Sustainable Solutions in Structural Engineering and Construction
Edited by Chantawarangul, K., Suanpaga, W., Yazdani, S., Vimonsatit, V., and Singh, A.

ISBN: 978-0-9960437-0-0

FLEXURAL PERFORMANCE OF RC BEAMS WITH NEAR SURFACE MOUNTED CFRP PLATE

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This study investigates the flexural performance of RC beams strengthened with Near Surface Mounted CFRP plate. In construction, deterioration tends to occur due to changes in loading capacity, improper design, or poor quality of workmanship. This will result in long-term effects as the strength decreases over time. To prepare for the long-term effects, the Near Surface Mounted (NSM) method can be used to strengthen the RC members. This is to ensure that a structure can continuously function for its intended purpose. Three beams of 125 mm x 300 mm x 1800 mm (width; height; length) were constructed for this study. The first beam was not strengthened, the second beam was strengthened with a CFRP plate horizontally positioned on the tension zone, and the third beam was strengthened with a CFRP plate vertically positioned on the tension zone. All three beams were then tested under a four point bending test. Results show that the beam with horizontal strengthening was able to increase the flexural strength of about 22% compared to the control beam, while the beam with vertical strengthening was able to increase the flexural capacity of about 43% compared to the control beam. This indicates that the NSM method can be used to significantly increase the flexural strength of RC members.

Keywords: Reinforced concrete, Four-point bending test, NSM method, Carbon Fiber Reinforced Polymer (CFRP).

1 INTRODUCTION

The use of Fiber Reinforced Polymer (FRP) in the construction industry is seen to be growing with various ways of application. FRP become an alternative because of sfor many reasons, such as more strength than steel, superior corrosion resistance, low unit weight, good fatigue behaviour, and magnetic neutrality (Thamrin *et al.* 2002). Properties contained in FRP material makes the material an alternative for strengthening and repair (Hashim *et al.* 2011).

During construction, deterioration tends to occur for many reasons that will result in long-term effects as the strength of materials decreases over time. To prepare for these long-term effects, the Near Surface Mounted (NSM) method can be used to strengthen the reinforced concrete (RC) members. This will ensure that a structure can continuously function for its intended purpose.

This study investigates the flexural performance of the NSM method for strengthening RC beams. NSM strengthens the flexural members by installing FRP composite materials into the concrete cover in a longitudinal position, namely the Carbon Fiber Reinforced Polymer (CFRP) plate. The NSM method is commonly used in the United Kingdom to strengthen building car park decks, jetties and dock-side structures. It is also widely used in the USA, Canada (Concrete Society Committee 2004), and Europe (De Lorenzis and Teng 2006).

2 METHODOLOGY

2.1 Material Properties

All specimens in this study were constructed using concrete with a targeted compressive strength of 30 MPa at 28 days. The main reinforcement consisted of steel rods with a diameter of 12 mm, while the transverse reinforcement had a diameter of 6 mm. The tensile strength for the main and transverse reinforcement was 460 MPa and 250 MPa respectively. The modulus of elasticity for both main and transverse reinforcement steel was 200 GPa. The CFRP plate used had a thickness of 1.2 mm with 3000 MPa tensile strength and 165 GPa modulus of elasticity, while the adhesive used to attach the CFRP plate into the groove has a tensile strength of 30 MPa and 2 GPa modulus of elasticity.

2.2 Specimen Setup and Procedures

Three beams with the size of 125 mm x 300 mm x 1800 mm (width; height; length) were constructed in this study. Each beam has a different condition. These beams were designed according to BS EN (2004) and BS EN (2005). Figure 1 shows the cross-sectional area of a control beam which did not receive any strengthening on the tension zone.

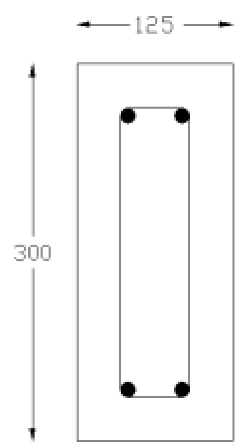
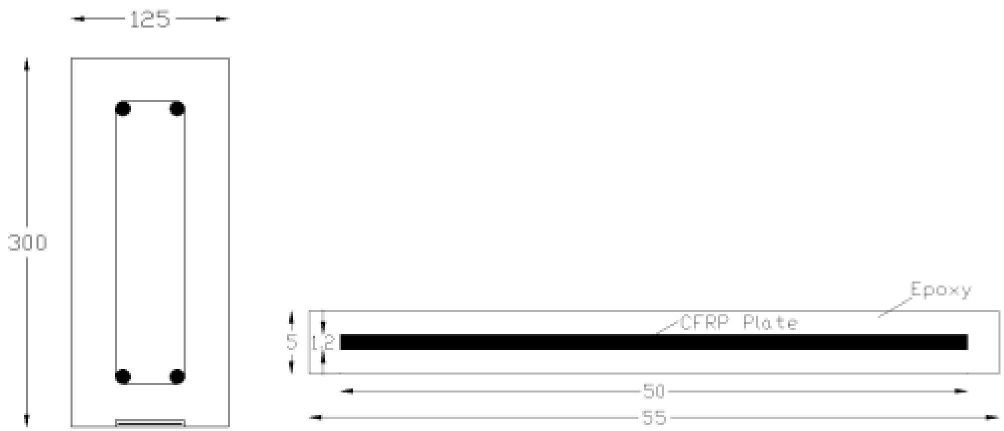


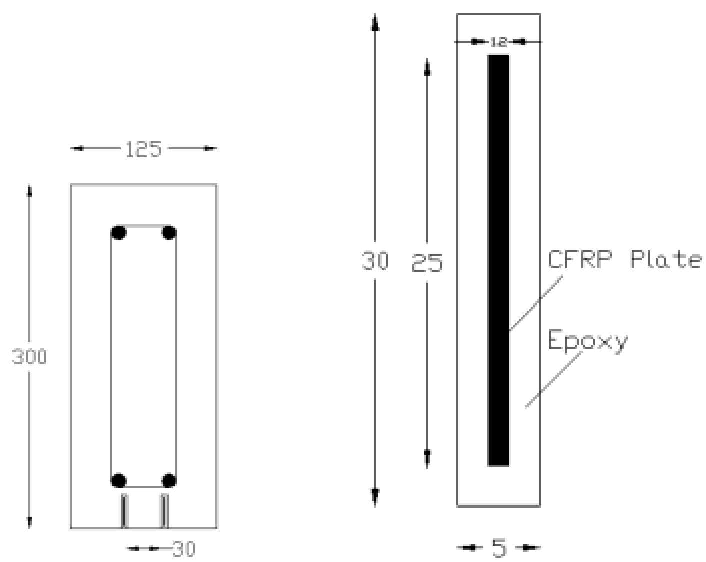
Figure 1. Cross sectional area of beam without strengthening (Units: mm).

Figure 2(a) is a beam horizontally strengthened on the tension zone with CFRP plate, while Figure 2(b) shows the horizontal groove's dimensions. Figure 3(a) is a beam strengthened with two CFRP plates vertically positioned on the tension zone. with groove dimensions of vertical strengthening shown in Figure 3(b). A CFRP plate with the size of 50 mm x 1500 mm (width; length) was used for horizontal strengthening, while the beam with vertical strengthening had two plates with the size of 25 mm x 1500 mm (width; length). After a groove was obtained, the adhesive was spread into the groove before installing the CFRP plate. All the three beams were then tested under the four point bending test.



(a) (b)

Figure 2. Cross-sectional area and dimension for horizontal-positioned CFRP plate (Units: mm).



(a) (b)

Figure 3. Cross-sectional area and dimension for vertical-positioned CFRP plate (Units: mm).

3 RESULTS AND DISCUSSIONS

3.1 Load-Deflection Behavior

Table 1 shows the tabulated data for the ultimate load and deflection at near failure. Beam B-03 recorded the highest ultimate load between the three beams with 115.51 kN, followed by beam B-02 and B-01 with 93.10 kN and 74.40 kN respectively. Both beams with strengthening have a higher ultimate load compared to the control beam. This demonstrates that beams with strengthening are able to increase the flexural performance of RC members. Beam B-01 has a lower deflection compared to beam B-02 and B-03. This happens because beam B-02 and B-03 were affected by debonding of CFRP plate on the tension zone, causing greater deflection compared to beam B-01.

Table 1. Ultimate load and deflection.

Beam Description	Beam ID	Ultimate Load (kN)	Deflection (mm)
Beam without strengthening	B-01	74.40	13.78
Beam with horizontal strengthening	B-02	93.10	16.51
Beam with vertical strengthening	B-03	115.51	15.90

Figure 4 shows the plotted data for load versus deflection curves. All the curves start with a linear line indicating an elastic state. After the yield point, the curves decrease slightly, and as the deformation continues, the curve increases until it reaches the ultimate strength. In the elastic phase, beam B-03 is seen to have greater deflection compared to beam B-02 at the same load level. After yielding, beam B-02 curve rises higher than beam B-02 as the vertical position of CFRP plate sustains a higher load.

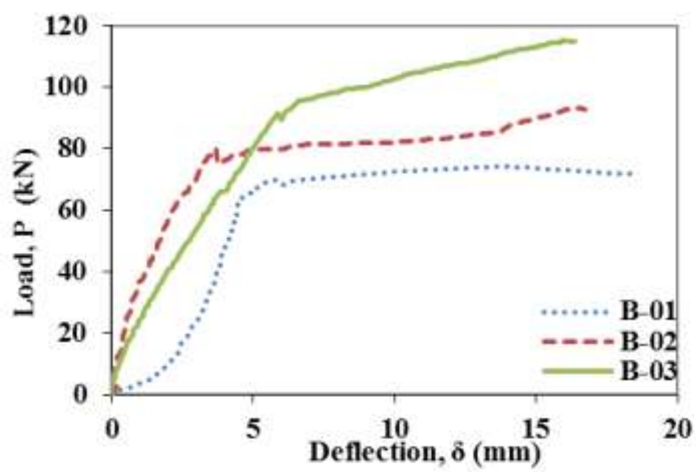


Figure 4. Load versus deflection curves.

3.2 Failure Mode and Crack Pattern

Figure 5 shows the failure mode and crack pattern for beam B-01. Beam B-01 failed by crushing of concrete at compression zone. Figure 6 and Figure 7 show the failure mode and crack pattern for beam B-02 and B-03. Beam B-02 and B-03 failed by debonding of CFRP plate without experiencing any crushing of concrete at the compression zone. The first crack for all three beams occurs at the middle of the beam before developing and moving towards the support.

Figure 5. Failure mode of the control beam.

Figure 6. Failure mode of beam with horizontal strengthening.

Figure 7. Failure mode of beam with vertical strengthening.

Table 2 shows the data related to cracks. First crack load for all three beams occurs at a load between 34% to 57% of the ultimate load. Beam B-01 recorded highest number of cracks formed while beam B-02 and B-03 has the same amount of crack formed. This shows that strengthening on the tension zone can reduce the number of cracks formed as the stiffness of the CFRP plate has an effect on the cracking behavior.

Table 2. Crack information.

Beam ID	First crack load (kN)	Total number of cracks	Largest crack width (mm)
B-01	34.68	27	11
B-02	32.00	12	10
B-03	66.14	12	11

4 CONCLUSIONS

Results show that the beam with horizontal strengthening was able to increase the flexural strength of about 22% compared to the control beam, while the beam with vertical strengthening was able to increase the flexural capacity of about 43% compared to the control beam. The use of the NSM method also increases the stiffness of the beam and reduces the amount of cracks formed by 44%. This indicates that the NSM method can be used to significantly increase the flexural strength of RC members.

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