Pakistan Journal of Engineering and Technology, PakJET
Multidisciplinary | Peer Reviewed | Open Access

Volume: 1, Number: 1, Pages: 57- 65, Year: 2018

Re-Strengthening/Retrofitting of Concrete Columns at Laboratory Scale Level

Dr. Abdul Ghaffar[1, *], Dr. M Burhan Sharif[2], Dr. Zia ur Rehman[2]

[1]Quaid-e-Azam College of Engg. and Tech. Sahiwal, [2]University of Engineering and technology, Lahore
*Corresponding author: Dr. Abdul Ghaffar (email: abdulpk@yahoo.com,)

Abstract— ***Natural disasters like Earthquakes, Tsunamis, Sea and Wind Storms are common in the world. Their intensity and location are unpredictable. Major effects of these natural forces are the loss of human life and property. The damage to the property is different for different locations and for different types of structures. Extensive damage requires demolishing of structures. But moderate to medium level damage to the structures can be compensated by using the re-strengthening / retrofitting techniques. Re-strengthening / retrofitting is not a latest technique used for reinforcing the structure. It is as old as humanity. Usually everyone wants to restore their property with minimum cost. These days the framed structures are very common. Moderate level damages to these structures includes plastic hinge formation at the beam column joints, spalling and partial crushing of concrete, etc. The structures which have failed to such extent but are staying at their position can be restored by retrofitting. Generally, the member dimensions are increased and a bond is created between the new material and the old material so that they both contribute against loads. In this laboratory scale level study columns are prepared and loaded to the certain damage level. After that columns are re-strengthened/retrofitted by reinforced concrete jacketing and their behavior is studied after jacketing. Testing results show that load carrying capacity of the columns is increased and columns are still useable. In this way huge cost required for demolition and rebuilding can be saved.***

Index Terms— Re-strengthening, Retrofitting, Concrete jacketing, Reinforced concrete.

I. INTRODUCTION

If we modify the structural members in order to increase their seismic resistance, or to bear excessive ground motions and ground failures during earthquakes, such modifications are called retrofitting. As understanding of seismic behavior / demand of structures is improving day by day, and also keeping in view the lessons learnt from the recent earthquakes near and around urban areas, the requirement of retrofitting is constantly increasing.

Before the development of seismic codes, structures were used to be designed without reinforcement detailing required for protection against seismic activity, and this was done in developed countries like Japan and US till 1960s and in countries like China and Turkey till 1970s [1]. Many research organizations realized this problem, and some state of the art reports and guidelines are published to assess the seismic damage etc. and to judge the quantum of rehabilitation and retrofit requirements. i,e. ASCE-SEI 41(American Society of Civil Engineers) [2] and NZSEE's guidelines (New Zealand Society for Earthquake Engineering) [3].

Although the usual techniques available for retrofit are equally applicable to natural hazards like tornados, thunderstorms, tropical cyclones and severe-winds, however the current focus of retrofitting is primarily for improving structural performance to reduce the seismic hazards. It must be kept in mind that there is nothing like earthquake-proof structure. However, by using proper design practices or subsequently carrying out adequate retrofits, structural performance during seismic activity can be enhanced up-to a great extent [1].

Some practical applications like strengthening and seismic retrofitting have been studied in the past. These applications include the use of braces, infills or jacketing. More recently, applications like supplemental damping devices, base isolations or advanced materials including SMA (Shape Memory Alloys) or FRPs (Fiber Reinforced Polymers) are used. Most of the above-mentioned techniques are developed through research and upgrades, but issues like invasiveness, cost effectiveness and practical implementation of these techniques are still posing challenges to the researchers [3].

During an earthquake, damages of columns are more detrimental as compared to other structural parts. If severe damage occurs then there is no option except to demolish the structure and to rebuild it with seismic design provisions. If damage is small, these columns can be reused after re-strengthening / retrofitting. Among the available techniques RC jacketing is the easiest to carry out in the field. To check the effectiveness of RC jacketing a small laboratory scale study is planned, details of which are presented in the following sections.

II. LITERATURE REVIEW

Repair of a deteriorated structure or rehabilitation of damaged concrete is a science as well as an art. For repair purposes, many techniques are available out of which a suitable and adequate technique is selected for a certain work site. The basic aims of rehabilitation and repair of concrete include improving the following [4]:

1. The integrity of a structure.
2. Appearance of a structure.
3. Durability of a structure.
4. Functional performance of a structure.
5. Water-tightness of a structure.

Concrete is not only damaged by earthquakes but there are many other processes which also damage the concrete and hence reduce its load carrying capacity and its useful life. By strengthening concrete, its service life can be considerably enhanced. Defects and damages in concrete may be due to: impact or earthquake loading (called accidental loading), attacks and reactions like acid, alkali-silica, aggressive-water, alkali-carbonate, sulfates, other chemical reactions and corrosion of embedded-metals (called chemical reactions), poor-design-details or inadequate design or structural errors (called errors), cavitation and abrasion (called erosions), settlements, freezing and thawing (called movements), drying and plastic shrinkages, fire damages, weathering and internal/external temperature changes etc.[4].

Strengthening of reinforced concrete structures may be required to increase their load carrying capacities. In such situations either additional concrete elements are required or whole structure needs to be retrofitted, repaired or strengthened. For strengthening of columns commonly used methods include FRPs (fiber reinforced polymers) jacketing, steel jacketing or reinforced concrete jacketing. All above mentioned jacketing techniques are proven to effectively enhance load carrying capacities of the columns [5].

Julio Garzón-Rocaet et al. [6] conducted a series of experiments on prototype columns with steel caging, using beam-column joint simulations under axial and bending load combinations. To monolith the beam-column joints with the caging, column capitals are provided either with steel bars or chemical anchors. After experimentation it was learnt that steel caging enhanced both the ductility and failure loads of the strengthened columns.

Khair Al-DeenIsamBsisu [7] conducted theoretical as well as experimental study on twenty different RCC columns, which were retrofitted using steel-jacketing technique. Concentric axial loads were used to test all these twenty columns. According to his conclusions retrofitted square RC columns using full steel jackets, enhancement in compressive strength is more than 100% above the strength of originally un-retrofitted column. The confinement provided by the steel jacketing has also improved the ductility of the column.

Pasala Nagaprasad et al. [8], suggested a rationalized design approach for concrete columns for proportioning the steel cage depending upon its confinement effects, and to validate the suitability of proposed design approach and steel cage detailing in the vicinity of regions of expected plastic hinges. From his study he concluded that RC columns found deficient under combined axial and cyclic lateral loading, their performance can be improved using steel caging technique, even without use of binding materials in the gaps existing between steel angles and the concrete. Encouraging results are obtained from the study and the proposed design approach was found to be reasonably accurate. Detailing of end battens of the steel cage located in the potential plastic hinge region played an important role in improving the column's overall behavior under lateral loads. By increasing the width of the end-battens, plastic rotational capacity is increased as well, while improving the lateral load resistance. However, a minor overall effect on energy dissipation was observed.

Rosario Montuori et al. [9], tested thirteen different specimens under axial load. He suggested a theoretical model for prediction of moment-curvature behavior of reinforced concrete columns which are confined using angles and battens. According to authors proposed theoretical model proved its ability for predicting the performance of strengthened columns with angles and battens.

This present study is conducted to evaluate effect of RC jacketing on the behavior of damaged RC columns. A comparison is made between the capacities of original column without jacketing and damaged column with jacketing.

III. EXPERIMENTATION

For the purpose of this research, columns of 6-inch x 6-inch x 36-inch (152 mm x 152 mm x 914 mm) were casted. Number of columns was three designated as C-1, C-2 and C-3 with varying concrete strengths. These columns were reinforced with 4 - # 3 (9.5 mm) bars. Stirrups of # 2 (6.4 mm) size were provided at 4-inch (100 mm) c/c. Four cubes are casted from the mix of each column and tested at the ages of 7 and 28 days. The observed concrete strengths are given in the Table 1, whereas columns casted in lab. and reinforcement details are given in Figure: 1.

Table 1 Strength of concrete used for casting columns.

Column	Type of Specimen	7 days strength			28 days strength		
		Load (tonns)	(psi)	Average	Load (tonns)	(psi)	Average
C-1	Cylinder	21.25	1684	**1654 Psi (11.4 MPa)**	26.6	2107	**2064 psi (14.23 MPa)**
	Cylinder	20.50	1624		25.5	2020	
C-2	Cylinder	24	1901	**2060 Psi (14.2 MPa)**	39	3090	**2733 psi (18.85 MPa)**
	Cylinder	28	2218		30	2377	
C-3	Cylinder	37	2931	**3010 Psi (20.76 MPa)**	52	4120	**3882 psi (26.77 MPa)**
	Cylinder	39	3090		46	3644	

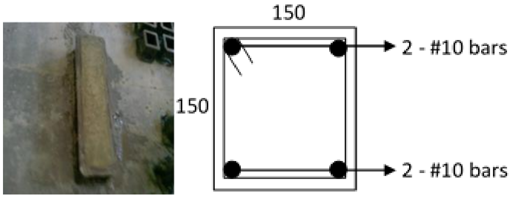

Figure 1 Casting of columns in the laboratory and reinforcement details.

After 28 days of curing, columns were tested using universal testing machine. Axial loads as well as deformation in all three axes were noted. Longitudinal axis was designated as z-axis whereas cross-sectional axes were designated as x and y axis. Deformations in all three axes were noted with the help of dial gauges and are reported in the following sections. Columns were loaded up to failure and failure load was recorded from the display of UTM. Different staged of testing and failure are shown in Figure: 2.

Stage 1

Stage 2

Stage 3

Stage 4

Stage 5

Stage 6

Figure 2 Different stages of experimentation.

After complete failure, columns were retrofitted by jacketing RCC around the failed columns. Thickness of jacketing was 1.5” (38 mm), hence column dimensions were 9” x 9” x 36” (228 x 228 x 914 mm) after jacketing. Column was reinforced with 4 - # 3 (9.5 mm) bars and stirrups of # 2 (6.4 mm) bars. Reinforcement bars of jacket were attached to dowels drilled in the failed columns. Process of jacketing and final cross-section of retrofitted column is shown in Figure: 3.

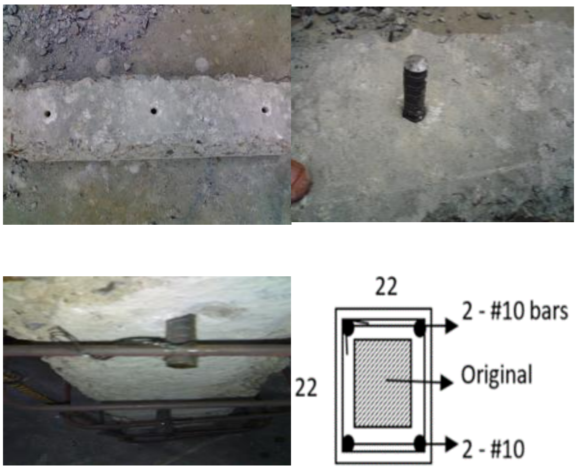

Figure 3 Reinforcement details of retrofitted column.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

Columns are tested using Universal Testing Machine installed in the Test Floor lab of UET, Lahore. Longitudinal axis is designated as z-axis whereas cross-sectional axes are designated as x and y axis. Deformations in all three axes are noted with the help of dial gauges and are reported in the following sections. Results obtained for column C-1 Before and after retrofitting are shown in tables 2. Whereas load deformation curves for column C-1 before and after retrofitting are shown in Figures 4 and 5.

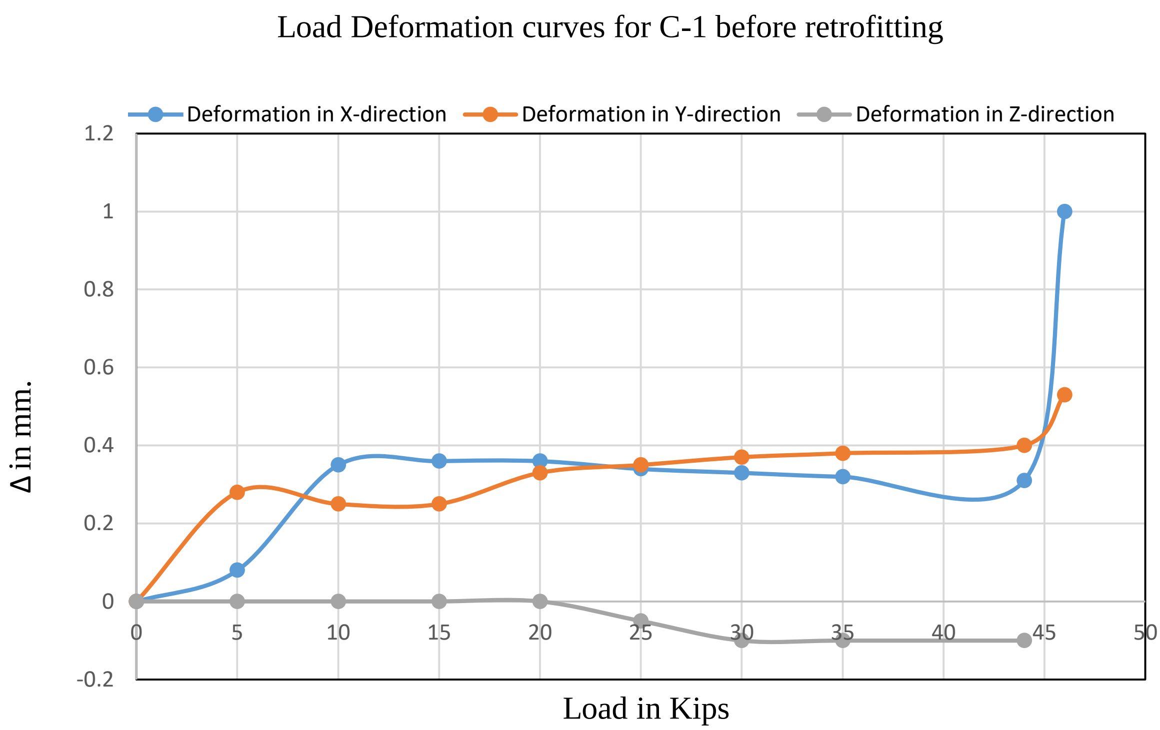

Figure 4 Load deformation curves of column C-1 before retrofitting.

Table 2 Performance of column C-1 before and after retrofitting.
Δ_x, Δ_y and Δ_z represent the deformations in x, y and z directions.

Sr. No.	**Performance Before Retrofitting**					**Performance After Retrofitting**			
	LOAD	Δ_x	Δ_y	Δ_z	**REM.**	Δ_x	Δ_y	Δ_z	**REM.**
	(Kips)	**mm.**	**mm.**	**mm.**		**mm.**	**mm.**	**mm.**	
1	0	0	0	0		0	0	0	
2	5	0.08	0.28	0		0.05	0	-0.1	
3	10	0.35	0.25	0		0.15	0.05	-0.1	
4	15	0.36	0.25	0		0.22	0.07	-0.1	
5	20	0.36	0.33	0		0.3	0.07	-0.2	
6	25	0.34	0.35	-0.05		0.33	0.1	-0.2	
7	30	0.33	0.37	-0.1		0.38	0.1	-0.2	
8	35	0.32	0.38	-0.1		0.4	0.1	-0.3	
9	40	0.31	0.39	-0.1		0.4	0.1	-0.3	
10	44	0.31	0.4	-0.1	major cracks appeared				
11	45					0.4	0.1	-0.3	
12	46	1	0.53		Failure	0.4	0.1	-0.3	
13	47.4					0.43	0.13	-0.4	major cracks appeared
14	50					0.45	0.2	-0.4	
15	55					0.45	0.1	-0.5	
16	69								Failure

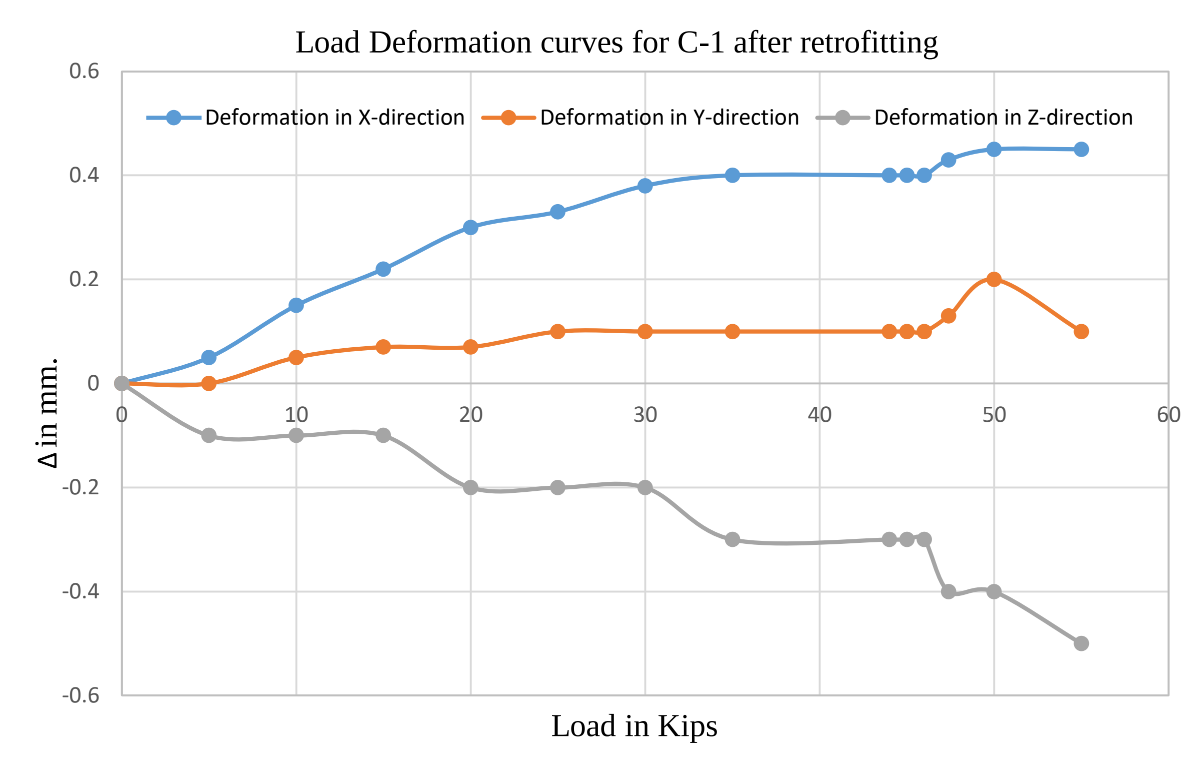

Figure 5 Load deformation curves of column C-1 after retrofitting.

Columns C-2 and C-3 are tested in the same manner. Results obtained for column C-2 and C-3 before and after retrofitting are shown in tables 3and 4 respectively. Whereas load deformation curves for columns C-2 and C-3 before and after retrofitting are shown in Figs 6 to 9.

Table 3 Performance of column C-2 before and after retrofitting.
Δ_x, Δ_y and Δ_z represent the deformations in x, y and z directions.

Sr. No.	**Performance Before Retrofitting**					**Performance After Retrofitting**			
	LOAD	Δ_x	Δ_y	Δ_z	**REM.**	Δ_x	Δ_y	Δ_z	**REM.**
	(Kips)	**mm.**	**mm.**	**mm.**		**mm.**	**mm.**	**mm.**	
1	0	0	0	0		0	0	0	
2	5	0	0.1	-0.1		0.23	0	0	
3	10	0.08	0.2	-0.2		0.23	0.03	-0.2	
4	15	0.13	0.25	-0.3		0.26	0.11	-0.5	
5	20	0.15	0.31	-0.3		0.64	0.59	-0.6	
6	25	0.16	0.36	-0.3		0.69	0.74	-0.7	
7	30	0.17	0.43	-0.4		0.76	0.89	-0.7	
8	35	0.18	0.5	-0.4		0.79	0.91	-0.7	
9	44	0.19	0.58	-0.5		0.84	0.94	-0.7	
10	45	0.25		-0.6	major cracks appeared	0.89	0.97	-0.8	
11	49	0.5			Failure				
12	50					0.89	0.97	-0.8	
13	55					0.89	0.97	-0.8	
14	60					0.89	1.05	-0.8	
15	67					0.89	1.27	-0.8	major cracks appeared
16	72					0.89	1.48	-0.8	
17	73					0.89	1.55		Failure

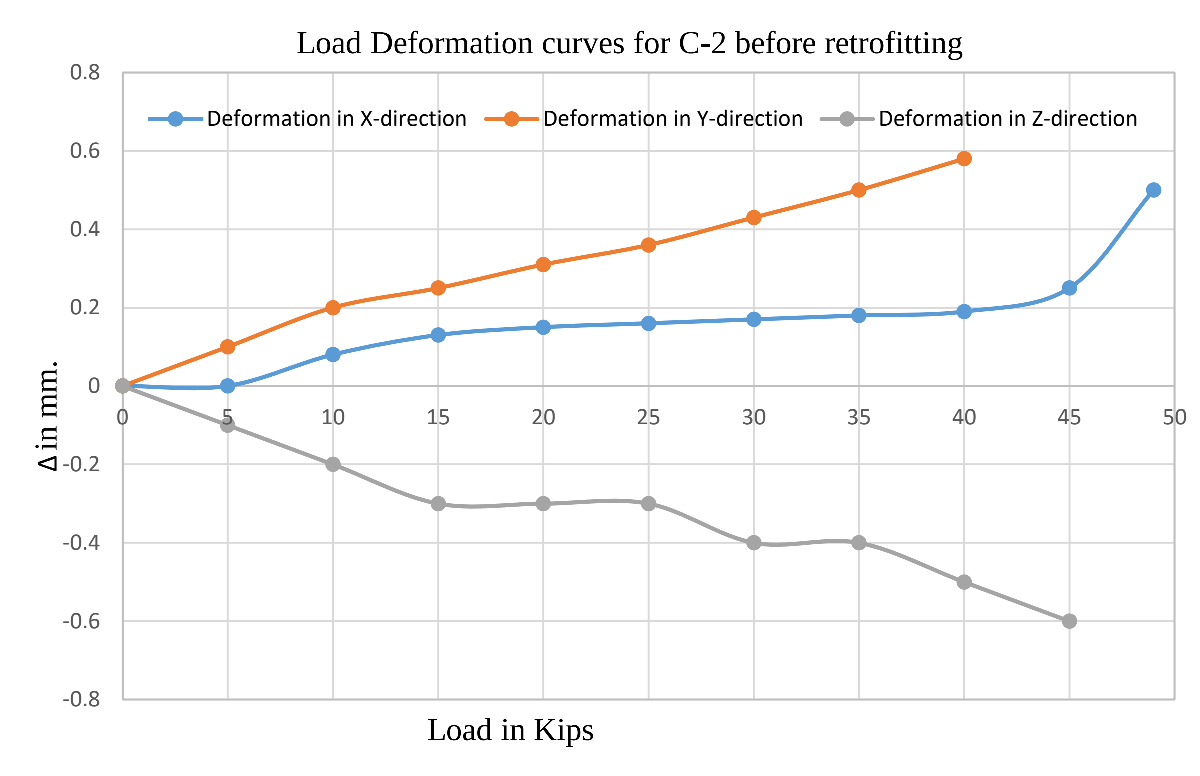

Figure 6 Load deformation curves of column C-2 before retrofitting.

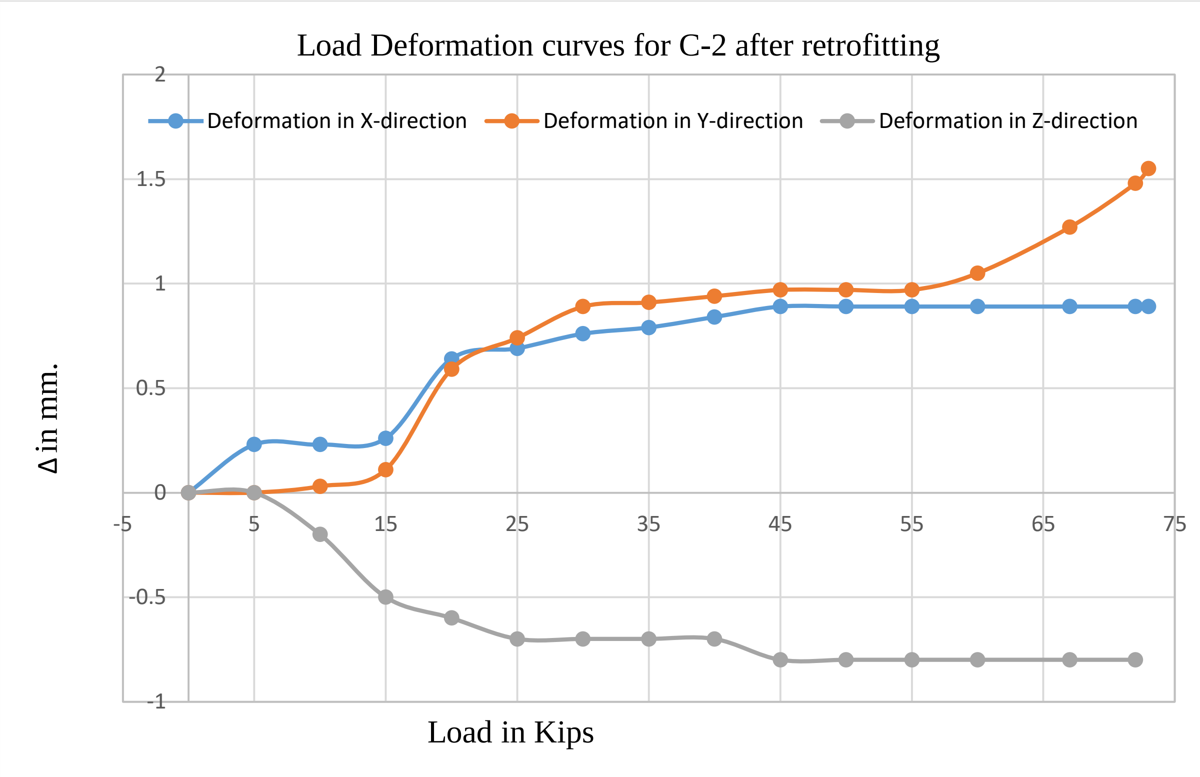

Figure 7 Load deformation curves of column C-2 after retrofitting.

Table 4 Performance of column C-3 before and after retrofitting.
Δ_x, Δ_y and Δ_z represent the deformations in x, y and z directions.

Sr. No.	Performance Before Retrofitting					Performance After Retrofitting			
	LOAD	Δ_x	Δ_y	Δ_z	**REM.**	Δ_x	Δ_y	Δ_z	**REM.**
	(Kips)	**mm.**	**mm.**	**mm.**		**mm.**	**mm.**	**mm.**	
1	0	0	0	0		0	0	0	
2	5	0.2	0.05	-0.1		0.06	0	-0.1	
3	10	0.25	0.05	-0.1		0.15	0.03	-0.2	
4	15	0.29	0.06	-0.1		0.46	0.23	-0.4	
5	20	0.32	0.08	-0.2		0.64	0.58	-0.6	
6	25	0.35	0.1	-0.2		0.71	0.7	-0.6	
7	30	0.37	0.11	-0.2		0.79	0.89	-0.7	
8	35	0.38	0.13	-0.3		0.81	0.91	-0.7	
9	44	0.38	0.13	-0.3		0.84	0.94	-0.7	
10	45	0.38	0.13	-0.3		1.31	0.94	-0.7	
11	50	0.38	0.13	-0.3		0.89	0.96	-0.8	
12	55	0.38	0.13	-0.4	major cracks appeared	0.89	0.99	-0.8	
13	59				Failure				
14	60					0.89	1.04	-0.8	
15	65					0.89	1.14	-0.8	
16	70					0.89	1.47	-0.8	
17	75					0.93	1.62	-0.9	
18	80					0.99	1.73	-1	
19	85					1.17	1.93	-1	major cracks appeared
20	87								Failure

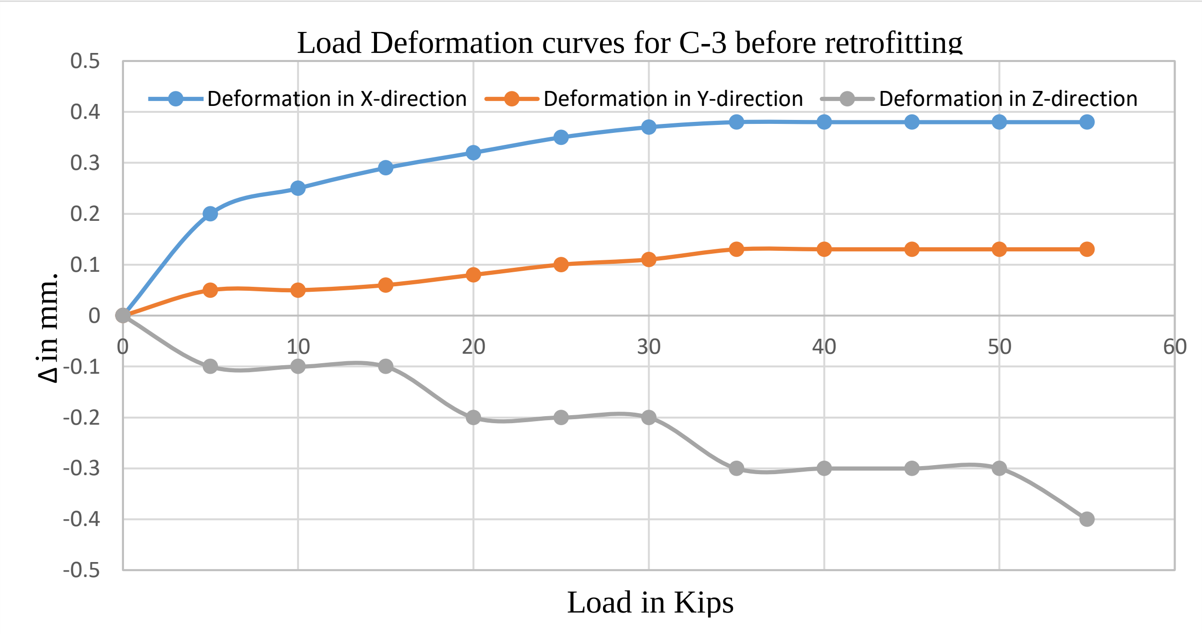

Figure 8 Load deformation curves of column C-3 before retrofitting.

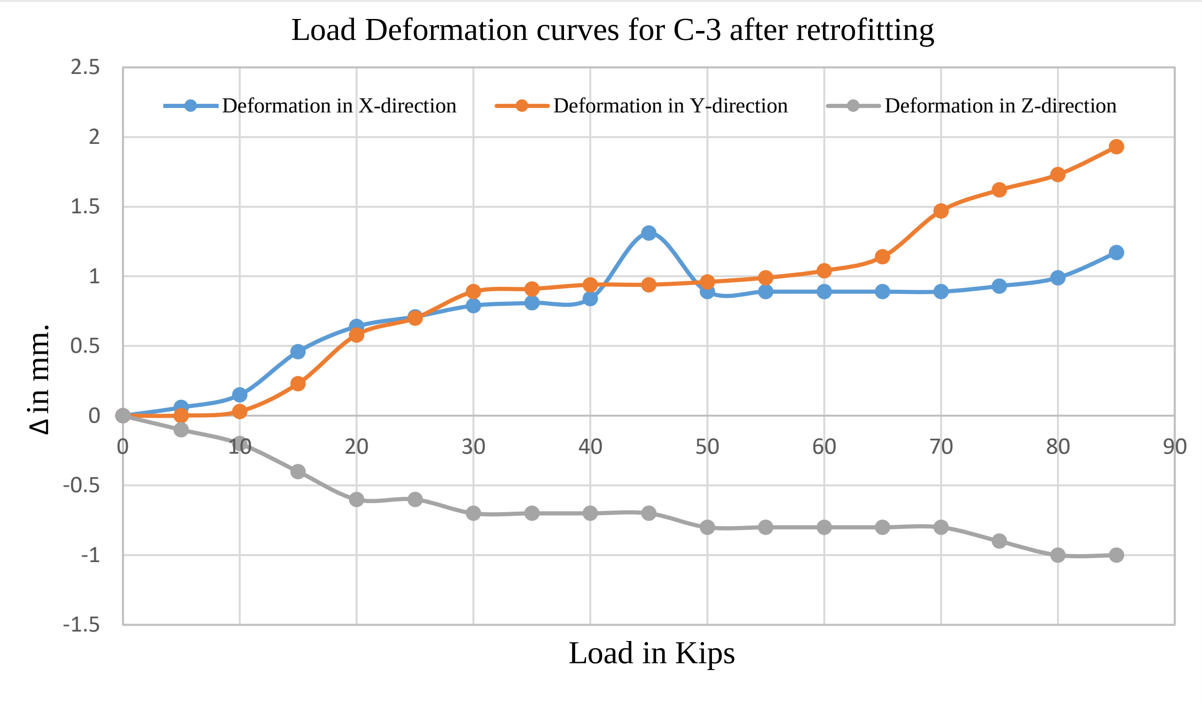

Figure 9 Load deformation curves of column C-3 after retrofitting.

Table 5 Over all summary of test results.

	Column C-1	Column C-2	Column C-3
Concrete Strength before Retrofitting	44000	49000	59000
Concrete Strength after Retrofitting	69000	73000	87000
Increase	56.82 %	48.98%	47.46%
Max. Deformation before Retrofitting	0.4	0.6	0.6
Max. Deformation after Retrofitting	1.17	1.93	1.0
Increase	179.3%	221.7%	66.7%

V. CONCLUSIONS

From the observations of the above study, it is evident that retrofitting by RC jacketing is an easy and viable method for re-strengthening of the damaged concrete columns. It is very simple and no precise and expensive equipment is needed for this purpose. Moreover, this kind of strengthening can be performed for any type of concrete column. On the basis of the experimentations following conclusions are drawn from the study:

1. Observed load capacity of the retrofitted columns increased upto 47.46 to 56.82 %.
2. Area of concrete is 36 in^2 (23104 mm^2) before retrofitting and 45 in^2 (29032 mm^2) after retrofitting. It means area of concrete increased by 25 %, whereas load carrying capacity increased upto 56.82 %. This extra benefit comes from decrease in slenderness ratio of the column.
3. Retrofitted columns show reduction in load capacity with increase in concrete strength.
4. Deformations of retrofitted columns are also increased upto 221.7 %. It means retrofitting also increase the ductility of concrete columns.

REFERENCES

[1] https://en.wikipedia.org/wiki/Seismic_retrofit, accessed On October 21, 2017.

[2] P. Ricci; G. M. Verderame; and G. Manfredi; "ASCE/SEI 41 Provisions on Deformation Capacity of Older-Type Reinforced Concrete columns with Plain Bars" Journal of Structural Engineering, Volume 139 Issue 12 - December 2013

[3] S. Pampanin, Controversial aspects in seismic assessment and retrofit of structures in modern times: understanding and implementing lessons from ancient heritage, bulletin of the new zealand society for earthquake engineering, Vol. 39, No. 2, June 2006.

[4] K. Soudki; Concrete Problems and Repair Techniques https://www.sefindia.org/forum/download.php?id=11783&sid., accessed on October 21, 2017.

[5] M. F. Belal; H. M. Mohamed; S.A., Morad; Behavior of reinforced concrete columns Strengthened by steel jacket, Housing and Building National Research Center Journal 11, 201–212, 2015.
[6] R. Julio, P. Joaquı´n, A. Jose, C. Pedro. An experimental study onsteel-caged RC columns subjected to axial force and bendingmoment, Eng. Struct. J. 33, 580–590, 2010.
[7] B. Khair, Retrofitting of Square Reinforced Concrete Columns Subjected to Concentric Axial Loading with Steel Jackets, The Third Engineering Consultant work conference, Palestine, 2009.
[8] N. Pasala, S. Dipti, R. Durgesh, Seismic strengthening of RC columns using external steel cage, Earthquake Eng. Struct. Dyn.J. 38,1563–1586, 2009.
[9] M. Rosario, P. Vincenzo. Reinforced concrete columns strengthened with angles and battens subjected to eccentric load, Eng. Struct.31, 539–550, 2008