



Strengthening of Edge and Corner Columns using Concrete Jackets

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Received 10 March 2021; Revised 22 May 2021; Accepted 03 June 2021; Published 01 July 2021

Abstract

Strengthening of columns using concrete jackets depends on friction at the interface between them. So strengthening of edge and corner columns in only one story needs a large cross section area due to the shortage of friction length which leads to architectural issues. This research aims to study strengthening the edge and corner columns using a concrete Jacket in more than one story which increases the friction area between the Jacket and the original column. As a result, the load transferred from original column to the jacket will be increased. Thirteen models were done using ANSYS program to study the effect of various factors on the Jacket capacity such as the number of strengthened floors, the Jacket type (two sides or three sides), and whether there were shear connectors or not. The results showed that in the case of the edge and corner columns, it is preferable to strengthen the column by making a concrete Jacket on at least two or three floors to increase the surface area, which leads to increase the friction and thus increases the capacity of the strengthened column by an acceptable percentage. The results of ANSYS models were compared with the Indian code IS 15988 (2013) and the results were shown differently because the code equations depend on the presence of a full bond between the concrete column and the Jacket, which does not occur, but rather the load is transferred by friction between the Jacket and the original column.

Keywords: Repair; Strengthening; Non-symmetric Jacket; ANSYS; Multi-story Jacket.

1. Introduction

Concrete structures consist of several elements, the most important of which is the column. When the column cannot sustain the applied loads because of an increase in load, a change in the use of the structure or an initial poor design of the structure, the column must be strengthened. Jacketing is one of the preeminent habitually utilized strategies to retrofitting R.C. columns. With this technique, axial strength, bending strength, and stiffness of the main column are expanded. It's notable that the achievement of this technique relies upon the monolithic behaviour of the composite component. As indicated by Finite Element Method (FEM) which used in this research. The structural behaviour of a reinforced concrete jacket under axial loads is transferring the load by friction which generated by confinement. Four-sided jackets give confinement more than three-sided and two-sided; thus, the capacity of interior

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 <http://dx.doi.org/10.28991/cej-2021-03091716>



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column jackets is greater than edge and corner Jackets. Unlike the numerical equations in IS 15988 (2013) [1] which expect full bond among jacket and column, this research is considered as a continuity of a previous work done by Mohamed Al Azzouny [2, 3]. Al Azzouny's research concerned columns strengthened in one story without the effect of story slab in the modelling, this research modifies Al Azzouny's work by strengthening the columns in more than one, two and three stories taking into account the effect of the floor slab in the models, then the surface area between the original column and jacket will be increased which leads to transfer more amount of load to jacket then the strengthened column capacity will be increased.

2. Literature Review

Lacking or deteriorating reinforced-concrete columns in many existing constructions must be retrofitted using most economic, effective, and quick techniques. The adequacy of fortifying strategies is subject to numerous components, e.g., for the CFRP repression; it was the sweep of the chamfer of the edges, for the steel confines, they were the components of the steel individuals and the pitch of the steel battens, and for the Ferro-cement; they were the thickness of the wire mesh and the mortar layer. Using steel fibbers increase Stiffness. On the other hand, The CFRP wrapping proved to be the costliest [4].

Many techniques can be used for retrofitting concrete column like FRB, Steel Jacket, and R.C Jacket. Changing building usage from residential to administrative or public or storage led to increase the applied loads on structure which need to increase the columns capacity [5-7]. Steel jackets are most recommended as a strengthening method for reinforced concrete columns because its cheap cost, doesn't increase the cross sections as well as being simple to manufacture and it can be done while the structure in use [8, 9]. Reinforced concrete column jacketing is the most traditional technique used in seismic retrofitting. It's been broadly utilized after earthquakes in Mexico, Japan, the Balkans, and the U.S. We don't need to make the interface between column and jacket rougher or add bonding material or use shear connectors in this technique [10-12].

Two to three decades ago, researchers attempted to create proper fortifying and fix procedures for R.C. columns that make a balance between the structural requirements to improve the strength, ductility, and drift with different non-structural requirements, such as fabrication time/construction costs. In case of evaluating an existing building, some elements may need to be strengthened to enhance their ductile strength. There are many strengthening methods such as concrete jackets, steel jackets and FRP. Each technique has advantages and disadvantages. Using hybrid jacketing is recommended to combine the advantages of these [13, 14].

Concrete jackets are recommended to increase the stiffness and capacity of reinforced concrete columns if we need to retrofit by more than 25% [15]. Slippage between the old and new concrete is one of the disadvantages of the concrete jacketing strengthening method to decrease the slippage, we can use rough surface or dwells which increase the coefficient of friction from 0.75 to 0.85 [16]. Concerning the column cracking before the strengthening stage has a significant effect on the capacity of strengthened column afterwards [17]. Many techniques are used for roughing the surface between column and R.C jacket such as shear dwells, mechanical scarification and wire brushing, but the most significant method is using dwells [18]. Sand blasting also could be used for making the interface rougher as it gives high bond in shear and tension. On the other hand, pre-wetting the surface does not affect the bond [19].

3. Research Methodology

3.1. Finite Element Material Models

ANSYS workbench R18.2 Software that uses Finite Element Analysis (FEM) was used in this research for modelling the strengthened columns. A three main elements were needed for the modelling, concrete element, reinforcement bars element and the interface between the original column and the concrete jacket. The concrete was modelled using Solid 65 element, Figure 1 show the element discretion from ANSYS [23], the steel bars and horizontal stirrups were modelled using link 180 elements [20, 23]. A column concrete geometry, steel bars, stirrups, and a jacket are all included in the model. The concrete solids have been meshing with reinforced bars.

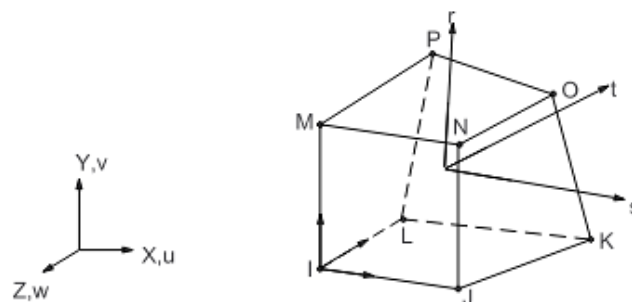


Figure 1. SOLID65 - 3-D Reinforced Concrete Solid

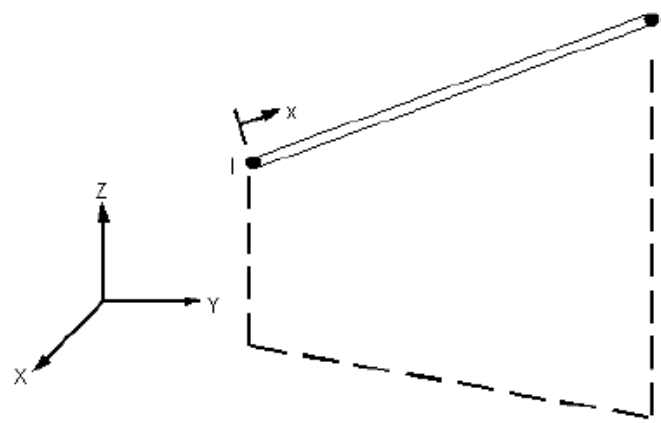


Figure 2. Link 180Element

A bonded connection was assumed between concrete and reinforced bars, on the other hand a surface-to-surface connection was established as a frictional interface between the column and concrete jacket with coefficient of friction=0.8. The sliding contact resistance calculation as per ANSYS Manual [23] shown in Equations 1 and 2.

$$\tau = \mu \times P \quad (1)$$

$$TAUMAX = \frac{F_{ck}}{\sqrt{3}} \quad (2)$$

Where, τ : Contact friction with units of stress; μ : Coefficient of friction; P : Normal contact pressure; $TAUMAX$: max contact friction with units of stress; F_{ck} : Concrete compressive Strength.

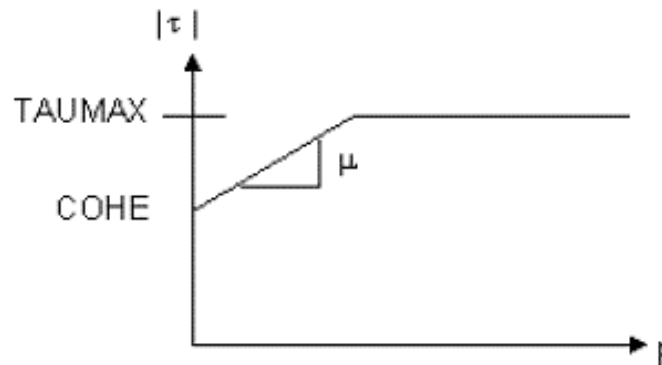


Figure 3. Sliding Contact Resistance

A Hinged base was assigned for all models at the lower plate ($U_x=U_y=U_z=0$) while it was assigned as a roller for the upper plate ($U_x=U_z=0$), but it was different for the slab sides ($U_x=0$) for side perpendicular to x axis and ($U_z=0$) for other side. The failure load was applied on the upper plate and 30 ton on the slab as a floor load.

3.2. Determination of Load-Carrying Capacity

The recommendation of Indian standard code IS 15988 (2013): Seismic Evaluation and Strengthening of Existing Reinforced Concrete Buildings – Guidelines issued by Bureau of Indian Standards [1, 20] are followed in this article. Column flexural strength and ductility are improved by reinforced concrete jacketing. The jackets closely spaced transverse reinforcement improves durability. The strength of the column is determined from the following equation with respect to IS 456:2000 [21].

$$P_u = 0.4 F_{ck} A_c + 0.67 F_y A_{sc} \quad (3)$$

Where, P_u : Ultimate Load; F_{ck} : Concrete compressive Strength; F_y : Yield Strength of Steel; A_c : Area of Columns; A_s : Steel Reinforcement area.

Using a factor of safety as 1.5, the failure load will be:

$$P = 1.5 \times P_u \quad (4)$$

4. Verification

In 1988 some experimental works done by EL-Dodo (1988) [22]. These works concern the strengthening of edge and corner column with two types of jacket, first using full height jacket and second type height is 5cm less than the column height. All of these were done three times, once using jacket stirrups not connected to the column, second time hooking the jacket stirrups to the column ends and finally using jacket stirrups welded to the column.

The original column was 200×200 mm having 4 ϕ 13 RFT, edge column was 300×400 mm having 14 ϕ 13 RFT and the corner column was 300×300 mm having 11 ϕ 13 RFT. Figures 4 and 5 show the verification for the compression strain for edge and corner columns.

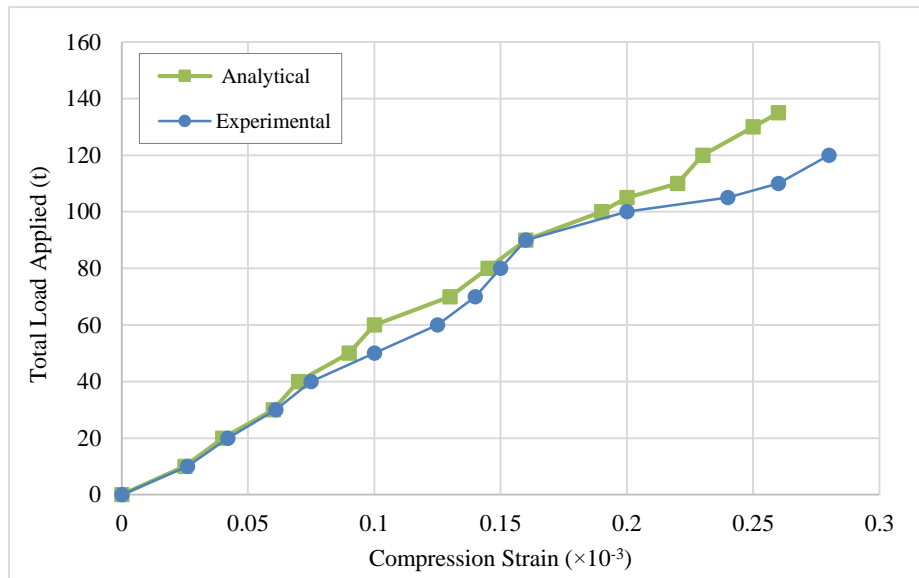


Figure 4. Verification for the Compression Strain of Edge column

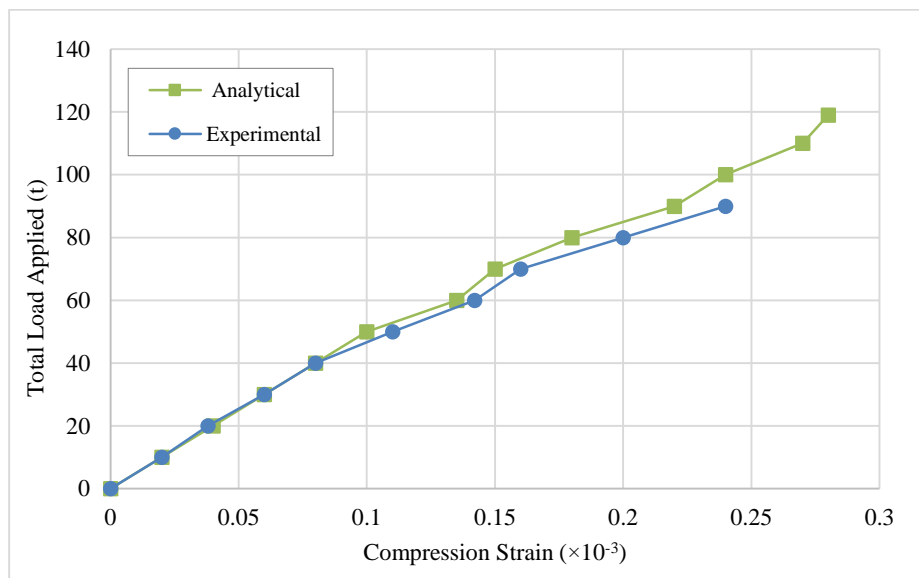


Figure 5. Verification for the Compression Strain of corner column

After modelling these groups of columns using ANSYS workbench we get almost nearest results to the experimental results as shown in Table 1

Table 1. Comparison between experimental work results and ANSYS results

	Experimental failure load	ANSYS failure load
Control column	80 (ton)	90 (ton)
3-sided jacket	120 (ton)	128 (ton)
2-sided jacket	90 (ton)	105 (ton)

This research is an extension of a previous work done by Al-Azzouny [2, 3]. In the last work a column with dimension 250×600 mm having 8φ16 RFT were modelled using ANSYS R13. And strengthened from 2sides and three sides for one story only but without adding the slab for the model. In this research the same models had been done using ANSYS workbench R18.2 [23] and getting the same result almost as shown in Table 1, then the models repeated after adding the slabs and compare the results with columns models strengthened for two stories and three stories.

Table 2. Comparison between previous work results (Al-Azzouny) and research results

	Previous results without floor slab effect	Research results without floor slab effect	Research results with floor slab effect
Control column	160 (ton)	153 (ton)	153 (ton)
4-sided jacket	355 (ton)	344 (ton)	365 (ton)
3-sided jacket	245 (ton)	243 (ton)	329 (ton)
2-sided jacket	220 (ton)	200 (ton)	218 (ton)

5. Application for Strengthening Edge and Corner R.C. Columns

5.1. Modelling

The R.C. column in this study is cast with concrete having a compressive strength 15 MPa, 250×600 mm dimensions, with longitudinal vertical bars of 8φ16 having yield stress 360 MPa and horizontal stirrups. 10φ8/m with yield stress 240 MPa at the top and bottom of column decrease to 5φ8/m at the middle as shown in Figure 3. The column has a clear height of 3 m and has upper and lower plates, as well as a slab 2×2 m above the column with a 20 cm thickness to represent load transference from the story and other stories load apply on the upper plate.

The distress in this case is in the form of low compressive strength of concrete leading to low load-carrying capacity. Due to this reason, a strength modification of the concrete compressive strength in the R.C. column is required to enhance the load-carrying capacity. In this case, the R.C. column is retrofitted with the external application of reinforced concrete R.C. jacket around it.

Two groups of jackets were modelled; each group consists of six models as shown in Figures 6 to 12. The first group present three-sided RC jacket 450×700 mm with 19φ16 RFT, and two-sided RC jacket 350×700 mm with 15φ16 RFT. The concrete jackets have compressive strength 35 MPa, thickness 100 mm, the same amount and distribution of stirrups as that for control column and they extend for one story, two stories and three stories. The concrete jackets stop at the bottom of the last story slab. The second group having the same characteristics of the first group, but the difference is using shear connectors to increase the bond at the interface between the old and new concrete. The upper plate loading until failure, this load represents the upper stories loads while the slabs have load 30 ton to simulate the strengthened stories loads that transference to the column.

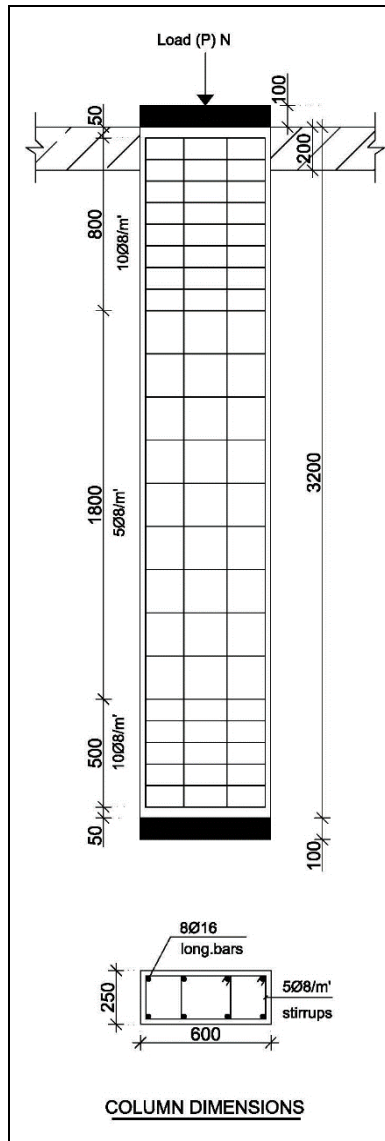


Figure 6. Control Column

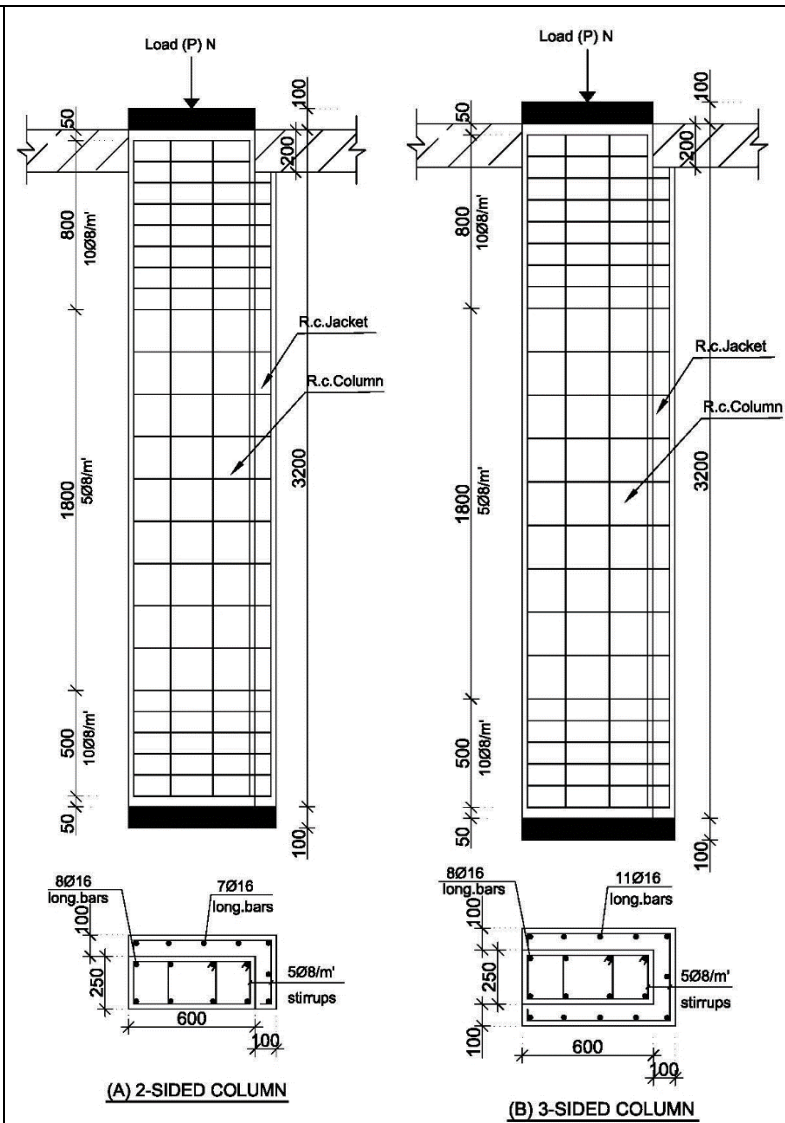


Figure 7. Typical R.C. Column Jacket (one story)

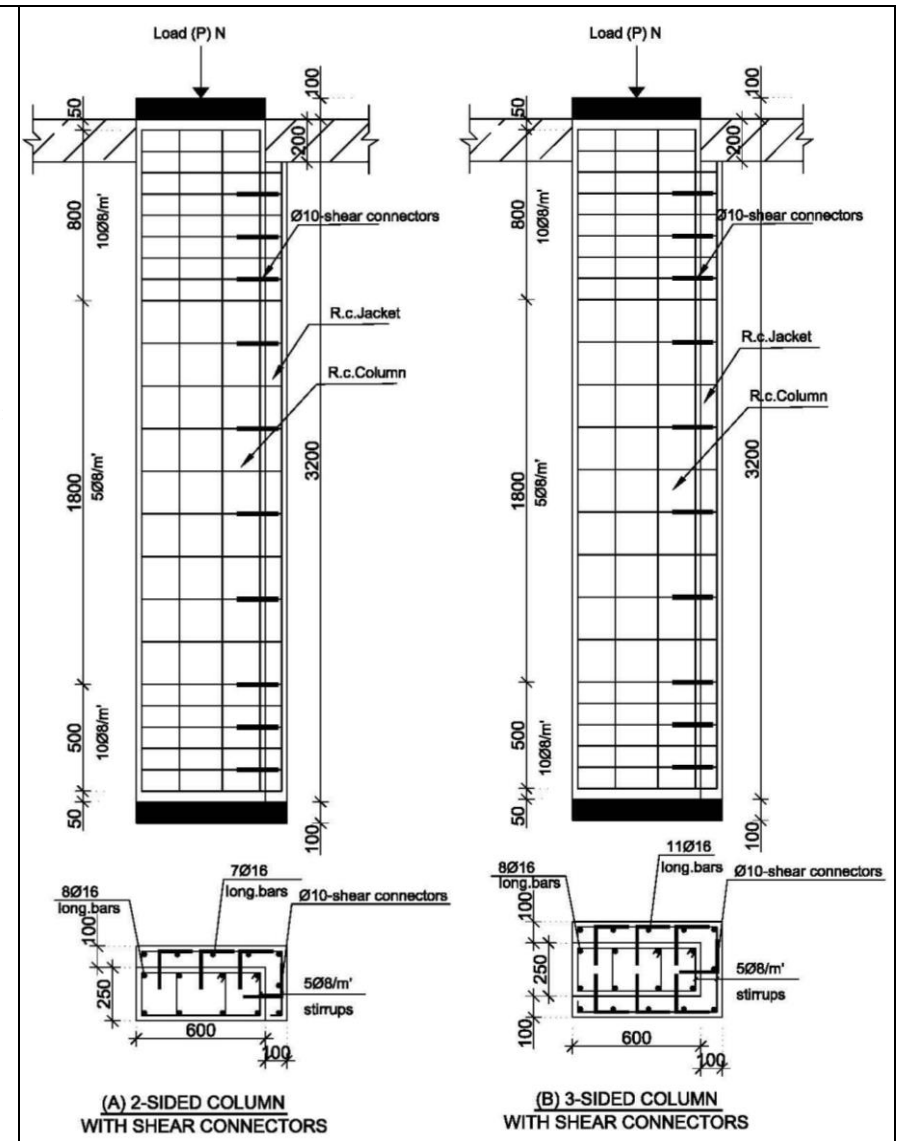


Figure 8. Typical R.C. Column Jacket (one story) with shear connectors

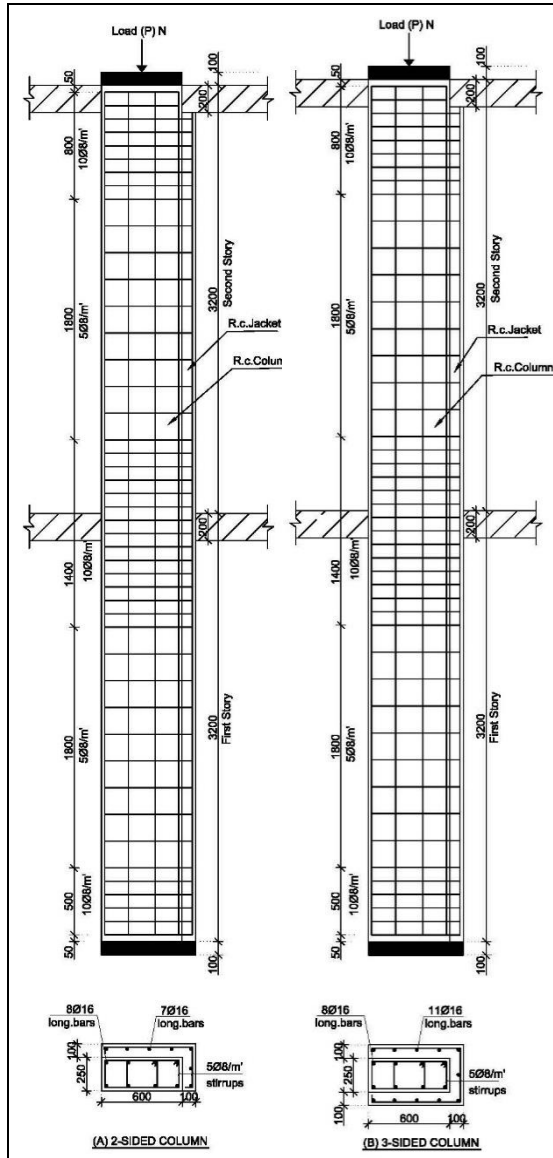
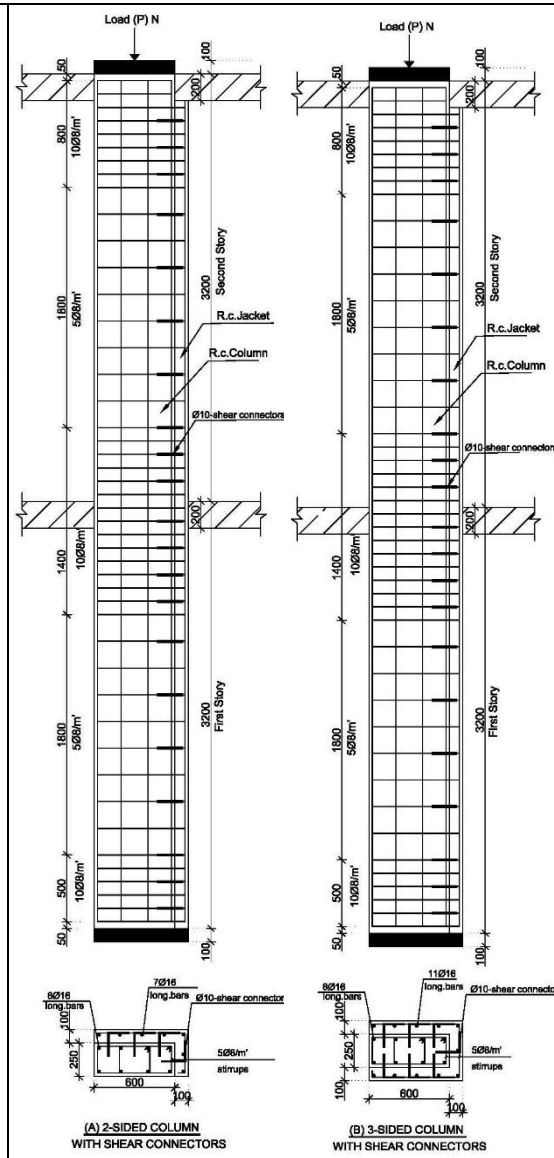
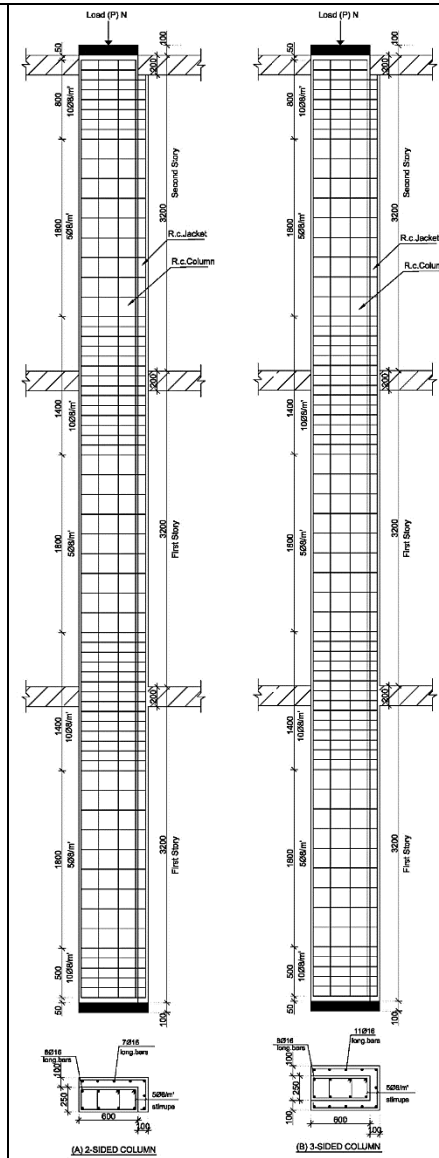


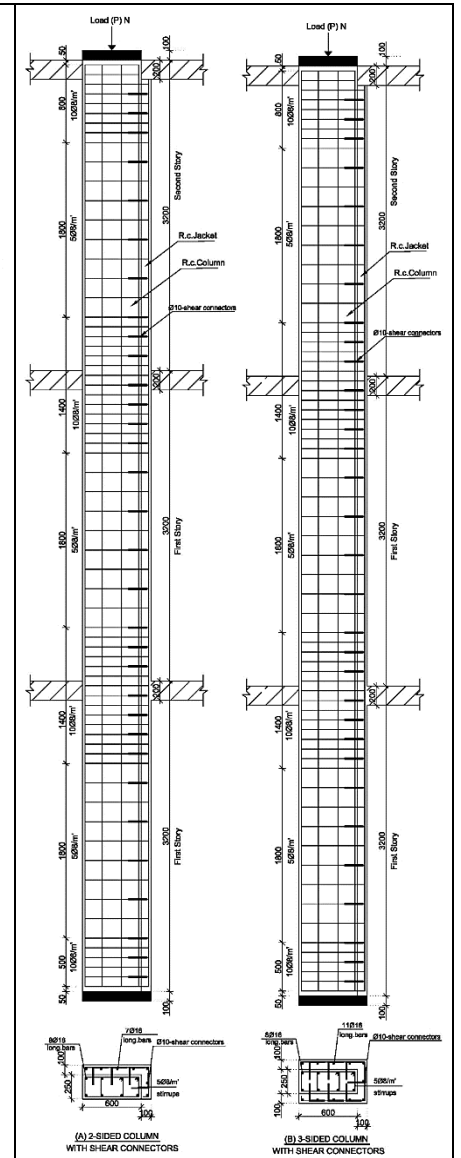
Figure 9. Typical R.C. Column Jacket (two stories)



**Figure 10. Typical R.C. Column Jacket (two stories)
with shear connectors**



**Figure 11. Typical R.C. Column Jacket
(three stories)**



**Figure 12. Typical R.C. Column Jacket
(three stories) with shear connectors**

5.2. Cases Study

In this paper three parameters will be studied to show its effect on the capacity of the column after repair.

- The concrete jacket type such as corner or edge column;
- The number of strengthened stories like one or two or three stories to study the effect of the friction length on the strengthened column behaviour;
- Using shear connectors to improve the bond between original column and concrete jacket at the interface.

5.3. Geometry Input

Below some snaps from the models to shows the concrete geometry for column, floor slab and concrete jacket, reinforcement bars for column and jacket, stirrups, and shear connectors as in Figures 13 to 17.

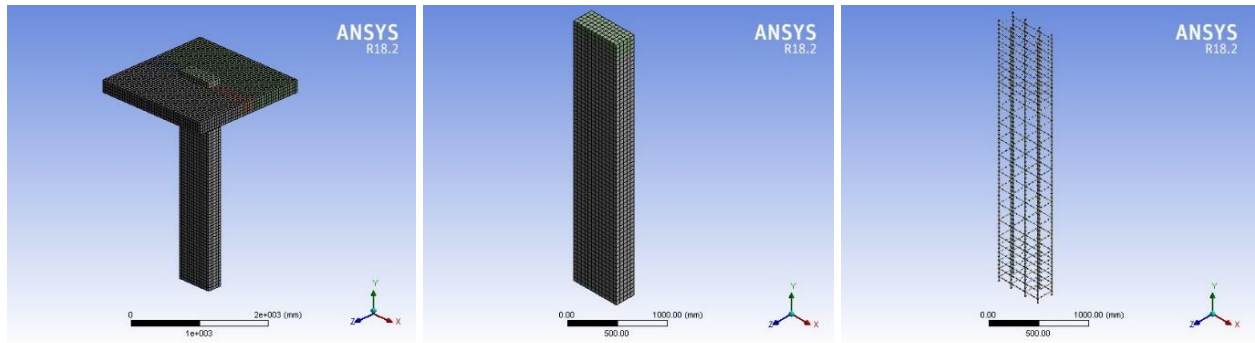


Figure 13. Geometry of Control Column

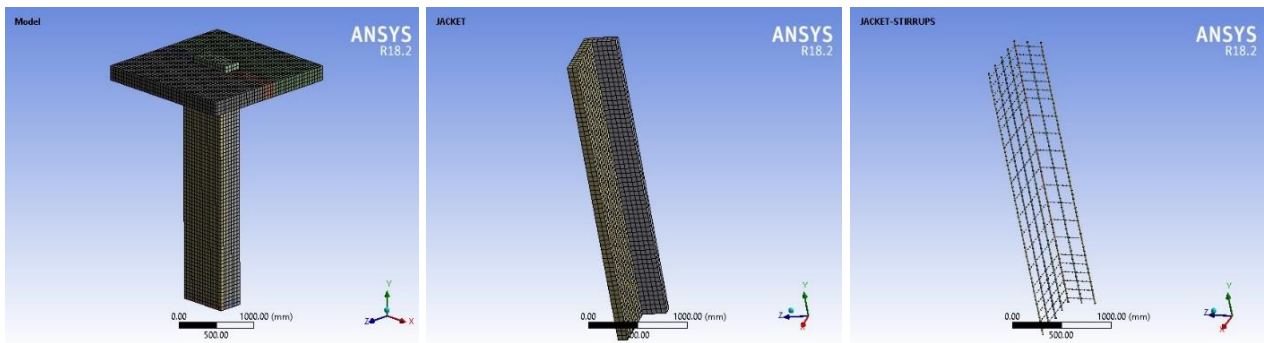


Figure 14. Geometry of Corner Column with Two Sides Jacketing for One Story

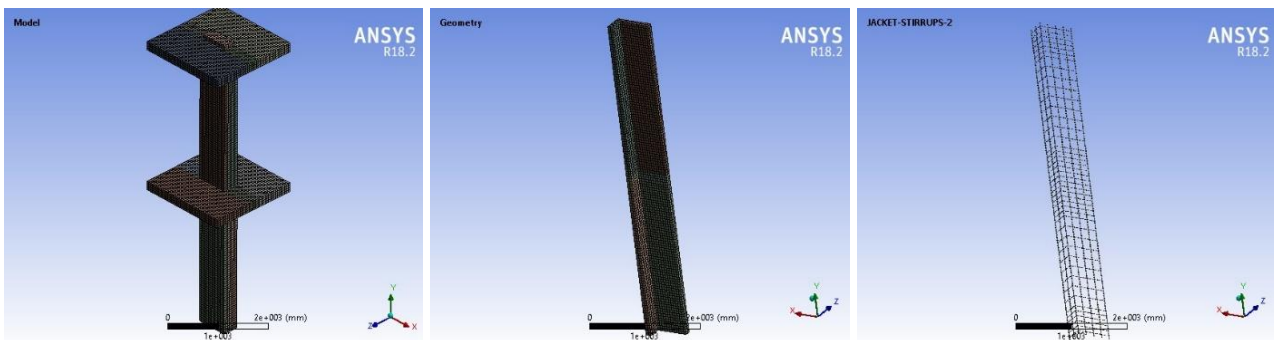


Figure 15. Geometry of Corner Column with Two Sides Jacketing for Two Stories

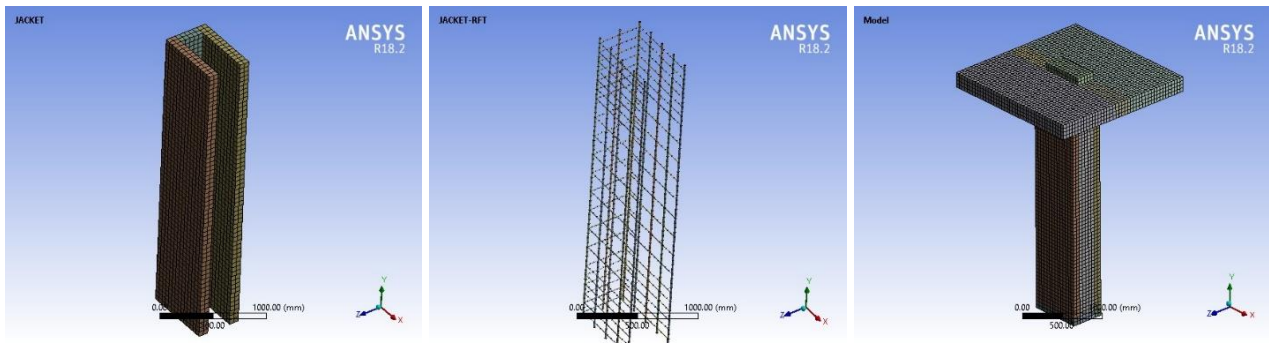


Figure 16. Geometry of Edge Column with Three Sides Jacketing for One Story

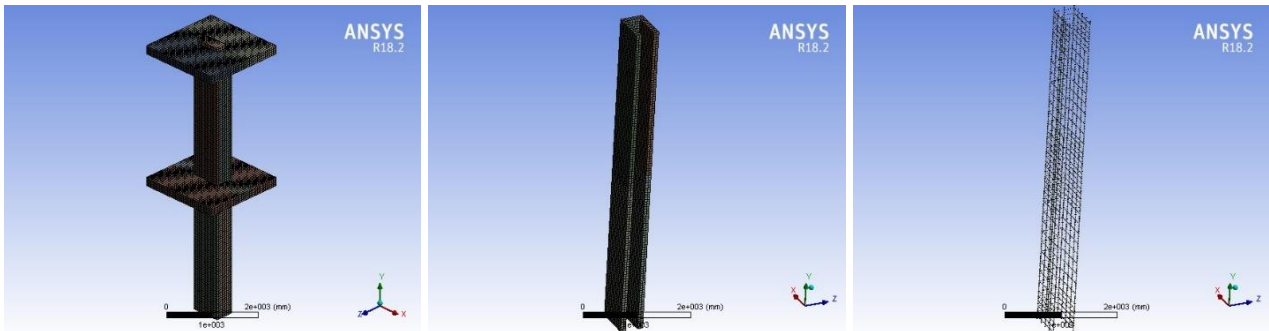


Figure 17. Geometry of Corner Column with Two Sides Jacketing for Two Stories

6. Results and Discussion

Control column has a failure load 153 ton and its deformations and normal stresses were compared with all models and shown in Tables 3 to 5. The main phenomenon is that the failure occurs in the upper part of the jacket due to the slippage in the jacket, so the figures concern this part of model to illustrate the results clearly.

6.1. Concrete Jacket in One Story Output

Analysis was done for four models edge strengthened column for one story, corner column strengthened for one story and repeat these two models again using shear connectors. Snap shots for the deformations and concrete normal stress at the failure were shown below in Figures 18 to 21 as the results show the edge column can sustain normal stress before failure more than the corner column because the three sides jackets give confinement more than two sides jacket, subsequently the edge column gives failure load bigger than the corner column, also the slippage decrease while using edge column. The results before and after using shear connectors were plot in figs 22-25, the figures show the effect of the shear connectors on the column behavior as it increases the column capacity because the interface became more rough and transfer large amount of load to the concrete jacket.

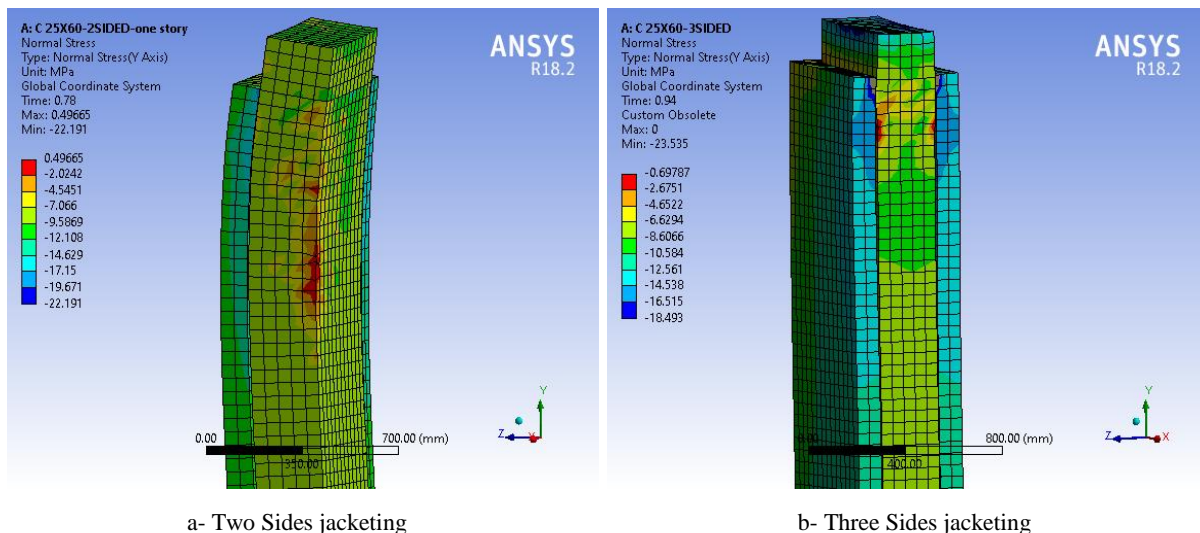
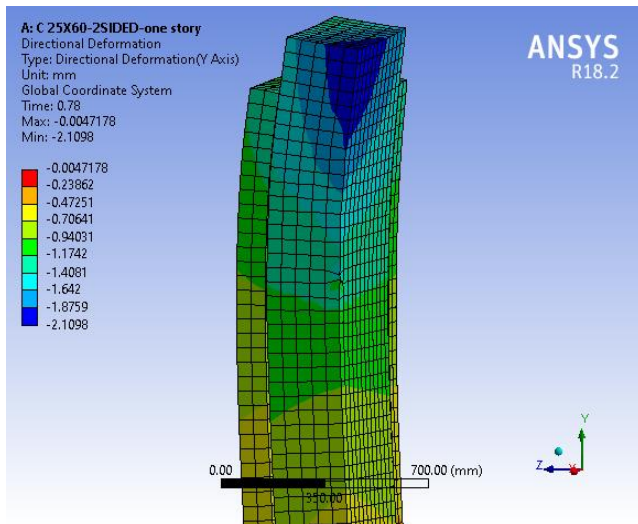
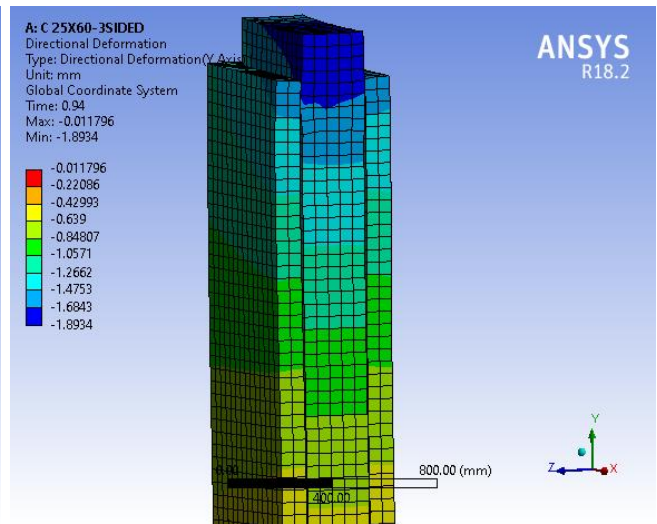


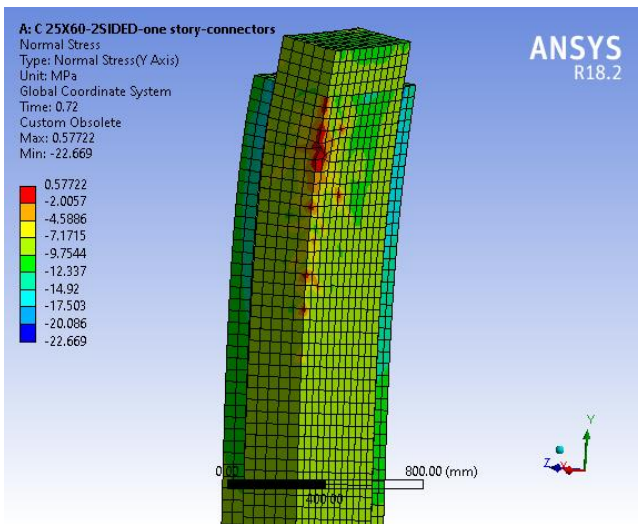
Figure 18. Normal stress of RC Jacketing for One Story



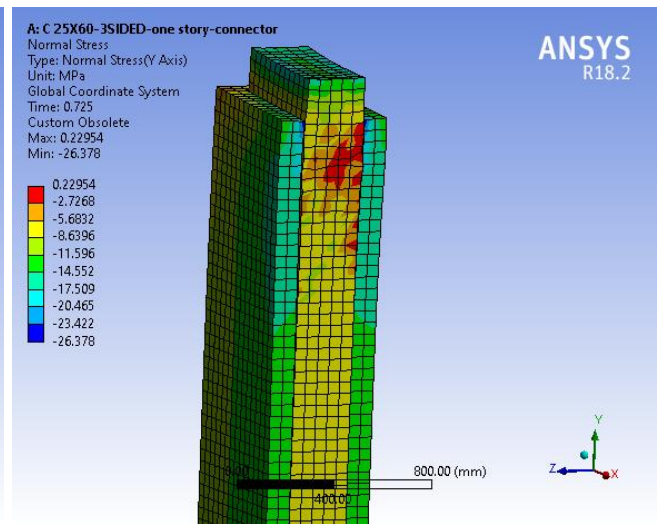
a- Two Sides jacking



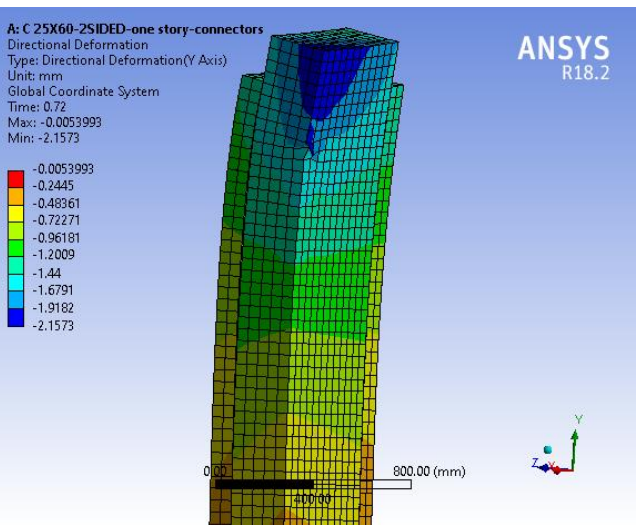
b- Three Sides jacking

Figure 19. Directional Deformation of RC Jacketing for One Story

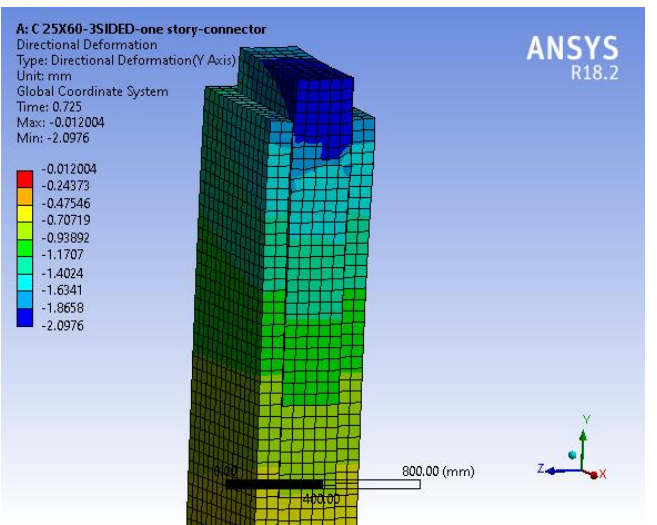
a- Two Sides jacking



b- Three Sides jacking

Figure 20. Normal stress of RC Jacketing for One Story-with shear connectors

a- Two Sides jacking



b- Three Sides jacking

Figure 21. Directional Deformation of RC Jacketing for One Story-with shear connectors

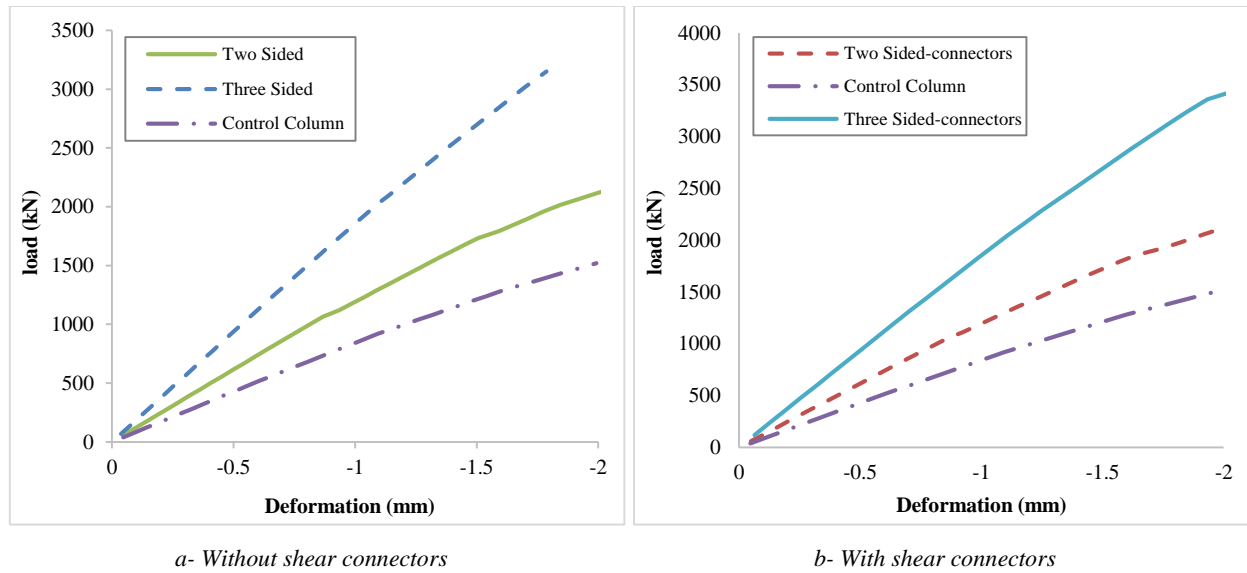


Figure 22. Deformation for RC jacketing for One Story

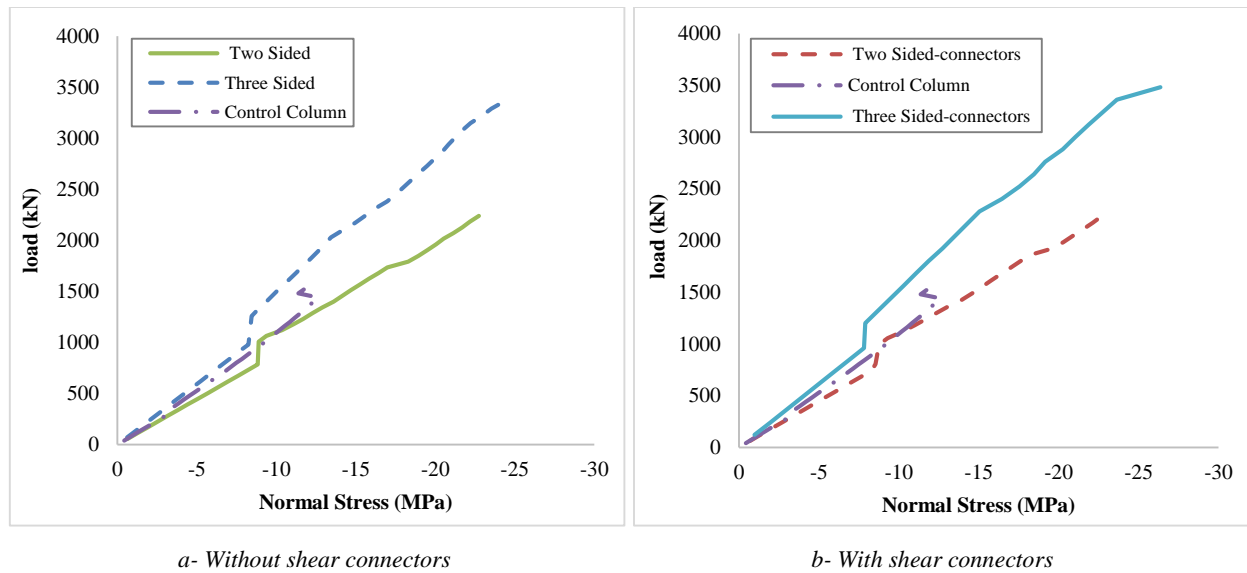


Figure 23. Normal stress for RC jacketing for One Story

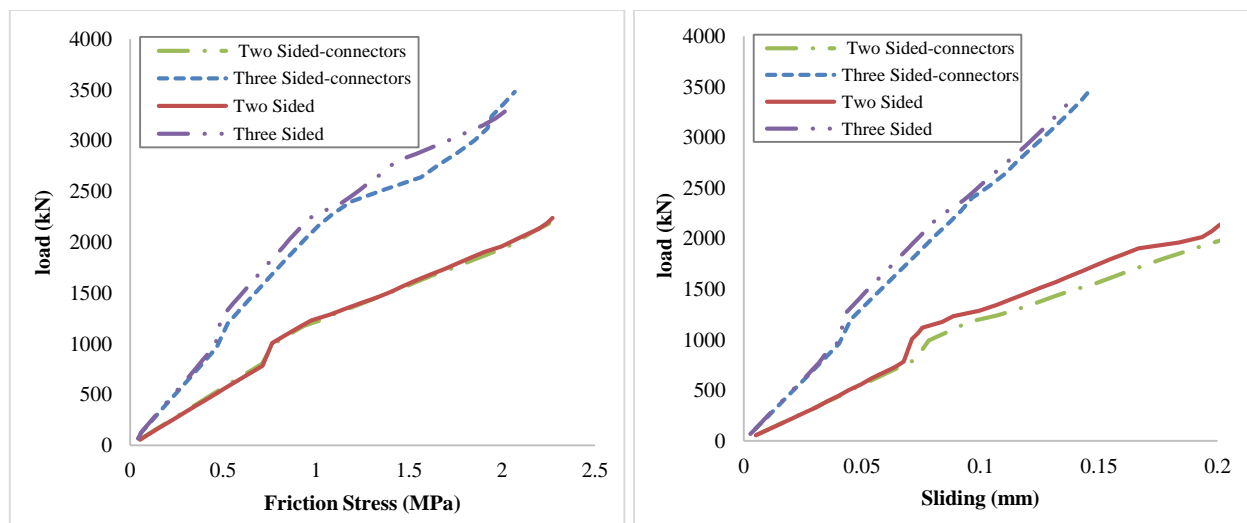


Figure 24. Frictional stress for interface in One Story

Figure 25. Sliding for interface in One Story

6.2. Concrete Jacket in Two Story Output

Investigation was accomplished for four models' edge and corner column retrofit for two story and rehash these two models utilizing shear connectors. Snap shots for the deformations and concrete normal stress at the failure were shown in Figures 26 to 29. The edge column normal stress before failure is larger than the corner column because the confinement increases with increase of the jacket sides, subsequently the edge column gives failure load bigger than the corner column, also the slippage decreases while using edge column. The results before and after using shear connectors were plot in figs 30-33, the figures show the effect of the shear connectors on the column behavior as it increases the column capacity because the interface became rougher and transfer large amount of load to the concrete jacket.

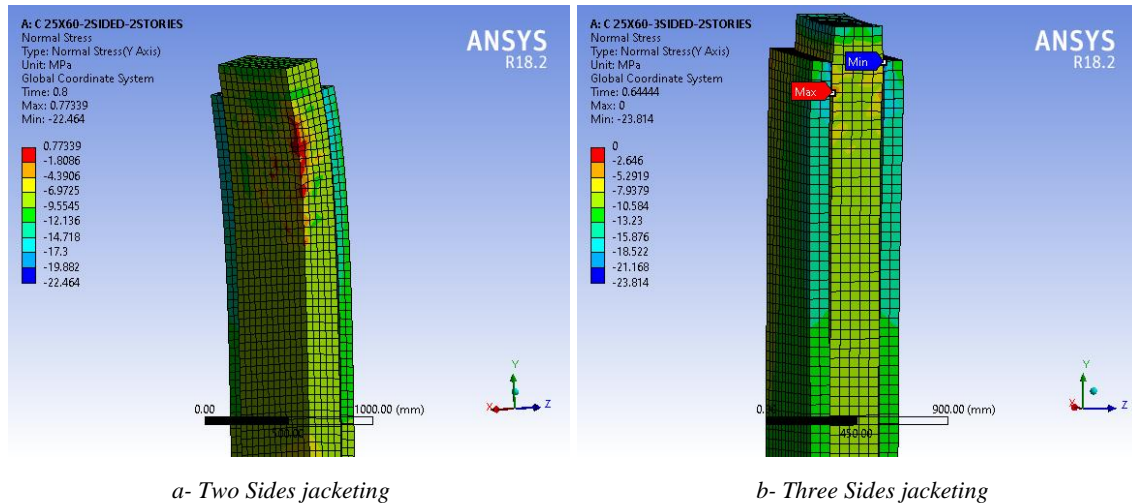


Figure 26. Normal stress of RC Jacketing for Two Stories

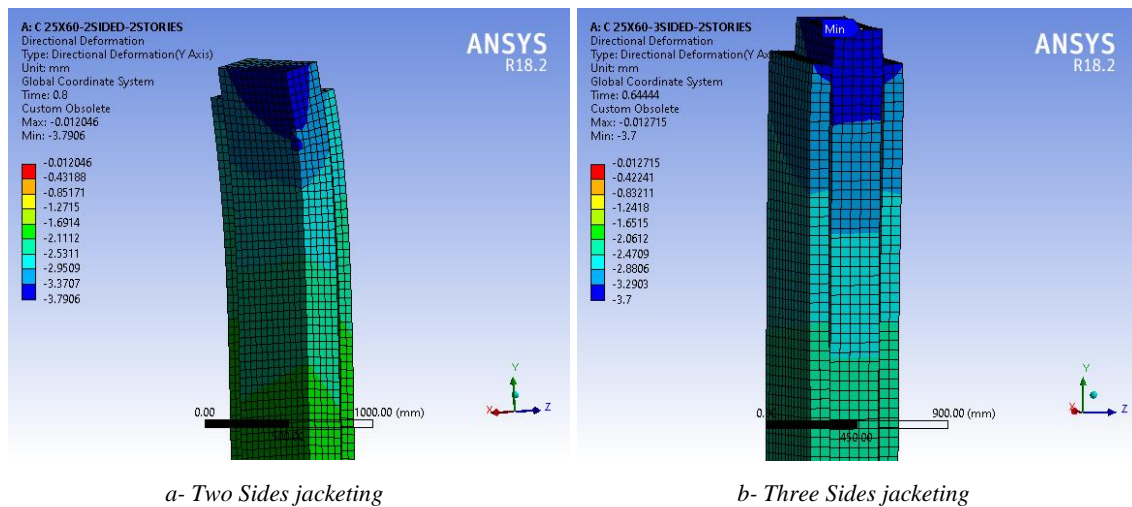


Figure 27. Directional Deformation of RC Jacketing for Two Stories

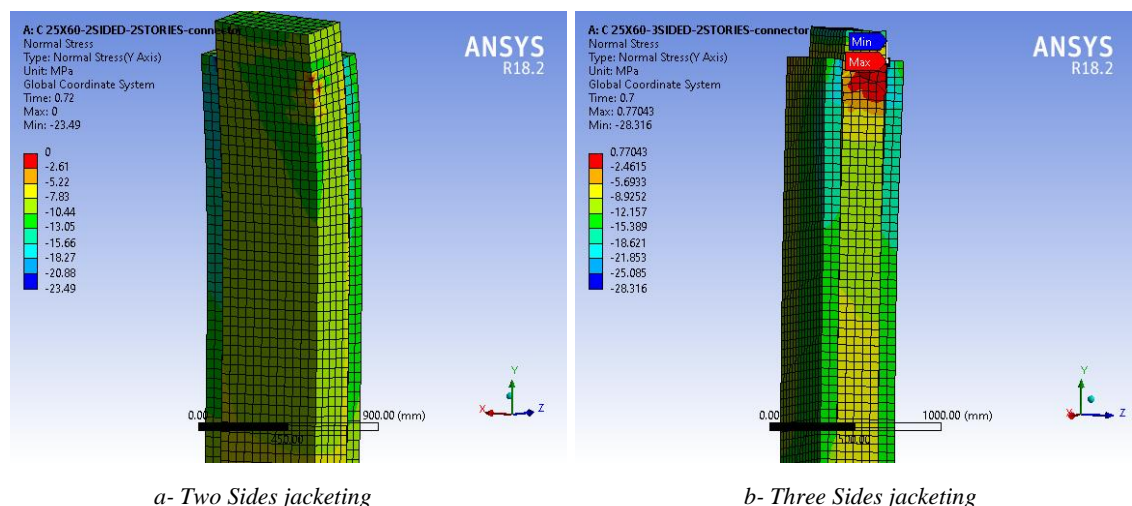


Figure 28. Normal stress of RC Jacketing for Two Stories-with shear connectors

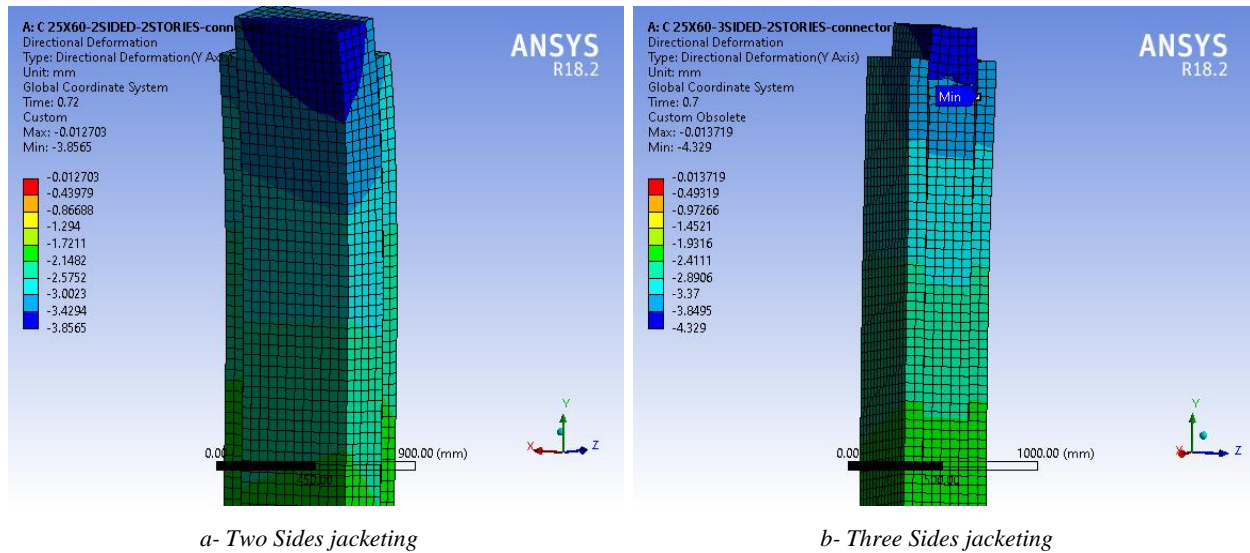


Figure 29. Directional Deformation of RC Jacketing for Two Stories-with shear connectors

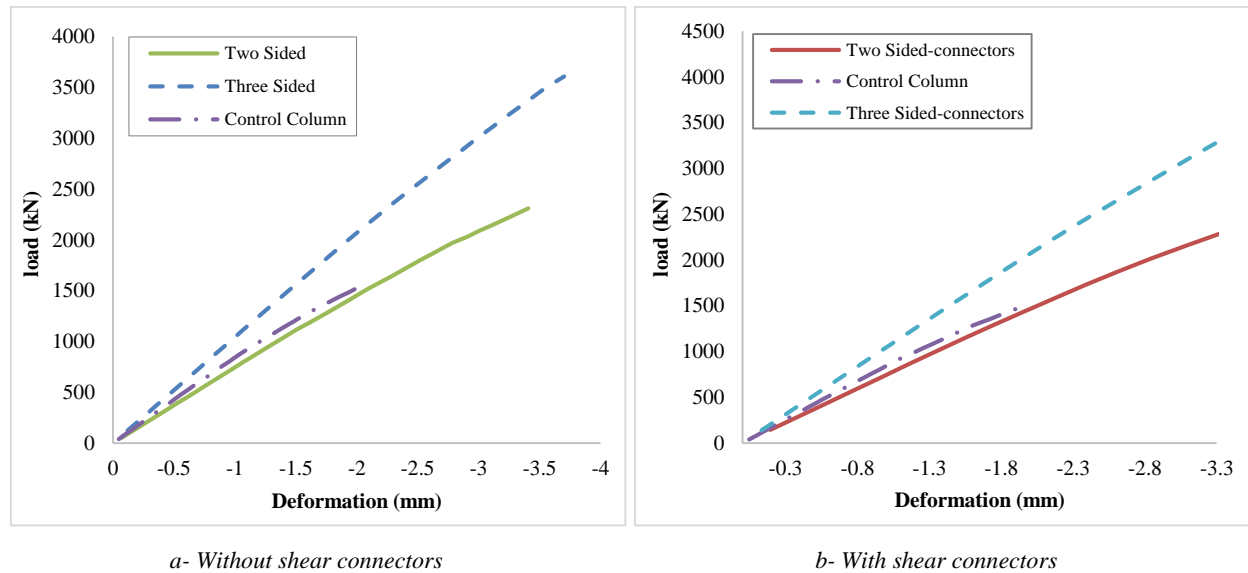


Figure 30. Deformation for RC jacketing for Two Stories

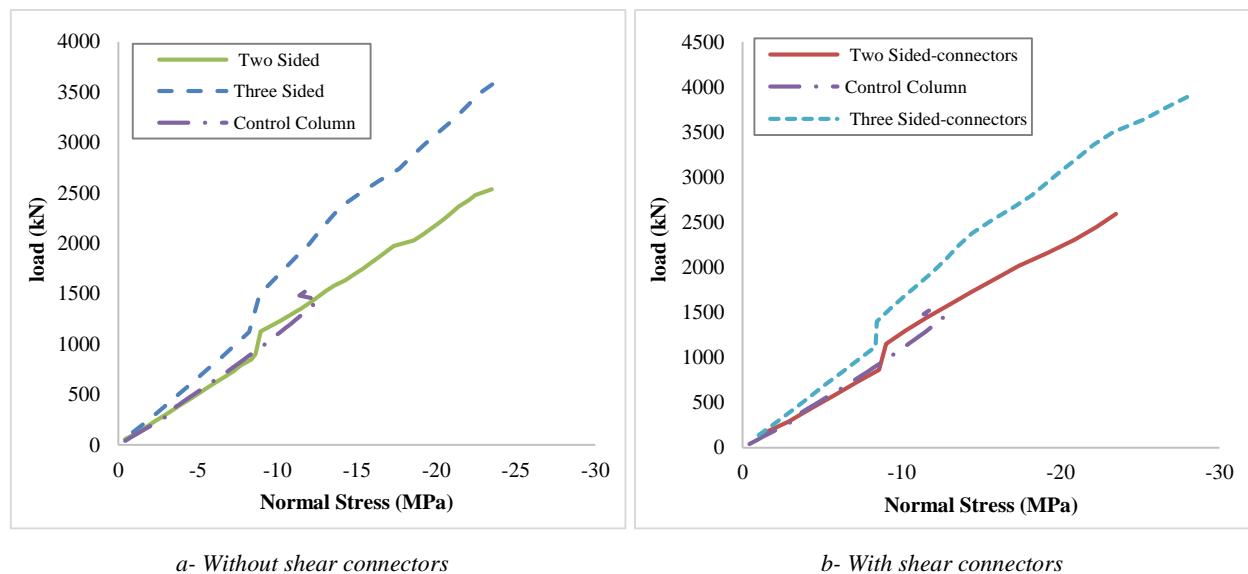


Figure 31. Normal stress for RC jacketing for Two Stories

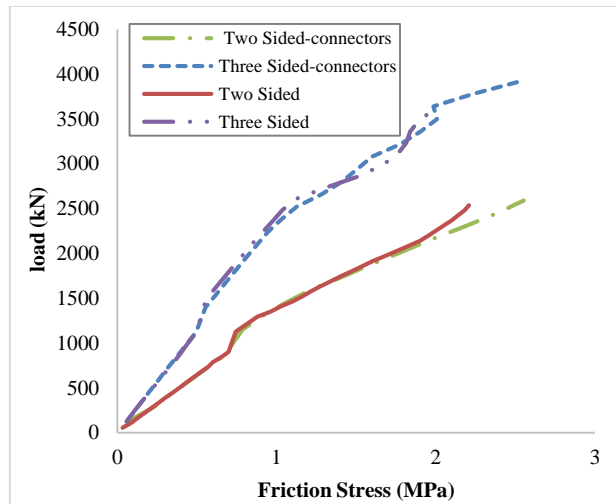


Figure 32. Frictional stress for interface in Two Stories

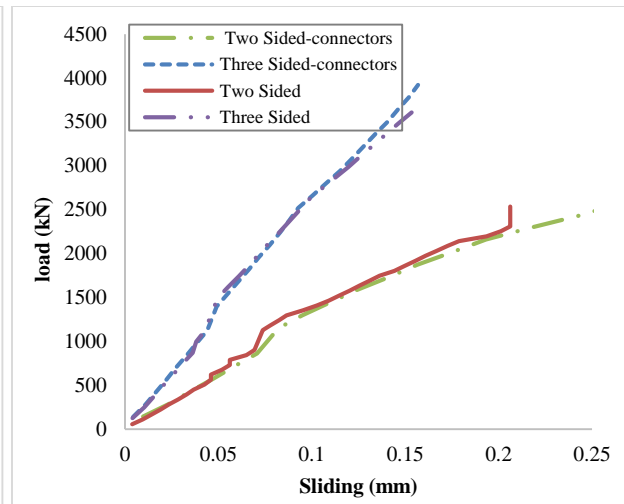
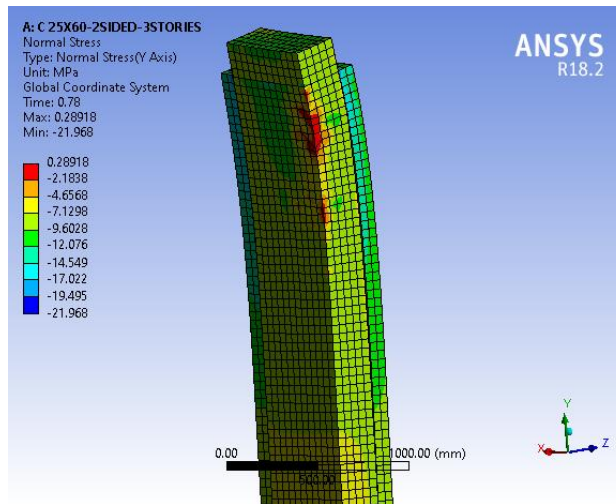


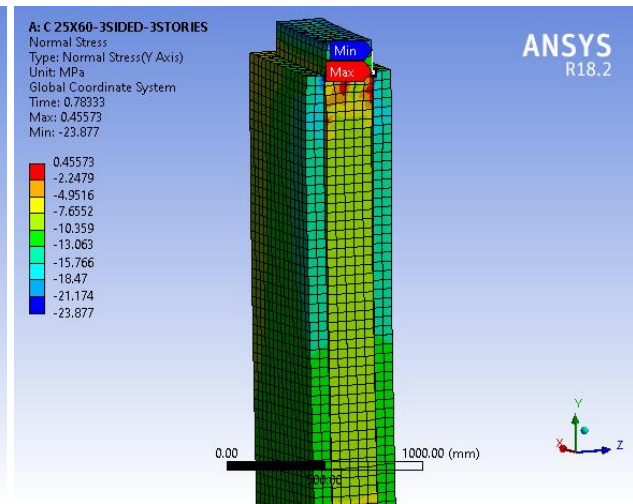
Figure 33. Sliding for interface in Two Stories

6.3. Concrete Jacket in Three Story Output

The same analysis was done for three stories as mentioned before and the results from the models were shown in Figures 34 to 37. Also, in this case the edge column is better than the corner column and it is recommended to use the shear connectors at the interface between the column and concrete jacket as it shown in Figures 38 to 41.

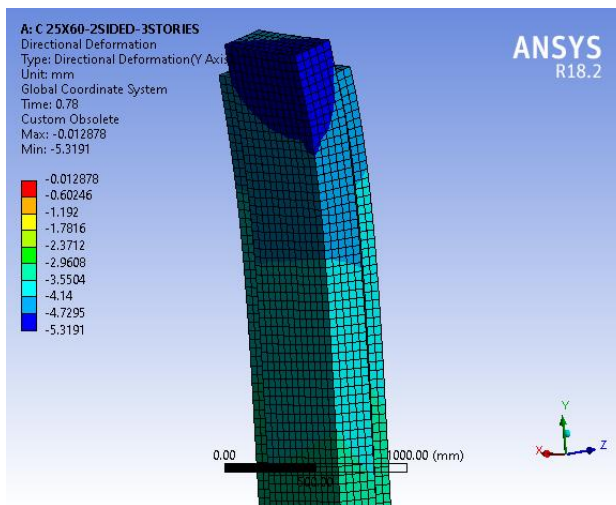


a- Two Sides jacketing

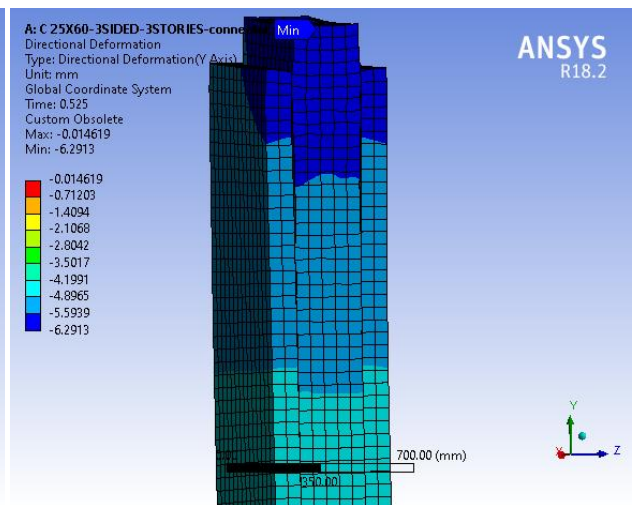


b- Three Sides jacketing

Figure 34. Normal stress of RC Jacketing for Three Stories



a- Two Sides jacketing



b- Three Sides jacketing

Figure 35. Directional Deformation of RC Jacketing for Three Stories

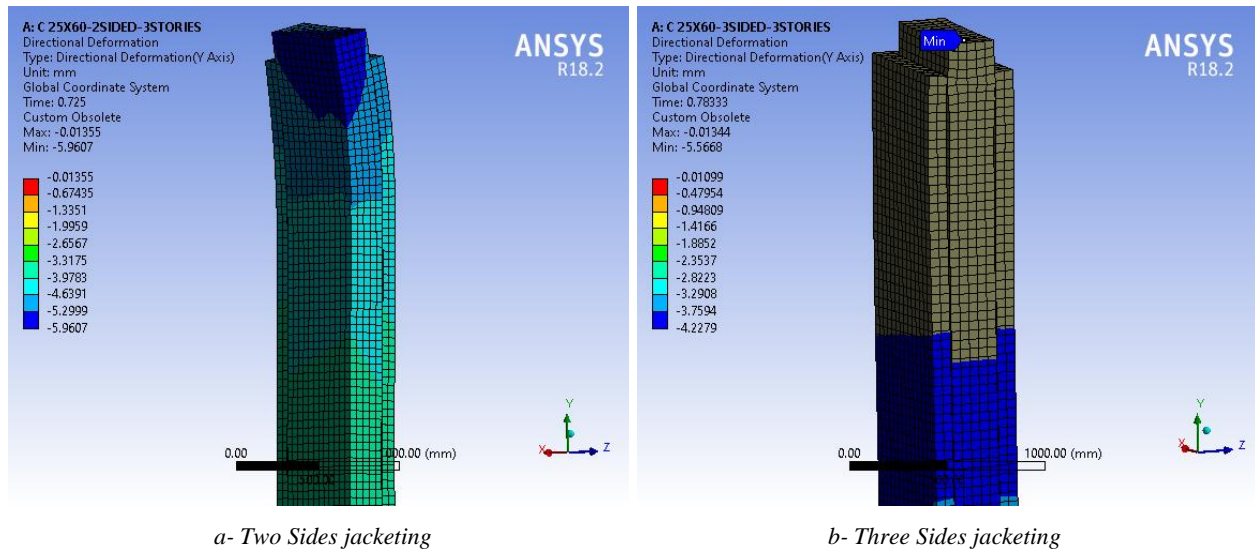


Figure 36. Normal stress of RC Jacketing for Three Stories-with shear connectors

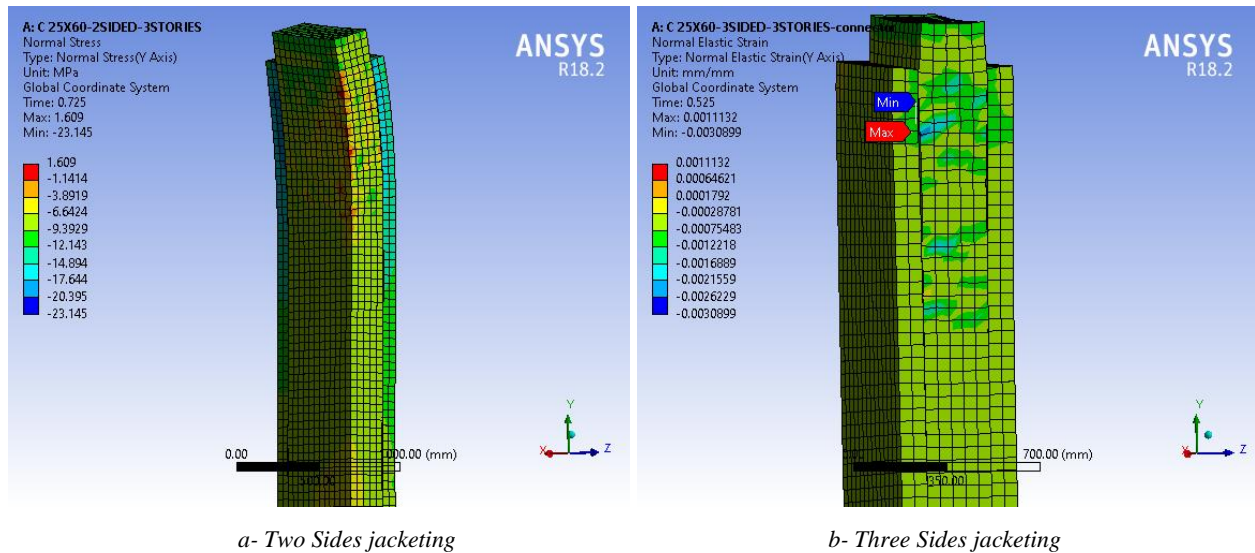


Figure 37. Directional Deformation of RC Jacketing for Three Stories-with shear connectors

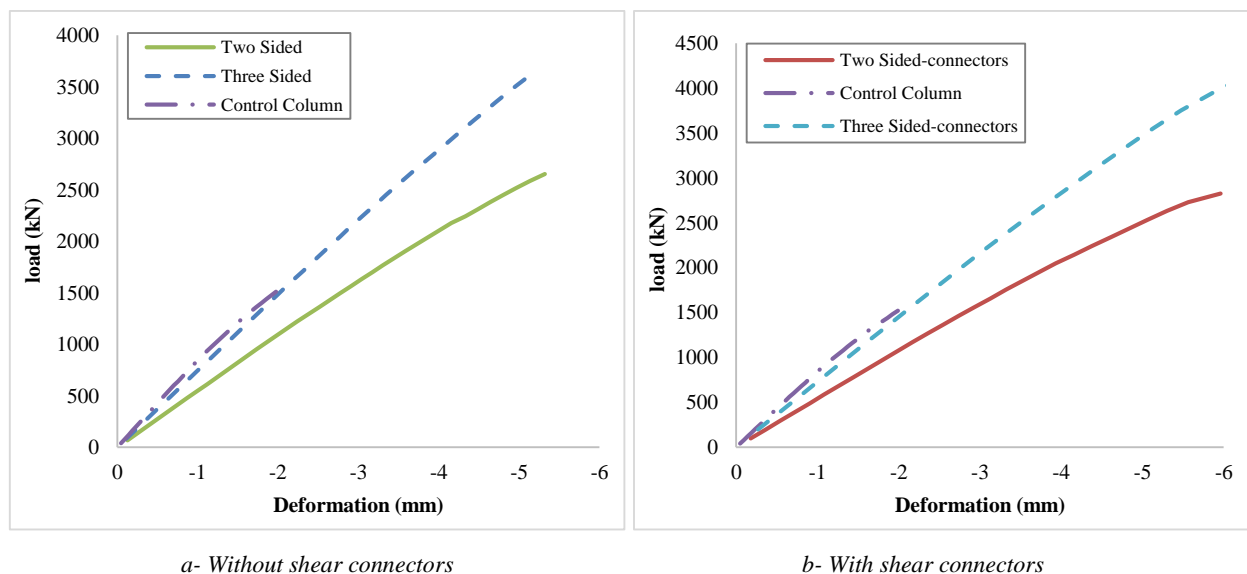


Figure 38. Deformation for RC jacketing for Three Stories

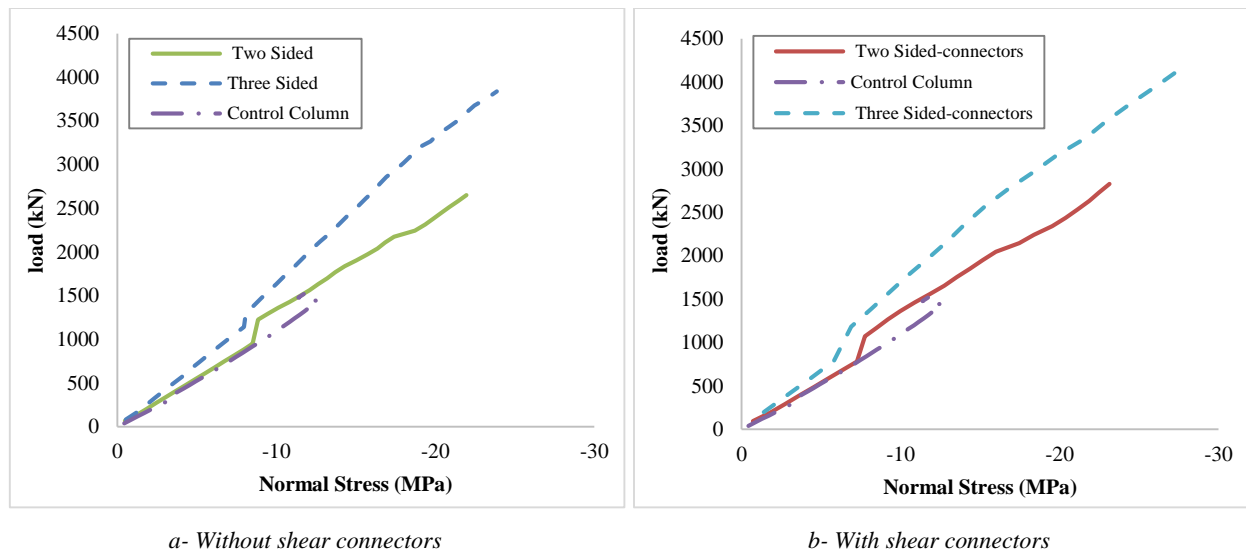


Figure 39. Normal stress for RC jacketing for Three Stories

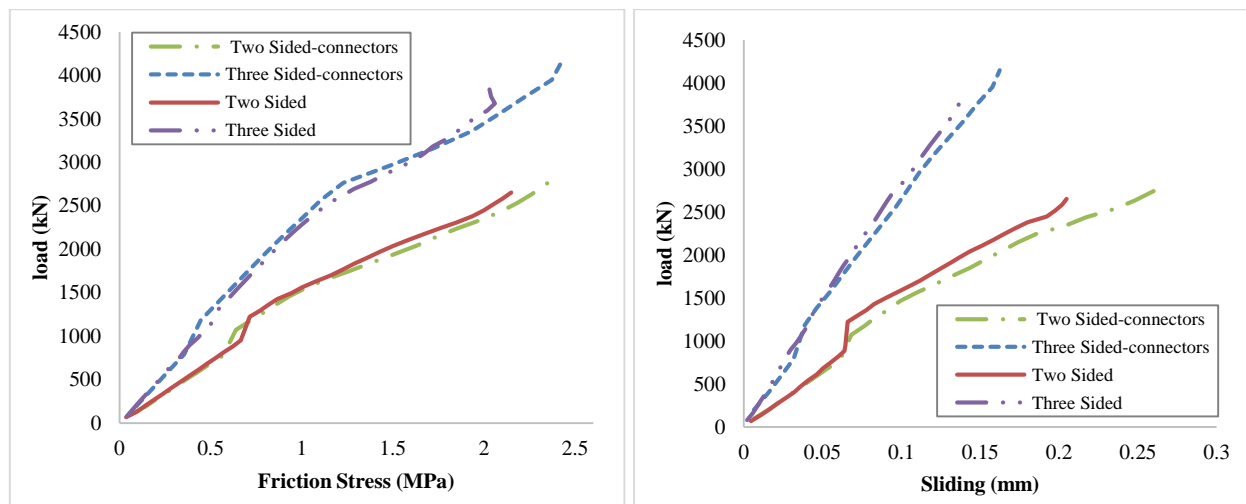


Figure 41. Sliding for interface in Three Stories

6.4. Overall Comparison

The control failure load for original column without jacket was 151 tons, after analysis all models its show that:

- The two sides jackets load capacity increase the capacity of the original column without strengthening by 43, 63 and 74% for one story, two stories and three stories respectively while for three sides jackets it became 116, 138 and 152% for one story, two stories and three stories respectively, which indicates that the increase in number of strengthened stories leads to an increasing in column-jacket capacity (Table 5).
- When using shear connectors, the results increase by 53, 70 and 86% for two side jacket and 129, 158 and 173% for three side jacket. These values show that using shear connectors increases the failure load since it gives more confinement than strengthening without shear connectors (Tables 3 and 5).
- FEM modelling results (load capacity, normal stresses, deformations and sliding) are varying according to the jacket type (3sided or 2sided), using shear connectors, and the number of strengthen story, this variation is due to the friction at the interface and the confinement of column by jacket. More confinement leads to increasing the normal stress that can be sustained by strengthened column before failure and decreasing the sliding between the original column and the concrete jacket (Figure 42).
- The capacities of the two sides and three sides strengthened columns were calculated using mathematical equations of the Indian code IS 15988 (2013) and compare with the models results, there are difference between FEM results and mathematical equations of the Indian code IS 15988 (2013) because the mathematical equations assume that the jacket is fully bonded with column and neglect the effect of confinement and the friction between the original column and concrete jacket (Table 4).

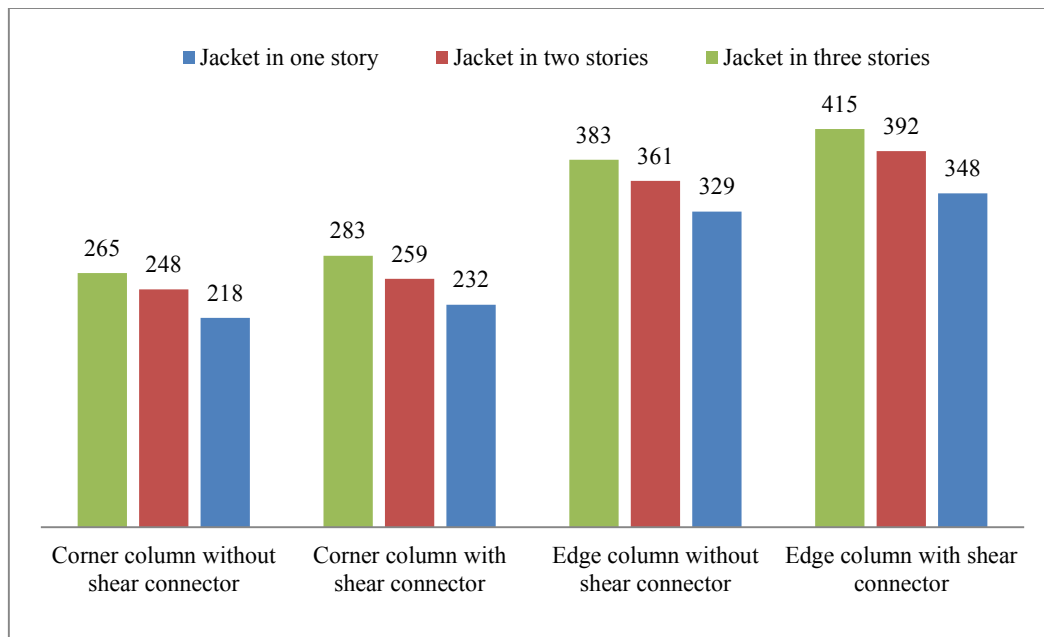


Figure 42. Comparison between strengthened in one, two and three stories capacity for all jacket types

Table 3. Strengthened Column failure load in all case

Jacket Type	Without Shear Connectors			With Shear Connectors		
	One story	Two stories	Three stories	One story	Two stories	Three stories
2 sided	218 (ton)	248 (ton)	265 (ton)	232 (ton)	259 (ton)	283 (ton)
	43%	63%	74%	53%	70%	86%
3 sided	329 (ton)	361 (ton)	383 (ton)	348 (ton)	392 (ton)	415 (ton)
	116%	138%	152%	129%	158%	173%

Table 4. Comparison between mathematical and FEM failure load calculations

Jacket Type	Mathematically	Without Shear Connectors			With Shear Connectors		
		One story	Two stories	Three stories	One story	Two stories	Three stories
2 sided	443.5 (ton)	218 (ton)	248 (ton)	265 (ton)	232 (ton)	259 (ton)	283 (ton)
		51%	44%	40%	48%	42%	36%
3 sided	617 (ton)	329 (ton)	361 (ton)	383 (ton)	348 (ton)	392 (ton)	415 (ton)
		26%	19%	14%	22%	12%	6%

Table 5. Summary of results

	Jacket Type	Failure load (ton)	Normal Stress (MPa)	Jacket Sliding (mm)
Control column		153	-11.7	
One story	2-Sided Jacket	218	-22.2	0.2
	3-Sided Jacket	329	-23.5	0.147
One story with connectors	2-Sided Jacket	223	-22.7	0.214
	3-Sided Jacket	348	-26.37	0.158
Two stories	2-Sided Jacket	248	-22.46	0.21
	3-Sided Jacket	361	-23.8	0.16
Two stories with connectors	2-Sided Jacket	259	-23.5	0.285
	3-Sided Jacket	392	-28.3	0.16
Three stories	2-Sided Jacket	265	-22	0.205
	3-Sided Jacket	384	-23.88	0.144
Three stories with connectors	2-Sided Jacket	283	-23.15	0.28
	3-Sided Jacket	415	-27.6	0.167

7. Summary and Conclusions

This research presents the analysis of strengthening edge and corner columns using ANSYS program, the analysis depends on transferring the load between the original column and the concrete jacket by friction between them. Thirteen models were studied (3 Models for edge column, 3 Models for corner column and one Model for control column) each column (Edge or corner) analysed by strengthening in one story, two stories and three stories. The Analysis made twice, once without shear connector between the original column and the concrete jacket then the analysis has been done using a shear connector between the original column and the concrete jacket. The analysis results of the models were presented in the form of figures and tables; the results were compared with the values derived from the equation of the Indian code IS 15988 (2013). From the analysis results we can conclude that:

- The Load capacity of concrete jacket increases with increasing the friction area between the original column and the concrete jacket;
- The strengthening of edge and corner jacket for two or three stories enhancement the efficacy of the column than strengthening in one story;
- Increasing the number of strengthened stories leads to more sustained normal stress before failure since the jacket gives more confinement for original column;
- The sliding became smaller with increasing the confinement by using shear connectors or strength using more than one story;
- It's recommended that for edge column the concrete jacket must be at least in two stories and for corner columns the concrete jacket must be at least in three stories;
- Using shear connectors between original column and concrete jacket increase the strengthened column capacity;
- Mathematical design based upon IS 15988 (2013) assumes full bond between the concrete jacket and the column which gives a higher value than FEM analysis, because the FEM depends on transferring the load from the original column to the concrete jacket by friction which gives more realistic values.

8. Declarations

8.1. Author Contributions

Conceptualization, M.E., M.N., H.A. and M.A.; modelling and analysis, M.E. and M.N.; analysis and interpretation of the results, M.N. and H.A.; writing - original draft preparation, M.E. and M.A.; writing - review and editing, M.E., H.A., M.A. and M.N. All authors have read and agreed to the published version of the manuscript.

8.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

8.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

8.4. Conflicts of Interest

The authors declare no conflict of interest.

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