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SHEAR DEMAND AND SHEAR DEFORMATION IN EXTERIOR BEAM-COLUMN JOINTS

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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 prestessing 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 prestessing of joint core should be implemented to these joints only.

In the second phase two exterior beam-column joint from previous experimental programme. They were model and analyse using ANSYS v13. Improvement in the ultimate load and failure pattern has been detailed in the thesis. From this phase we come to conclusion that this

new technique is more effective than the previous prestressing technique of joints.

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.

1.1What 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

1.2 Background Problem with the Beam-Column Joints

Beam-column joint is subjected to very high shear forces due to pulling of top rebar and pushing of bottom rebar's or vice versa in the concrete structure especially during the earthquake loading. These very high shear force leads to the brittle damage, which can't be accepted in the earthquake resistant building which has to be ductile in nature to deal with unseen forces. Building damaged by the joint failure is shown in Fig 1.1.2.

These failures on the technical ground can be classified into three types as mentioned below:

i) Shear failure of the joint before plastic hinge in the beam, J.

ii) Shear failure of the joint after the plastic hinge in the beam, BJ.

iii) Bond failure of the longitudinal due to slippage of the bar due to excess tension in the bar. From through study of the literatures on the beam-column joints it was interpreted that these individual or the combination of failure are depend on the sets of few parameter which are presented in the tabular form below.

The researchers are mainly concern about three things about the beam to column joints. i. Deformation due to joint behaviour,

ii. Joint shear demand and

iii. Joint shear capacity.

II. MECHANICS OF BEAM-COLUMN JOINT CORE: SHEAR FORCE

Shear force is very critical in the earthquake resistance design of the structure because of it induce brittle failures. But if the structure is subjected to lateral force due to wind or earthquakes most of the shear force is being concentrated in the joint cores, which leads to the brittle failure of the many structure in the past earthquakes. Even though the mechanic of the calculation of the shear force in the joint core is very simple it had been ignore for many decades with the wrong assumption of the rigid joint behaviour. The detail mathematical formulae to calculate the shear force demand and shear force capacity has been well presented in Chapter 2.

III. MECHANICS OF BEAM-COLUMN JOINT: SHEAR DEFORMATION

Deformation of the joints contributes significant lateral drift of the story and the global story displacement. But due incapability to calculate the shear deformation most of the code till present assume the rigid joint behaviour of the joint. Which may sometime leads to significant error in the calculation of the max story displacement. Estimation or calculation of lateral story drift due to shear deformation of the joint is very challenging. From the past many scientist has tried to solve this riddle. They proposed many different type of models starting with the rigid joint assumption, matrix method based on the central line analysis, implementation of the panel zone concept to add the shear deformation, adding rotational hinge and the use of full scale finite element analysis etc. with every advancement they are moving forward to the accurate estimate of the shear deformation. Detailed version will be discussed in the literature review section. Here we will over view the status of estimation and contribution of shear deformation in the global deformation of the building. Following are the deformation model propose in the timeline orders

1. Conventional rigid joint model
2. ASCE/SEI 41-06 joint model
3. Modelling inelastic joint action within the beam-column element
4. Rotational hinge models
5. Continuum models and FEM

IV. FINITE ELEMENT ANALYSIS

FEA is a powerful computational technique for approximate solutions to a variety of complex "real-world" engineering problems having complex domains subjected to general boundary conditions. FEA has become an essential step in the design or modelling of a physical phenomenon in various engineering disciplines including civil engineering, aeronautical engineering and many more. The second phase of this project is completed with the finite element software ANSYSv13. An introduction about the finite element method has been presented in following sections.

4.1 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 prestessing 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.

4.2 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.

4.3 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.
3. 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. SHEAR FORCE DEMAND AND CAPACITY

Bakir and Boduroglu (2002) 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 $(h_b/h_c)^{0.61}$.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 (2009) 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 (2011) 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 (2010) present paper to prevent the beam-column joints by enlarging the joint area. The paper concluded that the joint enlargement as shown in the Fig:

2.2.1 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 (2012) 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. (2009) 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.

VI. BEAM-COLUMN JOINT DEFORMATION MODELS

Modelling of the building against earthquake forces and any other types of lateral forces is based on the inelastic plastic hinge formation in the beam, slab and wall etc. But following researches proved the contrary (Meinheit and Jirsa, 1977; Durrani and Wight, 1985; Park and Ruitong 1988; Leon, 1990; Clyde et al., 2000; Mazzoni and Moehle, 2001; Lowes and Moehle, 1999; Walker, 2001) and showed that there are significant contributions by the beam-column joints to the overall deformation in the structure. So scientist has shown that the deformation contribution by beam-column joints can even goes up to 40% of the total deformation due to both elastic and inelastic deformation. Researcher has been trying to develop many different mathematical and FE model to accurately predict the deformation in the joint cores. As per study of different beam-column joint deformation models, the following literature review has been classified into five broad classes. This is mention below.

6.1 Conventional Rigid Joint Model

A common engineering practice has been to model the beam-column joints in concrete frames as rigid elements spanning the full joint dimensions. Some analysts have recognized that this model overestimates stiffness and instead have used a model in which the beam and column flexibilities extend to the joint centre-line. Studies show that the rigid joint model overestimates stiffness and underestimates drift because of ignoring join shear deformations and slip of reinforcement. The centre-line model can overestimate or underestimate stiffness. Rigid joint stiffness overestimation shortens natural period and affects the attracted seismic forces. Recent tests by ***Hassan (2011)*** showed that joint flexibility contributed significantly, up to 40%, to overall drift, especially in the nonlinear range.

6.2 ASCE/SEI 41-06 Nonlinear Joint Model

ASCE/SEI 41-06 suggests modelling joints in concrete frame linear analysis using rigid links that cover partially or fully the joint dimensions. The modelling approach accounts for beam bar slip rotation using reduced flexural column and beam stiffness. For nonlinear analysis, ASCE 41 suggests a backbone curve for joint shear strain modelling, with shear strength based on the number of members framing into the joint.

However, approaches to implement this model are not described. It is clear that ASCE 41 is quite conservative in terms of estimating joint shear strength and plastic shear deformations. These backbone curves will be implemented in a cyclic model for comparison with cyclic test data in a subsequent section.

The shear strength provisions of ASCE 41 are inaccurate for unconfined exterior and corner joints because they do not account for several parameters that may affect joint strength, including joint aspect ratio, beam reinforcement ratio, axial load ratio, and bidirectional loading. The ASCE 41 nonlinear modelling parameters for unconfined joints are overly conservative, especially with high axial loads, resulting in unrealistically severe strength degradation and low drift capacity.

6.3 Modelling Inelastic Joint Action within the Beam-Column Element

In this model researcher tried to model the beam or column elements such that whatever the deformation going to come in the beam-column joints can easily be predicted by the deformation in the beam or column by relating the beam or column inelastic or elastic deformation with some parameters. Many researchers has presented the papers on above philosophy like Townsend and Hanson (1973), Anderson and Townsend (1977) and Soleimani et al. (1979). 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 (1988) and Fillipou et al. (1988) proposed a model that could give due consideration to the effect of bond deterioration on the hysteretic behaviour of the joints (Fig. 2.4.3.1). 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.

6.3.1 Rotational Hinge Models

Beam-column joint rotational hinge models decoupled the inelastic deformation response of the beam-column joint from beams and columns as specified in the previous models. Zero- length rotational spring elements which are being used by *(El-Metwally and Chen 1988; Alath and Kunnath, 1995)*.They connect beam elements to column elements and thereby represent the shear distortion of the beam-column joints. Many nonlinear joint models are proposed on this concept. *Hassan (2011)* 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. *Alath and Kunnath (1995),* recommend the method to calibrate the beam- column joint moment-rotation data from beam-column sub assembly test. *El-Metwally and Chen (1998),* 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.

6.4 Continuum Models

With the advancement of the high performance computing technology researchers start using continuum-type

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elements to represent the inelastic deformation responses beam-column joints. These proposed elements behave as "transition element". Which are formulated to establish compatibility between beam-column line elements that symbolize the deformation behaviour of the element outside to the joint cores and other planar continuum elements that stand for the structure inside the beam-column joints. These types of FE formulation of the joint models are very accurate in predicting the deformation contribution of the beam-column joints but at the same time need very high computational demand. But presently due to limitation in the computational advancement researcher (Fleury et al. 2000; Elmorsi et al. 2000) has taken very simple idealisation to optimize the results

Pantazopoulou and Bonacci (1994) utilized modified compressive field theory (MCFT), which primarily considers reduction in compressive strength due to tension in orthogonal direction, to represent behaviour of concrete.

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.

VII. PHASE I: JOINT WITH MAXIMUM SHEAR FORCES

As I have already discussed in the introduction section that as per the new building codes detailing of few of the beam to column joint where the maximum shear force is being inducted faced the practical problem of the congestion. This research is basically to solve that problem. So the first phase of the work is dedicated to find out the beam to column joint which may goes under maximum shear force demand under all the possible parameter variation. So I have arbitrary chosen a building of 3 story and 3 bays with 3m as the height of the story and 3m as the width of the bay. For easy reference, this building is named as *"reference building"*. Many parameters have been selected from lot of literature review which are supposed to affect the shear demand of the beam to column joints. Taking these parameters studies has been done to find the influence of these parameters. All the different buildings with different parameters have been design with STAAD.Pro according to IS

456:2000 "Limit State Method" and shear force is calculated according to the ACI 352-02. Joints with the maximum shear force are shorted out where probable congestion is being expected. Final motive of this whole parametric study is to find the most critical combination of the parameters which give the most critical shear force demand at beam to column joints i.e. finding the location of most critical joint and value of shear force into that joints. Following are the range of parameters which has been taken for the parametric studies.

a. Story heights: it varied from 3m 3.5m and 4m in the reference buildings.
b. Number of story or height of the building: It is varied from 2^{nd} story to 10^{th}

story with each as 3m of height.

c. Width of the bays: Bays width has chosen as 3m 4m and 5m

d. Number of the bays: number of bays has also be chosen as 3 4 and 5

e. Grade of the concrete: Grade of the concrete is taken as 30MPa, 35MPa, 40MPa, 45MPa, 50MPa, 55MPa and 60MPa.

f. Size of the beams: Size of the beam are varied from 350, 400, 450 and 500mm g. Size of the columns: The sizes of the columns have been change from 400mm, 450mm, 500mm, 550mm and 600mm.

A step by step method for calculating the maximum shear forces in the joints is explained below.

1. A reference building of 3 story and 3 bay of 3m each has been selected

2. Following data has been used for the design of the building a. Reinforced concrete plain frame.

b. Material: M25 and Fe415 c. Type: Residential building d. Load:

i. Dead load 20kN/m (excluding self-weight)

ii. Live load 10kN/m iii. Earthquake load

1. Zone= V

2. Soil type= II

3. Response reduction= 5

4. Importance factor= 1

3. Design and analyzed using STAAD.Pro V8i according to IS 456:2000

4. Seven key factors are consider to study the influence on the joint shear demand for both fixed and hinge support:

a. Story height

b. Number of story or height of the building c. Width of the bays

d. Number of the bay

e. Grade of the concrete f. Size of the beam

g. Size of the column

5. Then shear demand of the exterior joints are calculated by the simple formula mechanics as given below.

Column shear in the joint, V_c

$$V_c = 1.4 \times \left(\frac{M_h + M_s}{h} \right)$$

$$V_j = T_1 + T_2 - V_c$$

VIII. PHASE II: MODELING IN ANSYS

8.1 Introduction

ANSYS is general FE software which could model the concrete and reinforced concrete with high level of accuracy. For the present study ANSYS v13.0 is being used. It is very accurate in predicting the cracks and crushing behaviour of the reinforced concrete.

Modelling in ANSYS is providing appropriate elements, defining geometry and assigning the suitable material models. Modelling is the most time consuming part of the FEM analysis. So it should be done with very care and patience. Few of the basic theory must be followed before going for the modelling in ANSYS specially of the concrete modelling. One major problem which has been encountered by the engineer/scientists working in the FEM of concrete in the convergence problem associated with it. Due to cracks, concrete is generally not able to converge so some of the convergence criteria has to be dropped to get the accurate results, ***Wolanski (2004).***

In present work an exterior beam to column joints taken from the experimental studies of ***Dar (2011)***. ***Dar (2011)*** conducted the experimental study to find the effect of different wrapping techniques on retrofitting of RCC exterior Beam to Column Joints using Ferro cement on the weak beam to column joint. First of all the exterior joint is being modelled in ANSYS as the experimental program to act as the control specimen as shown in the Fig 3.3.1. And the second ANSYS model is created with prestressing force through rebar is being applied at the joint with the help of the steel plates acting as the bearing as shown in the Fig 3.3.2. For the easy reference each exterior joint has specified B1 and D1 respectively.

8.2 Assumption

To model the real world problem into any of the FE software we have to make few assumptions to simplify the problem. Below is the assumption which has been taken during modelling of the present work.

- Concrete is assumed to be behaving as isotropic and homogeneous.
- Steel rebar and steel plate are also assumed as isotropic and homogeneous.
- Steel rebar is model as bilinear material model. With kinematic hardening model.
- No slip of rebar is assumed. Where ever the concrete element nodes and rebar nodes is coinciding it is taken as same. Leading to the perfect bonding between the concrete and rebar. And also between plate and concrete.

IX. MODELLING

Modelling of the Exterior Beam-column Joints B1 and D1 in ANSYS is done as per the experimental programme of ***Dar (2011)*** and the present proposed work.

9.1 Meshing

For the better results of Solid65 element, it is always meshed as rectangular brick mesh as recommended by ***Wolanski (2004).*** So, all the concrete Solid65 elements are meshed as rectangular brick element with 25mm size. As there is no requirement of the meshing of the rebar element, it is joined as element between the spacing of the nodes created by the meshing of the concrete.

9.2 Load and Boundary Condition

Both the top and the bottom of the column are fixed as per the experimental programme by ***Dar (2011)***. Beam is kept as cantilever and point loads up to failure are applied at 300mm from the face of the column with the help of steel plate to avoid crushing at the point of loading as shown in Fig 3.3.8.1. These loading and boundary conditions are kept same for both type of Exterior Beam-Column Joint i.e. B1 and D1.

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9.2.1 Analysis Type and Solution Control

Exterior Beam-Column Joint as per ***Dar (2011)*** and the proposed model of The Exterior Beam-Column Joint is analysing as the static analysis. The restart command has been used to restart the analysis with the dropped force convergence criteria after first crack to achieve the accurate result and to avoid the convergence problem due to loss of stiffness after the first crack. Following is the solution control and convergence criteria have been used.

Table 3.3.9.1: Solution control for the non-linear analysis by ANSYS	
Analysis option	Small displacement (geometry nonlinearity ignored)
Automatic time stepping	On
Write items to results file	All solution items
frequency	Write every sub steps
Equation solvers	Sparse Direct(for concrete)
Number of restart files	1
Line search	Off
Maximum number of iteration	100

All those values which are not specified here are taken as default to ANSYS (v13).

The nonlinear convergence criteria use in the analysis is being presented in the Table below. Force and deformation criteria are being used in the present nonlinear analysis.

Table. 3.3.9.2: Nonlinear convergence criteria		
Type	F	U
Ref. Value	Calculated	Calculated
Tolerance limit	0.005	0.05
Min. reference	Not applicable (-1)	Not applicable (-1)

Two different convergence criteria are being used in the whole non-linear analysis of the exterior beam-column joints B1 and D1. In the first phase of analysis before the first crack in the concrete there is being no problem of the convergence so both force and displacement criteria as mentioned in the Table 3.3.9.2. But after the first crack in the concrete, convergence was impossible with the above mention value. So after the convergence failure after the first crack, forced convergence criteria was dropped. And at the same time load steps are increased to consider the loss of stiffness due to increase in the crack of concrete.

X. PHASE I: STAAD.PRO RESULTS

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

As you can see from the figure that joint name E1 shear demand is more for only up to two- story building(fixed support) and thereafter E2 shear demand is leading. From this figure it is clear that joint shear demand of the 2nd story level is critical but the gap of difference goes on decreasing as the number of story goes on increasing.

Floor Level

3storey building	4 storey building	5 storey building
6 storey building	7 storey building	8 storey building
9 storey building		

This figure is also plotted on the same data but with respect to floor level (fixed support). As you can see that first story joint shear demand is less as compare to the above few joint but again the shear demand decrease very fast. This trend is same for all type of story.

This figure shows the shear demand of the joint at the various levels with increasing number of story for the hinge support. As you can see that due to hinge support there is drastic increase in the first level of joints.

XI. PHASE II: NONLINEAR ANSYS RESULTS

Comparison of results between “The Traditional Beam-Column Joints” and “The Prestressed Beam-Column Joints”:

In the following section ANSYS results are being used to demonstrate that how the prestressing the joint core as shown in Fig 3.3.3 with the normal stirrups confined joints as shown in Fig 3.3.1 as specified earlier.

B1: Exterior Beam-Column Joint with core stirrups as experimentally tested by ***Dar (2011)***

D1: Exterior Beam-Column Joint with prestressed core as proposed by the present work. There extra three rebar are crossed running through the joint with the stain of 0.005. Plates are used just as the bearing to avoid the crushing of the concrete at the corner.

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11.1 Comparison Between Crack of the Both Joints

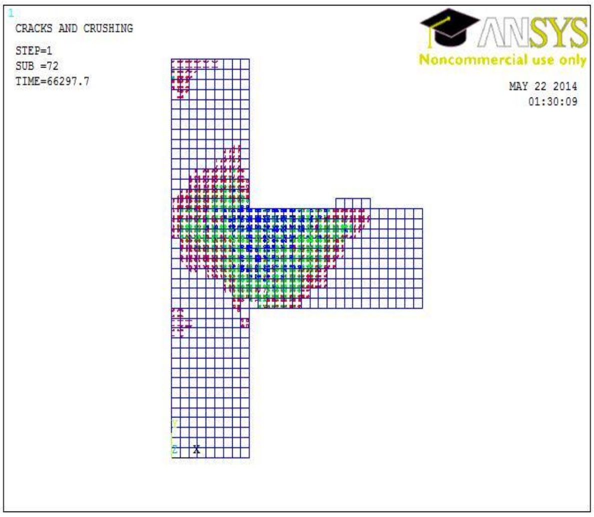

Fig. 4.12: Cracks Pattern of B1 at the Ultimate Loads of 66.3kN

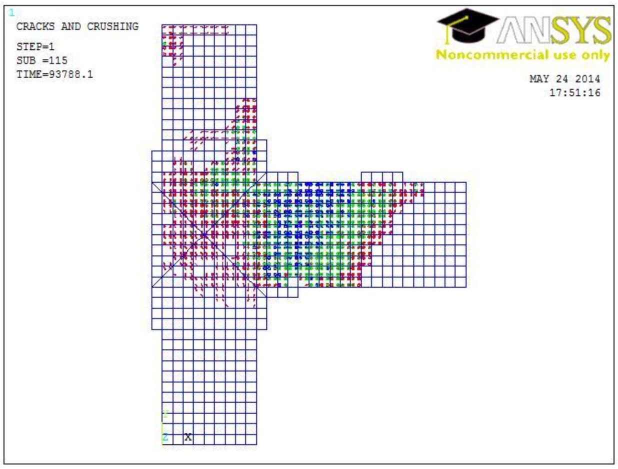

Fig. 4.13: Cracks Pattern of the D1 at the Ultimate Load of the 93.7kN

11.2 Comparison of the Shear Stress Distribution in the Joints of Both Type

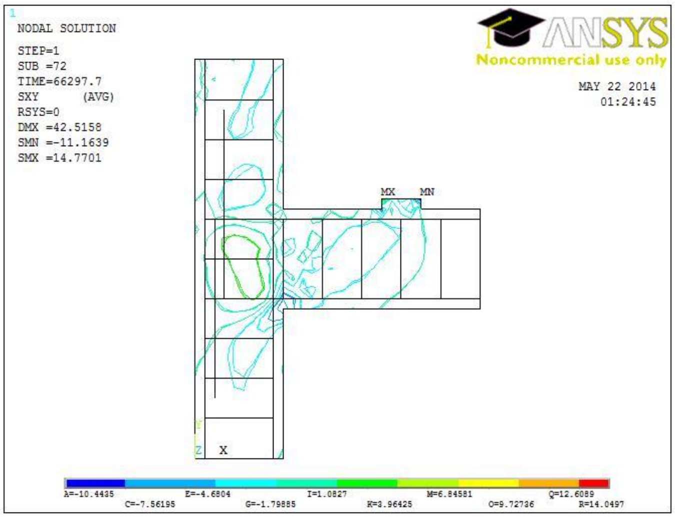

Fig. 4.14: Shear Stress Distribution of the B1 at the Ultimate Load 66.3kN

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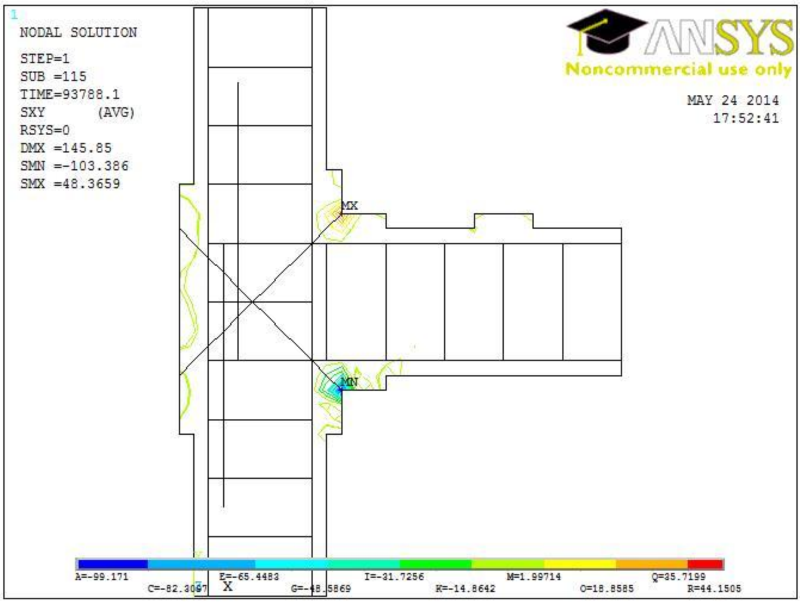

Fig. 4.15: Shear Stress of the D1 at the Ultimate Loads of 93.7kN

By comparing the fig 4.14 and fig 4.15 it can be clearly stated that in B1 the shear force is more concentrated in the joints. This proves the experimental test data of shear failure of joint. The fig 4.15 in which prestressing are being used clearly helped in putting the shear stress out of the joint core and ultimately avoiding the shear failure of the joint.

11.3 Deflection Comparison of the Both Type of the Joints

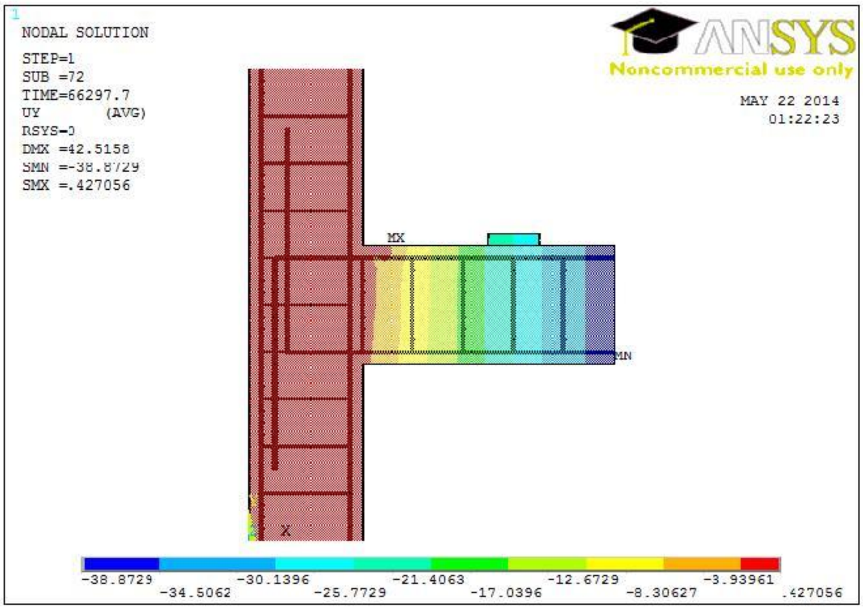

Fig. 4.16: Deflection Profile of B1 at the Ultimate Load of 66.3kN

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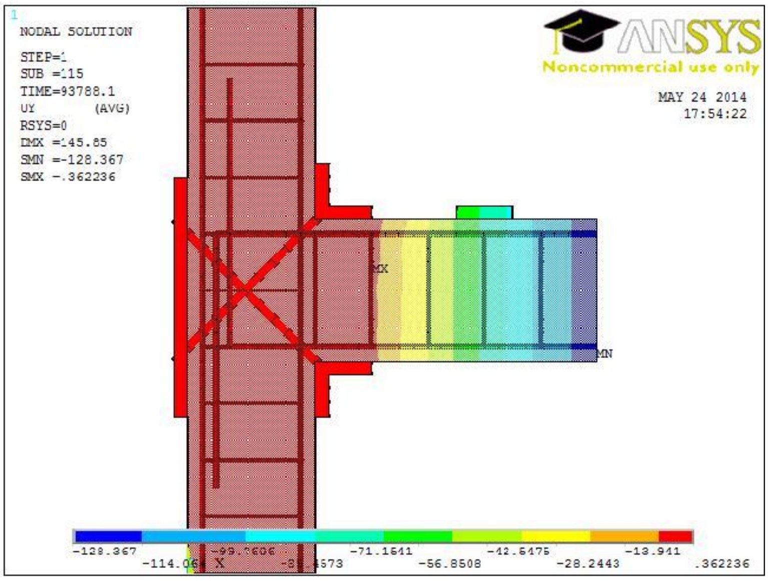

Fig. 4.17: Deflection Profile of D1 at the Ultimate Load of 93.7kN

Comparison of the fig 4.16 and fig 4.17 shows that the prestressing of the exterior beam- column joint as proposed behave as more rigid than Dar (2011). The free end deflection of the B1 at 66.3kN is 38.3mm while in the D1 it is just 14.9 at 94.34kN.

11.4 Comparison of the Total Mechanical Shear Strain

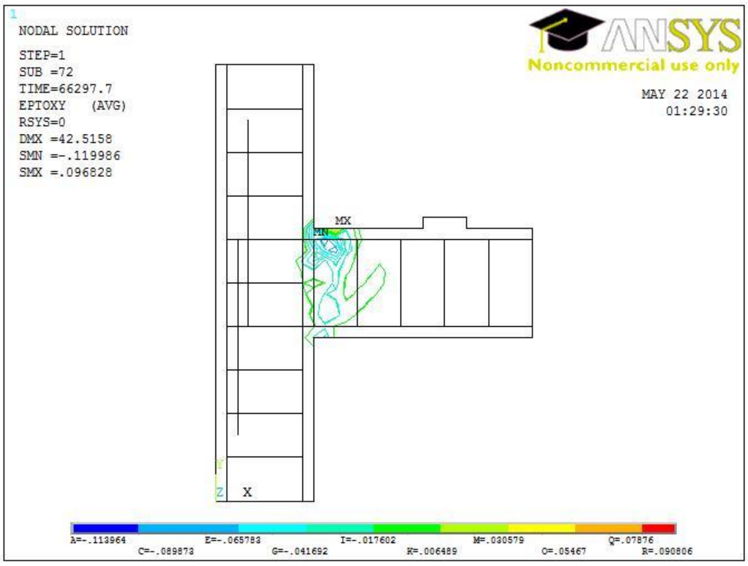

Fig. 4.18: Shear Strain of the B1 at the Ultimate Loads of the 66.3kN

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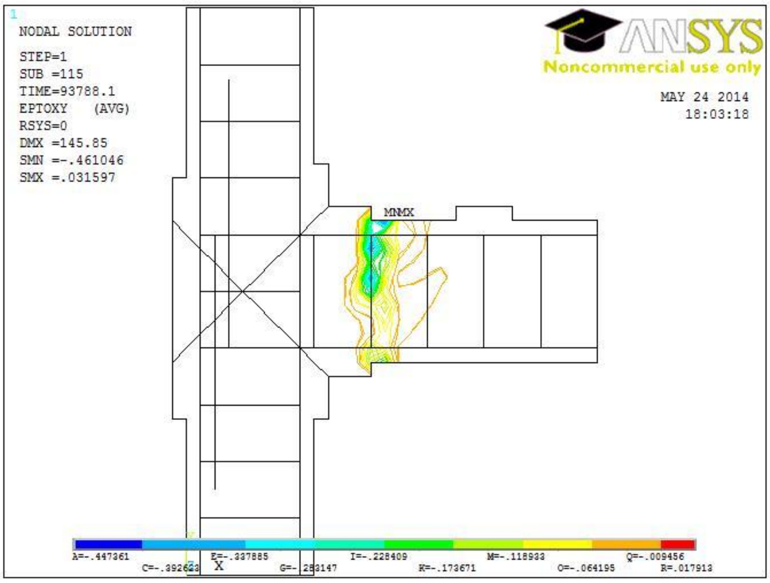

Fig. 4.19: Shear Stain of D1 at the Ultimate Loads of the 93.7kN

11.5 Summary of Comparisons

Comparison Summary of the Both Beam-Column Joints			
Sl. No.		Non-prestressed joints	Pre-stressed joints
1.	Crack location	In the Joints	Shifted to the Beam
2.	Ultimate collapse load	66.3kN	93.7kN
3.	Ultimate deflection	38.8 mm	145.8mm

XII. CONCLUSIONS

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

- ❖ 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.
- ❖ Maximum joint shear demand is located at first story joints for the hinge support condition for the both interior and exterior joints.
- ❖ The ratio of height of maximum shear to building height is coming out as 0.4 for the fixed support.
- ❖ 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.
- ❖ 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.
- ❖ 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.

- 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.
- 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.

XIII. FUTURE SCOPE

- 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.
- 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.

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