Strengthening of Reinforced Concrete Beams in Flexure Using Near Surface Mounted Steel Reinforcement

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Abstract – *Strengthening of reinforced concrete structures are necessary when they are in poor condition not only due to deterioration processes, but also due to errors that is made during design and execution. Thus deterioration of structures resort to strengthening techniques, one of such strengthening method is near surface mounted (NSM) reinforcement. This technique involves cutting of shallow grooves in the required direction at the bottom of the beam. The depth of the groove must be less than the concrete cover so that the existing reinforcement is not damaged. The grooves are then partially filled with epoxy, into which fibre reinforced polymer (FRP) or steel reinforcements are placed, later these grooves are fully filled with epoxy resin adhesive. In this paper steel reinforcement is provided as NSM reinforcement and polyester resin adhesive is used as groove filler for flexural strengthening of RC beam. The influence of diameter of steel reinforcement and size of groove on flexural behaviour of RC beams is studied. Also U wrapping using CFRP sheets is provided for NSM strengthened beams inorder to study its influence in RC strengthened beams as an end anchorage.*

***Key Words*: Strengthening, Near surface mounted (NSM), Groove, Groove filler, U – Wrapping, Flexural failure**

1. INTRODUCTION

Concrete experts commonly use the terms structural repair and structural strengthening to describe building renovation activities. Although the two terms sound similar, they refer to slightly different concepts. Structural repair describes the process of reconstructing a facility or its structural elements. This process involves determining the origin of the distress, removing damaged materials and causes of distress, as well as selecting and applying appropriate repair materials that restore the integrity of the structural elements and extend the structure's useful life. Structural strengthening, on the other hand, is an upgrade of a building's structural system designed to improve performance under existing loads or to increase the strength of the existing structural components to carry additional loads.

The method that is conventionally been used to strengthen structural members is external bonded reinforcement (EBR) in which fibre reinforced polymer (FRP) sheets or steel sheets are bonded to the surface of the member. A relatively new method known as near surface mounted (NSM) method is been adopted where FRP or steel reinforcements are inserted into grooves cut into the structural members [1]. It was observed from previous studies that reinforced concrete (RC) flexural members strengthened with EBR showed low efficiency, due to the premature FRP debonding failure [2,3]. The FRP materials used in EBR technique can be subjected to physical and fire damage. In order to overcome these drawbacks, and to ensure higher durability, NSM technique was recently introduced as an alternative strengthening technique to the EBR technique for increasing flexural strength of reinforced concrete members [2].NSM method is also been used to enhance the shear capacity of RC beams. This is done by cutting grooves at the side of the RC beams within the concrete cover. Various studies have been conducted in enhancing shear strength of RC beam with NSM CFRP reinforcement. It was observed that NSM bars installed at 45° to the axis of the beam are found to be most efficient for shear-strength enhancements, while the bars placed vertically are least effective [6]. It was also observed that as the NSM FRP reinforcements are close to each other, the performance of the beam in shear was enhanced [6].

Some of the advantages of NSM strengthening method are a) NSM reinforcements are less prone to debonding from the concrete substrate [3], b) NSM bars can be more easily anchored [4], c) NSM reinforcement can be more easily pre-stressed [4], d) NSM bars are protected by the concrete cover i.e. they are less exposed to accidental impact, mechanical damage, fire, and vandalism [5]. Some of the disadvantages of NSM strengthening method are a) Cutting of groove requires precision, time and labour, b) Positioning of groove is important. Care must be taken to avoid cutting of the main reinforcement in RC members, c) Surface finishing is needed after the strengthening of the structural element with NSM method.

2. EXPERIMENTAL PROGRAMME

2.1 Concrete Mix Proportion

M 25 Grade concrete was used for the experimental investigation. The mix design of the concrete mix was done as per IS 456:2000 and IS 10262:2009. Ordinary Portland cement of grade 53, coarse aggregate of size 20 mm, and M – sand was used as fine aggregate for the experimental investigation. Inorder to increase the workability of the concrete mix and to reduce the water – cement ratio MASTER GLENIUM SKY 8433 admixture was used, which was produced by BASF. Several trials were carried out to reach the final concrete mix proportion; the final mix proportion that was used in the experimental setup is shown in Table -1.

Table -1: Mix proportion of M 25 grade concrete

Mix proportion	1:1.94:3.24
Water-cement ratio	0.43
Percentage of admixtures by weight of cement (%)	0.2
Mass of cement per m^3 of concrete (kg)	378.70
Mass of fine aggregate per m^3 of concrete (kg)	737.31
Mass of coarse aggregate per m^3 of concrete (kg)	1225.73
Slump (mm)	110

2.2 Test Specimen and Specimen Configuration

A total of 6 RC beam specimens were casted and tested, one of the beams was casted as control beam without any strengthening, and all other beams were strengthened in flexure with single groove at the soffit of the RC beam. The cross-sectional dimensions of the specimens were 150 mm X 200 mm with a clear cover of 25 mm at the top and 30 mm at the bottom of the beam, and the length of the specimens was 1000 mm. Two numbers of 10 mm diameter bar was provided at the bottom of the beam as tension reinforcement, two numbers of 10 mm diameter bar was provided at the top of the beam as compression reinforcement and 8 mm diameter bar at 100 mm c-c spacing was provided as shear reinforcement. Fig -1 and Fig -2 shows the longitudinal detailing of RC control and strengthened beam specimen. Fig -3 shows the sections of the RC control and strengthened beam specimen.

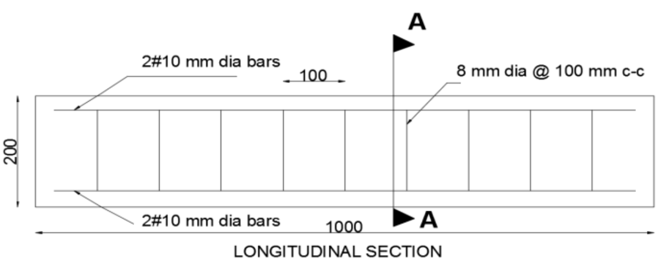

Fig -1: Detailing of RC control beam specimen

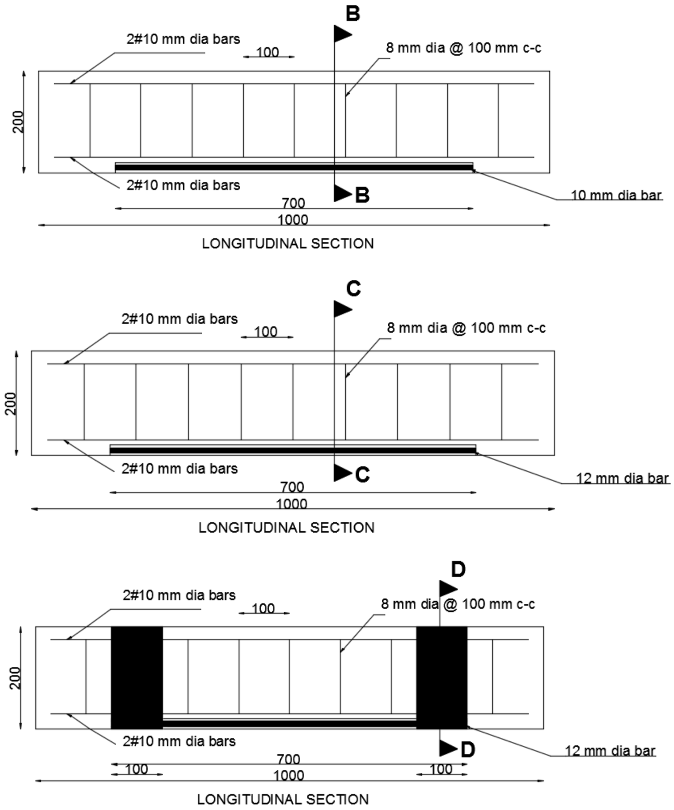

Fig -2: Longitudinal section of strengthened beams

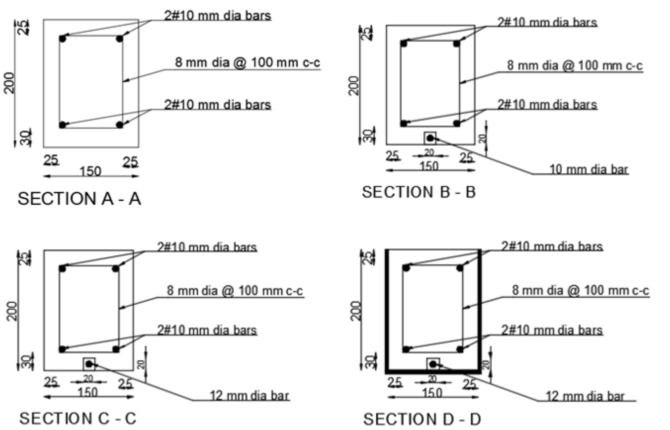

Fig -3: Sections of RC control and strengthened beams

One control beam i.e. beam without any strengthening was casted to compare with NSM strengthened beams. The influence of diameter was studied by strengthening beams with 10 and 12 mm diameter bars. The influence of CFRP U-wrap as end anchorage was studied by providing CFRP U – wrap at the ends of the NSM groove for a width of 100 mm as shown in Fig -2. Table -2 shows the specifications of test beam specimens that were casted for the experimental investigation. The designation CB stands for control beam, and NSM strengthened beam was designated as BD10G20, where B stands for NSM beam, D stands for the diameter i.e. 10 mm, G stands for groove size i.e. 20 x 20 mm. NSM strengthened beam with CFRP U – Wrapping was designated as UBD12G20, UB stands for U – wrapped NSM strengthened beams.

Table -2: Specifications of test beam

Sl No	Specimen Name	Diameter of steel NSM reinforcement (mm)	Groove Size (mm)	U -Wrap with CFRP sheet
1	CB	-	-	-
2	BD10G20	10	20 X 20	-
3	BD12G25	12	25 X 25	-
4	BD12G20	12	20 X 20	-
5	UBD12G25	12	25 X 25	0.25 mm thickness and width 100 mm
6	UBD12G20	12	20 X 20	0.25 mm thickness and width 100 mm

2.3 Strengthening Procedure

Steel reinforcement was provided as NSM reinforcement and polyester resin adhesive was used as the groove filler material, as epoxy resin adhesive is expensive and not readily available in Kerala. The polyester adhesive used in this experimental investigation is Lokfix P, a product of Fosroc Company. The control beam was casted as ordinary beam without any groove. All other beams that are to be strengthened were casted with a timber piece of suitable dimension (As per ACI 440.2R-08) at the bottom of the beam. The strengthening method consists of two steps: Groove preparation and insertion of steel reinforcement into the groove with polyester resin grout.

The groove was pre-cut during casting of the RC beams using timber pieces. The groove size was adopted as per ACI 440.2R-08 (13.3, Page 39); the minimum size of groove is 1.5 d x 1.5 d, where d is the diameter of the reinforcing bar used for strengthening. The groove is then cleaned to remove dust and dirt using a brush. The groove was then partially filled with polyester resin, and then steel reinforcement was inserted into the groove. The groove was then fully filled with polyester resin grout and then levelled. The beam was tested after 7 days. Fig -4 shows the NSM strengthened RC beam specimen.

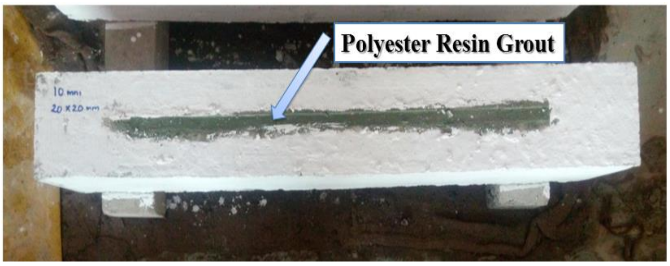

Fig -4: NSM strengthened RC beam specimen

Some of the RC specimen samples are provided with CFRP U –Wrap at the end of the groove inorder to avoid debonding failure. The CFRP sheet thickness is 0.25 mm, the sheet is provided for a width of 100 mm at both sides, as an anchorage for the NSM system. For bonding CFRP sheet onto the RC beam specimen Araldite epoxy resin has been used. Fig -5 shows the beam with CFRP U-wrap as end anchorage.

Fig -5: RC beam with CFRP U –wrap provided as end anchorage for NSM system

2.4 Test Setup

The RC beam specimens were tested in Universal testing machine (UTM) and the mid – span deflection of the beam was taken using dial gauge. The experimental setup used for testing RC beam specimens is three – point flexure test as shown in Fig -5. The RC beam specimens are laid horizontally over two points of contact (lower support) and then a force is applied to the top of the beam through single point of contact until the beam specimen fails. The length of the beam is 1000 mm with 880 mm as the effective span and a shear span of 440 mm. All the beams were designed as under reinforced beams to initiate failure in flexure.

Fig -5: Three – point bending test in UTM

3. RESULTS AND DISCUSSION

3.1 Failure Pattern

All the RC beam samples were designed to fail under flexure. This was done to study the enhancement of NSM steel reinforcement in flexural strengthening of RC beam. Most of the beams failed under flexure, whereas some of the beams failed due combined effect of shear and flexure. When the RC beam has sufficient flexural capacity the beam fails under shear, which is a proof showing the effectiveness of the strengthening technique in flexure. Fig -6 shows the failure pattern of control beam and Fig -7 shows the failure pattern of strengthened beams. It was observed that the control beam CB failed under flexure with large number of flexural cracks whereas all the strengthened beams failed with lesser number of cracks with finer cracks implying an increase in stiffness of the strengthened beams. Table -3 shows the failure mode of RC test beam specimens.

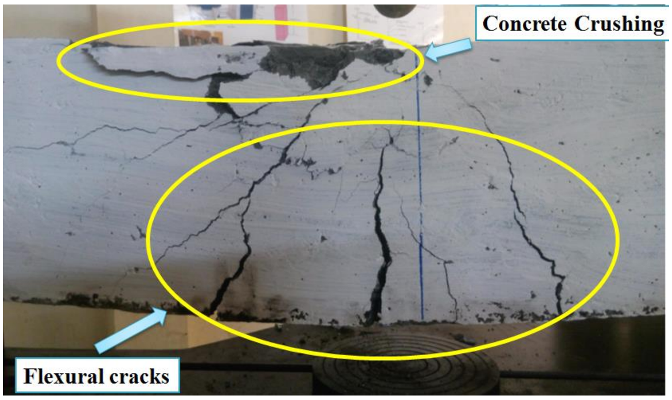

Fig -6: Failure mode of control beam specimen

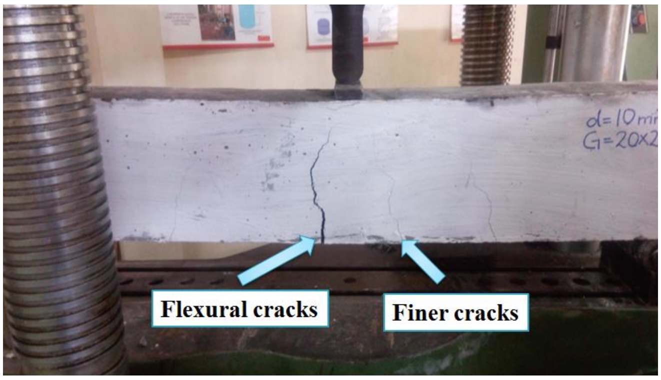

Fig -7: Failure mode of BD10G20 beam specimen

Table -3: Failure mode of RC beam specimens

Beam specimen	Failure Mode				
	Flexural failure	Shear failure	Cracking of Polyester resin	Concrete crushing	Debonding
CB	✔	X	X	✔	X
BD10G20	✔	X	X	X	X
BD12G20	✔	X	X	X	✔
UBD12G20	✔	✔	X	X	X
BD12G25	✔	✔	X	X	X
UBD12G25	✔	✔	X	X	X

3.2 Influence of Bar Diameter

The beams strengthened with 10 mm and 12 mm diameter bars showed an increase in load carrying capacity by 4.87 % and 7.31 % respectively when compared with control beam specimen. BD10G20 failed under flexure and no debonding failure at polyester–concrete interface or at bar polyester interface occurred and also cracking of polyester resin grout also did not occur. Similarly in the case of BD12G20 failed under flexure and cracking of polyester resin grout also did not occur whereas a slight debonding failure at polyester–concrete interface occurred near to the supports as shown in Fig -8. Due to this the increase in load carrying capacity of the beam BD12G20 is only 2.44 %. Table -4 shows the ultimate load carrying and the percentage increase in load carrying capacity.

Table -4: Test results

Beam specimen	Ultimate load (kN)	Percentage increase in load carrying capacity (%)
CB	82	-
BD10G20	86	4.87
BD12G20	88	7.31
UBD12G20	95	15.85
BD12G25	84	2.44
UBD12G25	90	9.75

Chart -1 shows the influence of steel NSM bar diameter in strengthening of RC beams.

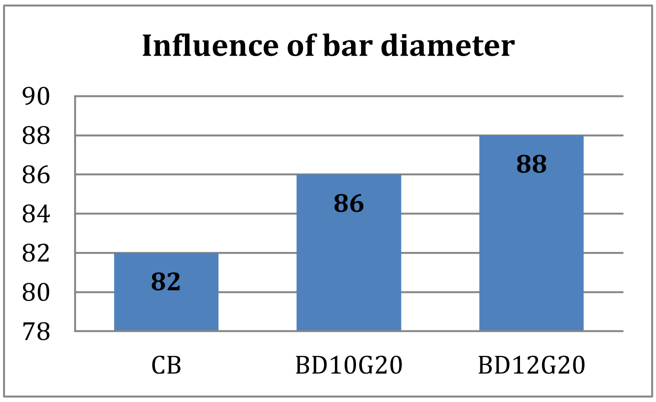

Chart -1: Influence of bar diameter

3.3 Influence of CFRP U-Wrapping

CFRP U – Wrapping was provided as end anchorage in steel NSM strengthened beams. In case of beam strengthened with 12 mm diameter bar (BD12G20) debonding failure occurred at polyester concrete interface as shown in Fig -8. Thus CFRP U – Wrapping was provided for a width of 100 mm nearer to the support at the end of NSM strengthened region to study its influence in strengthening of RC beam in case of beams strengthened with 12 mm diameter bar. It was observed that

CFRP U- Wrapped beam specimen failed under shear, with a combination of major shear cracks and minor fine flexural cracks as shown in Fig -9 and Fig -10. This implies that providing end anchorage in the form of U – Wrapping in combination with NSM technique can significantly enhance the flexural capacity of the beam.

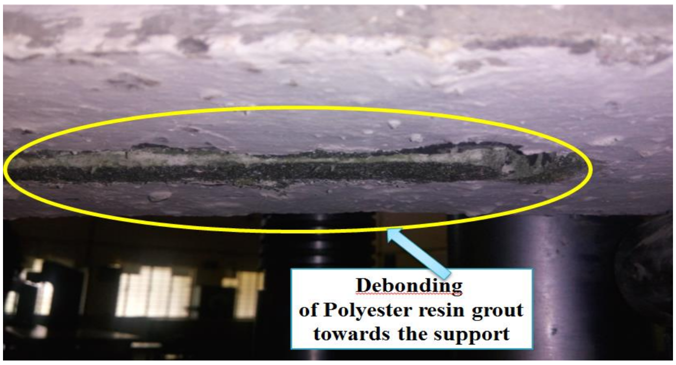

Fig -8: Debonding failure in BD12G20

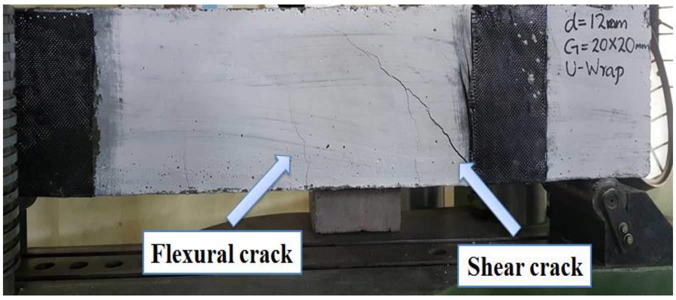

Fig -9: Shear failure in UBD12G20

Fig -10: Shear failure in UBD12G25

The U – Wrapped specimens showed an increase in load carrying capacity by 9.75 %, and 15.85 % in case of UBD12G25 and UBD12G20 respectively when compared with control beam specimen. Whereas specimens without U – wrapping showed an increase of 2.44 % and 7.31 % in case of BD12G25, and BD10G20 respectively when compared with control beam specimen. The load carrying capacity of U – Wrapped specimens UBD12G20, UBD12G25 increased by 7.95 % and 7.14 % when compared with NSM beam specimens without U wrapping i.e. BD12G20 and BD12G25 respectively. The deflection of the U – wrapped specimens reduced by 84.6 % and 90 % in case of UBD12G20 and UBD12G25 when compared with the control beam specimen as shown in Chart -2.

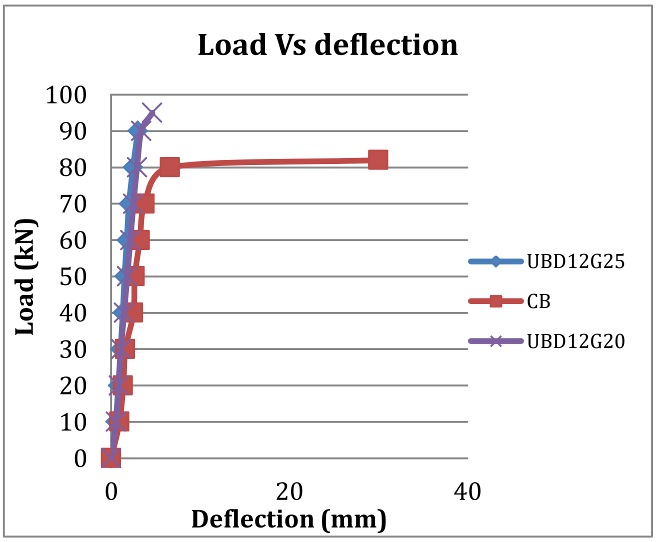

Chart -2: Load Vs deflection curve of U – wrapped and control beam specimen

3.4 Influence of Groove Size

As the groove size increased, the efficiency of flexural strengthening of beams reduced by 4.54 % and 5.26 % in case of BD12G25 and UBD12G25 respectively when compared with BD12G20 and UBD12G20 respectively. This shows that increase in groove size does not improve the efficiency of NSM strengthening method but it reduces the strengthening effect. Whereas these beam specimens showed an increase in load carrying capacity of 2.44 % and 9.75 % when compared with the control beam specimen. Chart -3 shows the influence of groove size for 12 mm diameter bar.

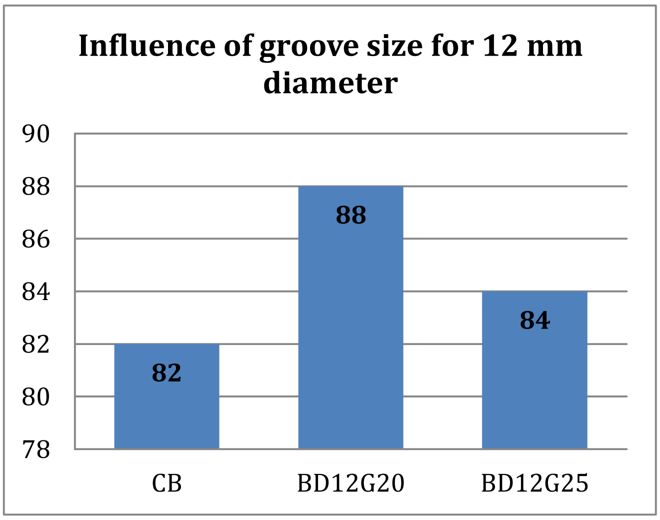

Chart -3: Influence of groove size

4. CONCLUSIONS

The major conclusions derived from the experimental study are as follows:

i. The flexural performance of RC beams strengthened with near surface mounted steel reinforcement was studied based on the ultimate load carrying capacity of the beam and it was found that the load carrying capacity of beams strengthened with NSM steel reinforcement showed an increase of maximum by 7.31 % when compared to control beam specimen. Hence a slight increase in load carrying capacity was observed for beams strengthened with NSM steel reinforcement. This shows that this method can enhance the flexural performance of RC beams.

ii. Strengthened beams showed lesser number of cracks with fine cracks implying increase in stiffness of the strengthened beams.

iii. The influence of parameters such as bar diameter and groove size in flexural strengthening was studied and it was found that the beams strengthened with 10 mm and 12 mm diameter bars showed an increase in load carrying capacity by 4.87 % and 7.31 % respectively when compared with control beam specimen. This shows that as the diameter of NSM steel reinforcement increases there is a slight increase in load carrying capacity of the beam specimen.

iv. The beam specimens with groove size of 1.6 times diameter of NSM bar and groove size of 2.1 times diameter of NSM bar showed an increase in load carrying capacity by 7.31 % and 2.44 % when compared with control beam specimen. Thus a minimum groove size as recommended by ACI 440.2R-08 of 1.5 times diameter of NSM bar is found to be effective for strengthening of RC beams.

v. CFRP U – wrapping was provided as end anchorages to resist the debonding failure which occurred at polyester concrete interface when the bar diameter increased.

vi. The influence of CFRP U- wrapping as end anchorage in NSM strengthened RC beam was studied and it was found that the U – wrapped specimens showed a maximum increase in load carrying capacity by 15.85 % when compared with control beam specimen. This shows that the beams strengthened with steel NSM reinforcement along with U –wrapping as end anchorage can increase the efficiency of the strengthening technique to a greater extent.

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