

# Strengthening of Prism Beam by Using NSM Technique with Roots Planted in Concrete

Douread R. Hassen, Abdul Aziz Abdul Samad, and Alyaa A. Azeez

**Abstract**—This paper presents experimental results of four prismatic concrete reinforced beam and strengthened by NSM (Near surface mounted) FRP (Fiber Reinforced Polymer) reinforced technique, with additional roots planted in the concrete. The strengthening technique causes load capacity of beams to increase from (6%-8%). A decrease in mid-span deflection was also observed from (4%-5%). Using this technique gave increasing in flexural beam resistant under the same conditions and this increasing was also noted in shear beam resistant.

**Index Terms**—Prismatic beam, concrete, carbon fiber reinforced polymer, strengthening.

## I. INTRODUCTION

Many researchers have focused on the importance of bonding and the type of material that used in bonding between concrete and CFRP to form composite Structural section and previous research indicate to use many materials to increase the bonding strength, for examples: Sikadur 30, 31, 32 and 330 and other materials. In this paper was used roots technology that existing in the teeth as a way to increase the bond between concrete and carbon fiber reinforced polymer by using NSM technique, and this will positively influence for thinking to use other ways.

Using fiber-reinforced polymer (FRP) was old technique to strength concrete for bridges and building and has been used widely in the last decade.

FRP has been used in different ways and techniques to find a new material that effective and to ensure long service life of the used structure. The near-surface mounted (NSM) was one of innovative ways that was as strengthening techniques style by place FRP reinforcing bars and strips into grooves precut into the concrete cover in the tension region of the strengthened concrete member Raafat El-Hacha, Sami H Rizkalla [1].

Shear and flexural strengthening using FRP materials has been the subject of considerable research, mainly on the use of externally bonded laminates and bars. However, internally bonded NSM reinforcement provides a viable alternative with numerous advantages as reported by De Lorenzis and Teng [2], [3]. For example, the internally bonded NSM reinforcement can be more easily anchored into adjacent structural members, possesses a better resistance to de-bonding, and is particularly more suitable

for strengthening negative moment regions of slabs and beams. In addition, it may require less amount of concrete surface preparation as only cutting the grooves is required, without the need for removal of plastering, smoothing of the concrete surface and removal of weak concrete laitance. The NSM reinforcement can also be easily protected by the concrete cover from mechanical damage, fire and vandalism, and the strengthened element is aesthetically unchanged [4], [5]. Internally bonded NSM reinforcement also allows visual inspection of the surface of the concrete to monitor the existing cracks while laminates hide these vital signs. In addition, a direct comparison showed that flexural strengthening using internally bonded reinforcement achieved higher ultimate loads than strengthening using externally bonded reinforcement with the same axial stiffness [6].

## II. EXPERIMENTAL PROGRAM

Numerous variables affect the behavior of shear strengthened reinforced concrete beams. This study is limited to investigating some of the more significant factors: (1) flexural and shear strengthening prismatic beam by using NSM technique and (2) flexural and shear strengthening prismatic beam by using NSM CFRP bars technique with roots inside concrete. Four prismatic concrete beams were cast and tested. Two p-beam (A1, A2) were strengthened for shear and flexural using NSM reinforcement. Last two p-beams (B1 and B2) also strengthened for shear and flexural with CFRP bars that have roots inside concrete. Hence, four results are reported. The following sections give details of the p-beam specimens as shown in Fig. 1, their instrumentation, testing procedure and results.

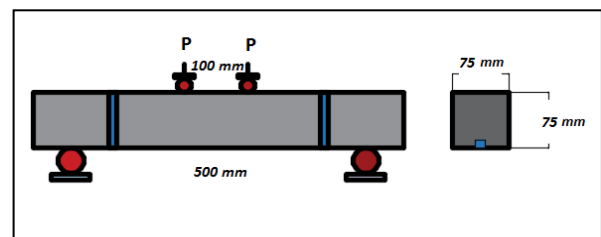


Fig. 1. P-beam scheme.

### A. Material Properties

#### 1) Properties of concrete

A local ready-mix company supplied the concrete, and the target compressive strength was 30 MPa. The design slump was 75 mm and the maximum aggregate size was 19

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mm. Table 1 summarizes the average values of the results obtained from 150 mm cubes and standard 100×200 mm cylinders. The 28-days cylinder strength ( $f_c$ ) as per the relevant ASTM Standards and the 28-days cube strength ( $f_{cu}$ ) results presented in Table 1 are calculated from the average values of six sample specimens each. The cylinder and cube strength on the day of testing the beams ( $f_c$  and  $f_{cu}$  respectively) are calculated from the average of two sample specimens each. As shown in the table, the measured  $f_c$  was close to the target strength. The compressive strength of the standard cylinders was consistently about 84.4% of the strength of the 150-mm cube as shown in Table I.

TABLE I: CYLINDER AND CUBES COMPRESSION TEST RESULT

No. of Cylinders	Ultimate Compressive Strength $f_c$ (MPa)	Ultimate Compressive Strength $f_{cu}$ (MPa)
1	24.963	29.72
2	23.81	28.73
3	25.89	30.52
4	25.84	30.4
5	26.5	31.2
6	27.75	32.67
Average	25.783	30.54

## 2) Properties of CFRP bars

The FRP strengthening was applied using 5 mm-deformed carbon FRP bars and CFRP properties shown in Table II. The typical deformation in some of these bars from testing shown in Fig. 2. The CFRP testing for the stress-strain relationship was linear and the modulus of elasticity for CFRP equal to 115 GPa and an ultimate strength of 2300 MPa. The calculated strain at rupture is 0.02.

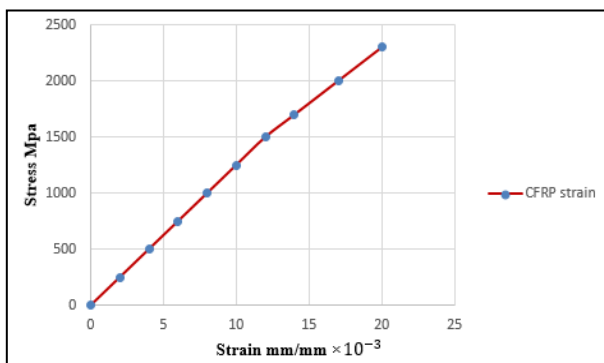


Fig. 2. Stress-strain diagram for FRP bar.

TABLE II: CFRP BAR PROPERTIES

Bar Diameter	Cross Sectional Area	Tensile Strength	Tensile Modulus	Ultimate Strain
(mm)	(mm <sup>2</sup> )	(MPa)	(GPa)	(%)
5	29.9	2300	115	0.02

## B. Specimen Preparation

The preparation of the strengthened p-beams involved: cutting of the grooves on both sides of the beams. After the beams had properly cured, the grooves were cut from concrete face and made some of drilling inside groove as shown in Fig. 3. All the grooves had square cross-section, with size of 10 mm. The grooves were cleaned with water jet and air blasted to remove the powdered concrete produced by the cutting process and all the possible loose material. Then the epoxy paste was prepared by mixing the two components (resin and hardener) in 3:1 proportion by volume with a power mixer. The groove was filled half-way with the paste; the CFRP rod was then placed in the groove and lightly pressed. This forced the paste to flow around the bar and fill completely between the bar and the sides of the groove. The groove was filled with more paste and the surface was leveled. The specimens remained in the laboratory environment for four weeks before being tested. After completing the CFRP rods installation, three days before the testing date.



Fig. 3. Groove and drilling scheme

## C. Test Setup and Procedure

The beams were tested in a two-point loading setup as shown in Fig. 1. The solid rod at the loading and support locations were 20 mm diameter. The load was applied to fail. The vertical deflections at mid-span of the p-beams were measured using digital dial gauges. The test started with a small pre-load cycle of about 0.5 kN to settle the beam and to maintain positioning before the beginning of the test. Once the readings and observations were taken, the loading was then increased by the next increment and the procedure was repeated.

## D. NSM Shear and Flexural Strengthening

The NSM shear and flexural strengthening were carried out before the application of the load on the beams. Grooves 20 mm deep and 20 mm wide were cut in the cast concrete. Then, the surface of the concrete in the groove was roughened and cleaned. Similar to the procedure used by De Lorenzis and Nanni [3], the epoxy resin was placed to half the depth of the grooves. Then the NSM bar was placed and pressed gently into the epoxy. Then the groove was fully filled with epoxy and the surface was leveled. The epoxy was allowed at least three days to cure before testing the beam specimens. Flexural strengthening of central regions in A1 and A2 by CFRP with out drilling. P-beam (B1 and B2) were strengthened for flexural and shear by using NSM 5 mm CFRP bars with drilling at 22mm c/c. drillings were vertical on concrete side face with 22mm depth and 8mm diameter.

### III. EXPERIMENTAL RESULTS

#### A. Flexure

$$M_n = 150P$$

$$a = \frac{A_{sfrp} \times f_{ycfrp}}{b_w \times f_c} \rightarrow a = \frac{19.635 \times 2300}{75 \times 25.783} \rightarrow a = 23.34 \text{ mm}$$

$$jd = (d - \frac{a}{2}) \rightarrow jd = 63.33 \text{ mm}$$

$$A_s^+ = \frac{M_n}{f_{ycfrp} \times jd} \rightarrow M_n = 2.86 \times 10^6 \text{ N.mm}, P = \frac{M_u}{150} \rightarrow P = 19.06 \text{ kN}$$

$$P_t = 38.2 \text{ kN}$$

#### B. Shear

$$\frac{M_u}{V_u \times d} = \frac{2.86 \times 10^6}{38.2 \times 10^3 \times 75} = 1 \rightarrow 3.5 - 2.5 \times \frac{M_u}{V_u \times d} = 1.0 < 2.$$

$$V_{C1} = \left( 0.16 \lambda \sqrt{f_c} + 17 \rho_w \frac{V_u \times d}{M_u} \right) \times b_w \times d, \rho_w = \frac{A_{sfrp}}{b_w \times d}$$

$$= \frac{19.635}{75 \times 75} = 0.0035,$$

$$f_c = 25.783 \text{ Mpa}.$$

$$V_{C2} = 0.17 \lambda \sqrt{f_c} \times b_w \times d, V_{C3} = 0.29 \lambda \sqrt{f_c} \times b_w \times d$$

$$V_{C1} = 4.9 \text{ kN}, V_{C2} = 4.8 \text{ kN}, V_{C3} = 8.3 \text{ kN}.$$

$$V_C = 4.8 \text{ kN}.$$

$$V_s = \frac{A_{vfrp} \times f_{frp} \times d}{s} \rightarrow V_s = \frac{2 \times 19.635 \times 2300 \times 75}{75} = 39.0 \text{ kN}.$$

$$V_n = V_C + V_{frp} \rightarrow V_n = 43.8 \text{ kN}.$$

$$P = 43.8 \text{ kN}.$$

The value of P is equal to:  
38.2 kN from flexural analysis.  
43.8 kN from shear analysis.

The nominal shear strength of an RC beam may be computed by the basic design equation presented in ACI 318-2008 [7]:

$$V_n = V_c + V_s \quad (1)$$

In this equation the nominal shear strength is given by the sum of the shear strength of the concrete and the shear strength provided by the steel shear reinforcement. In the case of beams externally strengthened with FRP, the nominal shear strength can be computed by adding a third term to account for the contribution of the FRP reinforcement [7]:

$$V_n = V_c + V_s + V_{FRP} \quad (2)$$

By observing both experimental results and the shape of failure occurs in concrete beneath CFRP rod the following equation can be suggested to predict the increasing in ultimate load with acceptable tolerance:

For orientation of CFRP 135°

$$V_{FRP} = 0.05 f_{tFRP} \frac{b_w d}{s} \quad (3)$$

For 90°

$$V_{FRP} = 0.03 f_{tFRP} \frac{b_w d}{s} \quad (4)$$

where is a tensile stress of CFRP rod.  $V_c$  as shear strength of concrete control beam where  $f'_c$  is the concrete compressive strength in MPa,  $b_w$  is the web width in mm and  $d$  the distance from the extreme compression fiber of the cross-section to the centroid of the longitudinal reinforcement, in mm. Table 3 gives a total load closer to the experimental value, so that calculated and experimental values of the shear strength can be compared focusing on the FRP contribution. The prism beams (A1,A2) that strengthened with CFRP bars as a NSM Beams had maximum load equal to (44 kN -44.6 kN) respectively. On the other hand, the maximum load for prism beams (B1, B2) that strengthened with NSM CFRP bars and using roots technique was (45.8 kN-46.3 kN) respectively with increased (6%-8%).

TABLE III: THEORITICAL AND EXPERIMENTAL LOAD

item	Theoretical load(Pt)		Experiential load(Pe)	%Pt(shear)/Pe	%Pt(flexure)/Pe
	Shear	Flexure			
A1	43.8	38.2	44.0	99.5%	86.82%
A2	43.8	38.2	44.6	98.2%	85.65%
B1	43.8	38.2	45.8	95.6%	83.40%
B2	43.8	38.2	46.3	94.6%	82.50%

#### C. Load — Mid Span Deflection

Under different stage of loading the mid span deflection for tested specimens were recorded and the following notes were registered:

- 1) At beginning of loading, load-deflection curves approach to be straight line.
- 2) Ultimate load and mid span deflection for beams (B1,B2)Strengthened with NSM CFRP that ones have roots in concrete were higher compared with control beams (A1,A2) without roots as shown in Fig. 4.

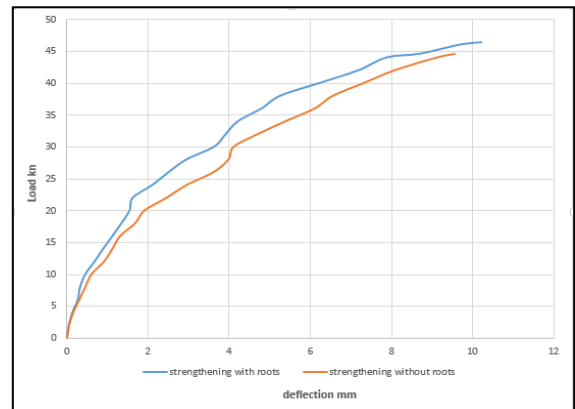


Fig. 4. Mid span deflection for strengthened P-beam.

### IV. CONCLUSIONS

The NSM strengthening way increased the capacity of the test regions to levels, which caused yielding in the longitudinal reinforcement in these regions and hence significantly improved their ductility. The most relevant conclusions of the present work can be summarized as follows:

The use of NSM FRP rods with roots that install in concrete is an effective technique to enhance the load

capacity of P-beams. In absence of NSM FRP rods with roots, an increase in load capacity as high as 6-8% with respect to the control beam could be obtained;

Experimental shear load increasing was from 4%-5.1% when the P-beam was strengthened with roots and experimental shear value for P-beam were larger than theoretical flexural results from 0.5%-5.4%. On the other hand, the length of root was 25 mm with 22 mm spacing .Length and Spacing of roots were effective parameters that will be changed to get deferent result when using roots technique. The experimental results for P-beam were bigger than theoretical flexural results from 13.18%-17.5%.

At same load (44.6 kN); the prism beams (A1, A2) gave deflection smaller than (B1, B2). The P-beams (A1,A2) have crack width and thickness of splitting area were smaller than P-beams (B1,B2) and that led to using drilling as roots for CFRP increase resistance of composite section and bond between concrete and CFRP.

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#### REFERENCE

- [1] R. El-Hacha and S. H. Rizkalla, "Near-surface-mounted fiber-reinforced polymer reinforcements for flexural strengthening of concrete structures," *Structural Journal*, vol. 101, no. 5, pp. 717-726, 2004.
- [2] L. D. Lorenzis and A. Nanni, "Shear strengthening of reinforced concrete beams with near-surface mounted fiber-reinforced polymer rods," *ACI Structural Journal*, vol. 98, no. 1, pp. 60-68, 2001.
- [3] D. L. Lorenzis and J. Teng, "Near-surface mounted FRP reinforcement: An emerging technique for strengthening structures," *Composites Part B: Engineering*, vol. 38, no. 2, pp. 119-143, 2007.
- [4] A. Palmieri *et al.*, "Fire testing of RC beams strengthened with NSM reinforcement," in *Proc. 10th International Symposium Fiber-Reinforced Polymer Reinforcement for Concrete Structures*, Ghent University, Department of Structural engineerin, 2011.
- [5] K. Rahal, "Near surface mounted shear strengthening of reinforced concrete beams," *American Concrete Institute, Special Publication*.
- [6] K. N. Rahal, and H. A. Rumaih, "Tests on reinforced concrete beams strengthened in shear using near surface mounted CFRP and steel bars," *Engineering Structures*, vol. 33, no. 1, pp. 53-62, 2011.
- [7] A. Committee *et al.*, "Building code requirements for structural concrete (ACI 318-08) and commentary," *American Concrete Institute*, 2008.



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