# Study of Shear Performance Evaluation in Beam-Column Joint at Peripheral Level

Anurag Soni[1], Prof. Nitesh Kushwaha[2]

[1]PG Scholar, [2]Head of Department

*Department of Civil Engineering, MITS, Bhopal, India*

***Abstract- Beam-column joint is the gap in the modern ductile design of building. Especially under the earthquake loading this is more susceptible to damage. Due to brittle nature of failure this type of failure cannot be afford. Since 1970's this areas is under the light of research, but with the paper of Park and Paul, It got momentum. But still due to versatile nature of the joints core behaviour, the problem is still persisting. The entire researchers till 1970's believed that RCC beam-column joints behave as rigid joint. So in none of the pre 1970 building codes, they had not provided the confining reinforcement in the joints. With lot of damage and destruction of building due to shear force under earthquake force most of the code committee to introduce the confinement in the joints. But recently due to use of high grade of concrete and better quality control in the RCC structures, confinements in the joints as per the new provision of codes leading us to the problem of the congestion. It has been observed at many construction sites that this congestion leads to poor workmanship at the joints, which actually making the joint more vulnerable than previous. Researcher has been working on this area to counter act by Increasing the size of the joints, Using the steel fiber in the joints, Using GRFP to wrap the joints, Prestressing the beam including the joint, Using of the crossed rebar at the joint cores. Due to prestressing of joint through the beam has not been so effective and economical, the present paper come up with the direct way of prestressing the joints. This paper tries to combine the benefits of the crossed rebar and prestressing in the joints together. The present work is divided into two phase. In first phase few sample of normal low and medium high building has been chosen and designed according to the IS 456:2000(LSD) and shear force are calculated as per ACI 352-02. From this phase we come to conclusion that first two stories have higher shear force demand and these are the joints more susceptible to congestion and prestressing of joint core should be implemented to these joints only.***

***Keywords: Beam-column joint, RCC, Crossed-rebar, Prestress, ANSYS, Shear force.***

## I. INTRODUCTION

Past is witness to many devastation and destruction of structure due to joint failures due to earthquakes. Beam-column joint has not been area of research for many decades because scientist believes that beam column joint behave as rigid joint with no deformation contributed by it. Beam-column joint has no problem in itself until the dead and live loads are concern. As soon as lateral loads, *i.e*. seismic force, comes into picture it will become a critical problem.

This problem has not been solved completely till date. It can be seen how the time has evolved to witness the development in the understanding of the beam-column joint core behaviour, specially related to shear force and shear deformation. Still we have translucent vision about this area. In the following discussion an endeavour is just tried to remove the dust from this area so as to make it as clear as pure water.

As we know that, practically we can't construct the structure earthquake-proof, so there must be way out to earthquake problem. And we are fortunate enough that the solution come in only one term and that is ductility. Make the structure enough ductile and forget about the force which is going to come on it.

So in short the solution to the problem of earthquake is ductility. So whatever going to come in the way of ductility and your structure you have to kill that, simple enough to understand? So in this process of removing our enemy through the research of 70 years in the seismic design, only beam-column joint shear failure is left behind. Before getting into the objective and scope of the project work on the beam-column joints an introduction is presented in the following sections.

***What is beam to column joint?***

The portion of the column where beam is use to join it is called beam-column joint. Beam-column joints are classified into three types based on the number of beams ending into the column.

i) Interior Beam-Column joints

ii) Exterior Beam-Column joints

iii) Corner Beam-Column joints

## II. BACKGROUND

**Bakir and Boduroglu (1991)** proposed a model for the prediction of the shear strength of the beam-column joints. The paper considers the three new parameters for the first time to predict the shear strength of the joint. These parameters are beam longitudinal reinforcement ratio, beam-column joint aspect ratio and the influence of stirrups ratio. It concluded that beam longitudinal reinforcement ratio has positive effect on the joint shear strength. Because the influence of beam longitudinal reinforcement ratio is taken into account, the proposed equation predicts that the joint shear strength is proportional to $(hb/hc)^{0.61}$.The paper also concluded that the column axial load has no effect on the shear strength but the high column axial load and high column longitudinal reinforcement is required to prevent the column failure.

**Park and Mosalman (1993)** given a shear strength model of the exterior beam-column joints without shear reinforcement, which can be useful in required confinement reinforcement to prevent the shear damage.

**Muhsen and Umemura (1995)** proposed a model to estimate the strength of the interior beam-column joint with consideration of the confinement reinforcement and axial force. The proposed model is similar to the current ACI and AJI codes with little modification in the effective area of the joint panel and considering the confinement due to axial force in the column and confinement reinforcement in the joint core. None of the codes has considered the confinement effect in the estimation of the shear strength of the beam-column joint.

**Pimanmasa and Chaimahawanb (1997)** present paper to prevent the beam-column joints by enlarging the joint area. The paper concluded that the joint enlargement. It is a very effective method to reduce the shear stress transmission in the joint panel and hence effective in preventing the damage. There has been also change in the failure mode with the relocation of the plastic hinge from the face of the beam to the face of the enlarge section. The model is well explain with the strut and tie model.

**Kang and Mitra (2001)** proved that the increasing development length, head thickness and head size and decreasing joint shear demand gives better beam-column joint performance. The paper also showed that increasing rebar yield strength, joint confinement reinforcement and axial load leads to unpredictability of the performance of the beam-column joints. After going through the every parameter they found that joint shear demand and bar yield stress are two major parameters from influential point of view.

**Jung et. al. (2003)** has given a method to predict the deformation of the RC beam-column joints with BJ (joint failure after hinge formation in the beam) joint failure. Also it shows that the deformation of the joint increases with the decrease in the beam rebar. The paper has given method to calculate the ductility capacity of the beam-column joints.

**Soleimani et al. (2005).** As the inelastic response of the plastic-hinges are defined by the hysteretic curve. For every different beam-column joints a separate curve has to be generated. So the generalization of this model is very hard to implement.

**Fillipou and Issa (2006)** proposed a model that could give due consideration to the effect of bond deterioration on the hysteretic behaviour of the joints. The proposed model consists of a concentrated rotational spring located at each girder end. The two springs are connected by an infinitely rigid bar to form the joint sub element.

**Hassan (2008)** summarizes the available macro models for joint simulation. However, some of these models may be unsuitable for older concrete building assessment, either because they were developed and calibrated for confined joints or because they are complicated to use. One of the models that may be suitable, designated the scissors model, is a relatively simple model composed of a rotational spring with rigid links that span the joint dimensions. This model is a simplification of macro model developed originally for steel panel zones.

**El-Metwally and Chen (2009),** given a model for predicting inelastic joints moment-rotation response under cyclic loading. Rotational-hinge model predict the deformation response of the beam-column joints moderate increase in the computational effort but unable to develop accurate calibration procedures. The model needs to develop the moment-rotation relationship to predict the deformation in the joints. The model is defined to dissipate the maximum amount of the energy through the bond-slip of the rebar.

**Kunnath et al. (2010)** modified the flexural capacities of the beams and columns of gravity load designed RC frames to model insufficient positive beam bar anchorage and inadequate joint shear capacity implicitly. The pullout moment capacity of the beam was approximated as the ratio of the embedment length to the required development length per ACI 318–89 multiplied by the yield moment of the section.

**Alath and Kunnath (2010)** modelled the joint shear deformation with a rotational spring model with degrading hysteresis. The finite size of the joint panel was taken into account by introducing rigid links. The envelope to the shear stress–strain relationship was determined empirically.

**Pampanin et al. (2011)** consisting of a non-linear rotational spring that permits one to model the relative rotation between beams and columns converging into the node and to describe the post cracking shear deformation of the joint panel. Beam and column elements are modelled as a one dimensional element with lumped plasticity in the end sections with an associated moment–curvature relationships defined by a section analysis. The definition of the moment–rotation relationship of the rotational spring is based on the results of experimental tests (2003). A relation between the shear deformation and the principal tensile stress in the panel region was found and transformed into a moment rotation relation to be assigned to the rotational spring. The shear deformation is assumed to be equal to the rotation of the spring and the moment is deduced as corresponding to the principal tensile stress evaluated on the basis of Mohr theory.

**Biddah and Ghobarah (2013)** modelled the joint with separate rotational springs for joint shear and bond–slip deformations. The shear stress–strain relationship of the joint was simulated using a tri-linear idealization based on a softening truss model, while the cyclic response of the joint was captured with a hysteretic relationship with no pinching effect.

**Elmorsi et al. (2014)** proposed an approach where beams and columns are described by elastic elements connected to the joint through the interposition of non-linear transitional elements. The effective node panel region is modelled with another element constituted by 10 joints.

## III. PROBLEM IDENTIFICATION AND OBJECTIVES

There are three major reasons which make this deformation model highly limited for the practical use:

(1) This approach for the deformation model needs very high computational effort and making the simple analysis too time consuming. With current computational advancement it is very hard for researcher and practicing engineers to implement it with their limited facilities.

(2) These types of deformation models could never meet the requirements for robustness under a wide range of joint designs and model parameters.

(3) This model required many material constitutive parameters. While most of these parameters will represent fundamental material properties, but few of them cannot be easily produce leads to some kind of assumption about the material models which constitutively leads to error in the response calculation.

With introduction presented in this chapter and literature review in the next chapter the salient objective of the present study is presented below:

(1) To find the joint height which is more critical from the point of view of reinforcement congestion and maximum joint shear demand.

(2) To find the effectiveness of the direct joint prestressing to divert the failure from the joint to the beam by reducing the shear demand at the joint by combine effect of crossed rebar and prestressing.

## IV. METHODOLOGY

The present work is divided in two phases. The first phase is to find the critical joints with respect to the reinforcement congestion and shear force demand. And second phase deals with the effectiveness of the direct prestressing of the beam-column joint in mitigating the brittle failure at the joint to the ductile failure in the beam. An introduction to methodology of both phase are presented here. More detailed one is presented in the chapter 3.

First Phase Methodology:

1. Few samples of the low and midrise 2D building are selected with standard dimensions and standard loading.
2. All building is being designed as per IS 456:2000(LSD).
3. Shear force has been calculated as per ACI:352-02
4. Critical joints have been shorted out on which the prestressing is being applied as going to be proposed in the phase 2.

Second Phase Methodology:

1. Two exterior beam-column joints which were going to fail at joints due to shear failure have been selected from the literature.
2. Both the joint has been modelled in ANSYS v13 as per the experiment performed in the literature to verify the result.

Direct prestressing is implemented in ANSYS model on both of the joints to see the improvement in shear deformation, shear strength, shear demand and failure pattern.

## V. RESULTS AND ANALYSIS

A parametric study has been done on the benchmark building to study the distribution of joint shear demand of the joints for the building designed as per IS456:2000 and detailed according to IS 13920:1993 if provision applied.

The benchmark building is selected as the 3 story and 3 bay structures. The following parameter are varied to the verified influence of these on the shear demands of the joint under the given most critical loading, which is found to be the 1.5DL+1.5EQ.

Followings are the parameter which has been checked to understand their influence on the joint shear demand. And following that the graph has been shown to discuss how they are affecting the shear force demand of the joints.

a. Support conditions
b. Story height
c. Number of story or height of the building

d. Width of the bays

e. Number of the bay

f. Grade of the concrete

g. Size of the beam

h. Size of the column

**Table 1: Analysis of Fx for without prestress and with prestress**

| Number of Level (Building) | Without Prestress (Fx kN) | Prestress (Fx kN) |
|---|---|---|
| 1 | 7068.769 | 7071.706 |
| 2 | -424.079 | -425.174 |
| 3 | -32.759 | -28.988 |
| 4 | -32.599 | -29.194 |
| 5 | 604.922 | 604.965 |
| 6 | 3231.5 | 494.524 |
| 7 | 94.536 | 109.275 |
| 8 | 94.465 | 61.842 |
| 9 | 528.94 | 529.113 |
| 10 | 2917.089 | 2911.543 |
| 11 | 4551.995 | 4541.972 |
| 12 | 4556.633 | 4577.882 |

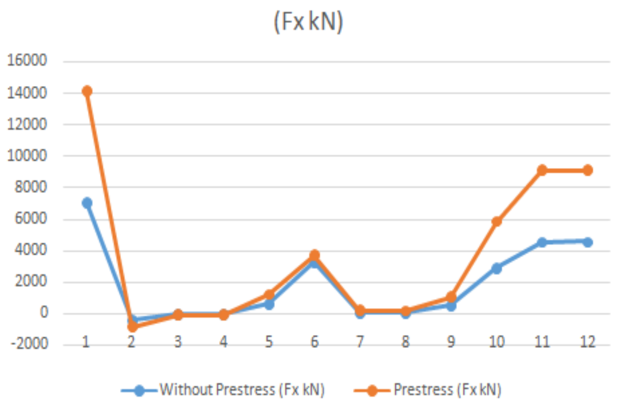


**Figure 1: Graphical comparison Fx for without prestress and with prestress**

As per table 1, the value of Fx (Shear force in x direction) has been improve in prestress case. When increase the level of building then improve Fx drastically. By apply to cross prestressing there is increase in the shear strength of the concrete in the joint core. A model can be formulated to calculate the increase in shear strength of the joint core. The above figure 1 also shown this situation.

As per table 2, the value of Mx (Shear Momentum in x direction) has been improved in prestress case. When increase the level of building then improve Mx drastically. By apply to cross prestressing there is increase in the shear strength of the concrete in the joint core. A model can be formulated to calculate the increase in shear strength of the joint core. The below figure 2 also showed this situation.

**Table 2: Analysis of Mx for without prestress and with prestress**

| Number of Level (Building) | Without Prestress (Mx kNm) | Prestress (Mx kNm) |
|---|---|---|
| 1 | 0.044 | -0.138 |
| 2 | -2.579 | -2.527 |
| 3 | 36.288 | 36.389 |
| 4 | -36.284 | -36.318 |
| 5 | 2.485 | -4.612 |
| 6 | -0.187 | -0.263 |
| 7 | 69.092 | 69.052 |
| 8 | -69.217 | -70.589 |
| 9 | 2.485 | 2.38 |
| 10 | 4.239 | -4.571 |
| 11 | -5.922 | -2.938 |
| 12 | 6.051 | 2.452 |

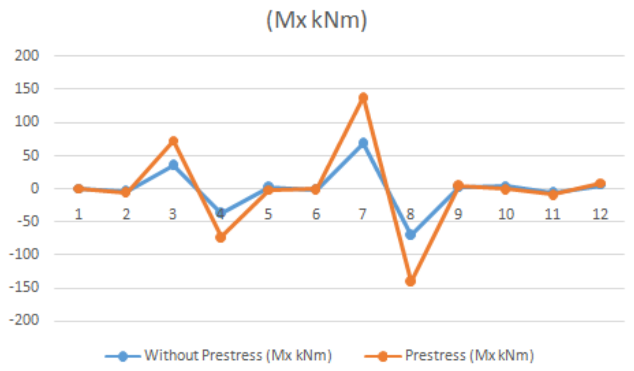


**Figure 2: Graphical comparison Mx for without prestress and with prestress**

## VI. CONCLUSIONS

The following are point-wise conclusions which are being drawn from the proposed Exterior Beam-Column Joints with pre-stressed joint core:

1. Maximum joint shear demand are located at lower portion of building, starting from second story joint for both interior and exterior joints for the fixed support.

2. Maximum joint shear demand is located at first story joints for the hinge support condition for the both interior and exterior joints.

3. The ratio of height of maximum shear to building height is coming out as 0.4 for the fixed support.

4. Shear forces demand increases with the increase of the Number of Story, Height of Story, Width of Bays and Decreases with the Increase of Depth of Beams.

5. Grade of Concrete, Number of Bays and Size of Columns has no effect on the demand of the shear forces in the beam-column joints.

6. Due to prestressing the Exterior Beam-Column Joints there has been increase in the shear strength of the concrete in the joint core. But model for the calculation of the shear strength of concrete in the prestressed beam-column joints has not been presented in the present work.

7. Due to crossed prestressing with the rebar, strut and tie model has been invoked in the joints enhancing the performance of the joints. With prestressed rebar acting as tie enhances the crack resistance in the joint and consequently enhance the strut concrete performance which will act as better than without stressed post crack condition.

8. Due to presence of the steel plate at the face of the Beam-Column joint, plastic hinge shifted at the edge of the plate. This shifting of the hinge toward the centre of the beam leads to the less lateral displacement at same given rotation at plastic hinge.

9. As per experimental work, proposed technique has improved shear force (Strength) and shear momentum in 3D environment by 4.15% and 1.31% respectively.

In future, following work may be extend

1. Due to cross prestressing there is increase in the shear strength of the concrete in the joint core. A model can be formulated to calculate the increase in shear strength of the joint core.

2. The above result clearly shows the increase in the performance of the joint due to cross-prestressing which may leads to the decrease in the joint confinement reinforcement. Further a formulation can be generated to calculate that how much reinforcement can be reduced due to this cross-prestressing.

## REFERENCES


[1] Rajagopal, S. and Prabavathy, S. (2013). Investigation on the Seismic behavior of the Exterior Beam-column joint using T-type mechanical anchorage with hair-clip bar. Journal of King Saud University-Engineering Sciences.

[2] Thomas H.K.Kang and Mitra N. (2012). Prediction and performance of Exterior Beam-Column Connections with the headed bars subjected to load reversal. Engineering Structures 41(2012) 209-217.

[3] Pimanmas, P. and Chaimahawan, P. (2011). Cyclic shear resistance of Expanded Beam-Column Joint. Procedia Engineering 14(2011) 1292-1299.

[4] Pimanmas, P. and Chaimahawan, P. (2010). Shear Strength of Beam-Column Joint with Enlarged Joint area. Engineering Structure. 32(2010) 2529-2545.

[5] Pantazopoulou, S. J. and Bonacci, J. F. (1994). On earthquake resistant reinforced concrete frame connections. Canadian Journal of Civil Engineering, 21, 307–328.

[6] Rots, J. G. and Blaauwendraad. J. (1989). Crack models for concrete: Discrete or smeared? Fixed, multidirectional or rotating? Heron, 34:1, 334–344.

[7] Will, G. T., Uzumeri, S. M. and Sinha, S. K. (1972). Application of finite element method to analysis of reinforced concrete beam-column joints. In Proceedings of Specialty Conference on Finite Element Method in Civil Engineering, CSCE, EIC, Canada, 745–766.

[8] Hegger, J., Sherif, A. and Roeser, W. (2004). Nonlinear Finite Element Analysis of Reinforced Concrete Beam-Column Connections. ACI Structural Journal, 101:5, 601-614

[9] Lowes, L. N., Altoontash, A. and Mitra, N. (2005). Closure to "Modeling reinforced concrete beam-column joints subjected to cyclic loading" by L. N. Lowes & A. Altoontash. Journal of Structural Engineering, ASCE, 131:6, 993–994

[10] Noguchi, H. (1981). Nonlinear finite element analysis of reinforced concrete beam-column joints. In IABSE Colloquium, Delft, the Netherlands, 639–653.

[11] LaFave, J. M. and Shin, M. (2005). Discussion of "Modeling reinforced concrete beam-column joints subjected to cyclic loading" by L. N. Lowes & A. Altoontash. Journal of Structural Engineering, ASCE, 131:6, 992–993.

[12] Baglin, P. S., and Scott, R. H. (2000). Finite element modeling of reinforced concrete beam-column connections, ACI Structural Journal, 886-894.

[13] Walker, S.G. (2001). Seismic Performance of Existing Reinforced Concrete Beam-column Joints. M.S. Thesis. University of Washington, Seattle.

[14] Alath, S. and Kunnath, S. K. (1995). "Modeling Inelastic Shear Deformation in RC Beam-Column Joints Engineering Mechanics: Proceedings of 10th Conference: University of Colorado at Boulder, Boulder, Colorado. May 21-24, 1995. Vol. 2. New York: ASCE: 822-825.