Investigation of the Most Effective Method of Installing CFRP Strips in Retrofitting Concrete Beams

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ABSTRACT: This paper is based on an experimental analysis carried out in order to identify the best method of installation of CFRP strips to enhance the flexural capacity of a reinforced concrete beam. Of the two methods of installation; EBR (externally bonded reinforcement) and NSM (Near surface mounted) the NSM method has been proven to be better in qualitative terms. The research gap of quantitative validation of this concept is fulfilled by this research paper. Two new methods of integration of EBR and NSM method were also experimented with the objective of increasing the flexural capacity of reinforced concrete elements by increasing the effective area of CFRP strips used. Suggestions to eliminate the failure modes observed in the experiment and to enhance the flexural capacity are also discussed in this paper.

1 INTRODUCTION

Carbon Fibre Reinforced Polymer (CFRP) has been identified as a material that can be used for remedying reinforced concrete, pre stressed concrete, masonry, timber and also steel. High in strength, light in weight, resistant to corrosion and ease in application of CFRP have earned the trust among its users and proved to be more promising in the construction industry.

CFRP can be installed either as Near Surface Mounted (NSM) or as Externally Bonded Reinforcement (EBR) on the element. For both these methods of application, an adhesive needs to be used. This could be either any specified epoxy or cement grout. Not only has the adhesive had an effect on the flexural capacity gain in CFRP strengthened elements but also the method of installation (Abdwais et al., 2013).

Near surface mounted CFRP has demonstrated a competitive advantage over externally bonded reinforcement due to many reasons (EI-Hacha and Rizkalla, 2004). NSM allows better adhesion compared to EBR, provides a larger specific area for binding with concrete, durable, can be easily pre stressed, thermal protection becomes easier, more convenient in installation since there is less preparation of the surface(Rankovic et al., 2010).

Even though the NSM method has been recognized as an effective method of installing CFRP, experimental values have not been provided to verify its effectiveness in terms of flexural strengthening, if the same effective area of CFRP is used. In the research described in this paper it has been proven that the NSM method provides better flexural strengthening compared to the EBR method and also an integrated method of EBR and NSM can also be used effectively if required.

2 TEST PROGRAM

2.1 Objectives

In this experiment the two methods of installation; NSM and EBR are compared in terms of flexural strengthening and a new method of integrating these two methods has also been experimented. In all these cases it had been determined to use the same effective areas of CFRP.

2.2 *Material Properties*

2.2.1 Concrete

Six concrete beams of 150 mm × 150mm × 750 mm dimensions were cast using G35 concrete. A total of six concrete cubes of size 150mm × 150 mm × 150 mm were cast to evaluate the compressive strength of the beam specimens. Cubes were tested after 28 days and the average compressive strength was 39.7 N/mm^2.

2.2.2 Steel

Two 6mm diameter mild steel bars were used for main bars and 6mm diameter galvanized iron bars were used for shear links with 75mm spacing.

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2.2.3 CFRP strips

Table 1 CFRP Manufacturer Specifications (Simpson Strong-Tie, C-FRP-2014/15)

Parameters	Value
Elastic modulus (GPa)	>170
Tensile strength (MPa)	>2800
Elongation at rupture	≥1.6
Fibre volume content (%)	>68
Bond strength (MPa)	≥1.5
Strip thickness (mm)	1.2

2.2.4 Epoxy adhesive

Two components of the epoxy were provided by the manufacturer namely; A and B. It was instructed to be mixed A to B in 4:1 ratio by weight.

Table 2 Epoxy specifications (Simpson Strong-Tie, C-FRP-2014/15)

Parameters	Value
Elastic modulus (MPa)	>7100
Compressive strength (MPa)	>70
Tensile strength (MPa)	≥3
Shear strength (MPa)	>26
Density (g/cm^3)	1.7-1.8

2.2.5 Test matrix

Table 3 Description of test specimens

Description	Beam No
Beams strengthened in EBR method	B1,B2
Beams strengthened in NSM method	C1, C2
NSM and EBR method in parallel direction (Fig.3)	D1
NSM and EBR method perpendicular to each other (Fig.4)	E1

2.2.5 Specimen preparation

Once the beams were cast and cured, the surface of the beams was prepared for installation of CFRP strips. Since external reinforcement is provided as tension reinforcement, the CFRP strips were required to be installed at the bottom surface of the beam.

Four different categories of test specimen were prepared as shown in Table 3.

For the NSM method two grooves of 5mm width and 15mm depth was cut with a centre to centre spacing of 30mm.

In the EBR method, the surface was prepared by grinding.

In the method of integration of the EBR and NSM methods, the surface was prepared first by grinding and then in one beam two grooves were cut parallel to main reinforcement and in the other beam, six grooves were cut perpendicular to the main reinforcement. (Fig. 1 and Fig. 2)

Fig. 1 Grooves prepared perpendicular to main steel reinforcement (at the bottom face)

Fig. 2 Grooves prepared parallel to main reinforcement (at the bottom face)

Surface preparation methodologies and groove dimensions were referred to from ACI 440-2R.08. After surface preparation was done, the surface and the grooves were cleaned with an air compressor. Acetone was used for further cleaning and CFRP strips were installed at the end

In both NSM and integrated systems, the grooves were first half filled with epoxy and then the CFRP strips were installed. The rest of the grooves were filled last. In addition to this, in the two integrated systems, after installing CFRP strips in NSM method, two strips were fixed on the surface in EBR method so that the strip in the groove was connected to the strip on the top of the surface through the epoxy adhesive (Fig. 3 and Fig. 4).

10mm wide CFRP strips were used and the length was maintained at 450mm for all specimens in order to maintain the same effective area of CFRP.

2.2.6 Testing procedure

The four point bending test was used to identify the flexural strength gain of the strengthened beams. The concrete beams were simply supported with a test span of 600mm. The supports were located at 75 mm away from the CFRP strips. The concrete beams were tested using Amsler testing machine.

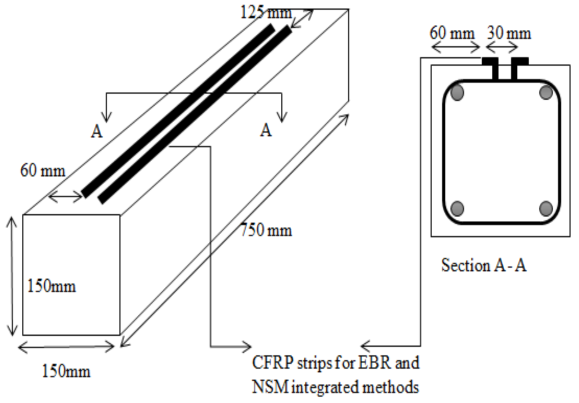

Fig. 3 Integrated in parallel direction

The concrete beams were gradually loaded by 2 kN and mid span deflection was recorded using dial gauges. Initiation of cracks was observed and the load at which a crack of 0.3 mm, initiated was considered as the failure load. The concrete beams were loaded further after reaching its failure loads to observe the failure modes.

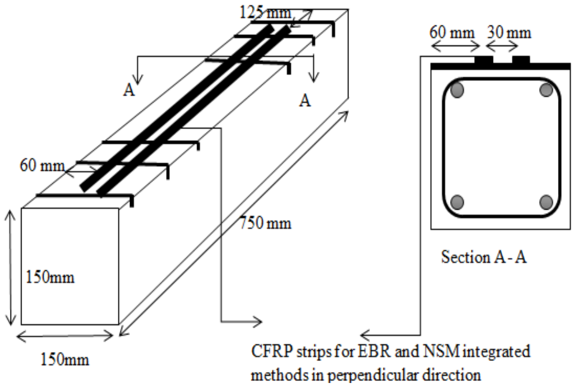

Fig. 4 Integrated in perpendicular direction

3 RESULTS AND ANALYSIS

3.1 Load deflection curve

From the results obtained from beam testing, the load-deflection curve was drawn. It is shown in Fig. 5. According to the graph the NSM method showcases the best performance under loading, and it is proven to be more ductile under loading.

But with the increase in loading the integrated method in parallel direction also yields better results. The higher the load, greater the ductility.

3.2 Flexural strength gain

Of the four methods of installation, the integrated method in parallel direction demonstrated the highest failure load. In Fig. 6, increase in percentage with comparison to theoretical load of unstrengthened beam is shown. In the y axis of the graph 1, 2, 3 and 4 indicates the EBR method (B type), NSM method (C type),integrated in parallel (D type) and integrated in perpendicular directions (E type) respectively.

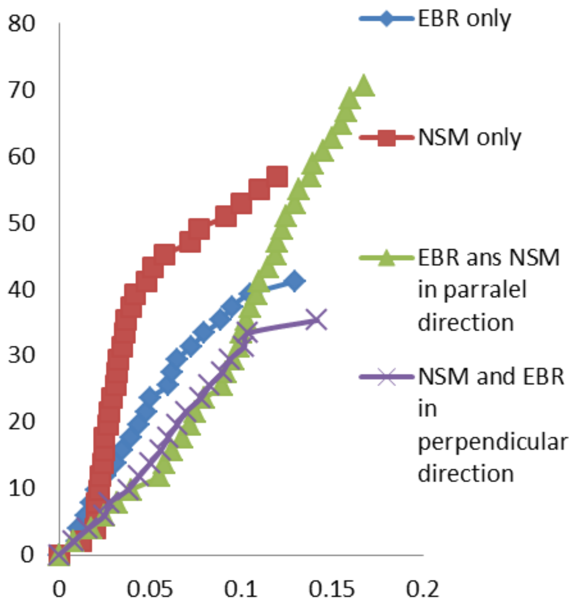

Fig. 5 Load deflection curve

3.3 Failure modes

Different failure modes were identified during the experiment. B1, B2 (EBR method) beams failed due to strip end de-bonding. C1, C2 beams that were strengthened in NSM method failed due to the splitting of epoxy. D1 beam failed in a similar way to C2 and C2 beams and E1 beam failed at a very low ultimate load due to de-bonding of the CFRP strips.

3.4 Methods for enhancing failure load

Had transverse clamping been used in beams B1 and B2, the failure load could have been increased. But this might cause a failure of those two beams under shear or plate end shear instead of strip end de-bonding. If an adhesive with better tensile strength was used, beams C1 and C2 could have failed under heavier loads. By increasing the depth of the groove, the failure load could have been increased further (Szabo and Balazs, 2007). Due to the space allocations required in installation of CFRP strips according to ACI 440-2R.08 and the minimum cover of a beam such methods will not yield better results. In beam D1, it was noticed, that it failed not under de-bonding but in a similar way to C1 and C2. This implies that when the two methods are integrated in parallel direction, the NSM method dominates and this method of integration also acts as transverse clamping to the CFRP strips bonded in EBR method on the surface. If the integration of the two methods were done in perpendicular direction to each other, the EBR method dominates the failure pattern of the beam.

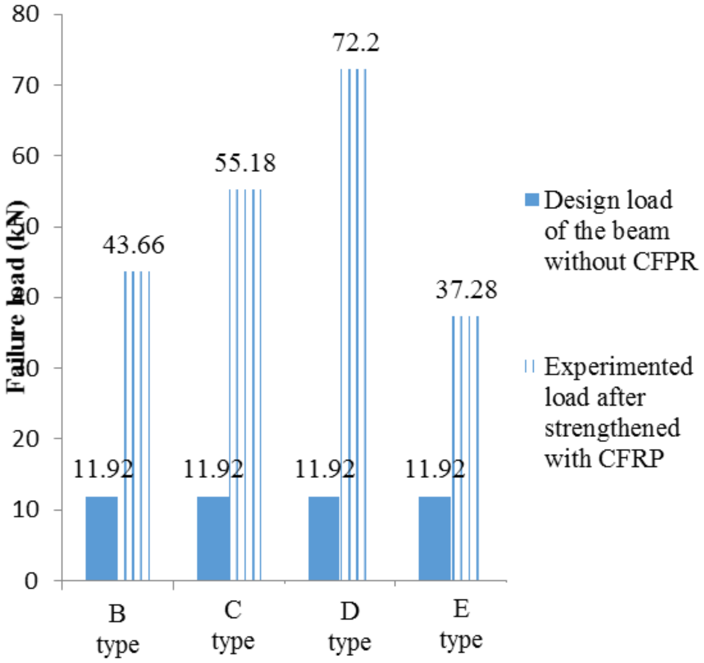

Fig. 6 Comparison of loads with unstrengthen CFRP beam

4 CONCLUSIONS

When the failure loads are considered, the integrated method in parallel direction is the best method of installation. In a given area, it is not easy to install as many strips as desired since there are space allowances that need to be allocated. But in this method easily the effective area was doubled without causing excessive tensile stresses due to congestion of grooves. It also improved the flexural capacity by nearly double compared to the typical EBR method.

When it is compared with early research conducted with CFRP textile, (Ariyachandra and Gamage, 2013) it can be concluded that better results, in terms of flexural capacity can be gained though CFRP strips with a minimum surface area. By adopting different methods to the installation systems, the failure loads can be increased. Those methods enhance the flexural capacity so that the beams tend to fail under shear. In order to eliminate this, the beams should be adequately strengthened in shear as well.

The NSM method and the integrated system in parallel direction perform better in terms of ductility, which makes them more appropriate in earthquake resistivity.

REFERENCES

A.Al-Abdwais, Al-Mahaidi, R., & Abdouka, K. (2013). Modified cement based adhesive for near surface mounted CFRP strengthening System. *Fourth Asia Pacific Conference on FRP in structures.* Melbourn: International Institute for FRP in Construction.

EI-Hacha, R., & Rizkalla, S. H. (2004). Near surface mounted fiber reinforced polymer reinforcement for flexure strengthening of concrete structures. *ACI Structural Journal*, 717-726.

Rankovic, S., Folic, R., & Mijalkovic, M. (2010). Effects of RC beams reinforcement using near surface mounted reinforced FRP composites. *Architecture and Civil Engineering*, 177-185.

Szabo, A. K., & Balazs, G. L. (2007). Near surface mounted FRP reinforcement for strengthening of concrete structures. *Periodica polytechnica*, 33-38.

Ariyachandra, M. and Gamage, J. (2013). Effects of surface roughness on flexural performance of CFRP/concrete composites. In: International conference on Structural Engineering Construction and Management (ICSECM 2013). Kandy.

ACI 440-2R.08 Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures.