Journal of Applied Sciences

ISSN 1812-5654

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 9 (1): 142-148, 2009
ISSN 1812-5654

Effects of Intermediate Anchors on End Anchored Carbon Fibre Reinforced Polymer Laminate Flexurally Strengthened Reinforced Concrete Beams

M.Z. Jumaat and A. Alam
Department of Civil Engineering, Faculty of Engineering,
University of Malaya, 50603 Kaula Lumpur, Malaysia

Abstract: This research presents the results of an experimental study to look into the effects of intermediate anchors on end anchored CFRP laminate strengthened beams. Three beams of 125×250×2300 mm in dimensions were cast. Out of these, one beam was left un-strengthened and acts as the control beam and another two beams were strengthened with CFRP laminates. Both strengthened beams were end anchored to prevent premature end peeling. From the strengthened beams, one beam was intermediate anchored in the shear span to prevent premature shear failure. The anchorage lengths provided by the end and intermediate anchors were of 200 and 40 mm, respectively. The results showed that the intermediate anchors in shear span zone prevented premature shear failure. Result also showed that the strengthened beams with intermediate anchors had significant effects on failure loads, failure modes, strain characteristics, deflections and cracking patterns over the end anchored strengthened beam.

Key words: Premature shear failure, L shape anchors, plate bonding method

INTRODUCTION

Fibre Reinforced Polymer (FRP) is one of the most popular material in the field of strengthening reinforced concrete beams due to its superior mechanical and physical properties compared to steel, particularly with respect to tensile and fatigue strengths. There are several Fibre Reinforced Polymer (FRP) systems now commercially available for external strengthening of concrete structures. Amongst these, Carbon Fibre Reinforced Polymer (CFRP) laminate is a popular choice due to its high strength. With the development of structurally effective adhesives and plating methods, strengthening using CFRP laminates have increased tremendously in recent years. However, the plate bonding methods often have serious premature failure problems due to separation of plates and concrete rip off along the tensile reinforcing bars (end peeling) or premature shear failure before reaching their ultimate capacities (Bencardino *et al*., 2007; Kim *et al*., 2007). Investigation on the failure mechanism of end peeling has been conducted by a number of researchers. It is reported by Gerco *et al*. (2007), Yao and Teng (2007) and El-Mihilmy and Tedesco (2007) that shear and normal (peeling) stress concentrations at the cut-off point or around the flexural cracks are the main reason for local failures. Due to these stress concentrations at plate end, a shear crack can be initiated at the plate end which induces a horizontal crack at the level of the tension reinforcement which propagates rapidly towards the load point and eventually causes separation of the plates (Xiong *et al*., 2007). However, researchers would find a solution to minimize end peeling using appropriate end anchors. Unfortunately, although lot of research studies had been carried out on strengthening r.c. beams using CFRP laminates, not much informations can be gathered on the effects of intermediate anchors on end anchored CFRP laminate strengthened beams to prevent premature shear failure completely. The main goal of the research is to study the effects of intermediate anchors using steel plate on end anchored CFRP laminate flexural strengthened reinforced concrete beams in view of failure loads, failure modes, strain characteristics, deflections and cracking patterns.

MATERIALS AND METHODS

Description of specimens: Three r.c. beams of rectangular cross-sections were tested in this study. These beams are designated as beams A1, C3 and C4. Beam A1 was left as the un-strengthened control beam's specimen and beams C3 and C4 were strengthened by CFRP laminate (1.2×80×1900 mm). Both strengthened beams, C3 and C4 were end anchored using L shape anchoring plates. The anchorage lengths used was 200 mm. From the

Corresponding Author: Ashraful Alam, Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia Tel: +6-0163040495

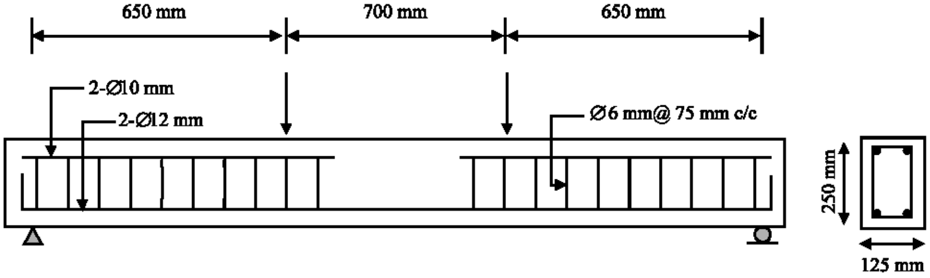

Fig. 1: Beam details

Table 1: Test specimens

		Strengthening materials			Anchorages	
Serial No.	Specimen	Type	Thickness (mm)	Width (mm)	End (200 mm)	Intermediate (40 mm)
1	A1	-----	-------	------	---------	-----------
2	C3	Steel plate	1.2	80	L shape	-----------
3	C4	CFRP	1.2	80	L shape	L shape

strengthened beams, C4 was intermediate anchored in the shear span of the beam using the same shape of anchoring plates. The anchorage lengths used was 40 mm. Both of the end and intermediate anchors were of steel plates, 2 mm in thickness with the vertical dimension of 250 mm (the full height of the beam) and horizontal dimension of 125 mm (the full width of the beam). The test variables are shown in Table 1.

Fabrication of specimens: All beam specimens were of 2,300 mm long, 125 mm wide and 250 mm deep as shown in Fig. 1. These beams were reinforced with two 12 mm diameter high yield steel bars in the tension zone. Ten millimeter mild steel bars were used as hanger bars and 6 mm bars were used for shear reinforcements which were symmetrically placed as shown in Fig. 1. The spacing of the shear reinforcements was 75 mm.

Strengthening and anchoring: For all beams, the length of the bonded plate was maintained at 1900 mm, which covered almost the full-span length of the beams (Fig. 2). The main reason for the full span-length strengthening with CFRP laminates was to maximize the strengthening effects.

The concrete surface treatment prior to plating works was very important to guarantee the perfect bonding between concrete and strengthening plates. Concrete was ground with a diamond cutter to expose the coarse aggregates. Dusts were then blown out by compressed air. Colma cleaner was used to remove carbon dusts form the bonding face of the CFRP laminate. The well mixed sikadur adhesive was then trawled on to the surface of the concrete specimens to form a thin layer. The adhesive was applied with a special dome shaped spatula onto the CFRP (Sika CarbaDur) laminates. The plates were positioned on the prepared surface. Using a rubber roller, the plates were gently pressed into the adhesive until the material was forced out on both sides of the laminates. The surplus adhesive was then removed.

L shape end anchors were placed at the end of both of the strengthened beams (C3 and C4). The intermediate anchors were only placed in the shear span of the strengthened beam C4 (Fig. 2). It was hope that the beam can carry the maximum load before failure by either plate or laminate rupture or concrete compression failure rather than premature shear failure. The spacing of the intermediate anchorages was 110 mm, which was equal to half of effective depth (d/2) so that every shear crack will cross the plate. The plate was sand blasted and the surface preparation and application methods were similar to that of the plating method. Before placing the end and intermediate anchors, the adhesive was applied on the prepared bonding face of the beams and an inner face of the anchors. The anchor-plates were fixed on to the beam and then pressed by a rubber roller. After fixing, they were clamped for 3 days for setting.

Materials: Ordinary Portland Cement (OPC) was used in casting the beams. The maximum size of coarse aggregate used was 20 mm. The concrete mix was designed with a targeted strength of 30 MPa. The mix proportion adopted is as shown in Table 2. The compressive strengths of the concrete were obtained from three cubes after 28 days curing according to British Standard (BS 1881).

Two 12 mm diameter of high yield deformed bars were used as the tensile reinforcement. The measured yield and tensile strength of these bars were 551 and 641 MPa, respectively. Ten millimeter diameter mild steel bars were used as hanger bars in shear span zone. Six millimeter diameter bars were used for stirrups. The measured yield

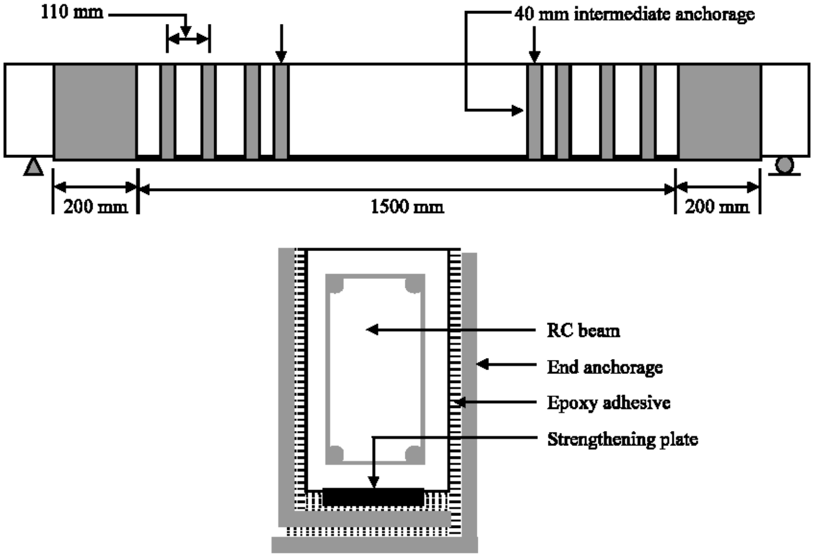

Fig. 2: Strengthening and anchoring details

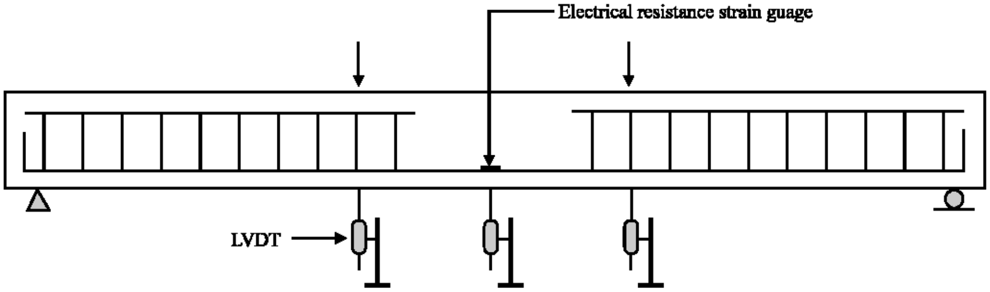

Fig. 3: Beam instrumentations

Table 2: Results of proportions mix design

		Contents (kg m^{-3})			
Slump	Water cement ratio	Water	Cement	Coarse aggregate	Fine aggregate
60-180	0.65	208	320	740	1120

and tensile strength of the stirrups were 520 and 572 MPa, respectively. The modulus of elasticity of all steel bars was 200 GPa. For beam strengthening, CFRP laminates (Sika CarboDur, S812) were used. The tensile strength and modulus of elasticity of CFRP laminates were 2800 MPa and 165 GPa, respectively. The design and ultimate strain of CFRP laminates were 0.0085 and 0.017 according to the manufacturer's instruction.

Instrumentation and test procedure: Figure 3 shows the location of the different instruments used to record data during testing. Electrical resistance strain gauges were used to measure the strains in the steel bar, CFRP laminate and the top of the r.c. beams. Demac gauges were attached along the height of beam at the mid-span region to measure the horizontal strains. Three linear variable displacement transducers (LVDTs) were used to measure the vertical deflection of the beam at mid-span and under the two load points (Fig. 3). The load was applied incrementally under a load control procedures up to failure using the Instron 8505 Universal Testing Machine.

RESULTS AND DISCUSSION

Mode of failure: Figure 4 shows the failure modes of control beam (A1), end anchored CFRP laminate strengthened beam (C3) and end with intermediate anchored CFRP laminate strengthened beam (C4). The control beam failed in the conventional flexural manner of steel yielding followed by crushing of concrete. The end anchored CFRP laminate strengthened beam failed by premature shear failure. The end with intermediate

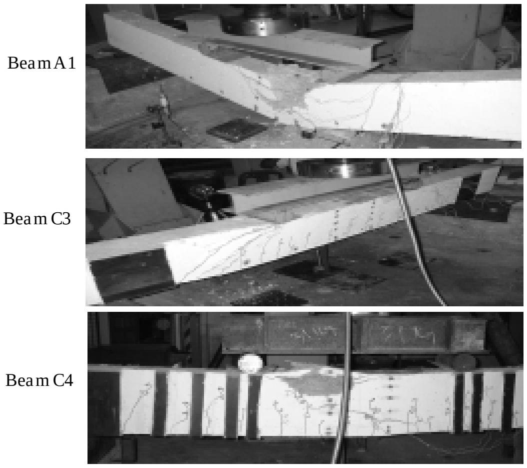

Fig. 4: Mode of failures

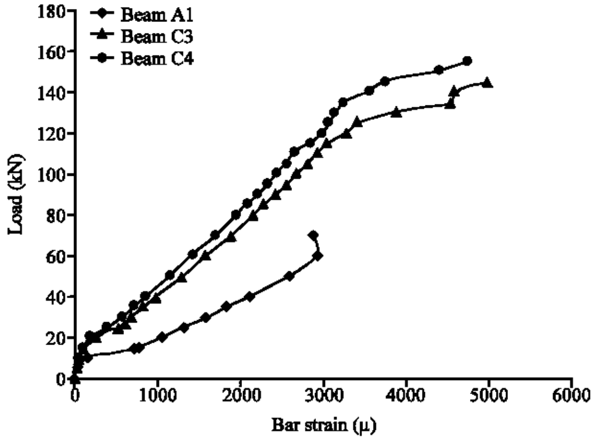

Fig. 5: Load versus bar strain

anchored CFRP laminate strengthened beam failed by crushing of concrete in ductile manner. It is investigated that the steel plate intermediate anchors completely prevented the premature shear failure. Whereas, Bencardino *et al*. (2007) and Kim *et al*. (2007) used CFRP wrap in FRP laminate strengthened beams to prevent premature shear and they examined that using of CFRP wrap premature shear failure could not be prevented completely. In this research mild steel plate was used as intermediate anchors with the spacing of half of the effective depth of the beam, which had significant effect to prevent premature shear failure completely. Further, the intermediate anchors enhanced the shear resisting capacity of the beam. Normally, when the shear resisting capacity is increased, then the beam would fail by either flexure or crushing of concrete. In this research, as the beam (C4) was over reinforced due to high strength of CFRP laminate, it failed by crushing of concrete rather than by flexure.

Though the beam C4 failed by crushing of concrete, the failure mode had some ductile characteristics. This was due to yield of the tensile bar before the failure of the beam that can be seen from the Fig. 5. Such type of failure has also been reported by a number of researchers (Ei-Mihilmy and Tedesco, 2001; Smith and Teng, 2002).

Failure load: The experimental failure loads of all the beams are shown in Table 3. The results showed that the failure loads of all the strengthened beams (C3 and C4) were higher compared to the control beam (A1).

In comparison, the failure load of the beam C4 was 8.2% higher than the beam C3. This is due to the usage of intermediate anchors in the shear span of beam C4. Because of the intermediate anchors, the beam failed by crushing of concrete rather than the premature shear failure. Since the beam C3 failed by premature shear and the beam C4 failed by crushing of concrete, the failure load of beam C4 was higher. Table 3 shows the comparisons between the measured and theoretical flexural failure loads. It is seen that the measured failure loads of beams C3 and beam C4 are higher than the theoretical flexural failure load.

Strain characteristics

Bar strain: The load versus bar strains of beams A1, C3 and C4 are shown in Fig. 5. The strengthened beams indicated smaller value of bar strains compared to the control beam. However, the bar strain of beam C4 was lower than the bar strain of beam C3. This was because of the higher stiffness of beam C4. It is noted that the stiffness of beam C4 increased due to the use of intermediate anchors.

Figure 5 also shows that, the strains of the control beam (A1) and strengthened beams (C3 and C4) increased suddenly after around 10 and 15 kN load, respectively. This would due to the occurring of first crack (invisible) in the concrete section. Figure 5 also shows that the tensile steel of both strengthened beams (C3 and C4) yielded at around 120 kN load which lead to fail the beams with ductile manner although the beams were failed by shear and crushing of concrete.

Laminate strain: Figure 6 shows that the laminate strain of the beam C4 was less compared to the beam C3 for its higher stiffness. The Fig. 5 also shows that the laminate strain increasing rate of beam C3 and C4 is linear up to 20 kN. After 20 kN load this rate is suddenly increases due to first crack (as explained before). The CFRP laminate strain of beam C3 and C4 is also linear up

Table 3: Test results of failure loads of all beams

Specimen	1st crack load in kN (% increase over control)	Failure Load in kN (% increase over control)	Design load in kN	Failure load/ design load	Theoretical flexural ultimate load in kN	Failure load/theoretical flexural ultimate load	Failure mode
A1	14	80.59	62.6	1.29	76	1.06	Flexural
C3	27 (93)	145.80 (81)	91.2	1.60	119	1.23	Shear
C4	25 (75)	157.80 (96)	91.2	1.73	119	1.33	Concrete compression

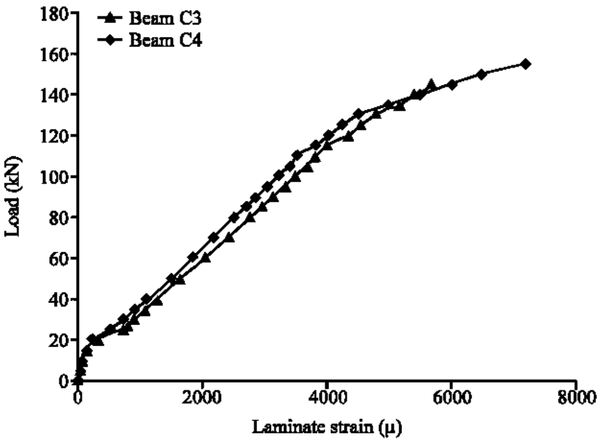

Fig. 6: Load versus laminate strain

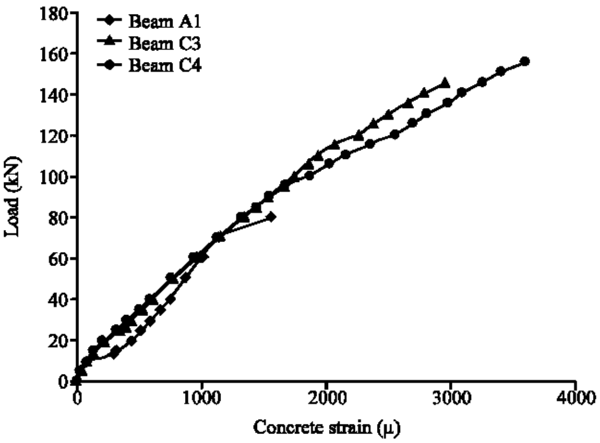

Fig. 7: Load versus concrete strain

to 120 kN load (bar yield point). It is seen from the Fig. 6 that the strain increment of CFRP laminate was changed after 120 kN load though the CFRP laminate doesn't have any yield point. This would because of the yield of steel bar.

Concrete compressive strain: The concrete compressive strains of strengthened beams C3 and C4 were less than the control beam due to their higher stiffness. At failure the concrete compressive strains of strengthened beams were also higher than the control beam due to the higher ailure loads. It is seen from the Fig. 7 that at failure the concrete strain of beam C4 exceeded 0.0035 which indicates to fail the beam by crushing of the concrete.

Strain variation on beam depth: Figure 8 shows that the strain variation and neutral axis depth of all strengthened beams is similar. This trend is as expected since the materials and the stiffness of strengthened beams are equal. It was also found that intermediate anchorages did not have any effect on strain variation.

Deflection: Figure 9 shows the load versus mid-span deflection curves for all the beams. All the beams indicated linear, elastic portions of the curves at the initial stages. Both of the strengthened beams showed smaller deflection compared to the control beam due to their higher stiffness. The beam C4 showed less deflection than beam C3 because of its higher stiffness. Figure 8 also shows that the deflection of beam C3 and C4 suddenly increased after around 120 kN. This might due to steel bar yielding. When the bar was yielding, the strain of the bar increased suddenly and would deflect the beam further.

Cracking patterns

Cracking load: The strengthened beams in general showed higher cracking loads compared to the control beam (Table 3). Since first crack load depends on the modulus of rupture of the concrete and the stiffness of strengthening materials, the first crack loads of both the CFRP laminate strengthened beams (end anchored and end with intermediate) were found to be similar.

Crack spacing: The total crack number of beams A1, C3 and C4 was 11, 18 and 18, respectively. The average crack spacing of beams A1, C3 and C4 was 182, 111 and 111 mm, respectively. The strengthened beams showed less crack spacing than the control beam. However the crack spacing of beams C3 and C4 was similar. It was noticed that in the case of beam C4, most of the crack had occurred near every anchoring plate. This would due to the stress concentration near the anchoring plates.

Crack width: It is seen in the Fig. 10 that the crack width of all strengthened beams were less than the control beam. It is also seen that the crack width of beam C4 is lower than the crack width of beam C3 though the number of crack of both beams are same. This may due to a slightly stiffer behaviour of beam C4 because of the usage of intermediate anchors in the shear span zone.

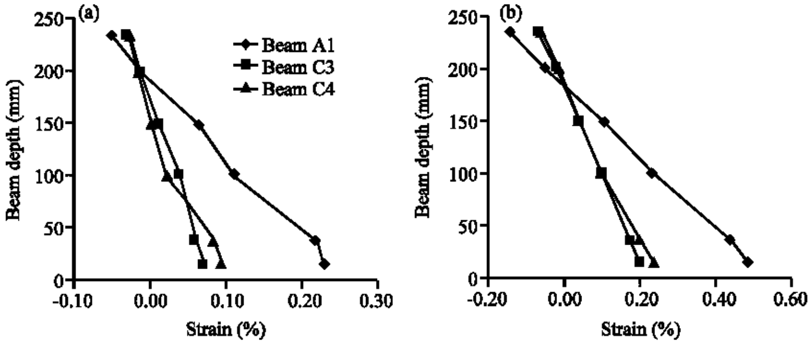

Fig. 8: Strain variations of beam, (a) Strain at 30 kN load and (b) Strain at 70 kN load

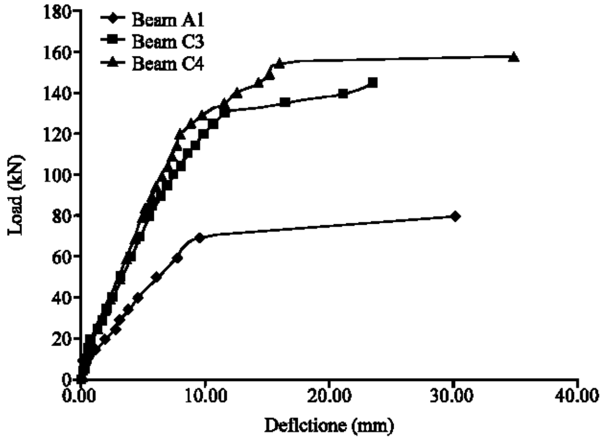

Fig. 9: Load versus deflection

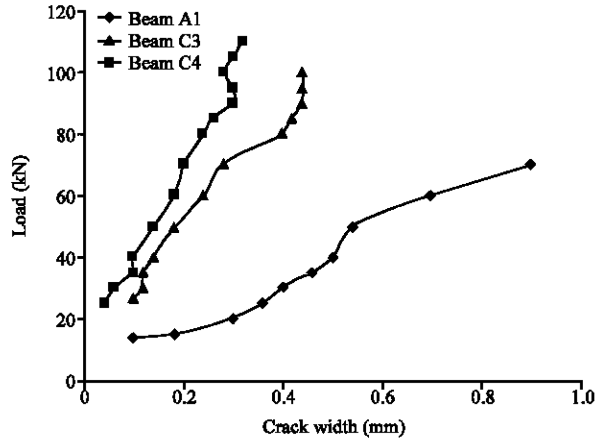

Fig. 10: Load versus crack width

Further, due to the stress concentration near the anchoring plate, most of the shear crack in the shear span zone had occurred from the end of the intermediate anchors. Normally shear crack would propagate in an inclined manner. Since, due to the intermediate anchorage, this shear crack was not propagated in an inclined manner, the crack width of beam C4 in the shear span zone was less.

CONCLUSIONS

The following conclusions can be drawn from the present study:

- The end and intermediate anchored CFRP laminate flexural strengthened beams gave higher failure loads than the control beam. The intermediate anchored strengthened beam showed higher failure load compared to the beam without intermediate anchors
- The control beam failed in a conventional manner, i.e., flexural failure. End anchored CFRP laminate strengthened beam failed in premature shear. End with intermediate anchored CFRP laminate strengthened beam showed a concrete compression failure tendency with a ductile mode. Steel plate intermediate anchors had completely prevented the premature shear failure of CFRP laminate flexurally strengthened r.c. beams
- The reinforcement strains of the strengthened beams were found to be less than the reinforcement strain of the control beam. At the same load, the intermediate anchored strengthened beam showed the least bar strain
- The maximum concrete compressive strain at the top of the mid-span of the control beam was found to be the least. Since the control beam and end anchored CFRP laminate strengthened beam failed by the conventional flexural and shear failure mode respectively, at failure, the concrete compressive strains were found to be less than 0.0035. For the case of end with intermediate anchored CFRP laminate strengthened beam, it failed

in a compression failure mode and thus the concrete compressive strain at failure load was found to be higher than 0.0035

- All strengthened beams showed lesser deflections than the control beam. At the same load, end with intermediate anchored CFRP laminate strengthened beam gave slightly lower deflection compared to the end anchored strengthened beam
- The cracking load of the control beam was found to be less than the strengthened beams. The crack width of all strengthened beams was less than the control beam. End with intermediate anchored strengthened beam showed less crack width compared to end anchored strengthened beam though the number of cracks of both beams were same

ACKNOWLEDGMENTS

The authors would like to thank the Majlis Penyelidikan Kebangsaan Sains Negera under the E-science Fund 13-02-03-3022 for providing the fund to carry out the research reported in this study. Thanks are also due to Sika Kimia and their staff for providing the technical and materials supports for this study. The authors would also like to express their gratitude to whomsoever had contributed to this work either directly or indirectly.

REFERENCES

Bencardino, F., G. Spadea and R.N. Swamy, 2007. The problem of shear in RC beams strengthened with CFRP laminates. Construct. Build. Mater., 21: 1997-2006.

El-Mihilmy, M.T. and J.W. Tedesco, 2001. Prediction of anchorage failure for reinforced concrete beams strengthened with fiber-reinforced polymer plates. ACI Struct. J., 98: 301-314.

Gerco, F., P. Lonetri and P.N. Blasi, 2007. An analytical investigation of debonding problems in beams strengthened using composite plates. Eng. Fract. Mech., 74: 346-372.

Kim, J.J., Y.M. Lim, J. Won, H. Park and K.M. Lee, 2007. Shear capacity and failure behavior of DFRCC repaired RC beams at tensile region. Eng. Struct., 29: 121-131.

Smith, S.T. and J.G. Teng, 2002. FRP-strengthened RC beams. I: Review of debonding strength models. Eng. Struct., 24: 385-395.

Xiong, G.J., X. Jiang, J.W. Liu and L. Chen, 2007. A way for preventing tension delamination of concrete cover in midspan of FRP strengthened beams. Construct. Build. Mater., 21: 402-408.

Yao, J. and J.G. Teng, 2007. Plate end debonding in FRP-plated RC beams-I: Experiments. Eng. Struct., 29: 2457-2471.