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Effect of Near Surface Mounted (NSM) Steel Bars on Shear Strength of RC Beams

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Abstract – *Shear strengthening of reinforced concrete (RC) beams is very essential as shear failure is a sudden failure without any warnings. The NSM technique is one of the techniques newly developed to strengthen a beam in shear. This method also has proved to be efficient than the conventional method like External Bonding of Reinforcement (EBR) method. The NSM technique involves fixing of NSM steel bars using adhesive into pre-cut grooves in the concrete cover of lateral surfaces of the beams. In this paper, the influence on NSM bar orientation and NSM bar diameter on the ultimate load carrying capacity of the RC beam is studied. Results have shown that, the load carrying capacity of the RC beams increases for those having NSM bars at inclined orientation than vertical orientation. Also, an increase in the NSM bar diameter increases the ultimate load carrying capacity of the RC beam.*

***Key Words*: Shear Strengthening, Near Surface Mounted (NSM) Technique, NSM steel bars, NSM bar orientation, NSM bar diameter.**

1. INTRODUCTION

The near-surface mounted (NSM) is an effective technique for the shear strengthening of reinforced concrete (RC) elements. This technique is based on cutting of grooves in the concrete cover of the elements to be strengthened, in which steel or fiber reinforced polymer (FRP) bars are inserted and bonded to the surrounding concrete substrate using an epoxy adhesive. Externally bonded reinforcement (EBR) was the conventionally used technique for shear strengthening of RC beams; however the NSM technique showed a significant increase in shear strength which indicates its efficiency over the EBR techniques [4]. The NSM technique can be used to enhance the flexural capacity, shear capacity and ductility of RC beams. NSM reinforcement is less prone to de-bonding failures because of their better bond performance than EBR techniques. NSM bars are less susceptible to corrosion and fire damages as they are protected by the concrete cover. It is also an aesthetically appealing technique. NSM techniques become particularly interesting in the seismic retrofit of deteriorated RC beam-column joints.

Andrea Rizzo *et.al* [2] conducted experimental tests on RC beams strengthened in shear using the near surface mounted (NSM) CFRP method and an average increase in shear capacity of about 44% was found for the NSM CFRP strengthened specimens. Khaldoun N. Rahal *et.al* [6] after conducting comparative study using steel and NSM CFRP bars in RC T-beams proved that NSM CFRP bars are more effective than NSM steel bars. Whereas, S.J.E. Dias *et.al* [9] studied the influence of inclination of NSM CFRP laminates and percentage of existing stirrups on the NSM shear strengthening efficiency. It was observed that, providing NSM bars at 45 degrees inclination increases the efficiency of shear strengthening as it arrests cracks. Also, as the percentage of existing stirrups increases, the NSM shear strengthening efficiency decreases.

2. EXPERIMENTAL PROGRAMME

2.1 Concrete Mix Proportion

For the experimental study, M25 grade concrete was used. IS 456:2000 was the design code used for the mix design of M25 grade concrete. M–sand, 20mm size coarse aggregates and Ordinary Portland Cement (OPC) of 53 grades were used. The admixture used was MASTER GLENIUM SKY 8233. The mix proportion selected for the experimental study is shown in Table -1.

Table -1: Mix proportion of M 25 grade concrete

Mix proportion	1:1.90:3.06
Water-cement ratio	0.4
Percentage of admixtures by weight of cement (%)	0.2
Mass of cement per m^3 of concrete (kg)	394.32
Mass of fine aggregate per m^3 of concrete (kg)	750.64
Mass of coarse aggregate per m^3 of concrete (kg)	1206.91
Slump (mm)	120

2.2 Test Specimen and Specimen Configuration

A total of seven RC beam specimens deficient in shear were casted and tested, one of them being the control specimen. The other six RC beam specimens were shear strengthened using NSM steel bars by varying the NSM steel bar orientation and NSM steel bar diameter. The total span of the beam specimen was 1 m and the effective span is 0.88m. The cross-sectional dimensions of the beam specimens were 150 mm X 200 mm with 25mm clear cover at the top and bottom and also at the sides of the beam.

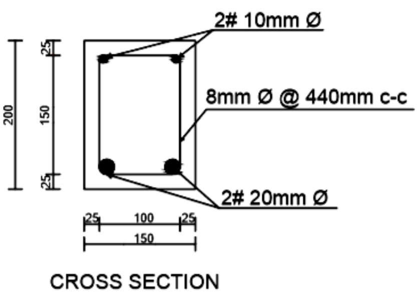
The percentage of tension reinforcement provided is 2.094% which is relatively a greater value, taken in order to cause shear failure in the strengthened beams so that we could study the shear strengthening effectiveness of the NSM method. Two numbers of 20 mm diameter bars were used as tension reinforcement, and two numbers of 10 mm diameter bars were used as compression reinforcement. Three stirrups of 8 mm diameter were provided at the two support points and also at the loading point. The steel bars of grade Fe 500 were used.

There are six NSM configurations in this study with parameters being NSM bar orientation and NSM bar diameter. The orientation of NSM bars used is 90 degrees and 45 degrees. Also, the diameters of NSM bars used are 8 mm, 10 mm and 12 mm respectively. Here, the NSM bars are placed at a spacing of 146.7mm i.e., one-sixth of the effective span, L of the beam. The specifications of specimens are shown in Table -2.

Table -2: Specifications of Specimens

Specimen ID	NSM Steel Bar Diameter (mm)	NSM Steel Bar Orientation (Degrees)
NCB	-	-
NB-8d-90	8mm	90
NB-8d-45	8mm	45
NB-10d-90	10mm	90
NB-10d-45	10mm	45
NB-12d-90	12mm	90
NB-12d-45	12mm	45

The Cross-section and Longitudinal section of Control beam is shown in Fig -1. Fig -2 shows the Cross-section and Longitudinal section of NB-8d-90.



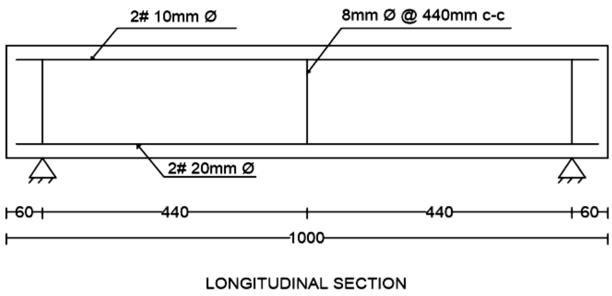


Fig -1: Cross-section and Longitudinal section of Control beam

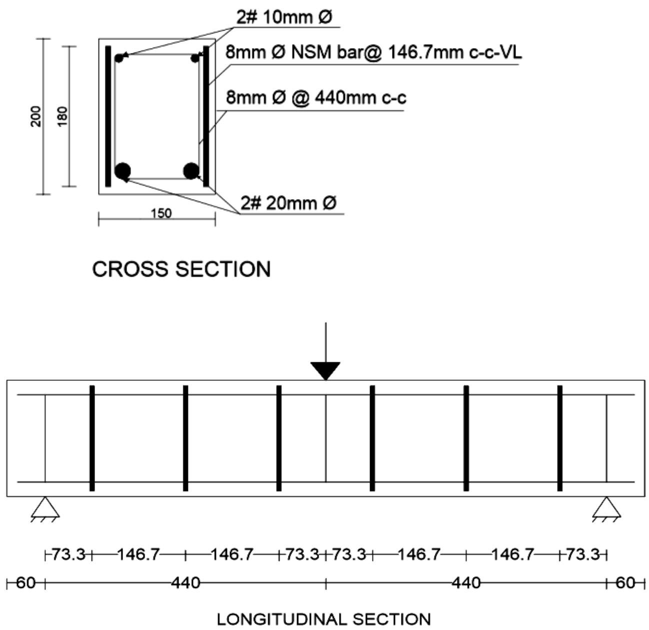
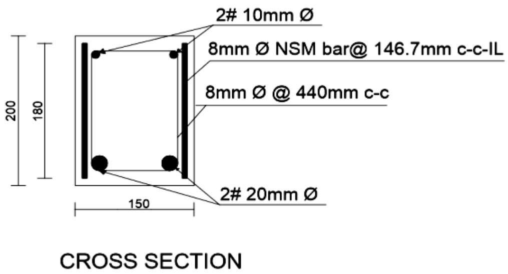


Fig -2: Cross-section and Longitudinal section of NB-8d-90



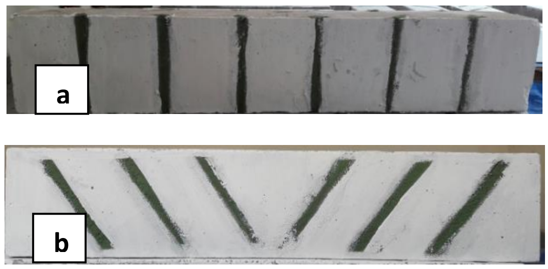


Fig -5: Strengthened beams; a.NB-8d-90 and b.NB-8d-45

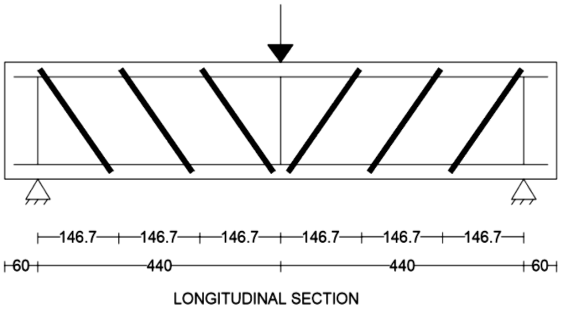


Fig -3: Cross-section and Longitudinal section of NB-8d-45

The Cross-section and Longitudinal section of NB-8d-45 is shown in Fig-3. The other strengthened specimens which used 10mm and 12mm diameter NSM steel bars followed a similar pattern to that of the specimens NB-8d-90 and NB-8d-45.

2.3 Procedure for Shear Strengthening

The seven beam specimens were cast in moulds of dimension 1m x 150mm x 200mm. For the purpose of introducing NSM steel bars in the beam specimens for shear strengthening, grooves of dimension equal to 1.5 times the diameter of NSM steel bars was adopted as per ACI 440.2R-08(13.3,Page 39), i.e.,12mmx12mm,15mmx15mm and 18mm x 18mm for NSM bar diameters of 8mm,10mm and 12mm respectively. A shear strengthened beam with grooves made on its two lateral faces is shown in Fig-4.

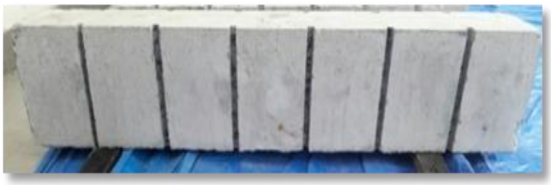


Fig - 4: A beam with grooves on its lateral faces

After 28 days of curing in water, the beams were taken out to dry for a day, the grooves of above mentioned dimensions were made in those beams using concrete cutter and the grooves were cleaned using water and then the NSM steel bars were inserted into the grooves and then bonded with surrounding concrete substrate using the adhesive Lokfix-S. A few NSM shear strengthened beams are shown in Fig-5.

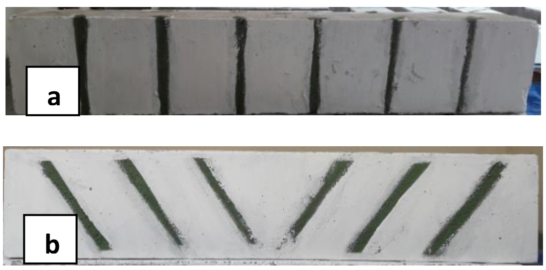


Fig -5: Strengthened beams; a.NB-8d-90 and b.NB-8d-45

2.4 Test Setup

The beams cast using the above procedure was tested in the Universal Testing Machine (UTM) with load range of 0-1000kN is shown in Fig-6 below. The specimens were arranged using simply supported conditions with an effective span of 0.88m. The load was applied at midpoint of the beam specimen. Dial gauge of least count 0.01 mm was used to measure the deflection of the beams. The three point loading arrangement for the beams is shown in Fig -6.

Fig -6: Three – point bending test in UTM

3. RESULTS AND DISCUSSION

The control beam and NSM shear strengthened beams were tested under three point bending test and the results were obtained in terms of the ultimate load and deflection at ultimate load. All the beams tested failed in shear. The crack patterns of NCB (Control beam), NB-8d-90 and NB-8d-45 are shown in Fig -7. The other strengthened beams also followed a similar shear failure pattern.

Fig -7: Crack patterns of specimens; a. NCB (Control beam), b. NB-8d-90 and c. NB-8d-45 The beam test results are tabulated in Table -3.

Table -3: Beam Test Results

Specimen ID	Ultimate Load (kN)	Increase In Ultimate Load (%)	Deflection At Ultimate Load (mm)
NCB	108	-	3

NB-8d-90	124	14.81	4.5
NB-8d-45	154	42.6	6.25
NB-10d-90	132	22.22	6
NB-10d-45	166	53.7	7
NB-12d-90	142	31.48	5.25
NB-12d-45	178	64.81	6.5

3.1 Influence of NSM Bar Orientation

The influence of NSM bar orientation in the load carrying capacity of the strengthened beams is one of the main parameters considered in this study. Two different orientations chosen for the study are vertical (90^0) and inclined (45^0) orientations for 8mm,10mm and 12mm NSM bar diameters respectively, placed at a spacing of L/6,where L is the effective span of the beam. In this study, all the beam specimens tested follow a similar fashion for its load-deflection curves till its yield point and then shows an abrupt increase in the deflection followed by a sudden shear failure with minimal warnings. No de-bonding failure at epoxy-concrete interface or at NSM bar-epoxy interface was observed for NSM shear strengthened beam specimens.

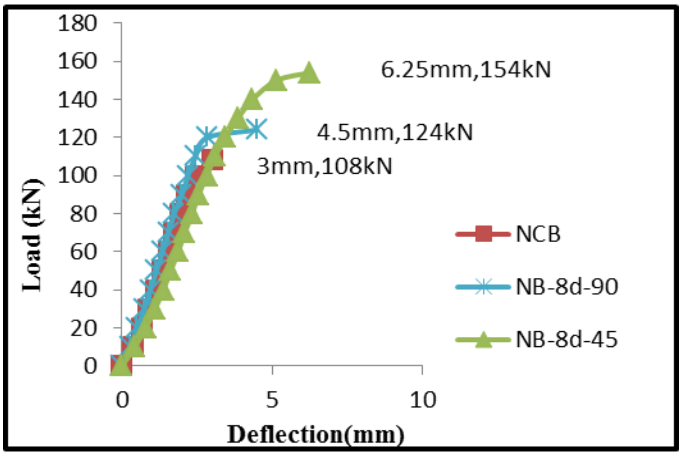


Chart -1: Load Vs deflection curves for 8mm diameter NSM bars for the two NSM bar orientations

The specimen NB-8d-45 has an increase in ultimate load of 42.6% compared to the 14.81% increase for the specimen NB-8d-90. It is evident from Chart -1 which shows the load Vs deflection curves for the strengthened specimens with NSM bar diameter of 8 mm for the two NSM bar orientation. From it, we can see that, the ultimate load is greater for the strengthened beam with NSM bar orientation of 45^0.

A very similar result is obtained for the next set of strengthened beams: NB-10d-90 and NB-10d-45. The specimen NB-10d-45 has an increase in ultimate load of 53.7% compared to the 22.22% increase for the specimen NB-10d-90 as shown in Chart -2 which shows the load Vs deflection curves for the strengthened specimens with NSM bar diameter of 10 mm for the two NSM bar orientation. Thus, the ultimate load is greater for the strengthened beam with NSM bar orientation of 45^0 when the NSM bar diameter is 10 mm.

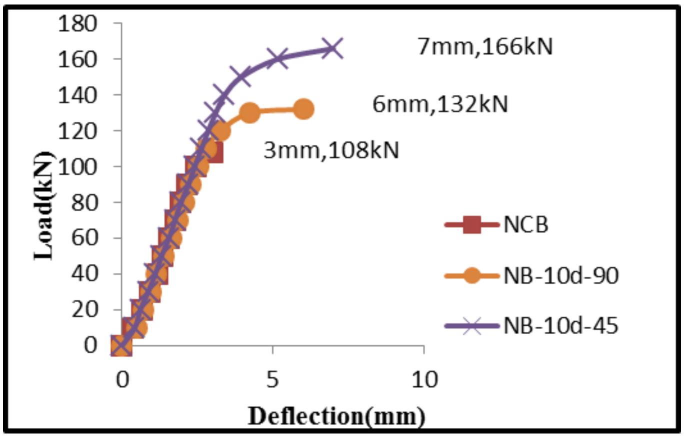


Chart -2: Load Vs deflection curves for 10mm diameter NSM bars for the two NSM bar orientations

Also, in the next set of strengthened beams: NB-12d-90 and NB-12d-45, the latter has an increase in ultimate load of 64.81% compared to the 31.48% increase for the former as shown in Chart -3 which shows the load Vs deflection curves for the strengthened specimens with NSM bar diameter of 12 mm for the two NSM bar orientation. The ultimate load is clearly greater for the strengthened beam with NSM bar orientation of 45^0 when the NSM bar diameter is 12 mm.

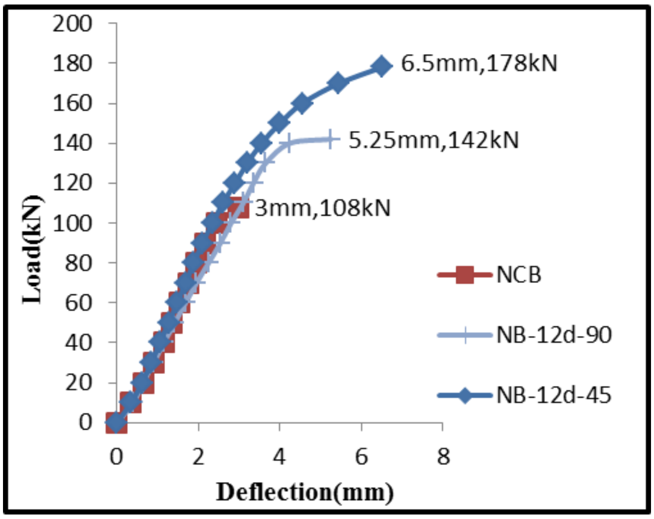


Chart -3: Load Vs deflection curves for 12mm diameter NSM bars for the two NSM bar orientations

Hence these test results clearly presents the significance of the NSM steel bar orientation in shear strengthening purpose, for its contribution towards load carrying capacity of reinforced concrete beams. The ultimate load carrying capacity for beam specimens strengthened with NSM bars at inclined (45^0) orientation is greater compared to those with NSM bars at vertical (90^0) orientation. It is because of its better crack arresting property, as the NSM bars are placed perpendicular or in a direction opposite to the diagonal shear cracks.

2 Influence of NSM Bar Diameter

The effect of NSM bar diameter on shear strength of RC beams is the second parameter considered in this study. The different NSM bar diameters chosen for the study are 8mm, 10mm and 12mm respectively, placed at a spacing of L/6, where L is the effective span of the beam as mentioned previously. The effect of these NSM bar diameters on the shear strength is elaborated in the current session.

The load Vs deflection curves for the strengthened specimens with NSM bar orientation of 90^0 for the three NSM bar diameters are shown in Chart-4, i.e., for the specimens: NB-8d-90, NB-10d-90 and NB-12d-90. From it, we can see that, the ultimate load is greater for the strengthened beam with NSM bar diameter of 12mm with an increase in ultimate load of 31.48% compared to the 14.81% and 22.22% increase for specimens NB-8d-90 and NB-10d-90 respectively. Also, as the diameter of NSM bars increases, its contribution towards the load carrying capacity of the RC beam also increases.

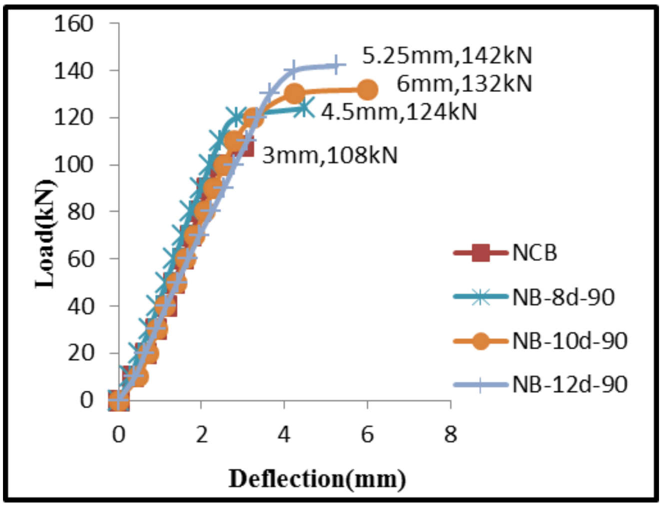


Chart -4: Load Vs deflection curves for NSM bar orientation 90^0 for various NSM bar diameters

Now, changing the orientation of NSM bars from 90^0 to 45^0- the graphs of which are given in Chart -5 similar results as aforementioned is obtained, which is of course an increase in the ultimate load of RC beams as a result of increasing the diameter of NSM bars i.e., 42.6%, 53.7% and 64.81% increase in ultimate loads for the specimens NB-8d-45, NB-10d-45 and NB-12d-45 respectively.

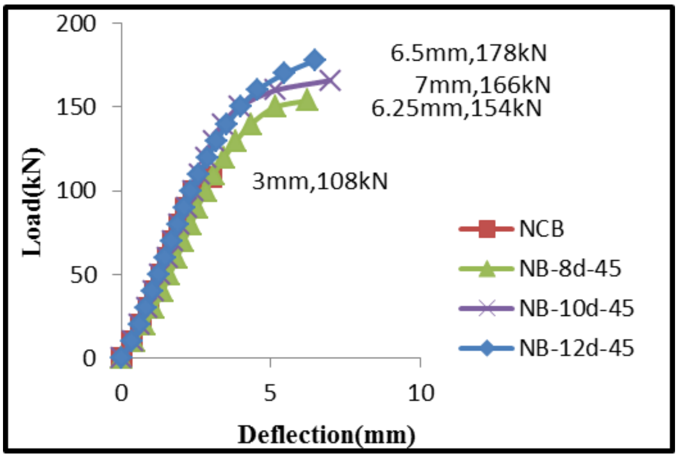


Chart -5: Load Vs deflection curves for NSM bar orientation 45^0 for various NSM bar diameters

From these results, it is clear that as the diameter of NSM bars increases, its contribution towards the load carrying capacity of RC beam also increases irrespective of varying NSM bar orientation. It is because; as the surface area of bars increases its ability to resist the shear cracks also increases. Also from the results, it clearly indicates that the NSM bars of greater diameter (12mm) at inclined orientation (45^0) show much better enhancement in load carrying capacity.

CONCLUSIONS:

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

- Shear strengthening of RC beams by NSM method is very effective in increasing its load carrying capacity. The NSM shear strengthened beams have 14.81% to 64.81% increase in ultimate load compared to the non-strengthened beam.

- The load carrying capacity of NSM strengthened beams increases for those having NSM bars placed at inclined (45^0) orientation. Up to 25.75% increase in ultimate load is found for the NSM bars oriented at 45^0 compared to those oriented at 90^0.
- The load carrying capacity of NSM strengthened beams increases as the diameter of the NSM bars increases. When the diameter of NSM bars increased from 8mm to 10mm, an average of 7.79% increase in ultimate load is found. Also, an average of 7.57% increase in ultimate load is found when the diameter of NSM bars increased from 10mm to 12mm.

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