Proceedings of International Conference on Planning, Architecture and Civil Engineering, 12 - 14 October 2023, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh

Paper ID: CE 0186

Theoretical Analysis of Steel Retrofitted Beam-Column Joint by ANSYS Modeling

S. A. M. Anachh[1], A. A. Momen[2], R. Ahmed[3], K. A. Manjur[4]

[1]Department of Civil Engineering, MEC, Bangladesh (anachhsam@gmail.com)
[2]Department of Civil Engineering, MEC, Bangladesh (abdullahalmomen1019@gmail.com)
[3]Department of Civil Engineering, MEC, Bangladesh (ratulahmed47@gmail.com)
[4]Department of Civil Engineering, DUET, Bangladesh (kamanjur@duet.ac.bd)

Abstract

The critical area of a reinforced concrete frame is the intersection of the beams and columns. This research shows the findings of an analytical examination into steel retrofitting using finite element analysis to boost the performance and load carrying capacity of reinforced concrete beam-column joints in interior joint and corner joint. This study presents the ETABS modeling and analysis of a reinforced concrete building. Both the original and improved joint models were subjected to a static finite element analysis to determine their relative performance. As it became clear that beam-column joints were weak spots, the steel jacketing was used as a technique in ANSYS to strengthen them so that they would conform to the latest design standards. The results have been studied to learn more about the load bearing capability, deflection, and failure pattern. The research reveals that the structure is strengthened by an increase in stress-strain ratio of 2.5 times in interior joint and 3.45 times in corner joint, and a decrease in load-deformation of 1.82 times in interior joint and 2.1 times in corner joint.

Keywords: *Retrofitting; ANSYS; Steel-plate Jacketing; Load carrying capacity; Concrete Strengthening.*

1 Introduction

The deformations and strength of beam-column joints impact the overall performance and load bearing capacity of reinforced concrete structures, leaving them vulnerable to progressive collapse owing to failure of one or more beam-column joints under gravity and seismic loadings(Bsisu et al., 2015)(Los, n.d.-a).

The term "retrofitting" refers to the process of making structural alterations in an existing structure in order to increase its durability, resistance to earthquake, strength and ductility. (Journal et al., 2020). One of the most popular approaches of retrofitting is known as the jacketing construction process. These are: Reinforced Concrete Jacketing, Steel Jacketing, Carbon Fibre Reinforced Polymer Jacketing, Textile Reinforced Mortar jacketing, Glass Fibre Reinforced Jacketing and so on(Bsisu et al., 2015)(Raval & Dave, 2013)(Koutas et al., 2015). On this paper, Steel jacketing will be analyzed with the help of finite element method in ANSYS.

1.1 Beam-Column Joint

In Reinforced Concrete moment-resisting frames, the beam-column joints are the shared column sections at the beam crossings, as indicated in the image.

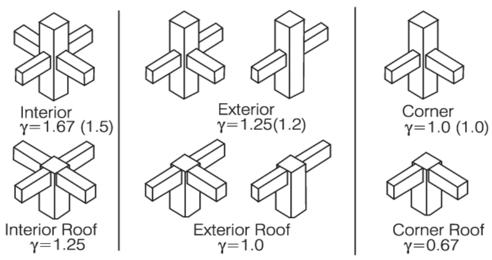

Figure 1. Beam-Column Joint Connection Types.

1.2 Purpose of Jacketing in Beam-Column Joint

There are primarily two goals to be accomplished when jacketing. (i) To increase the shear strength of the columns (using a design with strong columns and weak beams). (ii) To increase the column's flexural strength to better support the load. After carrying out detailed analysis experimentally and in ETABS, it is seen that multiple beam-column joint fails if maximum loads such as seismic load, wind load according to BNBC, comes into action at the same time. All these members are required to be retrofitted to get desired strength and ductility. Out of these failed joints, two joints are selected based on (i) the location of the beam-joint and (ii) the loads its undergoing. The interior and Corner joints are most vulnerable because the maximum load of the structure goes through the interior joint as it is connected with 4 beams and 2 columns on the same spot, again in the case of corner joint, effect of axial force, shear force and moment is maximum, also there is no beam on the opposite side of the beam to counter the moment. The higher the load its undergoing, the higher will be the chance for it to be failed soon.

1.3 Steel Jacketing

Steel jacketing is a promising method of strengthening in which steel angles or plates are used to enclose the column concrete in a variety of configurations, such as steel wrapping (for a circular column), steel plates, and steel caging(SH & FR, 2020). In the construction industry, RC columns with a square or rectangular cross section often benefit from this method of reinforcement(Raval & Dave, 2013). The strategy has widespread support because of its perceived practicality, efficiency, and low cost. The seismic performance of the building as a whole is enhanced as a result of the enhancement of the members' lateral strength, axial load carrying capacity, ductility, and shear(Amulya & Kumar, 2017).

1.4 Description of the Software Used

1.4.1 AutoCAD

AutoCAD is a computer-aided design and drafting software application. The software is vastly used in architectural and structural designs.

1.4.2 ETABS

Multi-story building analysis and design are a specialty of ETABS, an engineering software package. The grid-like geometry that is characteristic of this type of construction is taken into account while developing modeling tools and templates, code-based load prescriptions, analysis methods and solution strategies. (Gufran et al., 2022).

1.4.3 ANSYS

For our study, first an existing industrial building is selected, and an AutoCAD plan is extracted from the existing building. Next, the plan is modeled in ETABS and analyzed with the structural data provided from the existing building data. After analyzing, multiple beams and columns have failed due to the extensive load. Then, one of the beam-column joints is strengthened in ANSYS by steel jacketing. Following the development of the beam-column model, load is applied to the model both with and without the jacketing, and then the over stress of the original model and the model with the jacketing is compared.

2. Properties

2.1 Building Details

2.1.1 Structural Data

An industrial building with G+5 storied is selected to be retrofitted to increase the strength. Initial data comprising with the structure are, length of the structure 162 feet, breadth of the structure 62 feet, height of the structure 74 feet. The Structure consists of multiple columns and beams and their specifications are –

Table 1. Structural Parameter

Element	Name	Dimension (in)	Main Bar	Tie bar / Stirrup
Column	Corner	12 X 12	4 #8	#4 @ 6” c/c
	Interior	12 X 15	4 #8	#4 @ 6” c/c
Beam	All Beam	10 X 12	5 #6	#4 @ 6” c/c
	Grade Beam	10 X 10	5 #5	#3 @ 6” c/c

2.1.2 AutoCAD Design

As the existing structure is an industrial building, so the floor plan is different for each floor. Even though a basic beam and column configuration is taken into consideration:

Figure 2: Floor plan & Front elevation of the Building

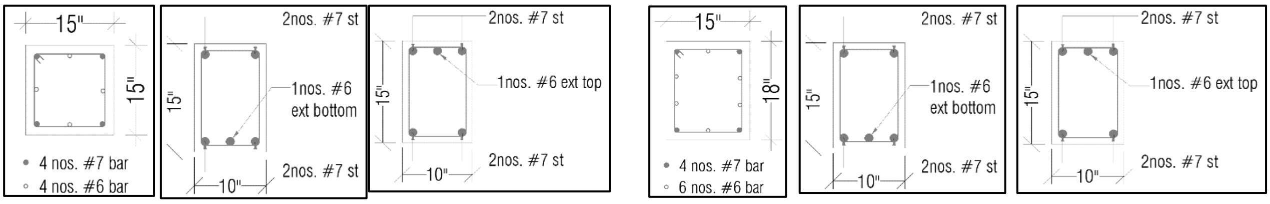

Figure 3. Studied Corner (first 3) and interior (second 3) Beam-Column dimension and reinforcement details.

2.1.3 ETABS Modeling

These AutoCAD data are then given in ETABS for further structural analysis. Two methods are usually followed to model the concrete reinforcing. The first one is the smeared concrete element method(Gufran et al., 2022). The second one is reinforcing discrete elements with geometrical properties similar to the original reinforcement was used in this study(Bsisu et al., 2015).

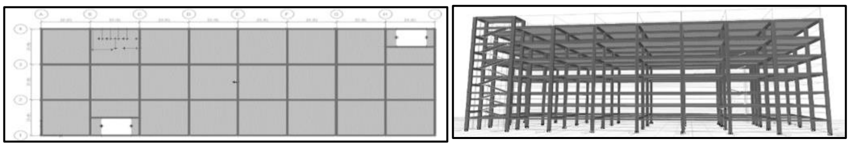

Figure 5. Plan & Elevation of the ETABS Model of the Building.

2.2 Material Properties

Table 2. Material properties of Rebar, Concrete & Steel Plate.

Sl No.	Properties	Reinforcement Bar	Concrete	Steel Plate used for Retrofitting
1	Density	490 lb/ft3	150 lb/ft3	490 lb/ft3
2	Mass/ Unit Volume	15.23 lb-s2/ft4	4.662 lb-s2/ft4	15.23 lb-s2/ft4
3	Modulus of Elasticity	29×106 psi	3016156.5 lb /in2	29×106 psi
4	Poissons Ratio	0.3	0.2	0.3
5	Thermal Expansion Co-Efficient	6.5×10-6 1/F	5×10-6 1/F	6.5×10-6 1/F
6	Shear Modulus	11153846.15 psi	1256731.88 psi	-
7	Compressive Strength, f/c	-	2800	-
8	Tensile yield stress	50,000 psi	-	40,000 psi
9	Ultimate tensile Strength	65,000 psi	-	70,000 psi
10	Grade	50 grade	-	40 grade

2.2 Control Specimen

After analyzing in ETABS, the failure pattern and data are collected. These are tabulated below:

2.2.1 Failure Pattern

The model is analyzed in ETABS according to the BNBC. It is found out after analyzing that the building is unfit if all the maximum loading to be taken at once. The failure pattern is generated from the software.

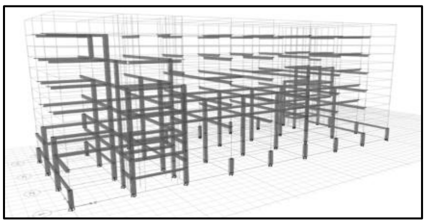

Figure 6. Failed Members of The Building Under Maximum Loading Conditions.

2.2.2 Column and Beam Data

Table 3. Analyzed data of Columns from ETABS.

Col. No.	P (kip)	Shear Force, V2 (kip)	Shear Force, V3 (kip)	Torsion, (kip-ft)	Moment, M2 (kip-ft)	Moment, M3 (kip-ft)	Analysis
C2	-332.152	-19.62	-32.426	-2.724	-254.1194	-177.8447	Pass
C5	-264.641	-25.55	-9.922	-2.4407	-129.146	-203.2791	Fail
C9	-593.36	-15.016	-23.54	-3.7965	-201.475	-130.2512	Fail
C11	-695.364	-9.271	-33.519	-2.683	-259.736	-133.01	Fail
C18	-294.02	-10.467	-34.322	-7.95	-261.84	-122.02	Pass
C19	-282.15	-10.234	-30.79	-2.76	-249.82	-119.67	Fail
C20	-583.12	-10.33	-26.28	-3.13	-219.23	-112.26	Fail
C28	-167.58	-25.5	-16.66	-1.96	-168.34	-159.33	Fail
C29	-763.07	-63.75	-46.16	-12.31	-298.5	-345.38	Fail
C40	-601.96	-36.53	-50.88	-11.46	-256.59	-220.09	Pass

The above table shows the column loads (for simplicity, only the relevant ones are shown). All the data shown here are in negative value because all the forces generated are in the opposite direction on the main reference axis. Here, shear force(V2) and Moment(M3) are generated on the same axis and shear force(V3) and Moment(M2) are generated on the same axis.

After analyzing the data, C9 and C11 are taken into consideration, because C9 carries the maximum load of 596.39 kip among the corner columns & C11 carries the maximum load of 695.364 kip among the internal columns. They have dimensions 12”*12” & 12”*15” respectively. Corner column C9 has connection with beams B8 and B69. And C11 has the connection with beams B25, B26, B32 and B33. So, these six beams are taken into consideration.

Table 4. Analyzed data of Beams from ETABS.

Beam No.	P (kip)	Shear Force, V2 (kip)	Shear Force, V (kip)	Torsion, M2 (kip-ft)	Moment, M2 (kip-ft)	Moment, M3 (kip-ft)	Analysis
B8	158.394	-84.177	-4.244	-4.244	-5.6749	-108.4704	Pass
B69	-3.51	-15.97	-0.676	-0.0189	-2.6946	-70.89	Fail
B25	0	-65.486	0	-0.8024	0	-113.3656	Pass
B26	0	-79.36	0	-0.7874	0	-100.1304	Pass
B32	0	-68.627	0	-1.5668	0	-74.5038	Fail
B33	0	-44.93	0	-1.3649	0	-74.5753	Fail

3 Method Statement

Within the context of this paper, an interior beam column connection and a corner beam-column connection is studied in both the unstrengthened and the strengthened cases respectively. The beam-column joint will be under bending stress, shear stress and axial stress. The initial pressure on the beam-column joint is 2800 psi on the existing building. That is, in this point the beam-column joint fails. On this joint, steel retrofitting will be done. The thickness will be increased gradually until it takes the pressure of 4500 psi. The developed stress will be examined by conducting static analysis, load carrying capacity, load-deflection behavior, ductility (Bsisu et al., 2015). The failure pattern on the joint will also be investigated and studied thoroughly. In addition, the load deflection response for each retrofitted beam-column joint and the unreinforced joint condition is compared.

3.1 Finite Element Method

The overall behavior of a structure is determined through the application of finite element analysis. This method involves dividing the structure into a series of simple elements, each possessing clearly defined mechanical and physical properties(Kandil et al., 2014). To mathematically represent physical problems, it is necessary to make certain assumptions, including boundary conditions and geometry. These assumptions collectively give rise to differential equations that govern the mathematical model. The mathematical model is solved using finite element analysis. The finite element solution technique is a numerical procedure. A mesh refinement can serve as a sophisticated solution parameter (Treffen, 2017)(Kandil et al., 2014).

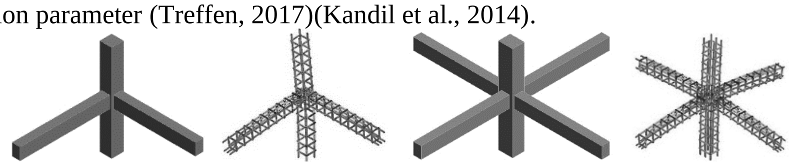

Figure 7. Corner & Interior Beam-Column Joint Before retrofitting & their Reinforcements

3.2. Loading and Boundary Condition

At the top of the column, there is a hinged support, and at the bottom of the column, there is a fixed support. The force is put on the model along the Z-axis. The force used in the model comes from E-TABS.

4. Analysis of the Model

4.1 Deformation

The selected beam-column joints are modelled in ANSYS and then persuaded to do a simulation in order to see the crack patterns on the joints.

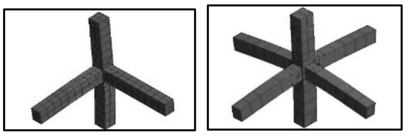

Figure 8. Deformation on Corner & Interior Beam-Column Joint in ANSYS

4.2 Increment of Thickness

The thickness on the beam-column joints is gradually increased after providing the jacketing to get the increased load carrying capacity on the joint. Then stresses in the joints and also deformations are noted down. The stresses and deformation are given below.

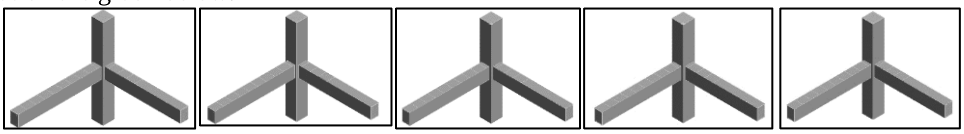

Figure 9. Corner Beam-Column Joint with 8mm, 10mm, 12mm, 14mm & 16mm Steel Retrofitting.

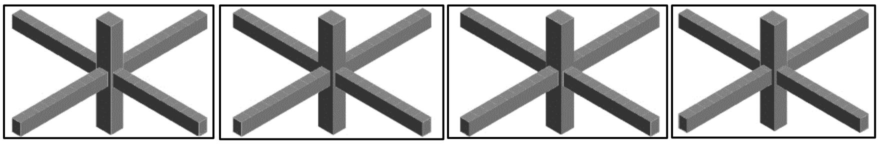

Figure 10. Interior Beam-Column Joint with 10mm, 12mm, 14mm & 16mm Steel Retrofitting.

Below are some of the data, that are taken during trialing in ANSYS while finding out the optimum thickness which can carry the load of 4500psi on each beam-column joint,

Table 5. Steel Plate jacketing Data from ANSYS

Beam-Column Joint	**Steel plate thickness (mm)**	**Concrete compressive stress (psi)**	**Steel tensile stress (psi)**	**Fail in:**		**Remarks: (Used F'c =2800 psi Fy =50,000psi)**
				Concrete	**Steel**	
Corner Joint-A: (C9+B8+B69) Initial stress: 6431.6 psi	8	4043.8	44949	NO	YES	FAIL
	10	3723.5	40305	NO	YES	FAIL
	12	3188	36068	NO	YES	FAIL
	14	2980	35263	NO	YES	FAIL
	16	2653	33760	YES	YES	PASS
Middle Joint-B: (C11+B25+B26 +B32+B33) Initial stress: 4439.3 psi	10	3140.8	49389	NO	YES	FAIL
	12	2899.3	43006	NO	YES	FAIL
	14	2850	41467	NO	YES	FAIL
	16	2566	38878	YES	YES	PASS

5. Results

5.1 Analyzed Data

5.1.1 Stress vs Strain

Table 6. Stress Vs Strain Values of Interior & Corner Joint With & Without Retrofitting.

SI. No.	**Before Retrofitting**				**After Retrofitting**			
	Interior Joint		**Corner Joint**		**Interior Joint**		**Corner Joint**	
	Stress	**Strain**	**Stress**	**Strain**	**Stress**	**Strain**	**Stress**	**Strain**
1	4283.2	0.000432	4164.7	0.000599	5853.2	0.000202	2049.1	0.000213
2	12849	0.001296	12494	0.001798	17560	0.000605	6147.2	0.000638

3	21416	0.002160	20866	0.003000	22873	0.000789	10245	0.001064
4	29982	0.003023	29534	0.004246	24100	0.000831	14341	0.001490
5	38548	0.003887	38495	0.005531	25328	0.000968	18425	0.001914

5.1.2 Load vs Deformation

Table 7. Load Vs Deformation Values of Interior & Corner Joint With & Without Retrofitting.

Sl. No.	Before Retrofitting				After Retrofitting			
	Interior Joint		Corner Joint		Interior Joint		Corner Joint	
	Deformation	Load	Deformation	Load	Deformation	Load	Deformation	Load
1	0.087873	47720	0.160800	35436	0.039978	47720	0.034405	35436
2	0.263620	143160	0.482400	106310	0.119930	143160	0.103220	106310
3	0.439370	238600	0.804030	177180	0.199890	238600	0.172030	177180
4	0.615110	334040	1.129200	248060	0.279860	334040	0.240820	248060
5	0.790860	429480	1.465100	318920	0.359820	429480	0.309620	318930

5.1.2 Stiffness

5.1.3.1 Interior Joint

Table 8. stiffness value for before and after retrofitting of interior joint

LOAD (KIP)	Stiffness before retrofitting (Kip/inch)	Stiffness after retrofitting (Kip/inch)
47.720	543.0564565	1193.656511
143.160	543.0543965	1193.696323
238.600	543.0502765	1193.656511
334.040	543.0573393	1193.596798
429.480	543.0543965	1193.596798
524.920	543.0131998	1193.569658
620.360	540.0539741	1193.527907
715.800	526.7108168	1193.437594
811.240	511.629667	1192.228558
906.680	499.2181478	1188.044603

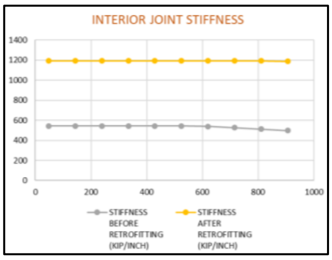

Figure 11. Stiffness graph for before and after retrofitting of interior joint

5.1.3.2 Corner Joint

Table 9. Stiffness value for before and after retrofitting of corner joint

LOAD (KIP)	Stiffness before retrofitting (kip/inch)	Stiffness after retrofitting (kip/inch)
35.436	220.3731343	1029.966575
106.310	220.3772803	1029.936059
177.180	220.3649118	1029.936639
248.060	219.6776479	1030.063948
318.920	217.6779742	1030.036819
389.800	215.359116	1029.85469
460.670	213.0660006	1028.533792
531.550	210.8906963	1024.951312
602.420	208.9704454	1016.845588
673.290	207.3001016	999.688196

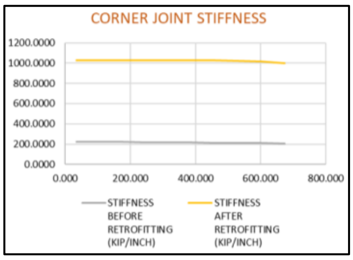

Figure 13. Stiffness graph for before and after retrofitting of corner joint

5.2 Comparison

5.2.1 Stress vs Strain

5.2.1.1 For Interior Joint

Table 10. Stress vs strain values of interior joint with and without retrofitting

Sl.	Before Retrofit		After Retrofit	
No.	stress	strain	stress	strain
1	4283.2	0.000432	5853.2	0.000202
2	12849	0.001296	17560	0.000605
3	21416	0.002160	22873	0.000789
4	29982	0.003023	24100	0.000831
5	38548	0.003887	25328	0.000968
6	44272	0.004798	28315	0.001184
7	52364	0.005751	33463	0.001340
8	40208	0.006719	36209	0.001539
9	41491	0.007696	38238	0.001695
10	40373	0.008675	38391	0.001902

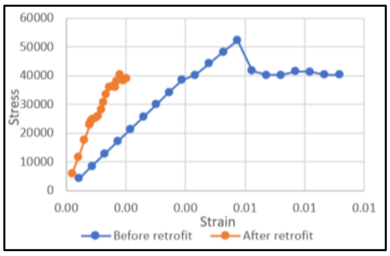

Figure 14. Stress vs strain values of interior joint with and without retrofitting.

5.2.1.2 For Corner Joint

Table 11. Stress vs strain values of corner joint with and without retrofitting

Sl.	Before Retrofit		After Retrofit	
No.	stress	strain	stress	strain
1	4164.70	0.000599	2049.10	0.000213
2	12494.00	0.001798	6147.20	0.000638
3	20866.00	0.003000	10245.00	0.001064
4	29534.00	0.004246	14341.00	0.001490
5	38495.00	0.005531	18425.00	0.001914
6	40015.00	0.006825	22501.00	0.002349
7	40085.00	0.008136	26629.00	0.002801
8	40193.00	0.009462	30859.00	0.003260
9	40223.00	0.010796	31052.00	0.003707
10	40295.00	0.012135	31843.00	0.004124

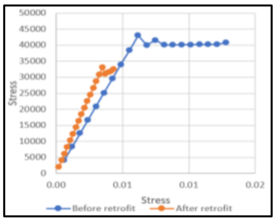

Figure 15. Stress vs strain values of corner joint with and without retrofitting

The stress-to-strain ratio improved following retrofitting, indicating that the new materials were more robust and less prone to deformation. It means the renovated building can withstand more pressure without becoming distorted beyond repair.

5.2.2 Load Vs Deflection

5.2.2.1 For Interior Joint

Table 12. Load vs Deflection values of interior joint with and without retrofitting

Sl.	Before Retrofit		After Retrofit	
No.	Deformation	Load	Deformation	Load
1	0.087873	47720	0.039978	47720
2	0.263620	143160	0.119930	143160
3	0.439370	238600	0.199890	238600
4	0.615110	334040	0.279860	334040
5	0.790860	429480	0.359820	429480
6	0.966680	524920	0.439790	524920
7	1.148700	620360	0.519770	620360
8	1.359000	715800	0.599780	715800
9	1.585600	811240	0.680440	811240
10	1.816200	906680	0.763170	906680

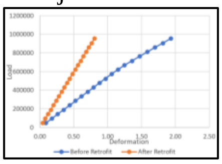

Figure 16. Load vs Deflection values of interior joint with and without retrofitting.

5.2.2.2 For Corner Joint

The load and deformation values in the failure beam-column Interior joint in building with and without jacketing is tabulated below:

Table 13. Load vs Deflection values of interior joint with and without retrofitting

Sl.	Before Retrofit		After Retrofit	
No.	Deformation	Load	Deformation	Load
1	0.160800	35436.00	0.034405	35436.00
2	0.482400	106310.00	0.103220	106310.00
3	0.804030	177180.00	0.172030	177180.00
4	1.129200	248060.00	0.240820	248060.00
5	1.465100	318920.00	0.309620	318930.00
6	1.465100	389800.00	0.378500	389800.00
7	1.465100	460670.00	0.447890	460670.00
8	1.465100	531550.00	0.518610	531540.00
9	1.465100	602420.00	0.592440	602420.00
10	1.465100	673290.00	0.673500	673290.00

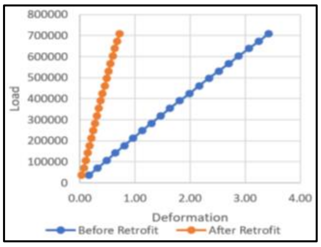

Figure 17. Load vs Deflection values of interior joint with and without retrofitting

The load deflection curve shows us the deflection it undergoes when applied with the same external load. The lower the deflection means, lower the chances of deformation and breaking down, thus increasing chance for more stability and safety of a structure.

6. Conclusion

In this paper, effect of steel plate jacketing of beam-column joint in reinforced concrete beam-column connections has been investigated. Initially an existing industrial building's data was taken which was needed to increase the strength upto 4500 psi. The failure members were deducted by ETABS analysis and the feeblest one from the corner joint and the interior joint is taken to retrofit. If these two can withstand the massive pressure then with the same thickness on steel, other joint can also withstand. To achieve this goal, multiple models have been built and analyzed using Finite Element package ANSYS with different steel plate thicknesses and axial load ratios. The result tables are obtained and the following conclusions were achieved:

- Strengthening techniques have the potential to be utilized as a workable option for the purpose of increasing the compression capacity of concrete members.
- Because there were steel layers surrounding the joint, the cracking behavior of the specimen was amplified. The high tensile capacity of the material helped to limit the number of cracks that started.
- The stress-strain ratio is increased by 2.5 times in the interior joint and 3.45 times in the corner joints for the non-retrofitted with the retrofitted wall.
- The load-deformation was decreased by 1.82 times in interior joint and 2.1 times in corner joints.
- The Deflection of column decreases as the steel thickness increases.
- Although axial load diminishes load bearing capacity of joints, replacing them by steel plates increases load capacity and ductility, making them perform much better than columns with lower axial loads.
- According to analyses results, using steel plates increase ultimate load of beam-column joints.

References

Amulya, V., & Kumar, A. D. (2017). Behaviour of RCC Column Strengthened using. 5(Ix), 1390–1396.

Bsisu, K., Al-Deen Bsisu, K., & Hiari, B. O. (2015). Finite Element Analysis of Retrofitting Techniques for Reinforced Concrete Beam-Column Joint Deformability and Failure Analysis for Amman' Marls View project Finite Element Analysis of Retrofitting Techniques for Reinforced Concrete Beam-Column Joint. Journal of American Science, 11(8), 48–56. http://www.jofamericanscience.org48http//www.jofamericanscience.org.8

Gufran, K., Mohammed, A., & Jyoti, G. (2022). Utilizing E-TABS to Analyze and Design Residential Buildings Structure. 10(3), 13–16.

Journal, I., Technological, F., & Kumar, D. (2020). STUDY ON RETROFITTING OF OLD REINFORCE CONCRETE. 8(1), 45–50.

Kandil, K. S., Nemir, M. T., Ellobody, E. A., & Shahin, R. I. (2014). Implicit and Explicit Analysis of the Response of Blast Loaded Reinforced Concrete Slabs. World Journal of Engineering and Technology, 02(03), 211–221. https://doi.org/10.4236/wjet.2014.23023

Koutas, L. N., Bousias, S. N., & Triantafillou, T. C. (2015). Textile-Reinforced Mortar (Trm) As Retrofitting Material of Masonry-Infilled Rc Frames. June, 437–444. https://doi.org/10.13140/RG.2.1.1541.1924

Los, U. M. D. E. C. D. E. (n.d.-a). No 主観的健康感を中心とした在宅高齢者における 健康関連指標に関する共分散構造分析Title. 36.

Raval, S. S., & Dave, U. V. (2013). Effectiveness of various methods of jacketing for RC beams. Procedia Engineering, 51, 230–239. https://doi.org/10.1016/j.proeng.2013.01.032

Science, O. F., & Civil, I. N. (n.d.). of Civil Engineering.