Structural Optimisation of Non-Seismically Detailed RC Beam-Column Joints using Prestressed and Prefabricated Steel Encasement

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***Abstract*— Beam–column joints in reinforced concrete moment resisting frames are key components to guarantee integrity and overall stability when the frame is subjected to seismic loading. Poor reinforcement detailing at critical locations such as beam-column joint core can have detrimental consequences as it may lead to a global failure mechanism. An innovative and practical seismic retrofit method is proposed for non- seismically detailed external beam– column joints of existing concrete structures that do not meet current seismic design requirements. The objective of the study includes proposing a retrofit method based on two-dimensional enlargement of the beam–column joint using steel angles that are mounted on the prestressed cross-ties. The exterior reinforced concrete beam- column joints are tested under lateral loading with a constant axial load on the column and the analytical study is expected to show significant enhancement in seismic capacity of non-seismically detailed beam column joint. The proposed retrofitting method effectively prevent the brittle joint shear failure, relocate beam plastic hinges to outside the joint panel zone, increase the joint strength and energy dissipation. The complete analytical study is carried out using nonlinear analysis method in ANSYS software.**

Keywords: External beam–column joints, brittle joint failure, ANSYS software

I. INTRODUCTION

Beam column joint is defined as the portion of the column within the depth of the deepest beam that frames into the column. It is the Crucial zone and weakest link in a reinforced concrete (RC) moment resisting frame. Beam- column joint will enable adjoining members to develop and sustain their ultimate capacity. It is subjected to large forces during severe ground shaking and should have adequate strength and stiffness to resist the internal forces induced by framing members. Behavior of beam-column joint has a significant influence on the response of the structure. Catastrophic failures with Turkey and Taiwan Earthquake in 1999 is attributed to beam- column joint failure. Constituent material used for the construction of reinforced concrete structure have limited strength. So the joints have limited force carrying capacity when forces larger than these are coming on the joint. During earthquake, joints are severely damaged and repairing damaged joints are difficult. Thus beam-column joints must be retrofitted to resist earthquake effects. Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion or soil failure due to earthquakes. The main aim of the present study is to determine the behaviour of RC beam-column joints retrofitted with steel plates and angles. Retrofitting is carried out based on two dimensional joint enlargement with steel angles that are mounted using prestressed cross ties.

II. BJECTIVES

- To model a beam- column joint
- To propose a retrofitting method for non-seismically detailed RC beam-column joints of existing concrete structures based on two dimensional enlargement of the beam- column joints using steel angles that are mounted using prestressed cross ties.

III. SUMMARY OF LITERATURE REVIEW

Various literatures are reviewed including the base journal [1]. There exist different methods for seismic retrofitting of RC beam-column joints. It includes retrofitting based on steel plates and angles, carbon and glass fibre reinforced polymer, concrete jacketing etc. Seismic retrofitting based on steel angles and plates is an effective method which will increase strength, energy dissipation etc. Overall performance of the structure under seismic loading can be improved through this method.

IV. JOINT ENLARGEMENT USING PRESTRESSED STEEL ANGLE CONCEPT

Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion or soil failure due to earthquakes. One of the methods of retrofitting is based on joint enlargement using prestressed steel angle concept. Two steel angles and one plate is associated with each joint retrofit. Three steel elements are fixed in place using high tensile strength bars and the retrofitting is completely done using bolted connection. The

prestressing force on the steel angles applied by high tensile strength bars will confine the joint region, provide the compression stress in the joint panel, delay tensile cracking of the joint panel zone.
Presence of prestressed steel angles will create an enlarged or triple panel zone. The width of the enlarged section should be more than that of the beam and column. Some parts of the column in the enlarged area contribute to transfer the shear force from beam to column. It is employed to prevent joint shear failure and form flexural hinge in the beam.

V. FINITE ELEMENT MODELLING

The model is a half-scale beam- column joint. ANSYS, the finite element software, is employed to develop the models. Control, defective and retrofitted beam column joints are modelled and analyzed. Mesh size of 50 mm is selected for the analysis.

A. Control Specimen

Cross-sectional dimensions of the extruded beam is 200x 300 mm and its length is 900 mm. The beam is connected to the column at its mid-height point. Cross section of the column is 200x 300 mm and its total length is
2.3 m. The top and bottom reinforcement of the beam in addition to the main longitudinal steel reinforcement of the column is made of high tensile steel. The main steel reinforcement of the beam is three bars of 16 mm diameter and the secondary steel reinforcement is two bars of 12 mm diameter. The column is reinforced with four bars of 16 mm diameter at each corner of the column cross-section. The stirrups for beam and column are mild steel bars of 8 mm diameter spaced 100 mm and 150 mm for the beam and the column respectively. In addition, three stirrups are added at the beam–column joint.

B. Defective Specimen

Joint transverse reinforcement is removed and defective specimen is modelled. Retrofitting is done on the defective specimen and the effectiveness of the method is found out.

C. Retrofitted Specimen

Retrofitting is done based on two dimensional enlargement of the beam- column joints using steel angles that are mounted using prestressed cross ties. Steel angles of dimension 150x150x18mm and a plate of dimension 200x200x18mm is associated with each joint retrofit. Post tensioned bars of diameter 16 mm, length 125 mm and thickness 18 mm are used to mount steel elements and a pretension of 35 KN is applied to the bolts.

VI. MATERIAL PROPERTIES

The concrete used is a normal strength concrete of 25 MPa. The longitudinal reinforcement for both beam and columns are deformed bars of 400 MPa yield strength while the stirrups are mild steel of 240 MPa yield strength. Yield strength of post tensioned bar is 1000 MPa and that of plate is 345 MPa.

VII. MODEL OF THE BEAM COLUMN JOINT

Modelling of the beam- column joint is done and the performance of the models are analyzed.

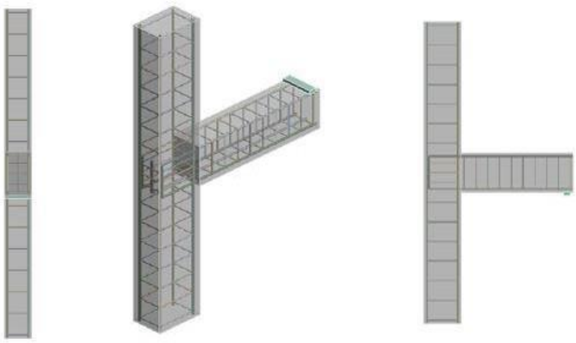

Fig. 1 Model of the Beam- Column Joint

VIII. VALIDATION

Model from the base journal [1] is selected and analyzed for the purpose of validation. Control specimen is modelled and validation is carried out using ANSYS software.

Fig. 2 Validating Specimen

IX. SEISMIC RETROFITTING

Seismic retrofitting is done on the defective specimen based on two dimensional enlargement of the beam- column joints using steel angles that are mounted using prestressed crossties. Fixed boundary conditions are provided at the beam column joint are and monotonic loading is applied at the beam tip.

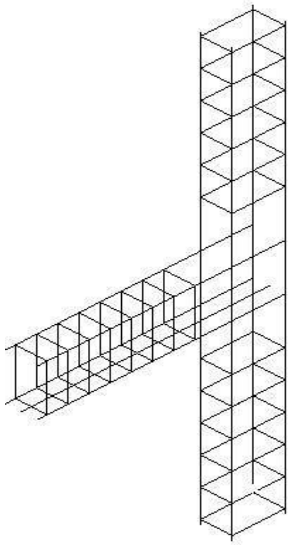

Fig. 3 Defective Specimen

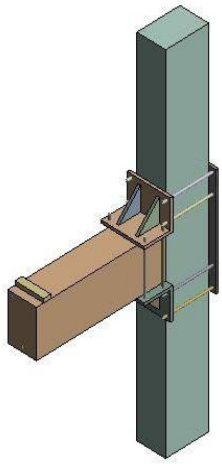

Fig. 4 Retrofitted Specimen

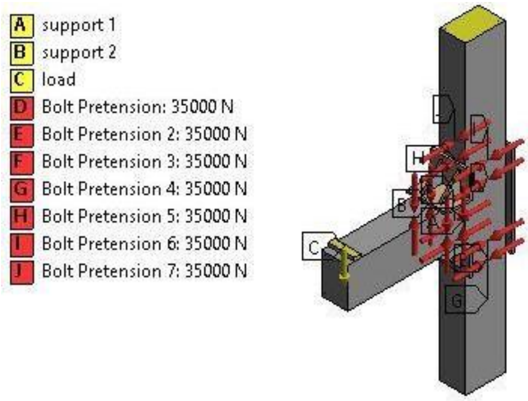

Fig. 5 Boundary Conditions and Bolt Pretension

X. RESULTS AND DISCUSSIONS

A. Validation

Validation is carried out and the results are obtained for deformation, equivalent plastic strain and force reaction.

1. Failure Mode at Joint

Failure mode at the joint given in the journal [1] and obtained through Finite Element Analysis (FEA) is plotted and compared.

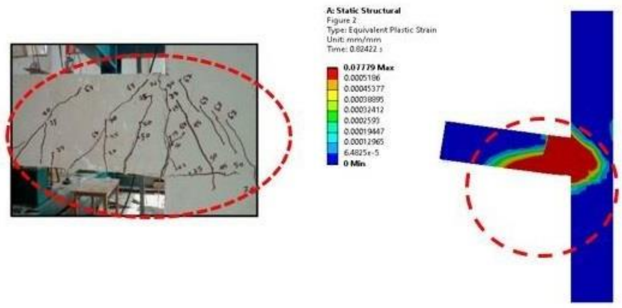

Fig. 6 a) Failure Mode (Journal) b) Failure Mode (FEA)

2. Load Deflection Curve

Load deflection curve (J0) given in the journal [1] and obtained through FEA are plotted and compared.

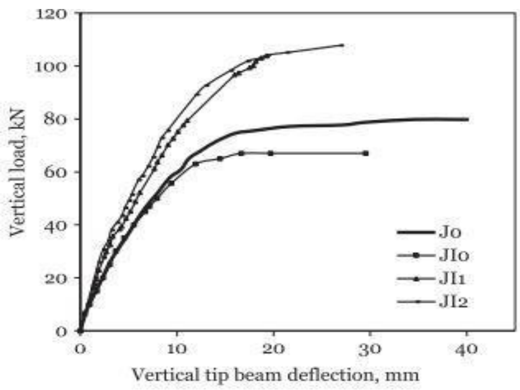

Fig. 7 Load Deflection Crve (Journnal)

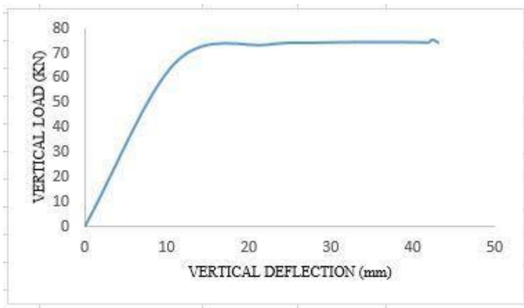

Fig. 8 Load Deflection Curve (FEA)

3. Ultimate Load and Deflection

Ultimate load and deflection given in the journal [1] andobtained through FEA are considered and compared.

Table. 1 Ultimate load and Deflection (Validation)

Models	Ultimate Load (KN)	Deflection (mm)
Journal	79.80	40.20
FEA	75.28	42.384
Error (%)	5.66	5.43

Obtained failure mode and load deflection curve are similar to that given in the journal [1]. Ultimate load obtained through Finite Element Analysis is 75.28 KN and corresponding deflection is 42.384 mm. Ultimate load and corresponding deflection mentioned in the journal is 79.80 KN and 40.20 mm. Obtained results are almost similar to thatgiven in base journal.

B. SEISMIC RETROFITTING

1. Load Deflection Curve

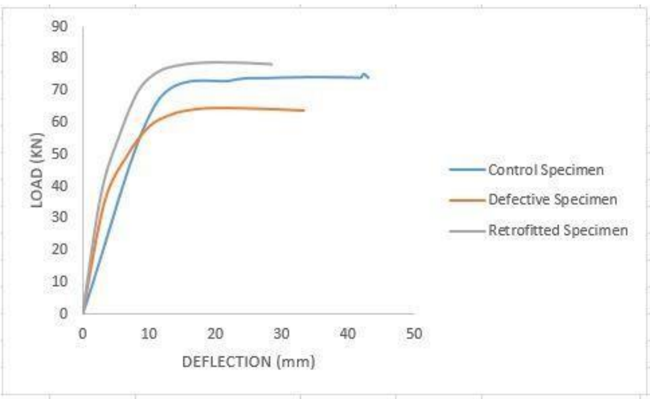

Fig. 9 Load Deflection Curve

2. Ultimate Load and Deflection

Ultimate load of control specimen is 75.28 KN and that of defective specimen is 64.524 KN. Load carrying capacity is decreased when there is no joint transverse reinforcement in the beam column joint. Deflection of defective specimen is less compared to control specimen. The values of deflection are 42.384 mm for control specimen and 23.355 mm for defective specimen. Retrofitted specimen has higher ultimate load compared to control and defective specimen and the value is 78.847 KN. Deflection of retrofitted specimen is 19.821 mm which is less than both control and defective specimen.

Table. 2 Ultimate Load and Deflection

MODELS	ULTIMATE LOAD (kN)	DEFLECTION (mm)
Control Specimen	75.28	42.384
Defective Specimen	64.524	23.355
Retrofitted Specimen	78.847	19.821

XI. CONCLUSION

From the analysis, it can be concluded that;

- Modelling of the beam- column joint is done
- Validation of the beam-column joint is done usingANSYS software
- Failure mode at the joint and load deflection curves are obtained.
- Obtained failure mode and load deflection curves are similar to that given in the base journal.
- Ultimate load obtained through Finite Element Analysis is 75.28 KN and corresponding deflection is 42.384 mm.
- Ultimate load and corresponding deflection mentioned in the journal [1] is 79.80 KN and 40.20mm.
- Obtained results are almost similar to that given in base journal with an error of 5.66% in ultimate load and 5.43% in deflection.
- Error in the results are less than 10% so the model isvalidated using ANSYS software.
- Behaviour of non-seismically detailed beam–column joints retrofitted using the method called ‘‘joint enlargement using prestressed steel angles’’ is investigated.
- Proposed retrofitting method leads to increased load carrying capacity and decreased deflection compared to control and defective joints.
- Proposed retrofitting method is an effective method in terms of load carrying capacity.

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