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Vertical Structural Element Using Different Retrofitting Techniques

P Vijaya Kumar[1] , Prof. B. Sesha Srinivas[2]

[1]*Ph.D. Scholar, Civil Engineering Department, Kakatiya University, Warangal, Telangana, India.*
[2]*Professor Civil Engineering Department, Kakatiya University, Warangal, Telangana, India.*

Abstract: Many reinforced concrete structures are deficient in stiffness, ductility, and strength capacity compared to current standards. When a powerful event, such as an earthquake, occurs, un-strengthened and inadequate concrete members may fail and produce catastrophic results. In order to counteract this problem, many different retrofit and repair methods have been studied, implemented and have produced a variety of results. This research is focused on comparing local retrofit and repair methods for reinforced concrete columns in order to analyze the efficacy of these methods. The primary methods compared are reinforced concrete jacketing, steel jacketing and FRP jacketing. A variety of constraints are compared across the methods including the loading capacity, connection methods, deformation, shear stress and shear strain in the member. Each retrofit method functions differently under each constraint, and the benefits and downsides of each were discussed and compared.
Keywords: Jacketing, concrete jacketing, steel jacketing, FRP jacketing.

1. Introduction

A number of reasons may involve the need to retrofit of existing structures. It may be the rehabilitation of a structure damaged by an earthquake or other causes, or the strengthening of an undamaged structure made necessary by revisions in structural design or loading codes of practice. The decision to strengthen it before an earthquake occurs depends on the building's seismic resistance. The existing building can be retrofitted using various techniques like Jacketing existing beams, columns, or joints, Use of Fiber Reinforced polymer, Use of carbon fiber reinforced polymer, use of steel plates, steel bracing, size modification in column. In many seismically active regions of the world there are large numbers of masonry buildings in which most of these buildings have not been designed for seismic loading. Recent earthquakes have shown that many such buildings are seismically inadequate and should be considered for retrofitting. There has been much research on the topic of seismic retrofit of structures in recent years. A number of techniques may be used to retrofit concrete structures. Retrofitting may be carried out on a global basis by adding extra load-resisting elements such as steel frames or steel braces to the structure or it can be performed on a local basis by retrofitting the existing structural elements. Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. Rehabilitation denotes repairing buildings damaged during service or by earthquakes without upgrading the seismic resistance, while seismic retrofitting denotes upgrading the safety of damaged or existing deficient buildings. With the number of structurally deficient structures and structures vulnerable to high impact events such as natural disasters or blasts, understanding how to retrofit existing structures is important. While the relevancy of structural retrofit has increased more recently, research into the retrofit of reinforced concrete structures has been performed for years. However, with the amount of information available, little work has been done comparing the efficacy of different methods or under different scenarios, since many studies are focused on structure-specific retrofit. Given the structural retrofit needs of columns, relative to other structural elements such as beams, walls or slabs, retrofit of columns is of particular importance. Additionally, retrofitting structures that may be vulnerable can improve their resiliency and potentially increase the lifespan of both the column and the structure.

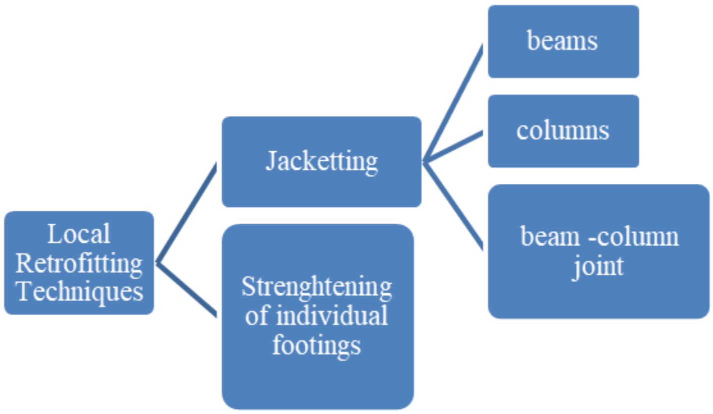
This research was focused on understanding and comparing the efficacy of reinforced concrete jacketing, steel retrofit and FRP jacketing methods. Additionally, the structural performance is a primary
consideration of this research; however, the practicalities of the methods are considered.
This research contains the following objective:

- Analysis of Reinforced concrete column under static loading using ANSYS.
- Retrofitting of failed reinforced concrete column by using concrete jacketing.
- Retrofitting of failed reinforced concrete column by using steel jacketing.
- Retrofitting of failed reinforced concrete column by using FRP jacketing.

2. Local Retrofitting Methods

Local retrofit technique refers to retrofitting of column, beam, joint, slab, wall and foundations. It is based on the reduction of seismic demands. Types of local retrofitting techniques:

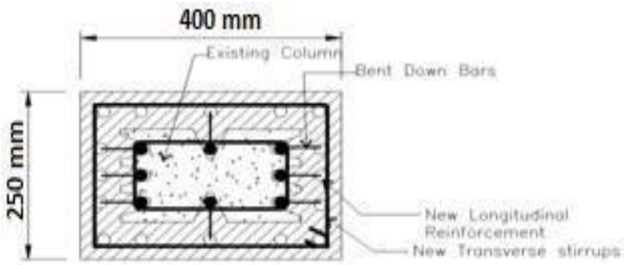
- Concrete jacketing.
- Steel jacketing.
- FRP sheet wrapping



2.1 Jacketing of Column

Figure 1: Local retrofitting techniques

Columns in RC framed buildings may fail under the seismic loading, either in shear or in bending. Shear failure occurred due to the column sizes provided are inadequate to resist the seismic load and also due to the inadequate lateral ties provided. Bending failure occurs because of inadequate amount of steel bars provided vertically in the columns, particularly near the beam column joints or column foundation junctions, and it may also occurred due to poor quality of concrete. An example of typical section showing column Jacketting has been shown in Figure 8. The original section of the column was 250mm X



400 mm. RC Jacketting can be done by using Indian standard code IS 15988:2013.

Figure 2: Typical section showing column jacketting

2.1.1 Concrete jacketing of column

Reinforced concrete jacketing can be employed as a repair or strengthening scheme. Damaged regions of the existing members should be repaired prior to their jacketing. There are two main purposes of jacketing of columns: (i) increase in the shear capacity of columns in order to accomplish a strong column-weak beam design and (ii) to improve the column's flexural strength by the longitudinal steel of the jacket made continuous through the slab system and anchored with the foundation.

2.1.2 Steel jacketing of column

Local strengthening of columns has been frequently accomplished by jacketting with steel plates. Steel sheets are used in beam to increase their flexure and shear strength. A steel sheet is bonded or bolted at the bottom face of the beam. This is considered for the strengthening of beam for gravity load. For seismic load, the shear strength can be enhanced by bonded or bolting sheet on the side face near the two ends of the beam.

2.1.3 FRP jacketing of column

Several researchers have investigated the possibility and feasibility of fiber reinforced polymer composite jackets for seismic strengthening of columns winding them with high strength carbon fibers around column surface to add spiral hoops. The merits of this method are : (i) carbon fiber is flexible and can be made to contact the surface tightly for a high degree of confinement is of high ; (ii) confinement is of high degree because carbon fibers is of high strength and high modules of elasticity are used ; (iii) the carbon fiber has light weight and rusting does not occur.

3. FEM Modeling of Column

The finite element method is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. The finite-element program ANSYS v12 workbench is used for the numerical modelling of columns. The element details of each material are presented subsequently in table 2. The finite element analysis is an assembly of finite elements which are interconnected at a finite number of nodal points. In the present study, discrete modelling approach is used to model the behavior of reinforced concrete columns using ANSYS software. In this approach, concrete columns are modelled by Solid65 elements while the reinforcement (steel) is modelled by Link8 elements. The nonlinearity is derived from the nonlinear relationships in material models and the effect of geometric nonlinearity is not considered. The parameters to be considered for Solid65 element are material number, volume ratio and orientation angles (in X and Y direction). The parameters to be considered for Link8 element are cross sectional area and initial strain. The columns are designed for the static loading.

3.1 Specification of materials

The following material properties and element details (Table 1 & 2) are used for the present Finite element analysis for static structure under static loading. Grade of concrete used is M25 and grade of steel is fy 415.

Table 1: Properties of concrete, steel and FRP

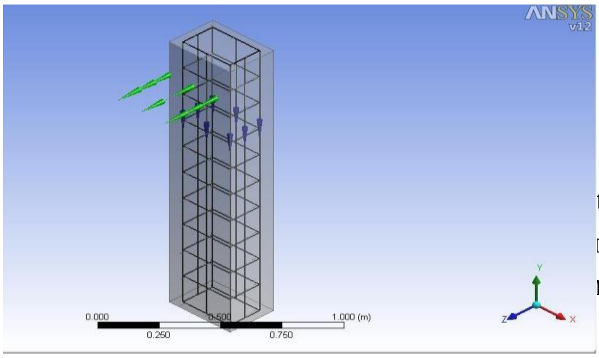
Sr. No.	Type of Jacketting	Properties			
		Density (Kg/m^3)	Young's modulus E (GPa)	Poisson's ratio	Tensile yield Strength (GPa)
1	Concrete	2300	30	0.18	0
2	Steel	7850	200	0.3	0.25
3	FRP	1960	517	0.3	1.86

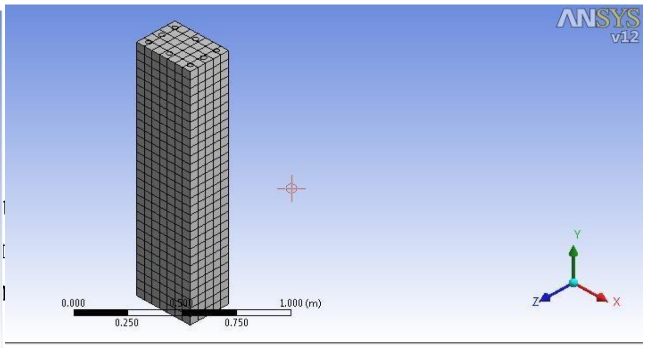
Table 2: Element details

3.2

Meshing and Reinforc ement detailing

The geometric
design and reinforcement detailing of columns is shown in Figure 3. To obtain good a result from the Solid65 element, a square mesh is used (Figure 4). Therefore, the mesh is setup such that square or rectangular elements are created. The volume sweep command of ANSYS v12 is used to mesh the support. This properly sets the width and length of elements in the concrete support and makes it consistent with the elements and nodes in the concrete portions of the model. In the analysis, the specimen was modelled with square concrete elements by using a 50 mm mesh configuration. The maximum layer of meshing is 5 and the Transition ratio is 0.272.



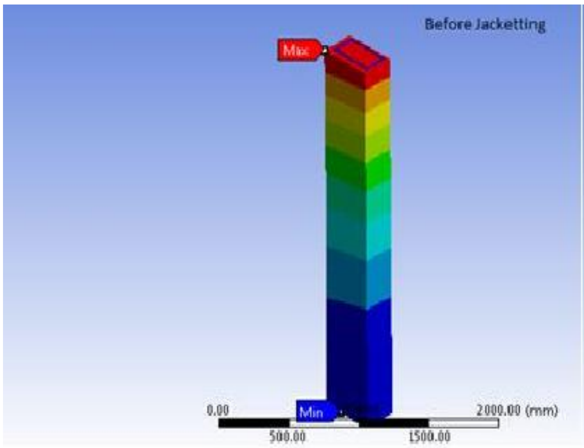


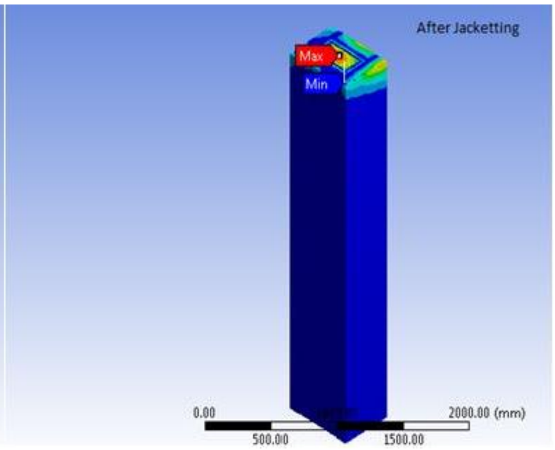
4.1 Result values of RC jacketing of column

A reinforced concrete (RC) jacket of 100mm thickness each is provided at all four sides of the column. It is found that after jacketing the deformation and stress in column C1 is decreased by 43.58% and 12.13 % respectively. In contrast to it the strain values increased by 50%. In case of column C2 the deformation and stress is decreased by 99.70 % and 9.72 % respectively but the strain increase by 4.53%.The results and figures are shown below.

Table 3: Concrete jacketting results before and after jacketting

Column number	Before Jacketting			After Jacketting		
	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)
C1	**2.96**	**59.4**	**0.00020**	**1.670**	**52.192**	**0.0003**
C2	**17.192**	**15.034**	**0.000507**	**0.051**	**13.572**	**0.000530**





Col. no.	Size of column (mm)	Height (m)	Reinforcement	Stirrups	Load, Pu (kN)	Moment, Mz (kN-m)	Moment, My (kN-m)
C1	250 x 400	1.5	8-16 Φ	8-150 c/c	1528.68	72.33	39.92
C2	250 x 400	3	8-16 Φ	8-150 c/c	1589.70	95.41	51.50

Figure 5: Total deformation for column C1 before & after concrete jacketing

4.2 Result values of steel jacketing of column

A reinforced concrete (RC) jacket of 100mm thickness each is provided at all four sides of the column. It is found that after jacketing the deformation and stress in column C1 is decreased by 49.69% and 1.51% respectively. Whereas the strain values remains in-effected. In case of column C2 the stress and strain is increased by 250 % and 5.86 % respectively but the deformation decreases by 99.60%. The results and figures are shown below.

Table 4: Steel jacketing results before and after jacketting

Column number	Before Jacketting			After Jacketting		
	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)
C1	2.96	59.4	0.00020	1.489	58.501	0.00020
C2	17.192	15.034	0.000507	0.068	38.841	0.000530

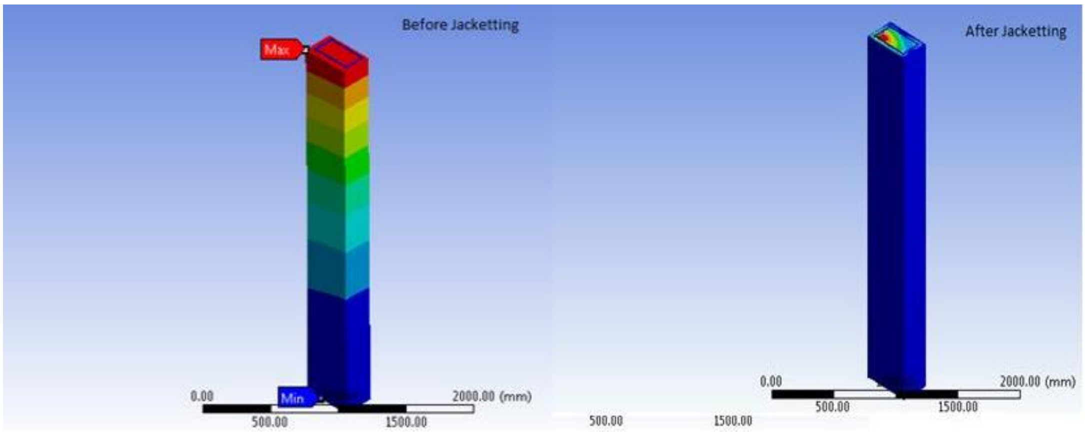


Figure 6: Total deformation of column C1 before and after steel jacketting

4.3 Result values of FRP jacketing of column

A reinforced concrete (RC) jacket of 100mm thickness each is provided at all four sides of the column. It is found that after jacketing the deformation and stress in column C1 is decreased by 69.19% and 24.62 % respectively. On Contrary the strain values increased by 50%. In case of column C2 the deformation and stress is decreased by 99.70 % and 74.16 % respectively but the strain increase by 28.2%.The results and figures are shown below.

Table 5: FRP jacketing results before and after jacketting

Column number	Before Jacketting			After Jacketting		
	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)
C1	2.96	59.4	0.00020	0.9119	44.77	0.00097
C2	17.192	15.034	0.000507	0.0068	3.8845	0.000649

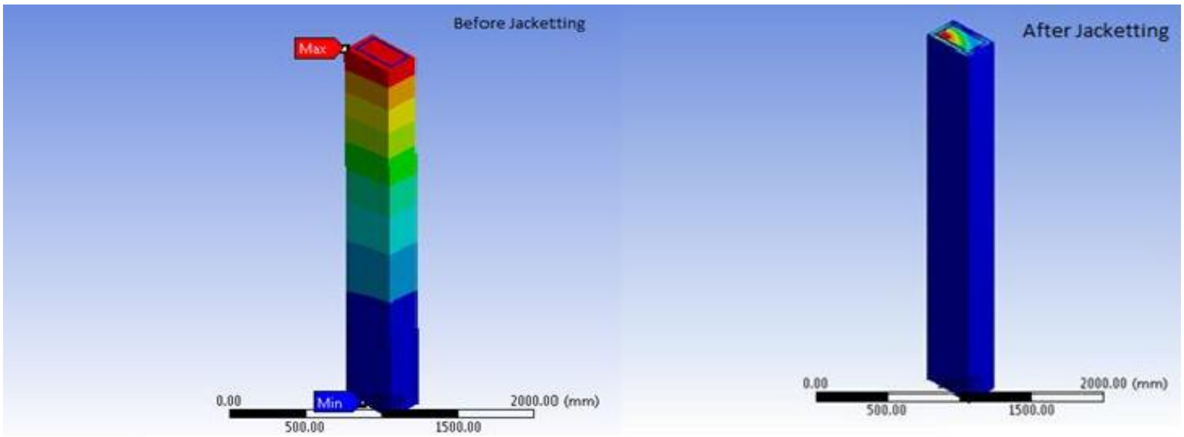


Figure 7: Total deformation of column C1 before and after FRP jacketting

4.4 Safety Comparison

The comparison of all the above techniques is made in terms of load and moment carrying capacities, deformations, Maximum principal elastic stress and Maximum principal strain.

4.4.1 Loads and Moment Carrying Capacities

After performing jacketting, the load and moment carrying capacity has been significantly increased. Considering Column number C2, the load carrying capacity before jacketting was 1325.15 KN. However, the capacity after performing RC jacketting increased to 2660.79 KN. Moreover, the moment carrying capacity (Mz) before jacketting was 79.78 KN-m. However, the capacity after performing jacketting increased to 213.55 KN-m. Thus, it can be concluded that jacketting the building or by using any such retrofitting method can guarantee the safety of the building and its occupants.

4.4.2 Deformations

In column number C2, it can be seen that the deformation almost get reduced to zero in case of FRP jacketting. The value gets reduced from 17.192 *mm* to 0.0068 *mm.* Moreover, after applying steel jacket, the deformation value decreased from 17.192 *mm* to 0.0681 *mm.*

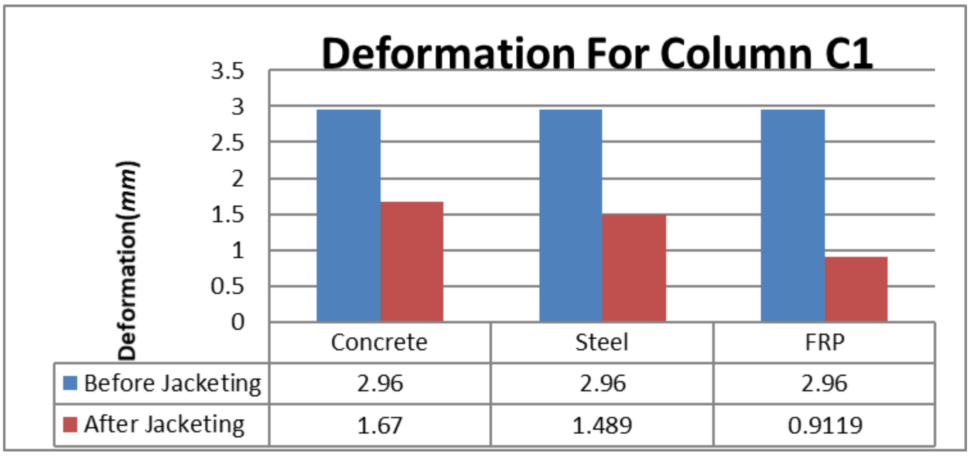


Figure 8: Comparison of total deformation of column with different jacketting

4.4.3 Maximum Principal strain and Maximum Principal Stress

The value of Maximum principal stress gets reduced from 15.034 MPa to 3.8845 MPa after applying FRP jacket for column C2. Also, Maximum principal strain is decreased from 0.000507 to 0.00145.

5. Conclusions

After performing RC, Steel and FRP jacketting, the merits and de-merits of each of these techniques can be fully interpreted. RC jacketting though increases the column size but at the same time, increases the lateral load carrying capacity. Some damage to concrete cover is inevitable in this work. However, in case of FRP jacketting, no damage to the existing building element is required. There is no significant increase in the size of the column by FRP jacketting. This technique controls the deflection, stress and strain up to a maximum extent. Steel jacketting involves welding of the steel plates to the reinforcement of existing concrete column. Indian Standard code is available for RC jacketting of the columns. However, research is still going on in the field of FRP. FRP jacketting reduces the deformation, stress and strain to a significant value when compare with RC and steel jacketting. In column number C2, it can be seen that the deformation almost get reduced to zero in case of FRP jacketting. The value gets reduced from 17.192 *mm* to 0.0068 *mm.* The value of Maximum principal stress gets reduced from 15.034 MPa to 3.8845 MPa after applying FRP jacket. Also, Maximum principal strain is increased from 0.000507 to 0.000649. However, this is not true with steel jacketting in which stress increased from 15.034 MPa to 38.841 MPa. The value of deformation get reduced from17.192 mm to 0.0681 mm. But the value of maximum principal strain came out to be 22.45% less as that in case of FRP jacketing. FRP Jacketing, being light in weight, does not increase seismic weight of building but it improves lateral strength considerably.

Hence, FRP and steel jacketing prove to be the best technique for retrofitting of weak concrete columns as FRP and steel jacketting provides more protection.

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