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Strengthening of RC Continuous Beam Using FRP Sheet

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Abstract: **Strengthening structures via external bonding of advanced fibre reinforced polymer (FRP) composite is becoming very popular worldwide during the past decade because it provides a more economical and technically superior alternative to the traditional techniques in many situations as it offers high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry. Although many in-situ RC beams are continuous in construction, there has been very limited research work in the area of FRP strengthening of continuous beams. In the present study an experimental investigation is carried out to study the behavior of continuous RC beams under static loading. The beams are strengthened with externally bonded glass fibre reinforced polymer (GFRP) sheets. Different scheme of strengthening have been employed. The program consists of fourteen continuous (two-span) beams with overall dimensions equal to (150×200×2300) mm. The beams are grouped into two series labeled S1 and S2 and each series have different percentage of steel reinforcement. One beam from each series (S1 and S2) was not strengthened and was considered as a control beam, whereas all other beams from both the series were strengthened in various patterns with externally bonded GFRP sheets. The present study examines the responses of RC continuous beams, in terms of failure modes, enhancement of load capacity and load deflection analysis. The results indicate that the flexural strength of RC beams can be significantly increased by gluing GFRP sheets to the tension face. In addition, the epoxy bonded sheets improved the cracking behaviour of the beams by delaying the formation of visible cracks and reducing crack widths at higher load levels. The experimental results were validated by using finite element method.**

Keywords: **continuous beam; flexural strengthening; GFRP; premature failure; debonding failure.**

1 INTRODUCTION

Externally bonding fiber reinforced polymer (FRP) sheets with an epoxy resin is an effective technique for strengthening and repairing the reinforced con-crete (RC) beams under flexural loads. A large loss in beam ductility, however, occurs when FRP are used for flexural strengthening of RC beams, be-cause these materials have dissimilar behavior to that of steel, that is, they exhibit a linear stress-strain behavior up to failure (Spadea et al. 2001, Tou-tanji et al. 2006 and Thomsen et al. 2004). Hybrid FRP laminates, which consist of a combination of ei-ther carbon and glass fibers or glass and aramid fi-bers have non-linear stress–stain behavior (Belarbi et al. 1999). Verification of research show that using the Hybrid FRP for strengthening RC simply sup-ported beams cause to increase both of their capacity and ductility (Xiong et al. 2004, Hosny et al 2006 and Xiong et al. (2007)). Although many in-situ RC beams are continuous construction, there has been very limited research into the behavior of such beams with external rein-forcement (Akbarzadeh and Maghsoudi 2009a, b, Ashour et al. 2004, El-Refaie et al. 2003 and Grace et al. 2004, Liu et al. 2007 and Aiello et al. 2007). In addition, most design guidelines were developed for simply supported beams with external FRP lami-nates (ACI 440.2R 2008, JSCE 2001 and fib 2001). Ductility is even more important for statically inde-terminate structures, such as continuous beams, as it allows for moment redistribution through the rota-tions of plastic hinges. Moment redistribution per-mits the utilization of the full capacity of more seg-ments of the beam. Akbarzadeh and Maghsoudi (2009a, b), Ashour et al. (2004) and El-Refaie et al. (2003) found out that strengthening both the top surface at the negative moment and the beam soffit at positive moment re-gion to be the most effective arrangement of the CFRP and GFRP laminates to enhance the load ca-pacity, but ductility and moment redistribution are very low . In this paper, the experimental behavior of six RC continuous (two-span) beams strengthened with externally bonded CFRP, GFRP and hybrid CFRP/GFRP (HCG) sheets along their negative and positive moment regions are investigated. The beams were loaded with a concentrated load at the middle of each span. Type of FRP (CFRP or GFRP or HCG) and lyres number of FRP were the main parameters investigated. The responses of the strengthened continuous beams were examined and discussed in terms of load-deflections, failure modes, moment and load capacity, moment redistribution and ductility.

II EXPERIMENTAL PROGRAMS

Six large-scale continuous (two-span) beams (150×250×6000 mm) were tested to failure. Beams geometry and reinforcement as well as the loading and support arrangements are illustrated in Figure 1. Type of FRP (CFRP or GFRP or HCG) and lyres number of FRP were the main parameters investi-gated as summarized in Table 1. Thickness each layer of CFRP and GFRP are 0.11 mm and 0.2 mm respectively. Width of each layer of CFRP sheet was 145 mm for SC1 and SC3; and 120 *mm* for SC1G1 and SC2G2. Width of each layer of GFRP sheet was 150 mm. The end anchorage system, con-sist of three or four plies of CFRP sheets was wrapped and bonded around the sides and the soffit or top of the concrete beams near the end of longitu-dinal FRP sheets (Figure 1). The average concrete compressive strength (f'_c) for each beam is shown in Table 1. Yield stress of bars of diameter 16 mm is 412.5 MPa, and maxi-mum tensile strength was 626.4 MPa. The modulus of elasticity of steel bars was 2×10^5 MPa. The Young's modulus (E_{fu}), ultimate tensile stress (f_{fu}) and ultimate strain of CFRP sheet are 242 GPa, 3800 MPa and 1.55%. Also, the Young's modulus (E_{fu}), ultimate tensile stress (f_{fu}) and ultimate strain of GFRP sheet are 73 GPa, 2250 MPa and 3.1% re-spectively. The properties of epoxies used for bond-ing the FRP sheets were obtained from the supplier and given in author's paper (Akbarzadeh and magh-soudi 2009a).

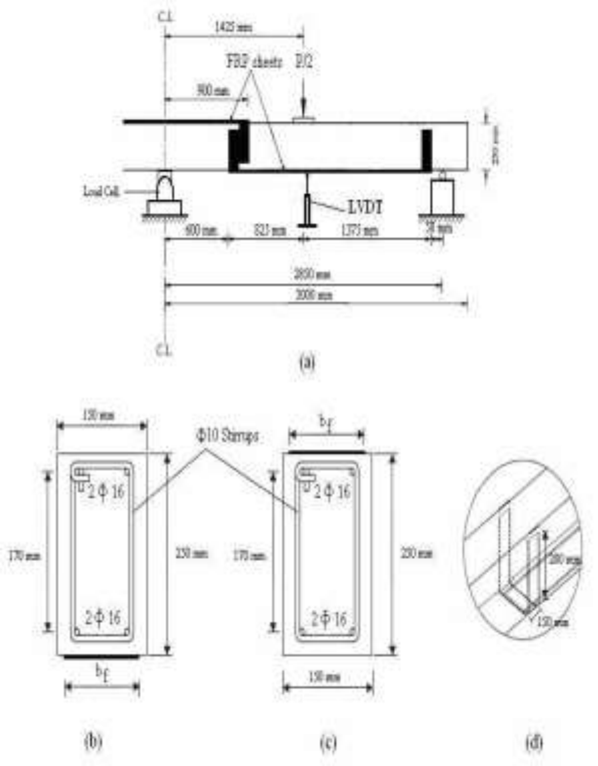


Figure1. Test set-up and strengthened RC continuous beam details (a) longitudinal profile of beam (b) typical cross section of beam in sagging region (c) typical cross section of beam in hogging region (d) end anchorage system.

III TEST RESULTS AND DISCUSSIONS

The beams were loaded with a concentrated load at the middle of each span. The obtained experimental results are presented and discussed subsequently in terms of the observed mode of failure, load-deflection, moment and load capacity, moment re-distribution and ductility.

3.1 *Failure mode and load -deflections responses*

Three different failure modes were observed for tested beams and given in Table 2. The results of test show that with increasing the number of FRP sheet layers will change the failure mode from ten-sile rupture to IC debonding of FRP sheets in con-tinuous beams. Because of the beams were strength-ened at both the sagging and hogging regions, beams have two failure level including first failure (maxi-mum load) and comprehensive failure. The different typical of failure are shown in Figure 2. The total applied load versus deflection at mid-span section of the beams is shown in Figure 3. As indi-cated in Figure 3, the beams did not lose their full load bearing capacity at the first failure, as the beams were strengthened at both the sagging and hogging regions. In other word, the beam can be re-loaded after first failure and with bearing high de-flection the comprehensive failure occurred. In the uncracked elastic stage, the same behavior was ob-served for all tested beams, indicating very similar beams stiffness prior to concrete cracking. In the cracked preyield stage, the stiffness and yield load of the FRP strengthened beams were moderately lar-ger than that of the control beam. However, signifi-cant decreases in beams stiffness was observed after yielding the tensile steel, but by increasing the num-ber of FRP layers the loss in beams stiffness are re-duced. The stiffness of SG3 is less than SC3 beam after yielding the tensile steel, it is because the elas-tic modulus of GFRP is much lower than CFRP sheets. Although stiffness of RC continuous beam strengthening with CFRP and GFRP is increased, but mid span deflection at first failure is decreased. But, both the stiffness after yielding load and mid span deflection at first failure significantly was in-creased by strengthening RC continuous beams with HCG compared to the strengthened beams with CFRP and GFRP.

3.2 *Enhancement of failure load*

Table 2 summarizes the ultimate failure load, P_u (i.e., the sum of the two mid-span point loads at fail-ure), the ultimate load enhancement ratio (□), which is the ratio of the ultimate load of an externally strengthened beam to that of the control beam, yield-ing load of tensile steel at central support (P_y) and the yielding load enhancement ratio *(□)*, which is the ratio of yielding load of the strengthened beam to that of control beam. The increase in the number of CFRP and HCG lay-ers, the yield load of tensile steel at central support is only slightly increased.

IV CONCLUSIONS

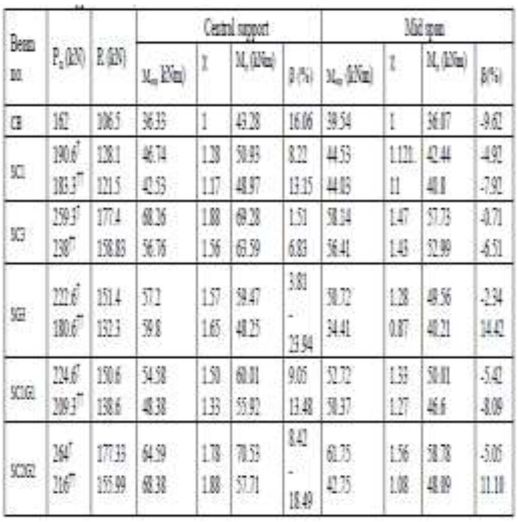
The following conclusions can be drawn based on the test results:

1-Both the stiffness after yielding load and mid span deflection at ultimate load was significantly in-creased by strengthening RC continuous beams with HCG compared to the strengthened beams with CFRP or GFRP.

2- Behavior of the beams strengthening with HCG by increasing applied load tended to become non-linear compared to the strengthened beams with CFRP.

3-Use of the HCG is needed for ensuring of mini-mum moment redistribution in continuous beams.

4-Assuming that an index value of 3 represents an acceptable lower bound to ensuring the ductile behavior of RC continuous beams strengthened.



Beam no.	P_u (kN)	P_y (kN)	Central support				Mid span			
			M_{ue} (kNm)	λ	M_u (kNm)	β (%)	M_{ue} (kNm)	λ	M_u (kNm)	β(%)
CB	162	106.5	36.33	1	43.28	16.06	39.54	1	36.07	-9.62
SC1	190.6* 183.3**	128.1 121.5	46.74 42.53	1.28 1.17	50.93 48.97	8.22 13.15	44.53 44.03	1.121. 11	42.44 40.8	-4.92 -7.92
SC3	259.3* 230**	177.4 158.83	68.26 56.76	1.88 1.56	69.28 65.59	1.51 6.83	58.14 56.41	1.47 1.43	57.73 52.99	-0.71 -6.51
SG1	222.6* 180.6**	151.4 132.3	57.2 59.8	1.57 1.65	59.47 48.25	3.81 - 23.94	58.72 34.41	1.28 0.87	48.56 40.21	-2.34 14.42
SCG1	224.6* 209.3**	150.6 138.6	54.58 48.38	1.50 1.33	60.01 55.92	9.05 13.48	52.72 50.37	1.33 1.27	50.01 46.6	-5.42 -8.09
SCG2	264* 216**	177.33 155.99	64.59 68.38	1.78 1.88	70.53 57.71	8.42 - 18.49	61.75 42.75	1.56 1.08	58.78 48.09	-5.05 11.18

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