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Strengthening of Concrete Structures with Near Surface Mounted (NSM) GFRP Strips and Wire Mesh Strips

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ABSTRACT: Strengthening of structural members are now quite common in the construction industry due to increase in loading requirements, change in the type of usage and even due to deficiencies in either material properties or design of the structure. Externally bonded reinforcement (EBR) and the near surface mounted (NSM) technique are among the most popular strengthening methods in existing reinforced concrete structures. EBR technique suffers from the high possibility of premature failure. Therefore NSM strengthening technique offers an effective substitute to the EBR technique. In this project, near-surface mounted (NSM) technique using strips of square woven wire mesh and laminated GFRP strip are used as a strengthening system to increase the load carrying capacity of concrete members. Wire mesh is a form of reinforcement that is well distributed and aligned reinforcement and behave like steel plates. Wire mesh are used in the strengthening of existing structure technology. Experimental data on load, deflection and failure modes of each of the beams were obtained. The detail procedure and application of GFRP sheets for strengthening of RC beams is also included. The effect of number of GFRP layers and its orientation on ultimate load carrying capacity and failure mode of the beams are investigated.

KEYWORDS ; NSM technology ,Square woven wire mesh, GFRP strip

I. INTRODUCTION

The maintenance, rehabilitation and strengthening of structural members is one of the most crucial problem in civil engineer application. That affect the life span of the structural member due to various reasons such as mechanical damage, environmental effects, increased service loads, and errors in design and construction. There are a number of methods for strengthening existing reinforced concrete structures. Externally bonded reinforcement (EBR) and the near surface mounted (NSM) technique are among the most popular strengthening methods. The EBR technique involves the external bonding of strengthening materials such as steel plates or fiber reinforced polymer (FRP) laminates. However, this technique suffers from the high possibility of premature failure such as debonding of longitudinal laminates, delamination and other types of premature failure. The most common NSM strengthening technique is based on the application of FRP rods that is, carbon fiber reinforced polymer (CFRP) and Glass fiber reinforced polymer (GFRP). In this study, near-surface mounted (NSM) technique using strips of square woven wire mesh fabrics was investigated to see its potential in preventing debonding failure due to concrete cover separation in flexurally strengthened NSM-steel RC beams. The cracking and ultimate loads, mid-span displacement and failure modes were analysed. Wire mesh is a form of reinforcement that is well distributed and aligned reinforcement and behave like steel plates. Application of Welded Wire Mesh Structural Slabs & Walls Welded wire mess instead of stirrups makes the reinforcement for domestic and Official Buildings most speedy and sophisticated.

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II. LITERATURE REVIEW

Alan *et al* (2013) conducted an experimental study to improve the transfer of post crack forces in concrete using fibre technology. The closed loop fibres used in this test were in the form of square loops of size 50 mm x 50 mm. The loops were created using stainless steel wire of diameter 1.2 mm. and grade 316L. From the results, the closed loop fibre beams

Laura De Lorenzis *et al* (2017) The objective of this research program was to investigate bond between NSM FRP rods and concrete. Some of the factors expected to affect bond performance were addressed, namely: bonded length, diameter and surface configuration of the rod, type of FRP material, and size of the groove in which the rod is embedded. From the Result, Three different failure modes were observed during the experimental tests, namely, splitting of the epoxy cover, cracking of the concrete surrounding the groove, and pull out of the FRP rod.

Md. Akter Hosen *et al* investigation on the flexural strengthening of reinforced concrete (RC) beams with NSM technique using different ratios of steel bars. Yield and ultimate strengths, flexural failure modes, cracking behaviour and ductility are reported and discussed based on measured load and deflection. The test results show that flexural strength increased up to 53.02% and energy and deflection ductility improved.

Kh Mahfuz ud Darain *et al* (2016): This study investigates the flexural behaviour of reinforced concrete (RC) beams strengthened through the combined externally bonded and near-surface mounted (CEBNSM) technique. From the result, the strengthened beams showed enhancement of ultimate load capacity, stiffness, cracking behaviour, and strain compatibility. The ultimate capacity of the CEBNSM-strengthened beams increased from 71% to 105% compared to that of the control beam.

Saeed Ahmed Al-Sheikh *et al* (2017): In this paper an experimental works was conducted to study the behaviour of RC beam with NSM CFRP with different adhesive materials exposed to elevated temperature of 550°C for different periods of time and cooling schemes. From the test results, it could be concluded that ready-mix mortar could be as an alternative adhesive material. The ultimate load-carrying capacity of the RC beam was reduced for longer duration of elevated temperature.

W.T.Jung *et al* (2014): This study presents the results of experiments performed on RC (Reinforced Concrete) beams strengthened with NSM (Near Surface Mounted) reinforcement. Experimental results revealed that NSM specimens used CFRP reinforcements more efficiently than the EBR specimens, but debonding failure between adhesive and concrete occurred.

Soo-Yeon Seo *et al* (2013): In this paper, bond capacities of EBR and NSMR using FRP plate were studied experimentally and results were compared each other. From the test results, it was found that the member strengthened by NSMR had almost 1.5 times higher bond strength than that by EBR. The contribution of shear key was not observed when the split failure of concrete governed

W.T. Jung *et al* (2008): This study presents the results of experiments performed on RC (Reinforced Concrete) beams strengthened with NSM (Near Surface Mounted) reinforcement. The measured ultimate load showed an increase of 15% compared with the common NSM specimens. The application of mechanical interlocking grooves made it possible to avoid debonding failure and to enhance strengthening performance.

M.F.Tahir *et al* (2017): They studied the effectiveness of locally available welded wire mesh (WWM) as an additional confinement in reinforced concrete square columns under axial loads. The study concluded that WWM as an additional confinement improves the performance of RC columns in terms of overall strength, core concrete strength and strength enhancement factor. However the efficiency of specimen with WWM wrapped around the external core is superior to the specimen confined with mesh wrapped around the internal core.

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III. EXPERIMENTAL INVESTIGATION

MATERIALS USED

The cement used for the entire experiment was Ordinary Portland Cement of grade 53 conforming to IS 12269:1987. The coarse aggregates conform to IS 2386:1963 and were of crushed angular type passing through 20 mm sieve and retaining on 4.75 mm sieve. The fine aggregate used was M sand conforming to zone II of IS 383:1970. The reinforcement bars used are 8mm diameter and stirrups at two ends used are of size 6mm diameter. Beams are strengthened using square woven wire mesh (fig 1), Glass Fiber Reinforced Polymer (GFRP) strip (fig 2) and steel bar of dia 8mm. The properties of square woven wire mesh shown in table 1.

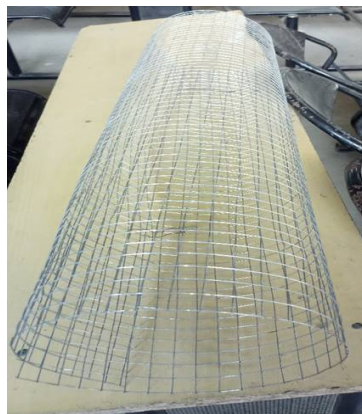


Fig 1 square woven wire mesh



Fig 2 GFRP strip

Table 1. Square woven wire mesh properties

Types of wire mesh	Wire type
Material	Steel
Mesh shape	Square
Mesh opening(cm)	1x1
Thickness (mm)	1
Diameter of mesh (mm)	1
Density (Kg/m ³)	7850
Melting temperature (°c)	800

CONCRETE MIX DETAILS

Mix design is the common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. The proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass. For this study M 25 was selected as conventional concrete. The mix design was done according to the IS recommendation mentioned in IS 456:2000 and IS 10262:2009. The mix proportion obtained is shown below table 2

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Table 2. Mix details of M25 grade concrete

Grade of concrete	M25
Maximum nominal size of aggregate	20mm
slump	mm
Fine aggregate zone	II
Exposure condition	Moderate
Specific gravity of cement of OPC 53 grade	3.14
Specific gravity of coarse aggregate	2.72
Specific gravity of fine aggregate	2.608

Table 3. Mix proportions of M25 grade concrete

Cement Kg/m ³	Fine aggregate Kg/m ³	Coarse aggregate Kg/m ³	Water Litre
1	1.72	2.93	0.5

IV. TEST SPECIMEN

Five sets of beams were tested for their ultimate strengths. In SET I three Conventional RC beams were casted using same grade of concrete and reinforcement detailing. It was observed that the Conventional RC beams had less load carrying capacity when compared to that of the externally strengthened beams using wire mesh and GFRP strip. In SET II beams is strengthened using Laminated GFRP strip, in SET III beams is strengthened using two strip of wire mesh parallel to each other, in SET IV Beam is strengthened using wire mesh bend in to triangular shape, in SET V Beam is strengthened using plain steel bar weak in flexure were casted using same grade of concrete and reinforcement detailing. The dimensions of all the specimens are identical. The cross sectional dimensions of the both the set of beams is 150 mm by 150 mm and length is 1000 mm.

Table 4 types of Beam

Types of beams	Beam ID
Conventional RC beams	CB
Beam strengthened using two strip of wire mesh	NSM 1
Beam is strengthened using wire mesh bend in to triangular shape	NSM 2
beams is strengthened using plain steel bar	NSM 3
Beam is strengthened using Laminated GFRP strip	NSM 4

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STRENGTHENING PROCEDURE

In NSM technique, strengthening materials are placed into grooves cut into the concrete cover of the RC beams and bonded using the cement grout as a filling material. When this was completed and the fabrics had been cut to size, the cement grout was applied to the concrete surface. Fill the slits and cover the lateral faces of the wire mesh, GFRP strip and steel bar with the cement grout. Insert each in to the slit, and slightly press it to force the grout to flow between the wire mesh and the slit borders. This phase requires a special care in order to assure that the slits are completely filled with cement grout. The composite fabric was then placed on top of cement grout and the cement grout was squeezed through the roving of the fabric. Air bubbles entrapped at the concrete or fabric interface were to be eliminated. Then the second layer of the cement grout was applied and each of the material was then placed on top of cement grout coating and the grout was squeezed through the roving of the fabric and the above process was repeated. This operation was carried out at room temperature. Concrete beams strengthened with glass fiber fabric were cured for 28 days at room temperature before testing.

TEST SETUP

All the specimens were tested in the loading frame. The testing procedure for the entire specimen was same. After the curing period of 28 days was over, the beam was washed and its surface was cleaned for clear visibility of cracks. The most commonly used load arrangement for testing of beams will consist of two-point loading. Two-point loading can be conveniently provided by the arrangement shown in Figure. The load is transmitted through a load cell and spherical seating on to a spreader beam. This beam bears on rollers seated on steel plates bedded on the test member with mortar, high-strength plaster or some similar material. The test member is supported on roller bearings acting on similar spreader plates. The loading frame must be capable of carrying the expected test loads without significant distortion. Ease of access to the middle third for crack observations, deflection readings and possibly strain measurements is an important consideration, as is safety when failure occurs. The specimen was placed over the two steel rollers bearing leaving 75mm from the ends of the beam. The remaining 925 mm was divided into three equal parts of 308 mm as shown in the figure. Two point loading arrangement was done as shown in the fig 3. Loading was done by hydraulic jack of capacity 100 KN. Dial gauges were used for recording the deflection.



Fig 3 Instrumentation and loading setup

IV RESULT AND DISCUSSION

Five sets of beams were tested for their ultimate strengths. Deflection behaviour and the ultimate load carrying capacity of the beams were noted. The ultimate load carrying capacity of all the beams along with the nature of failure

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LOAD-DEFLECTION CURVE

Fig. 4 shows the 7th day load versus deflection for all beam specimens. As can be seen from the figure, the curves exhibit a tri-linear response defined by elastic, concrete cracking to steel yielding and steel yielding to failure stages. In the first stage, the behaviour of all the beams is linear and elastic. Before the first crack, the bond between the wire mesh, GFRP, steel bar, cement grout and concrete is perfect. In the second stage, cracking initiates in the concrete section of the maximum moment zone of the beam. At the beginning of this stage, the cracks do not pass through the integrant materials because of their higher tensile strength and low elastic modulus.

As the loading increases, the cracks become more widespread and new flexural cracks arise. In the third stage, the internal tension steel reinforcement has yielded and the NSM wire mesh, GFRP strip and steel bar controls the cracks and the width of the cracks up to failure of the beam. The ultimate load increased by 6.85%, 8.87%, 4.83% and 2.41% for NSM1, NSM2, NSM3 and NSM4 respectively, compared the control beam.

Table 5 7th day load versus deflection for all beam specimens

Sl no	Types of beams	Ultimate load (KN)	Deflection(mm)
1	CB	62	3.4
2	NSM 1	66.5	3.2
3	NSM 2	67.5	3.2
4	NSM 3	65	3.1
5	NSM 4	63.5	3.3

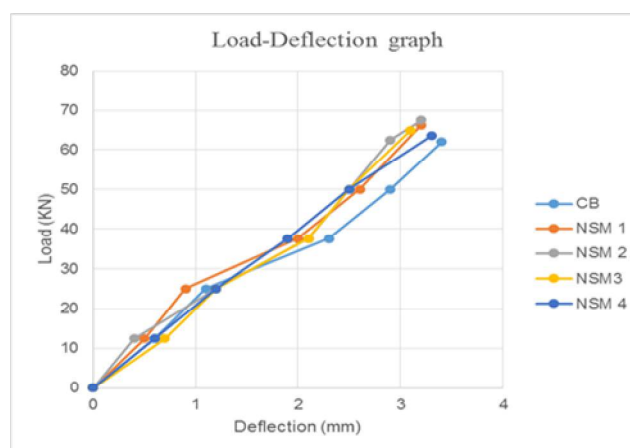


Fig 4 7th day Load-Deflection curve

Fig. 5 shows the 28th day load versus deflection for all beam specimens. As the loading increases, the cracks become more widespread and new flexural cracks arise. In the third stage, the internal tension steel reinforcement has yielded and the NSM wire mesh, GFRP strip and steel bar controls the cracks and the width of the cracks up to failure of the beam. The ultimate load increased by 6.03%, 7.42%, 4.01% and 2% for NSM1, NSM2, NSM3 and NSM4 respectively, compared the control beam.

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Table 6 7th day load versus deflection for all beam specimens

Sl no	Types of beams	Ultimate load (KN)	Deflection(mm)
1	CB	62	3.4
2	NSM 1	66.5	3.2
3	NSM 2	67.5	3.2
4	NSM 3	65	3.1
5	NSM 4	63.5	3.3

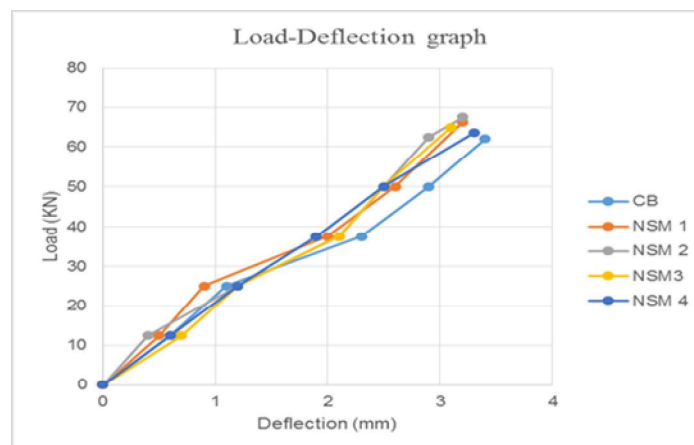


Fig 5 7th day Load-Deflection curve

Fig. 6 shows the 28th day load versus deflection for all beam specimens. As the loading increases, the cracks become more widespread and new flexural cracks arise. In the third stage, the internal tension steel reinforcement has yielded and the NSM wire mesh, GFRP strip and steel bar controls the cracks and the width of the cracks up to failure of the beam. The ultimate load increased by 6.03%, 7.42%, 4.01% and 2% for NSM1, NSM2, NSM3 and NSM4 respectively, compared the control beam.

Table 7 28th day load versus deflection for all beam specimens

Sl no	Types of beams	Ultimate load (KN)	Deflection(mm)
1	CB	87.5	4.3
2	NSM 1	92.75	4.1
3	NSM 2	94	4
4	NSM 3	91	4.1
5	NSM 4	89.25	4

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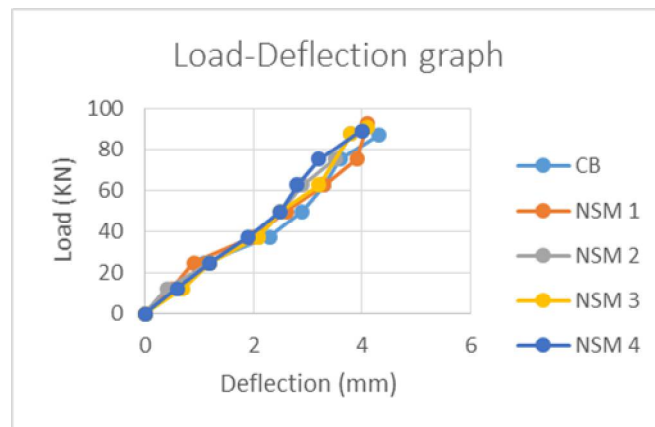


Fig 6 28th day Load-Deflection curve

FLEXURAL STRENGTH OF BEAMS

Flexure or bending is commonly encountered in structural elements such as beams and slabs which are transversely loaded. Flexural strength is measure of the tensile strength of OPC concrete, in other words it is a measure of a resistance against failure in bending. Although the probability of the structures being flexure deficient is low, failures have occurred due to a variety of factors: errors in design calculations and improper detailing of reinforcement, construction fails or poor construction practices, changing the function of a structure from a lower service load to a higher service load, seismic and wind action, reduction or total loss of reinforcement steel area causing the corrosion in service environments.

Table 8 shows the 7th flexural strength of all beams

Sl.No	Types of beams	Ultimate load (KN)	Flexural strength (N/mm ²)
1	CB	62	18.35
2	NSM 1	66.25	19.6
3	NSM 2	67.5	19.98
4	NSM 3	65	19.24
5	NSM 4	63.5	18.88

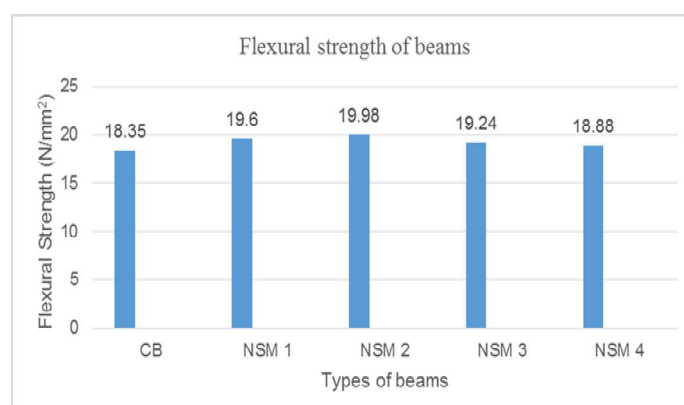


Fig 7. 7th flexural strength of beams

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Fig. 7 shows the 7th day flexural strength for all beam specimens. As can be seen from the figure, the strength of NSM 2 is higher than the other types of beams. As the loading increases, the cracks become more widespread and new flexural cracks arise. The flexural strength increased by 7%, 9%, 5% and 3% for NSM1, NSM2, NSM3 and NSM4 respectively, compared the control beam.

Table 6

Table 9. 28th flexural strength of beams

Sl.No	Types of beams	Ultimate load (KN)	Flexural strength (N/mm ²)
1	CB	87.5	25.9
2	NSM 1	92.75	27.45
3	NSM 2	94	27.82
4	NSM 3	91	26.93
5	NSM 4	89.25	26.4

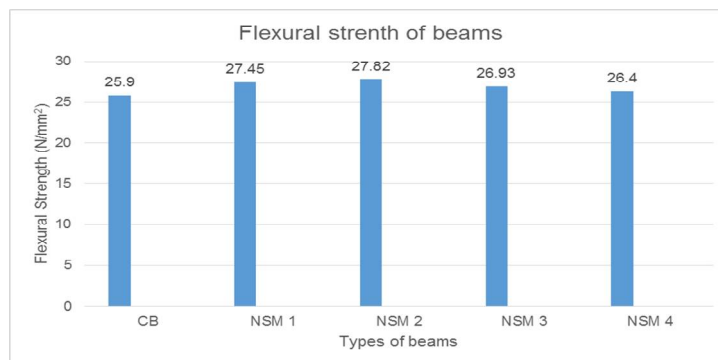


Fig 8. 28th day flexural strength for all beam specimens

Fig. 8 shows the 28th day flexural strength for all beam specimens. As can be seen from the figure, the strength of NSM 2 is higher than the other types of beams. As the loading increases, the cracks become more widespread and new flexural cracks arise. The flexural strength increased by 6%, 8%, 4% and 2% for NSM1, NSM2, NSM3 and NSM4 respectively, compared the control beam.

V. CONCLUSION

1. Initial flexural cracks appear at a higher load by strengthening the beam at soffit. The ultimate load carrying capacity of the strengthen beam The flexural strength increased by 7%, 9%, 5% and 3% for NSM1, NSM2, NSM3 and NSM4 respectively, compared to the control beam.
2. Load at initial cracks is further increased by strengthening the beam at the soffit as well as on the two sides of the beam up to the neutral axis from the soffit. The ultimate load carrying capacity of the strengthen beam NSM 1 beam was 92.75 KN which is lower than NSM 2 beam which carried an ultimate load of 94 KN and further higher than NSM 3 and NSM 4 beam which carried an ultimate load of 91 KN and 89.25 KN.
3. Flexural strengthening up to the neutral axis of the beam increases the ultimate load carrying capacity, but the cracks developed were not visible up to a higher load. Due to invisibility of the initial cracks, it gives less warning compared to the beams strengthen only at the soffit of the beam.
4. The NSM materials used in reinforced beam enhances the load- deflection response of the RC beams. At any load level, the deflections of the strengthened beams were higher than that of the control beam except in the case of NSM1 and NSM2 which was strengthened with a wire mesh.

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5. Beams strengthened with NSM wire mesh have significantly increased flexural strength than beams strengthened with NSM steel bar and GFRP strip.
6. Beams strengthened with NSM wire mesh have significantly increased yield and ultimate capacities with improvement in ductility.
7. The mode of failure observed in all strengthened beams was flexural failure.

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