

Strengthening of Existing Building Column Using FRP Wrap & GI Wire Mesh

Engr. Azam Amir, Dr. AmjadNaseer, Engr. Orooj Azam

Abstract—In this paper strengthening of deficient building columns with FRP wrap and comparison of its effectiveness with wire mesh has been studied. Three full scale building columns have been tested under cyclic loading in Earthquake Engineering Center, University of Engineering & Technology, Peshawar. The size of columns were 12"x12" with 10' in height, representing the most common size in practice. Same quality concrete and reinforcement details were used in all columns. The research was divided into four main phases: testing of cylinders for the achievement of desired strength; fabrication of columns; application of FRP wrap and wire mesh at the critical section; assemblage of testing plan for columns; and quasi-static testing of columns.

Index Terms—Concrete Cylinders, Fiber Reinforced Polymer (FRP), Quasi-Static Testing, Retrofitting, Reinforced Concrete Column, Strengthening, GI Wire Mesh.

1 INTRODUCTION

THIS universe is full of natural phenomenon from its origin which occurs in each and every second of time in different places of the world. Among these phenomenons some are favourable to mankind and some are very destructive which causes loss of both lives and assets. Various disasters like earthquake, land slide, volcanic eruptions, floods, cyclones and fire are natural hazards that kill thousands of people and destroy billions of dollars of habitat and property each year.

Pakistan is one of the highly seismically prone countries in the world. According to Pakistan Meteorological Department, more than 40 earthquakes of magnitude $M_s = 7$ have occurred from year 1900 to 2005. October 08, 2005 earthquake was one of them. Due to these earthquakes, many structures were completely damaged and some of them damaged partially. A good number of these partially damaged structures were reinforced concrete (RC) structures. As most of the people were unaware of the retrofitting techniques so they demolished their structures and rebuilt them which caused them huge financial loss. These buildings could have been saved by using proper retrofitting techniques.

There are many strengthening/retrofitting techniques which can be employed to enhance the capacity of such structures. Among many materials used for retrofitting, Fiber Reinforced Polymers (FRP) is one of the latest materials with a number of advantages which has been used worldwide. In order to enhance the shear and flexural strength, FRP materials have been widely used in the form of jacketing and proved to be very effective [1].

An extensive research on retrofitting of RC columns by using FRP wrapping has been carried out by various renowned researchers. They have used different approaches to simulate the effect of the FRP confinement and to assess the behavior of the FRP confined members [1]. A preliminary Finite Element Method (F.E.M.) analysis has been conducted in the elastic range to evaluate the stress field generated by external wrapping on concrete column. They found that

in the case of hollow concrete cross sections, FRP jacketing can enhance the ultimate load and significantly the ductility [2].

Similarly research on modeling of RC hollow square columns wrapped with CFRP under shear-type load has also been done [4, 5]. It was found that actual failure mode did not change by confinement but it was able to delay bars buckling and to resultantly compressive concrete strains attain higher values, thus resulting in higher load carrying capacity of the column (strength improvement is about 15%) and significantly in ductility enhancement [6].

The columns that need strengthening or retrofitting are in different shapes i.e. square, circular or rectangular and have both transverse and longitudinal steel reinforcement. The research on response of FRP-wrapped square reinforced concrete columns is limited [7].

This research will provide a foundation for a better understanding of the behavior of RC square columns strengthened with FRP wraps. For increasing resistance of Reinforced Concrete (RC) columns, which are subject to high axial loadings, strengthening by means of FRP wrapping system has been proposed since 15 years ago. The strengthening of RC vertical columns, either building columns or bridge piers, show different responses depending on whether the strengthening measures are carried out on a conventional structure or on a structure in a seismic area [5].

For traditional structures, the strengthening measures usually aims to increase the bearing capacity of RC column by either enlarging the cross sectional area or at enhancing the compressive strength of concrete by applying a confining action. These are usually applied in buildings where live loads have increased as a consequent of a change in use.

There are different types of FRP wraps/sheets which are available in Pakistan. Due to many advantages of FRP wrap, especially no need of evacuation of the structure during retrofitting/strengthening, people in Pakistan have also started using these FRP sheets. The scientific quantifiable evaluation of various properties of structures strengthened/retrofitted with FRP in the local environment is scanty so

This research aimed at evaluating the effectiveness of FRP wrap in increasing the flexural capacity of square RC columns.

- Engr. Azam Amir, MSc Structural Engineering, University of Engineering and Technology, Peshawar, Pakistan, PH-092912244036. E-mail: engi-neerazam@hotmail.com
- Dr. AmjadNaseer, PhD Structural Engineering, University of Engineering & Technology, Peshawar, Pakistan, PH-092919218569. E-mail: am-jad_naseer@yahoo.com

2 PROCEDURE OR EXPERIMENTAL PROGRAM

The experimental work consisted of three square reinforced columns of full scale with dimensions of 12 inches by 12 inches and 10 feet in height. The steel reinforcement consisted of four (4) No. 05 ($\varnothing=0.625$ in) axial reinforcing bars with No. 03 ($\varnothing=0.374$ in) stirrups at 10 in center to center. Low strength concrete having a compressive strength of 1500 psi has been used. The columns were casted into a heavily reinforced 15 inches deep and 7 feet long pad/ foundation. The foundation was so design so as to avoid punching shear failure and to best support the assemblage and testing plan. Only one type of commonly available FRP sheets has been used for horizontal wraps in strengthening schemes. Galvanised Iron (GI) wire mesh has been used in the 2nd strengthening scheme. The columns have been strengthened at critical sections as defined in provisions/codes for Special Moment Resisting Frame or simply SMRFs. The materials used were of identical properties for all the columns. The FRP manufacturer’s guidelines in the primer application and resin impregnation have been strictly followed.

2.1 Strengthening Plan

The first strengthening plan (scheme-1) consisted of one horizontal (0°) layer of FRP wrap that was bonded to the column surface and it was designated as HF1LC. The second scheme (scheme 2) consisted of strengthening of column with the GI wire mesh and it was designated as HW1LC. The control specimen without FRP was built for comparison purposes and was designated as CSC. The material properties and testing program are summarized in the table 1 and table 2:

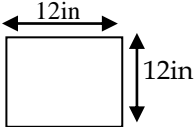
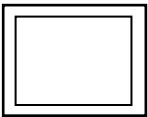
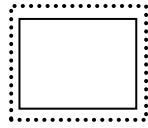
**TABLE 1
MATERIAL’S PROPERTIES**

Material	Properties
Concrete Strength	1500 psi
Reinforcement	1 % reinforcement of total X-section
Main Reinforcement	4 #5 bars
Steel Grade	Grade 40
Tie bar	# 3 bar @ 10” c/c
FRP wrap	230-C having manufacturing tensile strength of 131ksi
Wire mesh	GI wire mesh
Plaster	1:2 csm

2.2 Column Fabrication

The columns’ surfaces have been prepared before the application of FRP wraps. The critical section of the column (as defined in ACI section 11.12.1.2) has been marked i.e. 4-ft. Columns’ surfaces were abraded with the help of hand held grinder. The edges were chamfered to approximately 10mm round in order to avoid premature failure of wrap at corner points due to stress concentration in the FRP wrap. Debonding may occur due to improper surfaces. Dust and dirt particles were removed with pressurized air. Honeycombed surfaces were removed and patch up repair work was done with epoxy repair mortar (chemdur 41/42). Surface has been primed with Sikadur 300-impregnation epoxy via roller. Column has been wrapped with impregnated CFRP sheets up to a height of 4 ft. from the base of column.

**TABLE 2
SUMMARY OF TEST PROGRAM**

Scheme	Schematic Representation	Legend
Control (CSC)		Un strengthened Column
Scheme 1 (HF1LC)		1 horizontal FRP layer
Scheme 3 (HW1LC)		GI Wire mesh

Column tested for wire mesh/ ferrocement jacketing was also of same strength. Before application of ferrocement, the corners of the column were chamfered to approximately 10mm round in order to avoid premature failure due to sharp corners. The wire mesh was wrapped along the column up to critical section (4-ft). 10 inches overlap was given. Holes were drilled along all the sides of column at a distance of 1-ft with the help of 6-mm diameter bit. 1.5 inch rawlplugs were fixed in drilled holes. The wire mesh was applied on column by pressing it, so that, foldings of mesh may be avoided. The bolts were fixed in rawl plug. 1 inch thick of plaster with 1:2 cement sand mortar (csm) was applied around the wire mesh. Plastering was done in two layers. The commonly available wire mesh was used. The properties of the wire mesh are given below:

**TABLE 3
PROPERTIES OF WIRE MESH**

Characteristics	Properties
Wire Mesh	GI Wire mesh
Diameter of wire	16 gauge
Size of opening	18mmx18mm
Weight of one layer per unit area	1.08 kg/sq.m
Steel surface per unit volume	0.245 sq.mm/ cu.mm

2.3 Testing Setup

To determine the seismic load effect on strengthening efficiency, an external technique was adopted. The column’s behavior was studied under cyclic loading of transverse displacement under constant force. Quasi-static testing was done. Lateral force was applied at the height of 9.5-ft from the base of the column through Hydraulic Jack having capacity of 50 tons. The lateral load was recorded through load cell. Electronic data logger unit was used for recording test data. To closely study the cyclic behavior of the column, load history with closely spaced single cycle was chosen over the usual intervals of 3 cycles.

The figure 1 comprised of 10-ft column with heavily reinforced 18-inches deep foundation, hydraulic jack with capacity of 50 tons mounted on shear wall and 3 steel plates for connecting hydraulic jack with column.

2 Nos displacement transducers of 50-mm were attached on an aluminium frame at about 6-inches above the base column joint in opposite direction and one 500-mm displacement transducer was positioned at the top of the column. The location points for these displacement transducers were selected at the positions where stress concentration was more likely to occur as shown in Fig. 1. Load-displacement curves were used to understand the effects of strengthening techniques in a better manner.



Fig.1. 10-ft full column with testing setup

2.4 Testing Procedure

The control specimen (CSC) was first tested. The idea to strengthen the critical/ specific section of the columns was visually observed in control column (CSC) (as shown in Fig. 3). First crack was observed at a distance of 3-ft from the base.

The control specimen/ column was loaded first with the force control loading mode i.e. 0.4 tons, 0.6 tons, 0.8 tons and 1.2 tons. After the appearance of first crack at the force of 1.2 tons, the mode of loading was changed to displacement control loading.

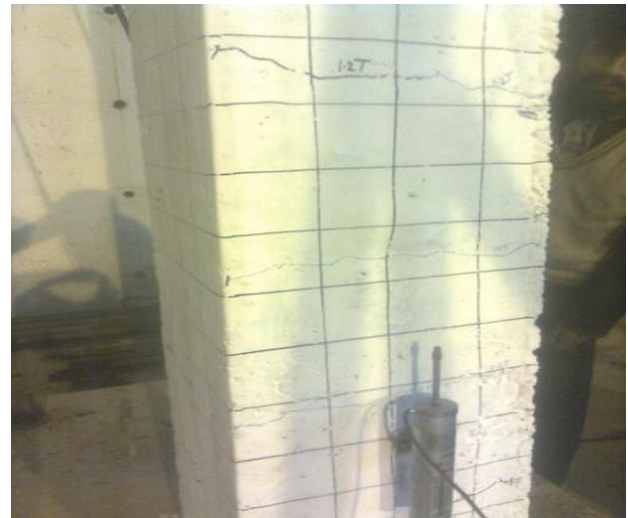


Fig.2. Critical section where the cracks were developed

The column was loaded at an interval of every 10 mm and corresponding force/ load was recorded until failure. Mode of failure was also recorded.



Fig.3. Crushing of concrete near the joint of Column-base of CSC

3 RESULTS AND DISCUSSION

It is very important that the member which is to strengthen must be subjected to the condition that are more likely similar to the field conditions for the effectiveness and performance of strengthening/ retrofitting scheme [3]. In this research, the mix design of concrete and the dimension of the columns so selected were more realistic and depict the general construction practices in this part of the world.

Control specimen column (CSC) was first tested. Initially force-control mode of testing was applied. The loading started from 0.4 tons. At the load/ force of 0.4 tons first crack appeared and its corresponding displacement was 4-mm (as shown in Fig.3). The mode of loading was then changed to displacement control. The displacement was increased at regular intervals of 10-mm. Different cracks were generated. At the displacement of 110-mm and at its corresponding force of 1.5-tons, the columns was not taking more load. The failure of the column was due to the observed crushing of concrete near the joint of column-base (as shown in Fig-3).

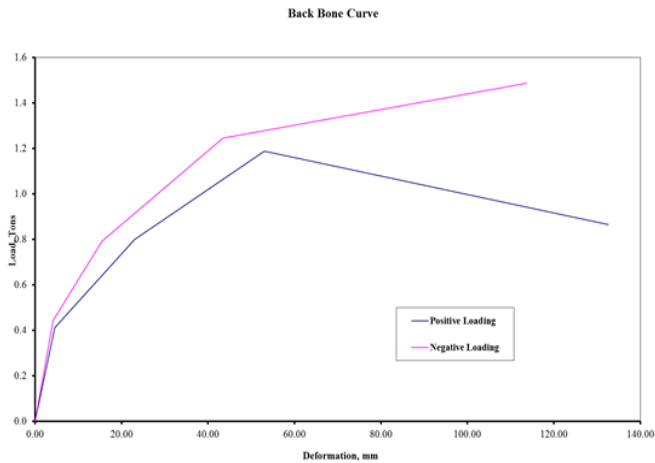


Fig.4. Load-Displacement BackBone Curve for Control Specimen (CSC) i.e. unstrengthened Column

The second testing was done on the specimen wrapped with FRP at the critical section (HF1LC). The critical section of the column was established on the basis of testing on the Control column (CSC). The specimen was tested under the same conditions in which CSC was tested. The procedure of application of loading was also same as shown in Fig.5.



Fig. 5. Testing setup and FRP wrapped section on HF1LC

During testing, at the displacement of 147 mm, its corresponding load increased to about 1.97 tons, and then the capacity of the column suddenly dropped. The failure of the column was due to the failure of joint between the column and the base/ foundation as shown in Fig. 6 (b). Minor cracks also appeared on FRP wrap due to the cracking of concrete as shown in Fig. 6(a). Visibly the strengthened section of the column did not fail and was still taking load.



Fig. 6(a)



Fig. 6(b)

The third testing was done on the column strengthened with the GI wire mesh (HW1LC). The critical section of the column established during the testing of CSC was strengthened. The testing conditions were similar to the earlier columns. The procedure of the application of load was also same. Minor cracks appeared at different positions during loading. These cracks were very symmetric from down to up in horizontal direction as shown in Fig. 7(a). At a displacement value of about 150 mm, the corresponding load was 1.8 tons, the capacity of the column dropped and load started decreasing. The failure of the column was near the column-footing joint as shown in the Fig 7(b).

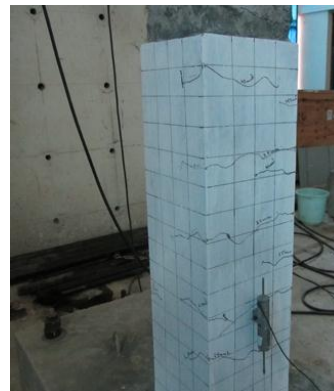


Fig. 7(a)



Fig. 7(b)

Table 4 shows load (P), applied at the distance of 9.5 feet from base, and the corresponding maximum displacement for all the columns.

TABLE 4
STRENGTH AND DISPLACEMENT FOR ALL THE THREE SCHEMES

Scheme	Load (Tons)	Displacement (mm)
CSC	1.5	110
HF1LC	1.97	147
HW1LC	1.8	150

It was observed that both the strengthening techniques i.e. FRP jacket and wire mesh enhances the strength and ductility capacity of the RC column. Moreover the FRP was found to be impressive in increasing the strength capacity.

The load-displacement curves for the three specimens (CSC, HF1LC, HW1LC) i.e. unstrengthened, FRP strengthened and GI wire mesh strengthened column are presented in Fig. 8, 9 and 10 respectively.

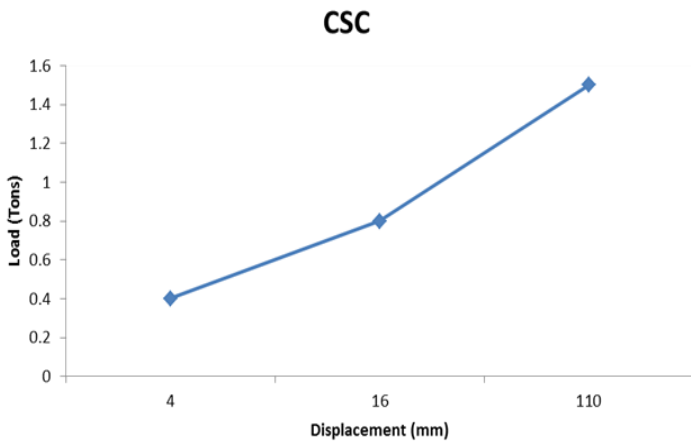


Fig. 8. Load-Displacement curve for CSC

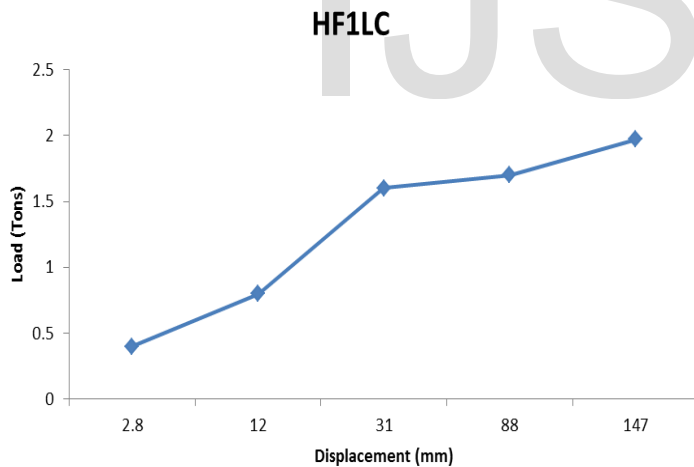


Fig. 9 Load-Displacement curve for HF1LC

It was also observed that due to the FRP wrap and wire mesh, the ductility of the column was greatly increased. In case of CSC, the column reached upto the maximum displacement of 110-mm where as in case of FRP wrap, the maximum displacement was 147-mm and similarly in case of wire mesh strengthened column, the maximum displacement was 150-mm.

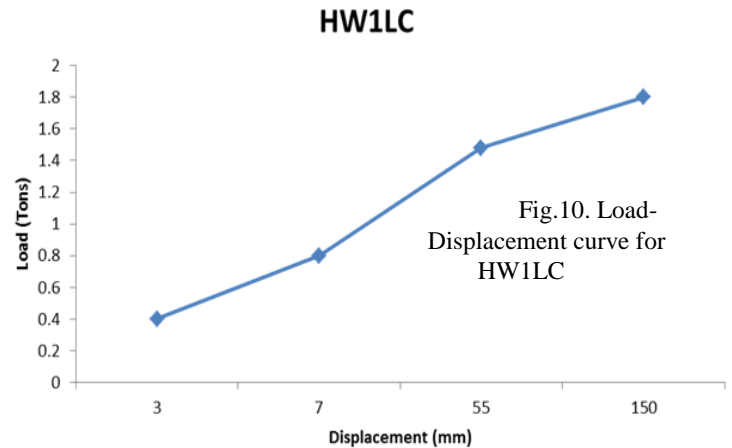


Fig.10. Load-Displacement curve for HW1LC

4 CONCLUSION

The research work was designed to study the two strengthening scheme for square RC columns, taking into account the effects of seismic loading to columns with low compressive strengths. From the experimental work, it can be concluded that both the FRP jacketing and application of wire mesh can increase the seismic capacity of the columns in increasing their strength and ductility. The efficiency of FRP jacketing was more than the other strengthening technique. Due to many advantages of FRP, especially no need of evacuation of the structure during retrofitting/ strengthening, it can be preferred over other strengthening/ retrofitting technique.

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