Results and discussion

3.1 Failure characteristics and crack patterns

For beam CB1, which is a conventional steel reinforced concrete beam, tiny cracks were first observed at a load of 23 kN in the pure bending region. After that, some inclined flexural shear cracks were found outside this region. As the



(a) Beam CB1 (b) Beam PB2

(c) Beam PB3 (d) Beam PB4

(e) Beam PB5

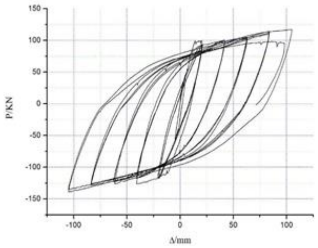
Fig. 5 Failure crack patterns of the test beams

magnitudes of the lateral loads increased, the numbers of flexural cracks in the beams increased, and the flexural shear cracks gradually extended from the bottom of the beam to its top surface. When the load was 98 kN, the cracks have extended to a height of approximately 184 mm. As the loads continued to increase, the crack width increased rapidly. Finally, beam CB1 failed by crushing of concrete in the compression zone. The final crack pattern of beam CB1 is shown in Fig. 5(a).

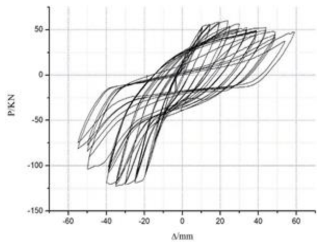
For beam PB2 with one 7 mm CFRP bar and two 12 mm steel bar as tension reinforcement, the first crack appeared in the middle span at a load of 29 kN. With increasing external loading, many tiny cracks developed in concrete, the crack width increased rapidly and only about six flexural cracks were observed along the pure moment region at final failure. The maximum crack width of beam PB2 at final failure was measured to be less than 0.3 mm.Under reversed loading, the beam finally failed by concrete crushing with serious concrete spalling, as shown in Fig. 5(b).

For beam PB3, which is a CFRP prestressed concrete prism beam, tiny cracks were first observed at a load of 25 kN in the pure bending region. After that, several inclined flexural shear cracks were found to form in the shear span and extended towards the loading point. With increasing external loading, additional cracks continued to form along the span, especially in the pure bending region where the average crack spacing was measure to be approximately 5-10 mm. And multiple diagonal flexural shear cracks were observed outside the pure bending region. Finally, beam PB3 failed by CFRP ruptured after concrete crushed, as shown in Fig. 5(c). Beam PB4, PB5 have the similar failure characteristics and crack patterns as beam PB3, as shown in Fig. 5(d), (e), respectively.

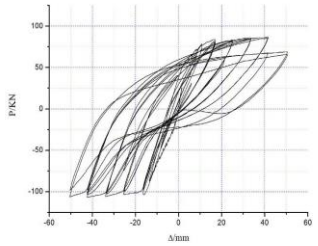
3.2 Lateral load(P) versus lateral displacement(Δ)curves



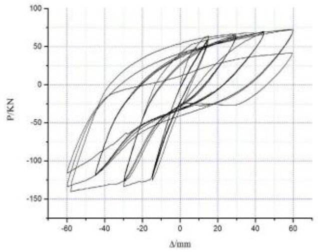
(a) Beam CB1



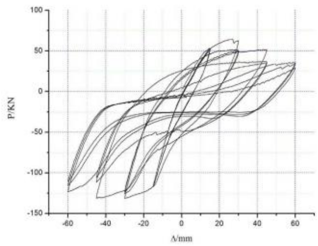
(b) Beam PB2



(c) Beam PB3



(d) Beam PB4



(e) Beam PB5

Fig. 6 Hysteresis loops of the test specimens

Fig. 6 shows the hysteresis curves of each beam. It can be clearly seen that the hysteresis curves of beam CB1 is relatively plumper and more stable than other beams. This is because beam CB1 failed in the flexural mode, and ductile deformation can be achieved by strain hardening of steel reinforcement after yielding. However, other beams failed in slip of CFRP bar or CFRP ruptured. The extent of strain hardening in the longitudinal reinforcement is limited, which results in lower ductility and energy dissipation capacity. It is also found from Fig. 6 that the hysteresis loops of CFRP prestressed prisms reinforced concrete beam (PB3, PB4 and PB5) are much larger than prestressed CFRP bar reinforced concrete beam (PB2), which is due to the superior deformation behavior of CFRP prestressed prisms over that of CFRP bar. Different parameters have different influences on the hysteresis loops of CFRP prestressed prisms reinforced concrete beams in the test. The investigated CFRP prestressed prisms reinforced concrete beams are similar in terms of the shapes of hysteresis loops regardless of the increasing level of effective prestress. However, the area of the hysteresis loops seems to decrease to some extent with level of effective prestress increase. With the increasing cross section of CFRP prestressed concrete prism, the displacement loading cycles decrease, and the deformation of tested beam decrease gradually. The CFRP prestressed prisms reinforced concrete beam with a small cross section of prisms shows the plump hysteresis loops. It indicates that the increasing cross section of prisms can reduce the seismic behavior of CFRP prestressed prisms reinforced concrete beams.

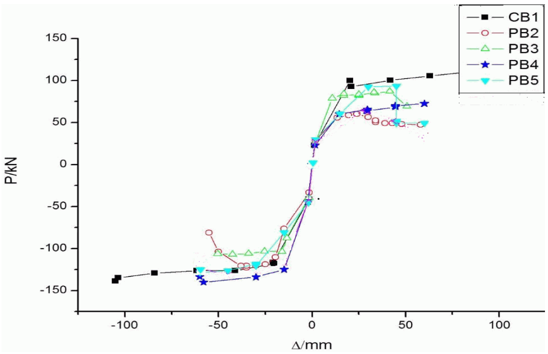


Fig. 7 Skeleton curves of test specimens

Table 3 Characteristic loads of test specimens

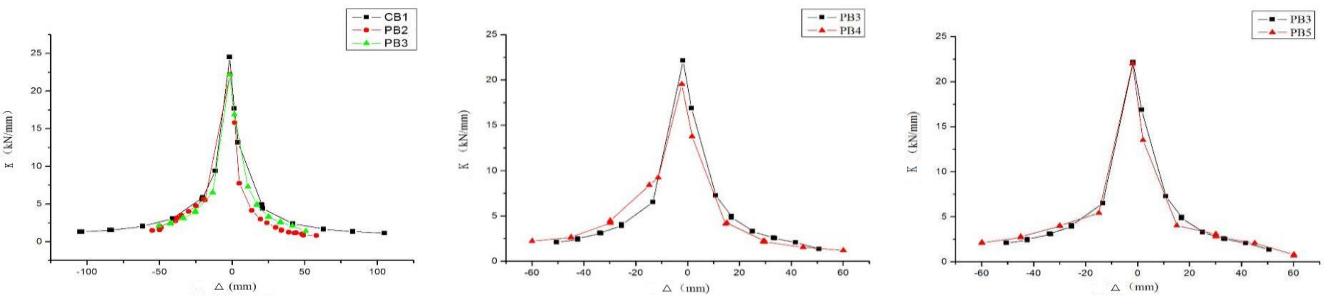
Beam no.	Crack point	Yield point	Failure point
	P_{cr}/kN	P_y/kN	P_u/kN
CB1	32.1	103.5	127.9
PB2	31.2	71.4	91.4
PB3	32.0	83.2	96.7
PB4	33.6	84.5	106.4
PB5	34.5	86.9	98

Fig. 7 shows the skeleton curves of each beam. It can be seen that the skeleton curve of beam is divided into the elastic, elasto-plastic, and failure stage. Most of the skeleton curves show the resistance of the beams to loading decreasing slowly, which indicates that the CFRP prestressed prisms reinforced concrete beams have good ductility. The skeleton curves of CFRP prestressed prisms reinforced concrete beams almost overlap in elastic stage, which indicates that the initial stiffnesses of the beams are similar, regardless of the level of effective prestress. And after that, the skeleton curves of CFRP prestressed prisms reinforced concrete beams exhibit some differences in the elasto-plastic and failure phases. This shows that the level of effective prestress had some influence on the bearing capacity and ductility of the beams. And the skeleton curves of CFRP prestressed prisms reinforced concrete beams with a large cross section of prisms exhibit obvious difference in the elasto-plastic and failure phases.

3.3 Characteristic loads

The characteristic loads of all beams are listed in Table 3. P_{cr}, P_y, P_u stands for the crack load, the yield load and the failure load, respectively. The failure load of a beam can be defined by the lateral load of beam declines to 85% of the beam' peak load.

Based on Table 3, the following conclusion can be made: compared to beam CB1, which contained steel bar, the crack loads are almost the same for beam PB3, PB4 and PB5.Compared to beam PB2, which contained CFRP bar, the crack loads are higher for beam PB3, PB4 and PB5. The CFRP prestressed prisms reinforced concrete beams (i.e., PB3, PB4) with different level of effective prestress had



(a) Beam CB1, PB2 and PB3 (b) Beam PB3, PB4 (c) Beam PB3, PB5

Fig. 8 Stiffness degradation of test beams

Table 4 Characteristic displacement and ductility factors

Beam no.	Crack point	Yield point	Failure point	Ductility coefficient
	Δ_{cr}/mm	Δ_y/mm	Δ_u/mm	μ
CB1	1.5	19.5	105.1	5.4
PB2	1.7	18.8	56.5	3.1
PB3	1.7	11.2	50.5	4.5
PB4	2.0	13.7	60.0	4.3
PB5	1.8	15.0	60.0	4.0

different characteristic loads. The difference values of the crack load and failure load for the beams (i.e., PB3, PB4) are 1.6 kN and 9.7 kN. And the cross section of CFRP prestressed prisms slightly influenced the characteristic loads of CFRP prestressed prisms reinforced concrete beams. The crack loads and failure load of beam PB3, PB5 are almost similar.

3.4 Characteristic displacement and ductility factor

Table 4 shows the characteristic displacement and ductility factors of test beams. Δ_{cr}, Δ_y, Δ_u stands for the crack displacement, the yield displacement and the failure displacement corresponding to the crack load, the yield load and the failure load, respective-ly. In addition, displacement ductility represented by displacement ductility coefficient, which was defined as $\mu=\Delta_u/\Delta_y$.

Table 4 illustrates the influences of design parameters on the beams' ductility factors. As shown in Table 4, the ductility factors of CFRP prestressed prisms reinforced concrete beam(i.e., PB3, PB4, PB5) are higher than that of prestressed CFRP bars reinforced concrete beam (i.e., PB2). It reveals that better seismic behavior of CFRP prestressed prisms reinforced concrete beam than prestressed CFRP bars reinforced concrete beam. And a CFRP prestre-ssed prisms reinforced concrete beam's ductility factor decreases as the level of effective prestress and cross section of CFRP prestressed prisms increase. The average ductility factorvalue is 4.27, which indicates the good seismic performance of the CFRP prestressed prisms reinforced concrete beams.

3.5 Stiffness degradation

Fig. 8 shows the degradation of the secant stiffnesses of the test beams under low cyclic reversed loading. All the beams had a larger initial stiffness because of the existence of reinforced bar in the specimens. After concrete cracked, the stiffnesses decreased dramatically. Fig. 8(b) shows the initial stiffnesses of CFRP prestressed prisms reinforced concrete beam with low level of effective prestress was greater than that of CFRP prestressed prisms reinforced concrete beam with high level of effective prestress. After cracks appeared, the rate of negative direction stiffness degradation in the CFRP prestressed prisms reinforced concrete beam with high level of effective prestress was slower than in the CFRP prestressed prisms reinforced concrete beam with low level of effective prestress. Fig. 8(c) illustrates the influence of cross section of CFRP prestressed prisms on the stiffness degradationof the CFRP prestressed prisms reinforced concrete beam. The initial stiffnesses were almost the same for beam PB3, PB5. After cracks in the specimens, the rate of stiffness degradation in the CFRP prestressed prisms reinforced concrete beam with large cross section of CFRP prestressed prisms was slower than in the CFRP prestressed prisms reinforced concrete beam with small cross section of CFRP prestressed prisms.

Table 5 The equivalent viscous damping coefficients of the tested beams

Beam no.	h_{ey}	h_{eu}
CB1	0.113	0.303
PB2	0.049	0.131
PB3	0.056	0.243
PB4	0.054	0.236
PB5	0.071	0.229

3.6 Energy dissipation capacity

In earthquake engineering, the energy dissipation capacity of a structure or structure component reflects its seismic energy absorption ability. The equivalent viscous damping coefficients h_e is used to quantify the energy absorption ability of structure or structure component.

Table 5 shows the equivalent viscous damping coefficients versus the different characteristic loading point of tested beams. The coefficients h_{ey}, h_{eu} correspond to the yield loading, the failure loading of the tested beams, respectively.

Based on the data of Table 5, the results can be made: compared to beam PB2, the equivalent viscous damping coefficients h_{ey}, h_{eu} of beam PB3, PB4, PB5 were higher. It shows that the seismic behavior of CFRP prestressed prisms reinforced concrete beam is better than that of prestressed CFRP bars reinforced concrete beam. Compared to beam PB3 with beam PB4, the coefficients h_{ey} and h_{eu} also decreased as the level of effective prestress increased. It suggests that the energy absorption ability of CFRP prestressed prisms reinforced concrete beam decreased gradually as the increasing level of effective prestress. Compared to beam PB3 with small cross section of CFRP prestressed prisms, the coefficient h_{eu} of beam PB5 was 5.76% lower. It reveals that the increasing cross section of CFRP prestressed prisms may reduce the energy absorption ability of CFRP prestressed prisms reinforced concrete beam.

5. Conclusions

Based on the experimental results, the following conclusions can be drawn:

• The concrete beams reinforced with various reinforcement, including ordinary steel bars, CFRP bars and CFRP prestressed concrete prisms (PCP) behaved differently in terms of their failure modes. The tension reinforcement had an obvious effect on the failure modes of concrete beams. All the tested beams suffered from flexural failure. Using PCP as reinforcement for concrete beams introduced compressive stresses to the tensile zone of concrete beam. Hence, the crack load of CFRP prestressed prisms reinforced concrete beams was higher than that of steel reinforced concrete beams and CFRP reinforced concrete beams.

• The CFRP prestressed prisms reinforced concrete beams have good seismic performance. The level of effective prestress and cross section of CFRP prestressed prisms had a little influence on the bearing capacity, the ductility and energy dissipation capacity of CFRP prestressed prisms reinforced concrete beams. Comparing with the concrete beam reinforced with CFRP bar, the hysteresis loops of concrete beams reinforced with CFRP prestressed prisms were more plump.

• Compared to CFRP reinforced concrete beams, the CFRP prestressed prism in reinforced concrete beams was effective in enhancing its seismic performance in terms of deformability, stiffness and energy dissipation.

Acknowledgments

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References

Bae, S., Murphy, M., Mirmiran, A. and Belarbi, A. (2013), "Behavior of RC T-beams strengthened in shear with CFRP under cyclic loading", *J. Brid. Eng.*, **18**(2), 99-109.

Banthia, V., Mufti, A.A., Svecova, D. and Bakht, B. (2003), "Transverse confinement of deck slabs by concrete straps", *Proceedings of the 6th International Symposium on Fiber-Reinforced Polymer Reinforcement for Concrete Structures*.

Carneiro, R. and Melo, G. (2011), "Analytical model for CFRP-strengthened prestressed concrete girders subject to cyclic loading", *J. Compos. Constr.*, **15**(5), 871-874.

Chen, B. and Nawy, E.G. (1994), "Structural behavior evaluation of high strength concrete beams reinforced with prestressed prisms using fiber optic sensors", *ACI Struct. J.*, **91**(6), 708-718.

Faustino, P. and Chastre, C. (2015), "Flexural strengthening of columns with CFRP composites and stainless steel: Cyclic behavior", *J. Struct. Eng.*, **142**(2), 161-167.

Hanson, N.W. (1969), "Prestressed concrete prisms as reinforcement for crack control", *PCI J.*, **14**(5), 14-31.

Kesavan, K., Ravisankar, K., Senthil, A. and Ahmed, A.K.F. (2013), "Experimental studies on performance of reinforced concrete beam strengthened with CFRP under cyclic loading using FBG array", *Measure.*, **46**(10), 3855-3862.

Liang, J.F., Deng, Y. and Bai, Y. (2016), "Flexural behavior of concrete beams reinforced with CFRP prestressed prisms", *Comput. Concrete*, **17**(3), 295-304.

Liang, J.F., Deng, Y., Wang, J.B. and Yi, P.H. (2016), "Mechanical properties of concrete beams reinforced with CFRP prestressed prisms under reverse cyclic loading", *Earthq. Struct.*, **11**(2), 315-326.

Liang, J.F., Deng, Y., Yang, Z.P. and Chai, X.J. (2016), "Tests of concrete slabs reinforced with CFRP prestressed prisms", *Comput. Concrete.*, **18**(3), 355-366.

Mirza, J.F., Zia, P. and Bhargava, J.R. (1971), "Static and fatigue strengths of beams containing prestressed concrete tension elements", *High. Res. Rec.*, **354**, 54-60.

Nawy, E.G. and Chen, B. (1998), "Deformational behavior of high performance concrete continuous composite beams reinforced with prestressed prisms and instrumented with brag grating fiber optic sensors", *ACI Struct. J.*, **95**(1), 51-60.

Realfonzo, R. and Napoli, A. (2012), "Results from cyclic tests on high aspect ratio RC columns strengthened with FRP systems", *Constr. Build. Mater.*, **37**, 606-620.

Realfonzo, R., Napoli, A. and Pinilla, J.G.R. (2014), "Cyclic behavior of RC beam-column joints strengthened with FRP systems", *Constr. Build. Mater.*, **54**(15), 282-297.

Saiedi, R., Fam, A. and Green, M. (2011), "Behavior of CFRP-prestressed concrete beams under high-cycle fatigue at low temperature", *J. Compos. Constr.*, **15**(4), 482-489.

Sakar, G., Hawileh, R.A., Naser, M.Z., Abdalla, J.A. and Tanarslan, M. (2014), "Nonlinear behavior of shear deficient RC beams strengthened with near surface mounted glass fiber reinforcement under cyclic loading", *Mater. Des.*, **61**, 16-25.

Selman, E., Ghiami, A. and Alver, N. (2015), "Study of fracture evolution in FRP-strengthened reinforced concrete beam under cyclic load by acoustic emission technique: An integrated mechanical-acoustic energy approach", *Constr. Build. Mater.*, **95**(1), 832-841.

Svecova, D. and Razaqpur, A.G. (2000), "Flexural behavior of concrete beams reinforced with carbon fiber-reinforced polymer (CFRP) prestressed prisms", *ACI Struct. J.*, **97**(5), 731-738.

Youssf, O., Elgawady, M.A. and Mills, J.E. (2016), "Static cyclic behaviour of FRP-confined crumb rubber concrete columns", *Eng. Struct.*, **113**(15), 371-387.

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