

## Investigation of reinforced concrete jacketed columns under different loading conditions

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### Abstract

*The behaviour of existing buildings depends upon the original structural design and the inadequacies associated with it. But, over the time such types of buildings become susceptible to the existing load and to the loads that it is going to be exposed to in the near future. Therefore, it becomes immensely important to strengthen or retrofit the vulnerable members to keep the whole structure safe. The objective of this study was to determine the strength enhancement of an existing Reinforced Concrete (RC) column after RC jacketing. In order to achieve the objective, the present study investigates the effectiveness of RC jacketing by evaluating the existing column as well as the strengthened column under three loading conditions viz. pure compression, eccentric compression and pure bending. The simulation has been performed in a finite element software ABAQUS whose results have been compared with the previously available experimental works. The results obtained post-simulation indicate a significant increase in the load carrying capacity of the strengthened columns under all three loading conditions.*

### Keywords

*Strengthening, RC column, Jacketing, Retrofitting.*

### 1. Introduction

Existing buildings may need to be strengthened to avoid the damage related to structures due to an increase in floor loads, inadequate detailing, a timely revision of design codes, etc. [1–3]. Retrofitting requires modifying an existing structure to make it more durable and resilient for the desired use. Several techniques for strengthening the existing buildings, such as enhancing the stiffness, improving discontinuity or irregularity in the distribution of stiffness of a building, have been examined and analysed in recent years. In the construction field, Reinforced Concrete (RC) is still the most widely used material being used [4]. Load bearing members such as beam and column largely utilises concrete and steel. But, due to poor construction practices and deterioration of materials, such members sometimes need to be strengthened. This paper covers the strengthening of RC columns. Various techniques such as RC jacketing, steel jacketing, Fibre Reinforced Polymer (FRP) jacketing exist which are being used worldwide to strengthen the columns [2].

One of the most influential techniques to retrofit the column is RC jacketing. This type of strengthening improves the axial, shear strength, and flexural capacity of columns, however, the increase in ductility is relatively less [2]. Secondly, it is easy to construct and install, therefore, is the most widely used technique of retrofitting all over the world. Besides RC jacketing, steel jacketing is also a widely used technique to strengthen the columns. Seismic performance of RC columns strengthened by externally wrapping the steel plates resulted in an increased bearing capacity of about 80% than the un-strengthened column [5]. The use of steel tubes as a retrofitting tool on the slender RC column has been proven to be very effective in enhancing the load bearing capacity, ductility and stiffness [6]. The effect of steel jacketing on the seismic performance of a 6 story RC building by jacketing the columns was investigated [7]. The results of the same indicated that the axial and flexural strength of an individual column increases by 184% and 261%, respectively, whereas the lateral strength of the building increases by 127% and 74% along X and Y direction respectively. Apart from RC and steel jacketing, another technique that has become the hotspot of strengthening practices is

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FRP wrapping. Different types of fibers such as Glass Fibre Reinforced Polymer (GFRP), Carbon Fibre Reinforced Polymer (CFRP), Hybrid Fibre Reinforced Polymer (HFRP) are available. Experimental analysis of an I beam with GFRP pultrudes and CFRP lamination on the flanges indicated linear elastic behaviour and significant shear deformation [8]. Performance of GFRP wrapped RC column under axial load indicated an increase of 31.86 % in the axial load carrying capacity with 25mm corner radii and 15.06 % for columns with sharp corners [9]. FRPs with Near Surface Mounted (NSM) rebars is another strengthening method that has proven to be effective when flexural strength is considered. An increase in the NSM reinforcement percentage from 0.16% to 1% of the total cross-sectional area leads to a 28% increase in the lateral capacity of the columns [10].

Besides the advantages associated with these strengthening techniques, each method has certain disadvantages. RC jacketing increases the cross-sectional area, thus reducing the carpet area. Steel jacketing requires heavy equipment for the handling process and also changes the aesthetic appearance. FRP jacket, though fast and efficient technique, however, it shows irregular plastic behaviour and possesses inadequate fire resistance capacity. Secondly, the use of FRP is limited only in some countries and industries. Analysis on a full-scale rectangular column indicated that FRP retrofit approach based on American Concrete Institute and Turkish codal provisions are not feasible and conservative, however, European retrofit approach is more economical and realistic [3].

The drawbacks associated with FRP and steel jacketing technique motivated the need to investigate a more feasible and effective method for strengthening. RC jacketing though reduces the carpet area and is time-consuming process, however is the most practical solution for strengthening of columns. This paper primarily focuses on the application of the RC jacket around the existing column and its influence on the load bearing of the column. The objective of the study was to find the additional load that the strengthened column would be able to carry post RC jacketing. To achieve this objective, an existing column is confined with an additional layer of RC jacket and analysed under pure compression, eccentric compression and pure bending. The thickness of the jacket is kept at 100mm. The simulation for the existing column and strengthened column has been carried out in a finite element ABAQUS which is a direct and economic method and helps in making a

comparative analysis. The increase in the load carrying capacity is observed from the load vs displacement curves for axial and eccentric loading and moment vs rotation curve for pure bending.

## 2.Literature review

Research fraternity investigating the application of several retrofitting techniques to the existing structures has proposed. It is developed and successfully applied several methods which have shown tremendous success, but revealed various drawbacks as well, which has motivated researchers to improve current practices. Concrete Jacketing has proved to be a very effective method in seismic retrofitting of columns which help in the conversion of strong beam weak column into a strong column and weak beam thus inducing the formation of hinges in beams and not in columns during the formation of a mechanism [11]. With this strong column weak beam principle, the shear capacity of the column also gets enhanced. The fundamental advantage of this technique is that it increases the shear and flexural capacity and is easy to construct. Secondly, a substantial increase in ductility, as well as stiffness of the section can be obtained depending upon the amount of reinforcement and type of concrete added to the jacket [12]. In another study, 25mm and 35mm jacket thickness with normal strength concrete and ultrahigh-performance self-compacting concrete respectively, indicated an increase of two to three times in the ultimate load carrying capacities of jacketed column [13]. The effect of combined loading i.e., axial loading and lateral cyclic loading was investigated. The strengthened columns with ultrahigh performance ferro-cement laminate showed significant improvement in the bearing capacity as compared to the un-strengthened specimen [14–15]. The influence of jacket height on RC columns subjected to cyclic loading was investigated [16]. Columns retrofitted with a jacket height of  $h/4$  and  $h/2$ , were investigated ( $h$  being the height of the column). It was observed that the variation in the lateral load carrying capacity of the columns with  $h/2$  jacket height was above 23% than the column with a jacket height of  $h/4$ .

To analyse the bonding between new and old concrete, and to establish a monolithic behaviour for the entire concrete, surface of the concrete column was roughened with an electric hammer [17]. Similarly, to assess the bond strength in shear and tension, slant shear test, pull-off tests and pull-out tests were performed [18–20]. It was concluded that all the tests were effective for reviewing the bond strength. The

impact of surface preparation, the use of epoxy resins and steel connectors was conducted [21–23]. The test results were analysed and it was concluded that a decent bond can be established by casting a new concrete layer against the existing concrete without using any bonding agent. A new material Engineered Cementitious Composites (ECC) having many favourable properties such as damage tolerance, delamination resistance, etc. It has been found very effective in improving the interfacial bond performance with the substrate concrete [4]. Use of ECC in combination with high-strength polyethylene

fibres to develop fibre RC jackets was examined [24]. The results showed that under the effect of axial load, the jackets with no fibre exhibited brittle behaviour while ductile behaviour was observed with the jackets containing stirrups and fibres. Similar to the interface treatment, different researchers have used different thickness of RC jacket based on their suitability. *Table 1* summarizes the details of the dimensions of the reference column and thickness of RC jackets adopted by the researchers.

**Table 1** Summary of thickness of jackets from previous research

Reference	$b_e$	$d_e$	$t_j$
Kaliyaperumal and Sengupta [1]	150mm	150mm	50mm
Tayeh et al. [13]	150mm	150mm	25mm & 35mm
Alcocer [25]	304.8mm (12in)	304.8mm (12in)	101.6mm (4in)
Júlio et al.[26]	200mm	200mm	35mm
Vandoros and Dritsos [27]	250mm	250mm	70mm
Lampropoulos and Dritsos [28]	200mm	200mm	35mm
Al-Dwaik and Armouti[29]	Ground and 1 <sup>st</sup> floor	700mm	125mm
	2 <sup>nd</sup> , 3 <sup>rd</sup> and 4 <sup>th</sup> floor	550mm	75mm
Dritsos and Moseley [30]		250mm	75mm
Anand and Sinha [31]		300mm	100mm

Where,  $b_e$ ,  $d_e$  being width and depth of the existing column while  $t_j$  is the thickness of the jacket

Numerous methods and techniques have been studied and practiced in recent years to strengthen the existing structures. On the basis of the literature review, it has been observed that the experimental or numerical behaviour of the jacketed column is less defined. Unresolved issues regarding the capacity of the strengthened column after jacketing exist, such as finding the increase in load carrying capacity after jacketing. Secondly, the effect of adding new elements i.e., jacketing elements on the overall performance of the column under different loading conditions is the area that lacks enough research and understanding. Although several pieces of research have been carried out in the past by varying the thickness of the jacket as stated in *Table 1*, optimum thickness of the jacket to be provided is still undefined. Most of the researches focus on strengthening the undamaged column. Enough research is not available which shows the effect of jacketing on damaged columns. Lastly, most of the experimental analysis of the column and jackets considered the prototype dimensions of the specimens. However, columns with such small-scale dimensions are not considered in practical situations. Due to the limitations of the testing facilities, analysis of standard full-scale is scarce and hence their analysis can be done through simulation.

### 3.Methodology

The methodology involves modelling a column having a cross-section of 300mm × 300mm with 3m length in a Finite Element tool ABAQUS. The mathematical results obtained from the previous analysis [31] for the RC column confined with RC jacket under axial loading have been used. For analysing the columns under different loading conditions, the experimental test setup [1] has been modelled. Columns under eccentric compression have been analysed for the eccentricity value ( $e$ ) of 50mm and 100mm for reference model and the jacketed model respectively. To validate the model, the column having a cross-section of 150mm × 150mm with 50mm jacket thickness has also been modelled and analysed. The experimental results obtained under the axial loading for the three specimens [1] have been used for validating the model. After the validation process is complete, the same analysis has been carried out for the columns with 3m length. The sectional sketch describing the dimensions and reinforcement details of the existing column is presented in *Figure 1*, whereas the dimensions and reinforcement details for the jacket with 100mm thickness are shown in *Figure 2*. The area of reinforcement in the existing column and the jacket has been considered as 1% of the gross cross-sectional area. The reinforcement provided for the

existing column consists of 8-12# bars and 16-14# bars for the RC jacket. The spacing of the stirrups in

the existing column has been kept at 200mm, whereas it is 100mm for the RC jacket.

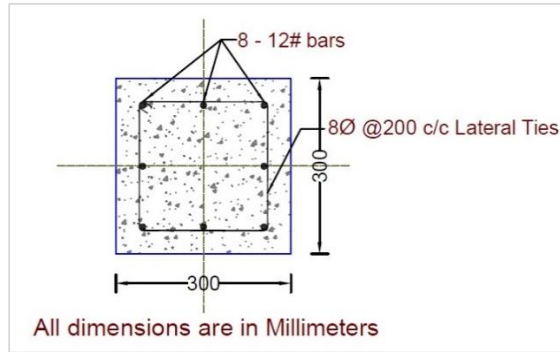


Figure 1 Cross-section of the existing column

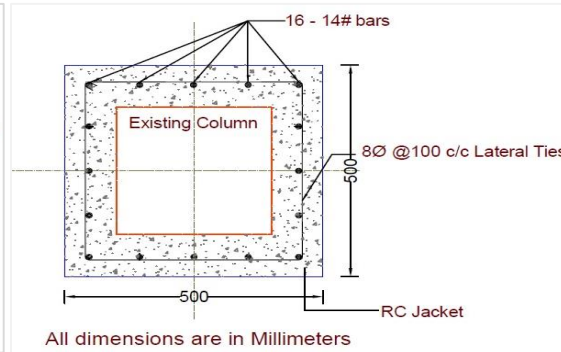


Figure 2 Cross-section of RC jacket

#### 4. Modelling and simulation

The current modelling and simulation were carried out using a finite element tool ABAQUS, which offers a very precise element library for modelling compressive plasticity and isotropic elasticity to approximate concrete behaviour. The Concrete Damaged Plasticity (CDP) model for simulation was used by adopting C3D8R brick element. The standard plasticity model was used for modelling the steel element by using T3D2 truss element. The embedded element technique to reflect the connection between concrete and steel was adopted, where the "guest" elements of the reinforcing bars are embedded in the "host" concrete elements. In this analysis column were fixed (with all the degree of freedom taken as zero) at the bottom while the top end was kept free in all directions where the application of load is supposed to take place. Step 1 is where the load is generated. The magnitude of the load is scaled up during the length of step 1 as the loading is generally static. The accelerated option alters the value of loading at a constant rate. The mesh element form that has been assigned to this model is "HEX," and the technique employed is "structured." The constraints used are embedded element and Multi-Points Constraints (MPC) coupling. The embedded element technique is used to embed the reinforcement inside the host element which is concrete. The reaction values that will be generated on the multiple nodes on column faces will be extracted using MPC coupling.

#### 5. Validation

In order to validate the finite element model used in this study, a column tested by Kaliyaperumal and Sengupta [1] was modelled and analysed. The existing column was referred as the reference specimen while the jacketed column was referred as retrofitted column. Three specimens were created for the reference column and three for the retrofitted column. All the models were tested for compression test. The cross-section of the existing column was 150 by 150 mm as shown by the finite element model in *Figure 3* and the stirrups are placed at an interval of 150 mm c/c. Similarly, the cross-section of the retrofitted specimen with 50 mm jacket thickness was 250 by 250 mm as shown by the finite element model in *Figure 4* and stirrups are placed at an interval of 75 mm c/c. The mean compressive strength (fcm) used for the reference specimen that is Pure Compression Original (PCO1), PCO2 and PCO3 were 23 Mpa, 31 Mpa and 22 Mpa respectively. Similarly, fcm for retrofitted specimens Pure Compression Retrofitted (PCR1), PCR2 and PCR 3 was 24 Mpa for each while fcm for jacket of PCR1, PCR2 and PCR 3 was 31 Mpa, 43 Mpa and 24 Mpa. The modulus of elasticity for steel used is  $2.02 \times 10^5 \text{ N/mm}^2$ . The finite element model for the reference and retrofitted column was tested for under monotonically increasing compressive load. The failure load is obtained by creating load vs displacement plot as shown in *Figure 5*. Comparison for the failure loads obtained from the previous experimental study and the finite element analysis in this study is presented in *Table 2*.

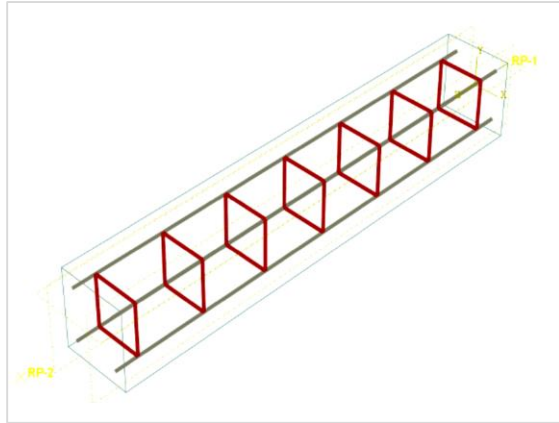


Figure 3 Finite element model of the reference column

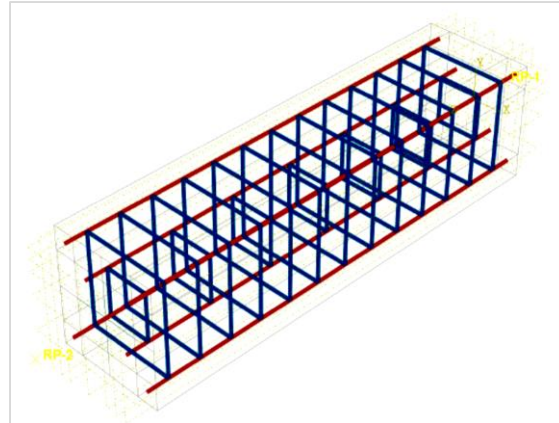
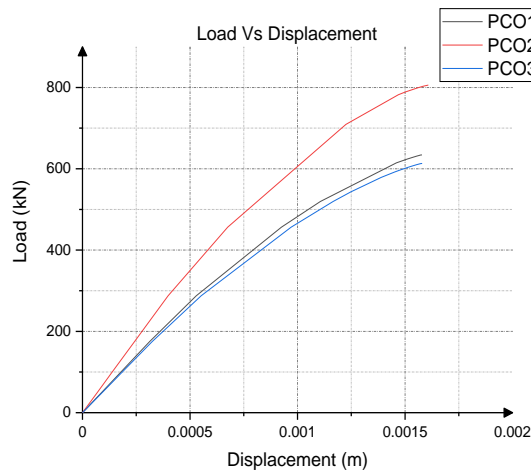
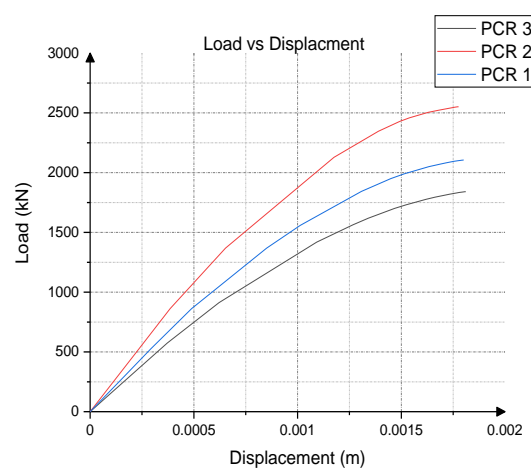


Figure 4 Finite element model of jacketed column



(a)



(b)

Figure 5 Load v/s displacement plots for (a) reference column models (b) jacketed column models

Table 2 Failure loads for reference and jacketed columns

Specimen	Failure load (kN) (Experimental) [1]	Failure load (kN) (After simulation)	Ratio
PCO1	646	634.2	0.982
PCO2	720	805.7	1.119
PCO3	560	613.1	1.095
PCR1	1350	2104.8	1.559
PCR2	2150	2550	1.186
PCR3	1565	1840.4	1.176

From Table 2, the surge in the load carrying capacity observed post-simulation is 231.8%, 216.5% and 200% for the PCR1, PCR2 and PCR3 columns as compared to PCO1, PCO2 and PCO3 respectively. Once the finite element model used was validated and proved to replicate the actual response of the RC column satisfactorily, analysis was carried forward to see the effect of different length and cross-section of the column and its behaviour post retrofitting. In further analysis the length of reference column used is 3m with the cross section of 300mm by 300mm while

the thickness of jacket adopted is 100mm which makes the cross-section of 500mm by 500mm for the jacketed column.

### 6. Analysis of the column model

This section includes the modelling and analysis results of a square column with 3 metre length, which will be strengthened by a 100mm thick jacket [32] along all sides. The cross-section of the column is same as mentioned in Figure 1 and Figure 2. The first step in modelling is to create all the individual parts of

the column. All different parts like column, reinforcement and jacket are created in this module. The column is created as a three-dimensional deformable solid by extrusion. Reinforcement is created as a three-dimensional deformable wire and jacket is created as a three-dimensional shell. The “deformable” option is chosen for all the parts; hence all parts can deform under the application of loads. When parts are created in the part module it exists in its coordinate system, independent of other parts in the model. While in the assembly module, when the instance of that part is created and positioned relative to another part instances, then we work in the assembly’s global coordinate system. The parts and their instances are positioned properly to create an assembly as shown in *Figure 6* and define the geometry of the finished model. Although a model may consist of many parts, but it will contain only one assembly. Characteristic compressive strength of concrete used for modelling the reference column is M20 whereas M25 is used for modelling the jacket. The grade of steel used is Fe415. The details of the

material properties are mentioned in *Table 3*. The best model believed to develop the behaviour of concrete is the CDP model. CDP properties used in the analysis are presented in *Table 4*. ABAQUS uses the symbol  $\psi$  for expressing dilation angle, the plastic potential eccentricity of concrete ( $\epsilon$ ), the ratio of compressive stress in the biaxial state to the compressive stress in the uniaxial state ( $f_{bo} / f_c$ ) and the shape factor of the yielding surface in the deviatoric plane ( $K_c$ ).

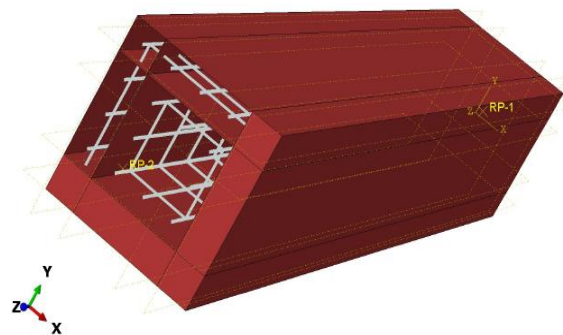
The modelling, analysis procedure follows the same steps and methodology as discussed in the validation section. The existing and jacketed column will be tested under pure compression, eccentric compression and pure bending. Hereafter, the existing specimen shall be referred as Pure Compression Existing (PCE), Eccentric Compression Existing (ECE) and Pure Bending Existing (PBE) while the jacketed specimens shall be referred as Pure Compression Jacketed (PCJ), Eccentric Compression Jacketed (ECJ) and Pure Bending Jacketed (PBJ).

**Table 3** Material properties

Type of Material	Density (g/cm <sup>3</sup> )	Modulus of elasticity (GPa)	Poisson’s Ratio (ν)	Yield Stress of the material	
				In Compression (GPa)	In Tension (GPa)
1. Concrete					
a. Column	2.4	20	0.13	.020	.00315
b. Jacket	2.4	20	0.13	.025	.0035
2. Steel	7.85	200	0.3	0.415	

**Table 4** CDP parameters [33]

$\Psi$	$K_c$	$f_{bo} / f_c$	$\epsilon$
13	0.7	1.16	0.1



**Figure 6** Assembling the parts (material view)

**6.1 Pure compression**

In order to test the column under pure compression, a monotonically increasing load is concentrically

applied to the column. The model is utilized to determine the ultimate compressive failure load for the reference column and jacketed column. The failure load is determined with the help of load v/s displacement curve. To create the point of load application, a reference point has been generated at the centroid of the column face in the XY plane. The deformation contour for the reference and retrofitted column after the application of monotonically increasing load is shown in *Figure 7*. With the help of this deformation contour, a plot of load v/s displacement curve under axial loading is generated which is presented in *Figure 8*.

From the plot in *Figure 8* failure load for the existing column under pure compression comes out to be 1801kN whereas for the jacketed column under pure compression failure load is 4480kN which is 2.48 times of the reference model.

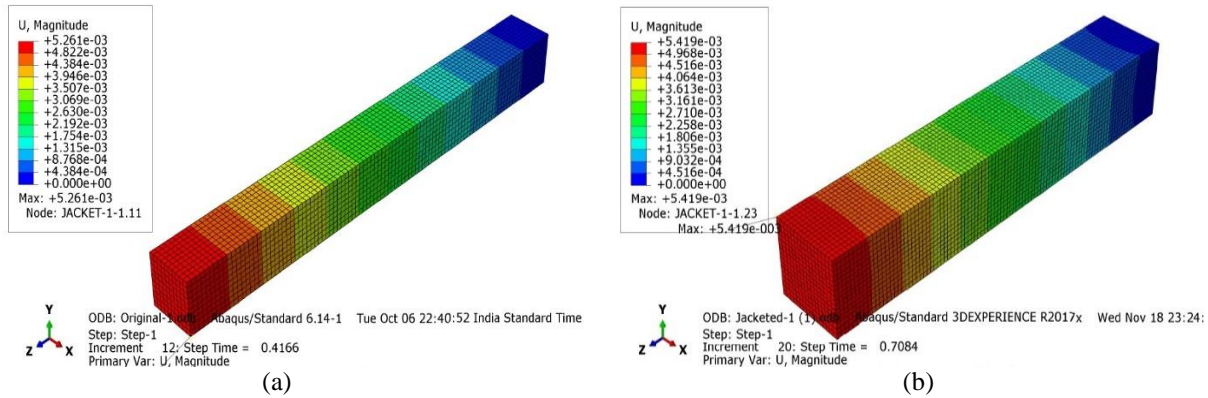


Figure 7 Deformation contours of the reference column (a) and jacketed column (b) under pure compression

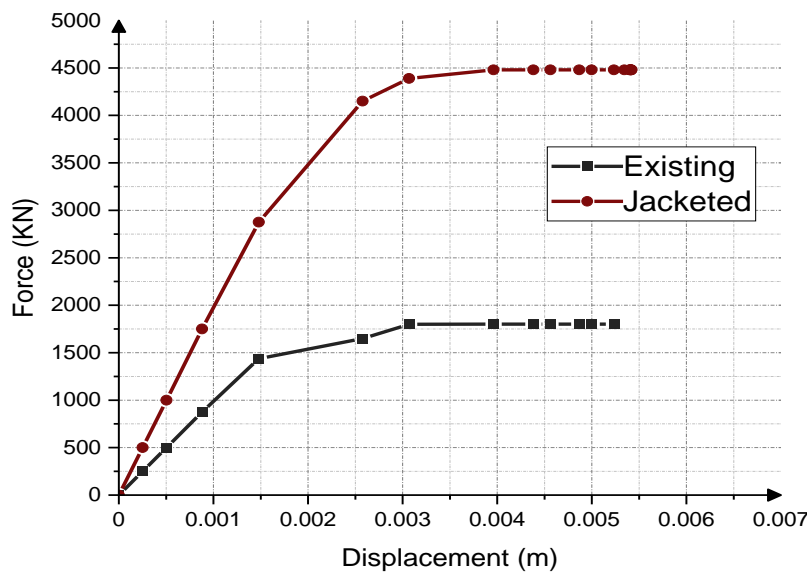


Figure 8 Force v/s displacement curves under pure compression

### 6.2 Eccentric compression

A cross-section subjected to axial force along with bending is referred as eccentric compression. In this analysis, uniaxial eccentricity has been considered to compare the performance of reference and jacketed columns. The value of eccentricity considered for the reference column is 50mm whereas e value for jacketed column is kept as 100mm which becomes a case of small eccentricity as e is less than D/4 i.e., 300/4 (reference column) and 500/4 (jacketed column). To create the point of load application a reference point has been generated at the top face of the column at a specified location. Cross-section and point of load application for both the columns are shown in Figure 9. Value of eccentricity is taken at the column face in the direction of positive X-axis. The deformation contour for the reference and retrofitted column after the application of monotonically

increasing load is shown in Figure 10. Due to the eccentricity, one side of the column in YZ plane experiences compression while the other side experiences tension. With the help of this deformation contour, a plot of load v/s displacement and moment v/s rotation curve under eccentric loading is generated which is presented in Figure 11 and Figure 12 respectively. From the plot in Figure 11 failure load for the existing column under eccentric compression comes out to be 1003.6kN whereas for the jacketed column failure load is 3880kN which is 3.86 times of the reference model. In the similar manner, the ultimate moment for the existing column under eccentric compression is 63kNm which becomes 386.58kNm after jacketing. This increase in the ultimate moment after RC jacketing is around 6 times than that of the existing column.

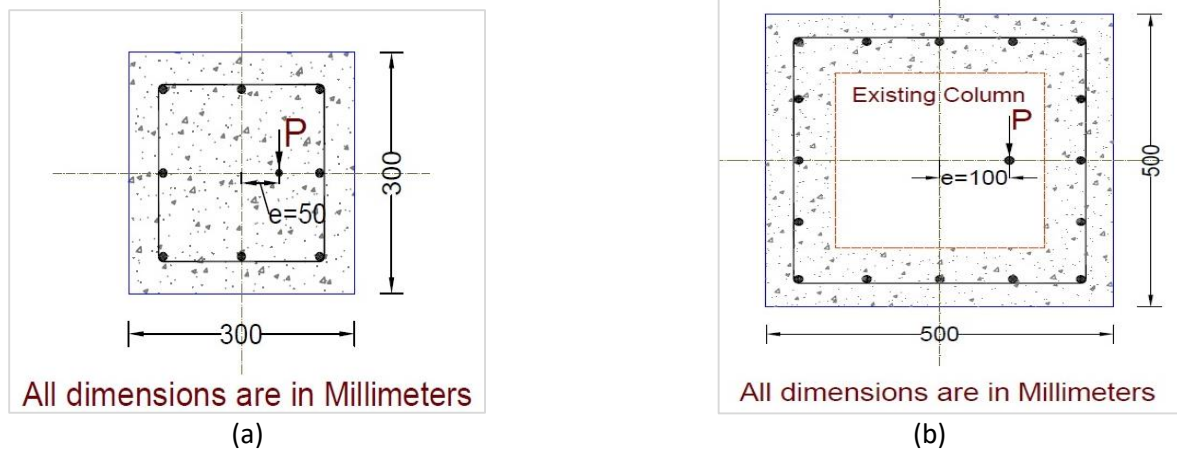


Figure 9 Cross-section of the (a) reference and (b) jacketed column with the point of eccentric load application

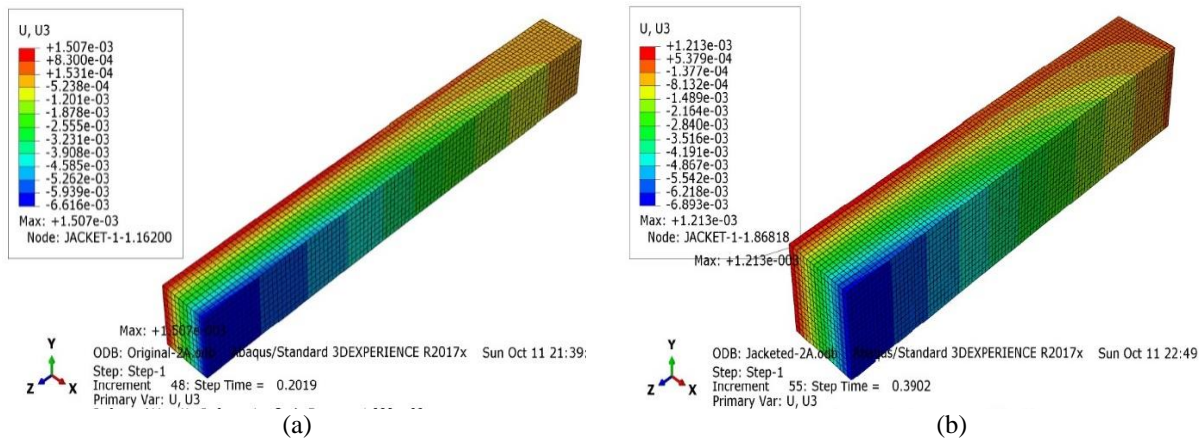


Figure 10 Deformation contours of the reference column (a) and jacketed column (b) under eccentric compression

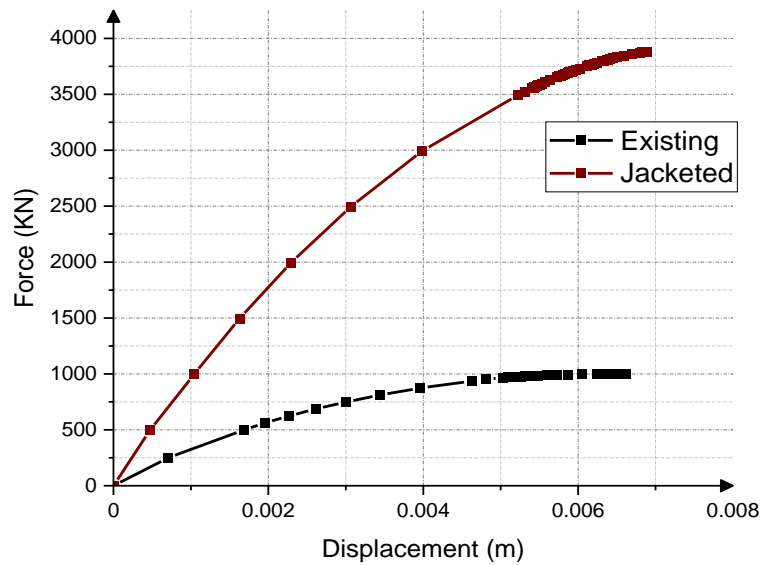


Figure 11 Force v/s displacement curves under eccentric compression



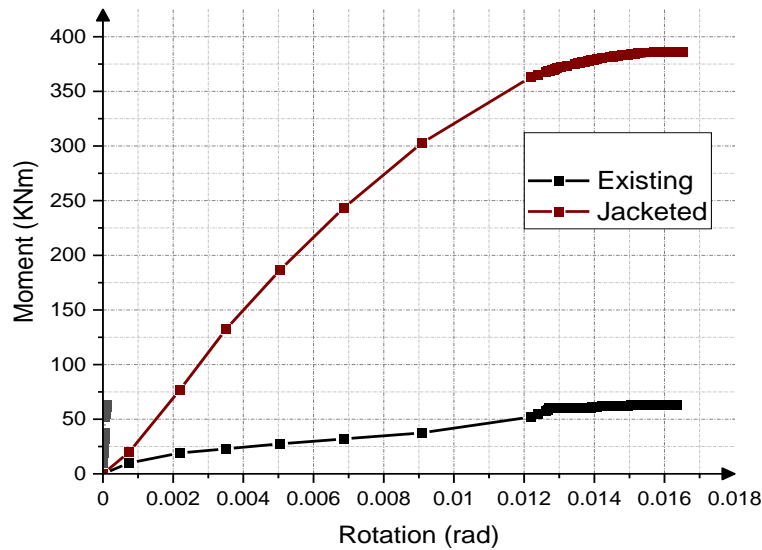


Figure 12 Moment v/s rotation curves under eccentric compression

### 6.3 Pure bending

To test the performance of the column under the effect of lateral load, bending test was performed by loading at two points. Steel plates of 25 mm thickness were attached at the top and bottom at respective locations to apply the load and establish the boundary condition. The plates were modelled as rigid elements with young’s modulus of 21,0000 MPa and a density of 7850 kN/m<sup>3</sup>. The setup and loading pattern for bending test through finite element analysis is shown in Figure 13. The bottom supports are provided at a distance of 300mm from the face of the column, which makes the clear distance between the supports of 2400mm. The point of application of load is kept as 1/3rd of clear distance i.e., 800mm from the supports. Analysis was carried under two-point load with each point load 800mm away from the support the

magnitude of which was being increased monotonically till the ultimate load is achieved. The deformation contour for the reference and retrofitted column after the application monotonically increasing load is shown in Figure 14. The region under the points of load application experiences maximum deformation. With the help of this deformation contour, a plot of moment v/s rotation under bending loading is generated which is presented in Figure 15.

From Figure 15 the ultimate moment for the existing column under pure bending is 37.5kNm which becomes 138kNm after jacketing. This increase in the ultimate moment after RC jacketing is around 3.68 times than that of the existing column.

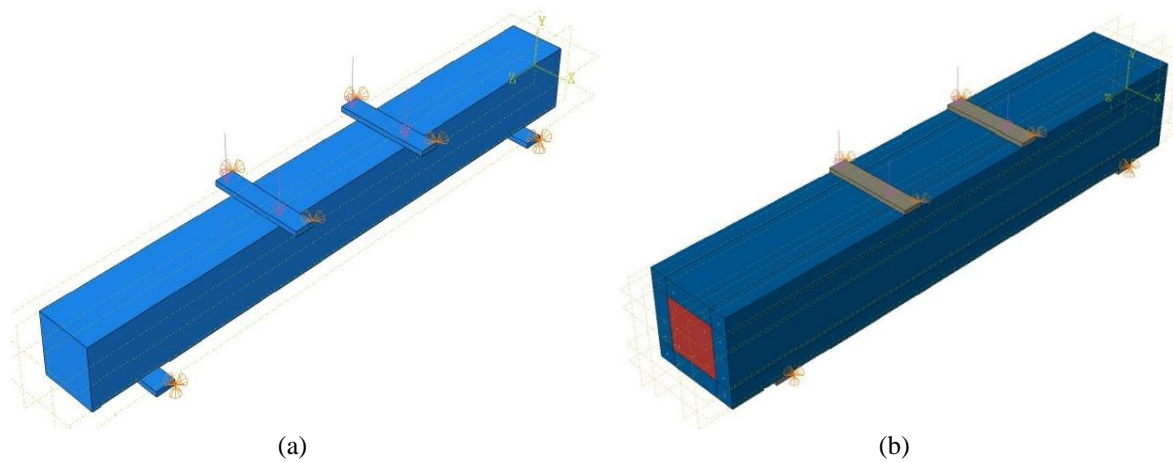


Figure 13 Finite element model setup of (a) reference column (b) jacketed column for pure bending test

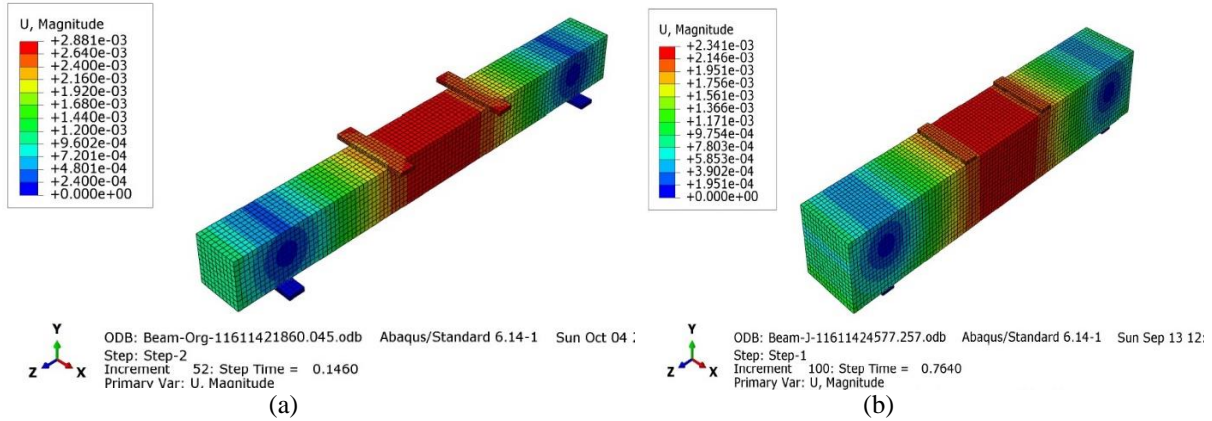


Figure 14 Deformation contours of the reference column (a) and jacketed column (b) under pure bending

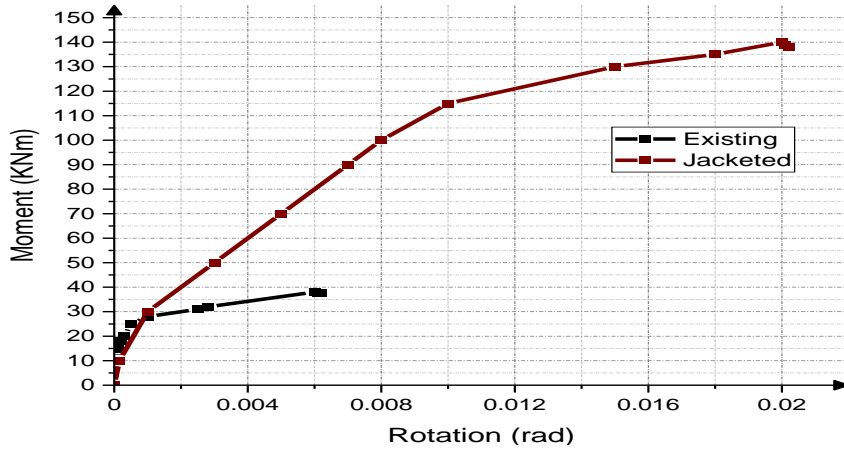


Figure 15 Moment v/s rotation curve under pure bending

### 7.Results

The confinement provided by the adding RC layer increases the strength of the existing column significantly. Comparative analysis of the existing and jacketed column is presented in Table 5. For the columns under pure compression the parameter used for making comparative analysis was failure load. For

the columns under eccentric compression the parameter used for making comparative analysis was failure load as well as ultimate moment. Similarly, for the columns under pure bending the parameter used for making comparative analysis was ultimate moments only.

Table 5 Failure loads and ultimate moments of column specimens

Type of specimen	Specimen designation	Failure load (kN)	Ultimate moment (kNm)
Existing	PCE	1801	-
	ECE	1003.6	63
	PBE	-	37.5
Jacketed	PCJ	4480	-
	ECJ	3880	386.58
	PBJ	-	138

From the data presented in Table 5 it can be clearly noticed, the failure load for column under pure compression is 1801kN which increases to 4480kN after jacketing taking the percentage surge to

148.75%. Also, under eccentric compression failure load is 1003.6kN before jacketing and increases to 3880kN after RC jacketing making the percentage surge of 286.60%. Similarly, the ultimate moment for

the model under eccentric compression increases to 386.58kNm from 63kNm after jacketing making a percentage increase of 513.6%. Also, under pure bending the ultimate moment increases to 138kNm from 37.5kNm after RC jacketing showing an increase of 268%. The finite element results obtained from ABAQUS in terms of load-deflection curves and moment rotation curves were found to be consistent with the experimental results obtained from the literature.

## 8. Discussion

Under the influence of axial load, the load carrying capacity of the jacketed frame column increased significantly i.e., the strength is improved. The jacketed column model showed a substantial increase in the load carrying capacity and ultimate moment under eccentric loading also. The ultimate moment limits of the jacketed column under bending were generously more than those of the existing columns thus showing a significant increase in the lateral strength of the column.

The scope of this research is limited to square columns with a medium grade of concrete where M20 has been used for the existing column and M25 for the RC jacket. It is suggested that for the construction of the RC jacket use of High-Performance Concrete (HPC) shall be preferred. The effect of preloading on the columns has not been considered. Therefore, the column analysed in this study was in undamaged condition which may result in overestimation of failure loads after RC jacketing. Since the proposed method is hypothetical, an experimental validation of the same cannot be performed due to unavailability of hardware and testing facilities. Complete list of abbreviations is shown in *Appendix I*.

## 9. Conclusion and future work

Our result suggests RC jacketing shows a tremendous increase in load carrying capacity of columns as compared to steel jacketing and FRP wrapping. This can be attributed to the fact that RC jacketing is able to provide a better composite behaviour. Comparative analysis for both cases has been performed. Analysis performed in ABAQUS was able to predict such an increase in capacity. The models were able to determine and predict the behaviour of the jacketed column with a very reasonable error level.

RC jacketing on a square column has resulted in a significant increase in the load carrying capacity. However, further investigations may be carried out on circular and rectangular columns by varying the

parameters associated with concrete and steel such as concrete grade, percentage of reinforcement, spacing of ties in the jacket. Such investigation can help in determining the optimum percentage of reinforcement and spacing of lateral ties for the RC jacket. Methods involving roughened surfaces or even with no surface treatment can be compared and used to demonstrate the efficiency of the interface mechanisms. Furthermore, the simulation carried out in ABAQUS only presents the idea and behaviour of the undamaged columns after jacketing. However, to find out practical solutions damaged columns shall be considered for jacketing. Exploring all possible aspects and including more parametric studies can help in achieving better insights to the technique. It can provide a clearer understanding of the possible outcomes.

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## Conflicts of interest

The authors have no conflicts of interest to declare.

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### Appendix I

S. No.	Abbreviation	Description
1	CDP	Concrete Damaged Plasticity
2	CFRP	Carbon Fibre Reinforced Polymer
3	ECC	Engineered Cementitious Concrete
4	ECE	Eccentric Compression Existing
5	ECJ	Eccentric Compression Jacketed
6	FRP	Fibre Reinforced Polymer
7	GFRP	Glass Fibre Reinforced Polymer
8	HFRP	Hybrid Fibre Reinforced Polymer
9	HPC	High Performance Concrete
10	MPC	Multi Points Constraints
11	NSM	Near Surface Mounted
12	PBE	Pure Bending Eccentric
13	PBJ	Pure Bending Jacketed
14	PCE	Pure Compression Existing
15	PCJ	Pure Compression Jacketed
16	PCO	Pure Compression Original
17	PCR	Pure Compression Retrofitted
18	RC	Reinforced Concrete