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RETROFITTING OF REINFORCED CONCRETE COLUMNS BY NSM REINFORCEMENT

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Abstract- Near surface mounted (NSM) method is one of the promising solutions for increasing the flexural and shear strength of deficient reinforced concrete (RC) members. It has also been used to increase the load-carrying capacity and ductility of poorly detailed RC columns. This paper presents the results of an experimental program aiming to study the compressive behavior of small sized RC column specimens strengthened with different configurations of near-surface mounted (NSM) steel reinforcement. The parameters considered were the number of stirrups added at (48mm and 96mm), diameter of stirrups (6.35mm and 9.5mm), bonding material (grout and epoxy), and type of confining material (steel rebar and wire). Test results indicated that both the peak and post-peak strengths were significantly increased by all the different configurations considered. NSM steel reinforcement also changed the failure mode from brittle to ductile. In general, providing additional steel stirrups to poorly detailed RC columns can significantly improve the post-peak behavior without changing the member sizes.

Keywords- Near surface mounted reinforcement; retrofitting; RC columns; stirrups.

1 Introduction

Recent earthquakes have proven the vulnerability of existing reinforced concrete (RC) columns to seismic loading. In a structure, columns are the critical members which may fail due to the crushing of concrete, rebar buckling, shear, flexural or the bond at lap-splice as a result of poor detailing. Retrofitting of RC columns may be addressed successfully by using externally bonded fiber reinforced polymer (FRP) composite materials. FRPs in the form of jackets provided in circumferential direction are quite effective in taking shear stresses and providing confinement to concrete which results in increasing deformational capacity of columns [1]. However, these FRPs are expensive for large scale applications in Pakistan, as these materials are not locally manufactured and imported from abroad. Secondly, a considerable amount is further required to cover and protect the retrofitted surfaces against fire. Previously, strengthening of RC columns was mostly achieved by providing RC or steel jacketing which is covered by shotcreting. RC or steel jacketing needs intensive labor work and artful detailing which increases the dimensions and weight of existing member resulting in substantial obstruction of occupancy and making the building more vulnerable to an earthquake. Moreover, due to an increase in stiffness, RC or steel jacketed members may attract more forces. Therefore, the development of low cost and minimal obstruction strengthening technique for RC columns is still a challenging task.

Near surface mounted (NSM) reinforcement, also named "grouted or embedded reinforcement", involves creating a series of grooves in the concrete cover and inserting reinforcing bars or strips inside to improve the strength of the members. Previous studies so far on NSM reinforcement for RC structures have focused on flexural strengthening of beams or slabs with an emphasis on bond aspects [2-4], and on flexural strengthening with prestressed NSM FRP bars [5-6]; the most recent studies in this area is reported in [7]. Hassan et al. presented both experimental and analytical investigations undertaken to evaluate bond characteristics of near surface mounted carbon FRP (CFRP) strips [8]. In another study by Jalalai et al. [9] they observed the effectiveness of NSM method by using innovative technique which involved manually made FRP rod for enhancing the shear strength of RC beams. They discussed the results of a series of tests conducted on simply supported RC beam with and without the proposed anchors. The proposed manually made fiber reinforced polymer (MMFRP) rods and end anchorage increased the shear capacity of beam from 25% to 48% along with significant increase in ductility.

Previous literature shows that very little work is done on the use of NSM steel reinforcement to strengthen the poorly detailed RC columns. The concept of providing additional steel stirrups without changing the column cross section has not been paid much attention in the past. Therefore, in this paper, findings of an experimental study are presented to explore the effectiveness of NSM steel stirrups in enhancing the poorly detailed RC column specimens.

2 Experimental Program

A total of sixteen small sized square RC column specimens were manufactured and tested under axial compression. All specimens had same dimensions which is 150×150mm, with 300mm height. In all specimens 4 #3 (9.5mm diameter) deformed longitudinal bars were used with two stirrups of #2 (6.35mm diameter) at the two ends to represent poorly detailed columns with a length-to-diameter ratio of about 20 for longitudinal bars. The parameters considered were the number of stirrups added at (48mm and 96mm), diameter of stirrups (6.35mm and 9.5mm), bonding material (grout and epoxy), and type of confining material (steel rebar and wire). Descriptions of specimens are given in Table 1.

Table 1- Specimen details

Specimen notation	**Stirrup spacing (mm)**	**Number of specimen**	**Type of NSM reinforcement**	**Bar size**	**Binder**
S_nU_{200}	200	2	Nil	Nil	Nil
S_nU_{96} R_2	96	2	Steel bars	6.35mm	Cement grout
S_nU_{48} R_2	48	2	Steel bars	6.35mm	Cement grout
S_nU_{96} R_3	96	2	Steel bars	9.5mm	Cement grout
S_nU_{48} R_3	48	2	Steel bars	9.5mm	Cement grout
S_nU_{48} W_{10}	48	2	Binding wire	0.82 mm	Cement grout
S_n U_{48} R_2E	48	2	Steel bars	6.35mm	Epoxy resin
S_nU_{96} R_2E	96	2	Steel bars	6.35mm	Epoxy resin

In Table 1, specimens' notation is as follows: the first symbol "S_n" denotes the specimen number, the second symbol "U" denotes the external stirrup spacing in mm, "R" denotes the reinforcement with number of bar in subscript, "W" denotes the binding wire, and "E" denotes the epoxy resin. For example, specimens $S_nU_{96}R_2$ and $S_nU_{48}R_2$ were strengthened with NSM stirrup at spacing of 96 and 48mm, respectively, using 6.35mm bar, while in specimens $S_nU_{96}R_3$ and $S_nU_{48}R_3$, 9.5mm bars were used. Specimen $S_nU_{48}W_{10}$ was strengthened with steel binding wire having diameter equivalent to that of 9.5mm. Similarly, for specimen $S_nU_{48}R_2$, high strength cement grout was used to fill the groove whereas for specimen $S_nU_{96}R_2E$, groove was filled with epoxy resin.

2.1 Material properties

Concrete with a mix ratio of 1:2:4 (cement: sand: aggregate) was used to cast the column specimens and cylinders. The 28-days concrete strength obtained by testing two cylinders was about 20 MPa. Sikagrout-114 was used as a filling material for grooves. Sikagrout-114 is a high-performance cementitious material that is free-flowing and general-purpose grout with a 65MPa ultimate strength at 28 days. For NSM steel stirrups, two sizes of deformed steel bars were used: #2 (6.35mm diameter) and #3 (9.5mm diameter) having yield strength of 422 and 450MPa, respectively. In one specimen, binding wire was used as NSM reinforcement in place of steel stirrups. The wire diameter was 0.82mm and it was wrapped 62 times around the specimen as an equivalent to 9.5mm. In some specimens, epoxy resin was used for NSM bar embedment having 7-day strength of 30MPa.

2.2 Specimen preparation

A total of sixteen specimens were prepared along with control specimens. Firstly, molds of required dimensions were prepared from plywood sheets. The steel cages were then prepared along with spacers which were connected to steel cage to maintain a 25mm clear cover, as shown in Figure 1.

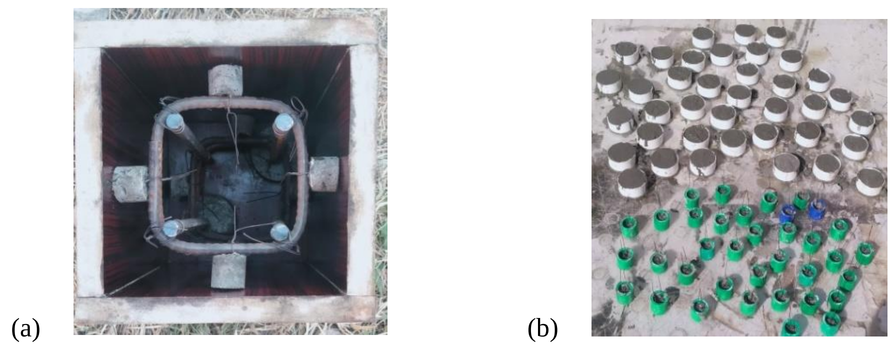

Figure 1: a. Mould of specimen with spacer of 25mm, b. 25mm spacer for both side and bottom cover

After 28 days of concrete casting, RC specimens were grooved 20mm wide and 20mm deep using concrete grinding machine. When the surface preparation was completed, the NSM reinforcement was placed as shown in Table 1 and Figure 2. The steel stirrups were in C shape which were then welded at the center of flat sides of square specimen. The grooves were filled by cement grout or epoxy resin, accordingly, as shown in Figure 2.

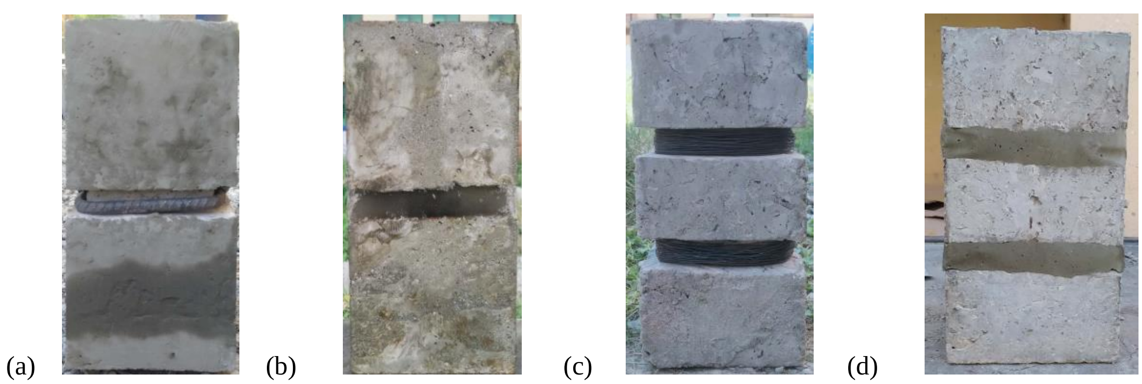

Figure 2: Grooved specimen, a. specimen with one horizontal groove, b. specimen (a) with epoxy resin, c. binding wire along with two horizontal grooves, d. specimen (c) with cement grout

2.3 Testing setup

All the specimens were tested under compression in a universal testing machine (UTM) of CONTROLS with a maximum capacity of 5000KN. The specimens were tested under displacement-controlled manner with a speed of 1 mm/min. Axial deformation of specimens was recorded through a dial gauge mounted on the specimen with a run of 50 mm. It is to be noted that in this paper only the strength results are presented. The load was obtained from the built-in load cell of UTM.

3 Results and Discussion

3.1 Failure modes

In control specimens with no NSM stirrups, small vertical cracks were developed near the peak strength at the specimen corners. These small cracks grew faster and projected towards the mid height in the post-peak region. The onset of buckling of longitudinal bars then resulted in the formation of major vertical cracks around the corners and spalling of concrete cover, as can be seen in Figure 4a. Because of large stirrup spacing i.e., 200 mm, central concrete core was poorly confined and was observed to be damaged badly. In specimens with one NSM stirrup and grout filling, comparatively less damage was observed at the central concrete core and cover. Buckling of longitudinal bars was reduced because of reduced stirrup spacing i.e., 96mm. Stirrups were remained closed, and no weld failure was observed. The grout filling in the grooves performed well and allowed only major cracks to be developed on surface, see Figure 4b. The addition of two NSM stirrups further reduced the buckling length of longitudinal bars i.e., 48mm, which resulted in even less damage both in the concrete core and cover. Figure 4c shows the damaged specimen with NSM steel binding wires. It is interesting to note that no wire failure was observed until the end of test. Furthermore, no appreciable major corner cracks and concrete cover spalling was observed at higher deformation level. Binding wire wrapped specimens had shown better result in ductility as well as in crack pattern, as shown in Figure 4c. Specimens with epoxy resin as filling material also showed better results by showing an obstacle to crack path which did not allow cracks to extend in their respective path. In these specimens, vertical cracks above and below the epoxy resin were observed, see Figure 4d.

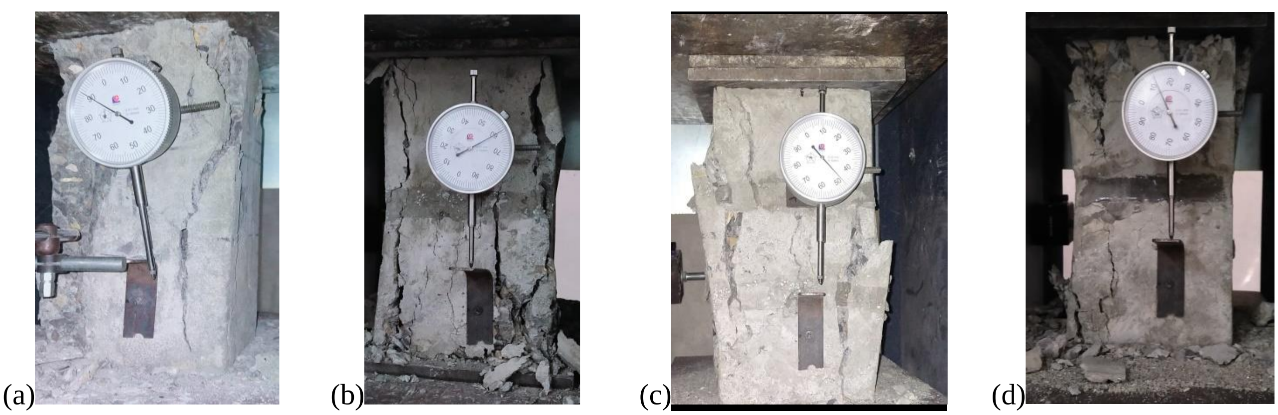

Figure 4: Cracked specimen, a. controlled specimen, b. specimen with one stirrup, c. wire wrapped specimen, d. specimen with epoxy as a bonding agent

3.2 Effect of number of NSM stirrups

Figure 5 shows the effect of NSM stirrup spacing on the peak and post-peak ultimate residual strengths of poorly detailed square RC column specimens. The post-peak ultimate residual strength is the strength in post-peak region when no further drop is observed, and the curve becomes almost horizontal. It can be observed in Figure 5a and 5b that both the peak and post-peak residual strengths were improved significantly with an increase in NSM stirrups. For example, the peak strength was increased from 434.4 to 570 and 639kN when control specimen was retrofitted with one and two NSM 6.35mm steel stirrups, respectively, see Figure 5a. It can be concluded that with the addition of NSM stirrups, not only the buckling length of longitudinal steel bars was reduced, but the central concrete core was also more effectively confined which resulted in higher peak and post-peak strengths.

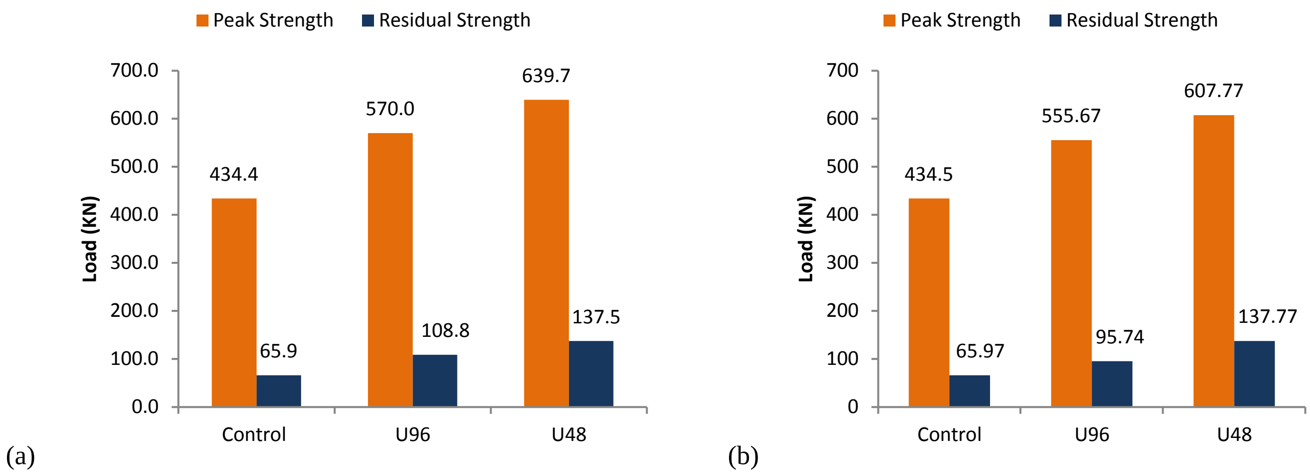

Figure 5: Effect of stirrup spacing, a. 6.35mm stirrup, b. 9.5mm stirrup

3.3 Effect of NSM stirrup diameter

Figure 6 shows the effect of NSM stirrup diameter for a particular spacing on the load caring capacity of square RC column specimens. It is interesting to note that the strength increment for NSM 6.35mm steel stirrups is more than that for 9.5mm both for 96 and 48mm spacings. For example, in specimens with 96mm stirrup spacing, compared to the peak strength of 569.9 kN for 6.35mm stirrups, strength was increased from 434.4 to 555.7kN for 9.5mm stirrups. It was observed during the testing that 9.5mm stirrup was fractured near the bent in the post-peak region which indicated its brittleness compared to 6.35mm stirrups. Similar observation was recorded for specimens with 48mm stirrup spacing.

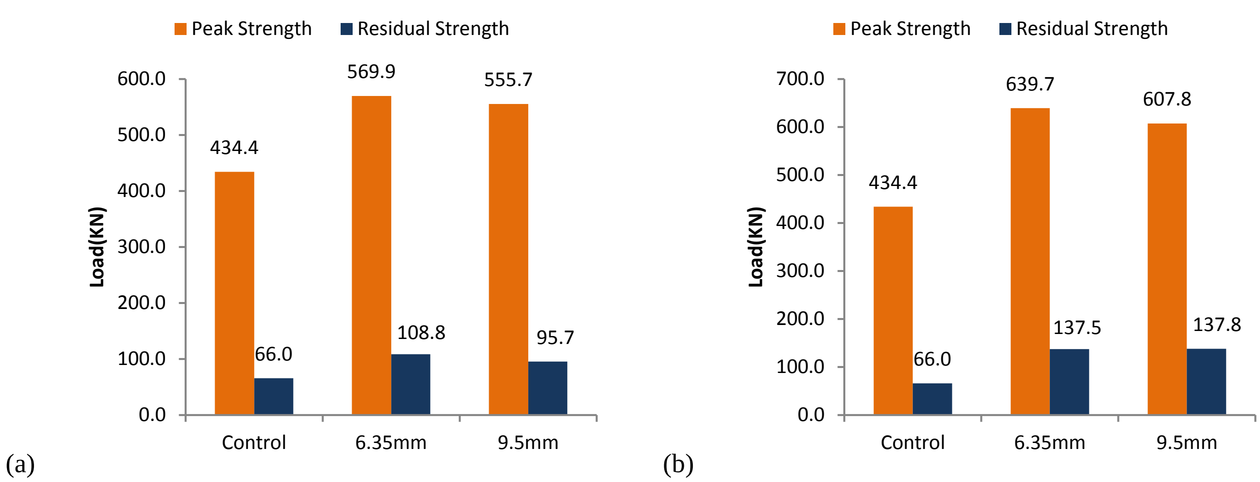

Figure 6: Effect of diameter of stirrup, a. 96 mm spacing, b. 48 mm spacing

3.4 Effect of bonding material

Figure 7 depicts the effect of groove bonding material on the peak and residual strengths of RC square specimens. In case of specimens with 96mm stirrup spacing, peak strength is higher for grout filling compared to the epoxy filling, however, the residual strength is higher for specimens with epoxy resin, see Figure 7a. On the other hand, in specimens with 48mm stirrup spacings, both the peak and residual strengths were higher for specimens with epoxy resin compared to the specimens with grouting, see Figure 7b. Higher strengths of specimens with epoxy resin could be due to better tensile properties of epoxy resin which did not allow cracks to pass through it and increased the effective confinement of stirrups. The high peak strength of specimens with 96mm stirrup spacing and grout filling in Figure 7a needs further investigation.

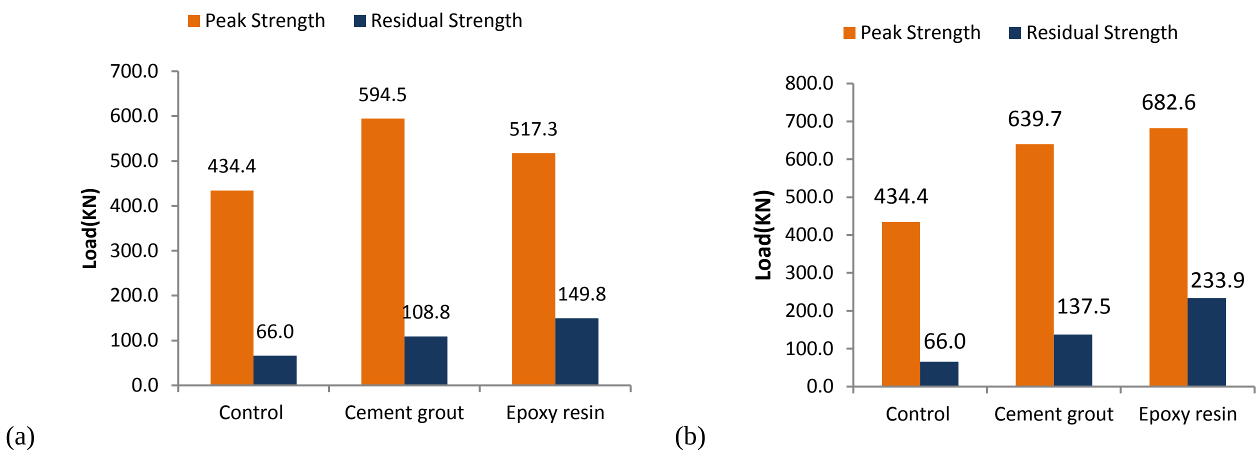

Figure 7: Effect of bonding material, a. 96 mm stirrup spacing, b. 48 mm stirrup spacing

3.5 Effect of stirrup type

Figure 8 shows the comparison of NSM binding wire and steel bar as a stirrup. The peak load capacity of specimen with steel bar is more than that of specimen with binding wire. The reason could be the less flexural stiffness of small diameter wires compared to the steel bars, however, the difference in strength is only 4%. Interestingly, the residual strength in case of binding wires is 167.9kN which is significantly higher than 137.8kN in case of steel stirrups. The reason could be the high tightness of binding wire achieved during wrapping compared to steel bar which were not so tight to the core.

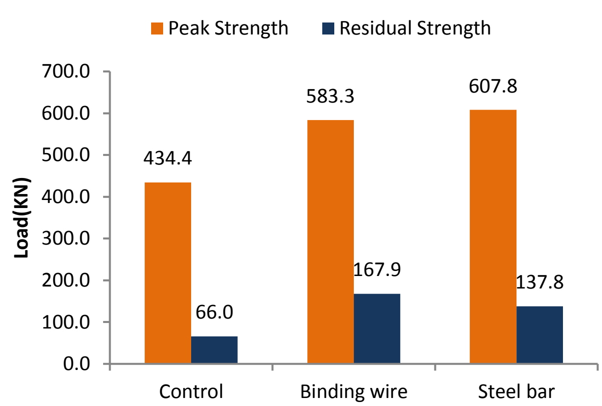

Figure 8: Effect of stirrup type at 48mm spacing

4 Conclusion

The main goal of this research work is to observe the effect of NSM steel stirrups on the axial compressive behavior of RC column specimens. The influence of NSM reinforcement type (steel stirrups/steel wires) and bonding material on the compressive behavior of reinforced concrete was is investigated. From the test results the following conclusions can be drawn:

- The peak and post-peak strengths of poorly detailed RC column specimens can be increased by providing confinement through NSM stirrups. In general, the overall compressive behavior improves with an increase in number of NSM stirrups.
- There is no significant impact of bar diameter on peak and ultimate strengths. The performance of 6.35mm stirrups is better than that of 9.5mm stirrups.
- Filling of grooves by epoxy resin is more effective for post-peak response because of its better tensile properties compared to grout.
- Binding wire, if used as NSM stirrup, has significant effect on the post-peak strength because of its high ductility and progressive nature of failure.
- In general, NSM steel stirrups are very effective in shifting the brittle failure mode of poorly detailed columns to ductile one.

Acknowledgment

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