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Numerical Studies on the Shear Behaviour of Near Surface Mounted RC Deep Beams with Longitudinal Hole

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***Abstract*—Near Surface Mounting(NSM) is one of the retrofitting methods which is widely used for the strengthening of structural members. Strengthening using NSM reinforcement improves the ultimate load bearing capacity of the member. This study mainly focuses on the numerical investigation on the shear behaviour of near surface mounted reinforced concrete beam under various parameters. The study investigates the ultimate capacity of the beam with longitudinal hole and beam without longitudinal hole. The hole size adopted for the study are 50mm, 65mm,75mm and 85mm. The study concentrates the strengthening of RC deep having longitudinal hole at a position 120mm from the bottom to the centre of the hole. Both horizontal as well as inclined alignment of the NSM bar were adopted. The ultimate shear capacity of the beam with and without hole by strengthening using NSM bar in both horizontal and inclined orientations are examined under two-point loading. The capacity of the beam was maximum in the case of beam with longitudinal hole strengthened with inclined NSM.**

Keywords—Longitudinal hole, NSM, RC deep beam, Ultimate capacity

I. INTRODUCTION

Concrete is a versatile building material which is widely used for the construction of several structural components. Generally, structures are built for transportation facility, living and other purposes. Among all the concrete structures about 80 to 90% structures will be required for the next 20 years after construction. But the structures may deteriorate because of the loss of ultimate capacity, corrosion of the reinforcement bars, etc. due to harsh environmental conditions. The environmental conditions include the temperature, humidity and exposure to salt water when the structure is at sea shore. The strengthening of these structures which are deteriorated is required for the long-life. There are many ways to strengthen the structural components of a structure such as beams columns etc. Some of the methods are section enlargement (jacketing), attaching steel plates to the surfaces of the beams, external reinforcement, fibre reinforced polymer (FRP) externally and unbounded-type strengthening techniques, steel clamping, and post-tension units.

Near Surface Mounting is a retrofitting method which is mainly applicable in reinforced concrete beams and slabs. This technique is used for the strengthening of beams by using different types of reinforcements. The reinforcement may be steel, carbon bars or carbon fiber reinforced polymer plates. This strengthening is provided by creating grooves on the surface at positive and negative moment regions of the beams and inserting the NSM reinforcement in the groove and filling by using the epoxy paste [1]. The groove should have the minimum size of 1.5 times the diameter of the NSM bar. The epoxy paste gives adequate bond between the reinforcement and the concrete. NSM reduces the mechanical damages, fire damages and vandalism. The stiffness and flexural strength of the beam can be increased by NSM method and crack width can be reduced. Fiber reinforced polymers are widely used for retrofitting using NSM method because of its promising performance. The efficiency of the NSM is very high as compared to Externally Bonded Reinforcement (EBR) method [5].

Since the concrete is very heavy, the self-weight can be reduced by providing the hole in it and this hole can be used for conveying cables of electricity, telephones etc. through it. [17,18].

NSM improves the load carrying capacity of the structural member. Normally the Near Surface Mounting methods will not take load at the beginning. So Post-tensioning technique in NSM in which the strengthening performance can be modified and it carries the load from the very begining itself [6]. For post-tensioning its good to use FRP laminates which improves the ultimate capacity by a large extent. FRP strips are also used for srengthening beams [20].

The flexural strength can be increased by Side Near Surface Mounting method on the damaged structural beam member. The SNSM method was introduced to overcome the demerits of NSM method and to increase the flexural strength and also the serviceability of the whole structure. SNSM can be done using steel and CFRP. [8,25]. Several studies were carried out under monotonic loading. Since cyclic also causes deterioration in beams in structures it should be considered. [13]. NSM method is also effective in glu-laminated timber beams. CFRP laminates are using for strengthening glulam beams [15]. Under shear strengthening the rods of NSM FRP are used for strengthening and which provides promising strength to the member [22].

For finding the shear strength contribution of the NSM FRP on RC beams, two factors should be considered. They are the constitutive law of the average-available bond-length NSM FRP strip effectively crossing the shear crack, and the maximum effective capacity it can attain during the loading process of the strengthened beam [4]. The shape of the beams also plays an important role. The ultimate capacity of the T beams strengthened with NSM were improved for an extent.

And the presence streel stirrups does not diminish the shear contribution of NSM FRP [19]. The strengthening is very much effective in the case of normal beams as well as in the case of deep beams [9,21].

The Near Surface Mounting is the best method of retrofitting deep beams. Since deep beams are very expensive to construct its mandatory to retrofit the beams that are deteriorated to improve the life span. For that NSM is one of the best method.

II. VALIDATION

A. *Description of experimental model*

The experimental result obtained from the experiment conducted on the continuous reinforced concrete beam with different NSM strengthening by researches [1] was numerically validated. The dimensions of the beam were 150mm X 225mm with a length of 3000mm. The results of the analysis of continuous beam under four-point bending were taken and modelled. Material properties were taken from the experimental data. The nonlinear static analysis of the beam was carried out. Numerical analysis results were compared with experimental results. The model used for validation was strengthened with NSM bars, which is provided with a length of 0.9 times the effective length at positive moment region and 0.8 times the effective length of the beam at negative moment region.

B. *Finite element model*

The validation of the continuous reinforced concrete beam is done using ANSYS workbench 19.1. The validation was done on a concrete specimen which was strengthened with NSM method using steel bar of 10mm diameter as the NSM material and was placed at top and bottom of the beam for a length, depends on the effective length of the specimen.

The model of the reinforced concrete beam specimen was developed with the help of design modeller in ANSYS workbench. The reinforcement provided are 4 bars of 10mm diameter two at tension side and two at compression side of concrete. The stirrups provided are of 10mm diameter at spacing of 100mm. The NSM was provided at top and bottom surface of the beam and the length of the NSM bar at top was 0.8 times the effective span and at the bottom was 0.9 times the effective span for the particular specimen [1].

Since the cross section of the specimen is uniform Beam element solid 187 was used for modelling the beam. Solid 188 is a two-node element with six degrees of freedom and solid 187 is a higher order 3-D ten node element having a quadratic displacement behavior. For providing steel concrete interaction CONTA174 and TARGE17 elements were used. The supports are simply supported and for analysis remote displacements were assigned for all three supports. The loading was applied as displacement at the top of the beam as two-point loading. The ultimate load as well as the displacement obtained from the finite element analysis were compared with the experimental data obtained by the researchers [1].

Since all the three supports are roller supports, remote displacements were given by allowing the rotation in Z direction.

The ultimate load obtained from the experiment is 260.8 kN and that from the finite element analysis is 279.89 kN. Hence it shows an error of 7.31%.

TABLE I COMPARISON OF RESULTS

	Experimental model	FEA model	Error percentage
Load (kN)	260.8	279.89	7.31

III. PARAMETRIC STUDY

The study was conducted by considering various parameters. In that the first one is analysis of the deep beam with longitudinal hole and checking the shear capacity of the beam and comparing it with the deep beam without hole. Another study was, introducing of Near Surface Mounted reinforcement in deep beams to improve the shear capacity of the beam. For that particular study two types of NSM orientation was chosen. One is horizontal orientation and the second one is inclined orientation. Horizontal NSM was provided at the sides of the hole and inclined NSM was provided at the side surface with 45^0 inclinations. By varying the diameter of the hole the shear capacity and load carrying capacity of the beams were checked. Fig. 1 and Fig 2. Shows the beams with horizontal NSM and inclined NSM.

For conducting the finite element analysis, a deep beam with longitudinal hole was chosen. The hole in the beam was positioned below the neutral axis of the beam. The exact position of the hole was that the distance from the bottom of the beam to the centre of the hole was 120mm. The size of the beam chosen was 400mm X 150mm with a length of 1400mm. The RC deep beam without hole was taken as the control specimen having same dimensions. The beams were simply supported over a clear span of 1140mm. The reinforcement provided for the beam was of three bars of 16mm diameter bars as tension reinforcements, 2 bars of 6mm diameter bars as tension reinforcements, 4 bars of 6mm diameter as horizontal shear reinforcement and vertical shear reinforcements are provided as 6mm diameter bars at 100mm centre to centre spacing. The grade of concrete was M25 and grade of steel was Fe415. The hole diameter adopted were 50mm, 65mm, 75mm and 85mm.Fig. 3 and Fig. 4 shows the cross section details of the deep beam.

The beams are loaded with two point loading. The load point was defined based on the shear span to effective depth ratio. For deep beams the shear span to effective depth (a/d) ratio should be less than 2. Here the shear span to effective depth ratio was taken as 1. The beam was simply supported. i.e, the beam was supported with hinge at one end and roller at the other end.

Fig. 5 shows the maximum shear stress Versus shear strain graph of the beams with horizontal NSM with hole sizes 50mm,65mm,75mm and 85mm. The result shows the increase in the hole diameter in the deep beam strengthened with horizontal NSM, the shear strength of the beam was decreasing. The maximum shear strength was obtained in the beam with 50mm hole diameter and minimum shear strength is obtained in the beam with 85mm hole diameter. The beam with hole of 50mm diameter gives a shear stress of 18.982 MPa with the corresponding strain of 0.00062617. Similarly, the

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lowest value of shear stress was, for the beam with 85mm hole diameter, which was 16.176 MPa with a stain of 0.00060492.

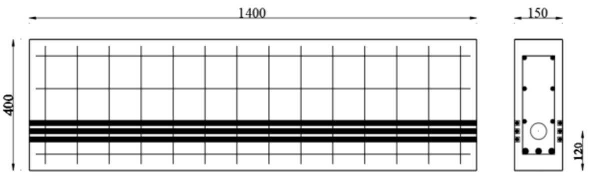

Fig 1. Beam with hole strengthened with horizontal NSM

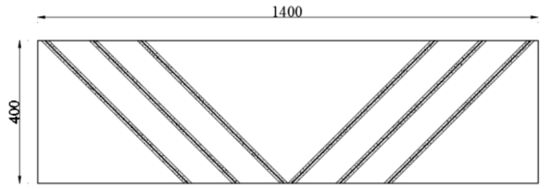

Fig 2. Beam with hole strengthened with inclined NSM

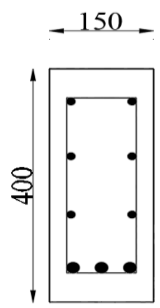

Fig. 3. Cross section of the deep beam without hole
(All dimensions are in mm)

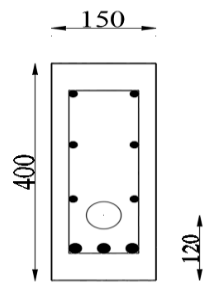

Fig. 4. Cross section of the beam with hole
(All dimensions are in mm)

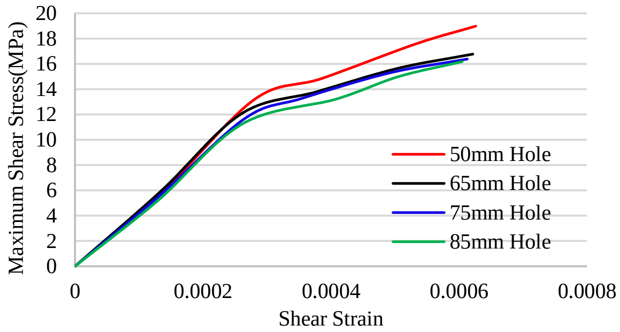

Fig. 5. Shear stress strain curve of beam with horizontal NSM

Fig. 6 shows the comparison of the maximum shear stress of the beam without longitudinal circular hole and beam with longitudinal circular hole at different hole sizes. the increase in the hole size decreases the shear capacity of the beam. The NSM provided gives a slight increase but it will not even be comparable with the beam without hole. The maximum shear stress comparison shows the reduction in the shear stress value of 25.67%,15.75%,13.68% and 12.37% for the beams with hole of diameter 50mm, 65mm, 75mm and 85mm respectively with the control specimen. The percentage increase in the minimum value of shear stress to the maximum value of shear stress is 14.78%.

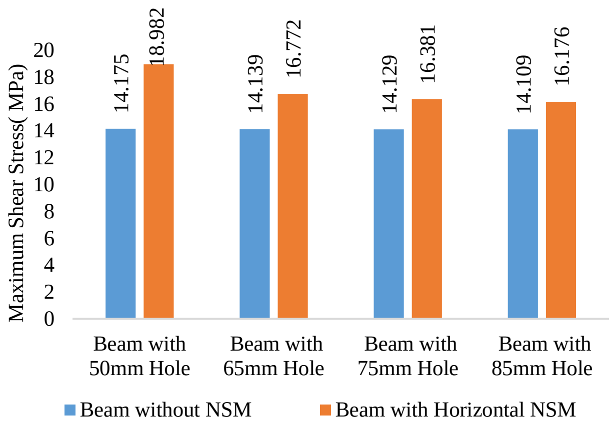

Fig. 6. Maximum shear stress diagram

The shear capacity of the RC deep beam with longitudinal hole at 120mm from bottom to the centre of the hole strengthened with inclined NSM were checked. Fig 7. shows the comparison of the stress strain curve of the hollow beam with hole size 50mm,65mm,75mm and 85mm strengthened with inclined NSM.

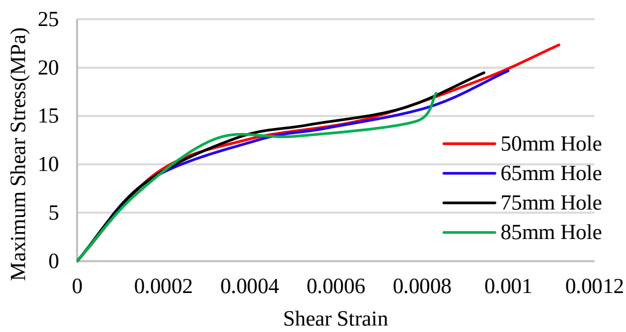

Fig. 7. Shear stress strain curve of beam with inclined NSM

Maximum shear capacity obtained from the analysis was for the beam with 50mm hole diameter and that of minimum shear capacity was for the beam with 85mm hole diameter. That is, by increasing the diameter of the hole the shear capacity of the beam is decreasing. The maximum shear obtained was 22.341 MPa the lowest value of shear stress obtained was 17.348 MPa. These shear stress values are of the beams with hole diameter of 50mm and 85mm respectively.

Fig. 8 Shows the comparison of the maximum shear capacity of the beam with longitudinal circular hole and the beam without longitudinal circular hole. The Maximum shear capacity obtained from the analysis was for the beam with 50mm hole diameter and that of minimum shear capacity was for the beam with 85mm hole diameter. That is, by increasing the diameter of the hole the shear capacity of the beam is decreasing. The maximum shear obtained was 22.341 MPa the lowest value of shear stress obtained was 17.348 MPa. These shear stress values are of the beams with hole diameter of 50mm and 85mm respectively.

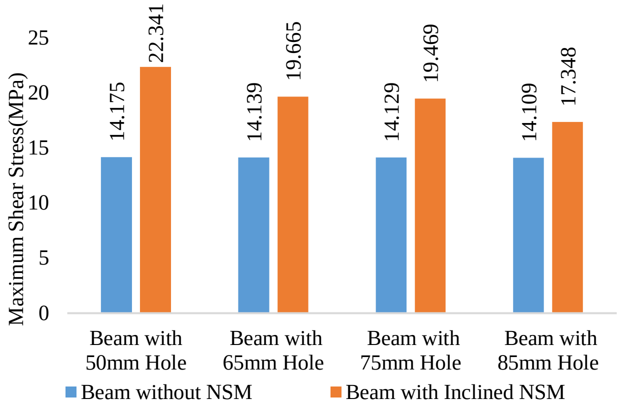

Fig. 8. Maximum shear stress diagram for beam with inclined NSM

Fig. 9 shows the comparison of the shear stress of the beam with hole size 50mm strengthened with horizontal NSM and the beam with hole 50mm strengthened with inclined NSM. The shear stress was more in the case of beam with inclined NSM as that of the beam with Horizontal NSM. The maximum shear obtained in the analysis of deep beam with horizontal NSM was 18.982 and that of inclined NSM was 22.341 MPa. The variation in the shear value in percentage was 15.03%.

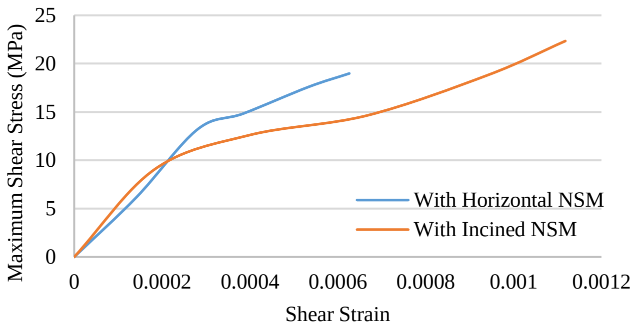

Fig. 9. Stress strain curve of beam with 50mm hole

Fig. 10 represents the shear stress verses shear strain curve of the beam with hole size 65mm strengthened with horizontal NSM and the beam strengthened with inclined NSM. the stress was more in the case of beam with inclined NSM. The beam with horizontal NSM has the maximum shear stress of 16.772 MPa and the beam with inclined NSM has the maximum shear stress of 19.665MPa which shows the increase in the shear stress value about 14.71%.

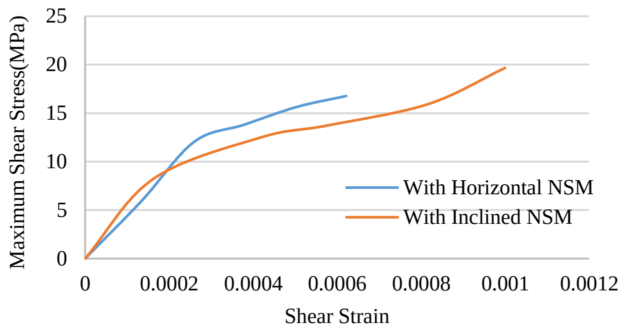

Fig 10. Stress strain curve of the beam with 65mm hole

The relation between shear stress and shear strain values of the beam with hole size 75mm strengthened with horizontal NSM and the beam strengthened with inclined NSM were represented by Fig.11. The maximum stress obtained for the beam with horizontal NSM was 16.381 MPa and that of beam with inclined NSM was 19.469 MPa. The both stress values were compared and the strength improvement was noted. The improvement in strength was 15.86%. That is the maximum shear capacity was for the beam strengthened with inclined NSM.

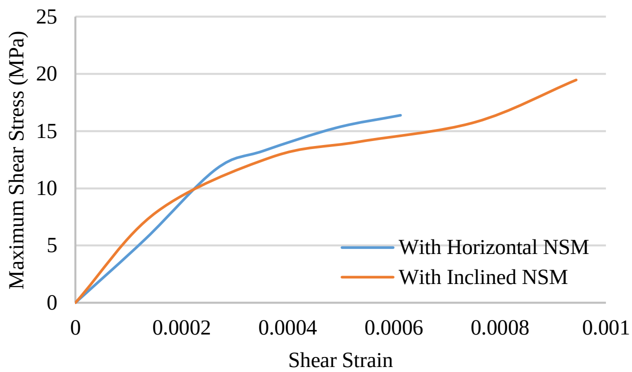

Fig.11. Stress strain curve of the beam with 75mm hole

Fig. 12 shows the comparison of the shear stress of the beam with hole size 85mm strengthened with horizontal NSM and inclined NSM. the shear capacity was more in the case of the beam with inclined NSM as compared to the beam with horizontal NSM. The percentage variation in the shear stress of the beam was 6.75%. The sudden decrease in the shear stress of the beam was because of the reduction in the cross sectional area.

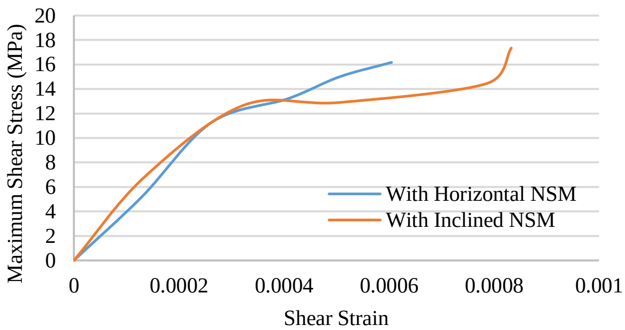

Fig. 12. Stress strain curve of beam with 85mm hole

IV. CONCLUSION

The intension of this study is to investigate the shear behaviour of Near Surface Mounted (NSM) reinforced concrete deep beams having hole along its length at 120mm from the bottom to the centre of the hole. A numerical model was validated against experimental model of Abdzaid H. M. et. al. (2019) and the following conclusions are drawn from the investigation.

- For the beams examined the shear capacity of the beams decreases with increase in the hole size from 50mm to 85mm.
- In the case of horizontal NSM, beam with 50mm hole shows the maximum increase in the strength of 25.67% and beam with 85mm hole shows minimum increase in strength of 12.37%.
- In the case of inclined NSM, beam with 50mm hole shows the maximum increase in the strength of 16.01% and beam with 85mm hole shows minimum increase in strength of 10.57% in the case of inclined NSM.
- For strengthening of deep beams with longitudinal hole, strengthening with inclined NSM is more effective as compared to the strengthening with horizontal NSM.

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