Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 51(1) (2019) 43-46
DOI: 10.22060/ceej.2017.13230.5351

Strengthening of RC Columns with NSM Bars and CFRP Jacketing

M. Esfandi Sarafraz[1*], F. Danesh[2]

[1] Department of Civil Engineering, Islamic Azad University, West Tehran Branch, Tehran, Iran
[2] Department of Civil Engineering, KNT University of Technology, Tehran, Iran

ABSTRACT: This paper shows the results of an experimental study on the behavior of rectangular reinforced concrete columns that strengthened in bending with NSM FRP bars and CFRP jacketing under combined compression axial load and cyclic lateral loading. Near surface mounted (NSM) fiber reinforced polymer (FRP) is one of the best retrofitting techniques for reinforced concrete (RC) structures. This technique is based on inserting fiber reinforced polymer bars into slits in the cover of reinforced concrete members. For this purpose, seven rectangular RC columns including one control specimen constructed and tested under constant axial load and lateral cyclic displacement. Experimental parameters include different ratios of NSM FRP bar, maximum lateral load capacity, and failure modes are describes based on the test results. The crack patterns in the specimens are also presented. Also, the study was designed to evaluate the necessity of anchoring the end of NSM FRP bars in the foundation. The test results show that a significant increase in the load carrying capacity, stiffness, and energy dissipation of rectangular RC columns can be achieved by using the NSM technique.

Review History:

Received: 5 August 2017
Revised: 2 December 2017
Accepted: 12 December 2017
Available Online: 26 December 2017

Keywords:
Flexural Strengthening
NSM
FRP
Reinforced Concrete Column

1- Introduction

Reinforced concrete columns are the most important elements in the structures hence their damage leads to the failure of the building, thus strengthening of these elements is very essential. The most conventional technique for flexural strengthening of RC columns consists of the adding of concrete and steel jackets. Yet, these methods may not be very feasible due to unfavorable section enlargement or construction limitation.

In recent years fiber-reinforced polymer (FRP) materials are used for retrofitting of reinforced concrete structures due to its benefits in the facility of installation, strength, weight, and durability [1, 2]. The FRP jackets can modify compression strength, shear strength, and ductility of the column, but it cannot improve flexural strength of RC columns [3]. Near-surface mounted (NSM) FRP bars are another method that could be used to modify the flexural strength of RC columns [4, 5].

Only a few research investigations are available that deal with RC columns strengthened in bending with NSM FRP bars [6-10]. In this study, a retrofitting method, based on the inserting of NSM FRP bars is used to improvement the flexural strength of RC columns. For this goal, a test program was carried out. Flexural strengthening was got by inserting NSM FRP bars on the cover of the columns. In addition, the strengthened columns were wrapped with carbon. The columns were tested to failure by applying constant compressive load and cyclic lateral displacement. The behavior of strengthened columns and their failure modes are described.

Corresponding author, E-mail: sarafraz.m@wtiau.ac.ir

2- Specimens

Seven specimens were constructed and tested. The height of all specimens was 1000 mm and the cross-section was 200 mm in width and depth. Four longitudinal reinforcement bars with 14 mm diameter were placed around the section sides (reinforcement ratio: 1.53%). The shear reinforcement hoops were 10 mm diameter with the spacing of 100 mm for all columns.

The following naming is used: Control was an un-retrofitted column as the benchmark for comparison with other retrofitted columns. R1-A-C0 was retrofitted with one anchored NSM bar symmetrically placed on each of two opposite sides of the column. R2-A-C0 was strengthened with two anchored NSM bars symmetrically placed on each of two opposite sides of the column. R1-NA-C0 was strengthened with one NSM bar symmetrically placed on each of two opposite sides of the column, similar to specimen R1-A-C0, but without end anchoring. R1-NA-C1 had the same NSM reinforcement as R1-NA-C0 and an additional one layer CFRP jacket. R1-A-C1 had the same NSM reinforcement as R1-A-C0 and an additional CFRP jacket, as used in R1-NA-C1. Also, R2-A-C1 had the same NSM reinforcement as R2-A-C0 and an additional confining jacket, as used in R1-NA-C1.

The nominal concrete strength at 28 days was 21 MPa. The nominal yield stress of longitudinal and transverse steel reinforcement was 400 MPa. The tensile strength of NSM bars and CFRP jackets were 760 and 3800 MPa, respectively. The modulus of elasticity of NSM bars and CFRP jacket were 40.8 and 240 GPa, respectively. The ultimate strain of NSM bars and CFRP jacket were 1.6% and 1.55%, respectively. The thickness of CFRP jacket was 0.176 mm. In the tests, the lateral displacement rates were chosen as the ratio of 5 mm. The lateral loading consisted of three cycles at each displacement level.

3- Results and Discussion

Test results including the increase in peak force, displacement ductility, and energy dissipation are given in Table 1. Figure 1 compares the envelopes of the load-displacement behavior of specimens. In general, columns with NSM bars showed an improvement in lateral strength capacity. Columns strengthened with more NSM bars, improved the overall lateral capacity when compared to the similar specimen strengthened with less NSM bars.

According to Table 1, specimens that were retrofitted by both jacketing and NSM FRP bar have the largest ductility ratios. As a result, the combination of NSM bar and CFRP jacketing is the best way for increasing ductility. Also, the ductility of specimen R1-A-C0 with the lower NSM bars is higher than that of R2-A-C0.

Comparing the energy dissipated capacity for specimens R1-A-C0 and R2-A-C0 show that the cumulative energy dissipated capacity for specimen R2-A-C0 with the larger number of NSM bar is higher than specimen R1-A-C0. So that, increasing the number of NSM bar increases the dissipated energy capacity. Comparing the lateral force-displacement envelopes shown in Figure 1, showed that anchoring the NSM bars to the foundation as in the case of column R1-A-C0 increased the lateral load capacity compared to the column R1-NA-C0, which was not provided with anchors. Compared with the control specimen, the peak force increased up to approximately 7% for specimen R1-NA-C0 and 36% for specimen R1-A-C0.

Table 1. Summary of Test Results

Specimen	Increase in peak force (%)	Ductility	Energy dissipation (kN m)
Control	-	2.9	14.2
R1-NA-C0	7	3.2	15
R1-A-C0	36	3.5	36.2
R2-A-C0	78	3.3	37.5
R1-NA-C1	15	6.8	39.9
R1-A-C1	47	6.9	43.8
R2-A-C1	86	6.5	51.3

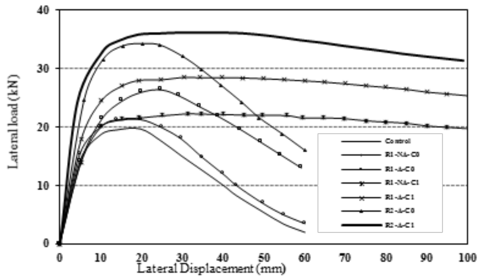

Figure 1. Envelope curves

According to Figure 1, the combination of bonded NSM bars and CFRP jacketing showed the best response with stable post-peak behavior and minimal strength degradation up to large lateral displacement. Also, at large lateral displacement, the column with the CFRP jacket showed a more ductile response without the recognizable decrease in lateral force resistance, due to improved confinement. Therefore, it seems that the combination of NSM FRP bars and CFRP jacketing is a viable means for increasing strength without decreasing deformation capacity.

4- Conclusions

According to the test results, NSM bar is very appropriate for enhancement the flexural strength of RC columns subjected to seismic loads, so that increasing the number of NSM bars increases the lateral strength capacity and energy dissipation capacity. Also, anchoring of the NSM bar to the foundation of the column is necessary and increases the column's flexural strength and energy dissipation capacities. As well as, The displacement ductility of the specimen with the lower NSM bars is higher than the specimen with higher NSM bars and using the CFRP jacketing with NSM rods, increases the ductility and energy dissipated capacity of the column.

According to the results obtained in this study can be said that, the most proper method for flexural strengthening of columns was found to be the use of NSM FRP bars and the additional confinement using CFRP jacketing.

References

[1] H. Saadatmanesh, M. R. Ehsani, and L. Mu-Wen, Strength and ductility of concrete columns externally reinforced with fiber composite straps, ACI Structural Journal, 91(4) (1994) 434-447.

[2] H. Saadatmanesh, M. R. Ehsani, and L. Mu-Wen, Seismic strengthening of circular bridge pier models with fiber composites, ACI Structural Journal, 93(6) (1996) 639-738.

[3] ACI Committee 440, Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures, American Concrete Institute, 2017.

[4] R. El-Hacha, and S. Rizkalla, Near-surface-mounted fiber-reinforced polymer reinforcements for flexural strengthening of concrete structures, ACI Structural Journal, 101(5) (2004) 717-726.

[5] L. De Lorenzis, and A. Nanni, Bond between NSM fiber-reinforced polymer rods and concrete in structural strengthening, ACI Structural Journal, 99(2) (2002) 123-132.

[6] J. A. O. Barros, D. Ferreira, A. S. Fortes, and S. Dias, Assessing the effectiveness of embedding CFRP laminates in the near surface for structural strengthening, Construction and Building Materials, 20(7) (2006) 478-491.

[7] J. A. O. Barros, K. V. Rajendra, J. Sena-Cruz, and A. Azevedo, Near surface mounted CFRP strips for the flexural strengthening of RC columns: Experimental and numerical research, Engineering Structures, 30(12) (2008) 3412-3425.

[8] D. A. Bournas, and T. C. Triantafillou, Flexural strengthening of RC columns with NSM FRP or stainless steel, ACI Structural Journal, 106(4) (2009) 495-505.

[9] X. Li, H. L. Lv, G. C. Zhang, S. Y. Sha, and S. C. Zhou, Seismic retrofitting of rectangular reinforced concrete columns using fiber composites for enhanced flexural strength, Journal of Reinforced Plastics and Composites, 32(9) (2013) 619-630.

[10] S. F. Jiang, X. Zeng, S. Shen, and X. Xu, Experimental studies on the seismic behavior of earthquake-damaged circular bridge columns repaired by using combination of near-surface-mounted BFRP bars with external BFRP sheets jacketing, Engineering Structures, 106 (2016) 317-331.

Please cite this article using:
M. Esfandi Sarafraz, F. Danesh, Use NSM FRP Rebars for Flexural Strengthening of RC Columns, *Amirkabir J. Civil Eng.*, 51(1) (2019) 119-128.
DOI: 10.22060/ceej.2017.13230.5351