Journal of Advanced Engineering Trends
ISSN : 2682 - 2091

Vol.43, No.2. July 2024

http://jaet.journals.ekb.eg

A Numerical Study of Strengthening the External RC Frame Connection with Steel Plates and RC Blocks

Rana Mohamed Mohsen [1] Alaa Abouelezz [2] Rabiee Aly Sadeek [3]

Civil Engineering Department, Faculty of Engineering, Minia University(1)
Faculty of Engineering, Minia University[2]
Civil Dept., Faculty of Eng., Minia University[3]

ABSTRACT

A theoretical examination of methods for strengthening the outside joints of an RC frame. Considering the variety of extensive methods available for retrofitting structures, selecting the most suitable technique or substance is frequently challenging. This research was performed to assess the efficiency of external steel plates and RC blocks to strengthen the connection. ABAQUS program analyzes the effects of several factors on the joints, such as steel plate thickness, different positions of steel stiffeners and RC blocks, the concrete's compressive strength for blocks, as well as the volume of rebar in blocks. The findings were assessed and contrasted with previous studies outcomes. The analysis highlighted that an optimum steel plate thickness is 6 millimeters. Also, steel plate has been associated with greater failure loads. Furthermore, employing stiffeners in the tension zone increases resistance by 33%, while applying them in both the tension and compression zones increases strength by 48.7%. On the other hand, utilizing RC blocks enhances resistance by 74%. Furthermore, using blocks on both sides increases the failure load and reversal moment resistance. Besides, using a greater number of smaller-diameter bars for the same area of steel in an RC block increases strength by 58%.

Keywords
Strengthening; frame connection; external steel plates; RC block; ABAQUS program

---

Revised: 9 July , 2023, Accepted: 3 August , 2023

1. Introduction

RC structures established all over the world are starting to sustain damage even before their service lives are up. Because of a variety of factors, including earthquakes, corrosion, overloading, changes in the code, improper planning, faulty building, explosions, and fire. The connection is the most crucial part of any framed structure, but this joint's structural design is frequently ignored. Frame connections proved to be a weak point in the structure, necessitating further improvements. Steel elements involve plates, angles, and bars. It provides an advantage in that it requires a smaller section enlargement, less curing time, and less weight. However, it is prone to corrosion. RC block, on the other hand, is an extremely simple and inexpensive technique for restoring the capacity of RC structures.

Likewise, Yen et al. [1] investigated three different attachment schemes for plates welded to the connection zone in a two-dimensional configuration. It was bonded with epoxy. The sections demonstrated greater than 50% improvements in resilience and also significant enhancements in stiffness and energy dissipation. Similarly to this, Ahmed A. et al. [2] examined the impact of the thickness of a steel plate on RC beam retrofitting. The clear span of all RC beams that were tested is 2.1 m, and their cross-sectional measurements are 175 x 450 mm. Beams have a 160 x 400 mm rectangular web opening. Steel plates with thicknesses of 2, 3, and 4 mm and plate width of 100 mm were used to repair beams. They emphasized how raising the steel plate's thickness has an insignificant impact on improving capacity. Additionally, Zhang et al. [3] focused on the utilization of steel enveloped plates for strengthening RC frame connections. It consisted of a 250 x 400 mm beam and a 400 x 400 mm column. Applying steel plates (Q235) of 8 and 5 millimeters in thickness, samples have been modeled via FEM software. They observed that the damaged, un-strengthened specimen had a yield load of 117 kN, whereas a strengthened specimen had a load at a yield strength of 169 and 142 kN for the 8- and 5- mm thick plates, respectively. Their findings highlighted how the thickness of steel plates affects loads and stiffness. Also, Kadhima et al. [4] investigated experimentally the molding of three flat slabs strengthened with various numbers and sizes of steel stiffeners, plus altered steel plate specimen sizes (SS1 (100x100mm), SS2 (200x200mm), and SS3 (300x300mm). They noticed that the strengthened slabs' load capacities had increased by, respectively, 39.84, 57, and 99.2%. On the other hand, Yamini et al. [5] found that by adding new concrete to the original connection, its measurements were increased. In addition, rebars were utilized to improve strength and ductility. It may involve vertical, horizontal, as well as diagonal bars.

A significant challenge is choosing appropriate methods for strengthening and maintenance. This study aimed to carry out a numerical analysis of the efficiency of strengthened substances in increasing the resistance and tensile strength of the connection. Steel plates, stiffeners, and RC blocks were used to strengthen the connection.

2. Simulation Applications

ABAQUS program [6] is a FE software that enables users to examine the structural responses subject to any kind of loads. It provides an innovative element and substance library to model two- and three-dimensional elements of multiple shapes and contacts, allowing it intended for use in the analysis of static and/or dynamic issues with the structure. It is a reliable modeling program that uses the technique of finite element analysis to solve problems ranging from straightforward linear analyses to extremely complex nonlinear. ABAQUS integrates and assesses the substance reaction at every point of integration for each element [6].

3. Methodology

RC frame connections are numerically simulated, with a focus on failure and deformation behavior. To assess different methods of strengthening resistance and ductility. ABAQUS [6] is used to analyze three-dimensional joints exposed to axial and monotonic loads on the column and beam, respectively. The control model's failure analyses and load-deflection curves are contrasted with outcomes provided by Hamid et al. [7].

Listed below are several techniques for strengthening:

1. Steel plate.
2. Steel plates and stiffeners.
3. RC block.

4. Numerical Simulation

3D continuum/solid stress displacement is used to construct models of connections. 8-node hexahedra (bricks) and truss elements are the elements that are taken into consideration for modeling the concrete and the reinforcement, respectively. For modeling steel stiffeners as well as plates, a shell is employed. Whereas the embedded strategy mimics the bond between concrete and reinforcement, tie constraints have been employed to create bonds within the connection and the steel plates or RC blocks. The tip of the beam has restraints in place. The top and bottom of the column have roller and hinged supports, respectively. Figure 1 shows the border condition.

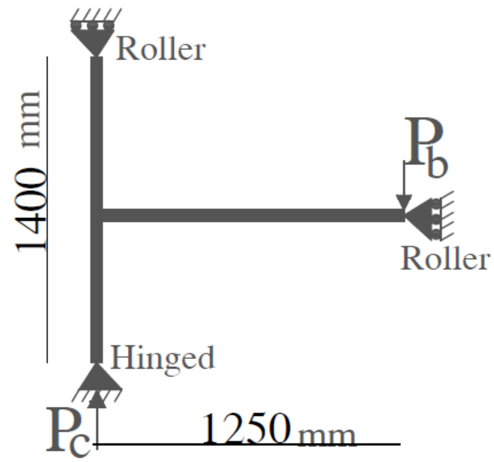


Fig. 1. Structural system of RC frame connections

Notation

C.M.: Control Model	Mrft: **M**ain **r**ein**f**orcemen**t**
FEA: Finite Element Analysis	FE: Finite Element
Es: **M**odulus **o**f **E**lasticity	F_{cu28}: concrete's compressive strength
$P_{C:}$ loads on the column	$P_{b:}$ forces acting on the beam
S.P.: **S**teel **P**late	CDP: Concrete damage plasticity
εc: Plastic strain of concrete	εs: the strain of Mrft

4.1. Mesh Sensitivity Analysis

A reasonable mesh and a convergence study are required in the initial stages of the FE model development to arrive at a trustworthy solution. An essential step in FE modeling is choosing the mesh density. Ahmed [8] calibrated the effect of mesh size by running several analyses with three different mesh sizes. For modeling RC beams, Ahmed [8] used mesh dimensions of 25, 50, and 75 mm. The initial stiffness of the three FEM beams is nearly identical, but they exhibit very different post-cracking behaviors. Additionally, when compared to test behavior, a beam with a mesh dimension of 25 mm provides the most precise reaction. According to Jasim [9] and Gebran et al. [10], the element mesh dimension was set to 25 mm for every model.

4.2. Bonding Method

To accurately determine the ultimate load carrying capacity, several debonding criteria are included in the cross-section analysis along with the material failures listed in compression (concrete) and tension (steel). Applying the ABAQUS [6] cohesive approach, surface-based cohesive behavior is used to simulate bonding stress versus slip behavior of steel plate as well as concrete. According to Mahini et al. [11], the master surface had a coarse surface, and the slave surface had a fine surface. Lastly, the tie constraint is used to simulate the bond between the joint and the strengthened substances, and the embedded constraint is employed to simulate the bond between concrete and rebars.

4.3. Constitutive of Model Material

4.3.1 Concrete

CDP is employed for the modeling of concrete materials. Because of the overall model's capability for analyzing concrete components subject to monotonic and cyclic loads. Based on Danial et al. [12], an isotropic damage model could be used to identify material degradation modes such as tensile cracking and compressive crushing. Some of the factors dealt with in the concrete's plasticity include the K_c parameter, dilatation angle, eccentricity, yielding concrete ratio, and eccentricity. The visible crushing takes place when compressive plastic strains develop greater than 0.3%, according to the ACI 318 Building Code [13], AASHTO [14], and ECP 203-2018 [15].

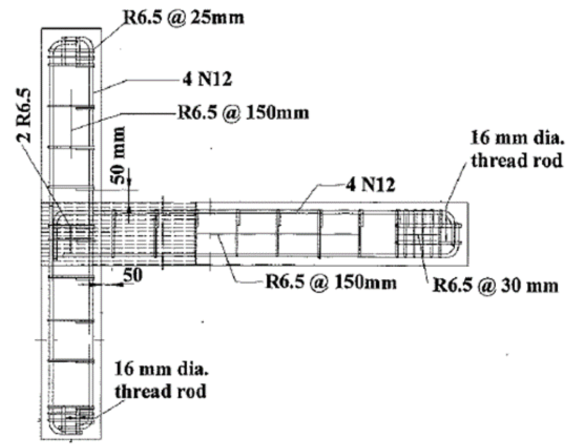
4.3.2 Steel (reinforcement and plates)

Steel reinforcement is a strain-hardening elastic-plastic substance. The material exhibits elastic linear behavior up until the yielding point, complying with a modulus of elasticity. When the yielding point has been reached, a strain- hardening effect occurs. Moreover, the first reinforcement yield corresponds to a strain of 0.002 [13–15–16].

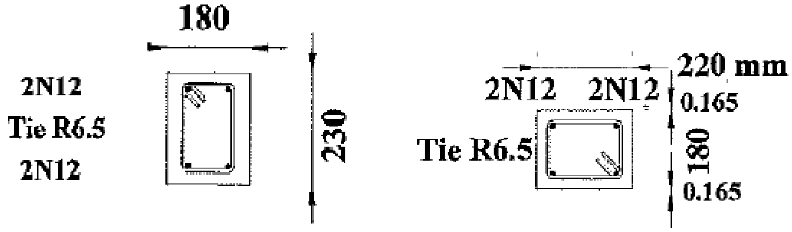
5. Models Analyzing

5.1. Control Model (C.M.)

Frame connection is identical to a model proposed by Hamid et al. [7], in which beams and columns have sectional dimensions of 180 x 230 mm and 180 x 220 mm, respectively. Figure 2 indicates vertical reinforcement of the column is 4 Ø 12 mm, despite the beam's lower and upper reinforcements being 2 Ø 12 mm for each one of them. For both the column and the beam, stirrups with a 150 mm distance are created using 6.5 mm-diameter bars. Also, set the dimension of the mesh to 25 mm. Mrft and stirrups possess yield strengths of 500 and 382 MPa, respectively. F_{cu} is 40 N/mm^2 and has an Es of 200 GPa and a Poisson's ratio of 0.3. Plus, the column's axial load is 305 kN, while the beam's monotonic load is 45 kN.



a) Reinforcements of C.M.



b) Beam's section c) Column's section

Fig. 2. The C.M. of the connection

5.2. Connections that have been strengthened

Steel plates and stiffeners are used to strengthen the C.M. Steel components possess the benefit of requiring less section enlargement, which results in weighing less. The disadvantages of steel elements include corrosion and the need for scaffolding. Stiffeners are used to resist lateral loading on the plate and reduce plate buckling. Furthermore, the installation of RC blocks for retrofitting the connection is influenced by material connectivity, new concrete and reinforcement characteristics, ease of implementation, and cost-effectiveness.

5.2.1 External steel plates—Strengthened Connections

In this research, the impact of the thickness of the steel plate on the connections was analyzed. Simulated models for As.p, Bs.p, Cs.p, Ds.p, Es.p, Fs.p, and Gs.p had a thickness of 1, 3, 5, 6, 8, 10, and 12 mm, respectively. The length as well as the shape of the plates are depicted in Fig. 3. Table 1 depicts the characteristics of steel plates (Q235).

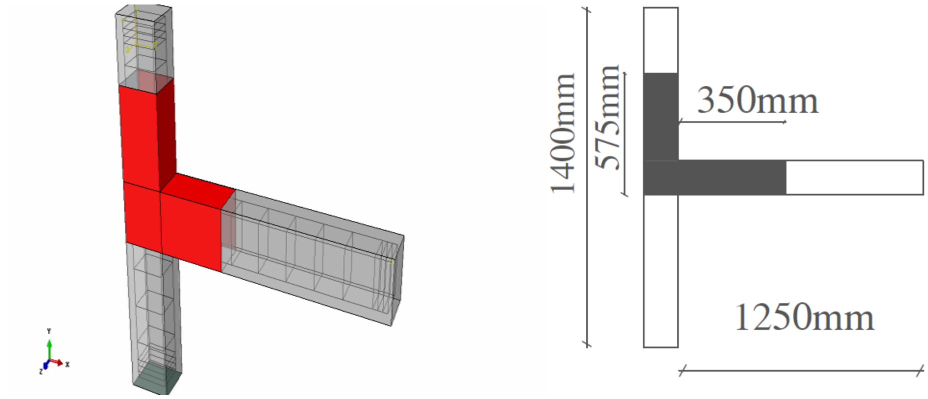


Fig. 3. Steel plate dimensions and shapes

Table 1: The mechanical characteristics of steel plates and stiffeners (Q235), Redstone Manufacturing [17]

Es	200000 N/mm^2
Yielding strength	250 N/mm^2
Ultimate strength	400 N/mm^2
Poisson's ratio	0.3
Density	7.85 g/cm^3

5.2.2 Steel Plates and Stiffeners - Strengthened Connections

Investigating the influence of stiffeners on the connection. Figure 4 shows that the steel plate lengths on the beam and column were 350 as well as 345 mm, respectively, and the triangle stiffener dimensions are 345 x 350 mm.

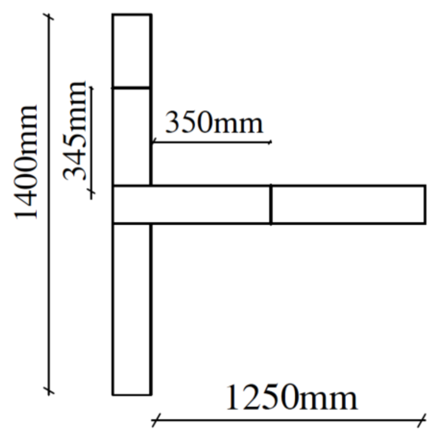
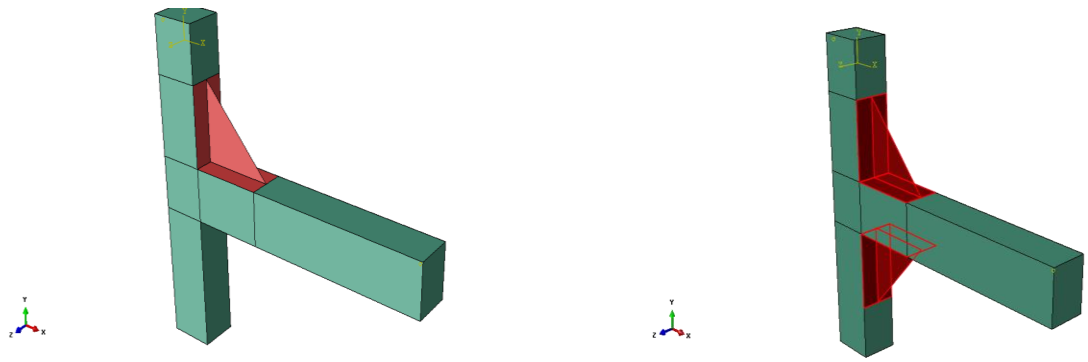


Fig. 4. The lengths of the steel plates

Simulations of connections S1 and S2 are illustrated in Figure 5. Stiffeners as well as 6 mm -thick steel plates (Q235) were used for each. Steel plates and one middle stiffener in the tension zone for S1 and both tension and compression zones for S2 are being used to strengthen the C.M.

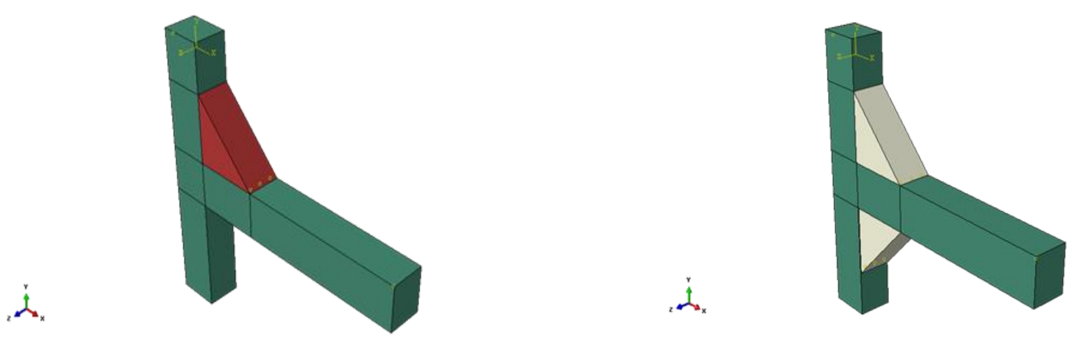


a) Strengthened Model-S1 b) Strengthened Model-S2

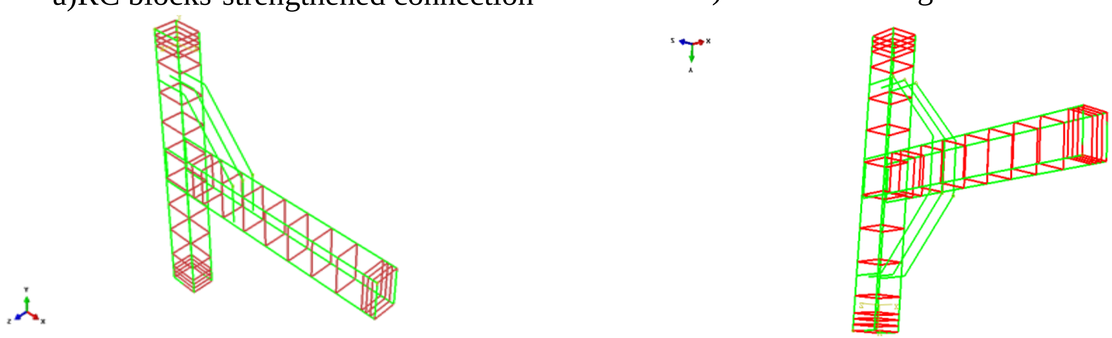
Fig. 5. The shape of the steel plates and stiffeners

5.2.3 RC Block -Strengthened Connections

RC blocks with the dimensions 350 x 345 x 180 mm are used to strengthen the C.M. Its parameters are the compressive strength (f_{cu}) and the volume of steel reinforcement. It has rebars of 3Ø12, a yield strength of 500 MPa. To analyze the impact of concrete's compressive strength using f_{cu} values of 30, 40, 50, and 60 N/mm^2 for strengthened connections Acu, Bcu, Ccu, and Dcu, respectively. On the other hand, strengthened connections are A_V, B_V, and Cv, which have reinforcement of 2Ø16, 3Ø12, and 4Ø10 for a constant steel area of 3.4 mm^2, and f_{cu} is 40 N/mm^2. Furthermore, Fig. 6 shows the use of an RC block (A_{cu}) in the tension zone and the same block in the tension and compression zones ($\bar{A}_{cu}$).



a)RC blocks-strengthened connection b)RC block-strengthened connection (Ācu)



c)Reinforcement of RC Blocks d)Reinforcement of (Ācu)

Fig. 6. The shape of the RC block and its reinforcement

6. Results and Discussions

Analysis of C.M. and strengthened connections produced the following results:

6.1. Verification of FEM Results

Comparisons with the outcomes produced by Hamid et al. [7] serve to validate the C.M. results. Figure 7 shows that the deflection of the beam for the control model is 30.8 mm at the failure load of 25.03 kN. The load-deflection curve of the C.M. at the beam tip agrees with the model result provided by Hamid et al. [7].

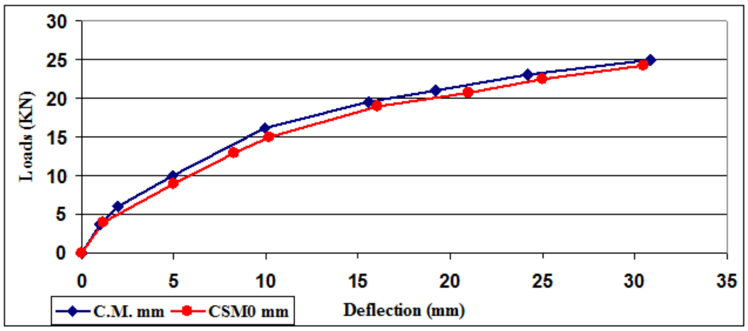


Fig. 7. C.M. and CSM0 load-displacement curves [7]

6.2. Analysis of Steel Plate-Strengthened Connection Results

Based on the findings in Table 2, steel plates possess various effects on deformations, beam deflection, and the distribution of stress in the connection:

- The load at ε_c and the load at ε_s = 0.002 of Mrft at the connection are not significantly increased when a steel plate thicker than 6 mm is used.

Table 2: Results of Using Variable-Thickness External Steel Plates

Models	(C.M)	$A_{s.p}$	$B_{s.p}$	$C_{s.p}$	$D_{s.p}$	$E_{s.p}$	$F_{s.p}$	$G_{s.p}$
Failure load (kN)	25.03	31.36	34.30	36.26	38.22	39.19	42.13	43.08
Load at ε_c= 0.003, kN	13.02	17.86	18.12	19.15	20.20	21.003	21.28	21.61
Load at ε_s = 0.002 (kN)	20.99	26.17	28.62	30.25	32.07	32.83	33.22	33.60
Load at the yield strength of Mrft (kN)	23.10	29.37	32.12	35.15	37.05	37.58	39.60	40.21
Maximum beam deflection (mm)	30.86	29.19	28.98	27.85	27.03	26.83	26.61	26.33

- Figures 8 and 9 highlight that the failure load and load at the yield strength of the Mrft are increased by 25.3% and 27%, respectively, by strengthening the connection with a 1 mm-thick steel plate. The 6-mm-thick plate improves the failure load to 52.68% and the load at yield strength to 60.38%. As a result, using steel plates affects the load at yield strength more than the failure load, which is similar to the result of Weng et al. [3].

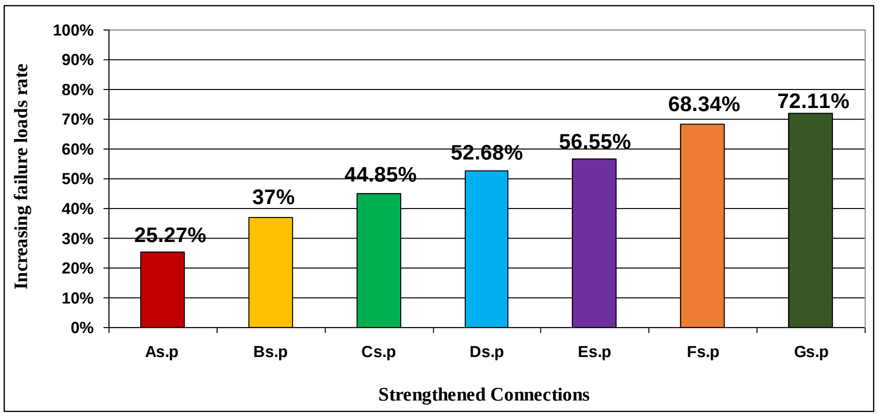


Fig. 8. Failure load increase rate for steel plate-strengthened connections

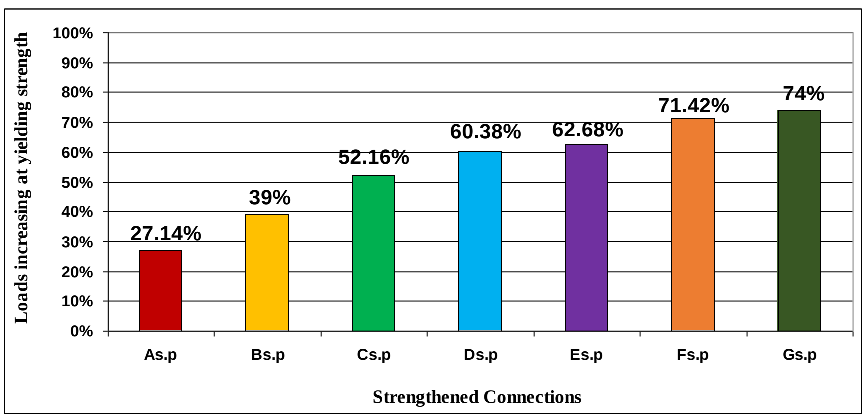


Fig. 9. Increasing rate loads at the yield strength of Mrft for steel plate-strengthened connections

- Maximum deflections at failure load for steel plates - strengthened connections are 29.19, 28.98, 27.85, 27.03, 26.83, 26.61, and 26.33 mm, respectively, as shown in Fig. 10. At the same failure load of the C.M., the deflections of the strengthened connections are 18.3, 16.2, 15.9, 15, 12.8, 10.4, and 10 mm, respectively. Raising the thickness of the steel plates decreased the deflection of the connection; this conclusion is in agreement with Swetha et al. [18], Rakgate et al. [19], and Chinchu et al. [20]. They observed that applying steel plate jacketing is the most effective choice if reducing maximal deflection is the objective.

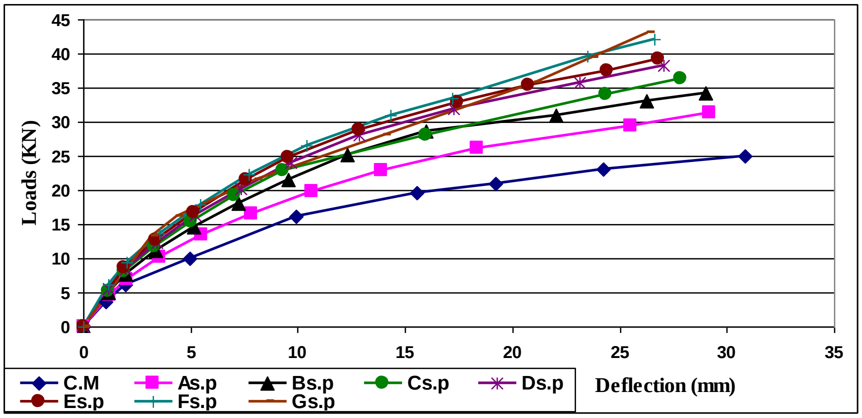


Fig. 10. Load-deflection curves for C.M. and steel plate-strengthened connections

6.3. Results of Externally Stiffened Steel Plates - Strengthened Connections Analysis

According to the results in Table 3, the steel plates and stiffeners have the following effects on the connection:

- Applying one middle stiffener with steel plates (S_1) enhances the concrete's load at plastic strain by 61.32%; while using it in both tension and compression zones (S_2) increases the load by 80.26%. As a result, installing stiffeners at the top and bottom of the connection-increasing the torque arm is more effective for strengthening the connection.
- When compared with the deflection of C.M., installing a middle stiffener with steel plates (S_1) reduces deflection by 18.7%. The deflection is reduced by 32.6% while the middle stiffener is used with steel plates in the tension and compression zones (S_2). As a result, employing stiffeners at the top and bottom of the connection reduces its ductility.

Table 3: Results of Using Externally Stiffened Steel Plates

Models	(C.M)	S_1	S_2
Failure load, kN	25.03	33.32	37.24
Load at ε_c= 0.003, kN	13.02	21.005	23.47
Load at ε_s = 0.002, kN	20.99	27.80	31.07
Load at the yield strength of Mrft, kN	23.10	31.20	34.87
Maximum beam deflection (mm)	30.86	25.09	20.80

- Figure 11 indicates that installing one stiffener with plates enhanced the connection's failure load by 33%, and employing it in both tension and compression regions increased the failure load by 48.76% compared to the C.M.

Figure 12 demonstrates that adding a single stiffener to a set of plates increased the load at the yield strength of Mrft by 35%, while adding the stiffener to both the tension and compression zones increased the load by 51% over the C.M. As a consequence, employing steel plates and stiffeners affects the load at yield strength and failure load; this finding can be compared to that of Weng et al. [3].

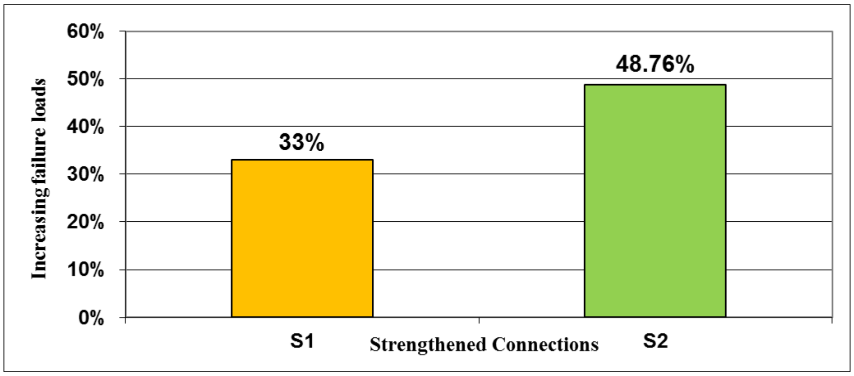


Fig. 11. Failure load increase rate for steel plate/stiffener-strengthened connections

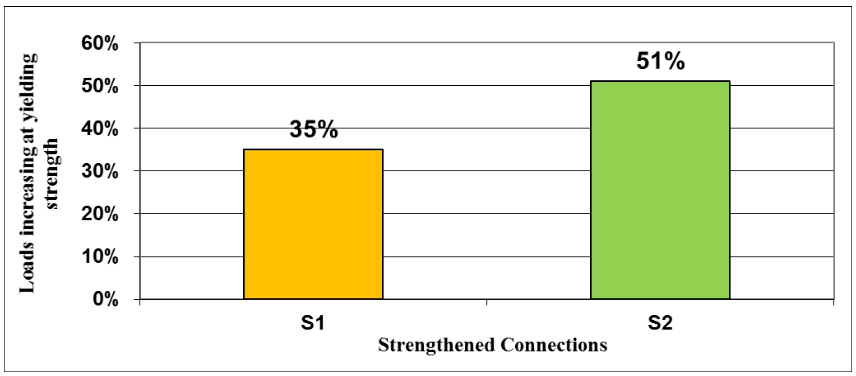


Fig. 12. Increasing rate loads at the yield strength of Mrft for steel plate/stiffener-strengthened connections

- Deflections at failure load for steel plate/stiffener-strengthened connections S_1 and S_2 are 25.09 and 20.8 mm, respectively, as illustrated in Fig. 13. As a consequence, using stiffeners in both the tension and compression zones improves the failure load and strength while decreasing the deflection of the connection. These results are consistent with those of Mahmoud et al. [21], who concluded that stiffened steel plates are a technique that reduces ductility by 89%, and thus a trade-off among resistance and ductility is possible if greater levels of ductility need to be obtained.

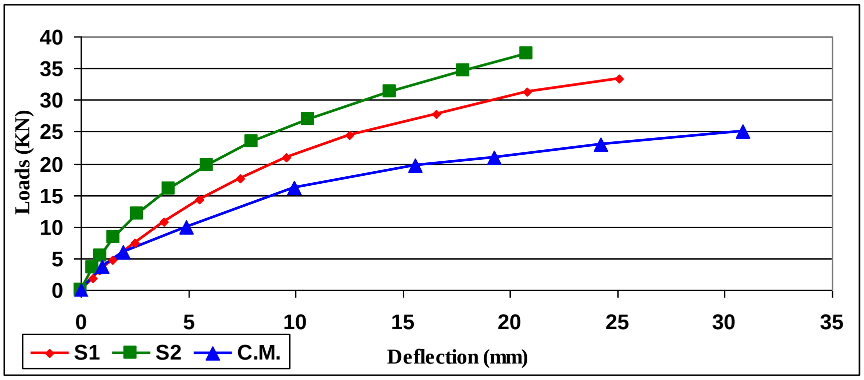


Fig. 13. Load-deflection curves for C.M. and steel plate/stiffeners-strengthened connections

Mahmoud et al. [21] studied the retrofitting method, which employs stiffened steel plate jacketing in the RC joint. The strength has been greatly improved. The retrofitting technique reduced the ductility of the joint. It should be noted that the retrofitting scheme resulted in an 89% decrease in the ductility ratio. However, strength capacity increased by 34.8%. Therefore, the results of stiffened steel-plate-strengthened connections agree with those presented by Mahmoud et al. [21].

According to the analysis of the results in Table 4, the compressive strength of concrete has the following effects on the connection:

- Employing RC blocks with high compressive strengths of concrete increases the plastic load of the concrete of the strengthened connections (A_{cu}, B_{cu}, C_{cu}, and D_{cu}) by 27.26, 40, 63, and 74%, respectively. Furthermore, it enhances load at ε_s = 0.002 by 24.67, 36.87, 40.2%, and 48.7%, respectively.

6.4. Results of RC Blocks-Strengthened Connections Analysis

Table 4: Results of Using RC Blocks (Variable: Compressive Strength of Concrete)

Models	(C.M)	A_{cu}	B_{cu}	C_{cu}	D_{cu}
Failure load(kN)	25.03	31.44	34.30	40.18	43.55
Load at ε_c= 0.003, kN	13.02	16.57	18.23	21.23	22.66
Load at ε_s = 0.002 (kN)	20.99	26.17	28.73	29.43	31.22
Load at the yield strength of Mrft (kN)	23.10	29.37	32.23	37.63	42.47
Max. beam deflection (mm)	30.86	32.53	35.63	37.11	40.15

- Figures 14 and 15 demonstrate that increasing the compressive strength of concrete improves the failure load and load at the yield strength of Mrft of strengthened connections; when using f_{cu} of 60 N/mm^2, the loads increased by 74% and 83.85%, respectively.

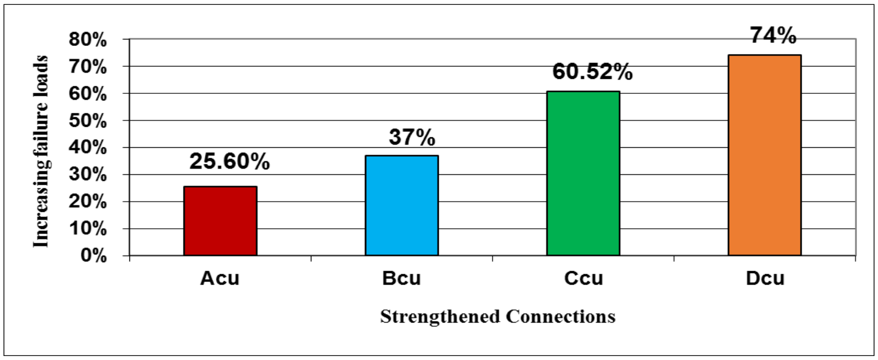


Fig. 14. Failure load increase rate for RC block (variable: f_{cu})-strengthened connections

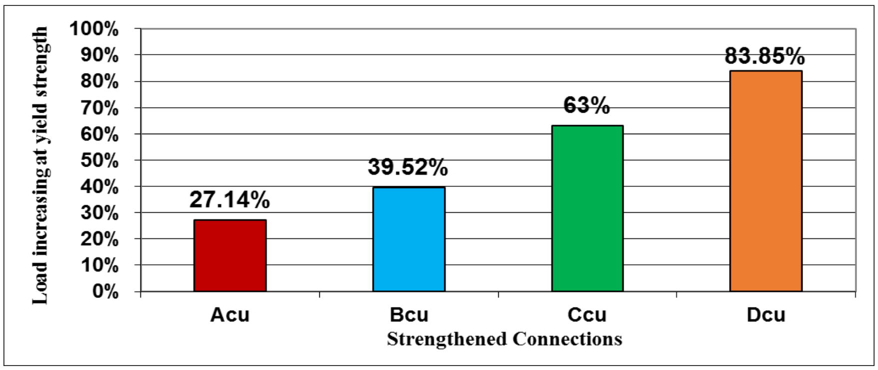


Fig. 15. Increasing rate loads at the yield strength of Mrft for RC blocks (variable: f_{cu}) - strengthened connections

- Figure 16 illustrates that maximum deflections at failure load for RC block-strengthened connections A_{cu}, B_{cu}, C_{cu}, and D_{cu} are 32.53, 35.63, 37.11, and 40.15 mm, respectively, even though at failure load for C.M. deflections are 23.5, 21.55, 18.68, and 10.14 mm, respectively. RC blocks with higher compressive strengths of concrete increase ductility by 30%. Consequently, RC blocks increase the ductility of connections.

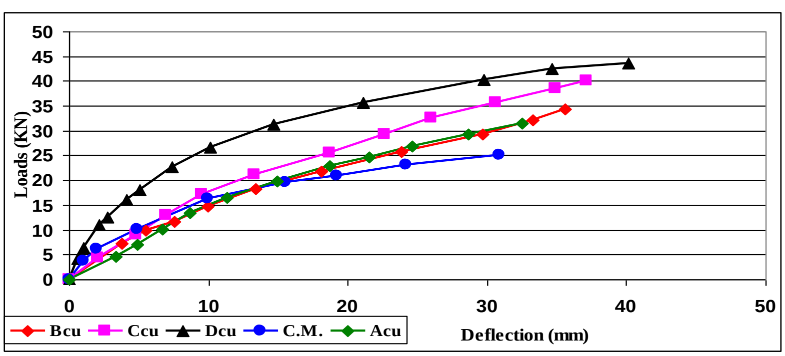


Fig. 16. Load-deflection curves for C.M. and RC blocks/ (variable: f_{cu}) -strengthened connections

- Table 5 demonstrates that employing RC blocks in both tension and compression regions improves the load at ε_c, failure load, and loads at the yield strength of Mrft by 47.7, 35.19, and 36.6%, respectively. Therefore, RC blocks are used in the tension and compression zones to increase strength and provide reversal moment resistance.

Table 5: Results of Using RC Block in Both Tension and Compression Zones

Models	**(C.M)**	**A_{cu}**	**$\bar{A}_{cu}$ Ten.+Comp.**
Failure load, kN	25.03	31.44	33.84
Load at ε_c= 0.003, kN	13.02	16.57	19.23
Load at ε_s = 0.002, kN	20.99	26.17	28.73
Load at the yield strength of Mrft (kN)	23.10	29.37	31.55
Max. beam deflection (mm)	30.86	32.53	19.52

- Implementing RC blocks in tension and compression zones reduced deflection at failure load by 36.7%, as shown in Fig. 17. This is due to a longer torque arm, which results in increased resistance and decreased deflection.

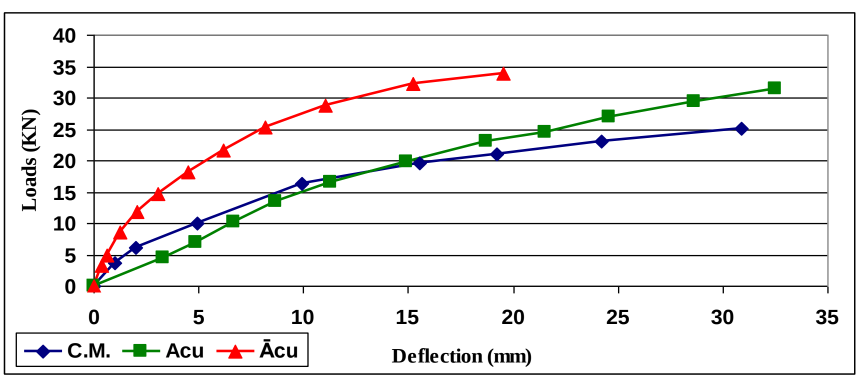


Fig. 17. Load-deflection curves for C.M. and RC blocks (A_{cu}- $\bar{A}_{cu}$) - strengthened connections

Depending on the results in Table 6, the volume of steel reinforcement in the RC block has the following effects on the connection:

- The steel reinforcement of the RC block influences increasing the load at the plastic strain of the concrete of the strengthened connections (A_V, B_V, and C_V) by 30, 40, and 44%, respectively. Additionally increasing the load at strain of Mrft (ε_s = 0.002) by 27, 36.87, and 45.3%, respectively.

Table 6: Results of Using RC Blocks (Variable: Volume of Steel Reinforcement)

Models	(C.M)	A_V	B_V	C_V
Failure load, kN	25.03	31.53	34.30	39.57
Load at ε_c= 0.003, kN	13.02	16.93	18.23	18.75
Load at ε_s = 0.002 kN	20.99	26.68	28.73	30.50
Load at the yield strength of Mrft, kN	23.10	29.93	32.23	34.75
Max. beam deflection (mm)	30.86	32.25	35.63	36.86

- Figures 18 and 19 show the steel reinforcement of the RC block's effect on increasing the failure load of the strengthened connections (A_V, B_V, and C_V) by 25.96, 37, and 58%, respectively. Moreover, raising the load at the yield strength of Mrft by 29.56, 39.52, and 50.43%, respectively. Consequently, the higher quantity of smaller-diameter bars, the greater the resistance of the connection due to the good bonding between steel and concrete.

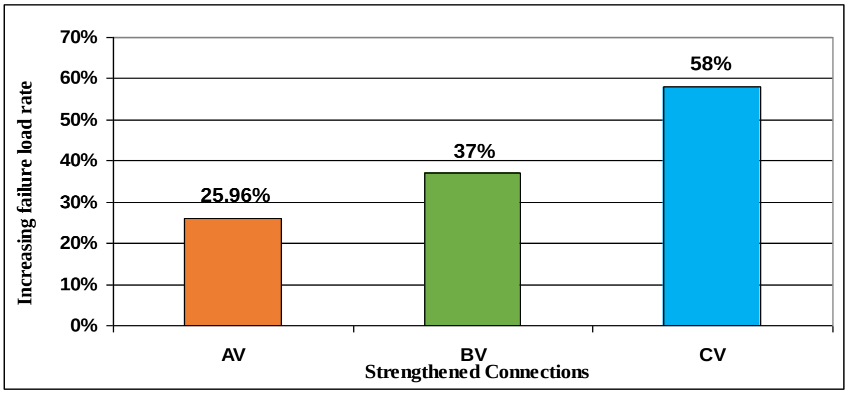


Fig. 18. Failure load increase rate for RC blocks/ (variable: volume of steel reinforcement) -strengthened connections

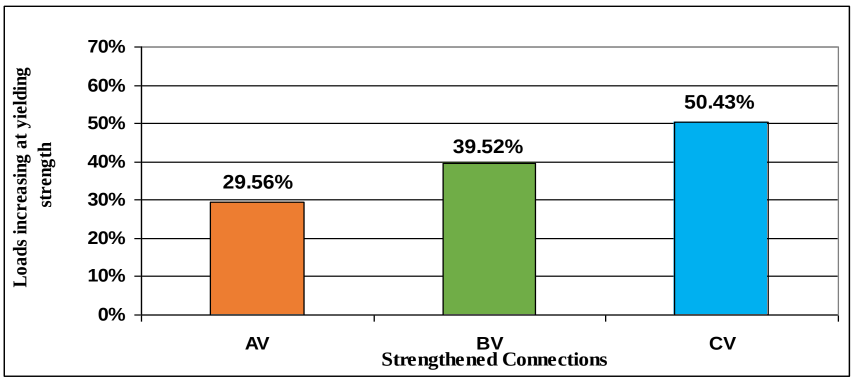


Fig. 19. Increasing rate loads at the yield strength of Mrft for RC blocks/ (variable: volume of steel reinforcement) -strengthened connections

- Figure 20 illustrates that maximum deflections at failure load for RC block-strengthened connections A_V, B_V, and C_V are 32.25 mm, 35.63 mm, and 36.86 mm, respectively, even though at failure load for C.M. deflections are 23.86 mm, 21.55 mm, and 10.33 mm, respectively. RC blocks with smaller-diameter bars increase ductility by 19.44%. Hence, increasing the number of smaller-diameter bars for RC blocks increases the ductility.

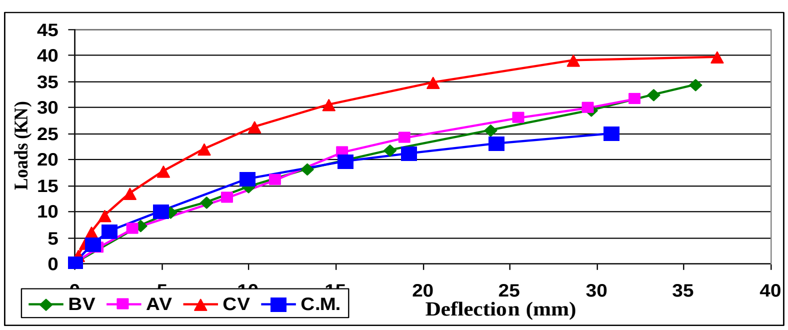
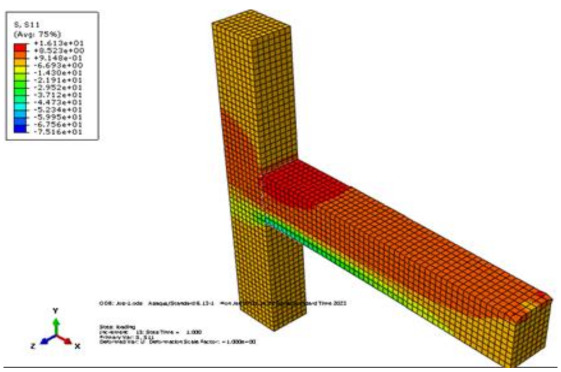


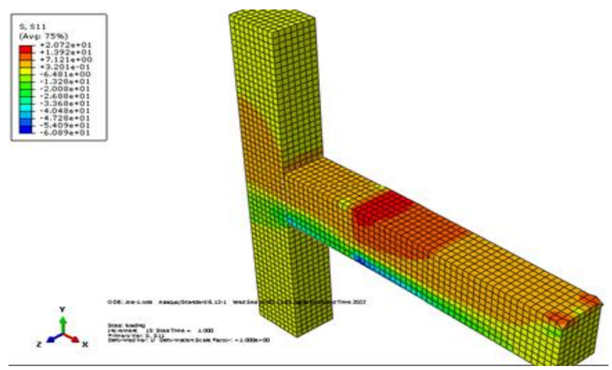
Fig. 20. Load-deflection curves for C.M. and RC blocks / (variable: volume of steel reinforcement) -strengthened connections

Janni et al. [5], Bindhu et al. [22], and Karayannis et al. [23] observed that the retrofitted beam and connections using RC jacketing showed a performance improvement. Hesham et al. [24] demonstrated that by using more of the smaller diameter of the bar than the larger one; will aid in creating RC beams that are stronger and more stable. As opposed to the beams with tensile reinforcement of 2Ø16 mm, which resulted in a yield load increase of 78%, the strengthened beams with tensile reinforcement of 2Ø10 mm noticed their yield loads increase by 139%. The findings of RC blocks enhancing the strength and ductility of connections are consistent with Janni et al. [5], Bindhu et al. [22], Karayannis et al. [23], and Hesham et al. [24].

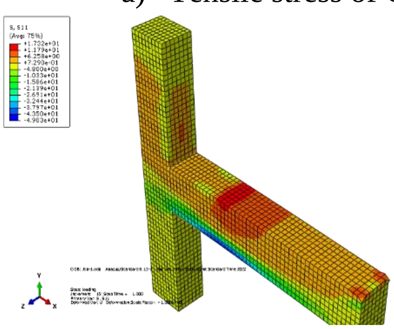
- Figure 21 shows how connections strengthened with RC blocks, steel plates and stiffeners, or steel plates with a thickness of 6 mm or more change the likelihood of stresses at the connection to the beam. Steel plates and RC blocks, then, have an impact on the behavior of connection failures.



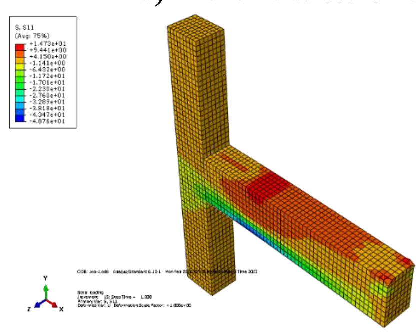
a) Tensile stress of C.M.



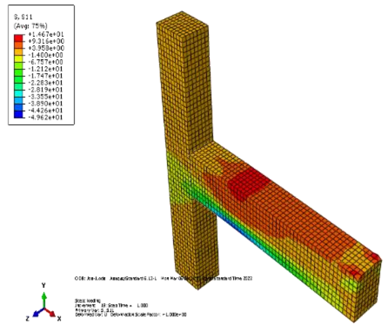
b) Tensile stress of $D_{s.p}$.



c) Tensile stess of S_1



d) Tensile stess of A_{cu}



e) Tensile stress of A_V

Fig.21. Tensile stress of concrete at failure for C.M. and strengthened connections

7. Conclusions

The data and analysis presented lead to the following conclusions for the range of the studied parameters:

- Utilization of a single middle stiffener in both the tension and compression zones increased the failure load, load at the plastic strain of concrete, and load at a yield strength of the Mrft of the connection by 48.8%, 80.26%, and 51%, respectively. Furthermore, it reduced ductility by 32.6%. These are due to the increased torque arm, which improves the efficiency of retrofitting the connection.
- A steel plate thickness of 6 mm is a more effective thickness in this case. It improves the failure load, the load at the plastic strain of the concrete, and the load at a yield strength of the Mrft of the connection by 52.6, 55, and 60%, respectively. It contributes to decreasing deflection at the same failure load of the control model by 51%.
- Steel plates and stiffened steel plates are more efficient methods for enhancing the yield load of reinforcement, the failure load, and the load at the plastic strain of concrete for the connection; besides, they also reduce deflection.
- Installation of stiffened steel plates applied to both tension and compression regions enhance failure load and deflection to levels comparable to an enveloped connection with steel plates with a thickness of 6 mm. Additionally, it is less expensive than steel plates.
- The resistance and ductility of the connection are both increased by 74% and 30%, respectively, by raising the compressive strength of the concrete in the RC block. Additionally, utilizing RC blocks in tension and compression zones increases

connection resistance and reversal moment resistance.

- Increasing the number of steel rebars for the same area of steel in RC blocks increases resistance by 58%. Furthermore, the smaller the bars and the greater the number, the greater the strength of the connection due to the good bonding between steel and concrete.

- Enveloped steel plate with a thickness of 6 mm or greater, steel plate/stiffeners, and RC block-strengthened connections transfer stresses from the connection to the beam. Therefore, a failure caused by the combination of maximum bending and shear stresses can be avoided.

- Steel plates or RC blocks are more efficient materials for strengthening the RC frame connection. Steel plates or RC blocks increase the resistance, though steel plates reduce ductility while RC blocks increase ductility. Therefore, a trade-off between strength and ductility is possible if higher levels of ductility are required.

7. 1. The following suggestions are provided based on the deduced conclusions:

- According to these models and analysis of the results; a steel plate in this case should be at least 6 mm thick for strengthening RC frame connections.

- It is more effective to apply steel plates and stiffeners in both tension and compression zones to obtain the highest resistance.

- Employing RC blocks in the tension and compression zones for resisting reversal moments.

- In the case of a cost comparison, RC blocks are less expensive than steel plates and provide strength and ductility for connection.

- It is preferable to use a greater number of smaller-diameter bars in an RC block.

8. References

[1] Yen, J. Y. R., and Chien H. K. "Steel Plates Rehabilitated RC Beam-Column Joints Subjected to Vertical Cyclic Loads"2009, Construction and Building Materials. 24 (3): 332-339. https://www.researchgate.net

[2] A. Ahmed A, S. Naganathan, K. Nasharuddin, M.M. Fayyadh, “Repair Effectiveness of CFRP and Steel Plates in RC Beams with Web Opening: Effect of Plate Thickness”2015, Article in International Journal of Civil Engineering. https://www.researchgate.net

[3] C. Zhang, D. G. Weng , J. D. Xia, X. L. Lu, and S. M. Zhang, “Experimental and Numerical Study on RC Frame Joint Strengthened with Enveloped Steel Plates” 2012, Tongji University, China, 15WCEE, LISBOA2012.

https://www.iitk.ac.in/nicee/wcee/article/WCEE2012_1653

[4] Safa S. Kadhima and Haider K. Ammash, "Steel Stiffeners for Enhancement of Slab-Column Connections"2019, Al-Qadisiyah Journal for Engineering Sciences 199–206, University of Al-Qadisiyah, College of Engineering, Iraq. https://www.iasj.net/iasj/download

[5] Janni Yamini Sudha, Ch. Chandra Mouli, P Markandeya Raju, "Retrofitting of Reinforced Concrete Structural Elements - Recent Technologies and Future Scope"2017, IJSRSET, Volume 3 | Issue 8, India. https://www.scribd.com/document

[6] ABAQUS Theory Manual, (v6.17), Training Manual.

[7] Hamid Reza Ronagh, and Saeed Mahini "Numerical Modelling of FRP Strengthened RC Beam-Column Joints" 2009, The University of Queensland, Australia, Article in Structural Engineering, Mechanics, Vol. 32, No. 5, 649-665. (DOI: 10.12989/sem.2009.32.5.649) https://www.researchgate.net

[8] Ahmed Abdel Hafiz Mahmoud, "Non-Linear Finite Element Model For Reinforced Concrete Deep Beams Failing In Shear" Journal of Al-Azhar University Engineering Sector, Vol.15, No. 56, July, 2020, 743-752. https://jaes.journals.ekb.eg/article_103353.html

[9] Jasim Ali Abdullah, "Finite Element Modelling of CFRP Concrete Specimens Subjected to Localized Axial Compression", Journal Kejuruteraan 33(4) 2021: 1123-1137. http://journalarticle.ukm.my/18966/1/35.pdf

[10] Gebran Karam and Mazen Riad Tabbara, "Confinement Effectiveness in Rectangular Concrete Columns with Fiber Reinforced Polymer Wraps", 2005, Journal of Composites for Construction. https://www.researchgate.net

[11] Mahini, S.S. and Ronagh, H.R, "Numerical modelling of FRP strengthened RC beam-column joints", Structure Engineering Mechanics. 2009, 32, 649–665. https://www.researchgate.net

[12] Daniel A. POHORYLES 1, José MELO 2 and Tiziana ROSSETTO, "Numerical Modelling of FRP-Strengthened RC Beam-Column Joints", Conference: Earthquake Risk and Engineering towards a Resilient World 9-10 July 2015, Cambridge UK. https://www.researchgate.net

[13] ACI Committee 318, Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318-14), American Concrete Institute, Farmington Hills, Michigan, 2014. http://aghababaie.usc.ac.ir/files/1506505203365.pdf

[14] AASHTO, "LRFD Bridge Design Specifications," 7th edition, American Association of State Highway and

Transportation Officials (AASHTO), Washington, D.C., 2014. https://www.academia.edu

[15] Egyptian Code of Practice: ECP (203-2018)-2018, “Design and Construction for Reinforced Concrete Structures,” Ministry of Building Construction, Research Centre for Housing, Building and Physical Planning, Cairo, Egypt. https://www.noor-book.com

[16] Materion Brush Performance Alloys, TECHNICAL TIDBITS, Issue No. 47 – November 2012, Updated from Original January 2005Publication. https://materion.com

[17] Redstone Manufacturing, https://redstonemanufacturing.com

[18] Swetha K S, Rona Maria James, “Strengthening of RC Beam with Web Bonded Steel Plates”2018, India, International Journal of Engineering and Techniques - Volume 4 Issue 3. http://www.ijetjournal.org

[19] S M Rakgate and M. Dundu, “Strength and Ductility of Simple Supported R/C Beams Retrofitted with Steel Plates of Different Width-to-Thickness Ratios”2006, University of Johannesburg, P O Box 524, Auckland Park, South Africa. https://core.ac.uk

[20] Chinchu Mohanan, Dr. K A Abubaker, and Ahsana Fathima, “A Comparative Study of Retrofitting of Beam Column Joint Using Concrete Jacketing, Steel Plate Jacketing, Glass Fiber wrapping”, 2016, International Research Journal of Engineering and Technology (IRJET), Volume: 03 Issue: 09. https://irjet.org/volume-3-issue-09-sep-2016

[21] Mahmoud R Maheri, Ashkan Torabi, "Strengthening Joints of RC Frames with Stiffened Steel Plates" 2019, 8th international conference on seismology& earthquake engineering, Iran. https://www.researchgate.net

[22] Bindhu, K. R., Mohana N., and Sivakumar S., "New Reinforcement Detailing for Concrete Jacketing of Nonductile Exterior Beam–Column Joints" 2016. Journal of Performance of Constructed Facilities. Vol.30 -issue1. https://ascelibrary.org

[23] Karayannis, C. G., Chalioris C. E., and Sirkelis G. M., "Local Retrofit of Exterior RC Beam-Column Joints Using Thin RC Jackets—an Experimental Study" 2007. Earthquake Engineering & Structural Dynamics. 37 (5): 727-746. https://www.researchgate.net

[24] Hesham EL-Emama, Alaaeldin El-Sisia, , Mohamed Bnenia, , Seleem S. E. Ahmada,Hossam El-Din M. Sallama, “Effects of Tensile Reinforcing Steel Ratio and Near Surface-Mounted Bar Development Length on The Structural Behavior of Strengthened RC Beams” 2020, Latin American Journal of Solids and Structures, https://www.researchgate.net, DOI: 10.1590/1679-78255836