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Effect of Column Load on Exterior Concrete Beam-Column Joint Strengthened with Ribbed Steel Angles

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Abstract - *This study aims to investigate the efficiency of steel ribbed-angles in strengthening external concrete beam-column joint. The bearing capacity and final deflection of this joint are studied for improving its behavior, moving the plastic hinge away from the face of column and choosing a suitable strengthening pattern. Numerically, using Abacus finite element software, by simulation of experimented concrete joint which is not designed according to seismic codes (without additional shear reinforcement in joint area), this research aims to compare between behaviors of joints supported with two ribbed angles at the external faces from top and bottom of the joint by several different shapes of angles. No study has been reported in open literature on geometrical dimensions of external steel angles and correlated effects on bearing capacity of concrete joint.*

The results of this study indicates that supporting technique with steel ribbed-angles increases bearing capacity about (11-120%) depending on angle length but decreases final deflection of the concrete joint. Before strengthening, bearing capacity of the joint increases with increasing of column-load, but the final deflection decreases. After strengthening, there is no effect of column-load because the failure occurs in the beam with existence of steel angles .Increasing the length of ribbed-angle plates increases bearing capacity and consequently strengthening effectiveness by about (20-120%) according to angle-length but the final deflection decreases by about (7-50%).

Increasing the rib-thickness (from 4mm to 30mm) has a very little effect but without a rib the strengthening effectiveness decreases and the final deflection increases. Also, a case study from Tartu's city is executed and presented in this paper supplied by photos of strengthening of joints in five-story concrete building. By 500mm-length, 250mm-width and 10mm-rib angle, bearing capacity will increase by about 283% but displacement of beam end at failure is decreased by about 31 %.

Keywords: reinforced concrete frame - beam column joint - steel angles - ribbed angles - strengthening.

1. Introduction

The RC (reinforced concrete) frame is an effective and commonly used system in RC buildings for resisting both vertical and horizontal load effects. Beam-column joints are important chains in transferring and resisting different buildings' loads [2]. The subject of studying a (column-beam) joint is one of the most important topics in the study of structural structures, especially when these structures are exposed to seismic loads, where the joint shows nonlinear behavior when subjected to large monotonic loads, and increases the degree of non-linearity in the behavior of the Moment-Resistant composite joint, as a result of multiple components within the joint in addition to the interdependence with each other in different ways.[5]

One of the central constituents of reinforced concrete moment-resisting frames are the beam-column joints which are responsible for the stability of the frames when it is under the influence of seismic excitation [4]. In many instances, post-earthquake inspections of structures with RC moment resisting frames damaged during earthquakes, have shown that the damage inflicted upon the frames was mostly concentrated in the beam-column joints [4]. Also, it has been noted that external beam-column joints are more exposed to damage compared to internal beam-column joints because of their geometrical discontinuity and subpart confinement [4]. Most of the buildings that have been built prior to the adoption of the Syrian Arab Code in 1995 and its Annex (2) in 2005 are structurally inadequate to withstand seismic loads. Many of these buildings are still in use with varying levels of seismic deficiencies. Development of knowledge and techniques related of seismic resistance and rise the efficiency of reinforced concrete frame buildings led to achieve more accurate codes.[12]

After war in Syria, there are a lot of buildings with damaged faces, which have exterior joints need to be fixed and retrofitted. Some of these joints are shown in Figure (1). Rehabilitation of buildings has very economical benefits. Also, there are a lot of seismically undersigned buildings and have inadequate shear reinforcement at joints areas.

Figure-1 Some of damaged exterior joints in the old city of Homs, Syria.

Strengthening effectiveness of concrete beam-column joint can be defined as the ratio between increasing in bearing capacity after strengthening and bearing capacity before strengthening. Final deflection is the deflection at peak ultimate load.

$$SE = \frac{BC_{af} - BC_{be}}{BC_{be}} \qquad (1)$$

Where: SE : Strengthening effectiveness (%)
BC_{af} : Bearing capacity of joint after strengthening (kN)
BC_{be} : Bearing capacity of joint before strengthening (kN)

The development of capacity design principles in New Zealand in the 1970's (Park and Paulay, 1976)[18] was an expression of the realization that the distribution of strength through a building was more important than the absolute value of the design base shear. It was recognized that a frame building would perform better under seismic attack if it could be assured that plastic hinges would occur in beams rather than in columns (weak beam/strong column mechanism), and if the shear strength of members exceeded the shear corresponding to flexural strength. This can be identified as the true start to performance based seismic design, where the overall performance of the building is controlled as a function of the design process. [19]

So, it is preferred to move the plastic hinge away from the face of column and choose a suitable strengthening pattern. This is conducted by adding external supports at joints zone to improve performance and structural efficiency.

Four performance levels are defined:
• **Fully Operational.** Facility continues in operation with negligible damage.
• **Operational**. Facility continues in operation with minor damage and minor disruption in nonessential services.
• **Life Safe**. Life safety is substantially protected, damage is moderated to extensive.
•**Near Collapse**. Life safety is at risk, damage is severe, structural collapse is prevented.

Displacement capacity, or ultimate displacement, has also had a number of definitions, including displacement at peak strength, displacement corresponding to 20% or 50% degradation from peak (or nominal) strength, and displacement at initial fracture of transverse reinforcement. [19]

Akhaveissy et al [4] investigated the performance of a defective RC beam-column connection with 9 different models and provided a method to improve the behavior of the connection. Tensile bolts were used to connect steel plates to each other

in the proposed models are of type A325 and according to the ASTM-A325 code. The bolts had been pre-stressed equal to either 40 or 70 percent of their yield stresses. Figure (2) illustrates model 9 and the placement of the straps and the bolts.

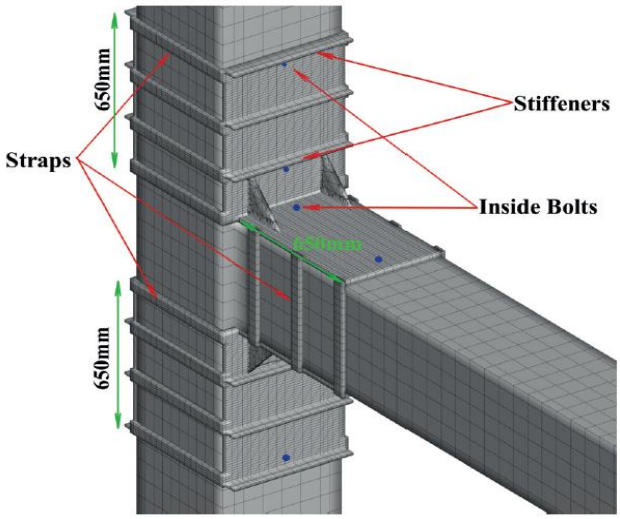


Figure-2 View of model 9 and the placement of the straps and the bolts [4]

The experimental model of joint is illustrated in Figure (4). By comparing the load-displacement diagram of model 9 to those of the other models, the load bearing capacity of the connection has considerably increased by about (67.2-71 %) for (40%, 70%) respectively percent of pre-stressing of inside bolts. Chart (1) shows comparison between the load-displacement diagrams of model 9 and the initial model.

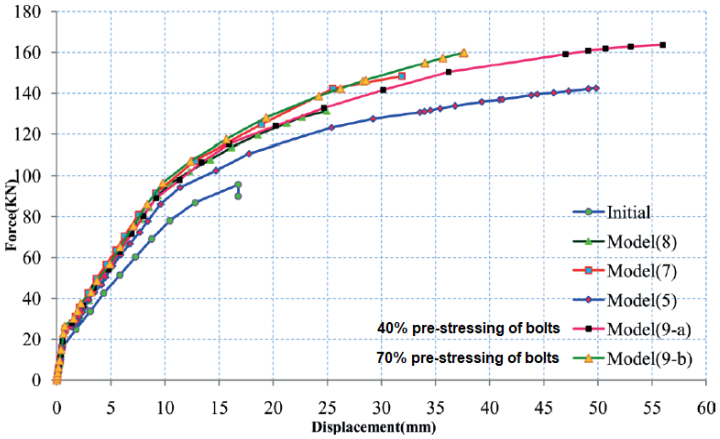


Chart-1 Comparison between the load-displacement diagrams of model 9 and the other models [4]

Zhang et al [23] proposed joint connection construction method based on the ribbed angle steel to improve construction performance of reinforced concrete column-steel beam composite joints. The bending bearing capacity of the joint with sliding failure between the fitting and the steel beam is controlled by the ant sliding bearing capacity of high-strength bolts between fittings and steel beams. The enlargement of cross sections of the beam and the column fails to improve the bending bearing capacity of joints effectively in this case. On the basis of the experimental investigation and finite element analysis, the reliability of the novel prefabricated RCS composite joint with top and bottom ribbed angle steel was proven. The simple structure improved the convenience in assembly construction and promoted its practical application in fabricated structural engineering. Figure (3) illustrates the concrete column-steel beam joint with ribbed angles.

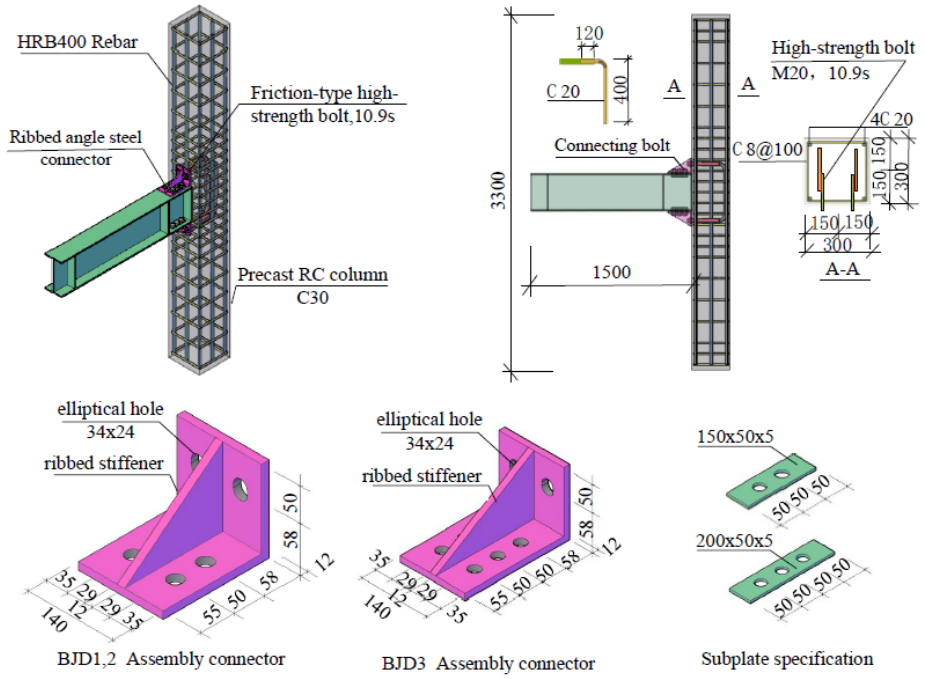


Figure-3 Graphical illustration of concrete column-steel beam joint with ribbed angles [23]

[Al rays] [6] used a channel to strengthen the column zone in beam-column steel joint and investigated the performance using materially nonlinear analysis and T-stub model which takes the component method into account. It had been shown that adding a channel enhances the ductility and the resistance moment.

[ACI-ASCE committee 352] [3] For joints in structures built before the development of current design guidelines do not conform to the current requirements, recommends that "these joints need to be studied in detail to establish their adequacy and to develop evaluation codes for building rehabilitation". Methods for improving the performance of older joints need to be studied to avoid joints failure in earthquake areas.

Choosing the most suitable shape of angle depends on the geometry of joint, architectural view, seismic classification and economic issues. Seismic classification means performance-based design when we need target deflection to control performance level (e.g. Life Safety), so when changing angle width and angle thickness, there are optimum values which give maximum final deflection and maximum deflection at failure of joint. Most researchers use a specific mode of external strengthening or confinement. No study has been reported in open literature on geometrical dimensions of external steel angles and correlated effects on bearing capacity of concrete joint. Parameters are including many levels of load on column and geometrical shape of steel angles (length, width, thickness, rib……). The aim is to reach more efficient pattern of strengthening and flexibility for implementation in complex architectural plans.

2. Materials and Methodology

The compressive strength of concrete is 25 MPa. The tensile strength of the longitudinal steel bars and the stirrups used in the beams and columns is 400 Mpa. The tensile strength of the angles steel is 528 Mpa. The dimensions of the column of the studied connection are 250*250 mm. Also, the beam has a height of 250 mm and a width of 220 mm. The details of the poorly constructed connection in the high school, including the dimensions and the reinforcements are depicted in Figure (4).

Using *Abacus* software for modeling and simulation of reinforced concrete joint supported with steel ribbed-angles, the variables are angle plates thickness, angle length, angle width, rib thickness (45º-Rib) and the load applied on the column. Also there is need to study the effect of adding unrobed-angle for comparing strengthening effectiveness and final deflection. High strength bolts 8.8 (yield strength = 640 Mpa, ultimate strength = 800 Mpa, length = 12.5 cm, diameter = 24 mm) are used and partially embedded in concrete. Angles are fully connected to concrete surfaces.

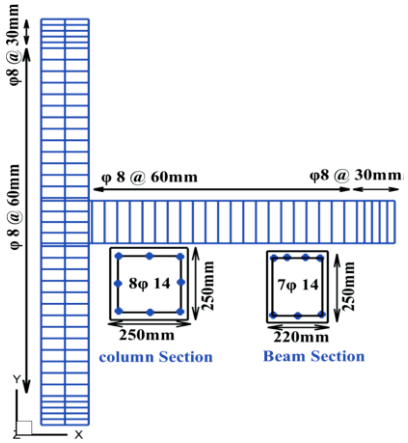


Figure-4 The experimental model of joint. [4]

One of angle models is shown in Figure (5). Figure (6) shows the methodology graph of this research.

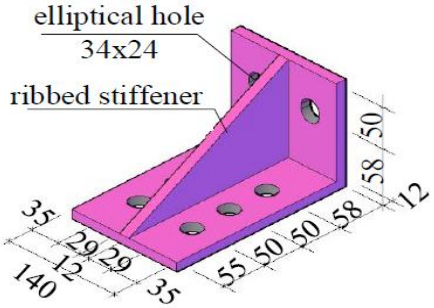


Figure-5 Graphical illustration of the steel angle for strengthening concrete joint (dimensions in *mm*). [22]

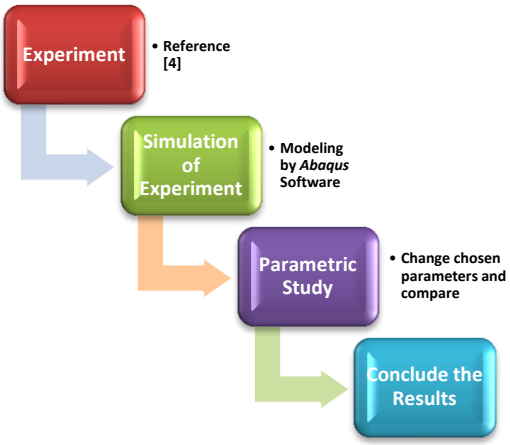


Figure-6 Methodology of research

3. Models

The numerical finite element model is depicted in Figure (7). Using *Concrete Damaged Plasticity* Model [7,9] for modeling of concrete, *Tie* method for the connection between steel angles and concrete (full connection surfaces) and *embedded region* for steel bars in concrete.

By comparing the load-displacement diagrams of the joint model and its simulation on *Abaqus* software using the obtained parameters, a good agreement can be seen (Chart-2). By keeping the strength parameters of concrete and steel constant, the retrofitting of the constructed joint with steel angles is investigated.

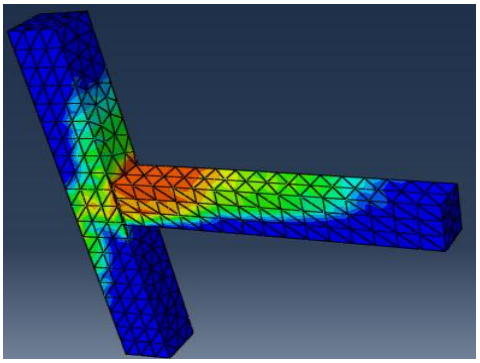


Figure-7 The finite element model of joint.

Element types depend on the geometry of the model. Element types used in our models of joints are:

C3D10: A 10-node quadratic tetrahedron used for the concrete, steel angles and heads of high resistance bolts.

C3D8R: An 8-node linear brick, reduced integration, hourglass control, used for bodies of high resistance bolts.

T3D3: A 3-node quadratic 3-D truss, used for steel bars and steel stirrups. Boundary conditions for the joint are illustrated in Figure (8).

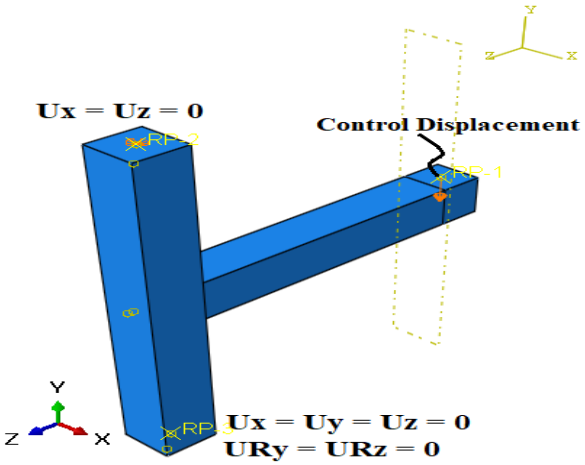


Figure-8 Boundary conditions for joint model.

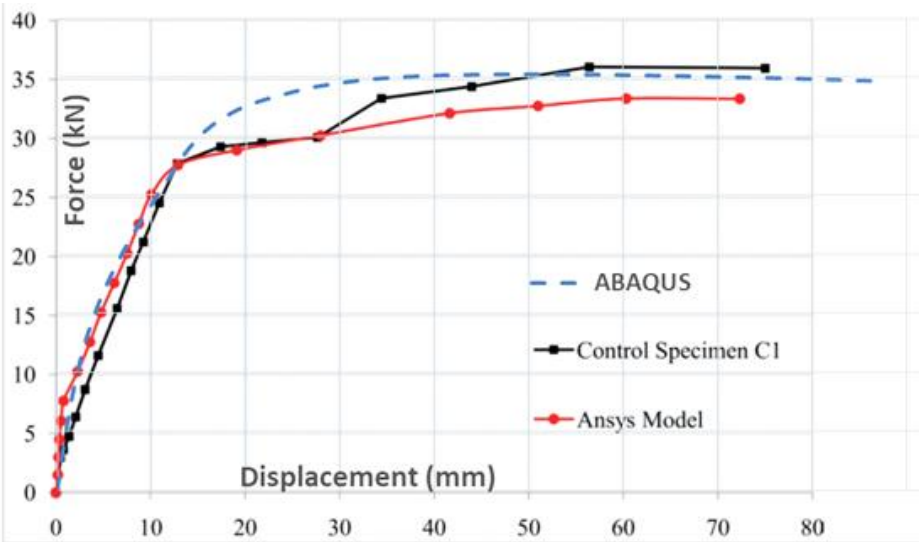


Chart-2 Load-Displacement curves for joint model.

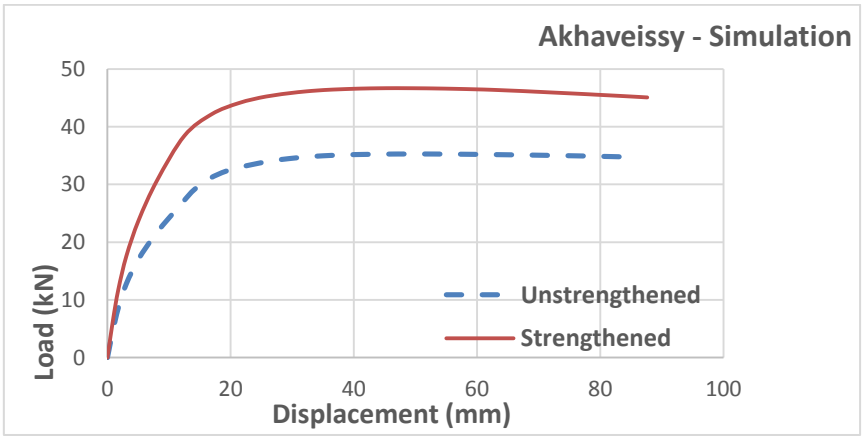


Chart-3 Load-Displacement curves for joint model before and after strengthening.

As it shown from Chart (3), for this model, load carrying capacity increases by about (32%) for strengthened joint. Angles and high strength bolts are shown in Figure (9).

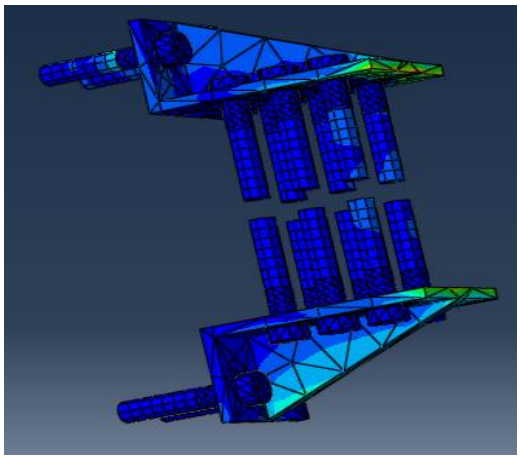


Figure-9 Angles and high strength bolts.

Parameters for CDP concrete material is presented in Table (1). Details and naming of the test specimens were concise in Table 2.

Table.1 Parameters for concrete damaged plasticity in *Abacus* for the tested joint model.

Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
43	0.1	1.16	0.667	0.005

Table.2 Models' ID and their brief details

Group	Model ID	Angle Length (mm)	Angle Thickness (mm)	Angle Width (mm)	Rib Thickness (mm)	Column Load (kN)
1 Column Load Before Strengthening	L0-T0-W0-R0-C0	0	0	0	0	0
	L0-T0-W0-R0-C0	0	0	0	0	5
	L0-T0-W0-R0-C0	0	0	0	0	10
	L0-T0-W0-R0-C0	0	0	0	0	50
	L0-T0-W0-R0-C0	0	0	0	0	200
	L0-T0-W0-R0-C0	0	0	0	0	500
2 Column Load After	L225,108-T12-W140-R12-C0	225	12	140	12	0
	L225,108-T12-W140-R12-C5	225	12	140	12	5
	L225,108-T12-W140-R12-	225	12	140	12	10

Strengthening	C100					
	L225,108-T12-W140-R12-C50	225	12	140	12	50
	L225,108-T12-W140-R12-C200	225	12	140	12	200
	L225,108-T12-W140-R12-C500	225	12	140	12	500
3 Angles Length	L100-T8-W140-R4-C0	100	8	140	4	0
	L200-T8-W140-R4-C0	200	8	140	4	0
	L300-T8-W140-R4-C0	300	8	140	4	0
	L400-T8-W140-R4-C0	400	8	140	4	0
	L500-T8-W140-R4-C0	500	8	140	4	0
	L600-T8-W140-R4-C0	600	8	140	4	0
4 Rib Thickness	L300-T12-W140-R0-C0	300	12	140	0	0
	L300-T12-W140-R4-C0	300	12	140	4	0
	L300-T12-W140-R8-C0	300	12	140	8	0
	L300-T12-W140-R12-C0	300	12	140	12	0
	L300-T12-W140-R16-C0	300	12	140	16	0
	L300-T12-W140-R20-C0	300	12	140	20	0
	L300-T12-W140-R30-C0	300	12	140	30	0
5 Angles Thickness	L300-T4-W140-R4-C0	300	4	140	4	0
	L300-T8-W140-R4-C0	300	8	140	4	0
	L300-T12-W140-R4-C0	300	12	140	4	0
	L300-T20-W140-R4-C0	300	20	140	4	0
6 Angles Width	L300-T8-W40-R4-C0	300	8	40	4	0
	L300-T8-W80-R4-C0	300	8	80	4	0
	L300-T8-W120-R4-C0	300	8	120	4	0
	L300-T8-W140-R4-C0	300	8	140	4	0
	L300-T8-W160-R4-C0	300	8	160	4	0
	L300-T8-W180-R4-C0	300	8	180	4	0
	L300-T8-W220-R4-C0	300	8	220	4	0

Where Symbols are as:

$$\underbrace{Li}_{\substack{Angles\ Length \\ (mm)}} - \underbrace{Ti}_{\substack{Angles\ Thickness \\ (mm)}} - \underbrace{Wi}_{\substack{Angles\ Width \\ (mm)}} - \underbrace{Ri}_{\substack{Rib\ Thickness \\ (mm)}} - \underbrace{Ci}_{\substack{Column\ Load \\ (kN)}}$$

3.1. Effect of column's load on bearing capacity and final deflection before strengthening: (Group 1)

In the first phase, the column top face is subjected to uniform pressure, and in the second phase, the beam's free end is subjected to the action of a controlled vertical displacement till reaching the model maximum capacity and failure.

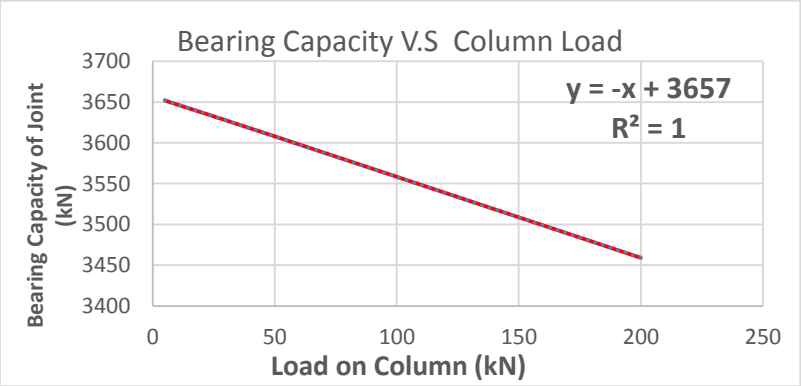


Chart-4 Bearing Capacity VS. Column Load before strengthening.

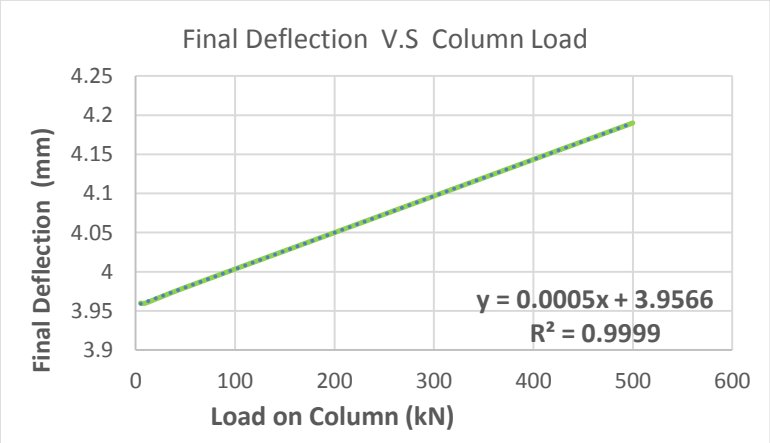


Chart-5 Final Deflection VS. Column Load before strengthening.

Load carrying capacity of the joint is related to the load of column. As can be seen from Charts (4, 5), bearing capacity decreases while column's load increases, but final deflection increases.

3.2. Effect of column's load on bearing capacity and final deflection after strengthening: (Group 2)

By the same methodology, a plot was provided for the relationships between column's load and both strengthening effectiveness and final deflection (Chart-6). There is clearly no effect. This is because the maximum plastic strain is transferred from the face of column to the beam by the steel angles. In general, sensitivity analysis provides users of mathematical and simulation models with tools to appreciate the dependency of the model output from model input, and to investigate how important is each model input in determining its output. The impact of small input perturbations on the model output is studied. Sensitivity analysis is used when there is a multi-variables function by changing one variable and fixing other variables to investigate how much this variable affects the all system.

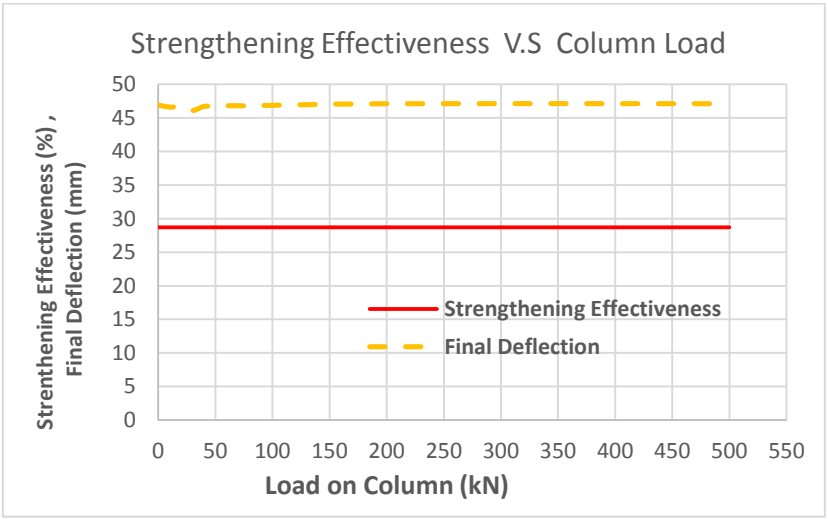


Chart-6 Strengthening Effectiveness and Final deflection VS. Column Load after strengthening.

Before strengthening, bearing capacity decreases while column's load increases, but final deflection increases. After strengthening, there is no effect of column's load on bearing capacity and final deflection, because the existence of steel angles transfers the maximum plastic strains from the face of column to the beam.

3.3. Effect of length of angle plates: (Group 3)

It is obvious numerically from Table (3) that when angle length increases, strengthening effectiveness increases but final deflection decreases. This is illustrated graphically in Charts (7, 8).

Table.3 Numerical values for the effect of angles length in strengthening exterior joint

Angle Length (cm)	Strengthening Effectiveness (%)	Final deflection (mm)
10	13.4	32.7
20	23.7	30.6
30	41	23.4
40	62.5	21.4
50	90	18
60	126.5	13.6

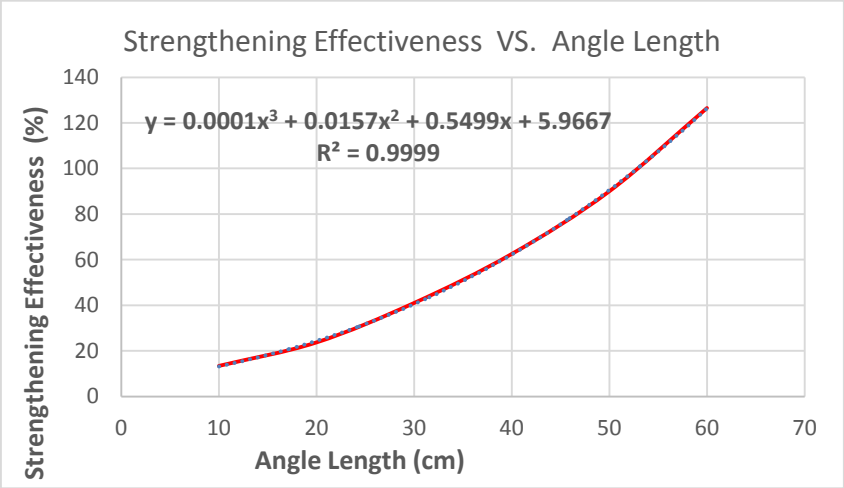


Chart-7 Strengthening Effectiveness VS. Angle Length.

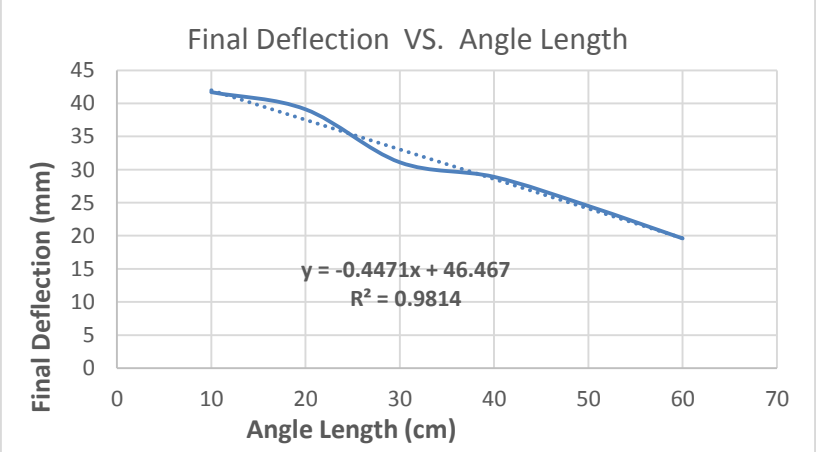


Chart-8 Final Deflection VS. Angle Length.

From Charts (7, 8), it can be seen that strengthening effectiveness is increased when angle length is increased but final deflection is decreased. It is rational results because the supported part of joint is increased. However angle length is controlled by architecture and economic issues.

3.4. Effect of rib thickness: (Group 4)

As shown in Chart (9), there is a very little effect when the rib thickness changes from (4mm) to (30mm). However, if there is no rib, strengthening effectiveness decreases and final deflection increases.

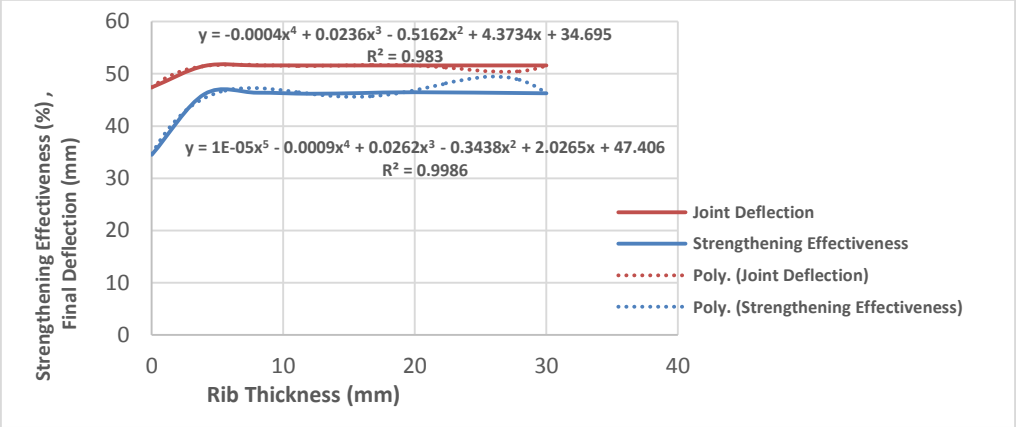


Chart-9 Strengthening Effectiveness and Final deflection VS. Rib Thickness.

3.5. Effect of angle-plate thickness and angle width: (Groups 5,6)

There is a little increasing in strengthening effectiveness when angle width increases, schematically clarified in Chart (10). Perversely, angle thickness has an optimum point which gives a maximum bearing capacity of concrete joint. In o ur case, Chart (11) shows that 12-mm-plate thickness gives the maximum strengthening effectiveness. This result can't be generalized and it is maybe especially for the condition.

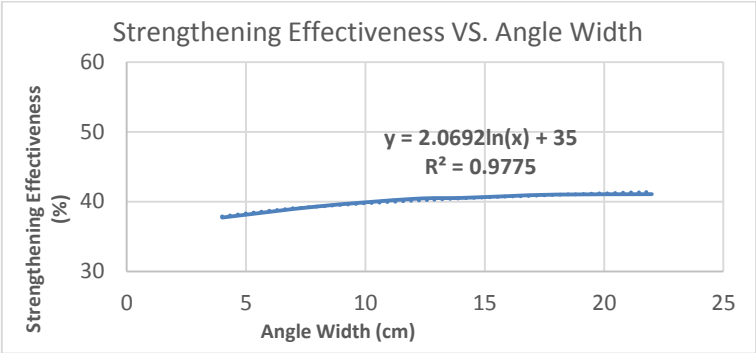


Chart-10 Strengthening Effectiveness VS. Angle Width.

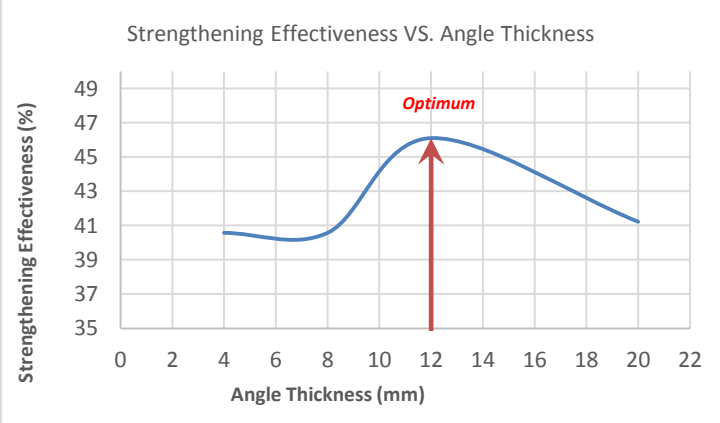


Chart-11 Strengthening Effectiveness VS. Angle Thickness.

Note that, for concrete joint strengthened with steel ribbed angles, maximum deflection of beam generally decreases while load capacity of joint increases. But there are optimum values of thickness and width of the angles which give maximum deflection at failure of joint, schematically illustrated in Charts (12, 13).

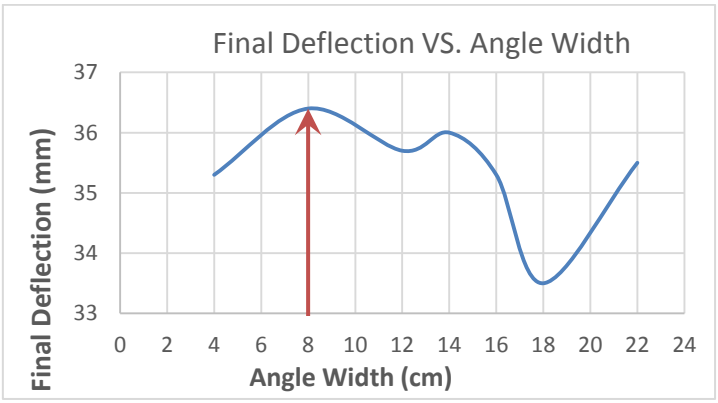


Chart-12 Final Deflection VS. Angle Width.

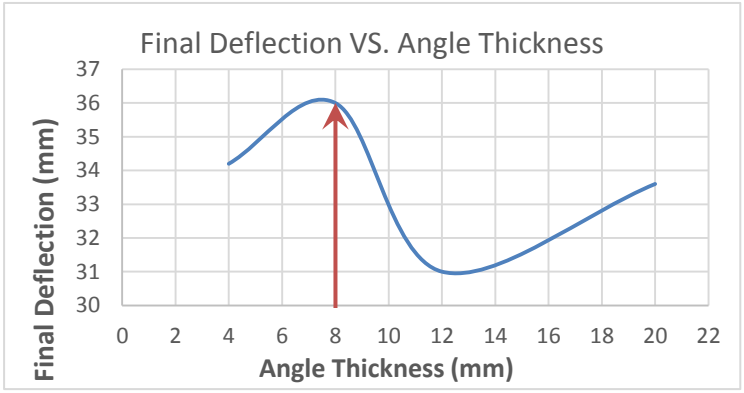


Chart-13 Final Deflection VS. Angle Thickness.

It can be seen that thickness (8mm) and width (8cm) of ribbed-angles are the best choices for final deflection of strengthened concrete joint. Further researches are needed to relate these parameters to joint dimensions.

4. Case Study

As case study, an exterior concrete joint in Hordy slab in 5-storey and basement building in *Tartous* City. Strengthening is conducted for specific joints in the five stories (intersection of B-B and 5-5 axes, intersection of H-H and 5-5 & 2-2 axes). 3D-model of the building is illustrated in Figure (10).

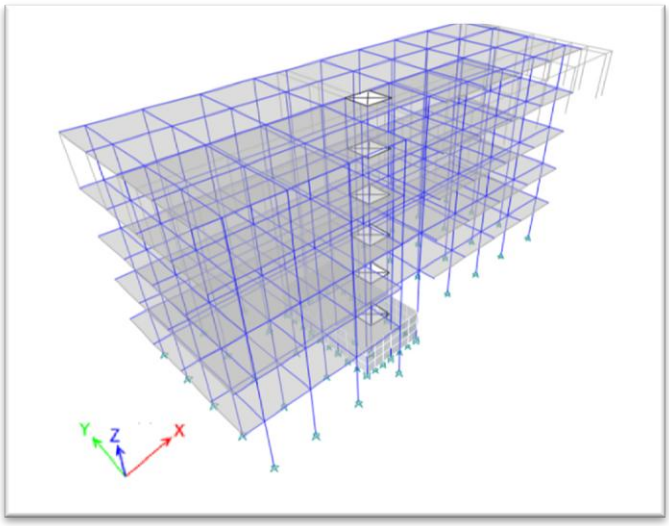


Figure-10 3D-model of the building on *Etabs V18*.

The plan of building is illustrated in Figure (11). Evaluation of the building is done by equivalent static method on *Etabs* V18 software and the results of drifts on X & Y directions are presented in Table (4). So, as can be seen, the building in need to be strengthened. The joint and details illustrated in Figure (12).

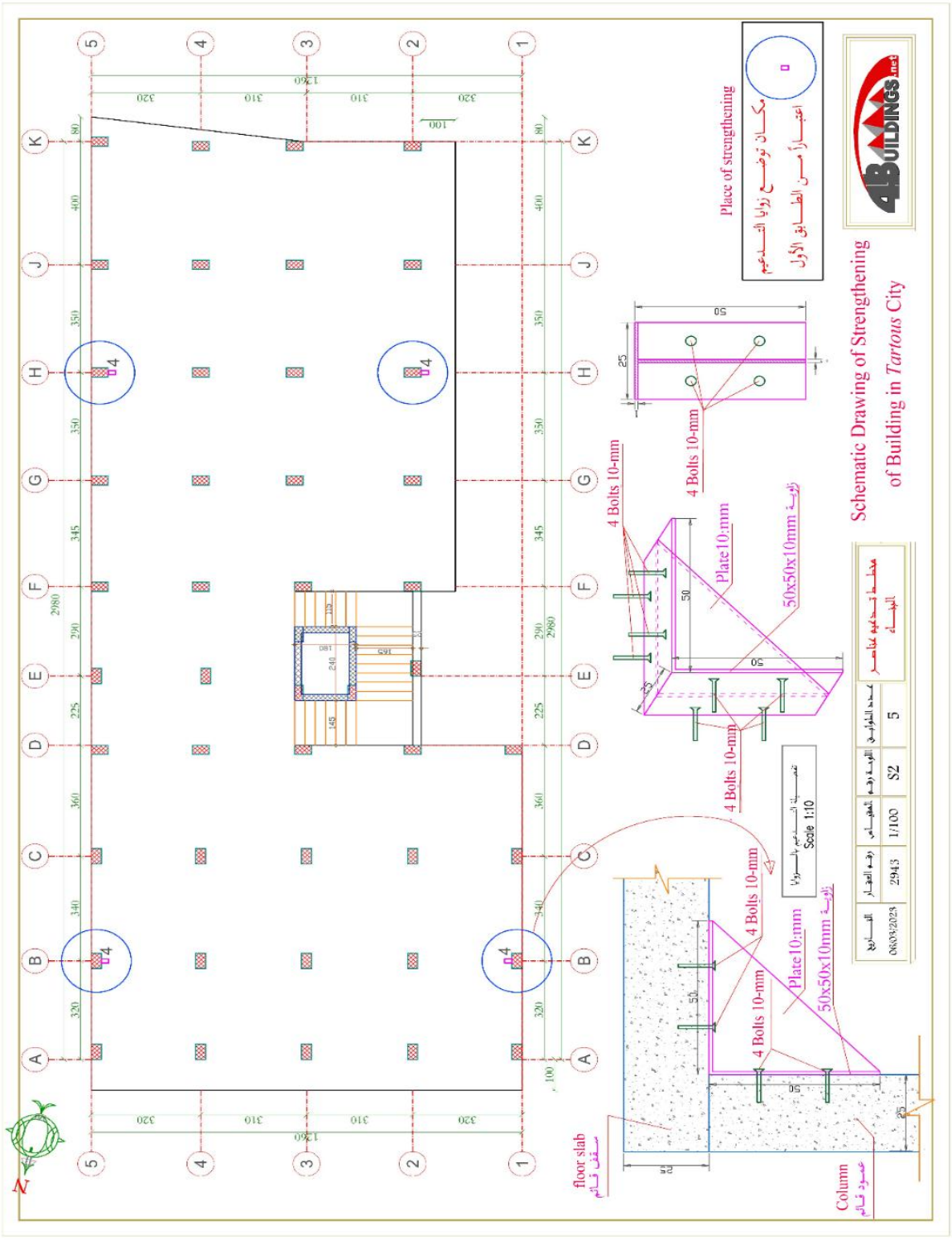


Figure-11 Plan of 5-storey concrete building with strengthened joints positions.

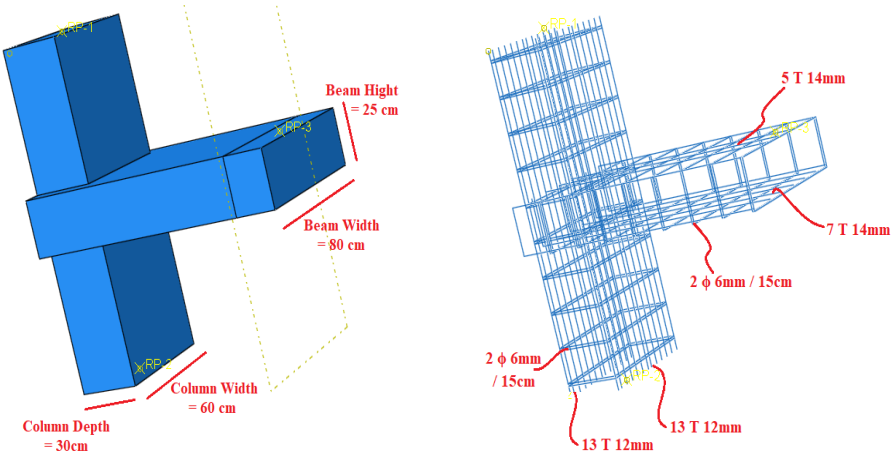


Figure-12 The joint and steel reinforcement details in Basement.

Table.4 Drift Values for the building under overview

Elastic Drift (mm)		Period (sec)		Response Modifying Factor R	Plastic Drift (mm)		Allowed Value (mm)
Y-direction	16.254	Ty=	0.409	Ry = 3	0.7*R*Dy	34	25
Y-direction	14.36	Tx=	0.409	Rx = 3	0.7*R*Dx	30	25

Illustrated in Figure (13), the used steel angle is L: 500x500x10 mm, width is 250mm, with rib of thickness 10 mm and four high strength 8.8 bolts of diameter 10 mm using epoxy to cohere with concrete. Concrete compressive strength was 22 MPa. The yield strength of steel was 528 MPa and ultimate strength was 657 MPa at 5% elongation.

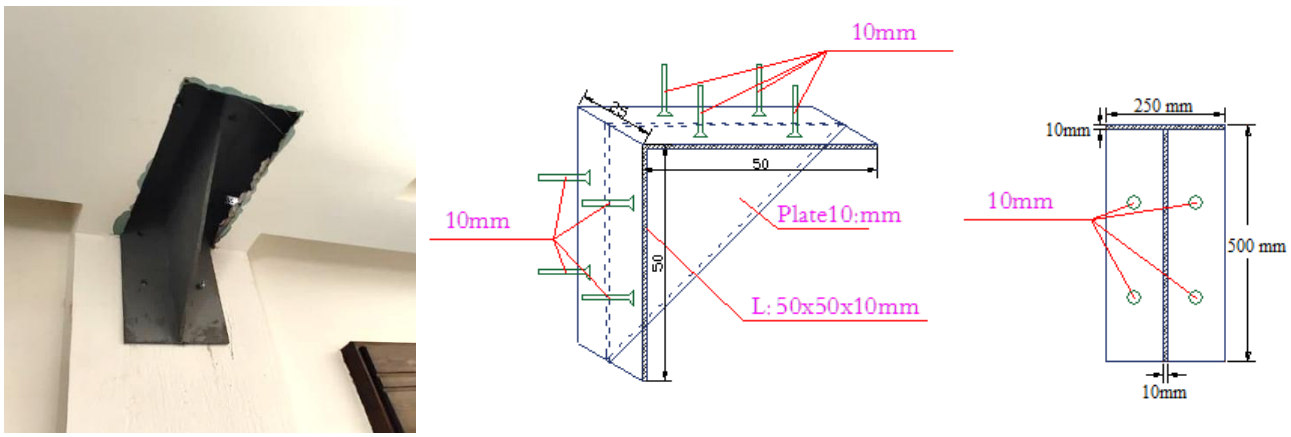


Figure-13 The steel angle used in strengthening joint in the 5th story of the concrete building.

Load-Displacement curve for joint case study before and after strengthening is illustrated in Chart (14). Notice that Load Capacity of joint is increased by 283 %. But displacement of beam end at failure is decreased by about 31 %, from 29.7 mm to 20.6 mm.

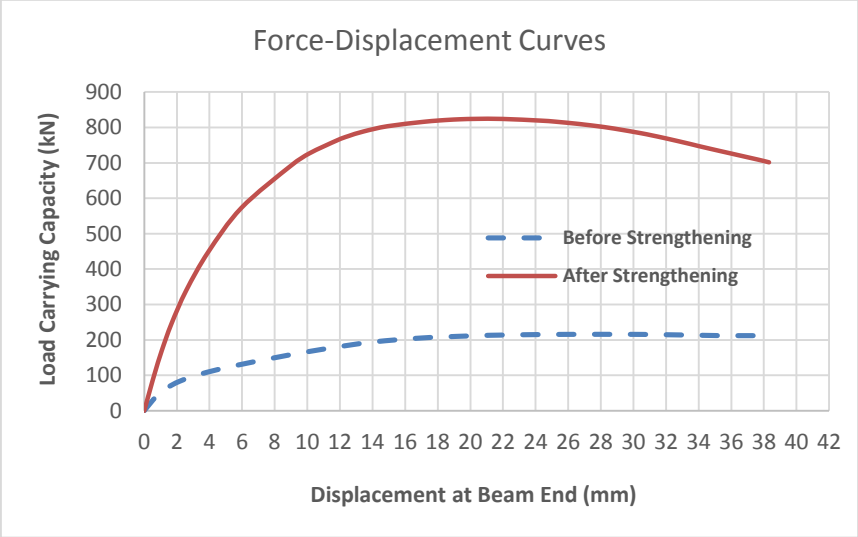
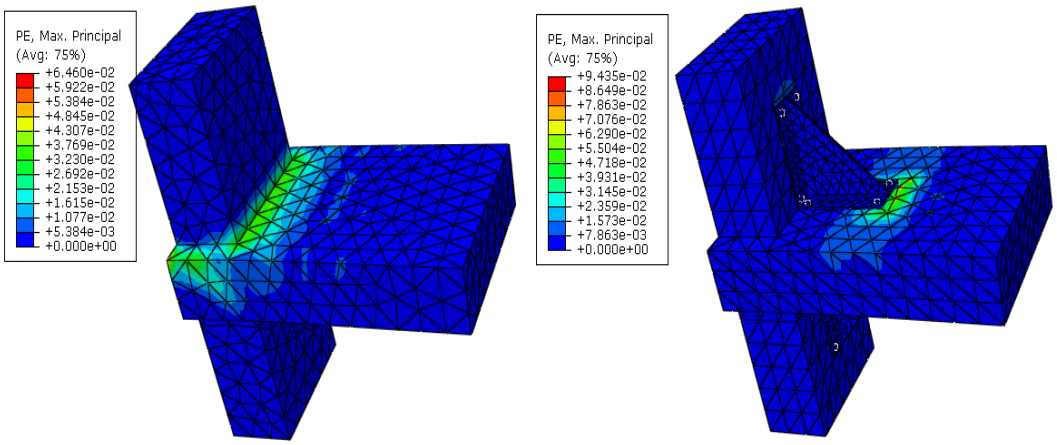


Chart-14 Load-Displacement curve for joint case study before and after strengthening.

Figure (14) shows comparison between plastic strain zones and values before and after strengthening. Notice that maximum plastic strains at failure is transferred from the connection zone between beam and column to the beam at surface contact between steel angle and beam. Second failure pattern is considered favorite against the first one.



(a) (b)

Figure-14 Comparison between plastic strain zones and values before and after strengthening.

5. Conclusions

In this study, numerical analytical comparing is made between the cases of using steel angles for strengthening exterior beam-column concrete joint by *Finite Element Method* and these results are observed:

- By using specified ribbed steel angles, the load carrying capacity of exterior beam-column concrete joint is increased by about (32%), in accordance with literature, but the final deflection decreases.
- Before strengthening, bearing capacity decreases while column's load increases, but final deflection increases.
- After strengthening, there is no effect of column's load on bearing capacity and final deflection, because the existence of steel angles transfers the maximum plastic strains from the face of column to the beam.
- There is barely a little effect when the rib thickness is increased from (4mm) to (30mm).
- In general, for concrete joint strengthened with steel ribbed angles, maximum deflection of beam generally decreases while load capacity of joint increases.

- The cracks move from the joint to the beam, the failure occurs in the beam with maximum plastic strains, and the joint area remains intact. This confirms that the steel angles are effective in protecting the joint and give more desirable failure pattern in a concrete joint.
- There are optimum values of thickness and width of the angles which give maximum final deflection at failure of joint. Further researches are needed to relate these parameters to joint dimensions.

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