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ISSN 0974-5904, Volume 10, No. 03

DOI:10.21276/ijee.2017.10.0312

International Journal of Earth Sciences and Engineering

June 2017, P.P. 545-557

Behaviour of Reinforced Cement Concrete Exterior Beam-Column joints under Seismic loading and Techniques of Improving the Joint Ductility

JOHNSON K AND G HEMALATHA
Department of Civil Engineering, Karunya University, Coimbatore- 641114, INDIA
Email: *johnsonkurieyes@gmail.com, hemalathag@karunya.edu*

Abstract: *The strength of beam-column junction plays a very important role in the strength of the structure under different loading conditions. Beam column joints can be critical regions in reinforced concrete frames designed for inelastic response to severe seismic attack. Lack of ductility in concrete members raises serious concerns for overall structural safety, especially for reinforced concrete beam–column joints. In the current study, research was performed to improve the seismic strength and performance of reinforced concrete exterior beam–column joints under static and dynamic loads. The exterior beam-column joints are studied with different parameters Maximum principle stress, Minimum principle stress, Displacement, Deformation, Stiffness variation of beam column joint using ANSYS modelling.The objective is to analytically illustrate those to highlight their assets and limitations and to identify future directions in this research area. All these details are presented.*

Keywords: *Types of beam-column joints, ANSYS modelling and analysis, earthquake behaviour of joints, improving joint ductility, cyclic loading in exterior joints.*

1. Introduction

The reversal in moment across the joint also means that the beam reinforcement is required to be in compression on one side of the joint and at tensile yield on the other side of the joint. The high bond stress required to sustain this force gradient across the joint may cause bond failure and corresponding degradation of moment capacity accompanied by excessive drift. In the analysis of reinforced concrete moment resisting frames the joints are generally assumed as rigid. In Indian practice, the joint is usually neglected for specific design with attention being restricted to provision of sufficient anchorage for beam longitudinal reinforcement. This may be acceptable when the frame is not subjected to earthquake loads.

There have been many catastrophic failures reported in the past earthquakes, in particular with Turkey and Taiwan earthquakes occurred in 1999, which have been attributed to beam-column joints. Study on joint shear behavior of poorly detailed beam- column connections in RC structures under seismic loads, Part I: Exterior joints by Akashu Sharma, R. Eligehausen and G.R.Reddy [1]. The poor design practice of beam column joints is compounded by the high demand imposed by the adjoining flexural members (beams and columns) in the event of mobilizing their inelastic capacities to dissipate seismic energy. Unsafe design and detailing within the joint region jeopardizes the entire structure, even if other structural members conform to the design requirements. Study on analysis of Reinforced Beam-Column Joint Subjected to Monotonic Loading. Design and detailing of beam-column joints in reinforced concrete frames are critical in assuring the safety of these structures in earthquakes. Such joints should be designed and detailed to Preserve the integrity of the joint sufficiently to develop the ultimate strength and deformation capacities of the connecting beams and columns; Prevent excessive degradation of joint stiffness under seismic loading by minimizing cracking of the joint concrete and by preventing the loss of bond between the concrete and longitudinal beam and column reinforcement; and Prevent brittle shear failure of the joint by S. S. Patil, S. S. Manekari [2] study on. Choudhury, A. M., A. Dutta, and S. K. Deb. (2011) [5] Study on size effect of RC deficient beam-column joints with and without retrofitting under cyclic loading. As a consequence, seismic moments of opposite signs are develop in columns above and below the joints and at the same time beam moment reversal across the joints. A horizontal and vertical shear force whose magnitude is many times higher than in the adjacent beams and columns developed at the joint region. If not design for, joint failure can result. Study on Seismic behaviour of interior RC beam-column joints with additional bars under cyclic loading by Lu, Xilin, Tonny H. Urukap, Sen Li, and Fangshu Lin. [10].

2. Criteria for the desirable performance of joints in ductile structures designed for earthquake resistance

- The strength of the joint should not be less than the maximum demand corresponding to development

Received: January 10, 2017; Accepted: May 15, 2017; Published: June 30, 2017
International Journal of Earth Sciences and Engineering, 10(03), 545-557, 2017, DOI:10.21276/ijee.2017.10.0312

of the structural plastic hinge mechanism for the frame. This will eliminate the need for repair in a relatively inaccessible region and for energy dissipation by joint mechanisms, which as will be seen subsequently, undergo serious stiffness and strength degradation when subjected to cyclic actions in the inelastic range.

- The Capacity of the column should not be jeopardized by possible strength degradation within the joint. The joint should also be considered as an integral part of the column.
- During moderate seismic disturbances, joints should preferably respond within the range.
- Joint deformations should not significantly increase story drift.
- The joint reinforcement necessary to ensure satisfactory performance should not cause undue construction difficulties. Study of RCC Beam Column Junction Subjected to Quasi- Static loading by S. S. Patil, C.G.Konapure & S. S. Manekari, [4].

3. Performance Criteria

Because the response of joints is controlled by shear and bond mechanisms, both of which exhibit poor hysteric properties, joints should be regarded as being unsuitable as major sources of energy dissipation. Hence the response of joints should be restricted essentially to the elastic domain. It is of particular importance to ensure that joint deformations, associated with shear and particularly bond mechanisms, do not contribute excessively to overall story drifts. When large diameter beam bars are used, the early break down of the bond within the joint may lead to story drifts in excess of 1%, even before the yield strength of such bars is attained in adjacent beams. Excessive drifts may cause significant damage to non structural components of the building, while frames respond within the elastic domain. By appropriate detailing, to be examined subsequently, joint deformations can be controlled.

3.1 Shear Strength

Internal forces transmitted from adjacent members to the joint as shown in figure 1, result in joint shear forces in both the horizontal and vertical directions. These shear forces lead to diagonal compression and tension stresses in the joint core. The latter will usually result in diagonal cracking of the concrete core. The mechanism of shear resistance at this stage changes drastically. Some of the internal forces, particularly those generated in the concrete, will combine to develop a diagonal strut. Other forces, transmitted to the joint core from beam and column by means of bond, necessitate a truss mechanism. To prevent shear failure by diagonal tension, usually along a potential corner to corner failure plane both the horizontal and vertical shear reinforcement will be required. Such reinforcement will enable a diagonal compression field to be mobilized, which provides a feasible load path for both horizontal and vertical shear forces. The amount of horizontal joint shear reinforcement required, may be significantly more than would normally be provided in columns in the form of ties or hoops, particularly when axial compression on columns is small. When the joint shear reinforcement is sufficient, yielding of the hoops will occur. Irrespective of the direction of diagonal cracking, horizontal shear reinforcement transmits tension forces only. The inelastic steel strains that may result are irreversible. Consequently, during subsequent loading, stirrup ties can make a significant contribution to shear resistance only if the tensile strains imposed are larger than those developed previously. This then leads to drastic loss of stiffness at low shear force levels.

The previous research for conventional joints, classifies three modes of transmission of component forces within the joint. Study on Experimental Investigation and Evaluation of Strength and Deflections of RC Beam-Column Joint using Nonlinear Static Analysis [11, 12, 13]. *They are*:

- Forces from the column flexural reinforcement.
- Forces from the beam flexural reinforcement
- Concrete compressive forces”

It can be seen that the bond stresses from the column bars in the outer layer are transferred into the joint core and distributed uniformly through the beam depth along the outer column bars. As concrete is strong in compression and weak in tension, the mechanism of shear resistance of concrete mainly depends on a diagonal compression field. However, the neglected tension strength capacity of concrete, the weakness of cementatious material, will lead to intersecting diagonal cracking after cyclic loadings. Study on Effectiveness of Reinforcement Details in Exterior Reinforced Concrete Beam-Column Joints for Earthquake Resistance [19,20,21,22]. Therefore an adequate horizontal confinement should be required.

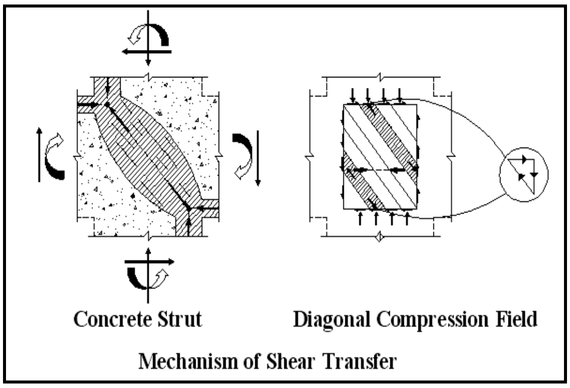

***Fig. 1** Shear Mechanism. S. S. Patil,[4]*

3.2 Bond Strength and Capacity design philosophy for beam-column joints

3.2.1 Bond Strength

At exterior column the difficulty in anchoring a beam bear of full strength can be overcome readily by providing a standard hook. In most practical situations bond stresses required to transmit bar forces to the concrete of the joint core consistent with plastic hinge development at both sides of the joint, would be very large and well beyond limits considered by codes for bar strength development. Even at moderate ductility demands, a slip of beam bars through the joint can occur.

3.2.2Capacity design philosophy:

It has been possible to avoid the potential structural brittle failure by using controllable inelastic deformations to dissipate the large seismic energy. To achieve this, the philosophy of capacity design leads to a weak beam-strong column mechanism and ensures that the energy is dissipated by beam plastic hinges. On the basis of capacity design approach, the strength of the joint should not be less than the maximum strength of the weakest member. Moreover, the capacity of the column should not be jeopardised by strength degradation within the joint. Otherwise, column failure or joint shear failure may occur and cause column side-sway mechanisms in multi-storey frames. If the joint is designed according to capacity design, the energy dissipation occurs mainly in the beam plastic hinges, which prevents the joint suffering from excessive strength and stiffness degradation when subjected to seismic load in the inelastic range.

3.2.3 Beam-column joint flexural and shear design

The force from the concrete stress (Cc) added to the force created by the compression steel (Cs) must equal the force created by the tension steel (Ts). Study on joint shear behavior of poorly detailed beam-column connections in RC structures under seismic loads, Part I: Exterior joints [1,7].

$$C\,c = \alpha\, fc'\, \beta c$$
$$Cs = As'\, fs'$$
$$Ts = As\, fs$$

Both α and β are the same value 0.85

It is assumed initially that the steel is yielding and therefore fs and $f's$ are the yield stress fy= 415MPa.

The equation of equilibrium is $Cc+ Cs- Ts= N$

N is equal to zero for a beam as there is no axial load.

After the neutral axis position is found, if the compression steel is not yielding the equilibrium equation can be used to find the real neutral axis position and the real stress in the compression steel.

With the forces in the equilibrium equation known the moment capacity of the beam or column can be found by summing the moments of the forces about the centroid of the section. The maximum value of shear in the beam can be calculated using equation, where M^* is the moment capacity of the section and l is the distance from the beam-column interface. $V_{max}=M^*/l$. The maximum value of shear in the column is simply the lateral force applied to the top of the column at the point of yielding. These values of shear must be divided by a safety factor to allow for any imperfections in the materials or any other unexpected variables that might influence the testing. The shear that can be carried by the concrete alone is calculated with equation, where bw is the width and d is the depth of the beam or column, and vc is calculated from equation. Equation can be used to calculate ρw, where As is the area of longitudinal reinforcing steel on one side of the section. $f'c$ is the compressive strength of the concrete. The minimum area of horizontal shear reinforcement required in the joint is given by equation, where $f'c$ is the compressive strength of the concrete, β is the reinforcement ratio of the section, Cj is the axial load proportionality constant, N^* is the axial load, Ag is the area of the column section, fyh is the yield strength of the shear reinforcement and Ast is the tension longitudinal reinforcement. $Ajh=6vjh/fc'$ β (0.7-CjN*/fc"Ag)fy* Ast/fyh. The minimum area of vertical shear reinforcing required in the joint is given by equation, where hb is the depth of the beam, hc is the depth of the column and fyv is the yield strength of the shear reinforcement.

Ajv=(0.7/1+N*/fc'Ag)hb*Ajh/hcfy/fyv

The column longitudinal reinforcement was found to provide sufficient resistance to vertical shear; however stirrups were required to provide resistance to horizontal shear, as well as to cater to the confinement needs of the concrete.

4. ANSYS 16 WORKBENCH (WB)

4.1Modeling Geometry and Analysis

ANSYS WB 16 has been used for conducting the finite element modeling and analysis of the Concrete Beam Column Joint. ANSYS has many features which help to carry out detailed study for such kind of complex problems. The design of Beam Column Joint is done using ANSYS WB Design Modeler. The ANSYS Design Modeler application is designed to be used as a geometry editor of existing CAD models or designers can design models with Design Modeler alone. The ANSYS Design Modeler application is a parametric feature-based solid modeler designed so that designers can intuitively and quickly begin drawing 2D sketches, modeling 3D parts, or uploading 3D CAD models for engineering analysis pre-processing. In the designing of Beam Column Joint it is used line body method to design reinforcement bar and fiber. This method gives advantages of less system resource and analysis time and better result accuracy.

4.2 Modeling Finite Element Model

Modeling the Finite Element model is nothing but the descretization of model into elements. The goal of meshing in ANSYS Workbench is to provide robust, easy to use meshing tools that will simplify the mesh generation process. These tools have the benefit of being highly automated along with having a moderate to high degree of user control. The finite element modeling is done using Elements SOLID185, and BEAM188.SOILD 185 is used for 3-D modeling of solid structures. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastic plastic materials, and fully incompressible hyper elastic materials. BEAM 188 is suitable for analyzing slender to moderately stubby/thick beam structures. The element is based on Timoshenko beam theory which includes shear-deformation effects. The element provides options for unrestrained warping and restrained warping of cross-sections. The element is a linear, quadratic, or cubic two-node beam element in 3-D. BEAM 188 has six or seven degrees of freedom at each node. These include translations in the x, y, and z directions and rotations about the x, y, and z directions. A seventh degree of freedom (warping magnitude) is optional. This element is well-suited for linear, large rotation, and/or large strain nonlinear applications.

4.3 Material Properties in ANSYS WORKBENCH and ANSYS Analysis

4.3.1 Loading Systems

The structures are being imposed by many loads e.g. dead load, live load, imposed(wind) load, snow load, earthquake load etc. The structures have to be designed in such a way that they can bear these loads to overcome the collapse or failure of the structures. The behavior of joints is studied with different types of loads. **Static loading:-**Static means slow loading in structural testing. Test of components:-Beams (bending), column (axial), beams and columns. **Dynamic (random) loading**:- Shake at the base or any other elevation of the structure shaking similar to that during earthquakes.

4.3.2 Engineering Data

Use the Engineering Data cell with the Mechanical application systems or the Engineering Data component system to define or access material models for use in an analysis. To add an Engineering Data component system to the Project Schematic, drag the Engineering Data component system from the Toolbox to the Project Schematic or double-click the system in the Toolbox. Study on Steel fibre reinforced high performance concrete beam-column joints subjected to cyclic loading [7,8,9,10].

The non linear analysis of Beam Column Joint is done in Static and Transient (dynamic) analysis system. The acceleration data given for analysis is taken from earthquake data of zone -III. The exterior beam-column joint is modeled and a monotonic loading of 17 kN is applied at the tip of the beam till the failure of the beam takes place. The behavior of this joint is studied with different parameters and loading conditions. The exterior beam-column joint is considered to study joint behavior subjected to static, dynamic loading. Preparation of FE model is carried out based on results obtained from space frame analysis of the structure located in zone-III. Model construction is done by defining geometrical joints and lines. Material definition is carried out prior to assigning of macro elements. The load is applied at the column ends and tip of the beam in one direction. The load of 17 kN was applied at the tip of the beam end with 6 load steps

5. Proposed work

5.1 ANSYS modelling of Exterior beam column joints under static loading

ANSYS is modelling and analysis under static and dynamic loading with different loading conditions using steel fibers, diagonal steel bars in the joint and at extended in column and beam directions to study the resistant of shear or bond failure.

Steel fiber= 1% by volume and extending in column and beam directions. Study on Use of fibre cocktails to increase the seismic performance of beam-column Joints [14,16,17,18].

5.2 Beam column joint design details for ANSYS modeling

Column size- 175 mm x 150 mm, Beam size- 175 mm (D) x 150 mm(B), Strength of concrete fck- 20 N/mm2., Yield strength of steel fy- 415 N/mm2.Column longitudinal steel- 16 mm diameter- 4 nos. Column lateral tie- 8 mm diameter @ 150 mm c/c.. Beam main reinforcement steel- 12 mm diameter- 4 nos. Beam stirrups- 8 mm @ 100 mm c/c. Maximum load on column – Pmax.- 336 kN. Beam point load- W max- 17 kN. Column height- 1500 mm, Beam length- 600 mm. RCC beam column joints were designed for analysis based on IS 1893-2002 Criteria for Earthquake Resistant design of structures and detailing based on IS 13920-1993 Edition 1.2 (2002-03) on Indian Standard Code of Practice Ductile Detailing of Reinforced and referring to relevant books[24,25,26,27].

6. External beam-column joint- analysis setup:

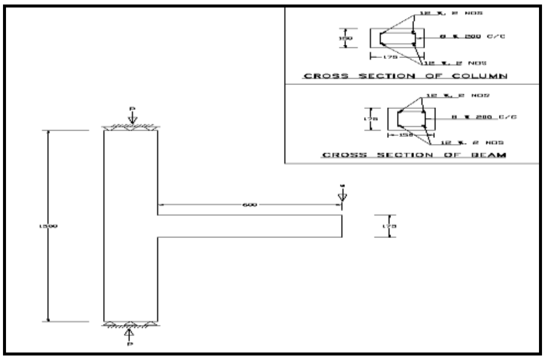

Fig 2. *External joint under static loading*

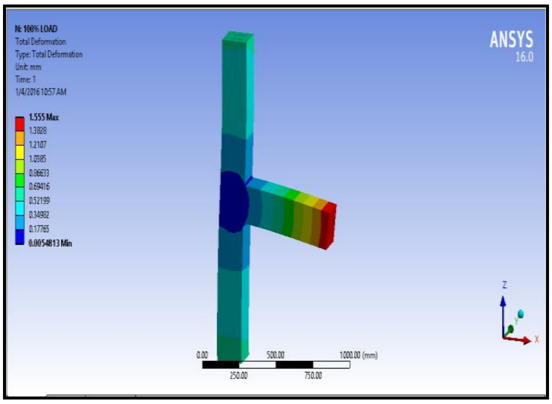

Fig 3. *ANSYS modeling under static loading.- Deflection*

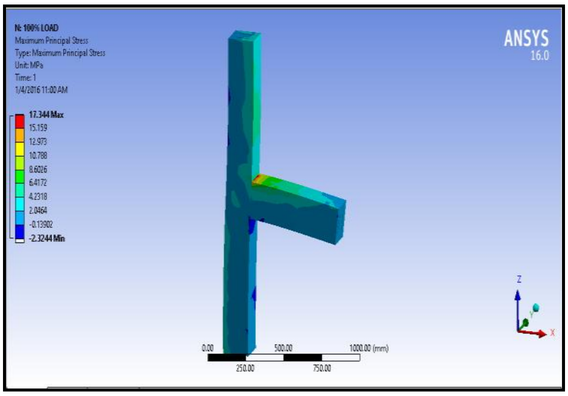

Fig 4. *Pu&Wmax- bending stress*

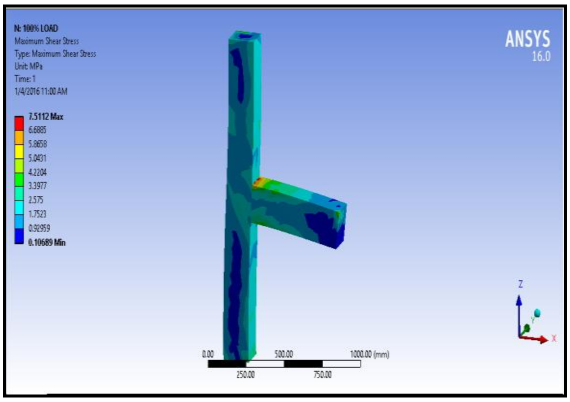

Fig 5. *Pu&Wmax- shear stress*

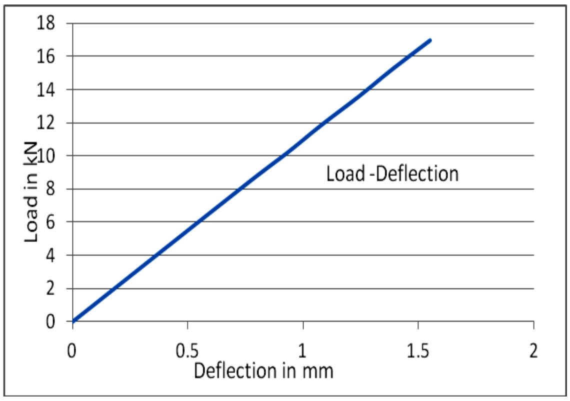

Fig 6. *Load- Deflection graph*

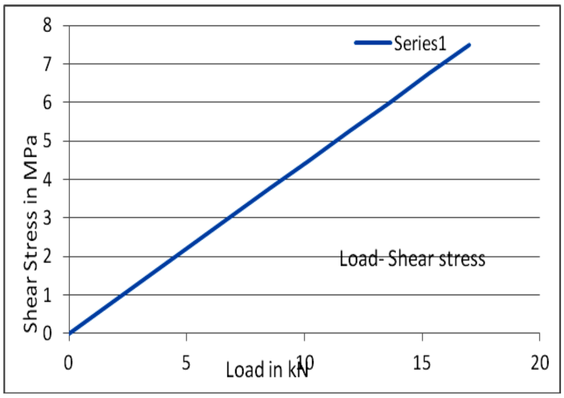

Fig 7. *Load- Maximum shear stress graph*

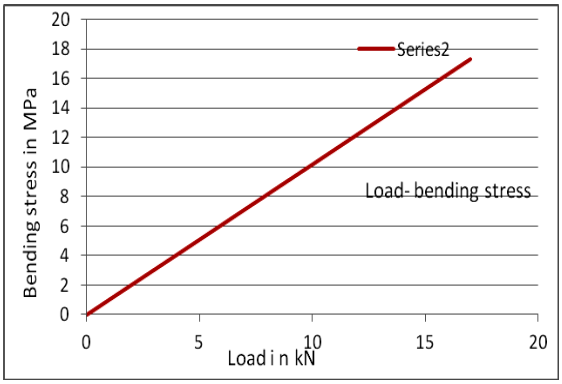

Fig 8. *Load-Maximum bending stress graph*

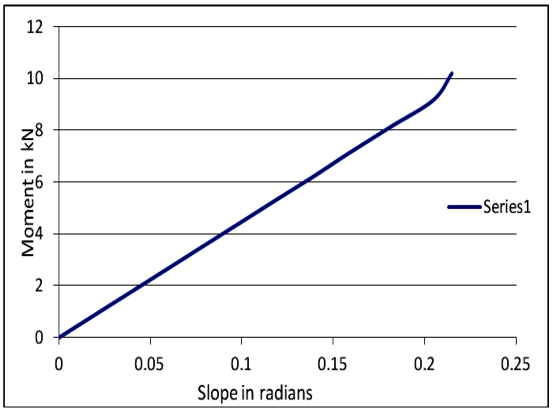

Fig 9. *Moment- slope graph*

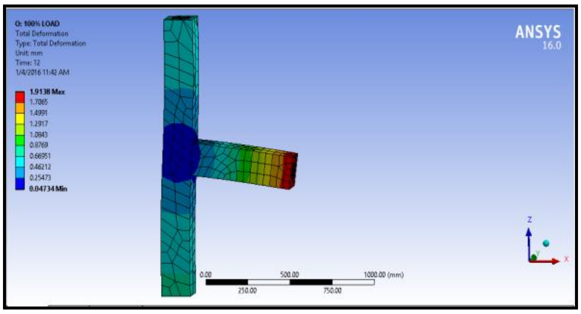

Fig 10. *ANSYS modeling under dynamic loading.- Deflection*

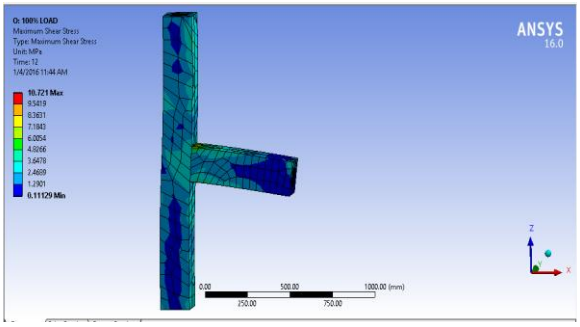

Fig 11. *Pu&Wmax- shear stress*

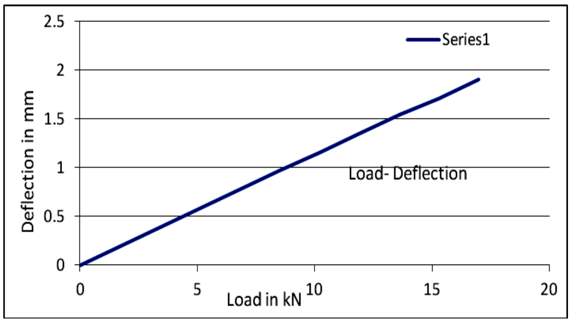

Fig 12. *Load-Deflection graph*

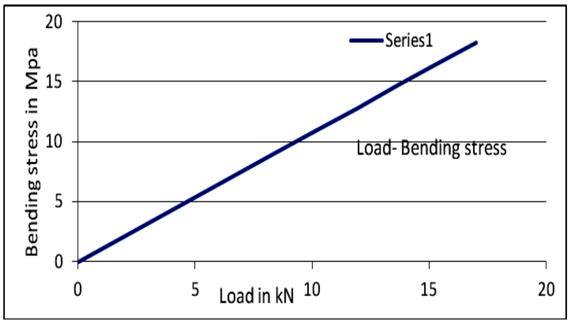

Fig 13. *Load- Bending stress graph*

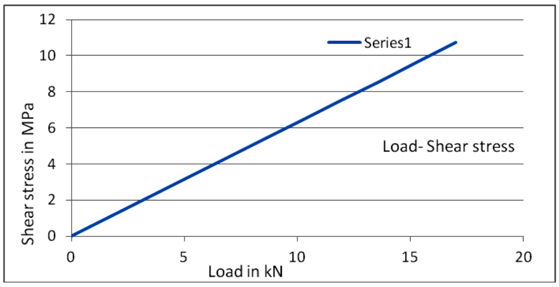

Fig 14. *Load- Shear stress graph*

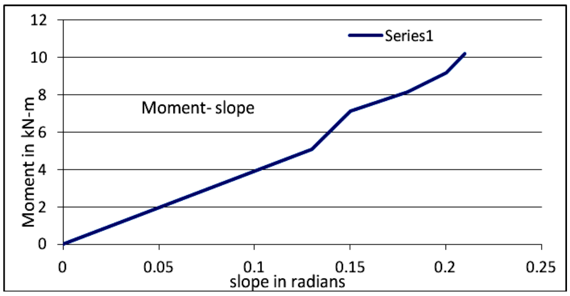

Fig 15. *Moment- slope graph*

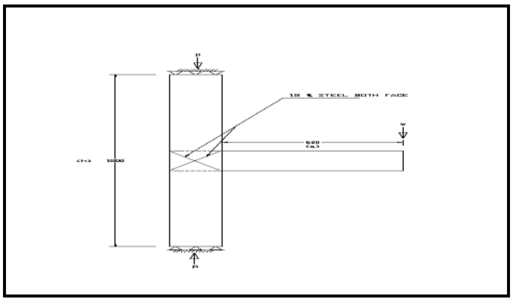

Fig 16. *External joint static analysis using diagonal bars at the joint*

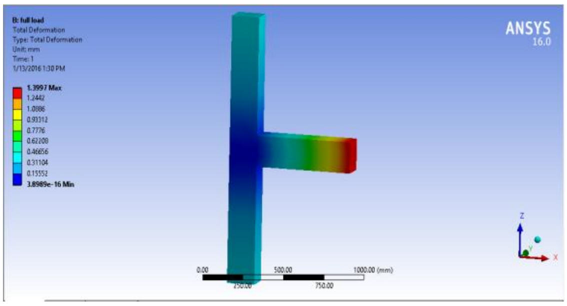

Fig 17. *Pu& W_{max}- deflection*

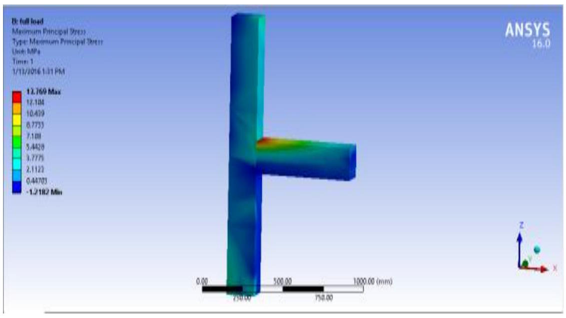

Fig 18. *Pu & W_{max}- bending*

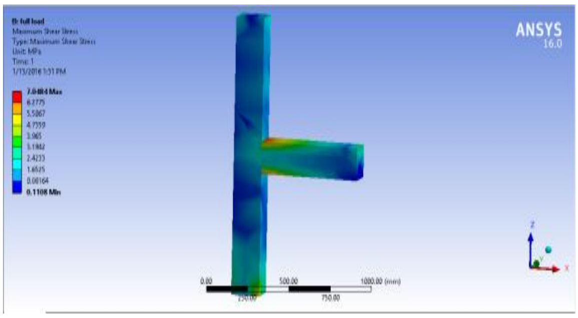

Fig 19. *Pu & W_{max}- shear*

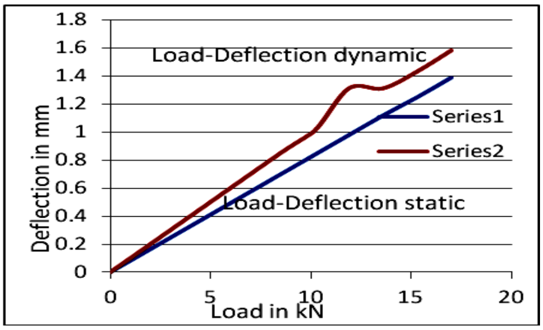

Fig 20. *Load-Deflection graph*

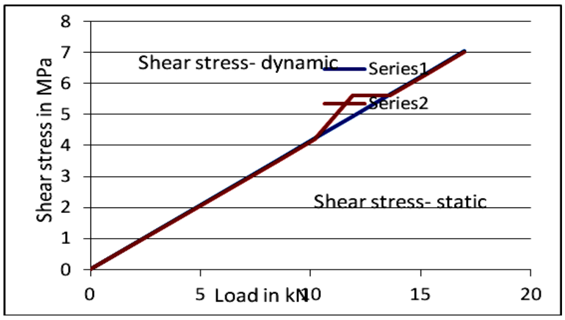

Fig 21. *Load- shear stress graph*

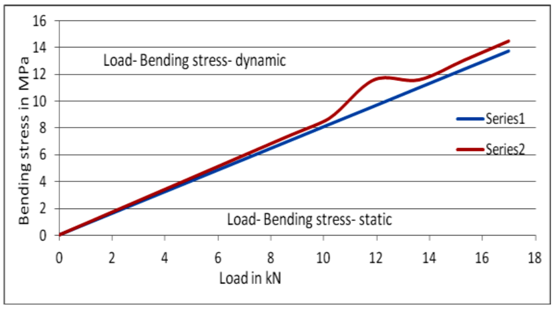

Fig 22. *Load- bending stress graph*

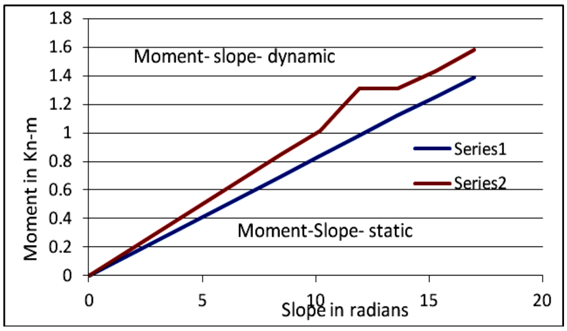

Fig 23. *Moment- slope graph*

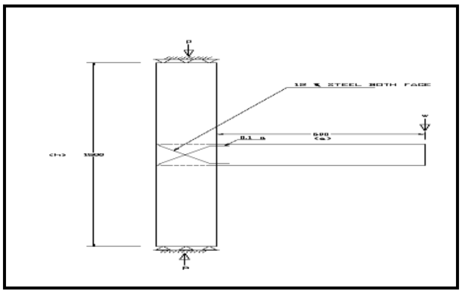

Fig 24. *External joint using diagonal bars at the joint extending in beam- Static*

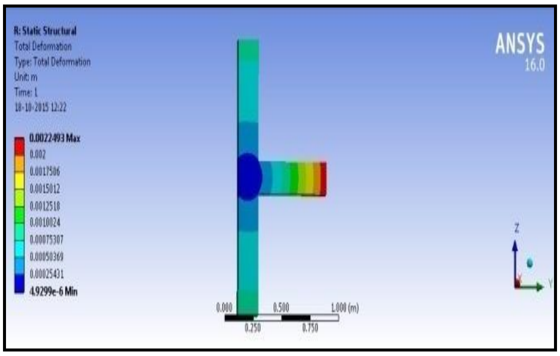

Fig 25. *Pu& Wmax-.1B static deflection*

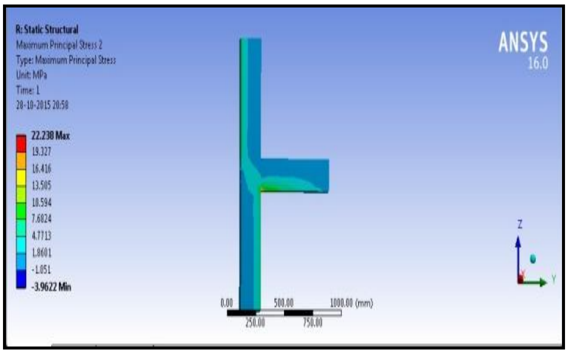

Fig 26. *Pu & Wmax-.1B static bending stress*

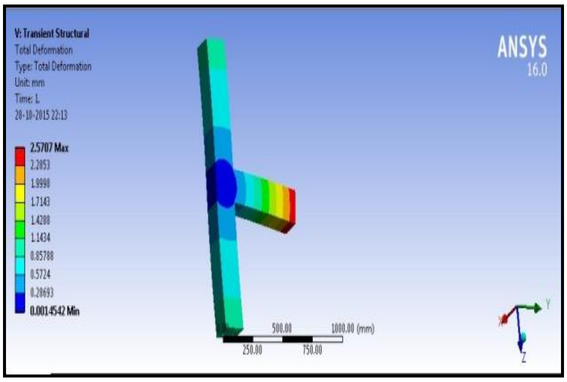

Fig 27. *Pu & Wmax-.1B dynamic deflection*

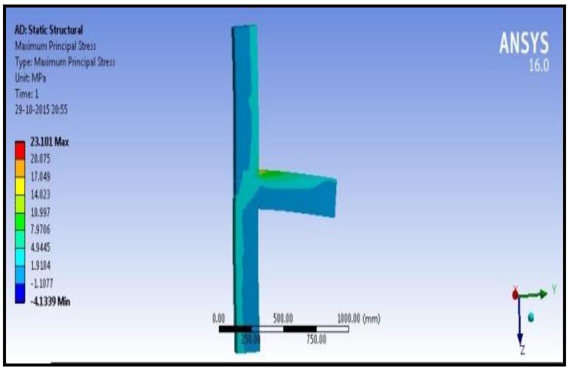

Fig 28. *Pu & Wmax-.1B dynamic bending stress*

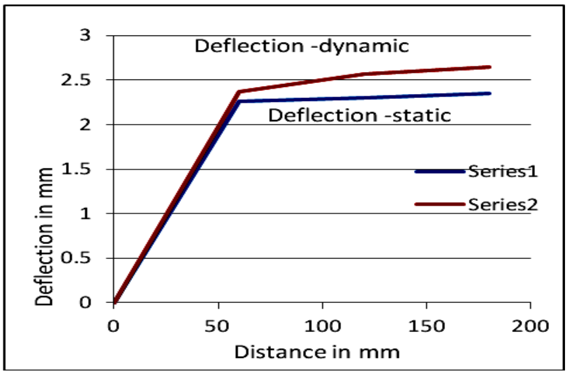

Fig 29. *Load-Deflection graph*

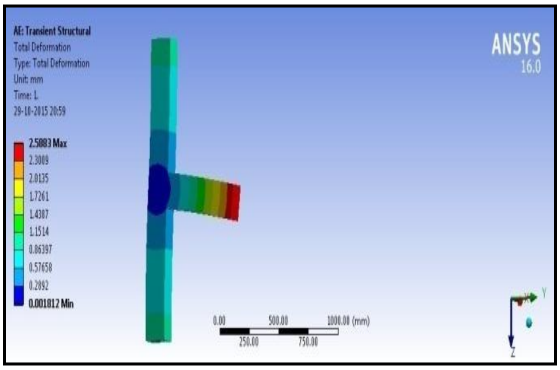

Fig 33. *Pu& Wmax-.1H Static Deflection*

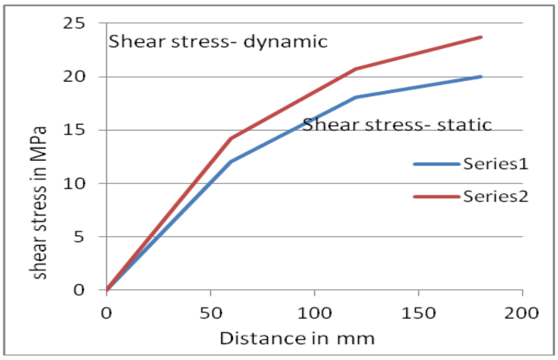

Fig 30. *Load- shear stress graph*

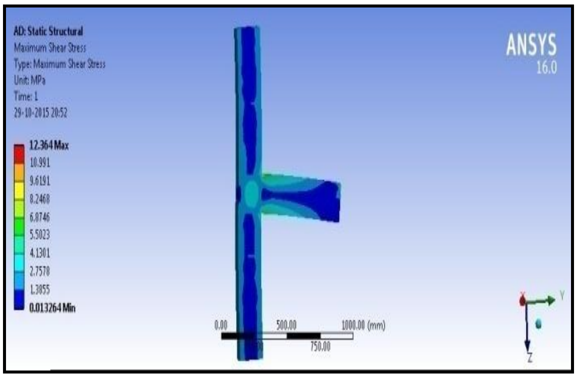

Fig 34. *Pu& Wmax-.1H static bending stress*

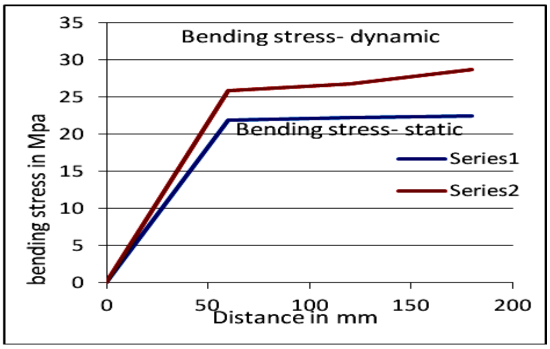

Fig 31. *Load- bending stress graph*

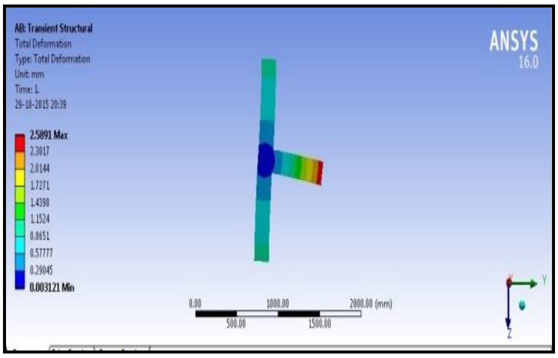

Fig 35. *Pu & Wmax-.1H dynamic deflection*

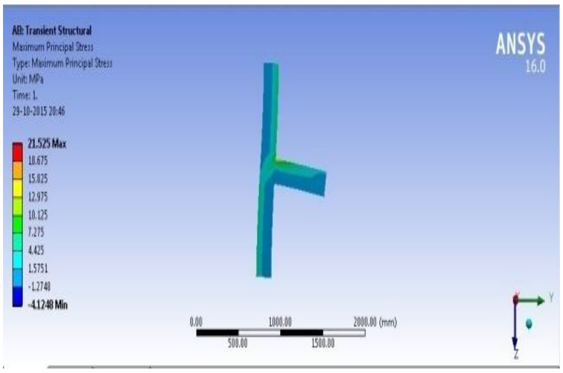

Fig 36. *Pu & Wmax-.1H dynamic bending stress*

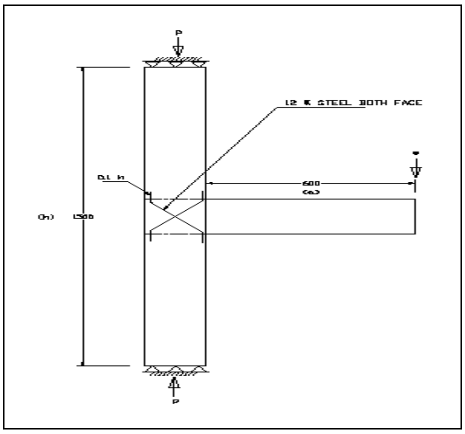

Fig 32. *External joint using diagonal bars at the joint extending in column*

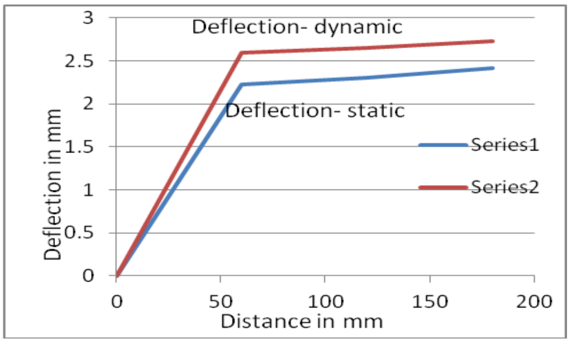

Fig 37. *Load-Deflection graph*

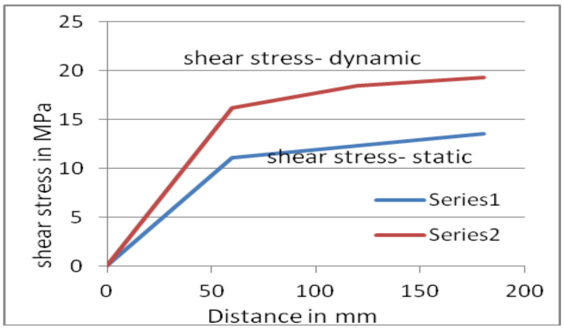

Fig 38. *Load- shear stress graph*

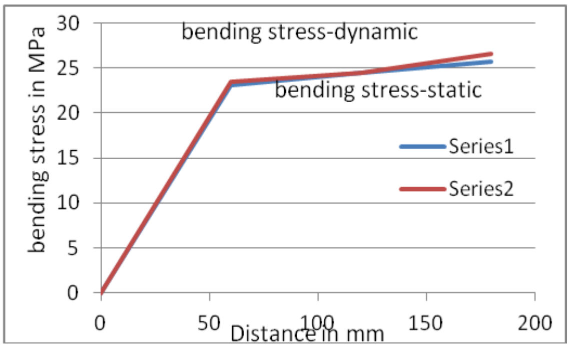

Fig 39. *Load- shear stress graph*

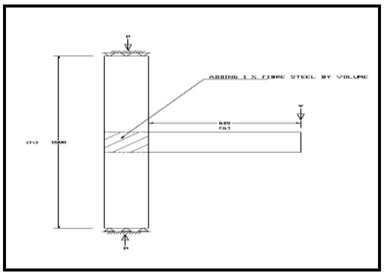

Fig 40. *External joint using steel fibers*

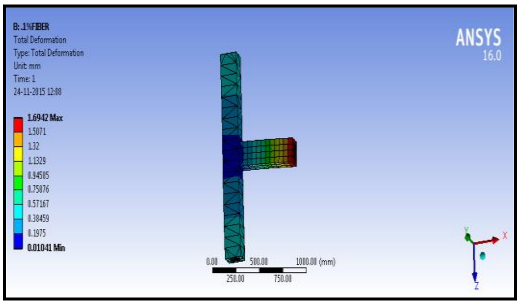

Fig 41. *Pu & Wmax-.1H static deflection*

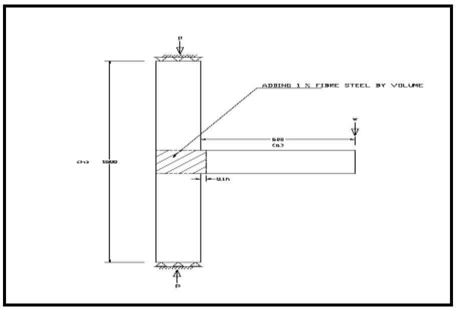

Fig 42. *External joint using steel fibers extending in beam*

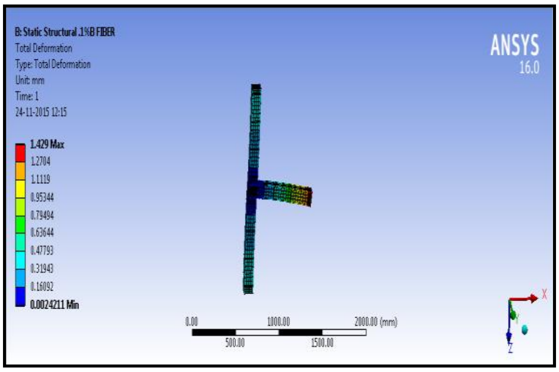

Fig 43. *Pu & W_{max} deflection*

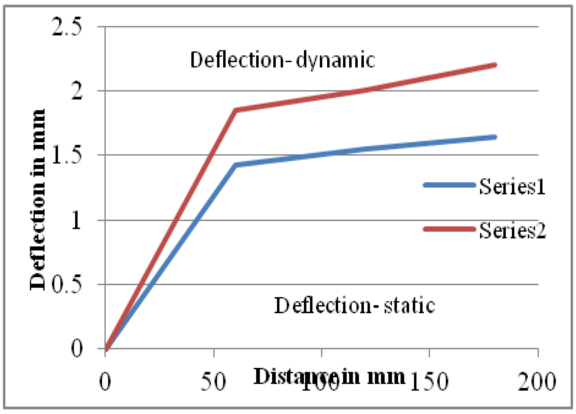

Fig 44. *Load-Deflection graph*

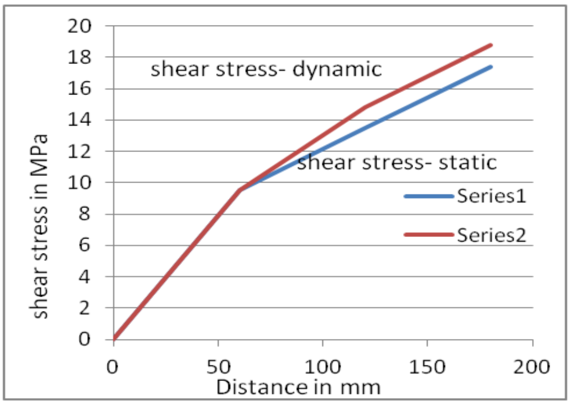

Fig 45. *Load- shear stress graph*

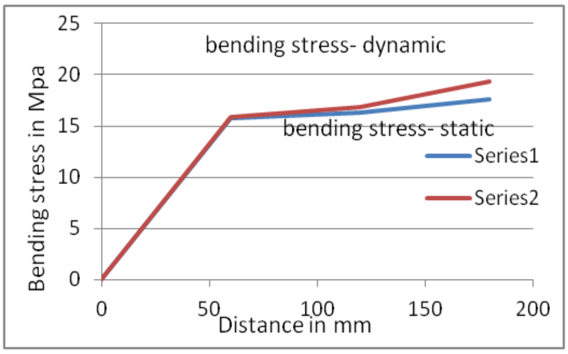

Fig 46. Load- bending stress graph

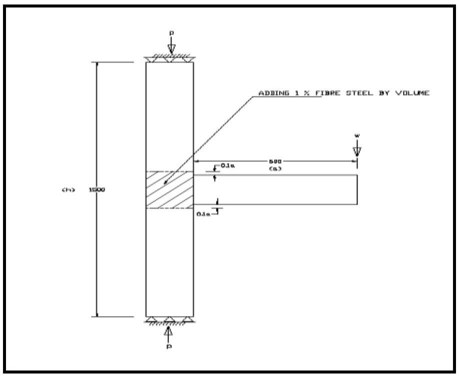

***Fig 47.** External joint using steel fibers extending in column*

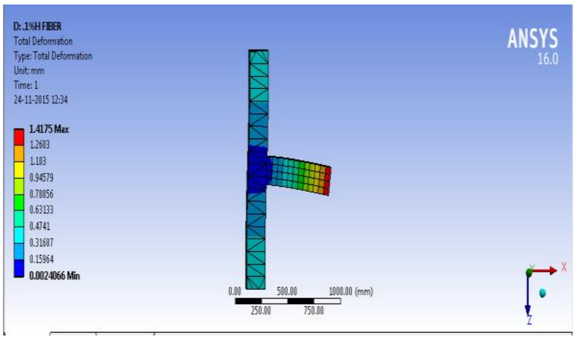

***Fig 48.** Pu& Wmax-.1H static deflection*

7. Results and Discussions

7.1 Parametric Study

The exterior beam-column joints are studied with different parameters of Maximum principle stress, Maximum shear stress, Deflection, rotations. ANSYS modeling and analysis of exterior beam column joints under static loading, seismic loading, using normal reinforcement steel, steel fibers, using diagonal bars at the joint, diagonal bars and fibers at varying depths and heights in beam and column directions are carried out to find out various factors affecting the failure of joints under different loading conditions. Fig.3,4,5 shows ANSYS modeling and analysis of exterior beam column joints under static loading using normal reinforcement steel designed as per IS-456-2002. Fig.10, 11 shows ANSYS modeling and analysis of exterior beam column joints using normal reinforcement steel designed as per IS-456-2002 under dynamic loading. It can be seen that the deflection obtained for exterior beam column joint under static full loading conditions at the beam and column is 1.55 mm (fig.6) where as the under dynamic loading for the same load pattern, the maximum deflection is 1.91 mm(fig.12). The maximum shear stress obtained under the same loading conditions in static loading is 7.51 MPa (fig.7) where as the maximum shear stress under dynamic loading is 10.72 MPa.(fig.14). The maximum bending stress obtained under the same loading conditions in static loading is 17.34 MPa (fig.8) where as the maximum bending stress under dynamic loading is 18.27 MPa.(fig.13). It can be seen that the bond stresses from the column bars in the outer layer are transferred into the joint core and distributed uniformly through the beam depth along the outer column bars.

7.2. Effect of additional diagonal bars within the joint under static and dynamic loading

Analytical study of RCC exterior beam column joint with additional diagonal bars within the joint subjected to static and seismic loading by nonlinear finite element analysis using ANSYS software for nonlinear analysis of reinforced concrete structures were carried out by increasing the diagonal reinforcement in beam directions and column directions by an increment in length of .1B,.2B,.3B and .1H,.2H and .3H respectively. Fig.17, 18, 19 shows ANSYS modeling and analysis of exterior beam column joints using additional diagonal bars at the beam column joint.

Fig. 25,26,27,28 shows ANSYS modeling and analysis of exterior beam column joints using additional diagonal bars at the beam column joint and extending in beam directions. Fig.33, 34, 35, 36 shows ANSYS modeling and analysis of exterior beam column joints using additional diagonal bars at the beam column joint and extending in column directions. All the results under different loading conditions are tabulated for reference (table-1). With additional diagonal reinforcement at the beam column joint, the maximum deflection is 1.39 mm for static and 1.58mm for dynamic loading for the same load pattern (fig.20). The maximum shear stress obtained under the same loading conditions in static loading is 7.01 MPa where as the maximum shear stress under dynamic loading is 7.05 MPa. (fig.21). The maximum bending stress in static loading is 13.76 MPa where as the maximum shear stress under dynamic loading is 14.48 MPa.(fig.22).

From the analysis it can be seen that the effect of diagonal bars in exterior beam column joint in reducing the deflections, shear stress and bending stress at the joint under static and dynamic loading conditions is effective when comparing with joint without diagonal bars.The additional bars effectively increased the strength capacity at the joint vicinity as well as sufficient development of ductility to the frame members under increasing lateral loading. The joint was fully restrained at the column ends. It was inferred from the analysis that as load increases displacement, minimum stress and maximum stress also increases. Also the stiffness of the structure changes the displacement, minimum stress and maximum stress changes with respect to loading. With the increase of ratio of bending moment of column to beam, the plastic hinges are more likely to develop in the beam, and the ductility of the joint improves. Additional diagonal bars prevented cracks at the edges of the joint interface between column and beam. Furthermore, these joints have been proven to behave in a ductile manner as beams undergo plastic hinging earlier than the columns. The specimen with additional bars effectively increased the strength capacity at the joint vicinity as well as sufficient development of ductility to the frame members under increasing lateral loading. The orientation of additional diagonal bars added strength in favour of members they were oriented to. That is, additional bars along beam added strength towards the beam ends and additional bars along column added strength towards the column.

7.3 Steel fibre reinforced concrete in exterior beam-column joints.

The performance of steel fibre reinforced exterior beam-column joints were compared with that of conventional joints. Results showed that using steel fibre reinforced concrete (SFRC) within beam-column joints by increasing the steel fibre reinforcement in beam directions and column directions by an increment in length of .1B,.2B,.3B and .1H,.2H and .3H respectively can significantly enhance the shear resistance capacity of joints. Fig.41 shows ANSYS modeling and analysis of exterior beam column joints using steel fibers at the beam column joint. Fig. 43 shows ANSYS modeling and analysis of exterior beam column joints using steel fibers at the beam column joint and extending in beam directions. Fig.48 shows ANSYS modeling and analysis of exterior beam column joints using steel fibers at the beam column joint and extending in column directions. It can be seen that the effect of steel fiber in exterior beam column joint in reducing the deflections, shear stress and bending stress at the joint under static and dynamic loading conditions is effective when comparing with joint without diagonal bars. All the results tabulated for reference (table-1). With additional steel fiber at the beam column joint, the maximum deflection under static loading is 1.41mm where as the under dynamic loading for the same load pattern, the maximum deflection is 1.42 mm (fig.44).

The maximum shear stress obtained under the same loading conditions in static loading is 8.49 MPa where as the maximum shear stress under dynamic loading is 16.24 MPa (fig.45). The maximum bending stress obtained under the same loading conditions in static loading is 15.37 MPa where as the maximum shear stress under dynamic loading is 15.50 MPa.(fig.46). It can be seen that the effect of steel fiber in exterior beam column joint in reducing the deflections, shear stress and bending stress at the joint under static and dynamic loading conditions is effective when comparing with joint without diagonal bars.The analysis results also showed that using steel fibre reinforcement is an effective method to reduce the lateral reinforcement in the beam plastic hinge region.

With the models so far developed, the energy absorption capacity of different joints can be studied since ductility is directly linked with energy absorption capacity of joints The analysis results also showed that using steel fibre reinforcement is an effective method to reduce the lateral reinforcement in the beam plastic hinge region. Steel fibre reinforced concrete is a concrete mix that contains discontinuous, discrete steel fibres that are randomly dispersed and uniformly distributed. The quality and quantity of steel fibres influence the mechanical properties of concrete. It is generally accepted that addition of steel fibres significantly increases tensile toughness and ductility, also slightly enhances the compressive strength. The benefits of using steel fibres become apparent after concrete cracking because the tensile stress is then redistributed to fibres. The results showed that using steel fibres can significantly increase the joint shear strength and also the shear stress corresponding to the first crack. The summary of results obtained in the ANSYS analysis of RC exterior beam column joint is given in table 1.

Table1: *Summary of results*

Loading conditions	Deflection (mm)	Maximum shear stress(MPa)	Maximum bending stress(MPa)
Static	1.55	7.51	17.34
Dynamic	1.91	10.72	18.27
Diagonal bars	1.39	7.01	13.76
	1.58	7.05	14.48
1B	1.30 1.40	6.50 7.00	12.50 13.10
.2B	1.25 1.35	6.00 6.50	11.10 10.50
.3B	1.20 1.30	5.50 6.00	12.80 12.30
.1H	1.35 1.40	7.50 7.80	13.10 13.70
.2H	1.28 1.36	7.10 7.50	12.90 13.45
.3H	1.25 1.32	6.90 7.30	12.45 13.10

1% fiber	1.40		9.70		15.85	
	1.48		10.10		16.15	
.1B	1.43	1.43	9.52	9.54	15.80	16.82
.2B	1.41	1.41	9.51	9.53	14.92	15.94
.3B	1.35	1.40	8.10	8.95	12.57	14.38
.1H	1.41	1.42	9.28	10.39	16.94	18.21
.2H	1.41	1.42	12.46	8.19	11.44	13.38
.3H	1.41	1.41	8.49	9.24	10.37	11.50

8. Conclusions

ANSYS modeling and analysis of exterior beam column joints under static loading, seismic loading, using normal reinforcement steel, steel fibers, using diagonal bars at the joint, diagonal bars and fibers at varying depths and heights in beam and column directions are carrying out to find out various factors affecting the failure of joints under different loading conditions.

The results shows that under dynamic loading, the shear stress and bending stress at the joint core increases enormously when comparing with static loading resulting in failure of the joint. Additional diagonal bars at the joint along with lateral reinforcement prevented cracks at the edges of the joint interface between column and beam. The additional diagonal bars extension in the beam and column directions analysis results shows increase the ductility of the joint under higher loading conditions. The orientation of additional diagonal bars added strength in favour of members they were oriented to. Additional bars along beam added strength towards the beam ends and additional bars along column added strength towards the column. The performance of steel fibre reinforced exterior beam-column joints were compared with that of conventional joints. Results showed that using steel fibre reinforced concrete (SFRC) within beam-column joints can significantly enhance the shear resistance capacity of joints. The analysis results also showed that using steel fibre reinforcement is an effective method to reduce the lateral reinforcement in the beam plastic hinge region and can significantly increase the joint shear strength and also the shear stress corresponding to the first crack. Further study of RCC exterior beam column joints can be carried out for increasing shear strength and ductility within the joint.

The exterior beam-column joints are studied with different parameters Maximum principle stress, Maximum shear stress, Deflection, rotations. All the results were tabulated and studied in detail. Beam column exterior joint under static and dynamic loadings were studied and results compared to see the ductility behaviour of the joint under seismic loading conditions.

9. Acknowledgement

ANSYS modeling and analysis of RCC exterior beam column joints under different loading conditions were carried out with the whole hearted help, support and directions of many people through their constructive criticisms in the evaluation and preparation of this paper. The author takes this opportunity to appreciate the works done by many researchers in this field. Thanks to all for extending the necessary support and guidance required to complete this paper.

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