STRENGTHENING OF PRECAST BEAM-COLUMN JOINT USING STEEL ENCASEMENT

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Abstract – *Precast concrete construction is widely used in many countries for its many advantages. But its construction is limited in high seismic zones because it depends on the behavior of connections of a precast structural system. Beam column joints were considered as the critical zone of reinforced concrete moment- resisting structure subjected to seismic loads. Seismic retrofitting is the modification of structures to make them more resistant to seismic activity. There are many methods of retrofitting adopted for cast in situ beam- column joint. A lot of studies are ongoing on the effectiveness of these retrofitting methods in the cast in situ beam- column joints. This report is an analytical investigation carried out for strengthening of precast beam- column joint subjected to monotonic loading using steel plates and angles. Strengthening is carried out in two different methods. One of the methods is the welding of steel plates and angles to the beam- column joint and another method is steel plates and angles are mounted by using prestressed bars. Results obtained from the analytical study are then compared with the experimental results of the cast in situ beam- column joint subjected to monotonic loading. Strengthening of precast beam- column joint aims to improve structural performance like joint strength, ductility, ultimate moment capacity, and ultimate deflection. This study also aims to ensure the effectiveness of these strengthening techniques in the cast in situ beam- column joints since it makes better results in the structural performance in precast beam- column joints.*

Key Words: **Precast, Cast in situ, Strengthening, Seismic, Joint, Beam, Column**

1. INTRODUCTION

Most of the reinforced concrete structures before the 1970s were not designed based on the current seismic guidelines. The studies showed that the failure of structures by the earthquake is due to the failure of the exterior beam-column joint. This was due to inadequate joint transverse reinforcement and poor anchorage length of beam longitudinal bars. Seismic retrofitting is adopted to strengthen these weakened beam-column joints. Concrete jacketing, steel jacketing, CFRP, bracing and buttress are some of the usually adopted strengthening methods. But these methods have advantages and also some disadvantages. Cast in situ beam-column joints using steel plates and angles showed strength improvement. Like cast- in- situ construction, precast construction is also gaining more importance nowadays for its benefits. Reduced requirement of formwork and scaffoldings, less time consumption, and reduced amount of waste materials at the site are some of their benefits. But its application is limited in high seismic zones because of scarce design guidelines compared with those of cast- in- place concrete structures. In high seismic zones, they depend on the behavior of connections because they constitute the weakest link in the structure. The observations from past earthquakes show that a lot of research has to be done to adopt the precast systems in high seismic zones. This paper presents the analytical investigation of the cast in situ beam- column joints and precast beam-column joint subjected to monotonic loading. The analytical investigation is carried out in software called ANSYS. It is a general-purpose, finite-element modeling package for numerically solving a wide variety of mechanical problems. These problems include static/dynamic, structural analysis, heat transfer, and fluid problems, as well as acoustic and electromagnetic problems. It helps in civil, automotive, aerospace, and wherever one needs to design something, and validate that design for the real world, inexpensively.

2. LITERATURE REVIEW

Mohie E Shoukry et al. (2021)[1] Studied the Seismic retrofit of deficient exterior RC beam- column joint using steel plates and angles. In this journal RC beam column joint is fitted with steel plates and angles around the joint with different configurations like X shape, horizontal, etc. six half scale exterior beam column joints including two control specimens representing code detailed and deficient joint in addition to four retrofitted specimens were tested. The result showed that deficient joint exhibited brittle joint shear failure, code detailed joint failed by flexure in the beam, and retrofitted specimens prevented brittle joint shear failure and increased joint strength, ductility, stiffness, and energy dissipation.

Jansi Rani K et al. (2019)[2] Studied the experimental investigation on seismic retrofitting of RCC structures. This journal is an experimental investigation on seismic retrofitting of RCC structure. A typical beam-column joint with detailing as per code scale down to laboratory conditions and subjected to reverse cyclic loading was examined for lateral load capacity. The specimens were classified into two types such as a non- ductile joint represented as a control specimen and a conventionally retrofitted specimen using concrete jacketing. The retrofitted specimen showed appreciable seismic behavior through plastic hinge formation in the beam.

Jalil Shafaei et al. (2014)[3] studied the Seismic retrofit of external RC beam–column joints by joint enlargement using prestressed steel angles. In this journal seven half-scale external RC beam–column joints were tested by applying lateral cyclic loading of increasing amplitudes. The tested specimens comprised three control units and four retrofitted units. Parameters on seismic behavior were determined, including strength, stiffness, ductility, energy dissipation capacity, equivalent hysteresis damping, and relative energy dissipation ratio. The results were compared to those of the control specimens. The proposed retrofit method resulted in the relocation of the plastic hinge away from the column face to the outside of the joint panel zone.

Mohamed H. Mahmoud et al. (2014) [4] studied the strengthening of defected beam column joint using CFRP. This journal deals with the experimental study of the structural performance of reinforced concrete exterior beam- column joints rehabilitated using carbon fibre reinforced polymer CFRP. An experimental study was conducted on ten half-scale specimens covering three possible defects in addition to an adequately detailed specimen. Three different strengthening schemes were used to rehabilitate the defected beam-column joints including externally bonded CFRP strips and sheets in addition to near- surface mounted (NSM) CFRP strips. The test result showed that CFRP strengthening configuration represented the best choice for strengthening from the viewpoint of the studied failure criteria.

R. Vidjeapriya and K. P. Jaya (2013) [5] studied an experimental study on two simple mechanical precast beam-column connections under reverse cyclic loading. In this journal precast specimen and monolithic specimen are designed for the same strength. The first precast connection the beam is connected to the corbel using a cleat angle with a single stiffener and for the second precast connection cleat angle with two stiffeners was used. The sub assemblage specimens have been subjected to cyclic displacement controlled lateral loading. The maximum load carrying capacity of the monolithic specimen was higher than precast connection and energy dissipation and ductility was higher for monolithic specimen compared to the precast specimen.

Studies on past earthquakes such as the 1994 Northridge earthquake **Mitchel et al.[6]** And the 1998 Adana-Ceyhan, Turkey earthquake **Gulkan[7]** showed extensive damage to precast structures due to the failure of connections. They also observed that even though these precast structures behaved ductile manner, the lack of proper diaphragm action and inadequate connections between beams and columns contributed to the collapse.

3. MODELING OF BEAM COLUMN JOINT USING ANSYS

Table -1: Dimensions of beam column joint

Parameter	Beam (mm)	Column(mm)
Cross section	200 X 300	200 X 300
Length	900	2300

Table-2: Material properties of beam column joint

Material	Concrete	steel		
Properties	Compressive strength	Longitudinal reinforcement yield strength	Stirrups yield strength	Modulus of elasticity-
Value	25 Mpa	400 Mpa	240 Mpa	200 Gpa

The beam-column joint is modeled in the ANSYS software. Element type SOLID 185 and REINF 264 is used for the 3-D modeling of concrete and reinforcement. Dimensions and material properties are briefly described in Table 1 and Table 2. The main steel reinforcement of the beam was three bars of 16 mm diameter and secondary steel reinforcement was two bars of 12 mm diameter. The column was reinforced with four bars of 16 mm diameter at each corner of the column cross- section. The stirrups for both beam and column were steel bars of 8 mm diameter and spaced every 100 mm and 150 mm for the beam and column. In addition three stirrups were added at the beam-column joint. Including a monolithic beam- column joint, a precast beam- column joint without strengthening, five models of strengthened precast beam- column joint with welded steel plates and angles, and six models of strengthened precast beam- column joint with prestressed bars; a total of 13 models are prepared. After modeling the monolithic beam- column joint, precast beam- column joint is developed using cleat angle with single stiffener, and corbel is used for supporting beam. A steel plate is installed on the top of the beam end to improve the load transfer capacity. After modeling the beam- column joint it was subjected to adaptive meshing. The end supporting condition was provided as both ends fixed and load applied monotonically on the top of the steel plate so that it behaves like a seismic lateral load. The load is applied in the ANSYS as a displacement control method.

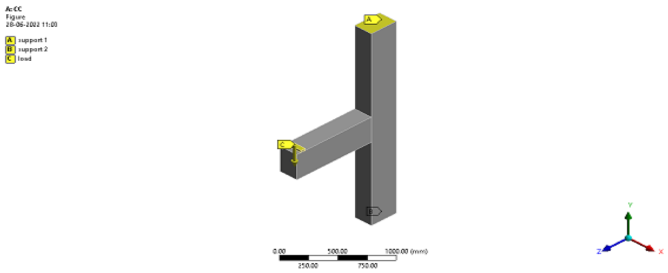

Fig-1: Monolithic beam-column joint with fixed supports and loading conditions

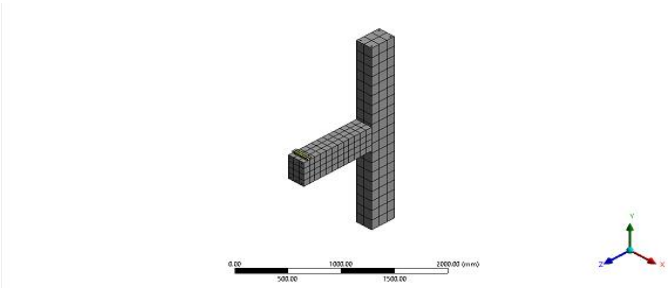

Fig-2: Meshing of monolithic beam-column joint

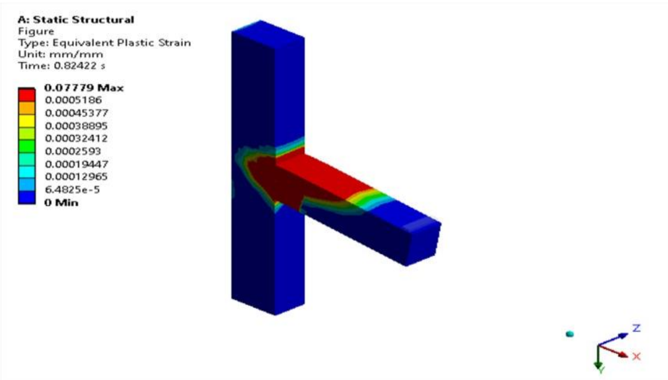

Fig-3: Plastic strain region of monolithic beam-column joint

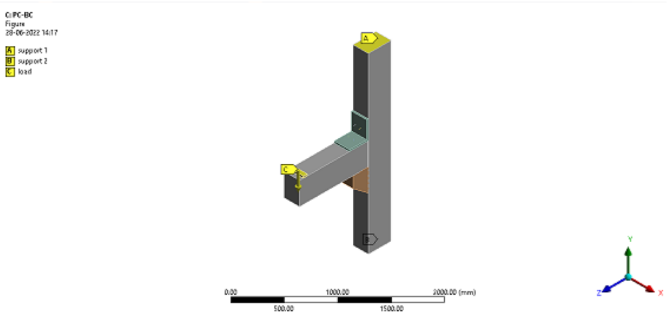

Fig-4: Precast beam-column joint with fixed support and loading conditions

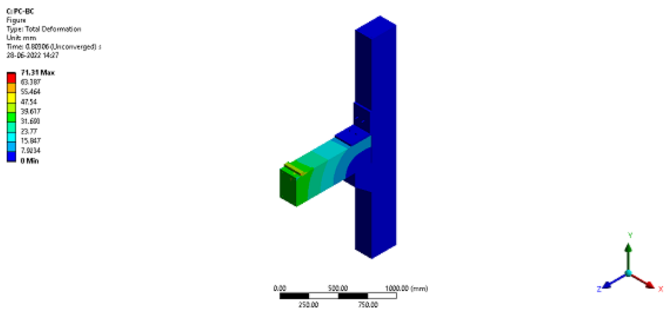

Fig-5: Total deformation of precast beam-column joint

4. MODELING OF STRENGTHENED PRECAST BEAM-COLUMN JOINT

In this study, two types of strengthening methods were adopted. One of the methods was the welding of steel plates and angles to the beam- column joint. The parametric study adopted here was changing no steel plates. These models are named EN1, EN2, EN3, EN4, and EN5. Horizontal and vertical Steel plates used in the column have dimensions of 200 X 50 mm and 700 X 50 mm with a thickness of 10 mm. Horizontal and vertical steel plates used in the beam have dimensions of 150 x 50 mm and 360 X 50 mm with a thickness of 10 mm. A stiffener plate used in the cleat angle has dimensions of 190 mm X 190 mm with a thickness of 20 mm. A steel plate with of width 50 mm and thickness of 10 mm was used to cover the corbel.

Another strengthening method was steel plates and angles were prestressed with prestressing bars and anchoring bolts. The first parametric study adopted here was changing the diameter of prestressing bars. The diameter of prestressing bars adopted here was 16 mm and 20 mm with a cleat angle dimensions 180 mm X 180 mm X 20 mm. The prestressing bar length used in the column and beam were 400 mm and 450 mm respectively. The bars were prestressed until a tension force approximately equal to 70 percent of the minimum tensile strength was produced in the bars and the minimum tensile strength was taken as 1000 MPa

[3]. Accordingly, for 16 mm and 20 mm diameter prestressing bars, prestressing loads was taken as 140 KN and 219 KN respectively. The second parametric study was by adopting a 16 mm diameter bar, cleat angle dimension varied. The various cleat angle dimensions adopted were 225 mm, 250 mm, 275 mm, and 300 mm with a thickness of 20 mm. The notations and their corresponding model name is shown in the Table 3.

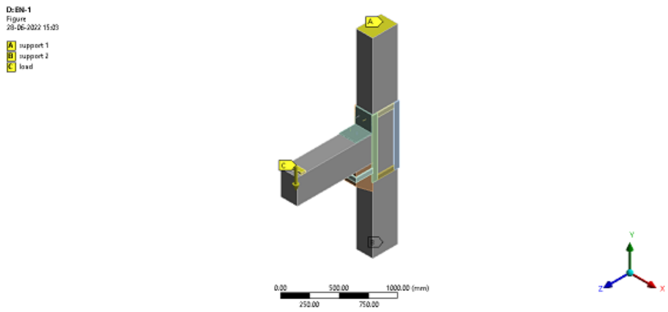

Fig-6: EN1 Model

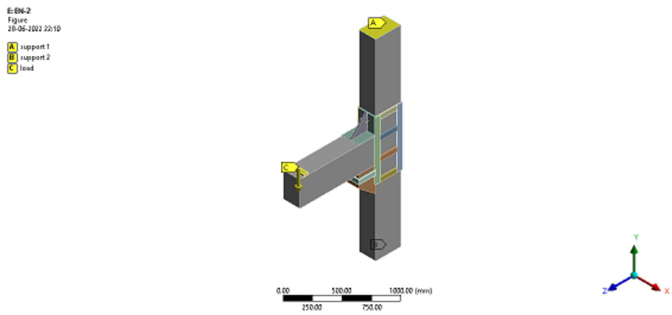

Fig-7: EN2 Model

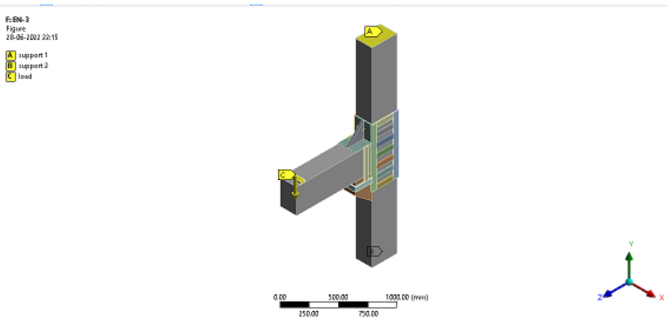

Fig-8: EN3 Model

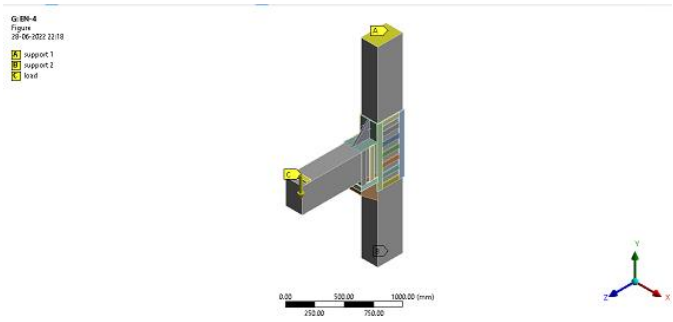

Fig-9: EN4 Model

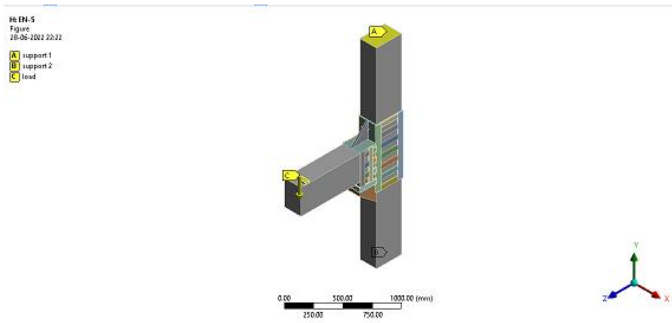

Fig-10: EN5 Model

Table-3: Notations and their corresponding model name

Name of model	Notations	
	Diameter of prestressing bar (mm)	Cleat angle dimensions (mm)
PS 16 180	16	180 X 180 X 20
PS 20 180	20	180 X 180 X 20
PS 16 225	16	225 x 225 X 20
PS 16 250	16	250 x 250 X 20
PS 16 275	16	275 x 275 X 20
PS 16 300	16	300 x 300 X 20

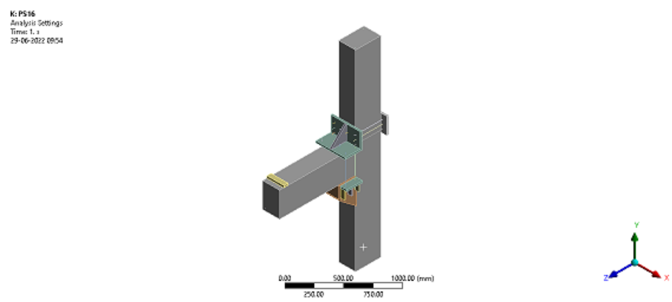

Fig-11: PS 16 180 Model

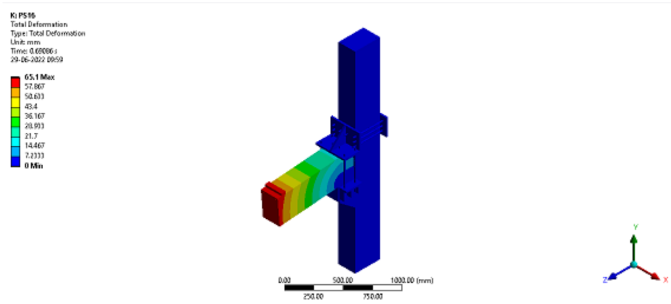

Fig-12: Total deformation of PS 16 180Model

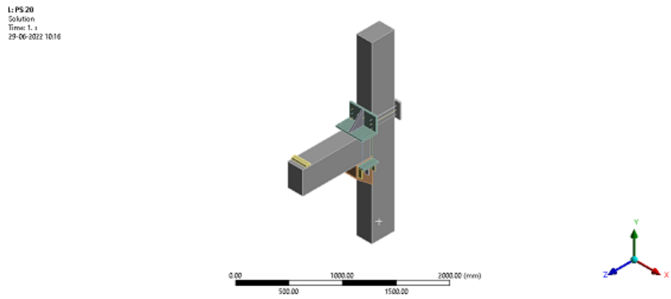

Fig-13: PS 20 180 Model

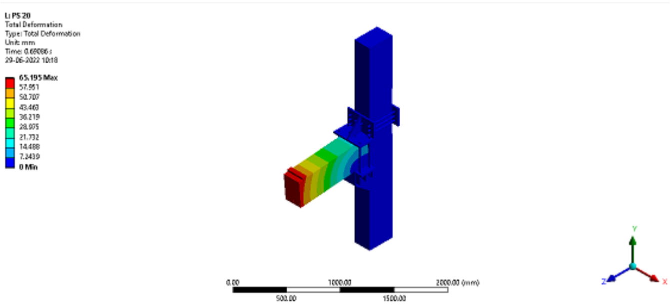

Fig-14: Total deformation of PS 20 180 Model

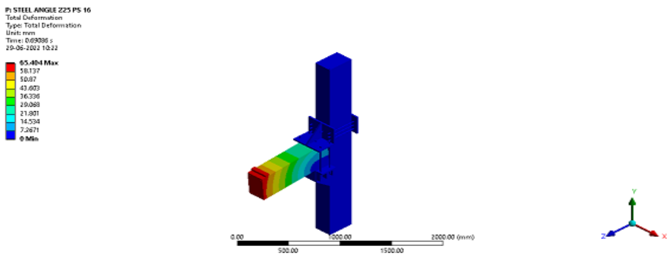

Fig-15: Total deformation of PS 16 225 Model

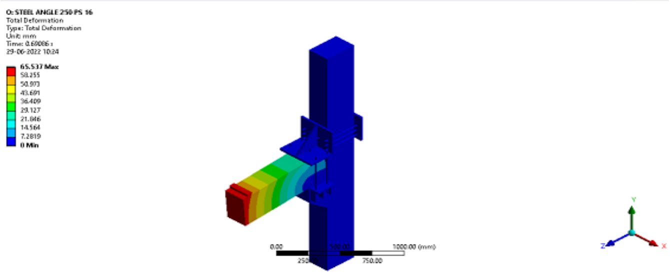

Fig-16: Total deformation of PS 16 250 Model

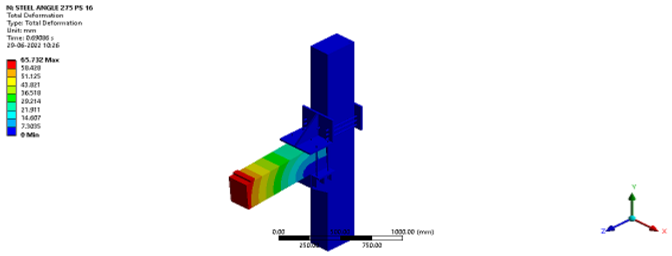

Fig-17: Total deformation of PS 16 275 Model

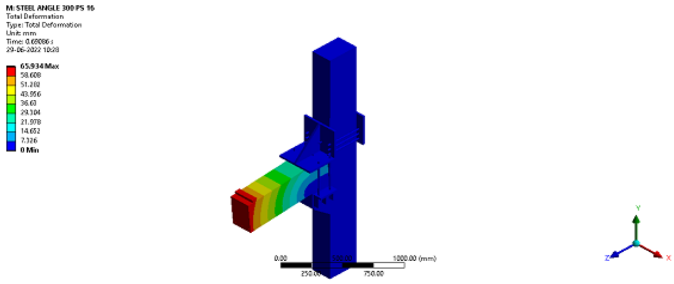

Fig-18: Total deformation of PS 16 300 Model

5. RESULTS AND DISCUSSION

The results obtained from the analysis of monolithic and precast beam- column joint, strengthening of precast beam- column joint by welding of steel plates and angles, and strengthening of precast beam- column joint by prestressing bars is tabulated in the Table 4, Table 5, and Table 6. Corresponding load deformation graph is also represented below.

Table-4: Analysis results of monolithic beam-column joint and non strengthened precast beam-column joint

Model	Deformation (mm)	Load (KN)	Yield displacement	Ductility
Monolithic beam-column joint	40.79	74.24	11.17	3.65
Precast beam-column joint	53.48	42.66	4.91	10.88

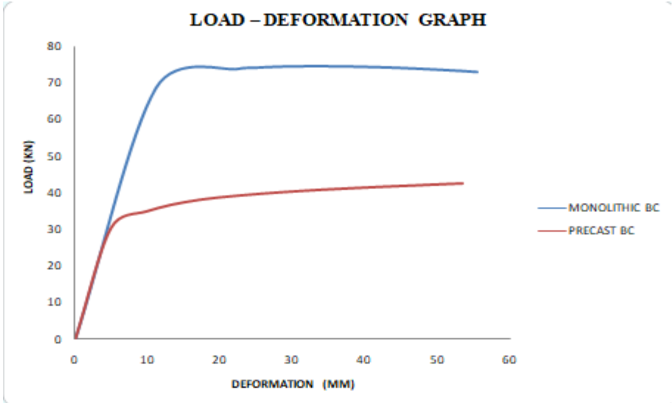

Fig-19: Load deformation graph of monolithic beam-column joint and non strengthened precast beam-column joint

Table-5: Result of strengthening of precast beam-column joint by welding of steel plates and angles

Model	Deformation (mm)	Load (KN)	Yield displacement	ductility	% increase in load
Precast beam-column joint	53.48	42.66	4.91	10.88	-
EN1	70.27	43.89	4.91	14.31	2.87
EN2	52.29	45.77	14.19	3.71	7.29
EN3	30.28	86.55	13.93	2.17	50.71
EN4	64.54	107.18	13.79	4.68	151.24
EN5	64.55	106.65	13.69	4.72	150.00

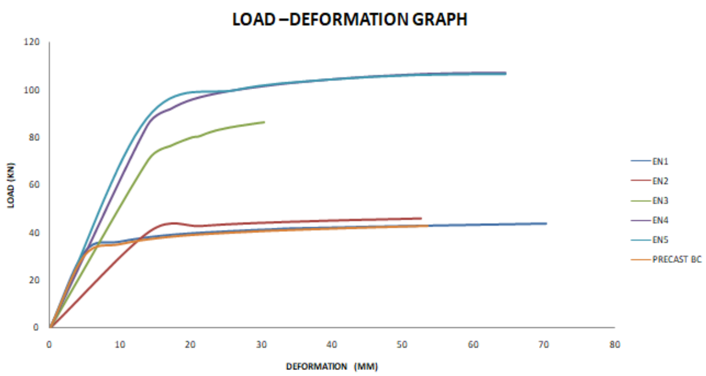

Fig-20: Load deformation graph of non strengthened precast beam-column joint model and strengthened models by welding of steel plates and angles.

Table-6: Result of strengthening of precast beam-column joint by prestressing bars and anchoring bolts.

Model	Deformation (mm)	Load (KN)	Yield displacement	ductility	% increase in load
Precast beam-column joint	53.48	42.66	4.91	10.88	-
PS 16 180	93.64	49.39	4.69	19.95	15.77
PS 20 180	79.93	48.64	4.71	16.98	14.02
PS 16 225	93.99	52.70	4.70	20.01	23.53
PS 16 250	94.27	61.40	4.70	20.06	43.92
PS 16 275	94.51	61.53	4.70	20.10	44.23
PS 16 300	88.17	72.74	4.70	18.74	70.52

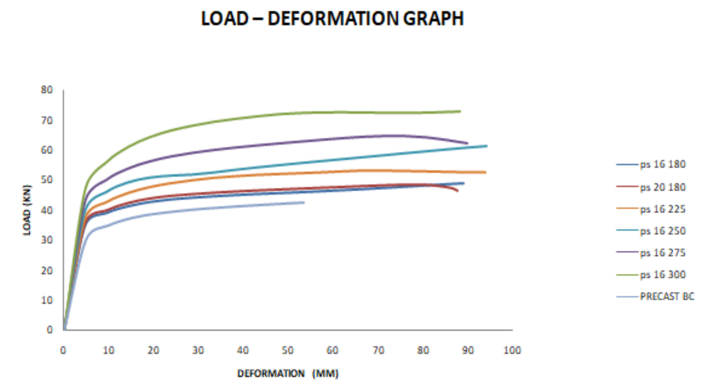

Fig-20: Load deformation graph of non strengthened precast beam-column joint model and strengthened models by prestressing bars and anchoring bolts.

This study was mainly focused on the structural performance like load carrying capacity, joint strength, ductility, ultimate moment capacity, and ultimate deflection. The results are summarized as follows:

- Monolithic beam-column joint have a higher load carrying capacity about 74.24 KN than the precast beam-column joint. But in the case of ductility precast connection showed a higher value of about 10.88 compared to monolithic beam- column connection.
- Strengthening of precast beam-column joint using welding of steel plates and angles showed improvement in load carrying capacity. Among them, EN4 model showed a 151.24% increase in load carrying capacity compared to the non

strengthened precast beam-column connection. Also EN1 model showed a 2.87% increase in load carrying capacity than the non strengthened precast beam–column connection and this one showed the least improvement. Except for EN1 rest of the other models showed a decrease in ductility when compared to non strengthened precast beam-column connection. EN1 showed maximum deformation of 70.27 mm among all models.

- Strengthening of precast beam-column joint using prestressing bars and anchoring bolts also showed improvement in load carrying capacity. The precast beam column joint having a 16 mm diameter prestressing bar showed a 15.77% increase in load carrying capacity when compared with the non strengthened precast beam-column connection. The model with 16 mm prestressing bar showed higher load carrying capacity than the model with 20 mm prestressing bar. This result, it shows that there will be no strength improvement by changing the prestressing bar diameter. So by taking 16 mm prestressing bar diameter, cleat angle dimensions changed. Among them, PS 16 300 showed a 70.52 % increase in load carrying capacity then non strengthened precast beam-column joint. The model PS 16 275 showed higher ductility and deformation compared to all models.

6. CONCLUSIONS

From the analysis of different beam-column joint models following conclusions can be drawn:

1. Monolithic beam-column joint have higher load carrying capacity than precast beam column joint.
2. Strengthening of precast beam-column joint by using welding of steel plates and angles showed improvement in joint strength than by using the prestressing method.
3. These strengthening methods showed better results in precast connection. So these strengthening methods can use in weak monolithic beam-column joint; thereby the effectiveness of these strengthening methods in the monolithic beam-column joints is proved.

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