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Retrofitting of RC Cylindrical Columns using Rubber re-bars Along with FRP

Peerzada Jafar Abass[1], Mandakaruhi Rymbai[2] and S. Ganesh[3]

[1,2,3]Lovely Professional University, Punjab (India)
E-mail: [1]pzjaffar@gmail.com, [2]manhidakaru@gmail.com, [3]ganesh.19421@lpu.co.in

Abstract—*This paper presents the results of a research program that evaluated use of rubber rebars in RC columns retrofitted with fibre reinforced polymer (FRP). The jacketing system of columns consists of glass fibre wound manually onto prototype RC columns. The research attempts to address a key issue involving strengthening of columns by comparing the strength values of pre and post retrofit prototype models. The principle of research study is to explore the feasibility of rubber rebars as reinforcement along with FRP. A total of 18 cylindrical RC columns were tested under varying axial load. Specimens consists of full scale cylindrical columns (150*300mm) reinforced by using steel and rubber rebars. The key parameters of this extensive research work includes thickness of jacket, concrete strength, loading type, amount of reinforcement, and bonding pattern(arrangement) of GFRP sheets. The varying parameter is loading and area cover by FRP over the column viz.mid, extreme ends and whole column retrofitted. It was demonstrated that high axial load has detrimental effect on deformation capacity. Compared with the performance of pre-retrofitted RC columns, test results showed that post-retrofitted columns having rubber re-bars results in increase in ultimate strength than pre-retrofitted ones. The amount of FRP greatly affects the drift capacity of retrofitted RC columns.*

Keywords*: Reinforced Concrete Columns; Rubber Rebars; Fibre Reinforced Polymer; Seismic Retrofitting; Bonding.*

1. INTRODUCTION

It is well known that retrofitting implies modification of existing building structures so that to make them more resistant towards seismic activity or ground motion, instead of demolishing and rebuilding. Mostly in developing countries, the structures show low seismic performance either because of low ductility or adequate construction practice, or other deficiencies. In recent years, retrofitting of existing columns through fiber reinforced polymer (FRP) has become popular.

A wide study on the seismic durability of RC columns between the eras 1950 to mid-1970 is reported [1]. Study reveals that stiffness of column didn't change with retrofitting. Moreover column strength didn't increase and the energy dissipated gets slightly increased. Introduction of advanced polymer composites has been a rapid process in civil engineering, and has demonstrated that advanced composite column jacket are as effective as conventional steel jacketing in improving the seismic performance of RC columns [2]. And was found that stiffness and deformation capacity increased were less than those obtained from steel jacketing. Consequently extensive research work has been carried out on bridge columns undergoing ground motion. The RC column undergoes ground motion and is investigated using shake table. It was found the stiffness of column decreases with increase in damage level while energy dissipation shows positive effect [3]. Another research work reveals that bridge columns having flares shows that plastic hinge doesn't act at sections or get started at sections having maximum bending moment when the column is having parabolic structural flares. The position of hinge depends upon the geometry of structural flares and steel details longitudinally or from moment curvature analyses performed at various cross sections [4].

Although extensive research work has been done on retrofitted hollow reinforced columns. Most of the studies found that composite wrapping enhances the strength of piers under eccentric loading. There was improvement in strength when specimens were loaded with smaller eccentricity but was opposite to ductility which shows improvement in strength loaded to bigger eccentricity [5]. Demonstration of models of low and medium RC concrete columns shows confinement has direct effect on strength and ductility. The strength was more in circular columns rather than rectangular/square ones [6]. Application of FRP bars in retrofitting RC cantilever beams is presented. Subjecting FRP retrofitted RC cantilever beams into monotonic and cyclic loading, showed diagonal cracks and FRP bars ruptured with stability failure in tension and compression bars along short or long shear beams [7]. Degradation of stiffness is independent on FRP confinement while leaving positive effect on ductility [8].

As for RC beam-column, lack of rationale explanation of the resistance mechanisms of beam-column joints being retrofitted with FRP which acts as key point for the development of more comprehensive design procedure while confirming effectiveness of FRP for retrofit of RC joints [9]. Research studies revealed that aspect ratio is directly proportional to drift capacity which in turn is greatly affected by confining FRP. However, there is reduction in deformation capacity when confinement goes beyond the critical value [10]. With increase in number of layers of CFRP undoubtly enhancement in strength occurs which saves both time and cost [11]. Under stimulated earthquake loading having different degrees, creep of column increases with increase in damage degree. Moreover at high earthquake or high axial load, the life of creep declines and causes rupture of FRP [12]. A relatively limited study has been done on RC frames retrofitted by textile-reinforced mortar (TRM) [13]. Such study focusses on TRM as retrofitting material with special anchorage and draws a conclusion that lateral strength and deformation capacity shows enhancement. According to study carried out on RC columns undergoing cyclic and seismic loading, fixed end rotation has effect on the column and accounts more than 15% of lateral displacement [14].

Substantial research work has been done on GFRP retrofitted damaged RC columns [15]. Such studies indicate that the seismic performance of damaged RC columns was improved and shear failure mode was changed to ductile-flexural-failure mode. According to the data, strength, ductility, and dissipated energy was increased. The combined retrofit and selective weakening scheme increases the ductility of pre 1970's beam-column joints by activating deformation in beams [16]. Jacketing by FRP is costlier than RC, and SFRC jacketing but is better one. Confining FRP jacketing enhances performance of columns [17]. Moreover, none of these studies took into account the alternate material (rubber rebars) used as reinforcement on the strength of column. Therefore, ultimate strength of the column needs more research work.

2. EXPERIMENTAL PROGRAM

Specimen Details

A total of 18 specimens were tested under the axial load throughout the test. The specimens so tested represents the part of building column or bridge column. All these specimens were divided into two groups according to reinforcement used. The reinforcement of first group was steel while for the 2nd one rubber Rebars were used.

The first group included six specimens and all were tested under "as built" condition. The height of the specimens H measured from bottom to the point of application of load is 300 mm. the aspect ratio H/D found is 2.0. The specimens were reinforced with 6 of 8mm diameter bars, yield stress of 500 MPa. Longitudinal bars were evenly distributed in a circle with a constant clear cover of 15 mm. Lateral reinforcement of two bars (diameter=6 mm) were provided with a spacing of 200 mm. The equivalent cylinder strength was 27.59 which was calculated from the relation

$$f^*_{ck} = f_{ck} + t * s$$

Where, f^*_{ck} is the 28 days compressive strength.

The second group included 12 specimens among which six specimens were tested under "as built" condition while others were retrofitted using FRP jacketing. Specimen size remains same and same number of bars were used in longitudinal and lateral reinforcement.

Applications of FRP and Rubber re-bars

FRP mainly find application in three broad categories viz. new construction, repair, and architectural application. Structures like bridge piers and columns draped with FRP have revealed remarkable strength and durability. The type of fabric used here is GFRP class-E. The fabric was first saturated and the draped over the column. The epoxy coat was applied on the column surfaces which were smoothened by sandpaper. The saturated GFRP was then draped around the RC column. The fibre was draped on the entire length of column.

Rubber re-bars used were cost effective having low compression set (25%) and good mechanical properties. The material properties of GFRP and Rubber re-bars are described in table 1 and 2.

3. TESTING AND INSTRUMENTATION

The test set up is shown in fig. 2. The pre-retrofit RC columns were tested using compressive testing machine while the post retrofit ones where tested using universal testing machine at National institute of Technology (NIT), Jalandhar (India). Stress-strain analysis was done at NIT, Jalandhar. The axial load was controlled by a pressure gauge. An average of three specimens was taken. Both crack value and failure values were noted down. The capacity of CTM was 2000KN which enables easy testing of specimens as the ultimate strength found was 286KN. Inclined cracks were always seen rather than lateral ones.

Fig. 1: Test step

3.1 Test observations and results

3.1.1 Test observation

The first group of specimens showed greater resistance towards the varying axial load rather than Columns possessing rubber re-bars. It was observed that the cracks were developed vertically starting from the upper edge and moving towards the bottom edge. Later increasing the load beyond peak value, column showed no response and the load capacity drops from the maximum, and the lateral cracks appears. The vertical reinforcement showed bent in bars.

These all kinds of failures were prevented by wrapping the glass fiber around the columns. It enables them to bear greater loads and hence increase in strength. All retrofitted RC columns showed same behavior towards axial loading. Subjecting the retrofitted columns under Loading, the GFRP sheets broke when load was increased beyond the column bears.

Table 1: Material properties of fibers.

Fiber	**Density (g/cm^3)**	**Tensile strength (GPa)**	**Young's modulus (GPa)**	**Elongation (%)**	**Coefficient of thermal expansion ($10^{-7}/^0C$)**	**Poisson's ratio**	**Refractive index**
GFRP	2.58	3.445	72.3	4.8	54	0.2	1.558

Table 2: Material properties of Rubber Re-bar.

Colour	**Material**	**Cross section type**	**Hardness (shore A)**	**Tensile strength (MPa)**	**Elongation at break (%)**	**Max. temp (^0C)**	**Min. temp (^0C)**
Black	Nitrile	circular	70	12	300	80	-20

(a) (b)

(C) (D)

Fig. 2: Views of specimen failure.

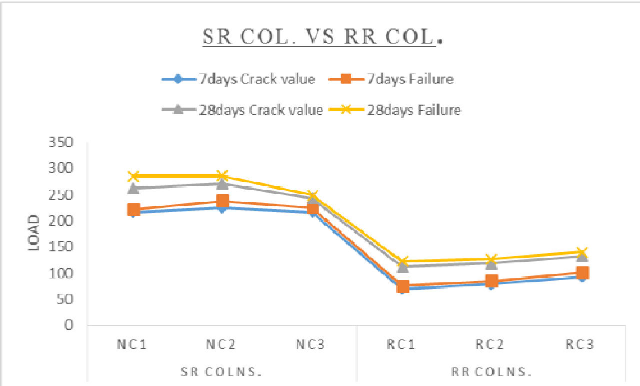
3.1.2 Test results

Table 3: Summary of test results

Serial no.	Columns	Strength (Days)KN			
1.	Steel reinforced columns	7 days		28 days	
		Crack value	Failure	Crack value	Failure
1.1.	NC1	217	222	262	285
1.2.	NC2	225	237.9	271	286
1.3.	NC3	217	225.3	243	249
2.	Rubber reinforced columns	7 days		28 days	
		Crack value	Failure	Crack value	Failure
2.1.	RC1	70	75.7	112	122.7
2.2.	RC2	79	84.8	119	127.2
2.3.	RC3	93	101.8	133	140.5
3.	Retrofitted columns(confined with GFRP)	7 days		28 days	
		Crack value	Failure	Crack value	Failure
1.1	CRC1	239.2	255		
1.2	CRC2	272	285.2		
1.3	CRC3	226	237.1		

4. ANALYSIS OF TEST RESULTS

While accessing the performance of FRP confined RC columns, two considerations are used: i) confinement ratio, which is defined as confinement pressure to unconfined concrete strength and, ii) stiffness of confinement which is mainly used for measuring the stiffness of confinement of FRP.



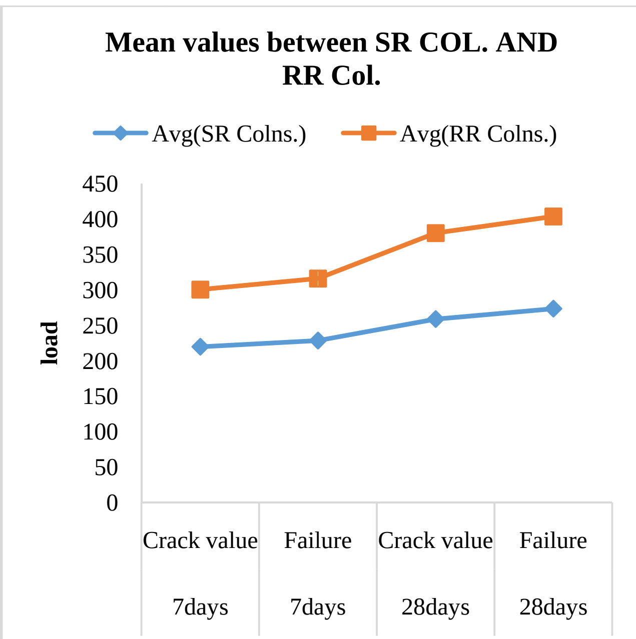
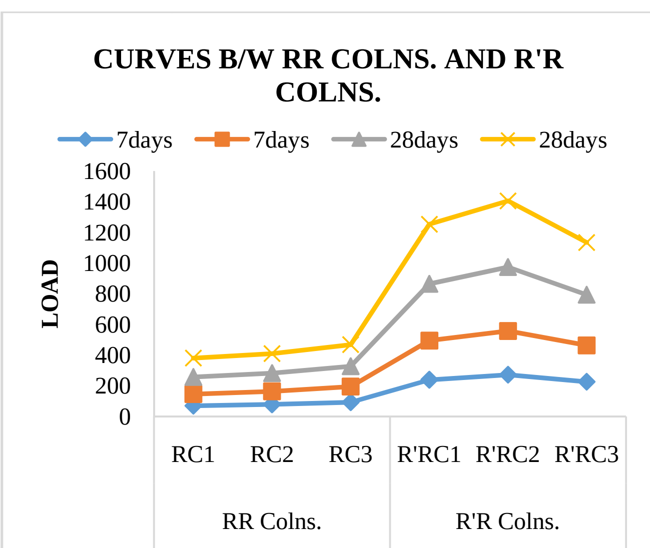


Fig. 3: Variation between steel reinforced columns and rubber reinforced columns



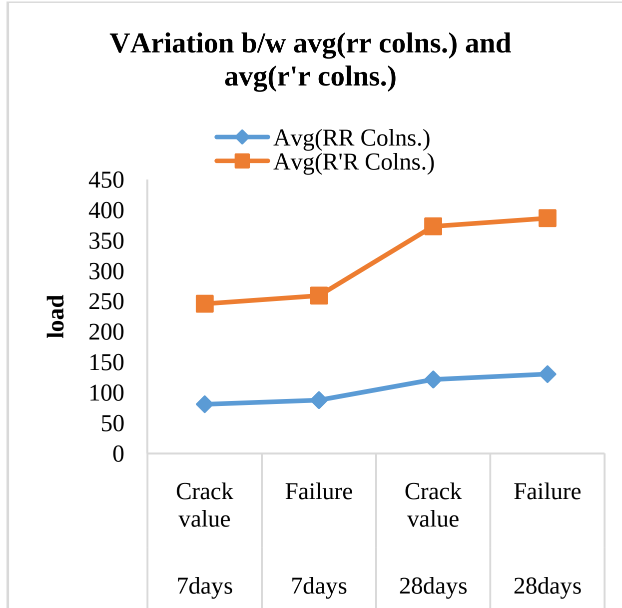
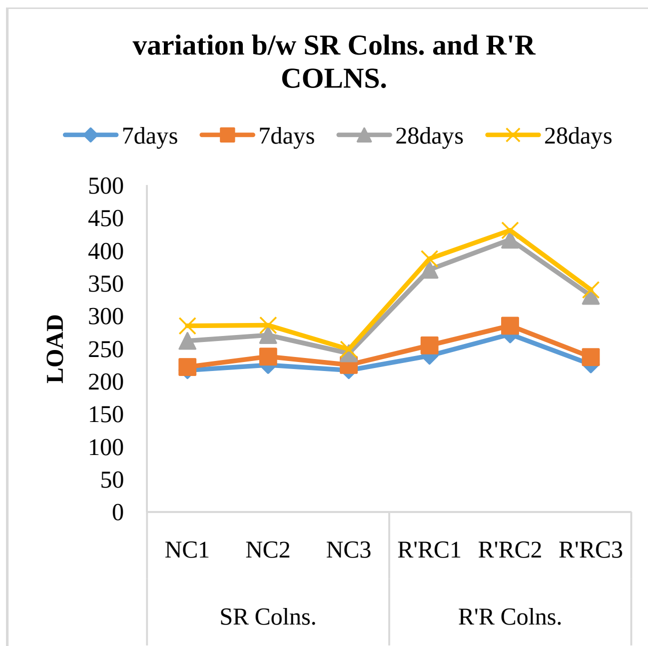


Fig. 4: Comparison between rubber reinforced columns and FRP retrofitted columns.



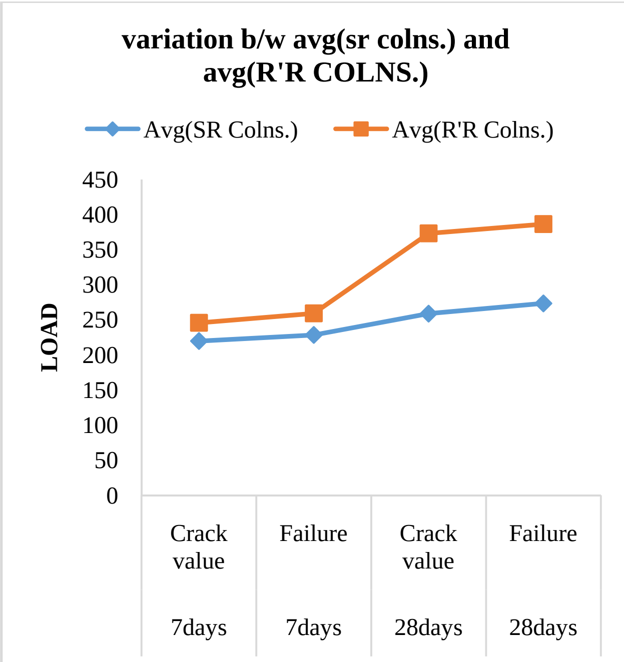


Fig. 5: Variation between steel reinforced columns and FRP retrofitted columns.

5. CONCLUSION

1. It has already been widely accepted that high loads have unfavorable effects on deformation capacity. Under different loads, the test results of columns can be used to analyze the effect of axial loads on retrofitted columns. The specimens having aspect ratios are retrofitted hence show more response towards axial load.
2. Aspect ratio has direct effect on drift capacity, as more the aspect ratio higher will be the drift capacity.
3. The amount of FRP affects greatly the deformation capacity. With increase in FRP layers, the deformation capacity shows negative response.
4. Maximum strength of retrofitted RC columns have increased. By taking unretrofitted RC columns as a reference, the failure performance of retrofitted columns rehabilitated from brittle-shear failure to ductile-flexural performance.
5. From the cost analysis and also possessing light nature, the rubber-rebars can be used in construction to improve the performance of RC Columns along with FRP.

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