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Innovation technique in strengthening of reinforced concrete columns

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ABSTRACT: Over the past recent years, research in the field of reinforced concrete has drawn great attention to the knowledge of repair and strengthening application techniques. The growing degradation of buildings, bridges and viaducts are mainly caused to aging processes, deficiencies in design and construction procedures, lack of maintenance, and accidental causes (such as earthquakes). The development of new polymeric materials, such as Carbon Fiber Reinforced Polymer (CFRP), has offered numerous trends for the strengthening of reinforced concrete structures. Several researches investigated the use of Near Surface Mounted (NSM) CFRP rods in strengthening columns and beams. However, the cost of CFRP rods is expensive compared with reinforcing steel rods. Moreover, the efficiency of the CFRP strengthening columns using NSM steel bars then wrapped with CFRP sheets has not been investigated. The objective of this research is to investigate the effect of using NSM steel bars followed by CFRP sheets wrapping in increasing the compressive strength on reinforced concrete columns. Sixteen large-scale reinforced concrete columns of dimensions 150x150x470 mm were tested under axial load till failure. The test parameters were NSM type (steel bars or CFRP slotted strips), and the number of layers of CFRP wrapping sheets. Control specimens, without strengthening, were tested to compare their results with those of the strengthened specimens. The results of the experimental investigation were discussed including ultimate strength, strains, and modes of failure. The test results indicated a remarkable gain in strength using the proposed strengthening technique which applies the NSM steel bars, NSM CFRP strips and/or the wrapping of the CFRP sheets but with different percentage. The outcome of this research provides information for both designers and researchers in the field of FRP composites.

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1 INTRODUCTION

Different techniques can be selected to upgrade underdesigned columns. Reinforced concrete jacketing, steel profile jacketing and steel encasement have been widely used in the past. All of them were characterized by disadvantages related to constructability (i.e., difficulty of ensuring perfect bond and collaboration between old and new parts, loss of space, construction time and high impact on building functions) and durability issues; in the case of reinforcing concrete jacketing, significant mass increase could also be generated. Innovative techniques based on Fiber Reinforced Polymers (FRP) materials have become valid alternatives to those solutions; along with high structural effectiveness, composite materials are light and easy to install, their application does not imply loss of space and, in some cases, it can be performed without interrupting the use of the structure.

Laboratory experiments have confirmed that FRP laminates can significantly improve the seismic performance of RC columns. CFRP strips were used by Ye et al. (2001) to confine square columns; tests were conducted under an axial load ratio of 0.48. Iacobucci et al. (2002) investigated the behavior of columns simulating members typical of multistory structures and designed with non-seismic provisions; the columns were wrapped using Carbon FRP (CFRP) laminates and the axial load ratio ranged between 0.33 and 0.56. The effectiveness of CFRP confinement to improve the seismic performance of rectangular underdesigned columns was assessed by Shaheen et al. (2003); the confinement provided by a continuous laminate was compared to that given by discountinuous strips.

Bousias et al. (2004) investigated the seismic behavior of rectangular underdesigned columns with axial load ratios ranging between 0.34 and 0.40; the columns were wrapped with either CFRP or GFRP and the effect of corrosion was also studied. The opportunity of using FRP to repair damaged columns has been also verified. Ilki & Kumbasar (2001) tested the effectiveness of longitudinal and transverse CFRP laminates to restore the performance of damaged square columns with axial load ratios ranging between 0.05 and 0.20. Chang et al. (2004) tested 2/5 scale rectangular columns repaired using CFRP confinement and the pseudo-dynamic tests confirmed that the original seismic performance could be recovered after the FRP repair. Shield et.al. (2005) studied the effect of adhesive type on the bond of NSM tape to concrete while Prota et al. (2005) proposed an innovative technique for seismic upgrade of RC square columns using steel spikes embedded in the foundation and glued on the surface of the column then the columns were wrapped with FRP. The FRP confined the spikes and enhanced the behaviour of the column at the junction with the footing. Kaminski & Trapko (2006) and Kaminski et al. (2008) tested reinforced concrete columns strengthened by NSM FRP strips and surface applied FRP followed by CFRP wrapping. Results of studies confirmed that the subject was worth investigating. The application of CFRP strips to strengthen compressed elements increases their boundary load-carrying capacity. This is caused by a decrease of longitudinal strains in relation to control elements at an equal increase of longitudinal force. The use of additional external CFRP band wraps prevents debonding of a strip till the moment of the wrap breaking and the element damage.

The present research investigates the application of NSM steel bars to existing reinforced concrete columns followed by CFRP wrapping tested under axially loaded forces as an innovative technique of strengthening columns. According to reviewed literature, no available research has so far tackled the proposed technique.

2 EXPERIMENTAL PROGRAM

This research program focuses on the strengthening of existing reinforced concrete columns using NSM steel bars followed by CFRP sheets wrapping. Five types of strengthening were investigated as shown in figure 1. The first type is using NSM steel bars. The second type is using NSM CFRP slotted strips. The third type is wrapping the columns with one or two layers of CFRP sheets. The fourth type is using NSM steel bars followed by wrapping with one or two layers of CFRP sheets. The fifth type is using NSM CFRP slotted strips followed by two layers of CFRP sheets.

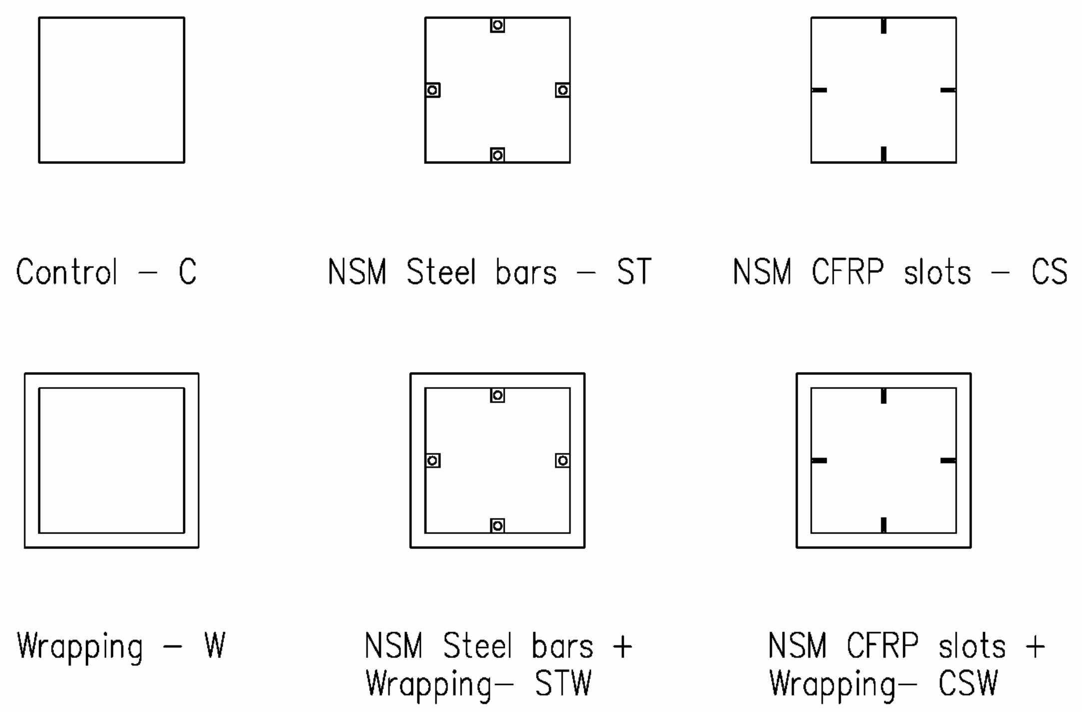

Figure 1. Different types of columns strengthening.

2.1 *Test Specimens*

Sixteen scale reinforced concrete column specimens were designed with the same concrete dimensions and internal reinforcement. The columns dimensions are 150x150x470 mm with 4 bars 10 mm diameter vertical reinforcement and 5 ties 10 mm diameter at vertical spacing 90 mm as shown in figure 2. The columns were cast and tested under axial load to failure.

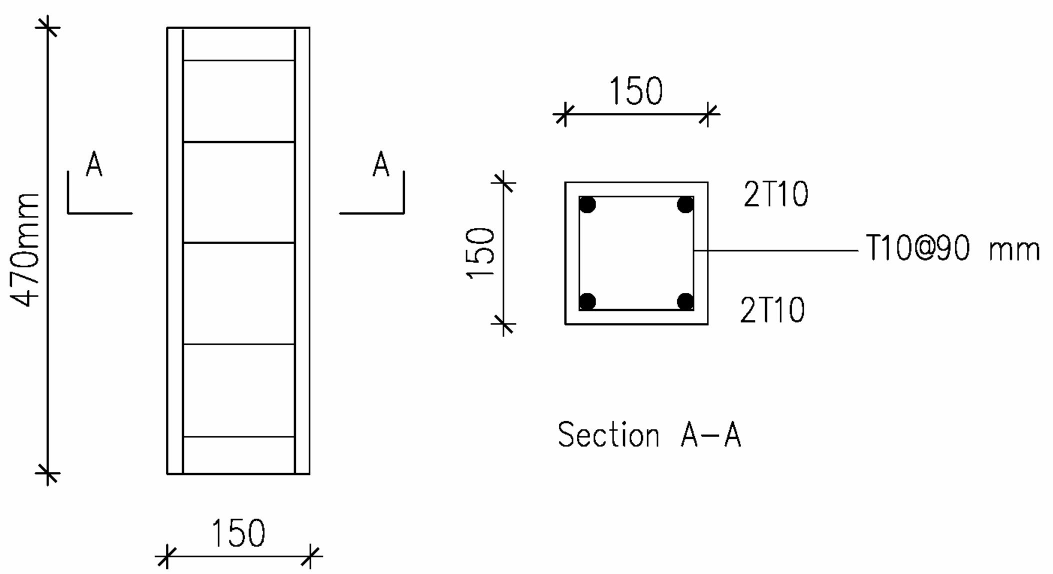

Figure 2. Columns dimensions and reinforcement.

Each specimen has been repeated twice to confirm the results. The control specimens SP1-C and SP2-C, are identical columns tested without any strengthening types to compare their results with those of the strengthened specimens. In the strengthened specimens SP3-ST, SP4-ST, four reinforcing bars 12 mm diameter were inserted into four slits each of dimensions 18 x 18 mm (shown in figure 3a) opened on the concrete cover of the column then the slits were filled with a solvent-free, thixotropic, epoxy-based two-component adhesive mortar (Sikadur-30). In the strengthened specimens SP5-CS, SP6-CS, four CFRP slotted strips of dimensions 16 x 2 mm were inserted into four slits each of dimensions 18 x 5 mm (shown in figure 3b) opened on the concrete cover of the column then the slits were filled with Sikadur-30. In the four strengthened specimens, SP7-W1, SP8-W1 and SP9-W2, SP10-W2, one layer and two layers of CFRP wrapping are applied to the columns, respectively. The strengthening specimens, SP11-STW1, SP12-STW1, are similar to the specimens SP3-ST, SP4-ST but with one layer of CFRP wrapping. The strengthening specimens, SP13-STW2, SP14-STW2, are similar to the specimens SP3-ST, SP4-ST but with two layers of CFRP wrapping. The strengthening specimens, SP15-CSW2, SP16-CSW2, are similar to the specimens SP5-CS, SP6-CS but with two layers of CFRP wrapping. The specimens were tested under concentric load. Load control was employed and the loading was applied in increments of approximately 5% of the expected failure load. The loading was continued up to failure of the specimen. In all the specimens, measurements were taken using extensometer for measuring the concrete longitudinal compressive strain, and strain gauges for measuring strain in the steel bars and in the CFRP wrapping layers.

Figure 3a. four slits each of dimensions 18 x 18 mm for specimens strengthened by four exterior steel bars 12 mm diameter.

Figure 3b. four slits each of dimensions 18 x 5 mm for specimens strengthened by four exterior CFRP slotted strips.

2.2 Material Properties

The reinforcing bars used as longitudinal and transverse reinforcement in the specimens are of yield strength of 460 MPa. The average 28 day concrete cylinder compressive strength is 36 MPa. The used CFRP Slotted strips (tape) are ASLAN 500 with tensile strength 2068 N/mm^2 and ultimate strain 0.017 mm/mm. The CFRP sheets used for wrapping are CF300HS from Conmix with tensile strength 3550 N/mm^2, sheet thickness 0.168 mm and ultimate elongation of 0.015 mm/mm.

3 TEST RESULTS

The experimental data of column axial strains, reinforced steel bars and CFRP strains and crack propagation was recorded at different stages of loading until the failure load of the tested specimens has been reached.

A summary of the experimental results is presented in Table 1. It includes the loads and concrete longitudinal strains at ultimate (failure) stage in addition to a description of the modes of failure. Figure 4 show the failure of specimens SP1-C, SP3-ST, SP5-CS, SP7-W1, SP9-W2, SP11-STW1, SP13-STW2 and SP15-CSW2.

Table 1. Failure loads, longitudinal strains and mode of failure of the tested specimens

Specimens	Load-carrying capacity, kN			concrete longitudinal strains at the specimen capacity (microstrain)*	$P/P_{control}$	Mode of failure
	First specimen	Second specimen	Average (P) *			
SP1-C, SP2-C	821	844	832**	2110	1.0	Crushing of concrete
SP3-ST, SP4-ST	1118	1109	1114	2337	1.34	Debond of NSM steel rods followed by crushing of concrete
SP5-CS, SP6-CS	1182	1150	1166	2275	1.40	Debond of NSM CFRP strips followed by crushing of concrete
SP7-W1, SP8-W1	1438	1417	1427	6230	1.71	Wrap cut after crushing of concrete
SP9-W2, SP10-W2	1645	1630	1637	4880	1.97	Wrap cut after crushing of concrete
SP11-STW1, SP12-STW1	1634	1596	1615	5400	1.94	Wrap cut followed by debond of NSM steel rods and crushing of concrete
SP13-STW2, SP14-STW2	1662	1698	1680	6350	2.01	Wrap cut followed by debond of NSM steel rods and crushing of concrete
SP15-CSW2, SP16-CSW2	1705	1680	1692	5745	2.03	Wrap cut followed by debond of NSM CFRP strips and crushing of concrete

* average for the two identical columns ** $P_{control}$

The load-carrying capacity versus the longitudinal concrete axial strains of the tested specimens is presented in figures 5 and 6. From Table 1, figures 4, 5 and 6 as well as the observed behaviour of the tested specimens, the application of reinforcement using NSM longitudinal steel rods improves strain abilities and load-carrying capacity by 34% in comparison with control specimens. The use of additional transverse reinforcement by means of CFRP wrapping prevents any debonding of the steel rods and increases the load-carrying capacity by 94% and 101% for the specimens with one layer of wrap and two layers of wrap, respectively, in comparison with control specimens. The use of transverse reinforcement by means of CFRP wrapping without NSM longitudinal steel rods improves strain abilities and load-carrying capacity by 71% and 97% for the specimens with one layer of wrap and two layers of wrap, respectively.

SP1-C SP3-ST SP5-CS SP7-W1

SP9-W2 SP11-STW1 SP13-STW2 SP15-CSW2

Figure 4. Failure of different tested specimens

Using NSM longitudinal steel rods with one layer of CFRP wrapping is almost equivalent to no longitudinal strengthening but with two layers of CFRP wrapping in terms of the increase in strength.

The application of reinforcement using NSM CFRP slotted strips improves strain abilities and load-carrying capacity by 40% in comparison with control specimens. The use of additional transverse reinforcement by means of CFRP wrapping prevents any debonding of the CFRP slotted strips and increases the load-carrying capacity by 103% for the specimens with two layers of wrap, respectively, in comparison with control specimens.
Observation of the damage mechanism and evaluation of the test specimens leads to the following:

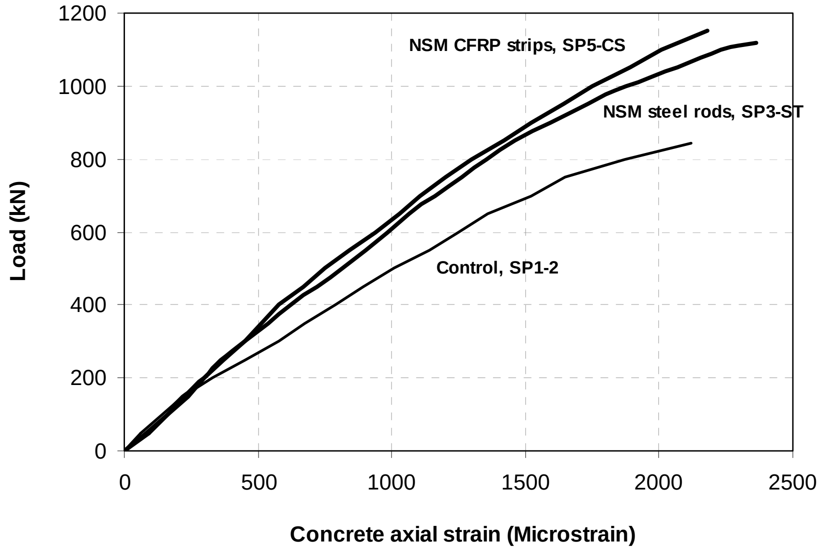

Figure 5. Load carrying capacity – axial strains relationship of SP1-C, SP3-ST, SP5-CS

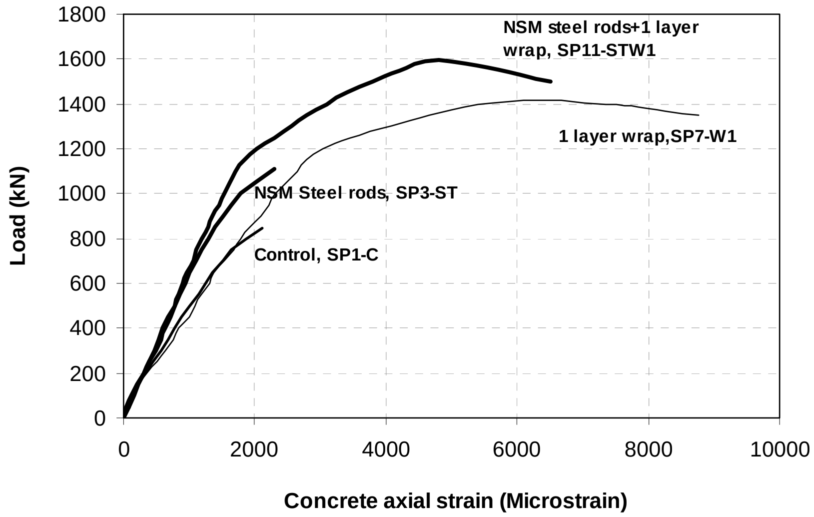

Figure 6. Load carrying capacity – axial strains relationship of SP1-C, SP3-ST, SP7-W1 and SP11-STW1

a- The failure of the control specimens is due to crushing of the concrete.
b- The failure of the NSM steel rods specimens is due to debonding of the adhesive and the concrete.
c- The failure of the NSM CFRP slotted strips specimens is due to debonding of the strip with adhesive and the concrete.
d- The failure of the NSM steel rods or slotted strips and wrapped using CFRP transverse layers specimens is due breakage of some bands followed by debonding of the steel rods or the CFRP strips and concrete crushing.
e- The failure of the transverse CFRP wrapped specimens without any longitudinal strengthening is due to breakage of some bands followed by concrete crushing.

4 CONCLUSIONS

Results of studies confirmed that the subject was worth investigating. The application of NSM longitudinal steel rods to strengthen compressed elements increases their boundary load-carrying capacity. This is caused by a decrease of longitudinal strains in relation to control specimens at an equal increase of longitudinal force. The use of additional external CFRP wrapping prevents debonding of the steel rods till the moment of the wrap breaking and the specimen failed. On the basis of the experimental studies the following conclusions are stated:

a) Use of NSM longitudinal steel rods as longitudinal strengthening in reinforced concrete columns causes an increase of stiffness and load-carrying capacity.
b) Use of NSM CFRP slotted strips as longitudinal strengthening in reinforced concrete columns causes an increase of stiffness and load-carrying capacity.
c) The increase of load-carrying capacity is caused exclusively with longitudinal strengthening.
d) The use of additional transverse reinforcement by means of CFRP wrapping prevents any debonding of the NSM steel rods or the NSM CFRP slotted strips and increases the load-carrying capacity.

References

Bousias S.N., Triantafillou T.C., Fardis M.N., Spathis L., O'Regan B.A., 2004. Fiber- Reinforced Polymer Retrofitting of Rectangular Reinforced Concrete Columns with or without Corrosion, ACI Structural Journal, Vol. 101, N 4, 512-520.

Chang, S.; Li, Y.; and Loh, C., 2004. Experimental Study of Seismic Behaviors of As-built and Carbon Fiber Reinforced Plastics Repaired Reinforced Concrete Bridge Columns, ASCE Journal of Bridge Engineering, V. 9, No. 4, 391-402.

Iacobucci, R.; Sheikh, S.A.; and Bayrak, O., 2002. Seismic Behaviour of Square Concrete Columns Retrofitted with Carbon Fibre Reinforced Polymers, Proceeding CD-ROM of the Seventh U.S. National Conference on Earthquake Engineering, Boston, Massachusetts, Paper N. 326.

Ilki, A.; and Kumbasar, N., 2001. Strengthening of Damaged Concrete Members by Carbon Fiber Reinforced Polymer Composites," *Proceedings of the International Conference on FRP Composites in Civil Engineering*, Hong Kong, Vol. 1, 781-788.

Kaminski, M. and Trapko, T. 2006. Experimental Behaviour of Reinforced Concrete Column Models Strengthened By CFRP Materials, Journal of Civil Engineering and Management, XII, 2, 109–115.

Kaminski, M., Trapko, T., M. Musial and Bywalski, Cz., 2008. The influence of longitudinal CFRP strips on the load-bearing capacity of RC columns, *Fourth International Conference on FRP Composites in Civil Engineering (CICE2008)*, Switzerland.

Prota A., Manfredi G., Balsamo A., Nanni A., and Cosenza E., 2005. Innovative Technique for Seismic Upgrade of RC Square Columns, *ACI Special Publication SP230 on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures – FRPRCS 07*, No. 21, 1283-1303.

Shaheen, H.; Rabik, T.; Hasmem, Y.; Shaaban, I.; and Abdelrahman, A., 2003. Behaviour of RC Columns Retrofitted by Fibre Reinforced Polymers under Cyclic Loads, *Proceeding of the Sixth International Symposium on FRP Reinforcement for Concrete Structures (FRPRCS-6)*, Singapore, pp. 663-672.

Shield C., French C., and Milde E., 2005. The Effect of Adhesive Type on the Bond of NSM Tape to Concrete," *ACI Special Publication SP230 on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures – FRPRCS 07*, American Concrete Institute, No. 21, 355-371.

Ye, L. P.; Zhao, S. H., Zhang, K.; and Feng, P., 2001. Experimental Study on Seismic Strengthening of RC Columns with Wrapped CFRP Sheets, *Proceedings of the International Conference on FRP Composites in Civil Engineering*, , Hong Kong, Vol. 1, 885-892.