STRENGTHENING OF BEAM COLUMN JOINTS WITH MODIFIED REINFORCEMENT TECHNIQUE

A PROJECT

Submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

Under the supervision of

Mr. Mani Mohan & Mr. Lav Singh

By

Aditya Kumar Tiwary
(132659)

To

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT SOLAN – 173 234

HIMACHAL PRADESH INDIA

May, 2015

Certificate

This is to certify that the work which is being presented in the project title ***"STRENGTHENING OF BEAM COLUMN JOINTS WITH MODIFIED REINFORCEMENT TECHNIQUE"*** in partial fulfillment of the requirements for the award of the degree of Master of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **Aditya Kumar Tiwary** during a period from August 2014 to May 2015 under the supervision of **Mr. Mani Mohan and Mr. Lav Singh**, Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

Date: - ………………………

Prof. Dr. Ashok Kumar Gupta
Professor & Head of Department
Civil Engineering Department
JUIT Waknaghat

Mr. Mani Mohan
Assistant Professor
Civil Engineering Department
JUIT Waknaghat

……………………
External Examiner

Mr. Lav Singh
Assistant Professor
Civil Engineering Department
JUIT Waknaghat

Declaration

I hereby declare that the research work presented in this Project entitled ***"Strengthening of Beam Column Joints with Modified Reinforcement Technique"***, submitted for the award of the degree of Master of technology in the Department of Civil Engineering, Jaypee University of Information TechnologyWaknaghat, is original and my own account of research. This research work is independent and its main content work has not previously been submitted for degree at any university in India or Abroad.

Date:

Aditya Kumar Tiwary

(132659)

Acknowledgement

I wish to express my sincere gratitude to **Mr. Mani Mohan** and **Mr. Lav Singh** for his excellent guidance and perennial encouragement and support during the course of my work in the last one year. I truly appreciate and value his profound knowledge, esteemed supervision and encouragement from the beginning to the end of this thesis.

My special thanks to **Dr. Ashok Kumar Gupta,** Professor and Head of Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat for all the facilities provided to successfully complete this Project.

I would like to thanks my project co-ordinator **Mr. Abhilash Shukla** for his guidance and support during the course of my project work and encouragement from the beginning to the end of this thesis.

I would like to thanks **Mr. Anil Dhiman** for his guidance and support during the course of my project work and encouragement from the beginning to the end of this thesis.

I am also very thankful to all the faculty members of the department, especially Structural Engineering specialization for their constant encouragement during the project.

I also take the opportunity to thank all my friends who have directly or indirectly helped me in my project work and in the completion of this Project.

I would like to thank my parents, who taught me the value of hard work by their own example. I would like to share this bite of happiness with my mother and father. They rendered me enormous support during the whole tenure of my stay at JUIT, Waknaghat, Solan, Himachal Pradesh.

Date: **Aditya Kumar Tiwary**

(132659)

Table of Contents

Abbreviation and symbols

l_o	Special confining reinforcement from each joint face
K	Stiffness matrix
Q	Nodal displacement vector
F	Nodal vector force
E_c	Elastic modulus
F_c	Ultimate uniaxial compressive strength
F_t	Ultimate tensile compressive strength
S	Confining reinforcement in the column
V_s	Joint shear carried by ties
d	Effective depth of beam
A_v	Total area of ties legs
σ	Amount of tension reinforcement
f'_c	compression concrete stress at the far face of joint
f'_s	Compression steel stress at the far face of joint
f_y	Yield stress of steel
A_s	Area of the outer column bar
T’’	Tensile force in reinforcement
C'_s	Compression in reinforcement

List of Figures

List of Table and Graphs

1. Table

2. Graphs

Abstract

In a beam column joint to meet the requirement of strength, stiffness and ductility under dynamic loading one of the existing solution is inclusion of high percentages of transverse hoops in the core of joints. The most important factor affecting the shear capacity of joints are the concrete compressive strength, joint aspect ratio, anchorage of beam longitudinal reinforcement and amount of stirrups inside the joint. The beam moment which induced during earthquake motion on the beam can produce high shear forces and bond breakdown into the joint resulting in cracking of the joints. Unsafe design and detailing within the joint region jeopardizes the entire structure, even if other structural members conform to the design requirements. Modified reinforcement technique (MRT) using crossed inclined bar at beam column junction is investigated in our work and it has been found that its presence introduces an additional mechanism for shear transfer. Modified Reinforcement Technique (MRT) can be proposed as a feasible solution for increasing the shear capacity and stiffness of the joint under dynamic loading.

The beam-column joints with crossed inclined bar modeled in ANSYS workbench v12 showed high strength. The analytical result done via ANSYS concludes that the specimen with diagonal cross bar at joint shows better performance under the cyclic loading and hence it can be a feasible solution for increasing the shear capacity of exterior and interior beam-column joints. From the analytical study it is observed that the provision of cross diagonal reinforcement increased the ultimate load carrying capacity, stiffness and ductility of joints in the both upward and downward loading conditions. The all joints are analyzed for the same loading with same arrangement of reinforcement for control and strengthened specimen and it was observed that the higher deformation and stress obtained in the corner joints as compare to the other joints. The results of control and strengthened specimen were compared through load-displacement hysteretic behavior; displacement time history curve, load cycle Vs shear stress and load displacement response. Form the graphs it was observed that the implementation of cross inclined bars at the joints give better results as compare to control specimen in terms of total deformation, stress and strain. The present study is confined to static load only.

CHAPTER 1

INTRODUCTION

1.1Background

The Beam-Column joints are the weakest link in moment resisting RC framed buildings subjected to seismic load. These joints, if not strengthen properlymay suffer substantial damage during earthquakes due to inadequate shear reinforcement in the joint region. Several techniques of repairing and strengthening of RC joints, damaged by earthquakes, have been reported in earthquake prone countries. Repairing of damaged joints is very difficult so damage must be avoided by using different techniques during construction. In earthquake resisting frame the column should be stronger then beam. In RCC buildings portion of column that are common to beam at their intersection are called beam-column joints. The constituent materials of joints have limited strengths; the joints have limited force carrying capacity. When forces larger than these are applied during earthquake, joints are severely damaged. The prime reason behind joint failure is the inadequate shear strength of the joints, and this is occurred due to the insufficient and inadequate detailed reinforcement in the joint region.

The shear strength and confinement pressure provided by joint panel stirrups are crucial to preserve joint panels from premature brittle failures; a suitable amount of transverse reinforcement allows the action between the beams and columns to be appropriately transferred. However, the lack of joint panel transverse reinforcement is very common in structural systems designed for gravity load or according to obsolete seismic codes, especially in the Mediterranean area. For this reason, several surveys carried out in the aftermath of major recentearthquakes have shown that beam column joints represent one of the main sources of vulnerability in existing reinforced concrete (RC) constructions. In most of earthquake prone countries, preseismic code designed reinforced concrete (RC) buildings do not comply with the current seismic codes requirements. In Recent earthquakes failure/collapse of moment resisting RC frame buildings in the existing beam column joints, especially exterior ones with inadequate shear strength and ductility is the prime reason.

1.2Project Objective

The objective of this project is the numerical investigation of beam column joint with or without modified reinforcement techniques. The behavior of beam column joint is observed for total deformation, stress and strain under the same cyclic loading for all joints. The results which observed after analysis of all joints for control specimen and strength specimen have been compared in terms of total deformation, stress and strain. The numerical investigations have been done by using ANSYS v12. In addition the analysis is performed in terms of variations in diameter and length of the cross bars(Modified Reinforcement Techniques). The FE results of control and strengthened specimens were compared through load-displacement hysteretic behavior, load cycle Vs shear stress behavior and displacement time history curves.

1.3Significance of Project

With reference to paper given by*Suhasini M Kulkarni, Yogesh D Patil, 2014,*titled as "Cyclic Behavior of Exterior Reinforced Beam-Column Joint with Cross-Inclined Column Bars." In this paper the author has considered a column with single beam and Cross inclined bars have been used at the joint and it was presented that, the most important factors affecting the shear capacity of exterior RC beam-column joints are the concrete compressive strength, joint aspect ratio of the joints and number of lateral ties inside the joint. Advanced Reinforcement Pattern (ARP crossed inclined bars) is a feasible solution for increasing the shear capacity of the cyclically loaded exterior beam-column joints. The presence of inclined bars introduces an additional mechanism for shear transfer. External beam-column joints with crossed inclined reinforcement (ARP) modeled in ANSYS Workbench showed high strength, and no appreciable deterioration even after reaching the maximum capacity.

The results obtained from the FE analysis of control specimen and strengthen specimen under cyclic loading on beam column joints show that the modified reinforcement technique is the additional mechanism of shear transfer. It observed that the joint shear capacity, stiffness, ductility, total deformation and directional deformation have been controlled by introducing modified reinforcement technique at joint region.

1.4Literature Review

Number of works has been reported on experimental and analytical studies of composite up gradation for strengthening beam column joint. The literature has been reviewed to get the experimental data for making comparison with analytical model of present study.

S. H. Alsayed, Y. A. Al-Salloum, T. H. Almusallam, and N.A. Siddiqui[1]*, in 2010,*epoxy-bonded CFRP sheets have been used with different scheme such as control, strengthened, repaired specimens at the joints for the upgrading the shear strength and ductility of exterior beam-column joints. The author compared the results of different scheme through hysteretic loops, load-displacement envelopes, joint shear distortion, ductility, and stiffness degradation and found that CFRP sheets are very effective in improving shear resistance and deformation capacity of the exterior beam-column joints and delaying their stiffness degradation.

K.R.Bindhu and K.P. Jaya[2]*, 2010* studied the seismic performance of exterior beam column joint with non-conventional reinforcement detailing. The specimens were sorted into two groups based on the joint reinforcement detailing. The first group (Group A) comprises of two joint assemblages having joint detailing as per construction code of practice in India (IS 456:2000) with two axial load cases. The second group (Group B) comprises of two specimens having additional cross bracing reinforcements for the joints detailed as per IS 456:2000 with similar axial load cases that in first group. The experimental investigations are validated with the analytical studies carried out by finite element models using ANSYS. The experimental results and analytical study indicated that additional cross bracing Reinforcements improve the seismic performance.

Suhasini M Kulkarni, Yogesh D Patil[3]*, 2014*"Cyclic Behavior of Exterior Reinforced Beam-Column Joint with Cross-Inclined Column Bars." In this paper it is presented that, the most important factors affecting the shear capacity of exterior RC beam-column joints are the concrete compressive strength, joint aspect ratio of the joints and number of lateral ties inside the joint. Advanced Reinforcement Pattern (ARP crossed inclined bars) is a feasible solution for increasing the shear capacity of the cyclically loaded exterior beam-column joints. The presence of inclined bars introduces an additional mechanism for shear transfer. External beam-column joints with crossed inclined reinforcement (ARP) modeled in ANSYS Workbench showed high strength, and no appreciable deterioration even after reaching the maximum capacity.

C.D.Vecchio, M.D.Ludovico, Albeeto Balsamo, Andrea Prota, Gaetano Manfredi, and Mauro Dolce[4]*,2014,* “Experimental Investigation of Exterior RC Beam-Column Joints Retrofitted With FRP system.” This paper investigates the behavior of unconfined joints that do not conform to current seismic codes and the effectiveness of externally bonded fiber-reinforced polymers as a strengthening technique, and it was observed that FRP sheets improve the shear resistance, ductility, and deformation capacity of the seismically loaded RC beam-column joints to a great extent.

Al-Salloum and Almusallam 2007 and Alsayed et al.[5] *2010* developed effective rehabilitation schemes for R/C beam-column interior and exterior joints, respectively, using advanced composite materials. Pampanin et al. 2007 carried out experimental and analytical investigations on carbon FRP CFRP retrofitted existing beam-column joint subassemblies and frame systems. Their experimental results provided very satisfactory confirmation of the viability and reliability of the adopted retrofit solution and of the proposed analytical procedure to predict the actual sequence of events.

Tarek H. Almusallam, Yousef A. Al-salloum[6]*, and M.sc student, dept. of civil engineering, king SaudUniversity, Riyadh, Saudi Arabia, 2007,* “seismic response of interior RC beam-column joints upgraded with FRP sheets. II: Analysis and Parametric Study.” In this paper a procedure for analytical prediction of joint shear strength of interior beam-column joints, strengthened with externally bonded FRP sheets, has been presented. The predicted shear capacities and joint shear stress variation for control and FRP strengthening beam-column joints were compared with experimental observation and they were found to be in good agreement with experimental results.

Tarek H. Almusallam, Yousef A. Al-salloum[7]*, and M.sc student, dept. of civil engineering, king saud university, Riyadh, Saudi Arabia,2007,* “Numerical Investigations on the seismic Behavior of FRP and TRM Upgraded RC Exterior Beam-column Joints I.” In this paper a detailed procedure for nonlinear finite element analysis of fiber reinforcement polymer (FRP) and textile reinforced mortar (TRM) upgraded reinforced concrete (RC) beam-column exterior joint is presented for predicting their seismic performance under simulated earthquake loading. Four specimens was prepared for testing out of these one specimen was tested as a control specimen and the other three were rested after strengthening with TRM, carbon FRP, and glass FRP sheets and the FE result were compared with the test result through load-displacement behavior, ultimate load, and crack pattern and it was observed that the nonlinear FE model can satisfactorily predict the behavior and response of the as built control, FRP, and TRM strengthening exterior RC beam column joint. It also observed that the ultimate load carrying capacity of the CFRP strengthening specimen is maximum and TRM upgraded specimen is minimum and for GFRP strengthening specimen, the capacity is in between CFRP and TRM strengthening specimens.

Ghobarah and El- Amoury[8] *2005* developed effective rehabilitation systems to upgrade the resistance to bond slip of the bottom steel bars anchored in the joint zone and to upgrade the shear resistance of beam column joints. *Antonopoulos and Triantafillou 2002, Gergely et al. 2000, and Almusallam and Al-Salloum 2007* presented analytical models for the prediction of shear capacity of the FRP strengthened beam-column joints. The above review of literature illustrates that despite a substantial work on FRP-upgraded interior and exterior joints, investigations related to FRP-strengthened and/or repaired corner or knee joints are very limited. Also, the behavior of seismically excited FRP repaired/strengthened corner beam-column joints is not well established at various stages of response, e.g., before and after yielding of reinforcements, crushing of concrete, fiber fracture, or debonding.

Modified reinforcement technique using crossed inclined bars at beam column junction increase shear capacity of the statically loaded beam-column joints. The cross inclined bars is intended for creating an additional mechanism for shear transfer. The beam-column joint modeled in ANSYS v12 Workbench shows high strength for crossed inclined bar arrangement at joint.

CHAPTER 2

BEAM COLUMN JOINT

The functional requirement of a joint, which is the zone of intersection of beams and columns, is to enable the adjoining members to develop and sustain their ultimate capacity. The demand on this finite size element is always severe especially under seismic loading. The joints should have adequate strength and stiffness to resist the internal forces induced by the framing members. The essential requirement for the satisfactory performance of a joint in a reinforced concrete structure can be summed up as follows:

i. A joint should exhibit a service load performance equal in quality to that of the member it joins.
ii. A joint should possess a strength that corresponds at least with the most adverse load combination that the adjoining member could possibly sustain, several times if necessary.
iii. The strength of the joint should not normally govern the strength of the structure, and its behavior should not impede the development of the full strength of the adjoining member.
iv. Ease of construction and access for depositing and compacting concrete are other prominent issues of joint design.

2.1 Types of Joints in frames

The joint is defined as the portion of the column within the depth of the deepest beam that frames into the column. In a moment resisting frame, three types of joints can be identified viz. interior joint, exterior joint and corner joint (Fig. 2.1.1). When four beams frame into the vertical faces of a column, the joint is called as an interior joint. When one beam frames into a vertical face of the column and twoother beams frame from perpendicular directions into the joint, then the joint is called as an exterior joint. When a beam each frames into two adjacent vertical faces of a column, then the joint is called as a corner joint. The severity of forces and demands on the performance of these joints calls for greater understanding of their seismic behavior. These forces develop complex mechanisms involving bond and shear within the joint.

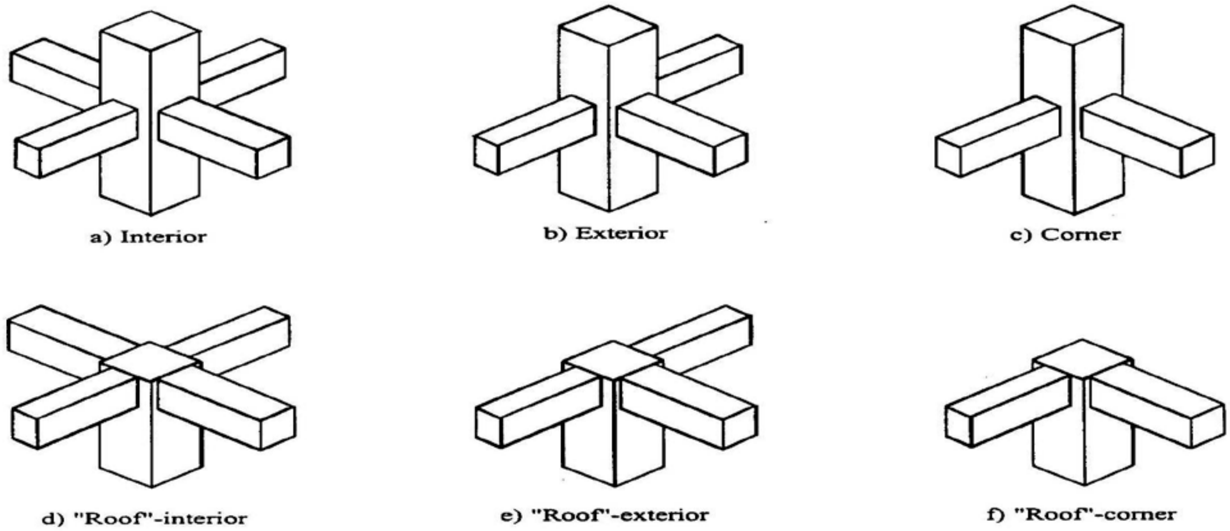


Fig 2.1.1 Types of beam-column Joints in frames

2.2 Forces acting on a beam column joint

The pattern of forces acting on a joint depends upon the configuration of the joint and the type of loads acting on it. The effects of loads on the three types of joints are discussed with reference to stresses and the associated crack patterns developed in them. The forces acting on an exterior joint can be idealized as shown in Fig.2.2.1 The shear force in the joint gives rise to diagonal cracks thus requiring reinforcement of the joint (fig. 2.2.2). The detailing patterns of longitudinal reinforcements significantly affect joint efficiency.

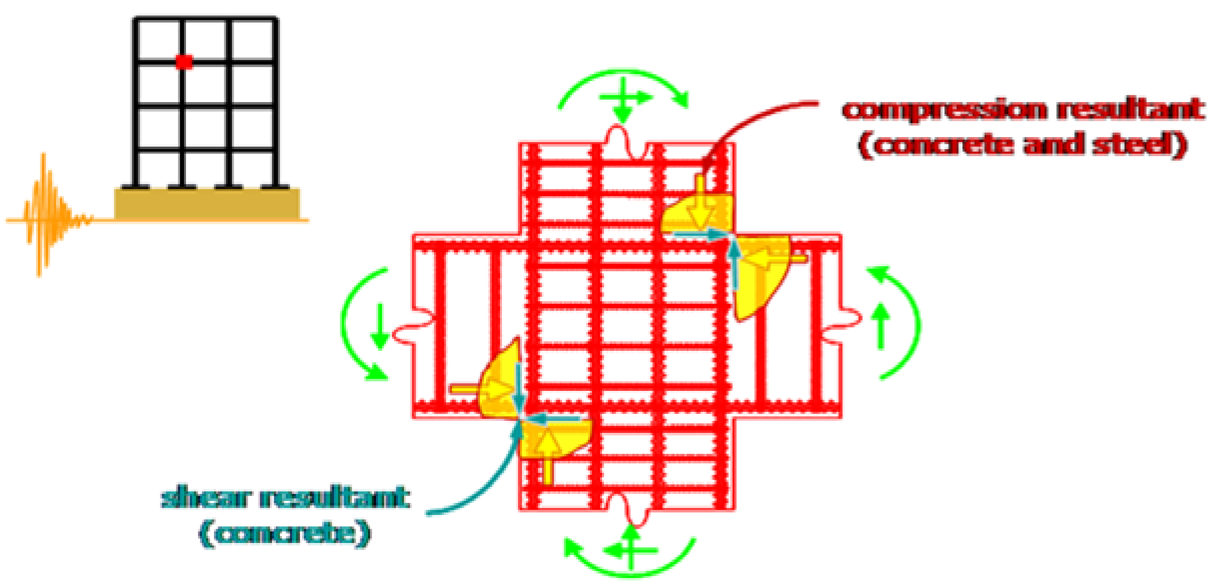


Fig. 2.2.1 Earthquake Loading on beam-column Joints

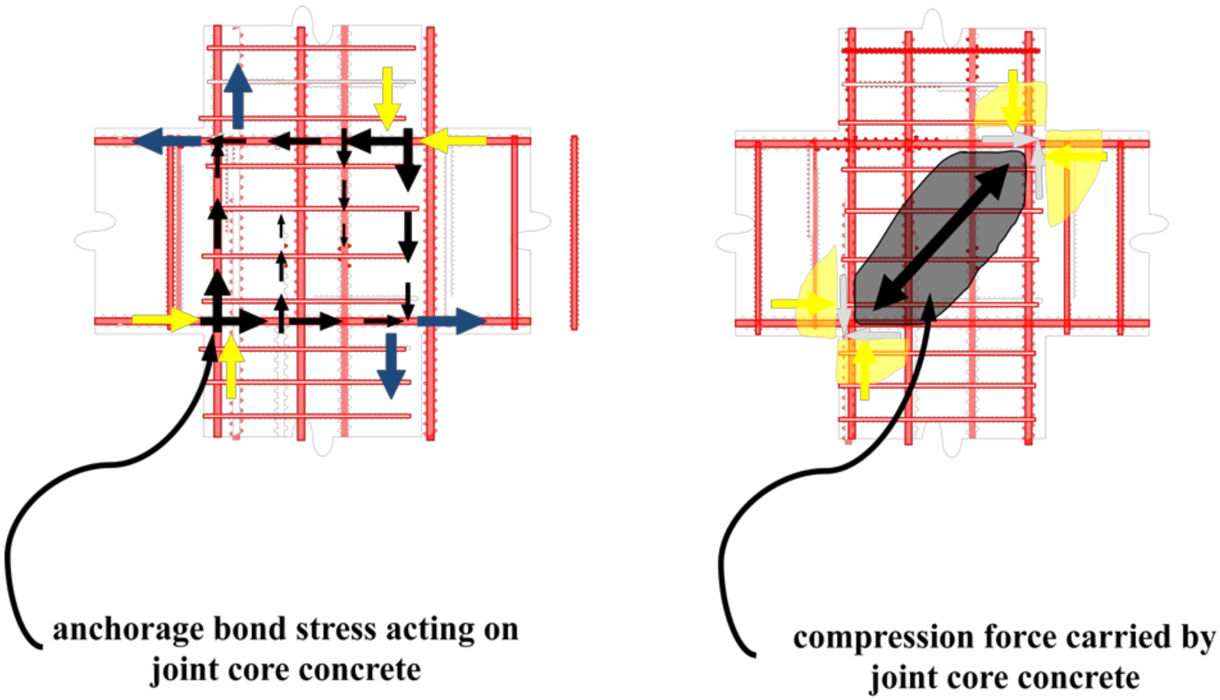


Fig.2.2.2 Internal load distribution in a joint

2.3 Joint Mechanisms

During earthquake shaking, the beams adjoining a joint are subjected to moments in the same direction either in clockwise or anti-clockwise. Under these moments, the top bars in the beam-column joints are pulled in one direction and the bottom one in the opposite direction (fig.2.3.1). These forces are balanced by bond stress developed between concrete and steel in the joint region. If the column is not wide enough or if the strength of the concrete in the joint is low, there is insufficient grip of concrete on the steel bars. In such condition the bar slips inside the joint region and beam lose their capacity to carry load (fig.2.3.1). Under these pull and push forces at top and bottom ends joints undergo geometric distortion, one diagonal length of the joint elongate and the other compresses and if the column cross-sectional size is insufficient, the concrete in the joint develops diagonal cracks (fig.2.3.1).These pull-push forces on joint cause two problems i.e. Loss of grip on beam bars in joint region and distortion of joints causing diagonal cracks and crushing of concrete.

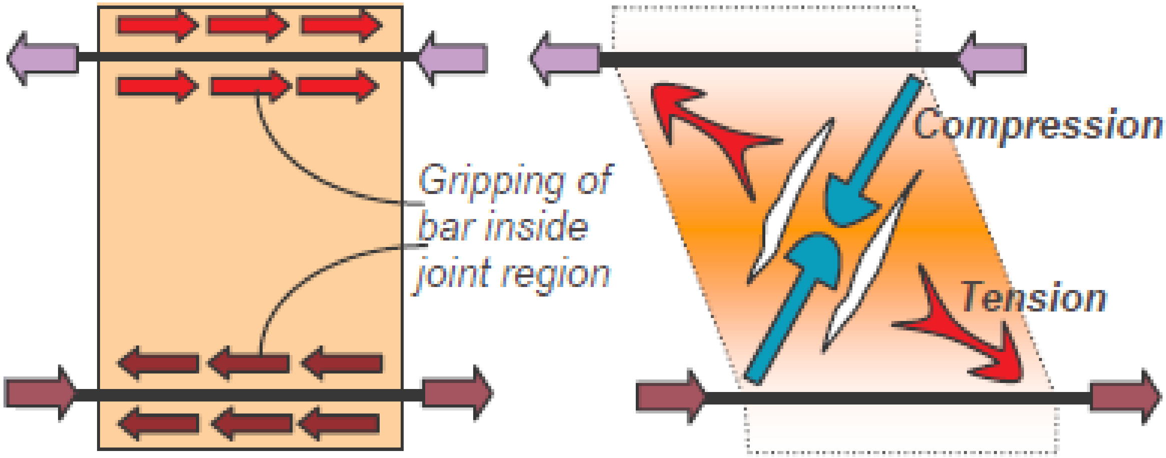


Fig. 2.3.1 Pull-Push Forces on joints

In strong column-weak beam design, beams are expected to form plastic hinges at their ends and develop flexural over strength beyond the design strength. The high internal forces developed at plastic hinges cause critical bond conditions in thelongitudinal reinforcing bars passing through the joint and also impose high shear demand in the joint core. The joint behavior exhibits a complex interaction between bond and shear. The bond performance of the bars anchored in a joint affects the shear resisting mechanism to a significant extent.

Fig. 2.3.2Loss of grip at joint region

Fig. 2.3.3 Distortion of joint causing diagonal cracks

2.4 Exterior Joint

In exterior joints the beam longitudinal reinforcement that frames into the column terminates within the joint core. After a few cycles of inelastic loading, the bond deterioration initiated at the column face due to yield penetration and splitting cracks, progresses towards the joint core. Repeated loading will aggravate the situation and a complete loss of bond up to the beginning of the bent portion of the bar may take place. The longitudinal reinforcement bar, if terminating straight, will get pulled out due to progressive loss of bond. The pull out failure of the longitudinal bars of the beam results in complete loss of flexural strength. This kind of failure is unacceptable at any stage. Hence, proper anchorage of the beam longitudinal reinforcement bars in the joint core is of utmost importance. The pull out failure of bars in exterior joints can be prevented by the provision of hooks or by modified reinforcement techniques. Modified reinforcement technique, is helpful in providing adequate anchorage when furnished with sufficient horizontal development length and the additional mechanism of shear transfer at joints. Because of the likelihood of yield penetration into the joint core, the development length is to be considered effective from the critical section beyond the zone of yield penetration. Thus, the size of the member should accommodate the development length considering the possibility of yield penetration.

The following observations may be made for the design of exterior joint:

i. The anchorage conditions for the top beam bars are extremely unfavorable where they enter the joint. The surrounding concrete is subject to sedimentation, and it is exposed to transverse tension. Usually a splitting crack forms along these bars at a relatively early stages of the loading.

ii. The bottom beam bars, in compression, enter the joint in a region of ideal bond conditions, since the surrounding concrete is also in compression transversely to the bars. The straight portion of the bars beyond the bend remains largely ineffective for compression loads. Therefore, after a few cycles of reversed seismic loading, serious anchorage losses can occur, particularly when the beam frames into a shallow column.

iii. The outer column bars are subjected to perhaps the most severe bond conditions. Over the depth h of the beam, a total bond force of

$$\mathbf{C'_s + T'' \leq 2A_s f_y} \quad (1)$$

Where A_s = area of the outer column bars.

2.5 Interior beam Column Joint

A detailed study on many collapsed or severely damaged preseismic code designed reinforced concrete RC framed structures in past earthquakes showed that, in most of the cases, the failure of interior beam-column joints initiated the collapse process of structures. Therefore, beam column joints were identified as the weakest link in existing RC moment-resisting frames. The prime reason behind joint failure is identified as inadequate shear strength of the joint. Inadequate joint shear strength is generally due to insufficient and inadequately detailed reinforcement in the joint region. Further, due to insufficient reinforcement particularly transverse reinforcement in the joint, joint brittleness increases, which, in turn, significantly reduces the overall ductility of the structure. Modified reinforcement technique, is helpful in the shear transfer or additional mechanism to shear transfer at joint region. The bond force to be disposed of by one of the top beam bars results from the force acting on the bar at the column faces.

$$\textbf{Bond Force} = \frac{\Pi d2}{4}(\mathbf{fy} + \mathbf{f's}) \qquad (2)$$

Where f'_s = Compression steel stress at the far face of the joint.

2.6 Corner RC beam Column Joint

In moment resisting reinforced concrete RC framed buildings, corner joints are generally found at the roof level. These joints, if designed only for gravity loads and based on preseismic codes, may suffer substantial damage during earthquakes due to inadequate shear reinforcement in the joint region. The internal forces generated at corner joint may cause failure within the joint before the strength of the beam or column, whichever is weaker, is attained. Several techniques of repairing and strengthening of RC joints, damaged by earthquakes, have been reported in earthquake prone countries such as Japan, Mexico, and China.

For the corner joint, adequate strength can be expected only the following condition:

i. The tension steel is continuous around the corner (i.e. it is not lapped within the joint).

ii. The tension bars are bent to a sufficient radius to prevent bearing or splitting failure under the bars. Nominal transverse bars placed under the bent bars.

iii. The amount of tension reinforcement is limited to

$$\boldsymbol{\rho \leq 6\sqrt{f'_c} / f_y} \qquad (3)$$

Where, stresses are in *psi* units

2.7 Detailing Recommendations

The following recommendations are made in connection with the requirement of anchorage, shear, and confinement within a joint core of earthquake resisting structures.

i. **Anchorage:** Due to loss of bond at the inner face of an exterior joint, development length of the beam reinforcement should be computed from the beginning of the 90^o bend, rather than the face of the column. In wide columns, any portion of the beam bars within the outer third of the column could be considered for computed development length. For shallow columns, the use of stub beams will be imperative. A large diameter bearing bar fitted along the 90^o bend of the beam bars should be beneficial in distributing bearing stresses. In deep columns and whenever straight beam bars are preferred, mechanical anchorage could be advantageous. Joint ties should be so arranged that the critical outer column bars and the bent-down portions of the bars held against the core of the joint.

ii. **Shear Strength:** When the computed axial compression on the column is small, the contribution of the concrete shear resistance should be ignored,and shear reinforcement for the entire joint shearing force should be provided. In exterior joints only the ties that are situated in the outer two thirds of length of the potential diagonal failure crack, which runs from corner to corner of the joint, should be considered to be effective. The joint shear to be carried by the ties is calculated as,

$$\mathbf{A_v} = \frac{\mathbf{1.5}\ \boldsymbol{VsS}}{\boldsymbol{dFy}} \quad (4)$$

Where V_s = joint shear carried by the ties, A_v = total area of tie legs in a set making up one layer of shear reinforcement, and d = effective depth of the beam.

To protect the core concrete against excessive diagonal compression, an upper limit must be set for the joint shear, normally expressed in terms of a nominal shearing stress. This value suggested for beams are, [$10\sqrt{f'_c}$ to $11.5\sqrt{f'_c}$ *(psi)*].

iii. **Confinement:** Shear reinforcement confines only the corner zones of the joint, and horizontal tie legs are quite ineffective in furnishing restraint against the volumetric increase of the core concrete. Hence additional confining bars must be provided at the right angle to the shear reinforcement. These bars should not be placed further than 150 *mm* apart.

2.8 Codal Provision

According to IS 13920:1993 (Ductile Detailing): -

i. **Cl-7.4.1** Special confining reinforcement (This requirement shall be met with, unless alarger amount of transverse reinforcement isrequired from shear strength considerations) shall be provided over a length *l*o from each joint face, towards mid span, and on either side of any section, where flexural yielding may occur under the effect of earthquake forces. The length '*l*o' shall not be less than (a) larger lateral dimension of the member at the section where yielding occurs, (b) 1/6 of clear span of the member, and (c) 450 *mm*.

ii. **Cl-8.1** The special confining reinforcement as required at the end of column shall be provided through the joint as well, unless the joint is confined.

iii. **Cl-8.2** A joint which has beams framing into all vertical faces of it and where each beam width is at least 3/4 of the column width, may be provided with half the special confining reinforcement required at the end of the column. The spacing of hoops shall not exceed 150 *mm*.

iv. Problem of diagonal cracking and crushing of concrete in the joint region can be controlled by providing large column sizes and providing closely spaced closed-loop steel ties around column bars in the joint region. The ties hold together the concrete in the joint and also resist shear force, thereby reducing the cracking and crushing of concrete.

v. Continuing the transverse loop around the column bars through the joint region. This is achieved by preparing the case of the reinforcement (both longitudinal bars and stirrups) of all beams at a floor level to be prepared on top of the beam formwork of that level and lower in to the case.

vi. The building columns in seismic zones III, IV, and V to be at least 300 *mm* wide in each direction of the cross section when they support beams that are longer than 5 *m* or when these column are taller than 4 *m* between floors.

vii. The American concrete institute recommends a column width of at least 20 times the diameter of largest longitudinal bar used in adjoining beam.

viii. In exterior joints where beams terminate at columns, longitudinal beam bars need to be anchored into the column to ensure proper gripping of bar in joint. The length of anchorage for a bar of grade Fe415 is about 50 times its diameter. This length is measured from the face of the column to the end of the bar anchored in the column.

ix. In column of small widths and beam bars are of large diameter, a portion of beam top bar is embedded in the column that is cast up to the soffit of the beam, and a part of it overhangs.

x. If column width is large, the beam bars may not extend below the soffit of the beam.

xi. In interior joints, the beam bars both top and bottom bars need to go through the joint without any cut in the joint region, and these bars must be placed within the column bars and with no bends.

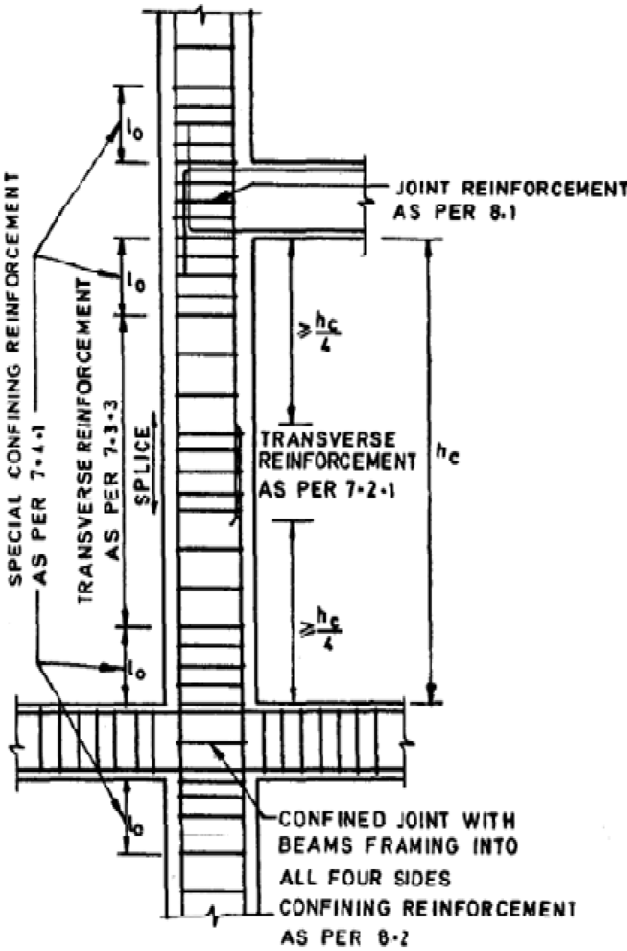


Fig 2.8.1 Column and joint detailing

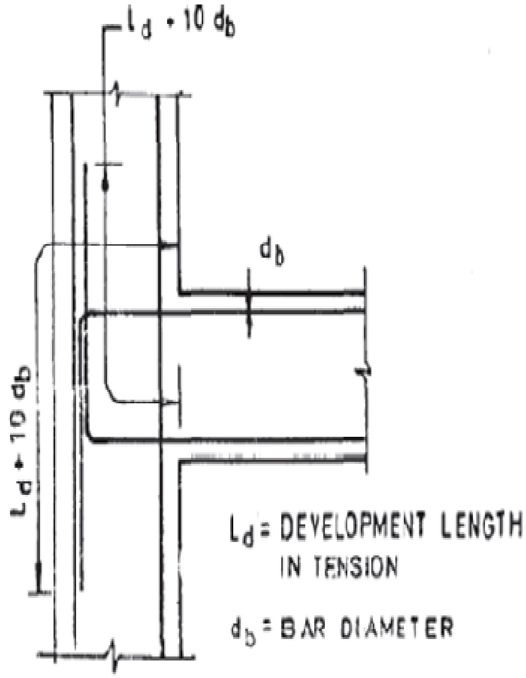


Fig 2.8.2Anchorage of beam bars in an External joint

[From IS-13920, page no. 9 & 3]

CHAPTER 3

FINITE ELEMENT MODELING

This chapter begins with a description of the control and strengthen specimen being modeled and then transitions to the geometry, element formulation, constitutive models, boundary conditions, and the mesh formulation.

3.1 Finite Element Modeling:

For many engineering problems analytical solutions are not suitable because of the complexity of the material properties, the boundary conditions and the structure itself. The basis of the finite element method is the representation of a body or a structure by an assemblage of subdivisions called finite elements. The Finite Element Method translates partial differential equation problems into a set of linear algebraic equations.

$$[K]\{q\} = \{F\} \quad (5)$$

Where, K = stiffness matrix

q = Nodal displacement vector

F = Nodal vector force

The modeling procedure is the following:

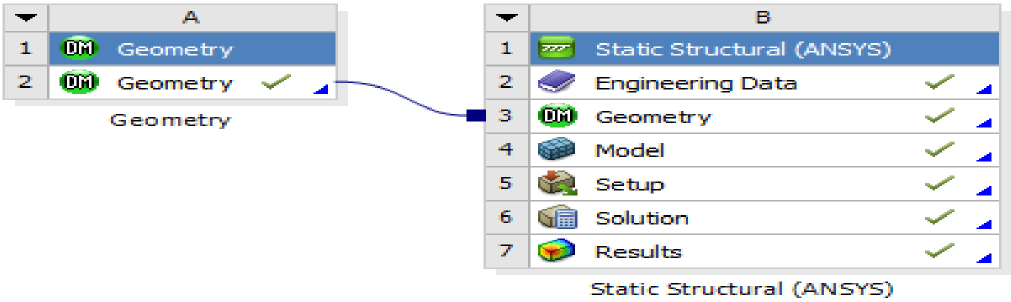


Fig. 3.1.1 Modeling Procedure in ANSYS Workbench v12

- Geometry
- Element type
- Material properties
- Mesh definition
- Boundary conditions
- Analysis
- Post processing

In this section, modeling, including meshing, details of beam-column joints, is presented. The finite-element program ANSYS Workbench Version 12 is used for this purpose. The element details of each material are presented subsequently. The finite element analysis is an assembly of finite elements which are interconnected at a finite number of nodal points. The main objective is to simulate the behavior of the beam-column joint under cyclic load on the beam by constraining the columns. In the present study, discrete modeling approach is used to model the behavior of Steel reinforced beam-column joints using ANSYS software. In this approach, concrete column and beam elements are modeled by Solid65 elements while the reinforcement (steel) is modeled by Link8 elements. The nonlinearity is derived from the nonlinear relationships in material models and the effect of geometric nonlinearity is not considered.

Concrete: To model the concrete an eight-node solid element, Solid65, is used. This solid element has eight nodes with three degrees of freedom at each node with translations in the nodal x, y, and z directions. Plastic deformation, cracking in three orthogonal directions and crushing capability can be utilized by the element.

Reinforcing Steel: Steel reinforcement in the experimental beam-column joint was constructed with typical Grade Fe 415 *MPa*. The steel for the finite-element model was assumed to be an elastic–perfectly plastic material with identical properties in tension and compression. A Link8 element is used to model the steel reinforcement. Two nodes are required for this element. Each node has three degrees of freedom, which are translations in the nodal x, y, and z directions.

3.2 Material Properties

The following material properties were used for the present FE analysis:-

CONCRETE:

Elastic Modulus, $E_c = 5000\sqrt{f_c}$, Ultimate uniaxial compressive strength, f_c = 25*Mpa*, Ultimate tensile compressive strength, $f_r = 0.62\sqrt{f_c}$, Poisson ratio for concrete = 0.2

STEEL:

Elastic Modulus, E_s =200000 *Mpa*, Yield stress of longitudinal steel bars, f_y = 415*Mpa*, Yield stress of transverse steel bars, f_y = 250*Mpa*, Poisson ratio for steel = 0.3

3.3 Geometric Properties of Exterior Joint with one beam

TABLE 1

Parameter	Value *(mm)*	Parameter	Value *(mm)*
Beam specification		**Column specification**	
Width	160	Width	160
Depth	350	Depth	300
Span	2000	Clear height	1450
Concrete cover	30	Floor to floor height	1800
Top steel	4-12	Concrete cover	30
Bottom steel	4-12	Longitudinal steel	10-10
Transverse steel diameter	6	Transverse steel diameter	6
Transverse steel spacing	220	Transverse steel spacing	140

3.4 Geometric Properties of Exterior, Interior and corner joints

TABLE 2

Parameter Beam specifications	Value *(mm)*	Parameter Column specifications	Value *(mm)*
Width	300	Width	300
Depth	400	Depth	300
Span	3000	Height	3500
Concrete cover	30	Floor to floor height	3250
Top steel	4-10	Concrete cover	30
Bottom steel	4-10	Longitudinal steel	4-12
Transverse steel diameter	6	Transverse steel diameter	6
Transverse steel spacing	220	Transverse steel spacing	200

3.5 Creation of Geometry and Reinforcement Detailing

Using the geometry tools of ANSYS software, beam column joint specimens is modeled as a 3D model. The created geometry and typical steel reinforcement detailing for the exterior joint with one beam, exterior joint with two beams, exterior joint with three beams, interior joints with four beams and corner joint are shown in Fig. 3.5.1-3.5.5 respectively. In the finite-element models, 3D spar elements, Link8, were employed to represent the steelreinforcement. Ideally, the actual bond strength between the concrete and steel reinforcement should be considered. However, in this study, a perfect bond between the two materials is assumed. To provide the perfect bond, the link element, representing the steel reinforcing bars, is connected between the nodes of each adjacent concrete solid element; thus, the two materials shared the same nodes.

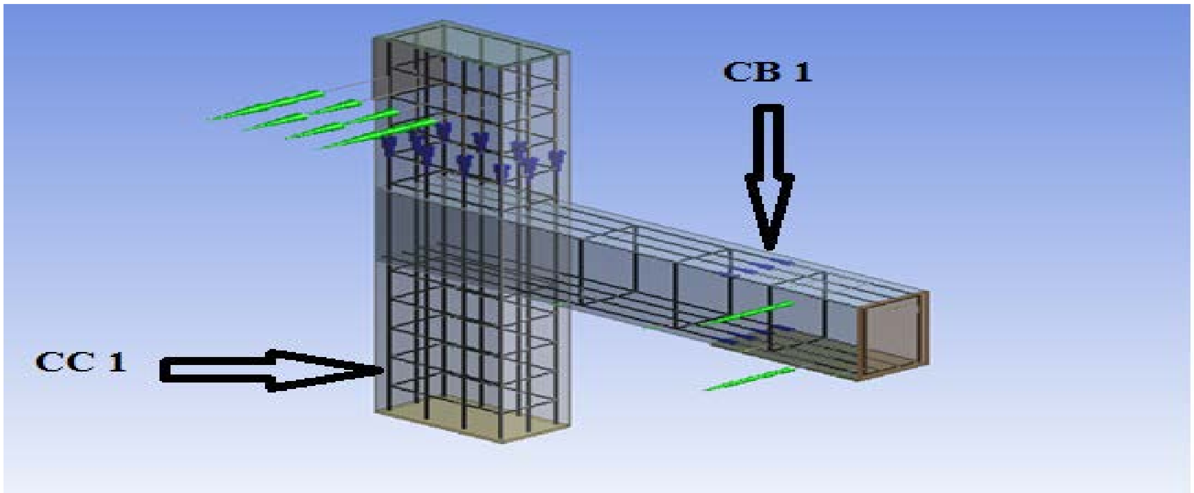


Fig 3.5.1 Geometric model and reinforcement detailing of Exterior joint (CS1)

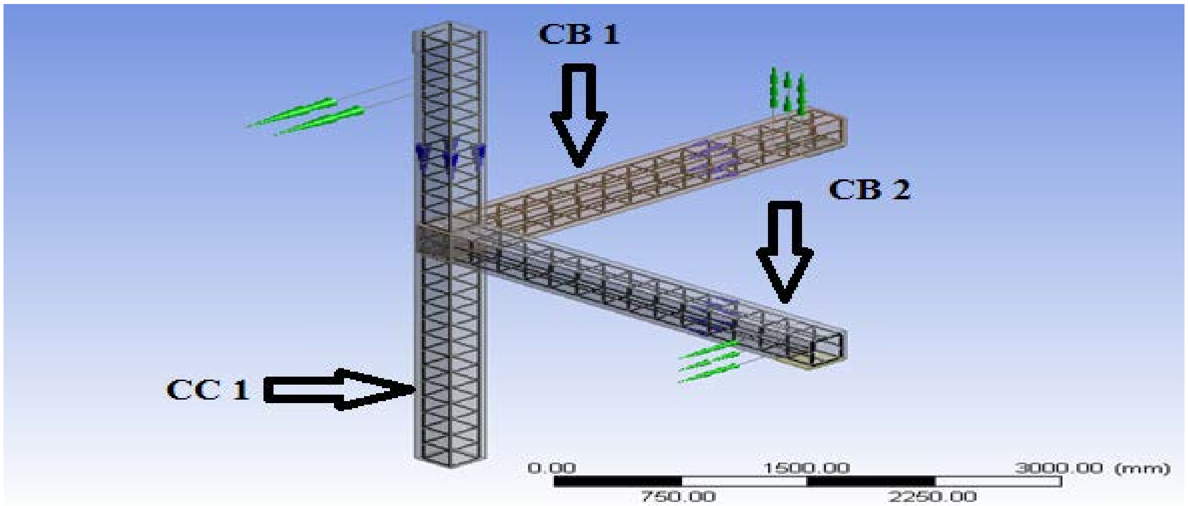


Fig 3.5.2 Geometric model and reinforcement detailing of joint with two beams (CS2)

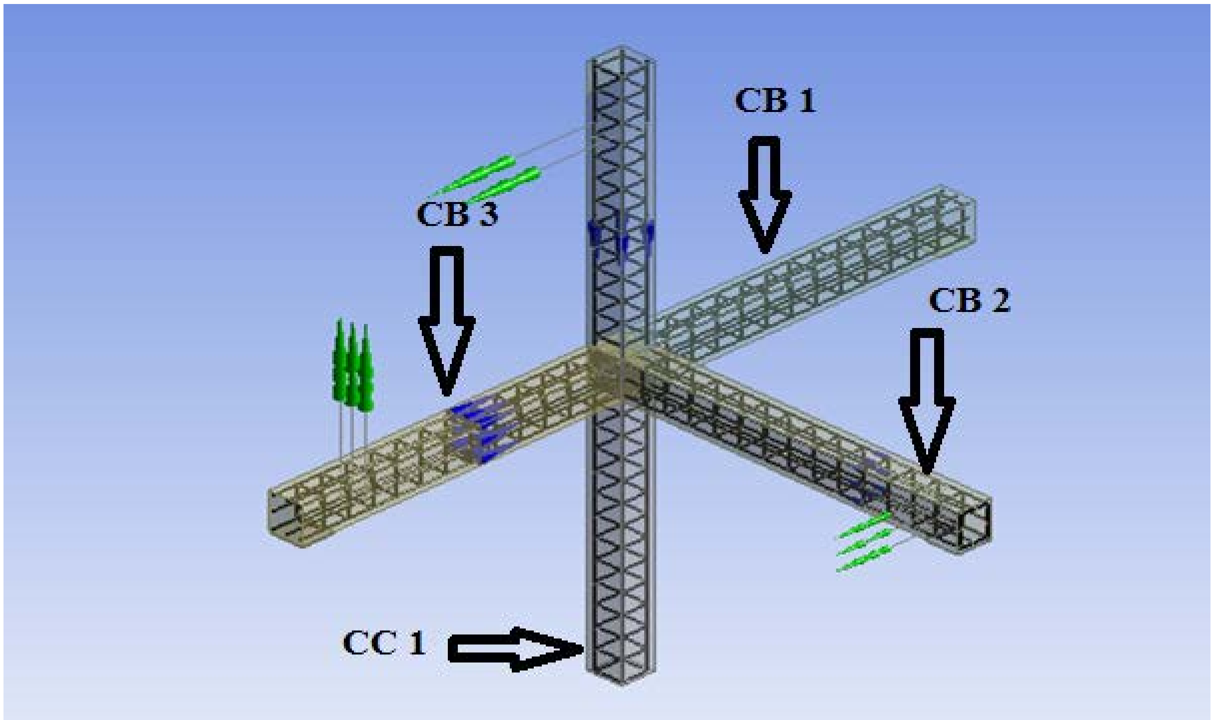


Fig 3.5.3 Geometric model and reinforcement detailing of joint with three beams (CS3)

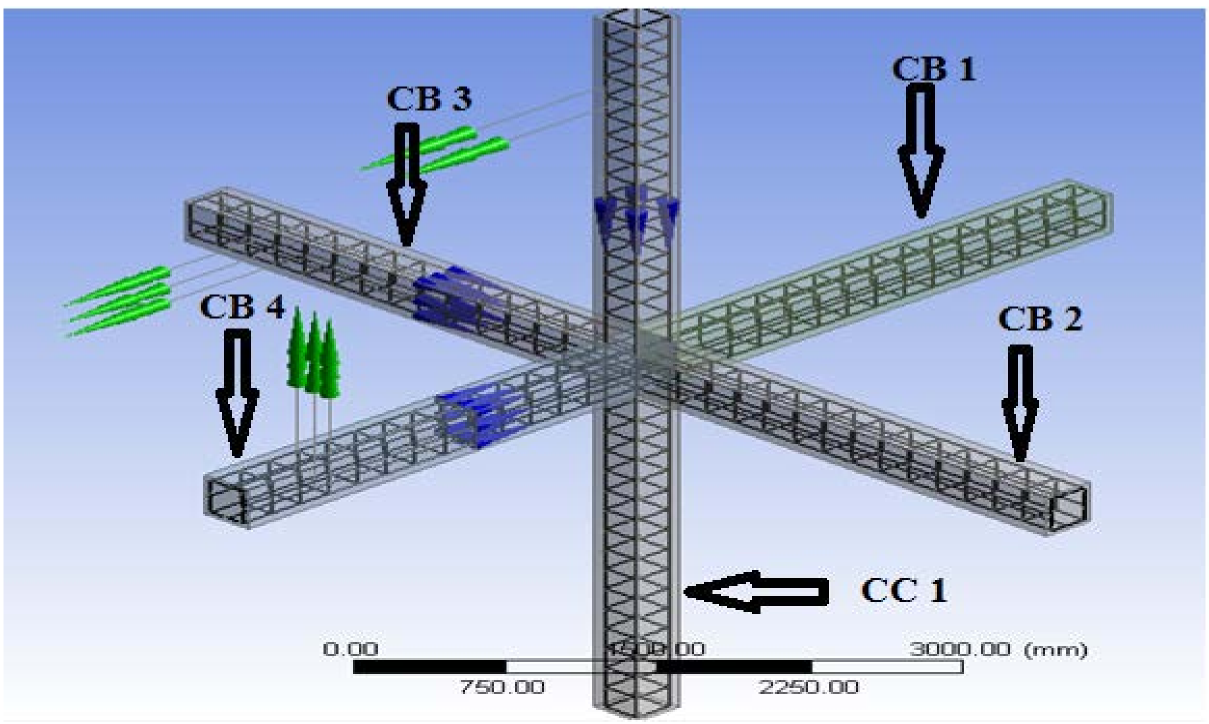


Fig. 3.5.4 Geometric model and reinforcement detailing of interior joint (CS4)

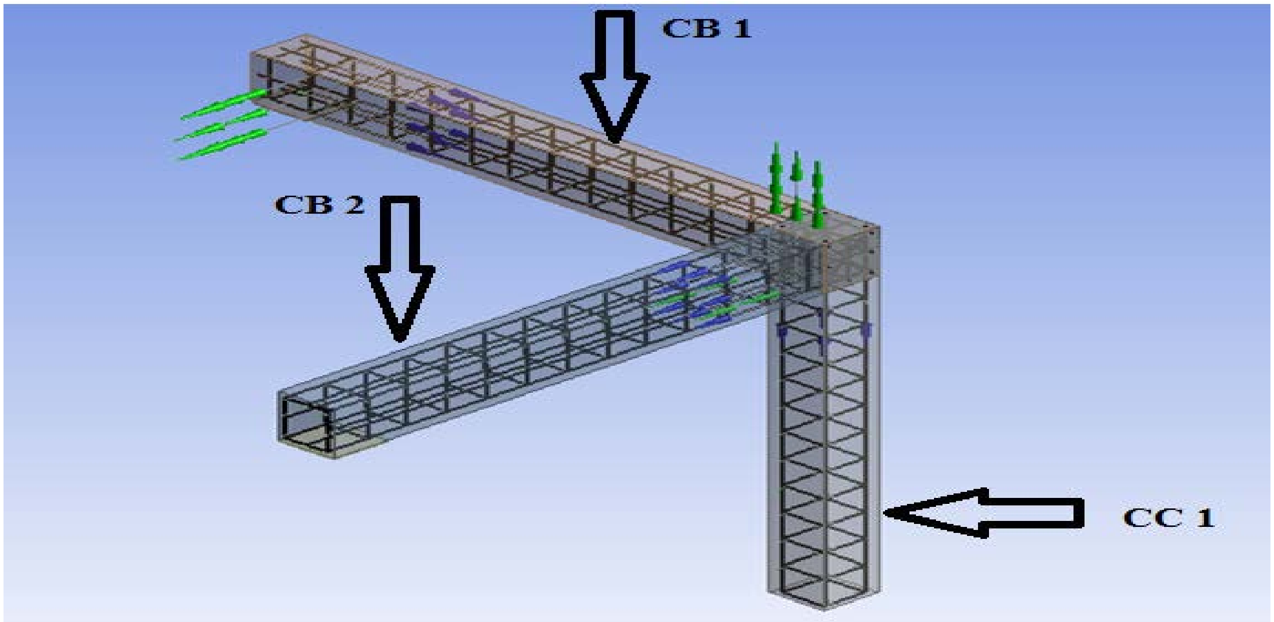


Fig. 3.5.5 Geometric model and reinforcement detailing of corner joint (CS5)

3.6Meshing

To obtain good results from the Solid65 element, a square mesh is used. Therefore, the mesh is setup such that square or rectangular elements are created (Fig. 3.6.1-3.6.5). The volume sweep command of ANSYS v12 is used to mesh the support. This properly sets the width and length of elements in the concrete support and makes it consistent with the elements and nodes in the concrete portions of the model. In the analysis, the specimen was modeled with square concrete elements by using a 50 *mm* mesh configuration.

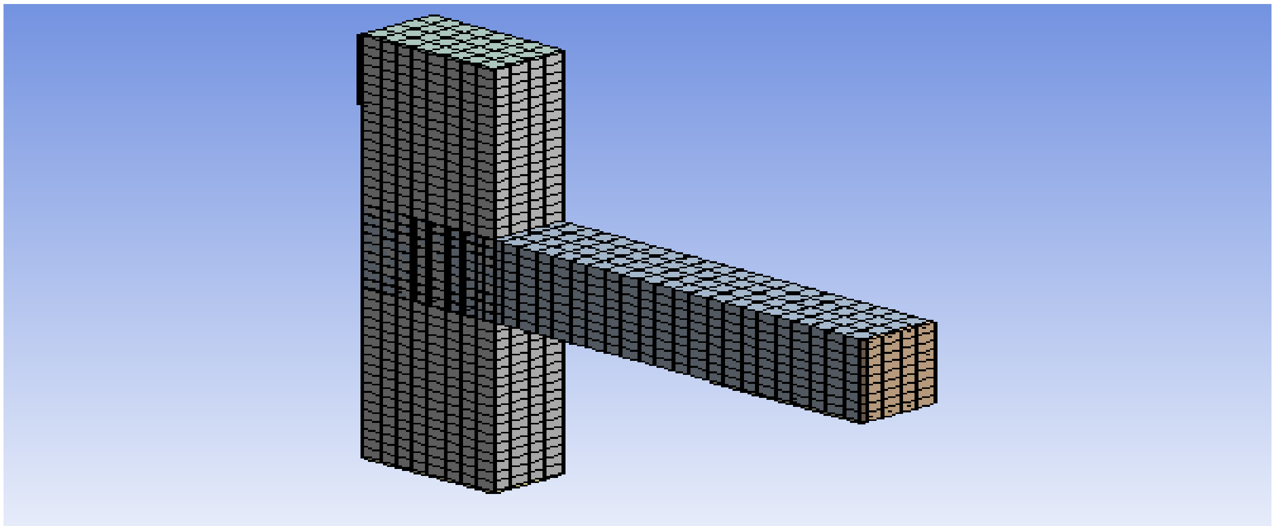


Fig. 3.6.1 square meshing of exterior joint

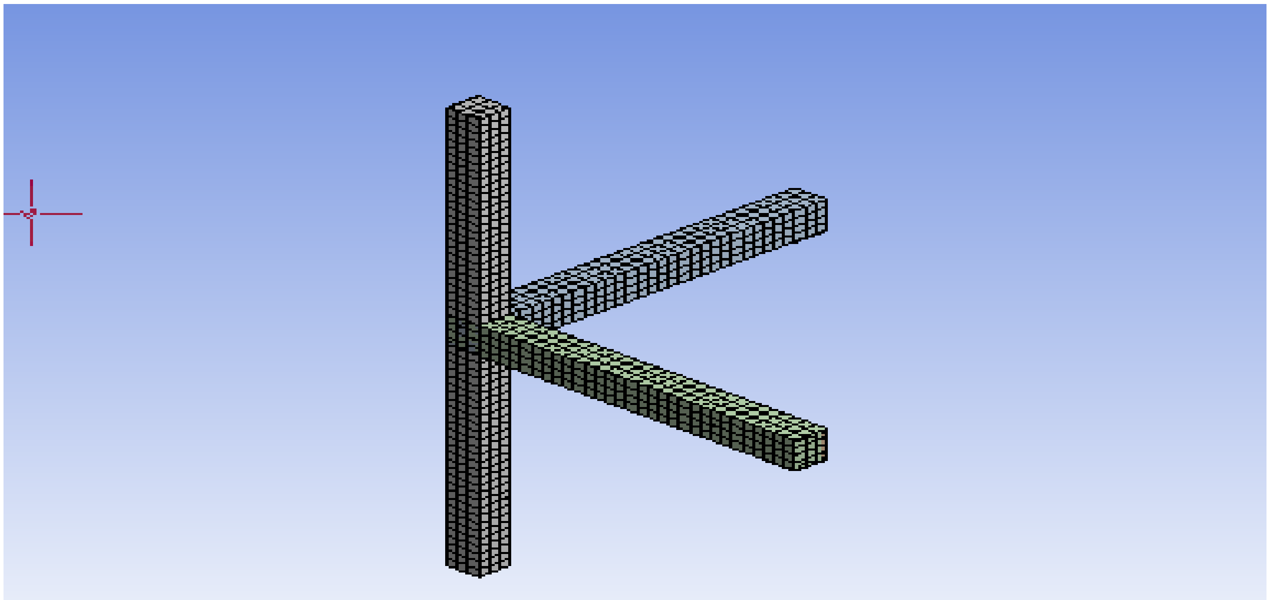


Fig. 3.6.2 square meshing of joint with two beams

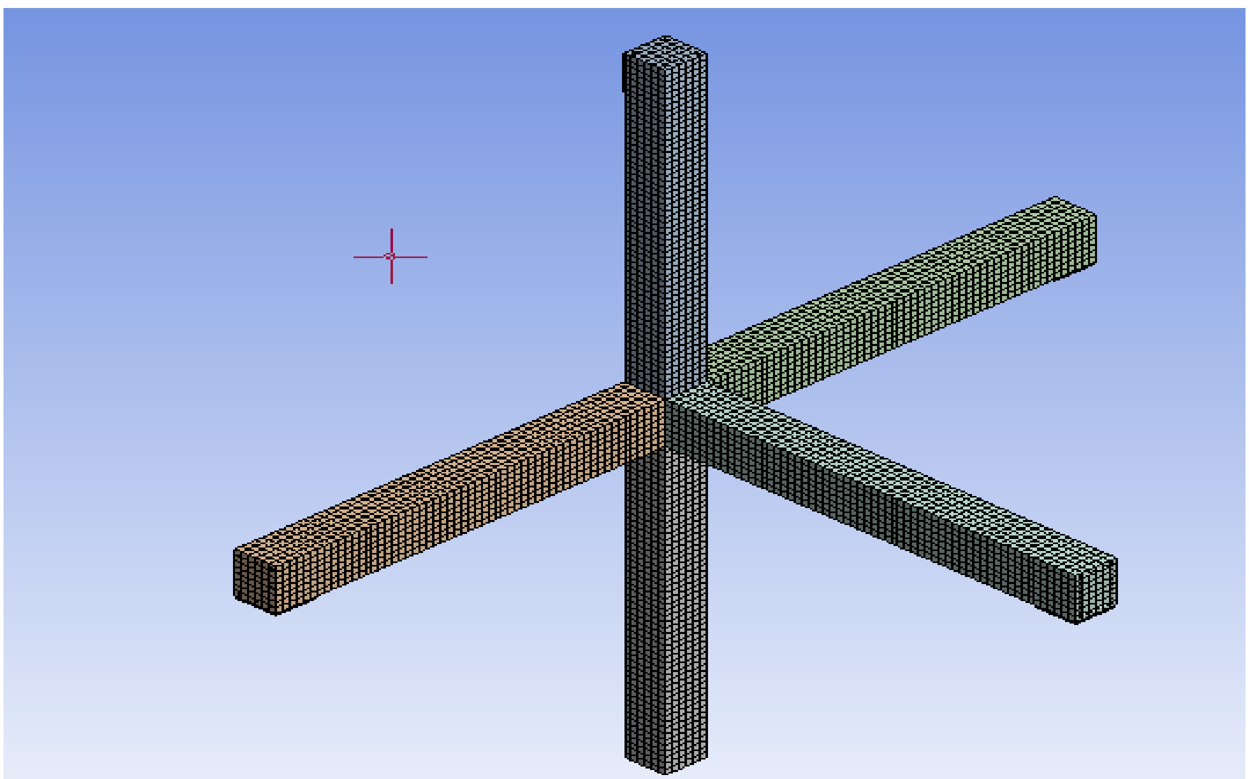


Fig. 3.6.3 square meshing of joint with three beams

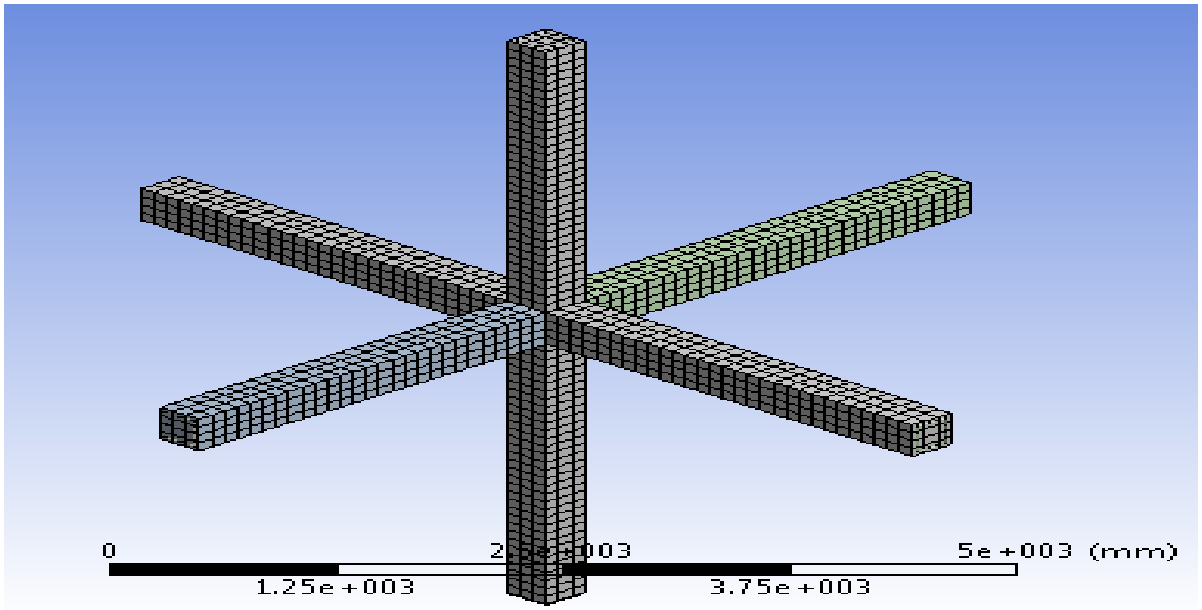


Fig. 3.6.4 square meshing of Interior joint

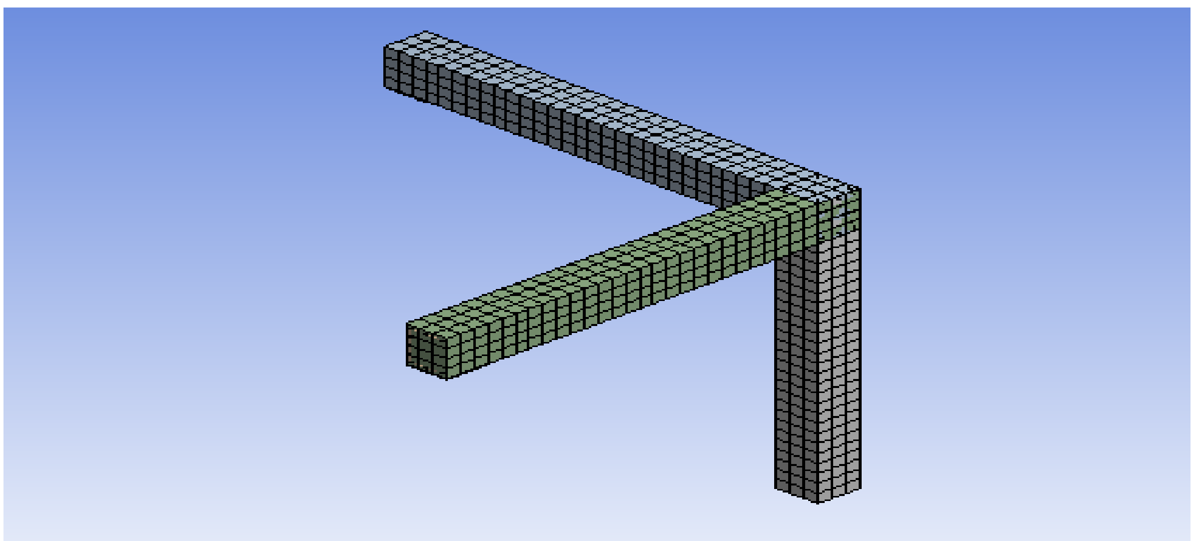


Fig. 3.6.5 square meshing of corner joint

3.7Modified Reinforcement Technique (MRT) Model

In a moment resisting frame, beam-column joints are generally classified with respect to geometrical configuration and identified as interior, exterior and corner joints. The basic requirement of design is that the joint must be stronger than the adjoining beam or column member. It is important to see that the joint size is adequate in the early design phase; otherwise the column or beam size will have to be suitably modified to satisfy the joint shear strength or anchorage requirements. The design of beam column joint is predominantly focused on providing joint shear strength and adequate anchorage within the joint. In addition to high shear force generated, the high bond stresses required to sustain this force gradient across the joint may cause bond failure and corresponding degradation of moment capacity accompanied by excessive drift. The joint is defined as the portion of the column within the depth of the deepest beam that frames into the column. A beam column joint becomes structurally less efficient when subject to large lateral loads, such as strong wind, earthquake, or explosion.In these areas, high percentages of transverse hoops in the core of joints are needed in order to meet the requirement of strength, stiffness and ductility under cyclic loading. Provisions of high percentage of hoops cause congestion of steel leading to construction difficulties. During strong earthquake, beam-column connections are subjected to severe reversed cyclic loading. If they are not designed and detailed properly, their performance can significantly affect the overall response of a ductile moment-resisting frame building. The performance of beam-column joints subjected to seismic forces may be improved only if the major design considerations are satisfied. Though there is no explicit Indian Code for design of beam-column joints for seismic forces, where as severe importance is given in many international codes for design and detailing of joints. For the increasing the stiffness, load carrying capacity and ductility of beam column joint, modified reinforcement technique is used. In this technique, the cross inclined bars at the joint region is implemented. The detailing of exterior with one, two, three, interior with four beam, and corner beam column joints with modified reinforcement technique is showed in Fig 3.7.1-3.7.5 respectively.

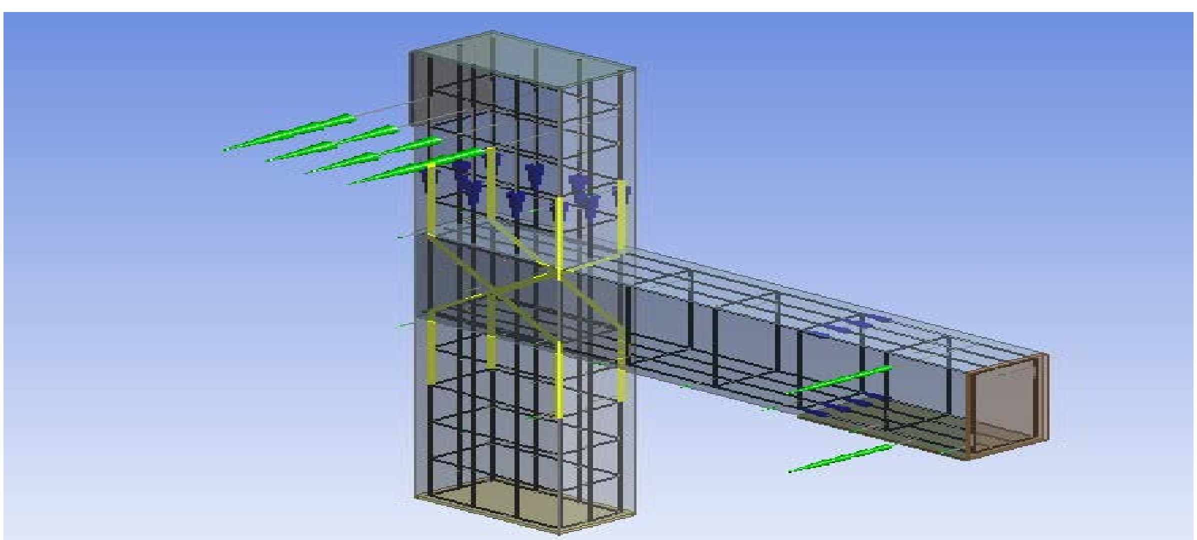


Fig. 3.7.1 Modified reinforcement detailing of exterior joint with one beam (SS1)

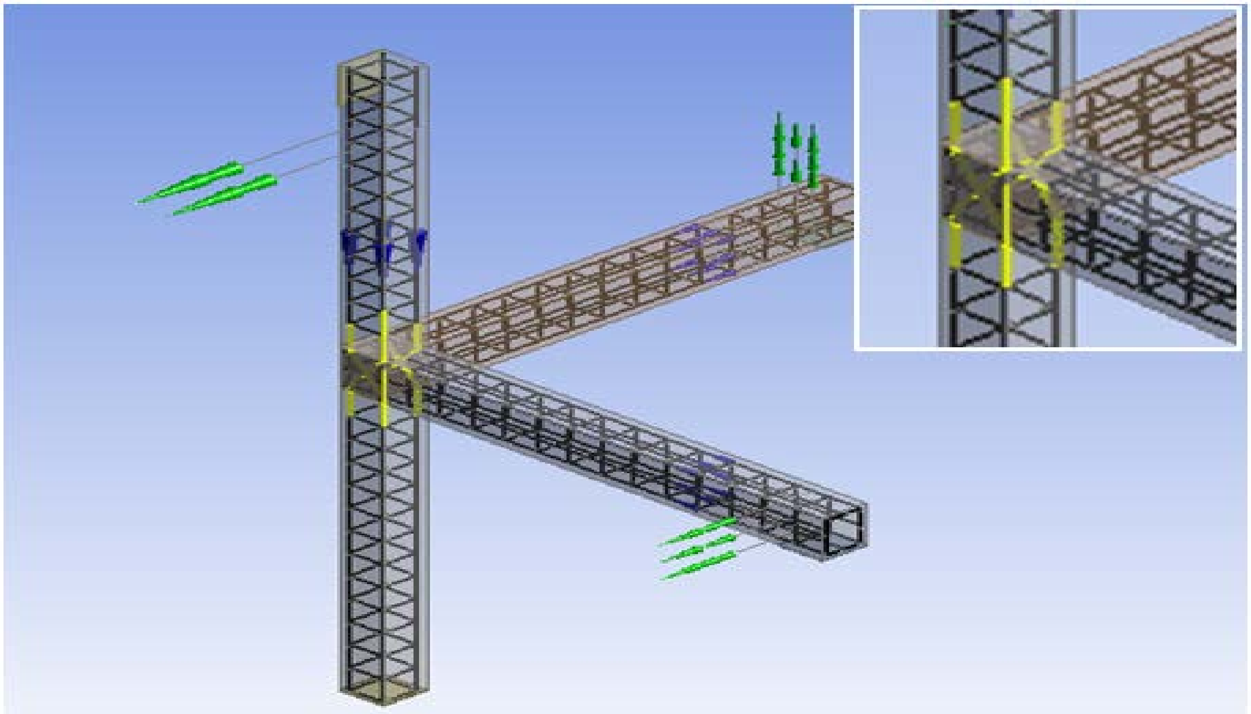


Fig. 3.7.2 Modified reinforcement detailing of exterior joint with two beams (SS2)

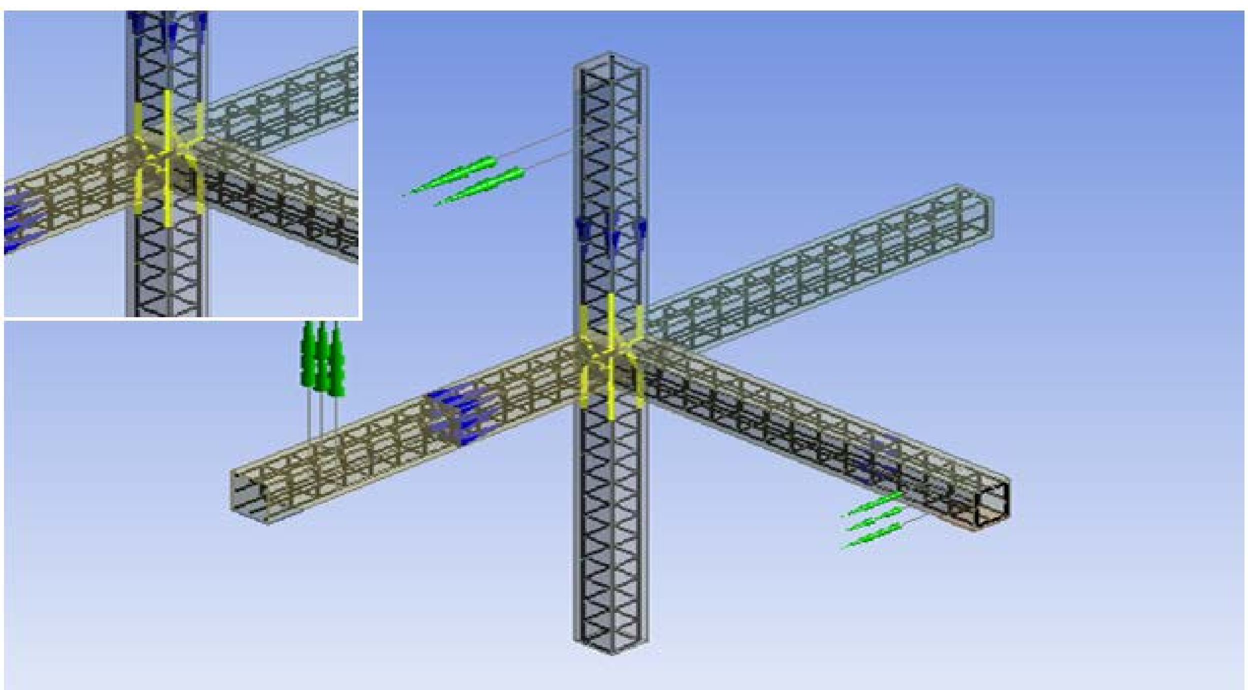


Fig. 3.7.3 Modified reinforcement detailing of exterior joint with three beams (SS3)

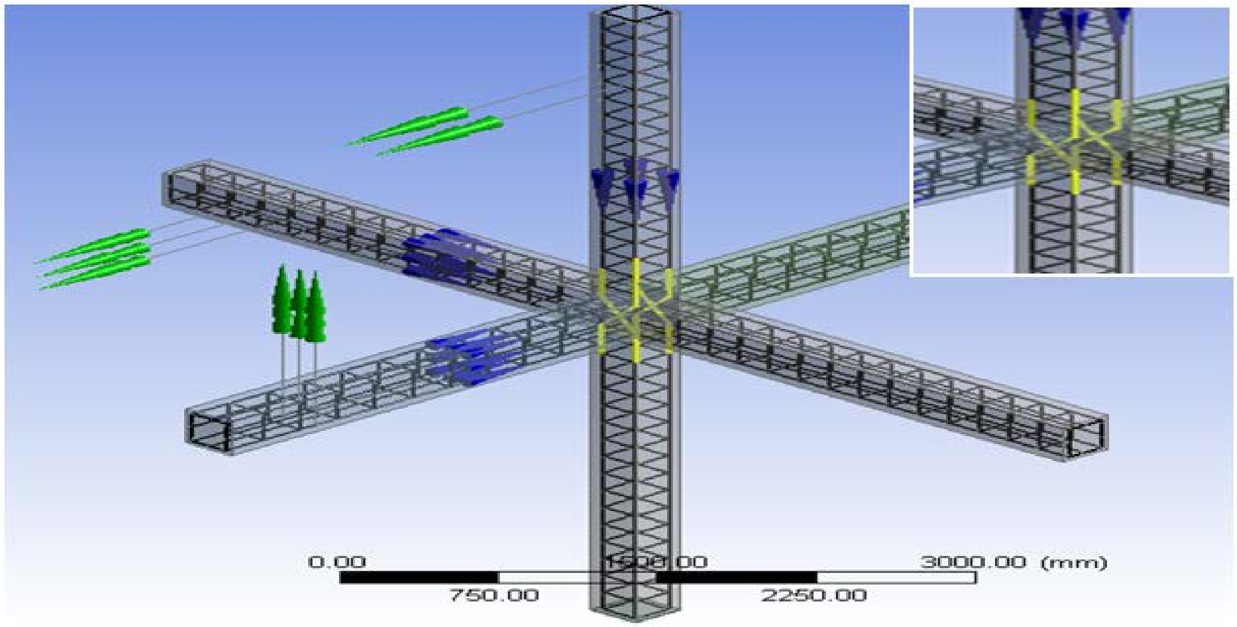


Fig. 3.7.4 Modified reinforcement detailing of interior joint with four beams (SS4)

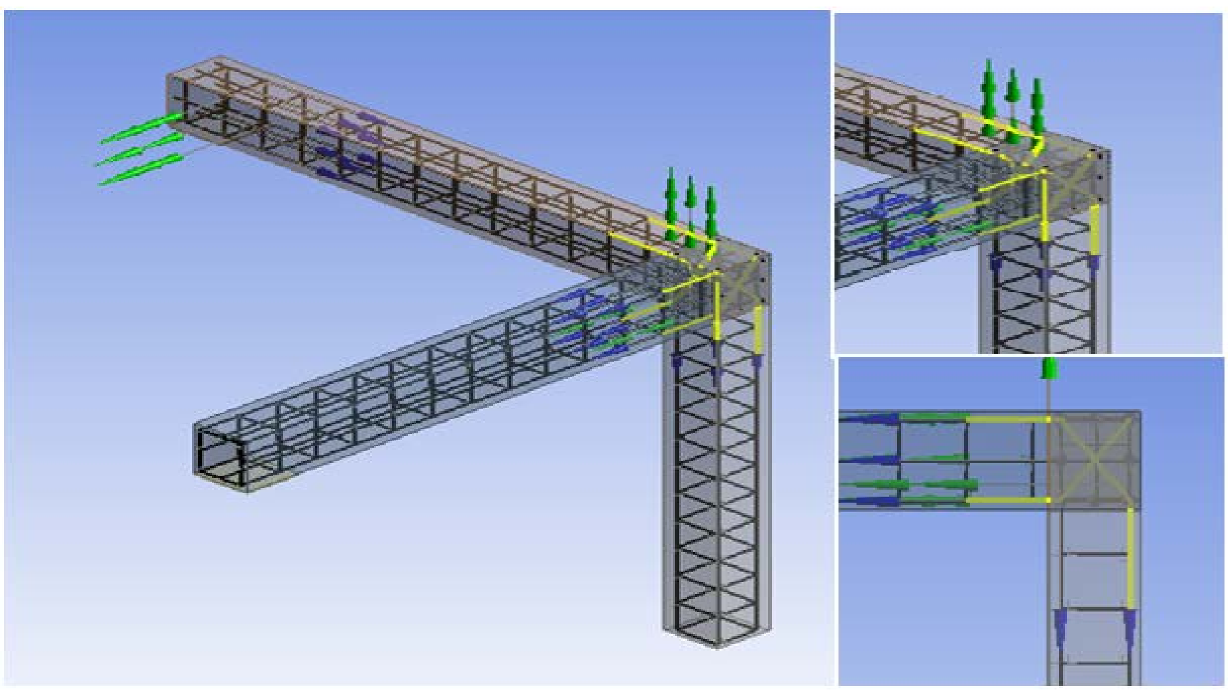


Fig. 3.7.5 Modified reinforcement detailing of corner joint (SS5)

A study of the usage of additional cross-inclined bars at the joint core shows that the inclined bars introduce an additional new mechanism of shear transfer and diagonal cleavage fracture at joint will be avoided. However, there were only limited experimental and analytical studies for the usage of non-conventional detailing of joints.

CHAPTER 4

LOADING AND BOUNDARY CONDITIONS

Static analysis is performed for the analysis of exterior, interior, and corner joint of control and strengthen specimen under the cyclic loading. A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. A static structural load can be performed using the ANSYS solver. The types of loading that can be applied in a static analysis include:

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (nonzero) displacements
- Temperatures (for thermal strain)

4.1 Loading and Boundary Conditions of Joints

Displacement boundary conditions were needed to constrain the model to get a unique solution. To ensure that the model acts in the same way as the experimental beam-column joint, boundary Conditions are applied at the supports and where loadings exist. In all model the joints are fixed and only upper joint of the column is kept free. The loading condition, applied cyclic loading from 0 to 500 kNin the lateral direction of the column and in the upper direction of the beam. A constant axial loading of 500 kN has been applied at the column. The loadings are applied in all direction with the time interval of 120 sec. Theloadings are applied in all direction small thickness of 5 *mm* thick concrete plate.

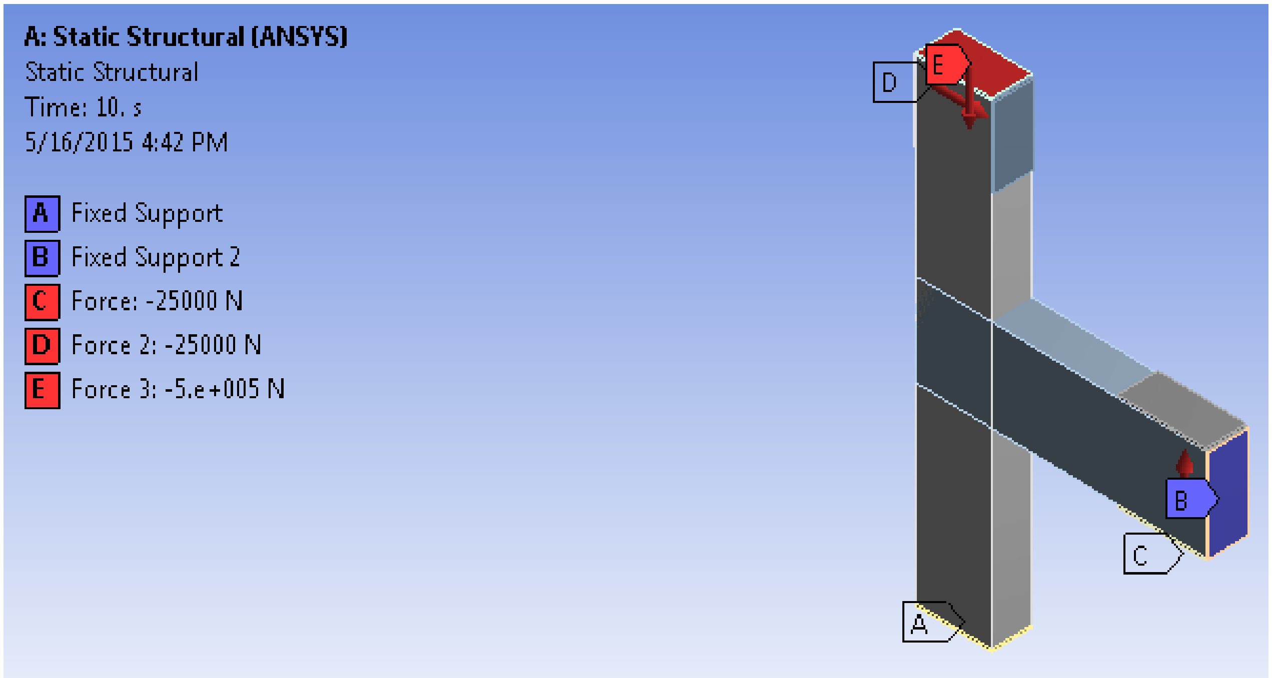


Fig. 4.1.1 Loading condition at exterior joint with one beam

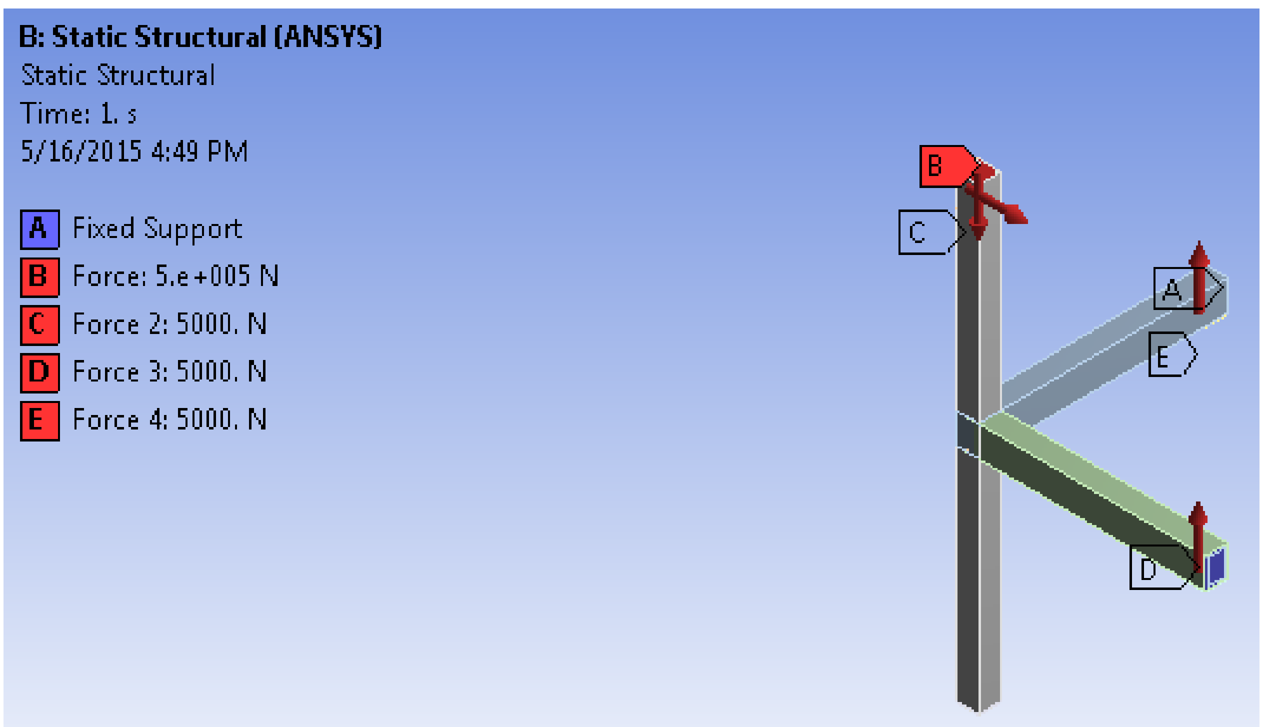


Fig. 4.1.2 Loading condition at exterior joint with two beams

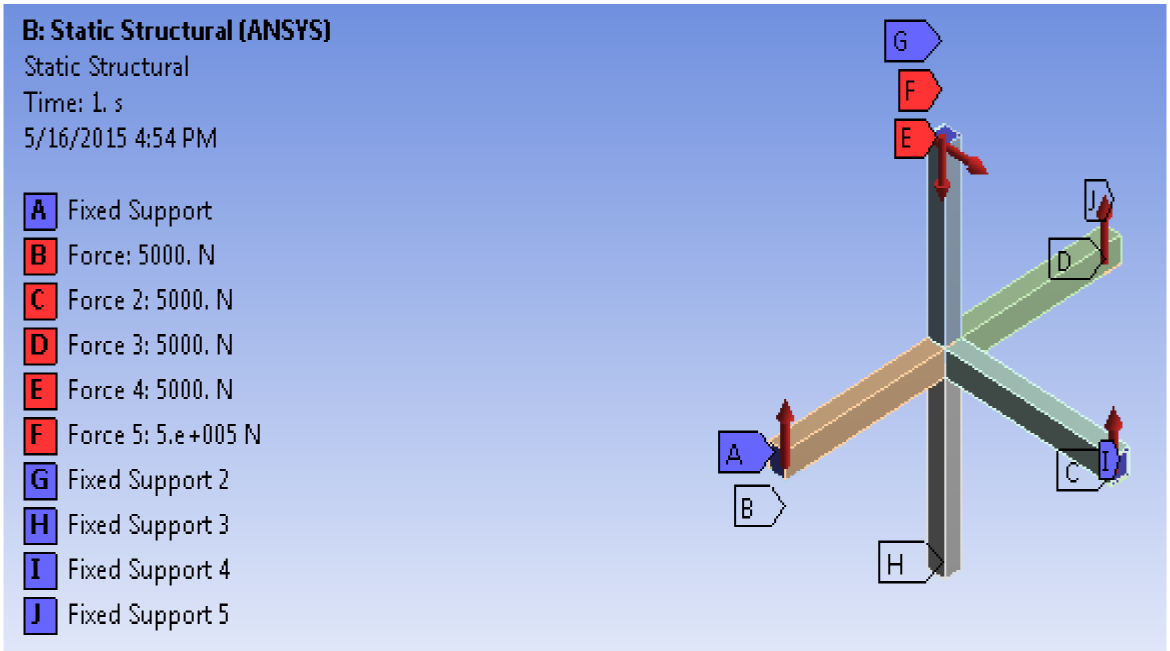


Fig. 4.1.3 Loading condition at exterior joint with three beams

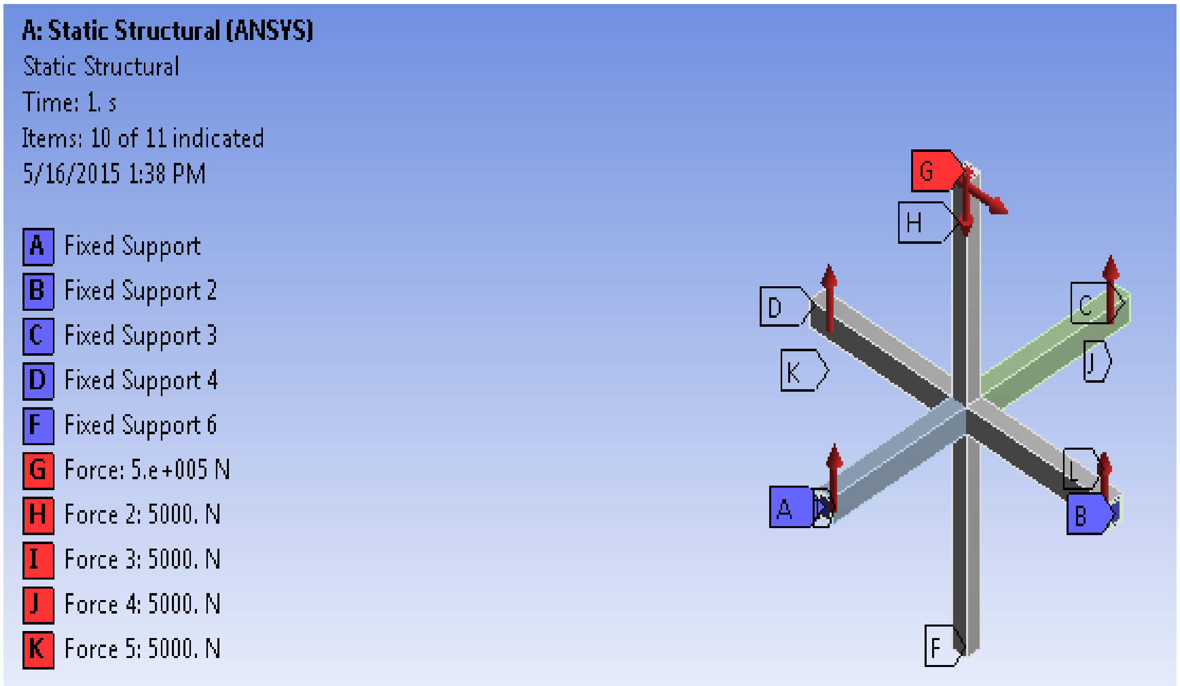


Fig. 4.1.4 Loading condition at interior joint with four beams

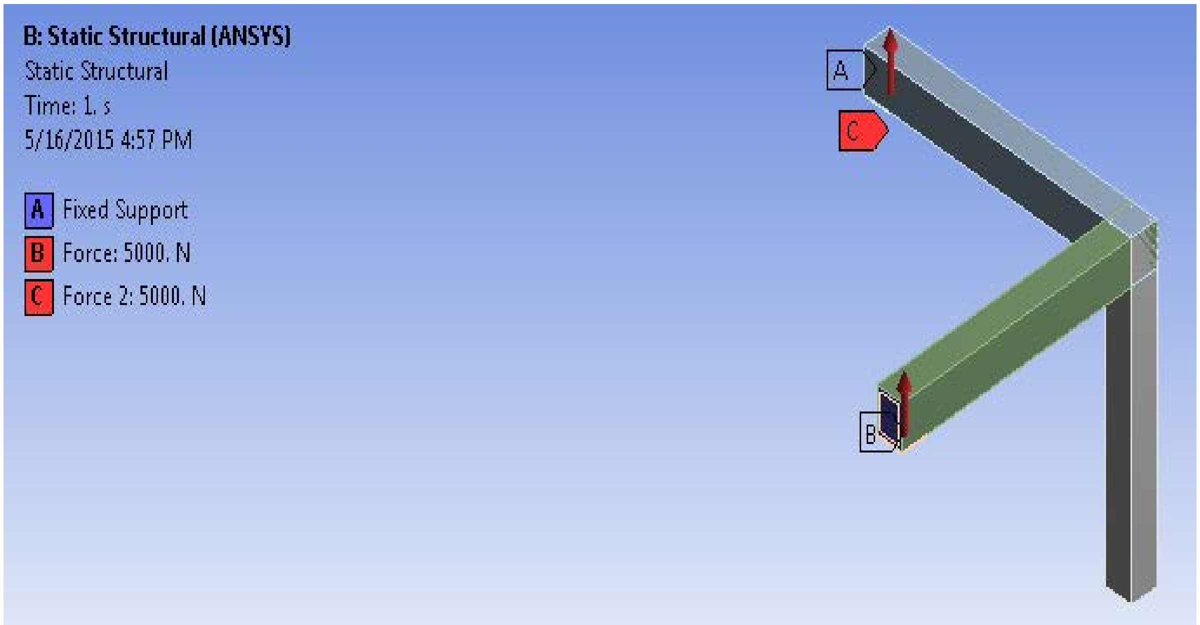


Fig. 4.1.5 Loading condition at corner joint

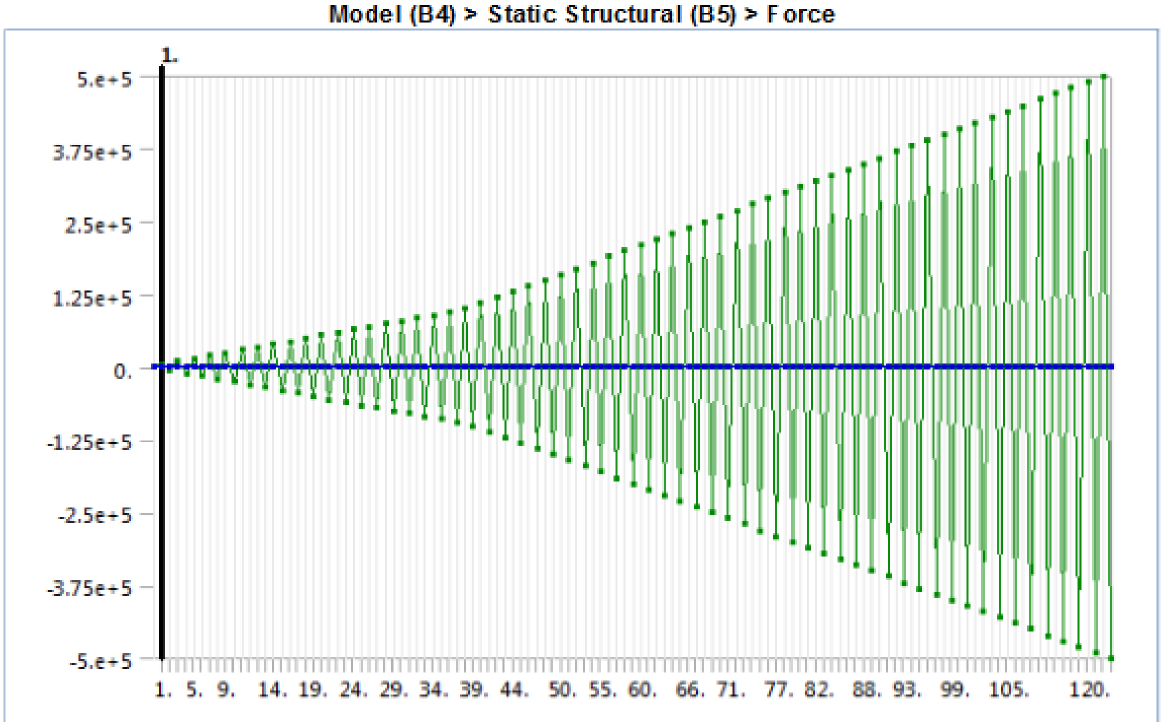


Fig. 4.1.6 Cyclic loading applied in lateral direction of column

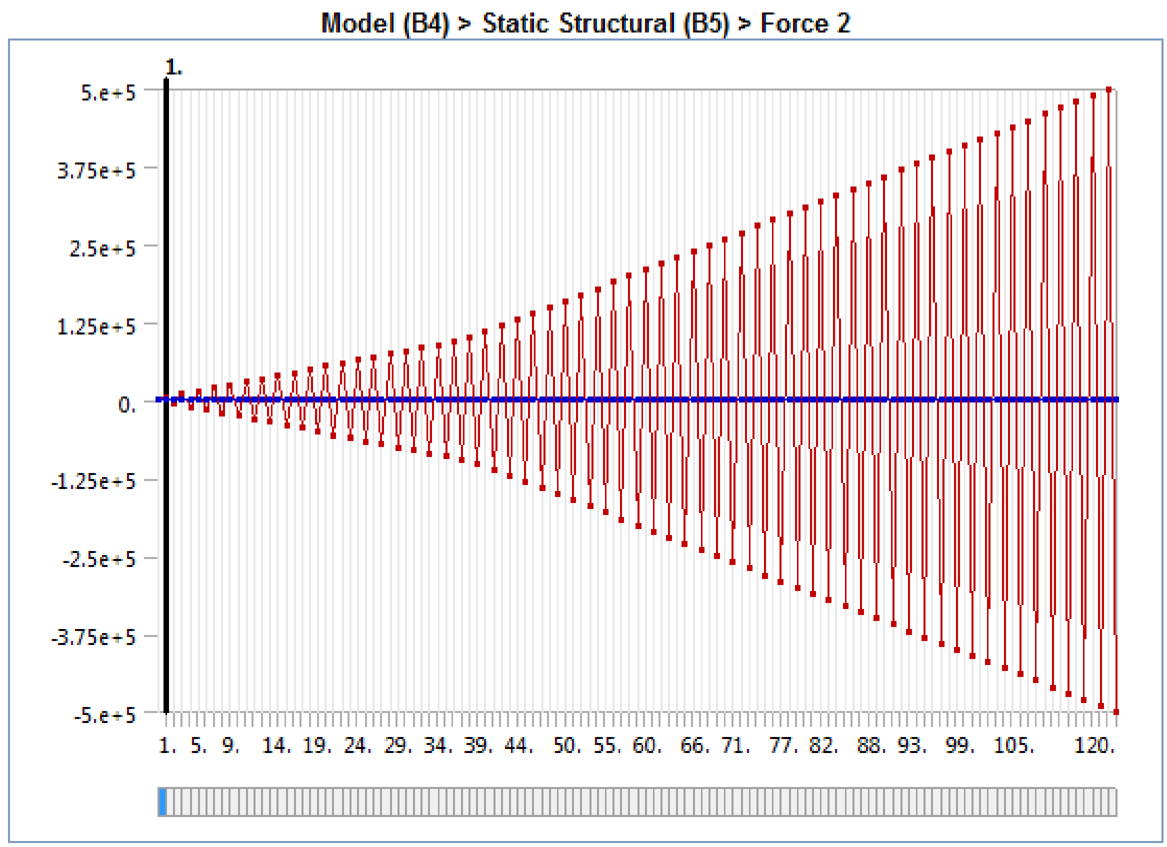


Fig. 4.1.7 Cyclic loading applied in upper direction of beam

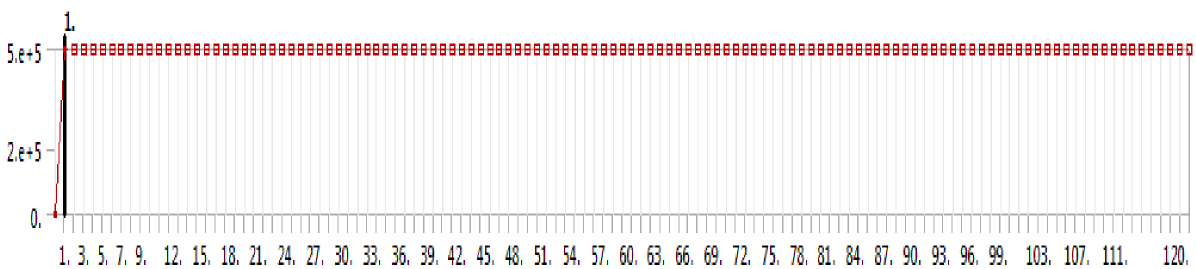


Fig. 4.1.8 Constant loading applied at axial direction of column

CHAPTER 5

ANALYSIS AND RESULTS

5.1Exterior joint with one beam

The result of FE analysis is obtained for control specimen and strengthen specimen using ANSYS Workbench under the cyclic loading from 0 to 500 kN (Fig. 4.1.6 & 4.1.7) and a constant axial loading at column of 500 kN (Fig. 4.1.8). In exterior joints the beam longitudinal reinforcement that frames into the column terminates within the joint core. After a few cycles of inelastic loading, the bond deterioration initiated at the column face due to yield penetration and splitting cracks, progresses towards the joint core. Repeated loading will aggravate the situation and a complete loss of bond up to the beginning of the bent portion of the bar may take place. The longitudinal reinforcement bar, if terminating straight, will get pulled out due to progressive loss of bond.

The results are compared in terms of total deformation, maximum principal stress and maximum principal elastic strain for both specimens. After the analysis of results, it is observed that with the implementation of modified reinforcement technique at the joint region, the total deformation of the joint is controlled and stress, strain is also reduced(Table 3).

From total deformation model of control specimen (fig. 5.1.1), it is observed that the deformation in column is larger than the beam. The all section of the beam showing 0 deformation while in the column section the variation of total deformation at different positions are observed. The maximum deformation is observed at the top surface (free support) of the column. The minimum deformation is observed at the beam support (fixed support). The total deformationafter strengthen with modified reinforcement technique (fig. 5.1.2); it is observed that the deformation in column is controlled as compare to control specimen (fig. 5.1.1).

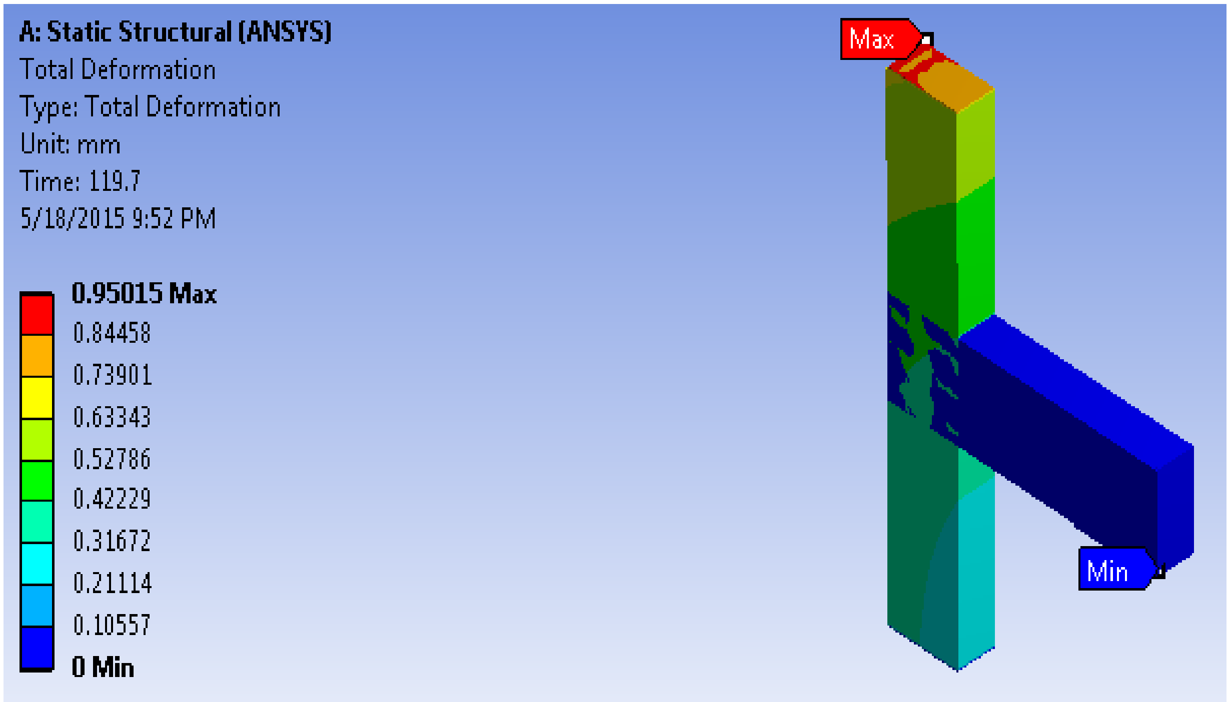


Fig. 5.1.1 Total Deformation for Control Specimen (CS1)

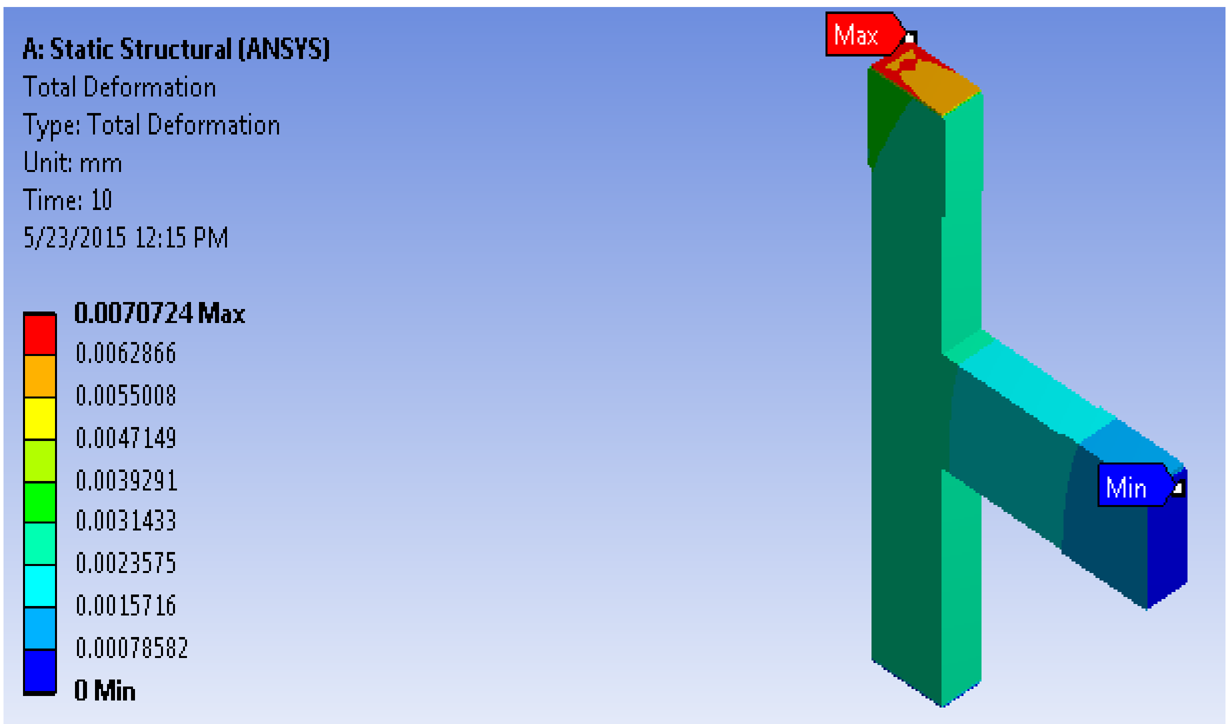


Fig. 5.1.2 Total Deformation for Strengthen Specimen (with MRT) (SS1)

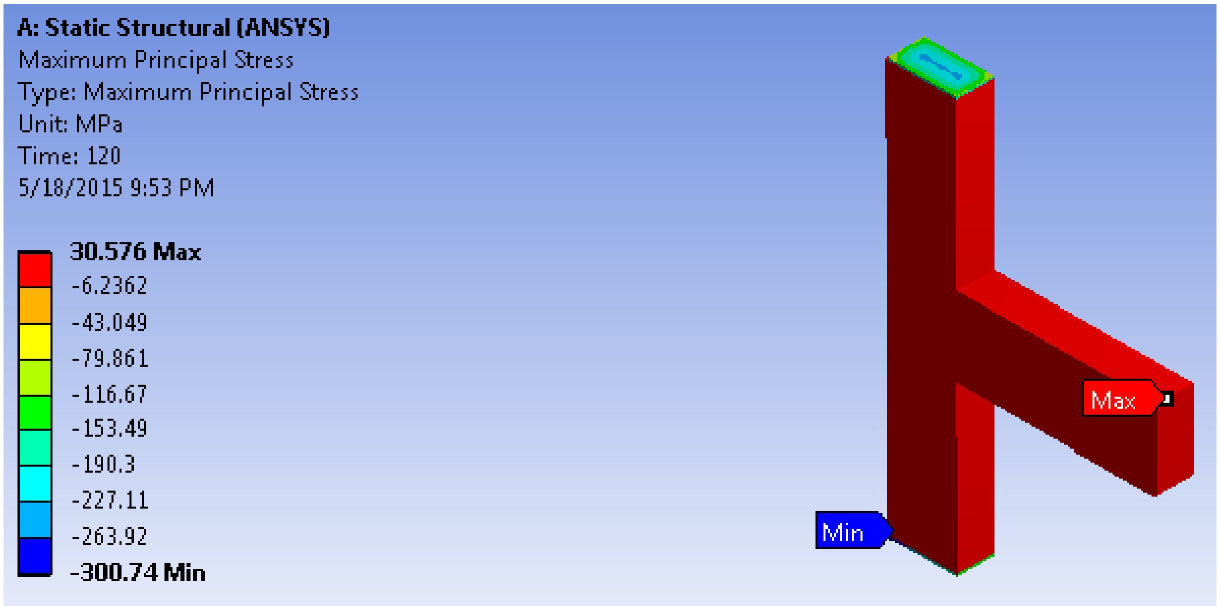


Fig. 5.1.3 Maximum Principal Stress for control specimen (CS1)

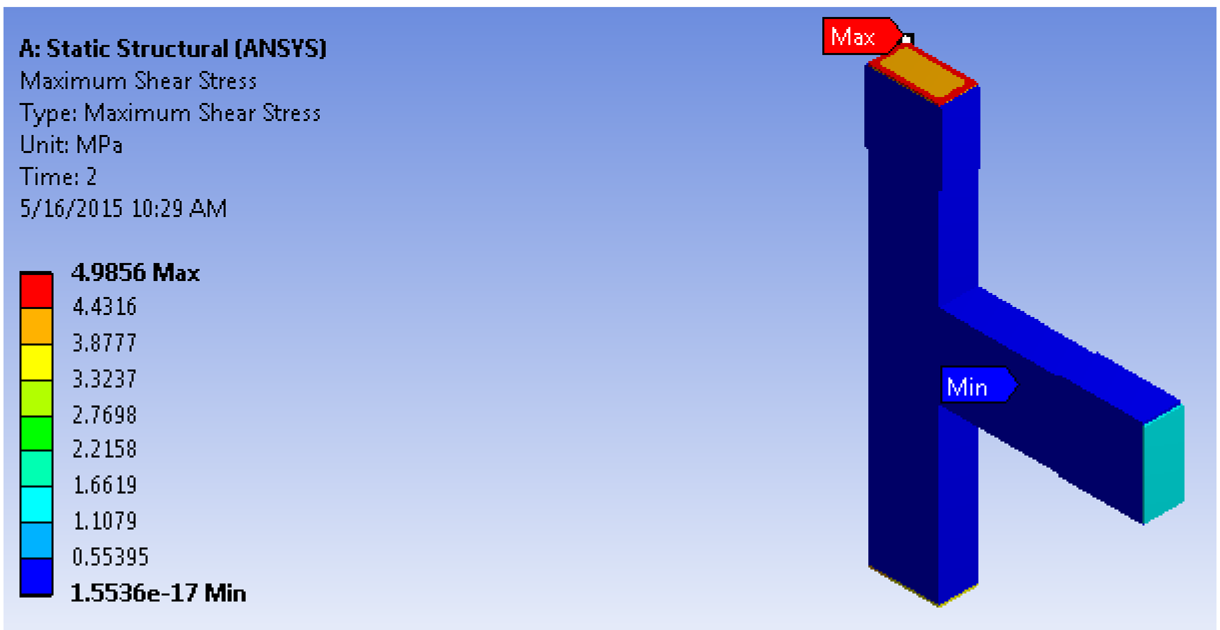


Fig. 5.1.4 Maximum Principal Stress for strengthen specimen (SS1)

From fig. 5.1.3, it is observed that the maximum principal stress for control specimen (without MRT) at the all section of exterior joint and the maximum shearstress for strengthen specimen from fig. 5.1.4, it is observed that the maximum stress at the top support (fixed support) of column and the overall principal stress in strengthen specimen is reduced as compared to control specimen. The maximum stress observed in column whiles the minimum stress in beam (fig. 5.1.4).

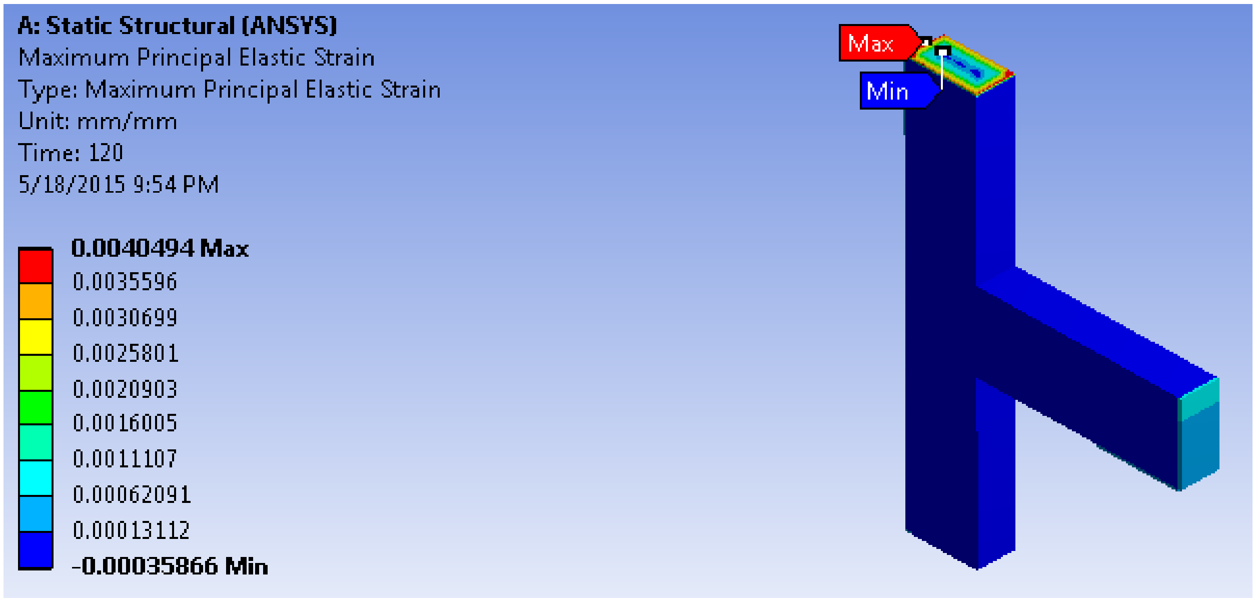


Fig. 5.1.5 Maximum Principal Strain for control specimen (CS1)

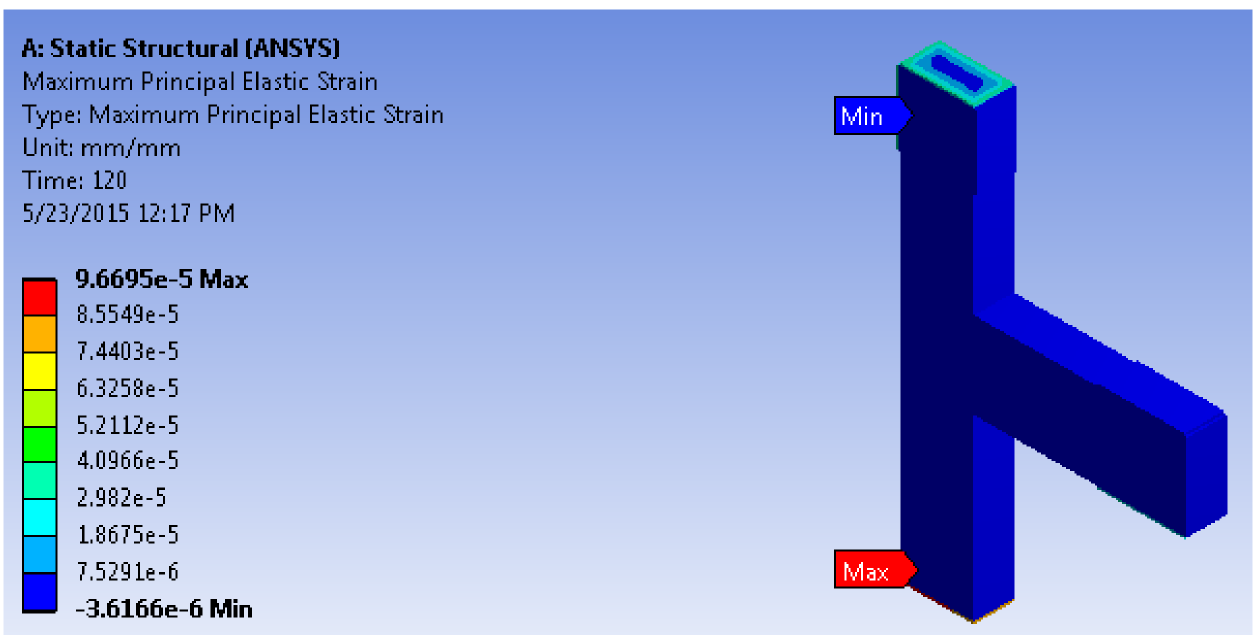


Fig. 5.1.6 Maximum Principal Strain for strengthen specimen (SS1)

From fig. 5.1.5, it is observed that, the maximum and minimum principal strain for control specimen (without MRT) at the top support of column and for strengthen specimen from fig.

5.1.6, it is observed that, the maximum principal strain for strengthen specimen (with MRT) at the base support of column and minimum principal strain at the top support of column (fixed support).

TABLE 3

Result	Maximum Value Without MRT	Maximum Value With MRT	% Difference
Total deformation	0.9541*mm*	0.00707 *mm*	99.2
Maximum principal stress	30.576*Mpa*	4.9856 *Mpa*	83.7
Maximum principal strain	0.00404*mm/mm*	0.000096 *mm/mm*	97.6

After analysis of exterior beam column joint with one beam, it is observed that the modified reinforcement technique is very effective to control total deformation, stress and strain. From table 3, the result of strengthen specimen as compared to control specimen under the cyclic loading from 0 to 500 kN is adequate. The total percentage differences in terms of deformation, stress and strain are 99.2, 83.7 and 97.6 respectively.

5.2 Exterior joint with two beams

The result of FE analysis is obtained for control specimen and strengthen specimen using ANSYS Workbench under the cyclic loading from 0 to 500 kN and a constant axial loading at column of 500 kN (Fig. 4.1.8). The results are compared in terms of total deformation, maximum principal stress and maximum principal elastic strain for both specimens. After the analysis of results, it is observed that with the implementation of modified reinforcement technique at the joint region, the total deformation, maximum principal stress and maximum principal strain of the joins is controlled(Table 4).

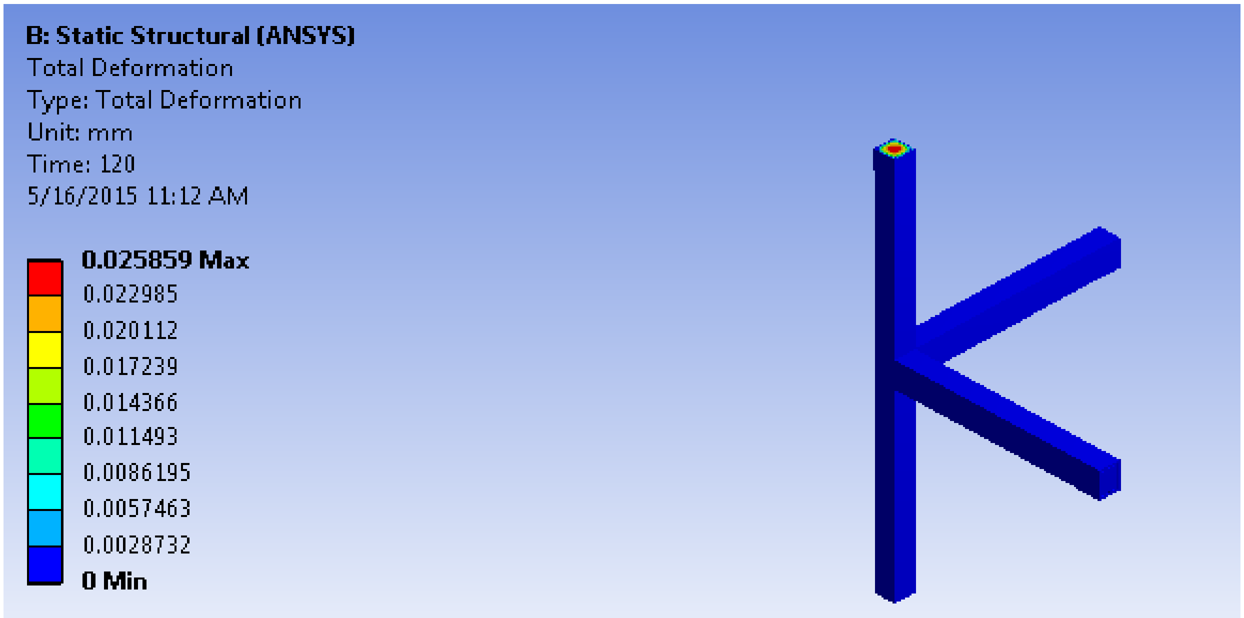


Fig. 5.2.1 Total Deformation for Control Specimen with two beams (CS2)

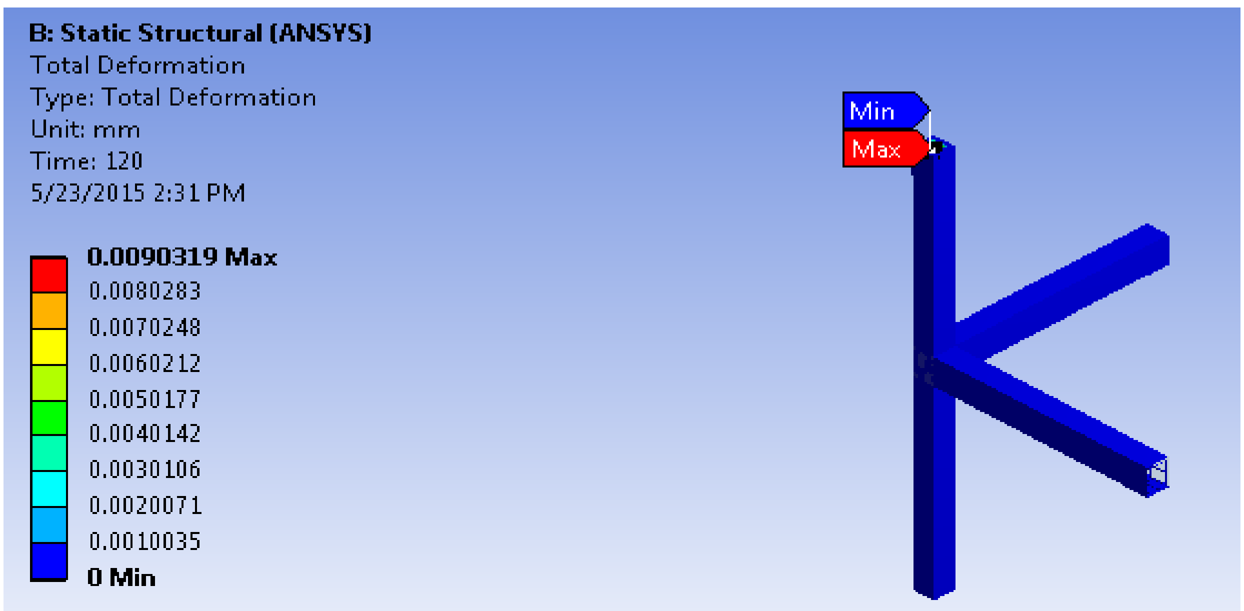


Fig. 5.2.2 Total Deformation for strengthen Specimen with two beams (SS2)

From total deformation model of control specimen (fig. 5.2.1), it is observed that the deformation in column is larger than the beam. The all section of the beam showed zero deformation. The maximum deformation is observed at the top surface (free support) of the column. The total deformation after strengthen with modified reinforcement technique (fig. 5.2.2); it is observed that the deformation in column is controlled as compare to control specimen (fig. 5.2.1).

Fig. 5.2.3 Maximum Principal Stress for control specimen with two beams (CS2)

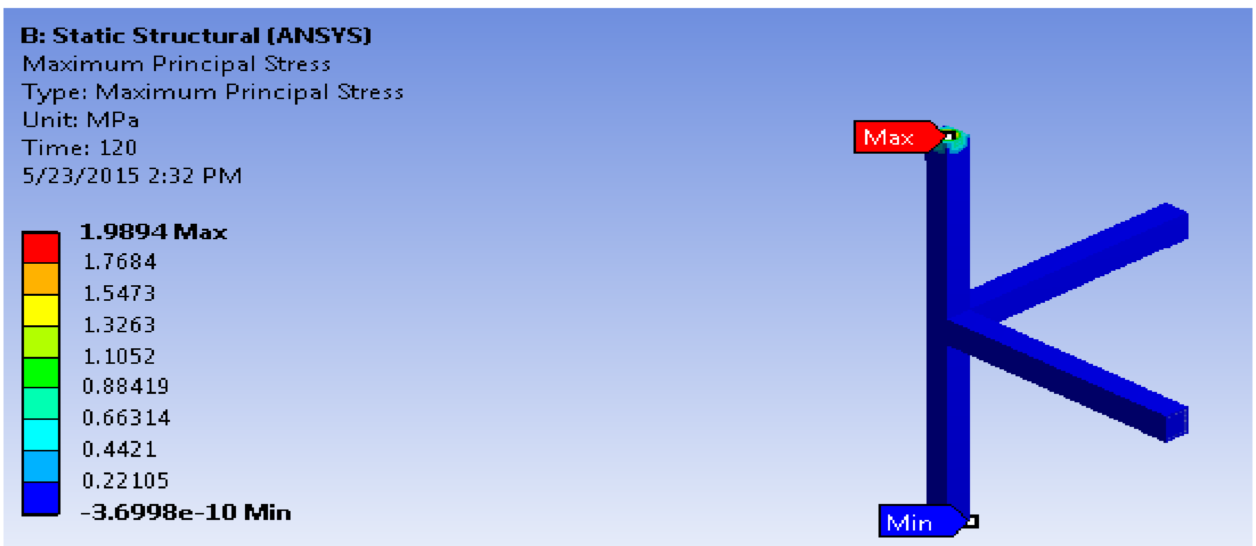


Fig. 5.2.4 Maximum Principal Stress for strengthen specimen with two beams (SS2)

From fig. 5.2.3, it is observed that the maximum principal stress for control specimen (without MRT) is equal in all section of exterior joint and the maximum principal stress for strengthen specimen from fig. 5.2.4, it is observed that the maximum stress at the top support (fixed support) of column and the overall principal stress in strengthen specimen is reduced to zero as compared to control specimen. The maximum stress observed in column whiles the minimum stress in beam (fig. 5.2.4).

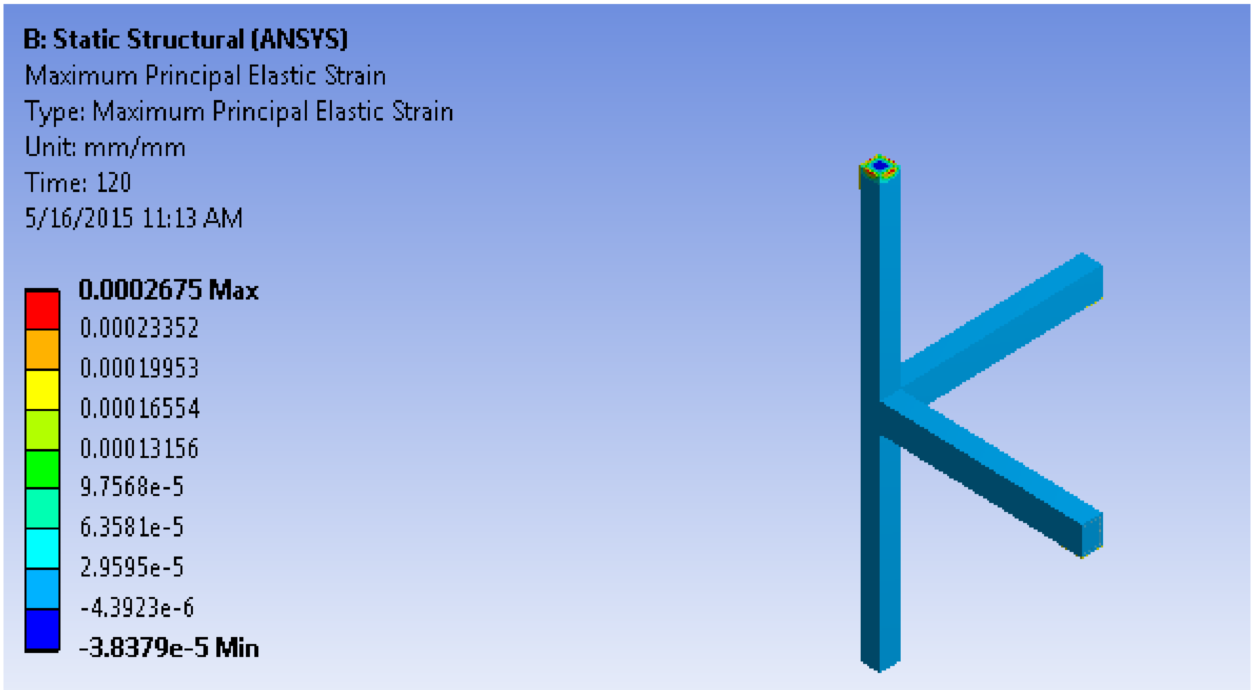


Fig. 5.2.5Maximum Principal Strain for control specimen with two beams (CS2)

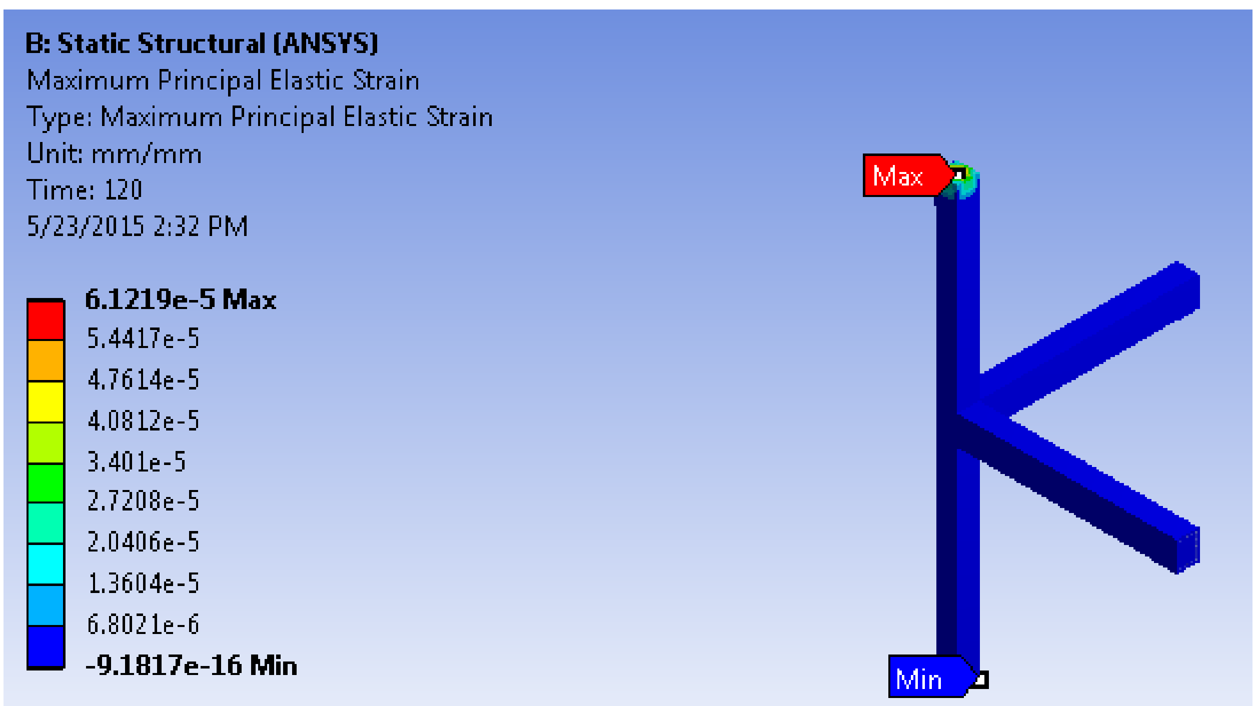


Fig. 5.2.6 Maximum Principal Strain for strengthen specimen with two beams (SS2)

From fig. 5.2.5, it is observed that, the maximum principal strain for control specimen (without MRT) at the top support of column and overall strain in the joint is equal, and for strengthen specimen from fig. 5.2.6, it is observed that, the maximum principal strain for strengthen specimen (with MRT) at the top support of column and minimum principal strain in the beam of joint.

TABLE 4

Result	**Maximum Value Without MRT**	**Maximum Value With MRT**	**% Difference**
Total deformation	0.02585*mm*	0.0090319 *mm*	65.1
Maximum principal stress	7.184*Mpa*	1.9894 *Mpa*	72.3
Maximum principal strain	0.0002675*mm/mm*	0.0000612*mm/mm*	77.1

After analysis of exterior beam column joint with two beams, it is observed that the modified reinforcement technique is very effective to control total deformation, stress and strain. From table 4, the result of strengthen specimen as compared to control specimen under the cyclic loading from 0 to 500 kN is adequate. The total percentage differences in terms of deformation, stress and strain are 65.1, 72.3 and 77.1 respectively.

5.3Exterior joint with three beams

The result of FE analysis is obtained for control specimen and strengthen specimen using ANSYS Workbench under the cyclic loading from 0 to 500 kN and a constant axial loading at column of 500 kN (Fig. 4.1.8). The results are compared in terms of total deformation, maximum principal stress and maximum principalelastic strain for both specimens. After the analysis of results, it is observed that with the implementation of modified reinforcement technique at the joint region, the total deformation, maximum shear stress and maximum principal strain of the joins is controlled (Table 5).

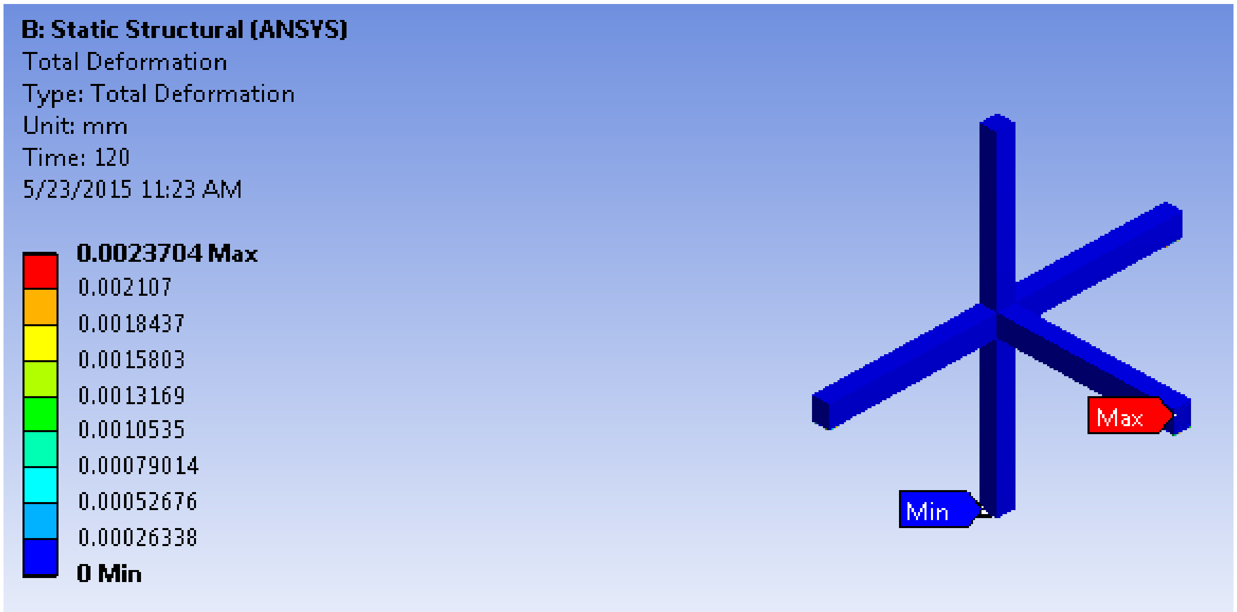


Fig. 5.3.1 Total Deformation for Control Specimen with two beams (CS3)

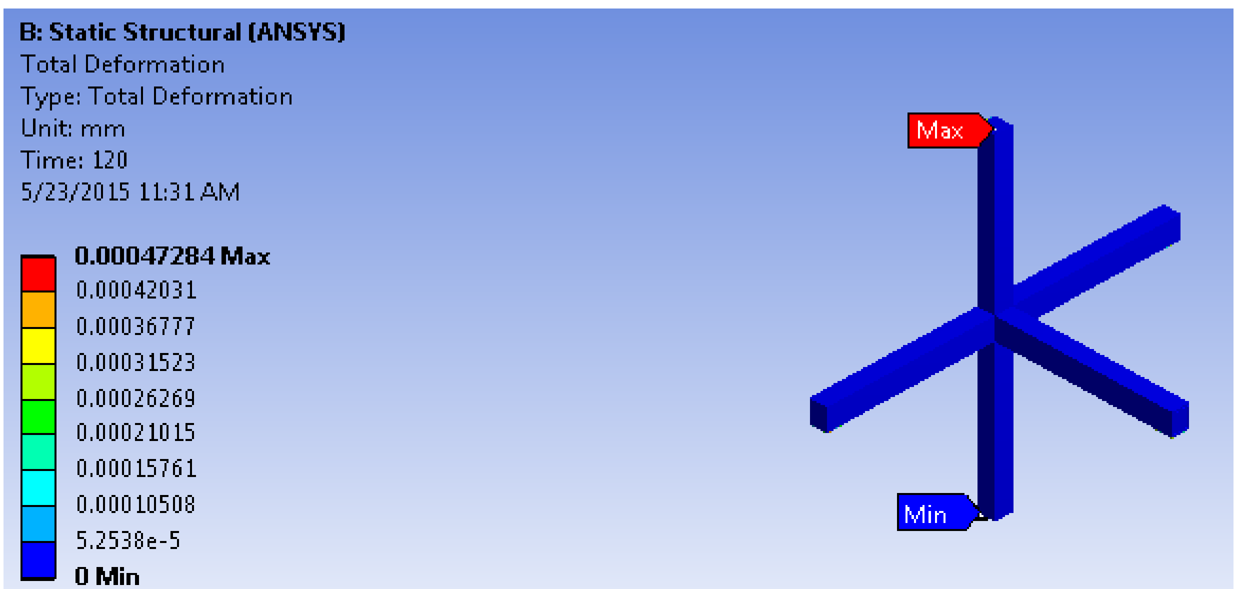


Fig. 5.3.2 Total Deformation for Strengthen Specimen with three beams (SS3)

From total deformation model of control specimen (fig. 5.3.1), it is observed that the maximum deformation in beam and the minimum deformation at the bottom support of column. The all section of the beam and column showed zero deformation. The total deformation after strengthen with modified reinforcement technique (fig. 5.3.2); it is observed that the deformation in the beam column joint is controlled as compare to control specimen.

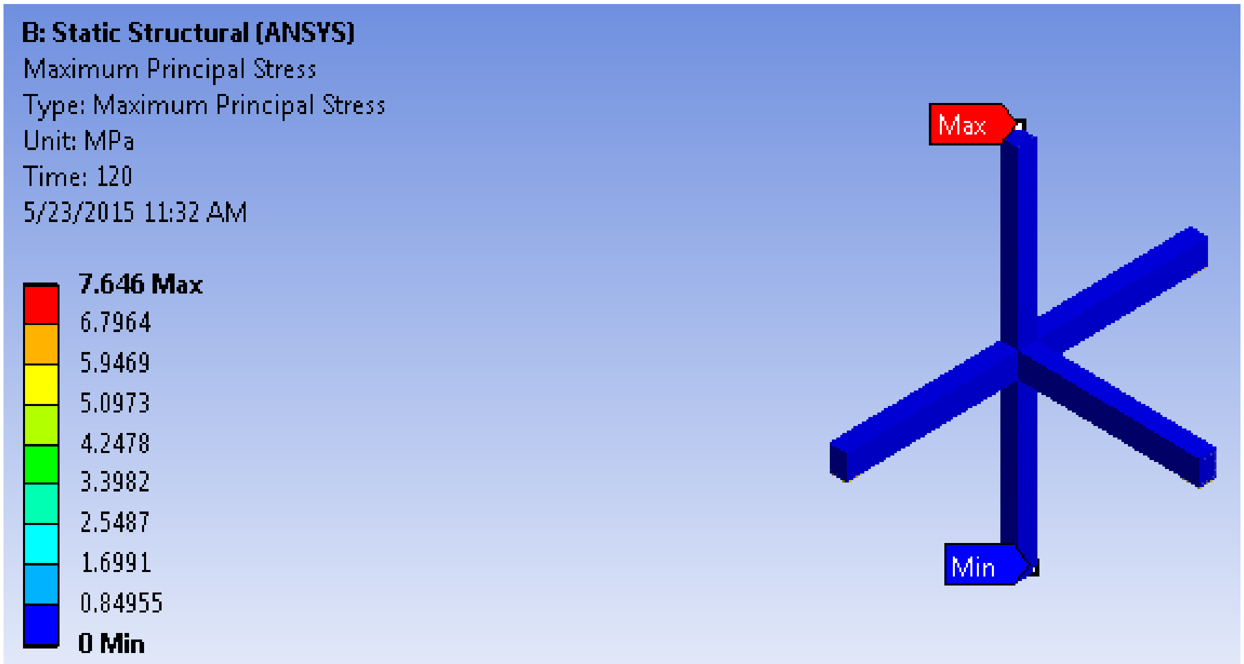


Fig. 5.3.3 Maximum shear Stress for Control Specimen with three beams (CS3)

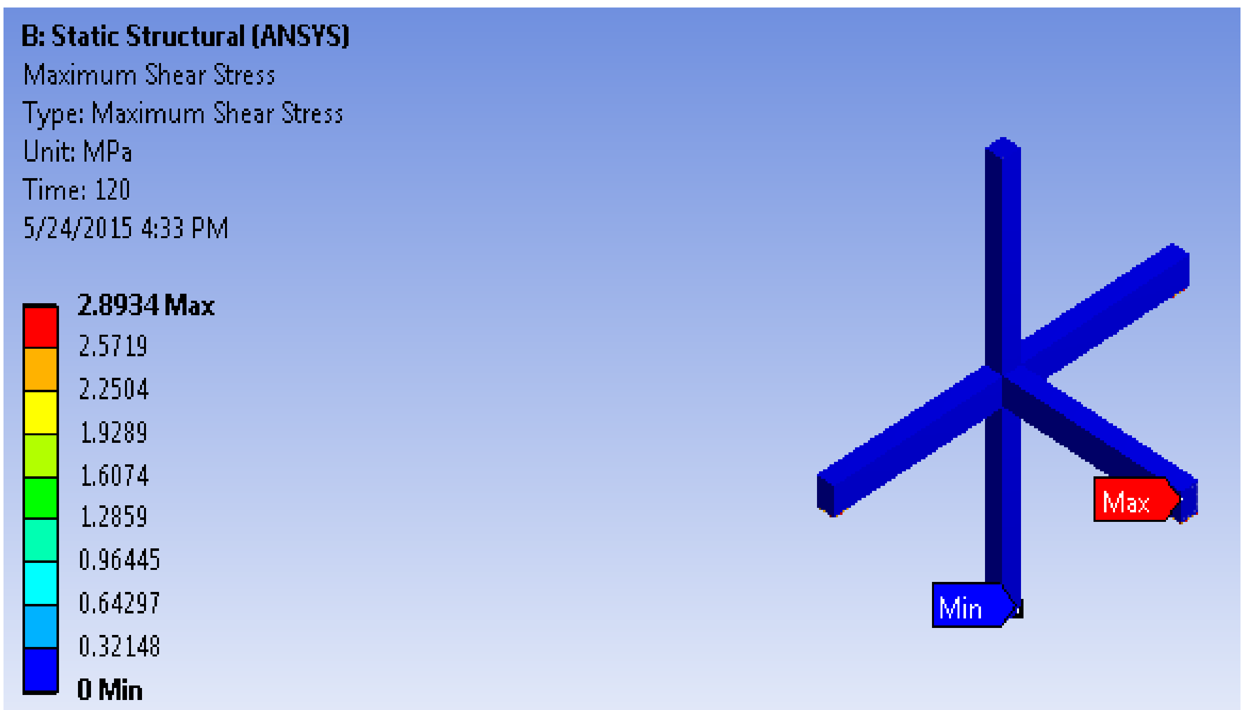


Fig. 5.3.4 Maximum shear Stress for strengthen Specimen with three beams (SS3)

From fig. 5.3.3, it is observed that the maximum shear stress for control specimen (without MRT) is equal in all section of exterior joint and for strengthen specimen from fig. 5.3.4, it is observed that the maximum stress in the beam and minimum stress at the bottom support of column.

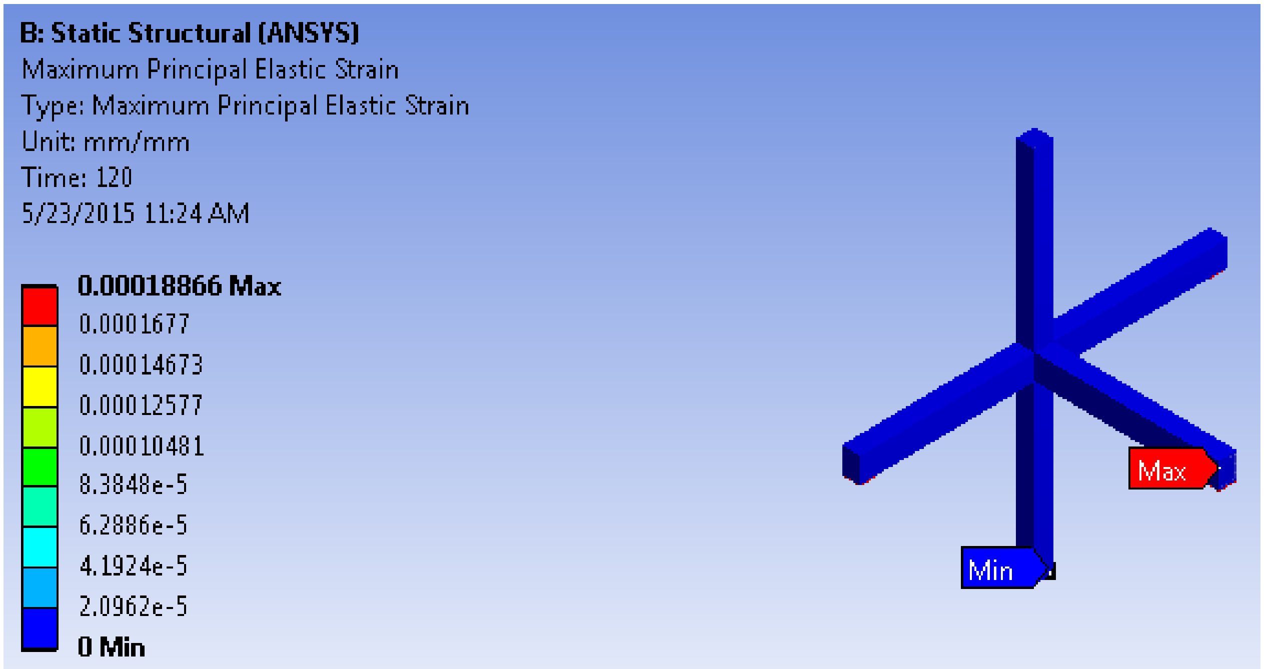


Fig. 5.3.5 Maximum Principal Elastic strain for Control Specimen with three beams (CS3)

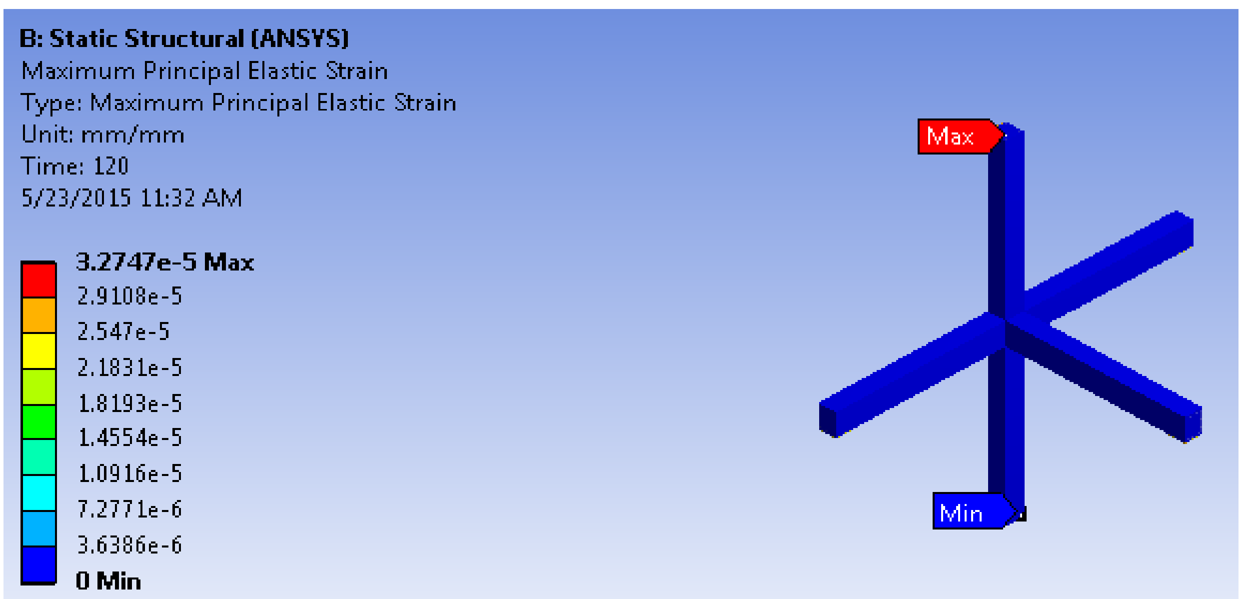


Fig. 5.3.6 Maximum Principal Elastic strain for strengthen Specimen with three beams (SS3)

From fig. 5.3.5, the maximum shear strain for control specimen (without MRT) is observed in the beam while the minimum strain at the bottom support of column, and for strengthen specimen from fig. 5.3.6, it is observed that, the maximum principal strain for strengthen specimen (with MRT) at the top support of column and minimum shear strain at the bottom support of column.

TABLE 5

Result	**Maximum Value Without MRT**	**Maximum Value With MRT**	**% Difference**
Total deformation	0.0023*mm*	0.0004728 *mm*	79.4
Maximum Shear stress	7.646 *Mpa*	2.8948*Mpa*	62.1
Maximum Shear strain	0.00018*mm/mm*	0.0000327 *mm/mm*	81.8

After analysis of exterior beam column joint with three beams, it is observed that the modified reinforcement technique is very effective to control total deformation, stress and strain. From table 5, the result of strengthen specimen as compared to control specimen under the cyclic loading from 0 to 500 kN is adequate. The total percentage differences in terms of deformation, stress and strain are 79.4, 62.1 and 81.8 respectively.

5.4 Interior joint with four beams

The result of FE analysis is obtained for control specimen and strengthen specimen using ANSYS Workbench under the cyclic loading from 0 to 500 kN and a constant axial loading at column of 500 kN (Fig. 4.1.8). The results are compared interms of total deformation, maximum principal stress and maximum principal elastic strain for both specimens. After the analysis of results, it is observed that with the implementation of modified reinforcement technique at the joint region, the total deformation, maximum shear stress and maximum principal strain of the joins is controlled (Table 6).

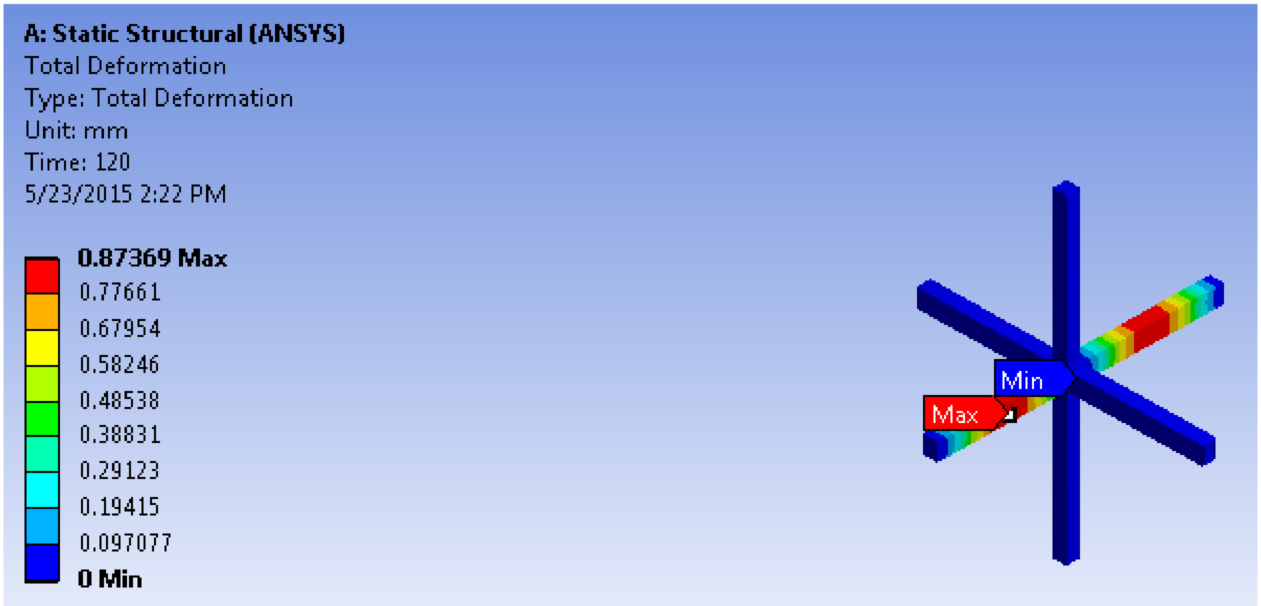


Fig. 5.4.1 Total Deformation for Control Specimen with four beams (CS4)

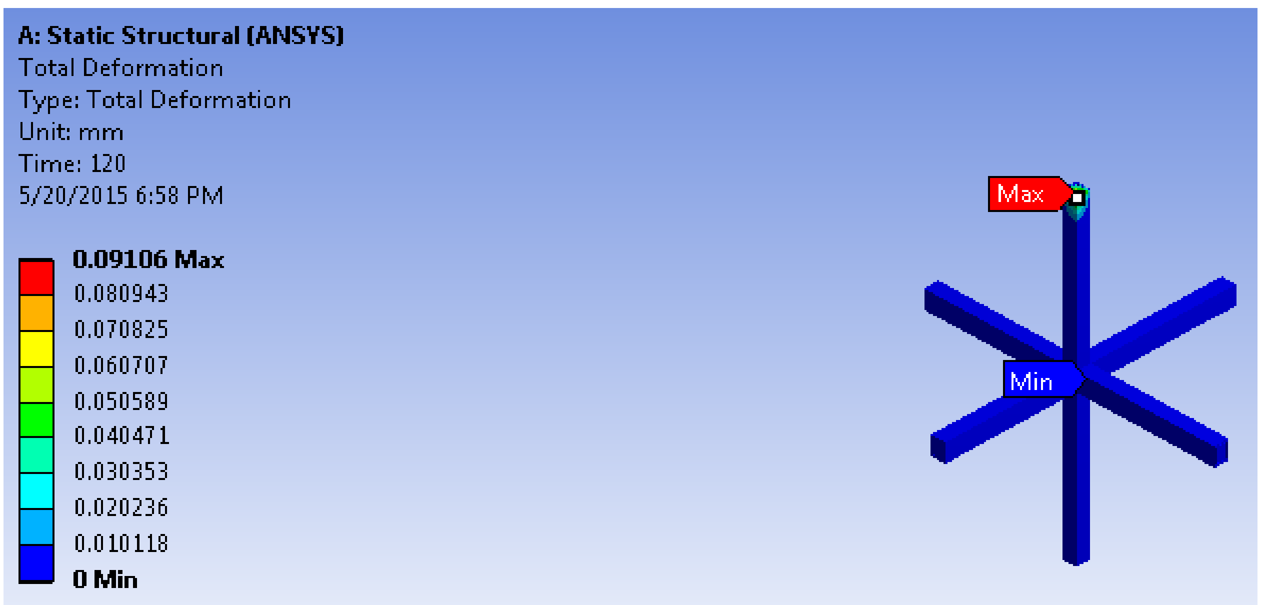


Fig. 5.4.2 Total Deformation for strengthen Specimen with four beams (SS4)

From total deformation model of control specimen (fig. 5.4.1), it is observed that the maximum deformation in beam and the minimum deformation in the column. The total deformation after strengthen with modified reinforcement technique (fig. 5.4.2); it is observed that the deformation in the beam is controlled as compare to control specimen.

Fig. 5.4.3 Maximum Principal Stress for Control Specimen with four beams (CS4)

Fig. 5.4.4 Maximum shearStress for strengthen Specimen with four beams (SS4)

From fig. 5.4.3, it is observed that the maximum shear stress for control specimen (without MRT) is equal in all section of interior joint and for strengthen specimen from fig. 5.4.4, it is observed that the maximum stress in the beam and minimum stress in the column and it is observed that the stress in beam column joint is controlled.

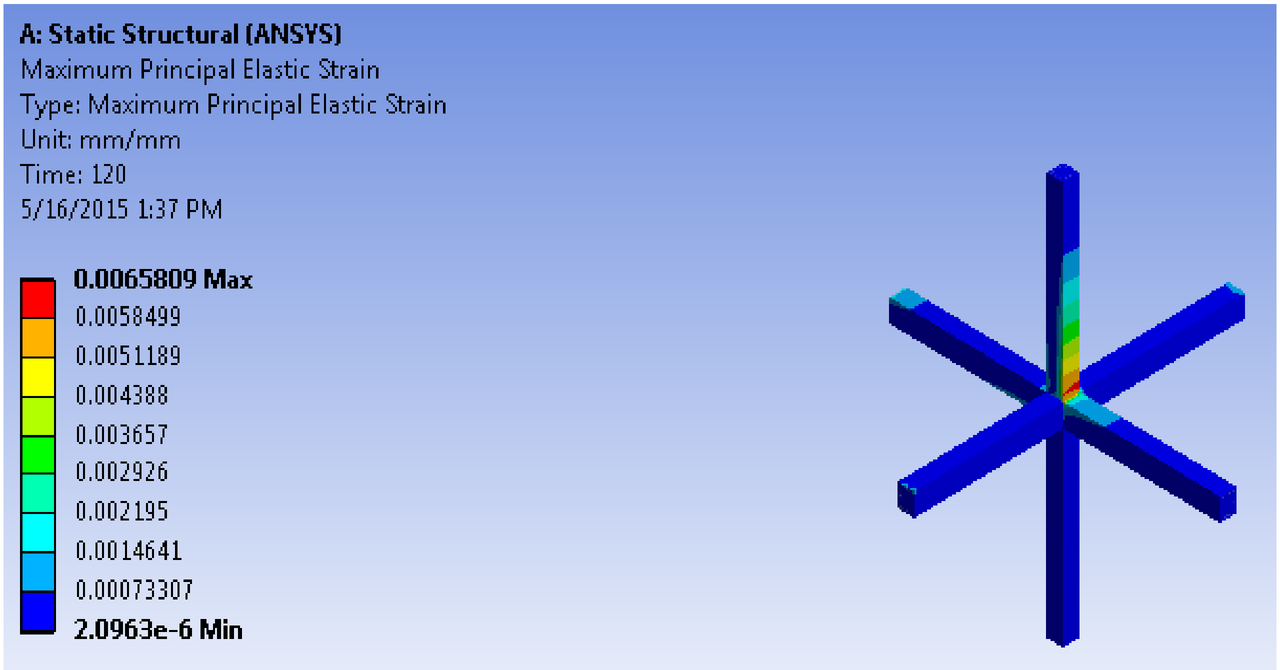


Fig. 5.4.5 Maximum Principal Elastic strain for Control Specimen with four beams (CS4)

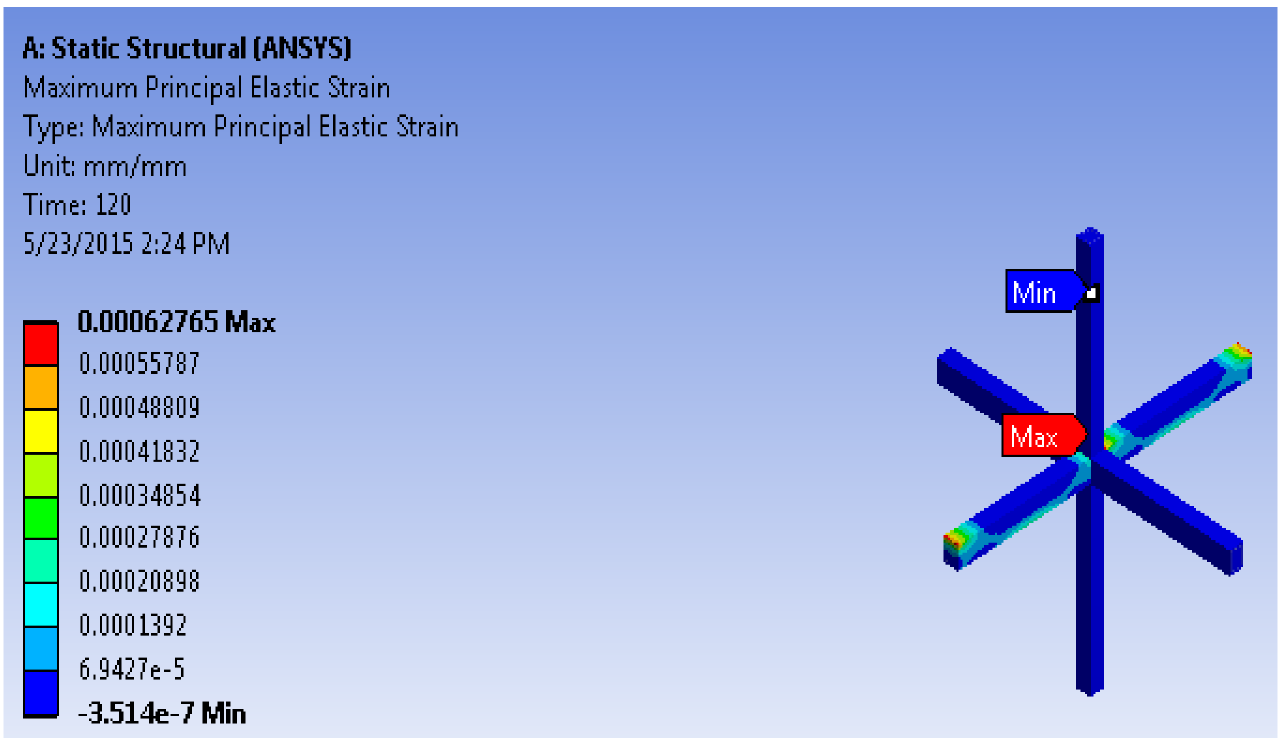


Fig. 5.4.6 Maximum Principal Elastic strain for strengthen Specimen with four beams (SS4)

From fig. 5.4.5, the maximum principal strain for control specimen (without MRT) is observed at the centre of column while the minimum strain at the bottom support of column, and for strengthen specimen from fig. 5.4.6, it is observed that, the maximum principal strain for strengthen specimen (with MRT) at the support of beam and minimum principal strain in the column. The strain in the joint is controlled by introducing MRT at joint.

TABLE 6

Result	**Maximum Value Without MRT**	**Maximum Value With MRT**	**% Difference**
Total deformation	0.87369*mm*	0.09106 *mm*	89.5
Maximum Shear stress	19.924*Mpa*	9.0418 *Mpa*	79.3
Maximum Shear strain	0.0065*mm/mm*	0.00062 *mm/mm*	90.4

After analysis of interior beam column joint with four beams, it is observed that the modified reinforcement technique is very effective to control total deformation, stress and strain. From table 6, the result of strengthen specimen as compared to control specimen under the cyclic loading from 0 to 500 kN is adequate. The total percentage differences in terms of deformation, stress and strain are observed 89.5, 79.3 and 90.4 respectively.

5.5 Corner joint

The result of FE analysis is obtained for control specimen and strengthen specimen using ANSYS Workbench under the cyclic loading from 0 to 500 kN and a constant axial loading at column of 500 kN (Fig. 4.1.8). The results are compared interms of total deformation, maximum principal stress and maximum principal elastic strain for both specimens. After the analysis of results, it is observed that with the implementation of modified reinforcement technique at the joint region, the total deformation, maximum shear stress and maximum principal strain of the joins is controlled (Table 7).

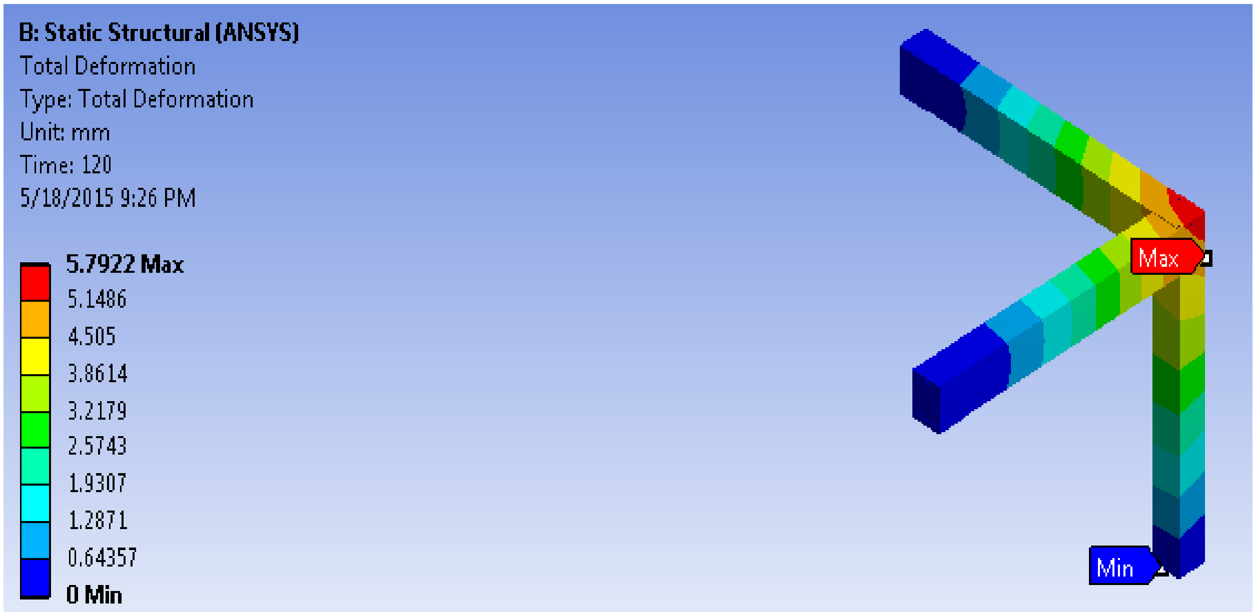


Fig. 5.5.1 Total Deformation of corner joint for Control Specimen (CS5)

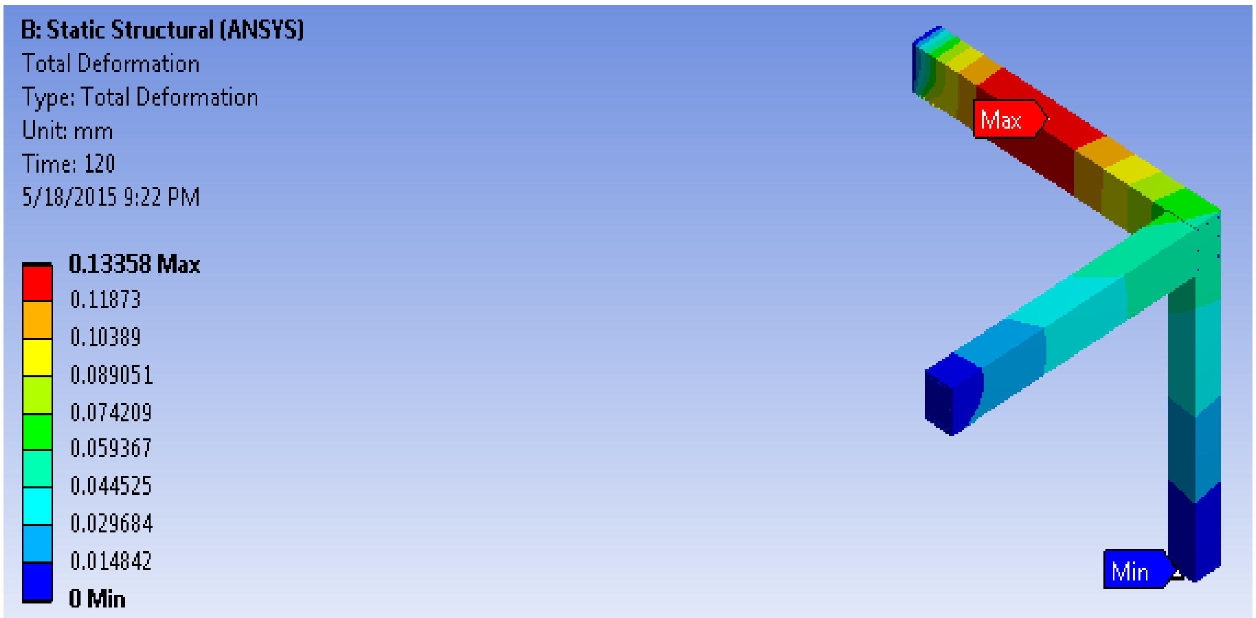


Fig. 5.5.2 Total Deformation of corner joint for strengthen Specimen (SS5)

From total deformation model of control specimen (Fig. 5.5.1), it is observed that the maximum deformation at the corner joint and the minimum deformation at bottom support of the column. The total deformations in corner joint after strengthen with modified reinforcement technique (Fig. 5.5.2); it is observed that the deformation at the corner joint is controlled as compare to control specimen.

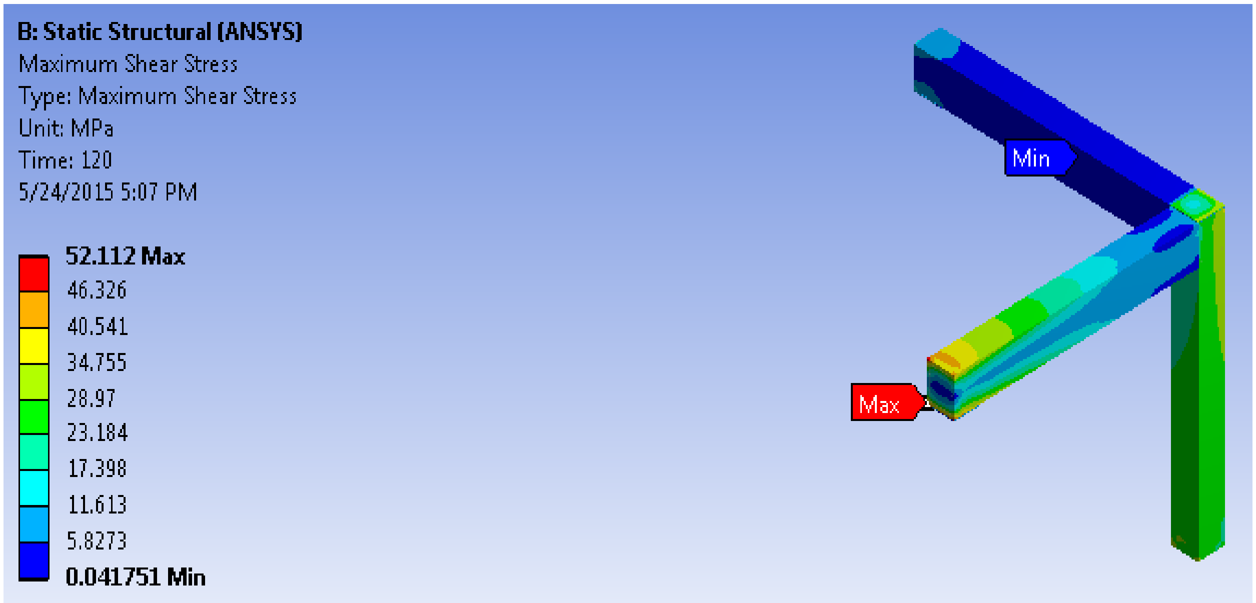


Fig. 5.5.3 Maximum shear stress of corner joint for control Specimen (CS5)

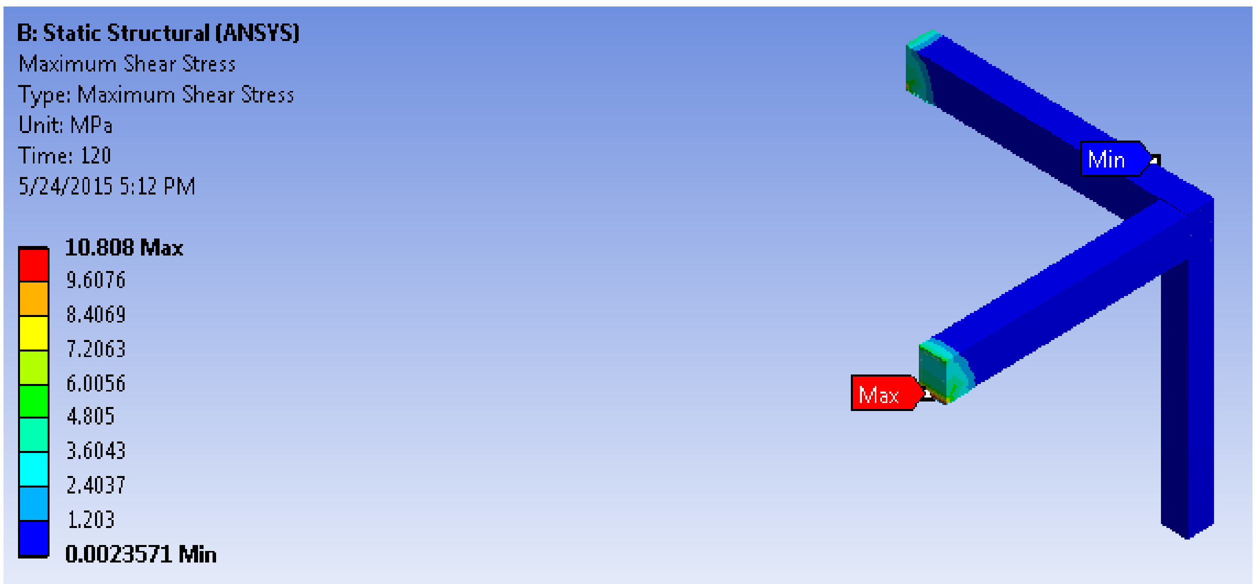


Fig. 5.5.4 Maximum shear stress of corner joint for strengthen Specimen (SS5)

From Fig. 5.5.3, it is observed that the maximum principal stress for control specimen (without MRT) is at the support of beam and for strengthen specimenfrom Fig. 5.5.4, it is observed that the maximum and minimum stress at the support of beam and it is observed that the stress in beam column joint is controlled.

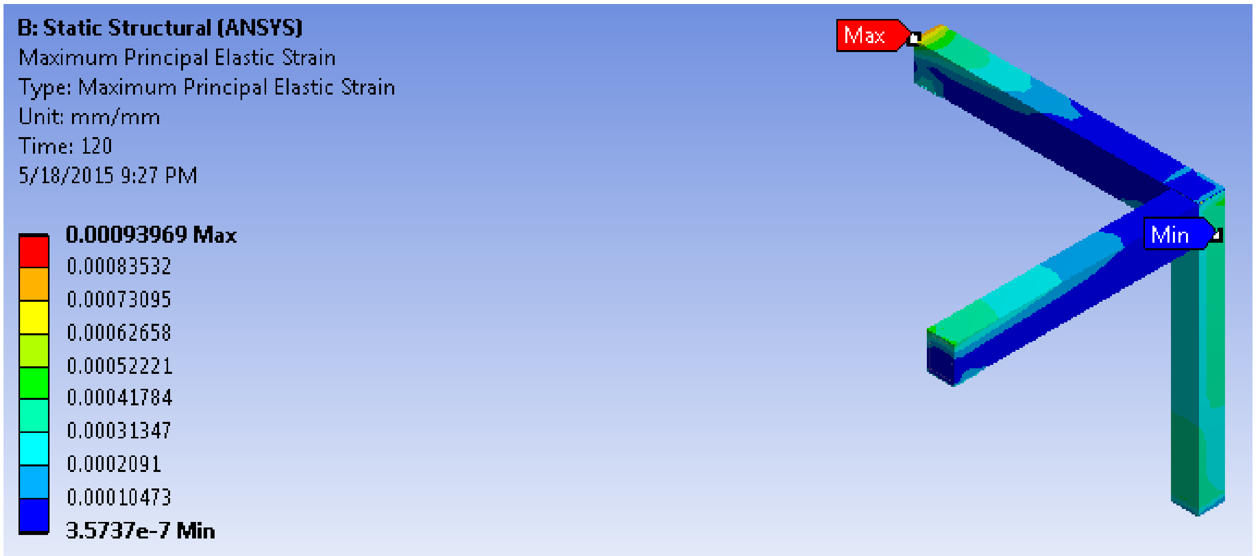


Fig. 5.5.5 Maximum principal strain of corner joint for control Specimen (CS5)

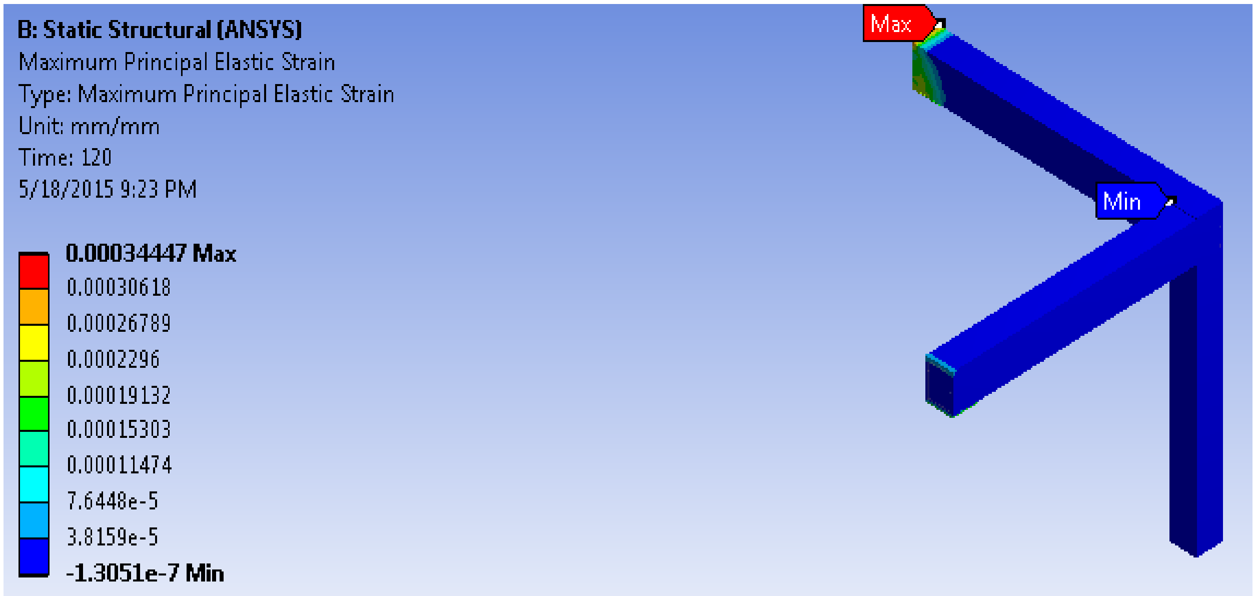


Fig. 5.5.6 Maximum principal strain of corner joint for strengthen Specimen (SS5)

From Fig. 5.5.5, the maximum shear strain for control specimen (without MRT) is observed at the support of beam while the minimum strain at the corner joint andfor strengthen specimen from Fig. 5.5.6, it is observed that, the maximum shear strain for strengthen specimen (with MRT) at the support of beam and minimum at the corner joint. The strain in the corner joint is controlled by introducing MRT at joint.

TABLE 7

Result	**Maximum Value Without MRT**	**Maximum Value With MRT**	**% Difference**
Total deformation	5.7922*mm*	0.13358 *mm*	97.7
Maximum shear stress	52.112*Mpa*	10.808 *Mpa*	79.3
Maximum Shear strain	0.0009396*mm/mm*	0.0003444 *mm/mm*	63.3

After analysis of corner beam column joint, it is observed that the modified reinforcement technique is very effective to control total deformation, stress and strain. From table 7, the result of strengthen specimen as compared to control specimen under the cyclic loading from 0 to 500 kN is adequate. The total percentage differences in terms of deformation, stress and strain are observed 97.7, 79.3 and 63.3 respectively.

CHAPTER 6

RESULTS COMPARISION AND DISCUSSION

The results have been discussed for the influence of key parameters on the joint behavior and improvement of joint performance with different joint configurations (modified reinforcement technique). The investigation of beam column joints has been pursued on four different fronts.

In the first approach, the parameters that influence the behavior of the cyclically loaded beam column joints are investigated. The detailing of the joints has been done by using IS 13920:1993. In this approach, the control specimen (without MRT) is analyzed under the cyclic loading and observed the results in terms of total deformation, maximum shear stress and maximum principal elastic strain.

In second approach, the control specimen is strengthened at the joint region by introducing modified reinforcement technique in which a cross bars of 12*mm* diameter of 450*mm* length (according to IS 456:2000) on both face of column with 30*mm*concrete cover. The joints are analyzed with equal cyclic loading as applied for control specimen and observed that the modified reinforcement techniques improve the shear resistance capacity of joint and controlled total deflection.

In third approach, the all results obtained from the FEM analysis for all joints are compared and it was observed that the implementation of modified reinforcement techniques improve the behavior of joints in terms of totaldeformation, maximum shear stress and maximum principal elastic strain. The comparison of results has been done through the load Vs deflection hysteretic curve, deflection time history curve, no of cycle-stress curve and lateral load Vs lateral displacement. The results which were observed from the analysis of beam column joints shown in table 8.

The variation of results for control specimen and strengthen specimen are shown in table 8.

TABLE 8

SPECIMENS	TOTAL DEFORMATION *(mm)*	MAXIMUM PRINCIPAL STRESS *(Mpa)*	MAXIMUM PRINCIPAL STRAIN *(mm/mm)*
CS1	0.951	30.57	0.00404
SS1	0.007	4.985	0.00009
CS2	0.025	7.184	0.00026
SS2	0.009	1.989	0.00006
CS3	0.002	7.646	0.00018
SS3	0.0005	2.894	0.00003
CS4	0.873	19.92	0.00062
SS4	0.091	9.924	0.00018
CS5	5.7922	52.11	0.00093
SS5	0.1336	10.81	0.00034

Where, CS1-Control specimen with one beam, CS2-Control specimen with two beams, CS3-Control specimen with three beams, CS4-Control specimen with four beams, CS5-Control specimen corner joint, SS1- Strengthen specimen with one beam, SS2-Strengthen specimen with two beams, SS3-Strengthen specimen with three beams, SS4-Strengthen specimen with four beams, SS5-Strengthen specimen corner joint.

From table 8, it is observed that the modified reinforcement technique using crossed inclined bars at beam column junction is a feasible solution for increasing the shear capacity of the cyclically loaded beam-column joints and control total deflection. The cross inclined bars aids in creating an additional mechanism for shear transfer. Beam-column joints reinforcement modified with crossed inclined bars modeled in ANSYS Workbench v12 showed high strength under cyclic applied load.A beam column joint becomes structurally less efficient when subject to large lateral loads, such as strong wind. One of the solutions to meet the requirement of strength, stiffness and ductility is by providing high percentages of transverse hoops in the core of joints. Another which can be proposed is the modified reinforcement technique as studied in present study in which the provision of cross diagonal reinforcement increased the ultimate load carrying capacity, stiffness and ductility of joints in the both upward and downward loading conditions.

6.1 Hysteretic Behavior of Beam-Column Joints

The hysteretic behavior of beam column joints was examined in terms of shear strength and deformation capacity. The load displacement relationship for control and strengthened specimen are shown as hysteretic curves in Fig. 6.1.1-6.1.10.

Exterior joint with one beam (CS1 & SS1): -

The load-displacement behavior of control and strengthened specimen (CS1 and SS1) with one beam are shown in Fig. 6.1.1 & 6.1.2. The result from hysteretic analysis shows that the ultimate load carrying capacity of SS1 is significantly higher than CS1. This is due to the implementation of modified reinforcement technique at the joint region.

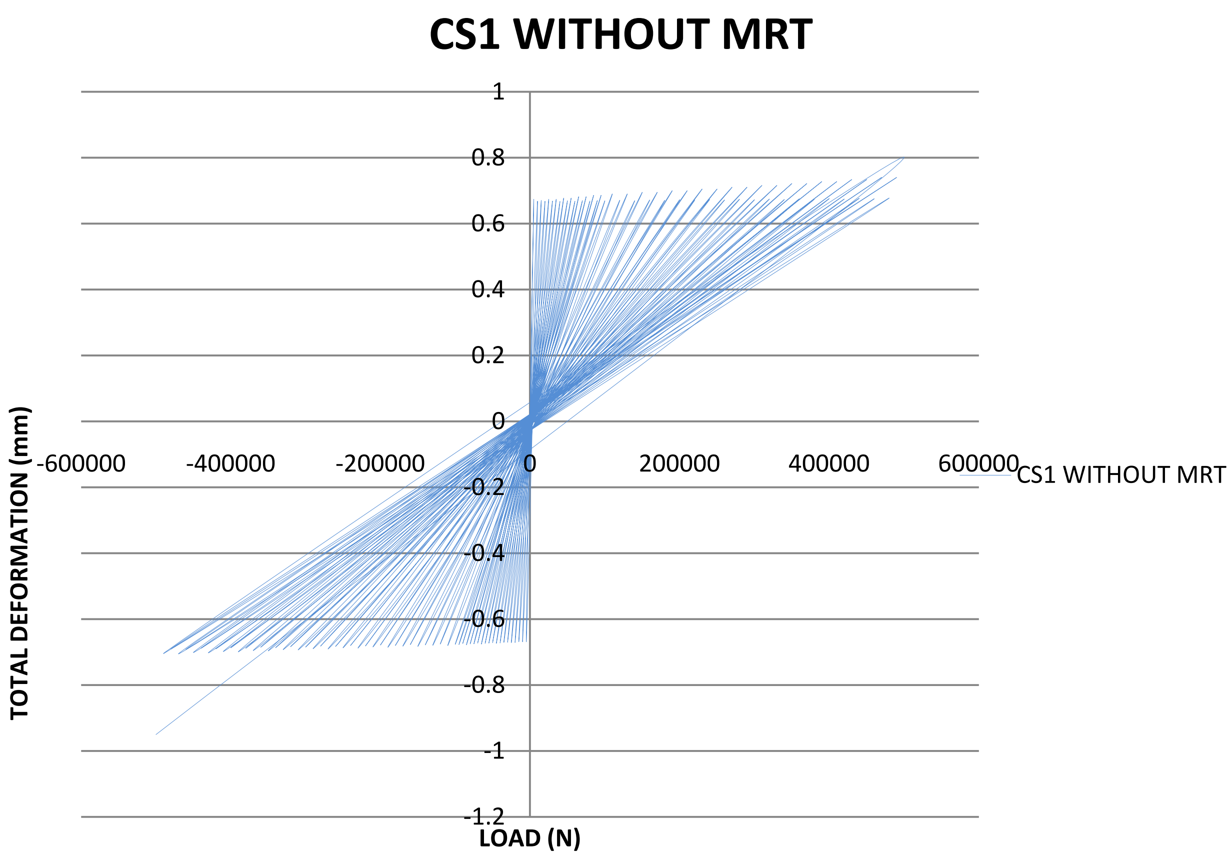


Fig. 6.1.1 load-displacement hysteretic plot for CS1

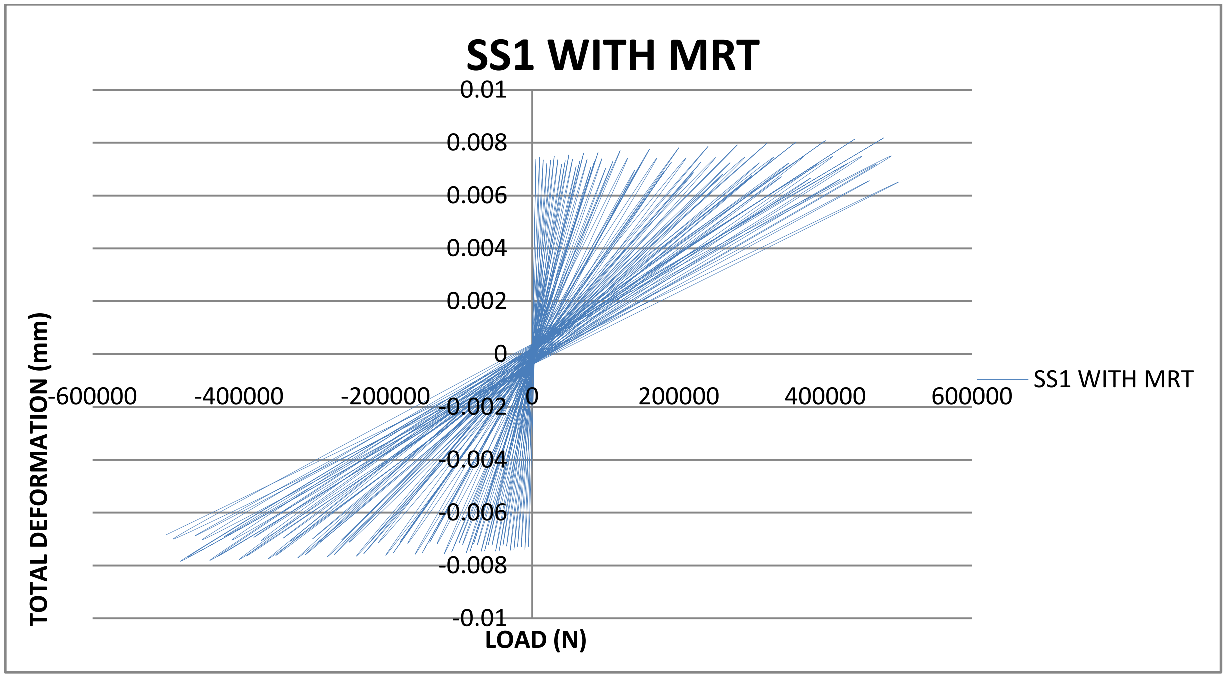


Fig. 6.1.2 load-displacement hysteretic plot for SS1

Exterior joint with two beams (CS2 & SS2): -

The comparison of control specimen with strengthened specimen (CS2 & SS2) through hysteretic load displacement behavior illustrate that the implementation of cross inclined bars at the joint region increase the deformation capacity of beam column joints (fig. 6.1.3 & 6.1.4). However, again it depends on the type of implementation.

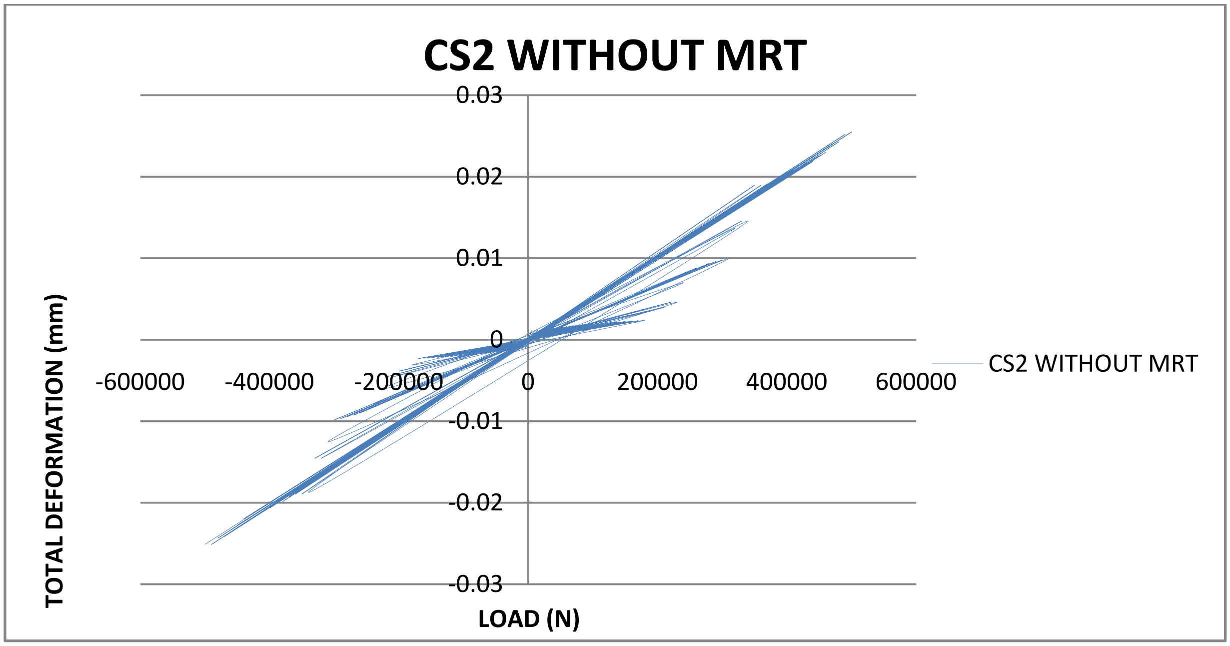


Fig. 6.1.3 load-displacement hysteretic plot for CS2

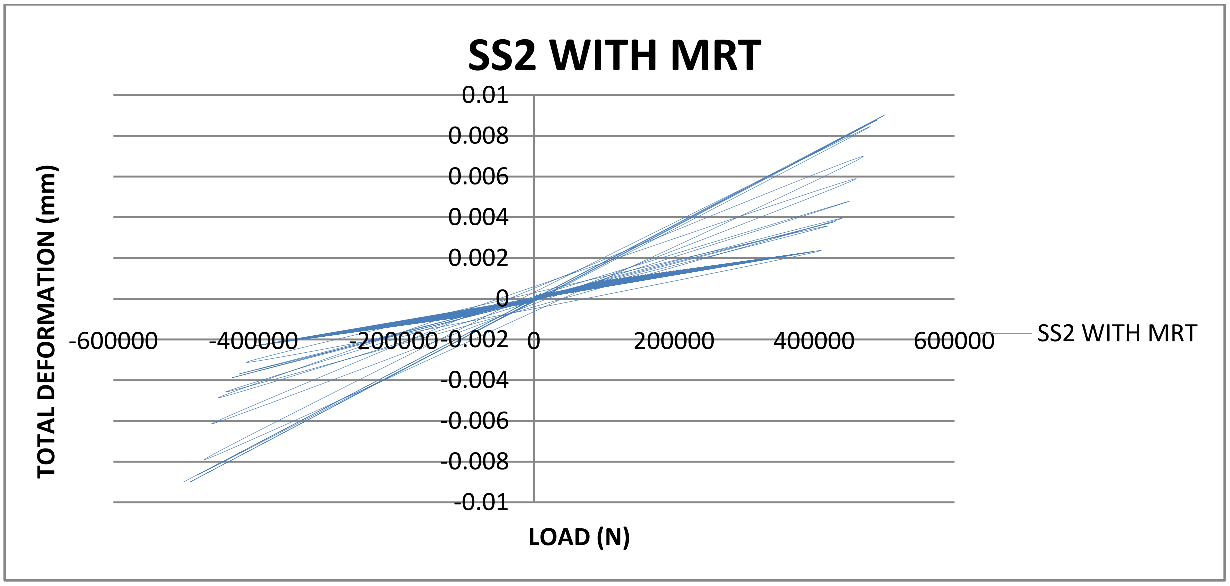


Fig. 6.1.4 load-displacement hysteretic plot for SS2

Exterior joint with three beams (CS3& SS3): -

The load-displacement hysteretic behavior of control and strengthened specimen (CS3 and SS3) with three beams are shown in fig. 6.1.5 & 6.1.6. The result from hysteretic analysis shows that the total deformation in CS3 is greater than strengthened specimen SS3 and the load carrying capacity of SS3 is significantly higher than CS3.

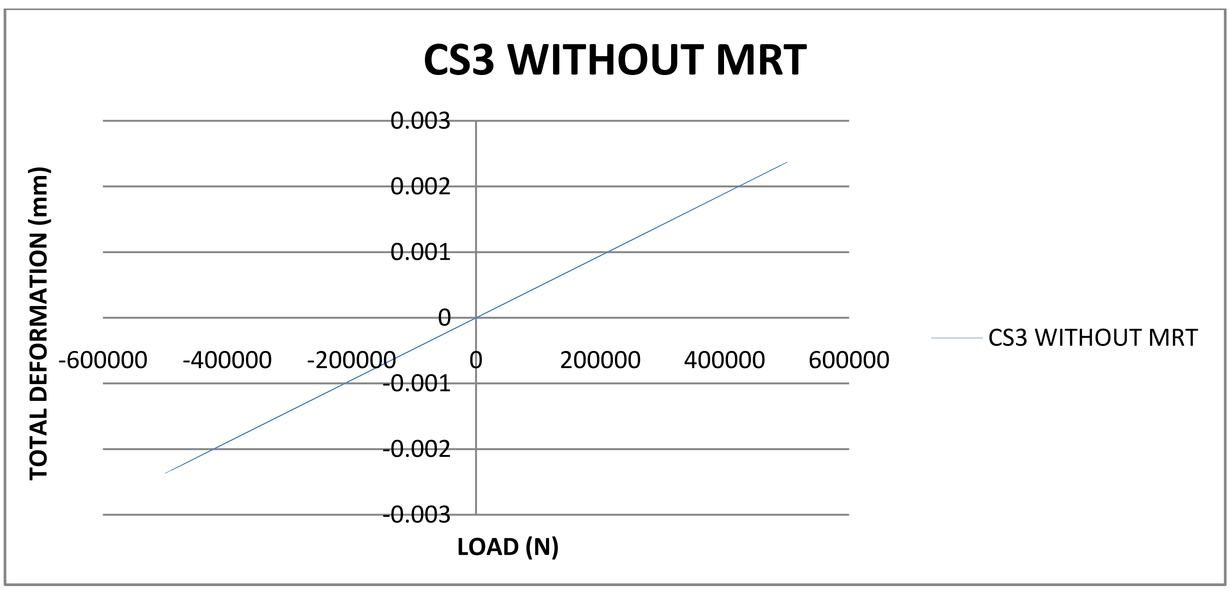


Fig. 6.1.5 load-displacement hysteretic plot for CS3

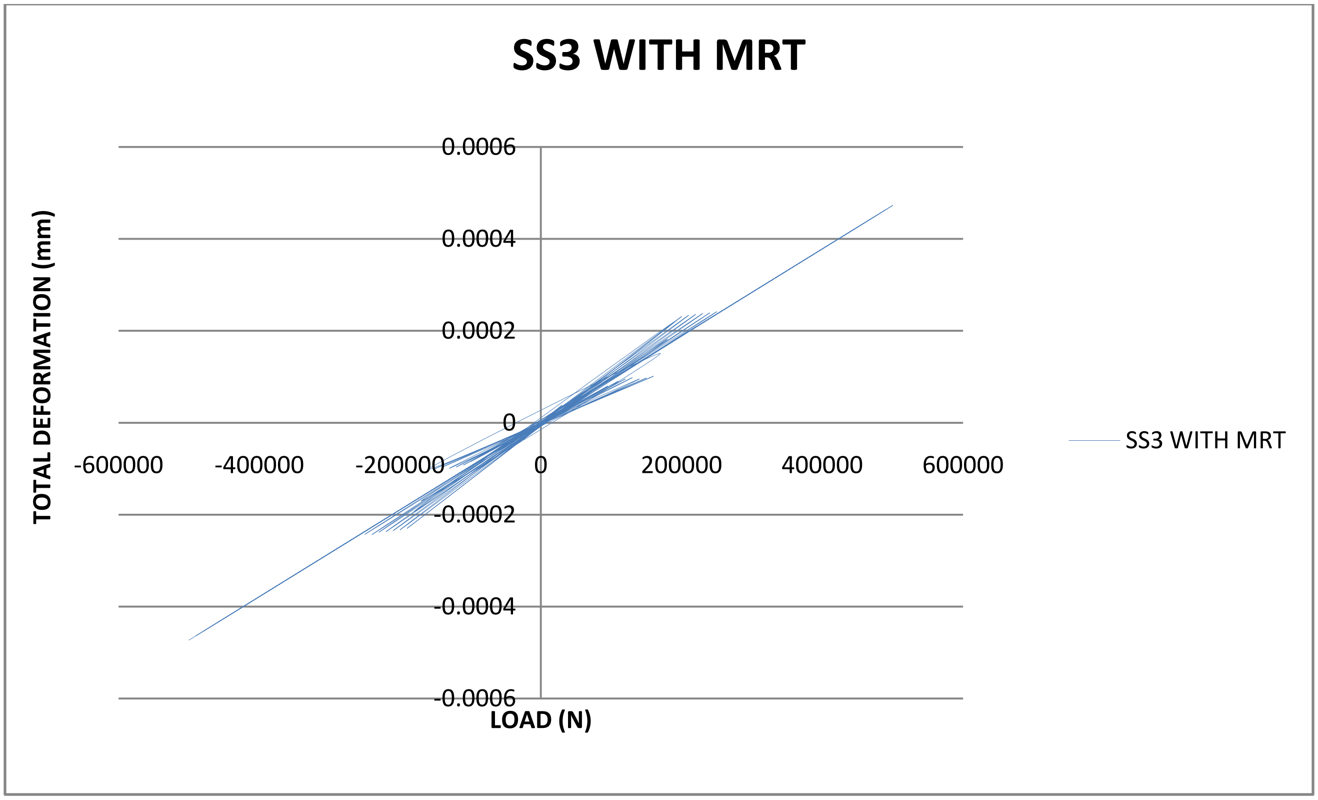


Fig. 6.1.6 load-displacement hysteretic plot for SS3

Interior joint with four beams (CS4& SS4): -

In comparison of control specimen with strengthened specimen (CS4 & SS4) through hysteretic load displacement behavior illustrate that the implementation of cross inclined bars at the joint region increase the deformation capacity of interior beam column joint (fig. 6.1.7 & 6.1.8). However, again it depends on the type of implementation.

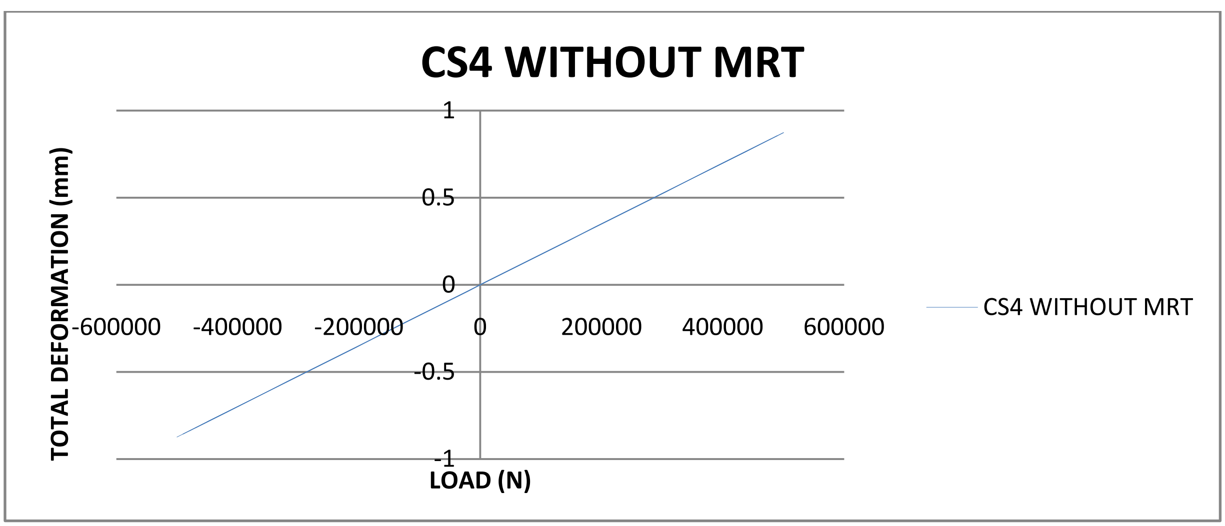


Fig. 6.1.7 load-displacement hysteretic plot for CS4

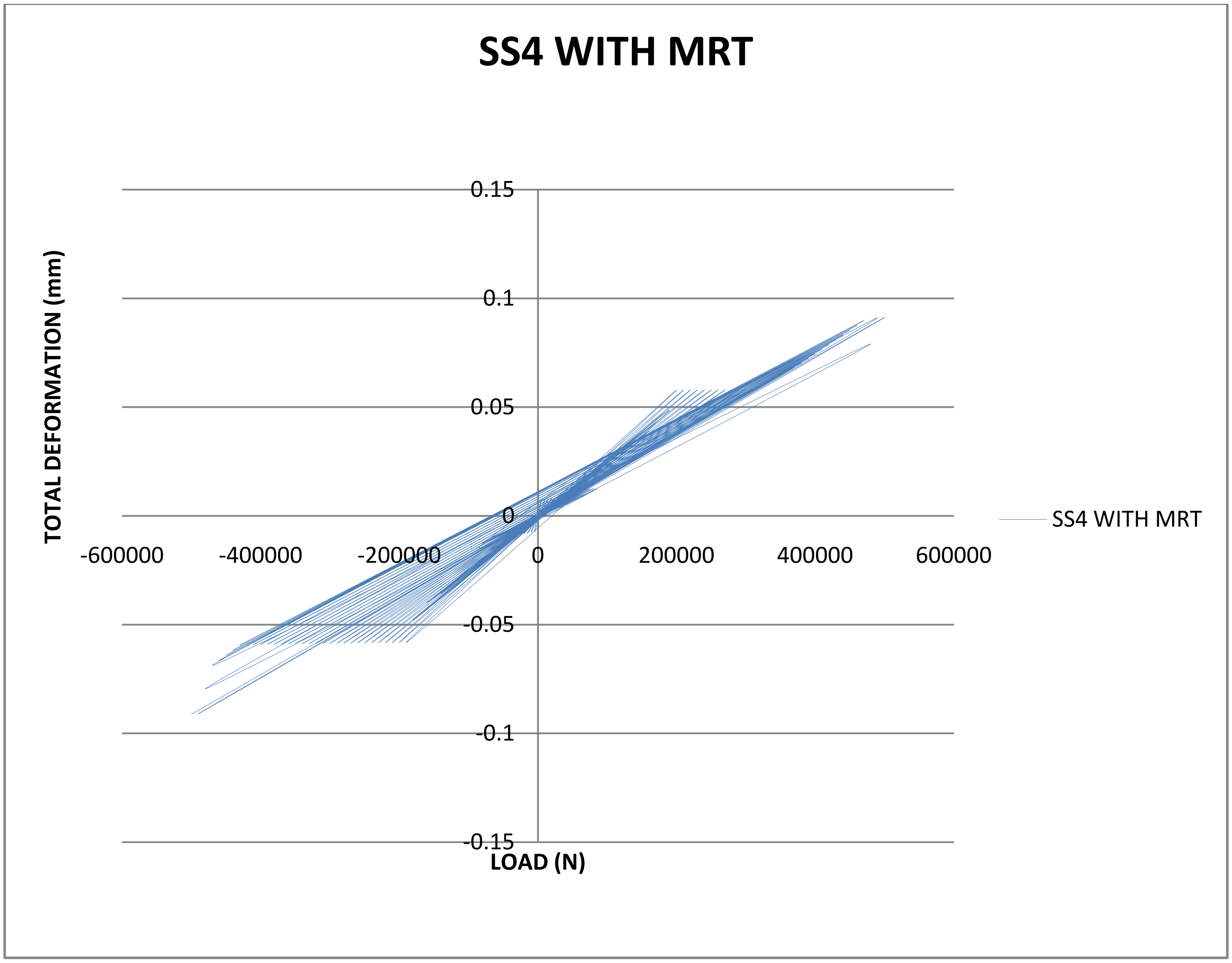


Fig. 6.1.8 load-displacement hysteretic plot for SS4

Corner joint (CS5& SS5): -

The load-displacement hysteretic behavior of control and strengthened specimen (CS5 and SS5) for corner joints are shown in fig. 6.1.9 & 6.1.10. The result from hysteretic analysis shows that the total deformation in CS5 is greater than strengthened specimen SS5 and the load carrying capacity of SS5 is significantly higher than CS5.

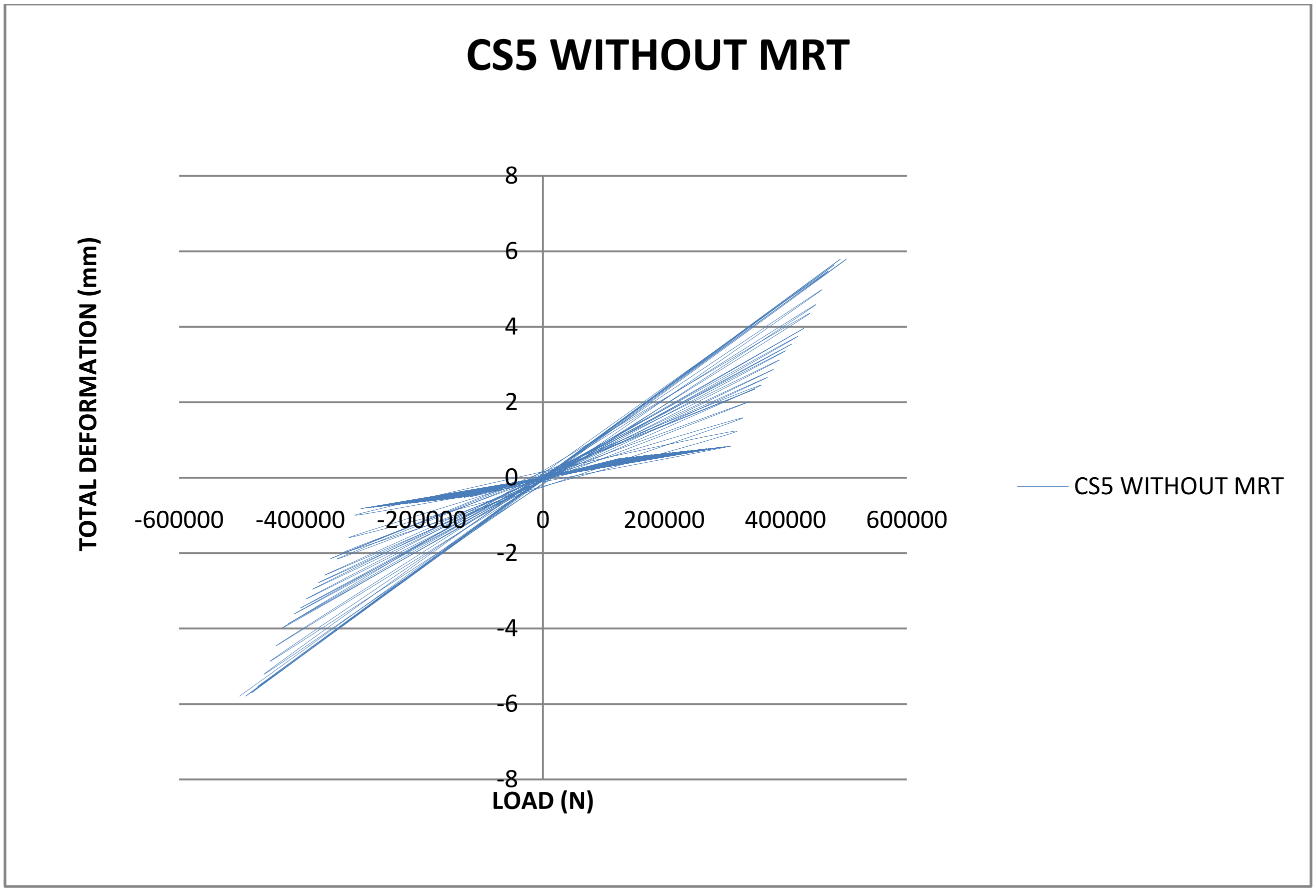


Fig. 6.1.9 load-displacement hysteretic plot for CS5

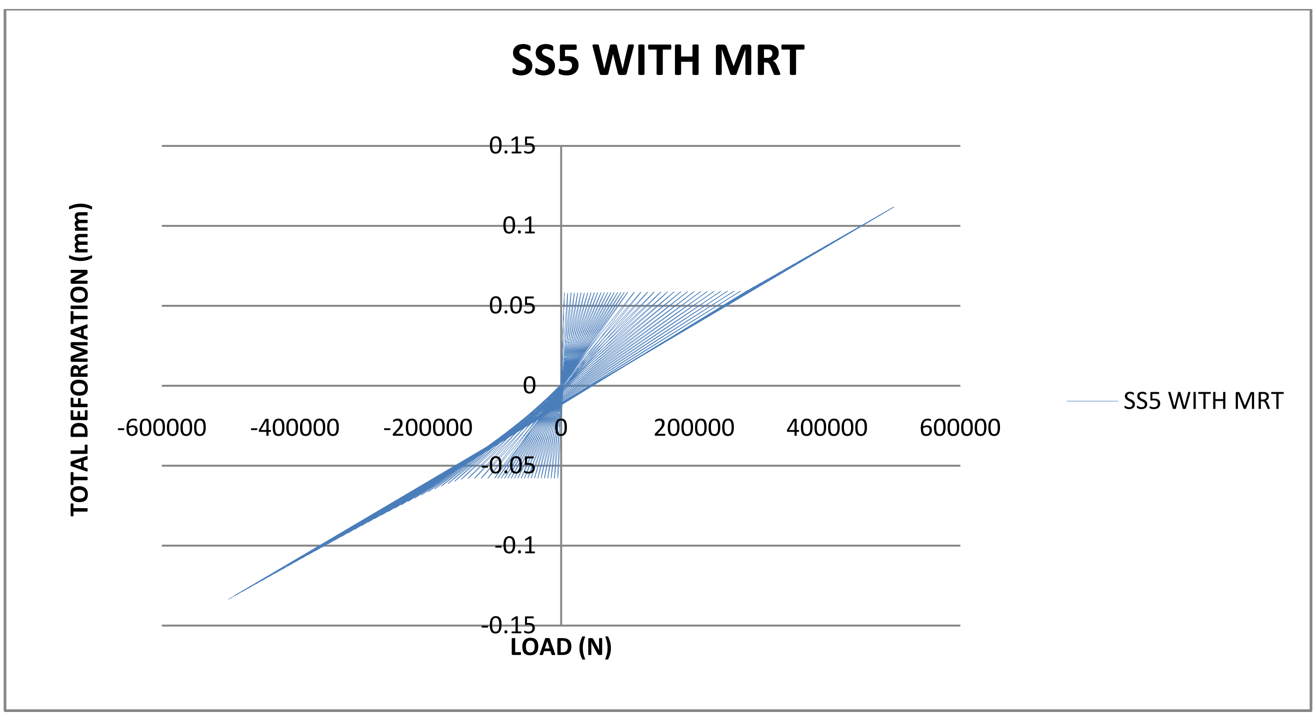
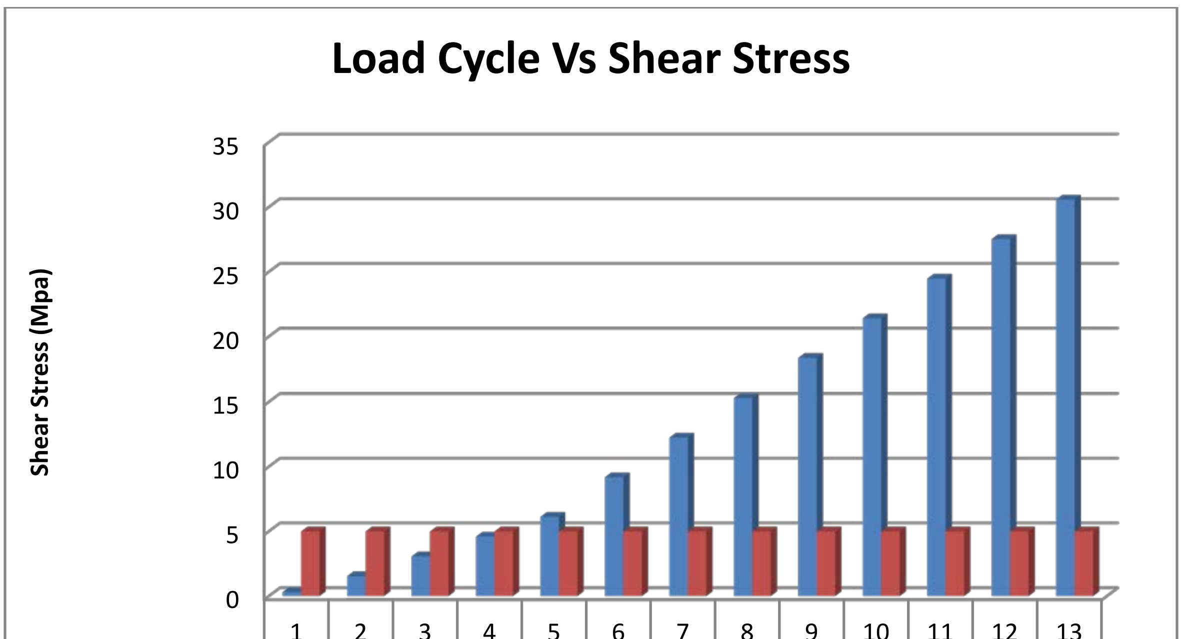


Fig. 6.1.10 load-displacement hysteretic plot for SS5

6.2 Shear Stress Vs Load Cycle Behavior of Beam Column Joints

The specimens are detailed as per IS 456:2000 with diagonal confining bars had improved ductility than the controlled specimen detailed as per IS 456:2000. From the analytical study it is observed that the provision of cross inclined reinforcement increased the ultimate carrying capacity and ductility of joints in the both upward and downward loading conditions. The presence of inclined bars introduces an additional mechanism of shear transfer. From graph 6.2.1-6.2.5, the beam column joints with crossed inclined reinforcement (MRT) showed high strength. The modified reinforcement technique increasing the shear capacity of cyclically loaded beam-column joints.

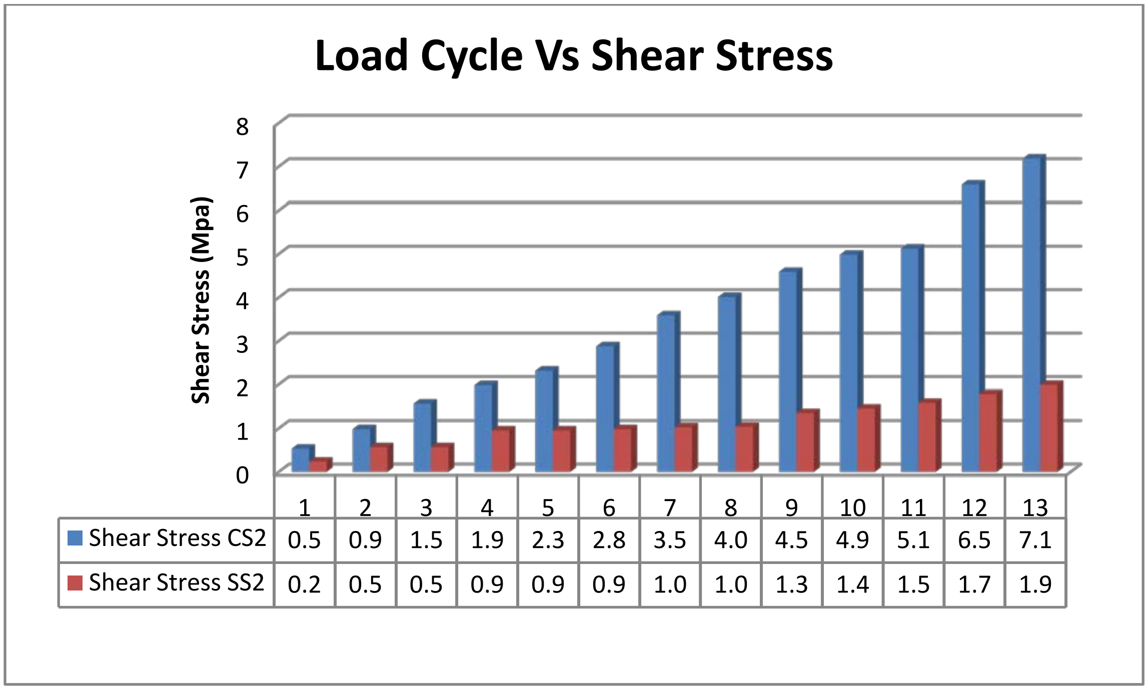
Exterior joint with one beam (CS1 & SS1): -



	1	2	3	4	5	6	7	8	9	10	11	12	13
Shear stress CS1	0.30	1.52	3.05	4.58	6.11	9.17	12.2	15.2	18.3	21.4	24.4	27.5	30.5
Shear Stress SS1	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98

Fig. 6.2.1 Shear Stress Vs Load Cycle for CS1 & SS1

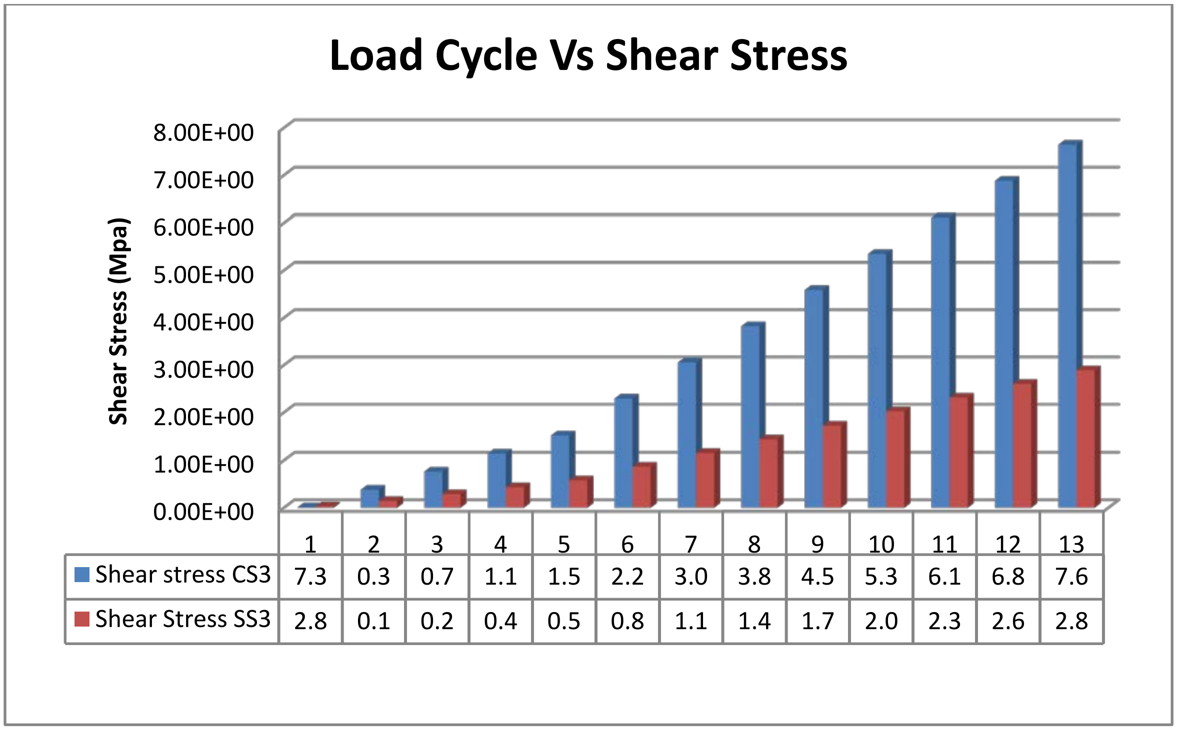
Exterior joint with Two beams (CS2 & SS2): -



	1	2	3	4	5	6	7	8	9	10	11	12	13
Shear Stress CS2	0.5	0.9	1.5	1.9	2.3	2.8	3.5	4.0	4.5	4.9	5.1	6.5	7.1
Shear Stress SS2	0.2	0.5	0.5	0.9	0.9	0.9	1.0	1.0	1.3	1.4	1.5	1.7	1.9

Fig. 6.2.2 Shear Stress Vs Load Cycle for CS2 & SS2

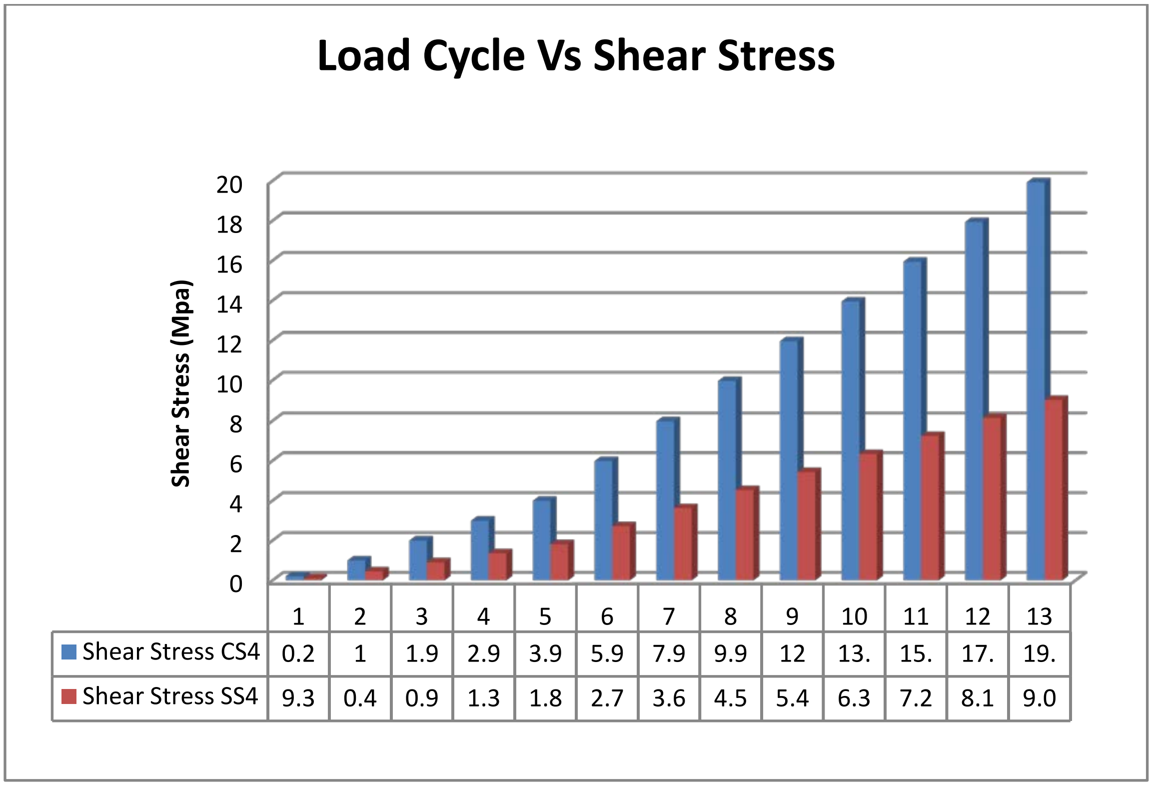
Exterior joint with Three beams (CS3 & SS3): -



	1	2	3	4	5	6	7	8	9	10	11	12	13
Shear stress CS3	7.3	0.3	0.7	1.1	1.5	2.2	3.0	3.8	4.5	5.3	6.1	6.8	7.6
Shear Stress SS3	2.8	0.1	0.2	0.4	0.5	0.8	1.1	1.4	1.7	2.0	2.3	2.6	2.8

Fig. 6.2.3 Shear Stress Vs Load Cycle for CS3 & SS3

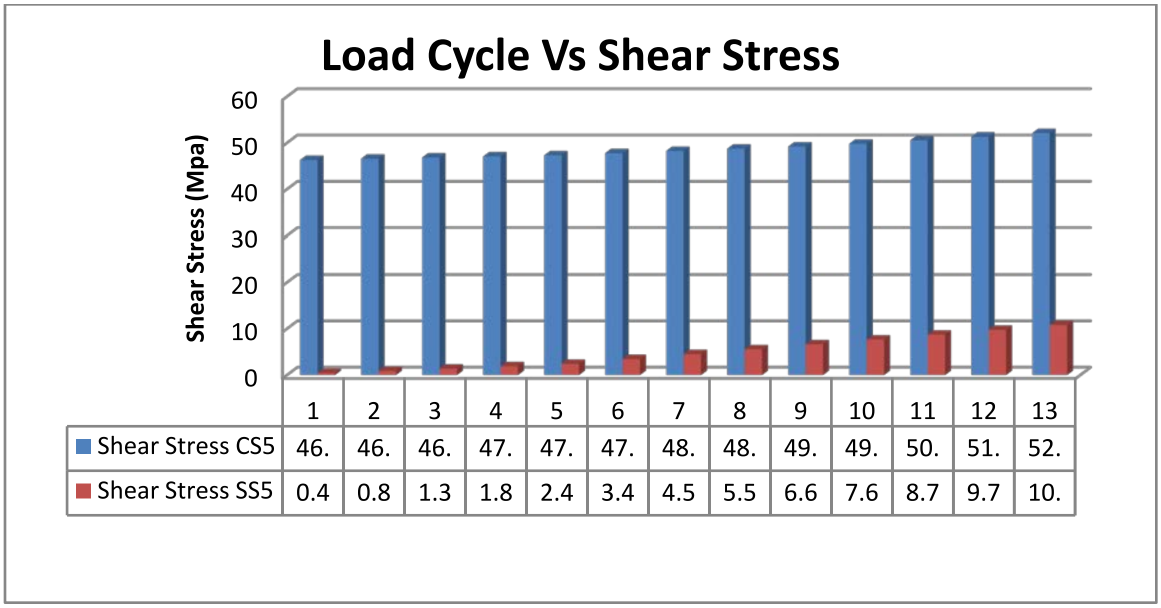
Interior Joints with four beams (CS4 & SS4): -



	1	2	3	4	5	6	7	8	9	10	11	12	13
Shear Stress CS4	0.2	1	1.9	2.9	3.9	5.9	7.9	9.9	12	13.	15.	17.	19.
Shear Stress SS4	9.3	0.4	0.9	1.3	1.8	2.7	3.6	4.5	5.4	6.3	7.2	8.1	9.0

Fig. 6.2.4 Shear Stress Vs Load Cycle for CS4 & SS4

Corner joints (CS5 & SS5): -



	1	2	3	4	5	6	7	8	9	10	11	12	13
Shear Stress CS5	46.	46.	46.	47.	47.	47.	48.	48.	49.	49.	50.	51.	52.
Shear Stress SS5	0.4	0.8	1.3	1.8	2.4	3.4	4.5	5.5	6.6	7.6	8.7	9.7	10.

Fig. 6.2.5 Shear Stress Vs Load Cycle for CS5 & SS5

6.3 Displacement Time History Curve for Bean-Column Joints

The lateral load-displacement time histories of the analytical results of control and strengthened specimens are shown in figs. 6.3.1-6.3.10. All cycles were started with the pull direction first, then went into the push direction. The strengthened of beam-column joints by implementation of cross inclined bars at the joint region provides better strength than control specimens.

Exterior joint with one beam (CS1): -

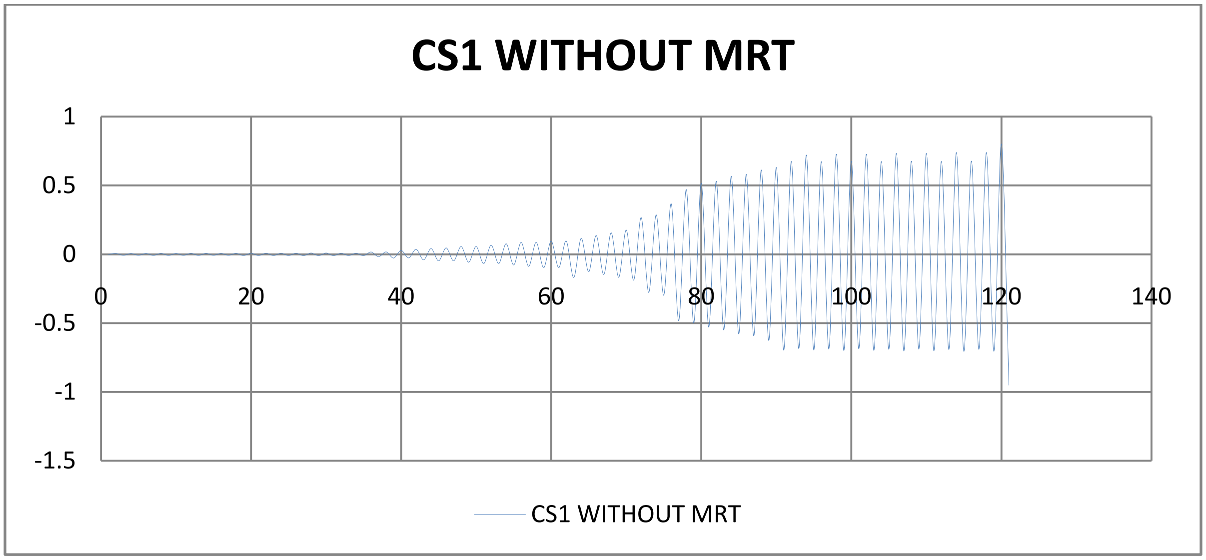


Fig. 6.3.1 Displacement Time history for CS1

Exterior joint with one beam (SS1): -

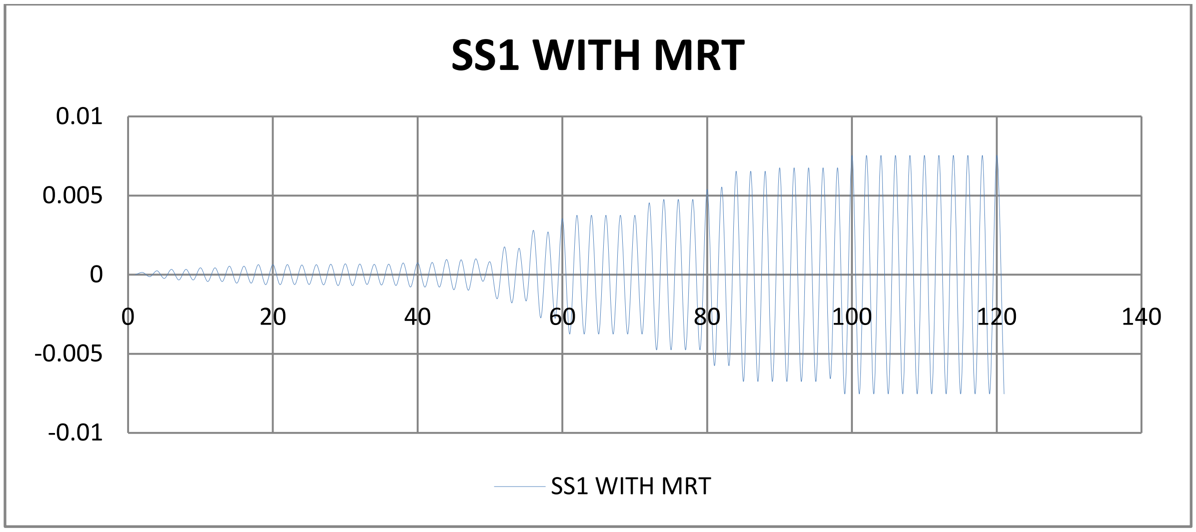


Fig. 6.3.2 Displacement Time history for SS1

Exterior joint with Two beams (CS2): -

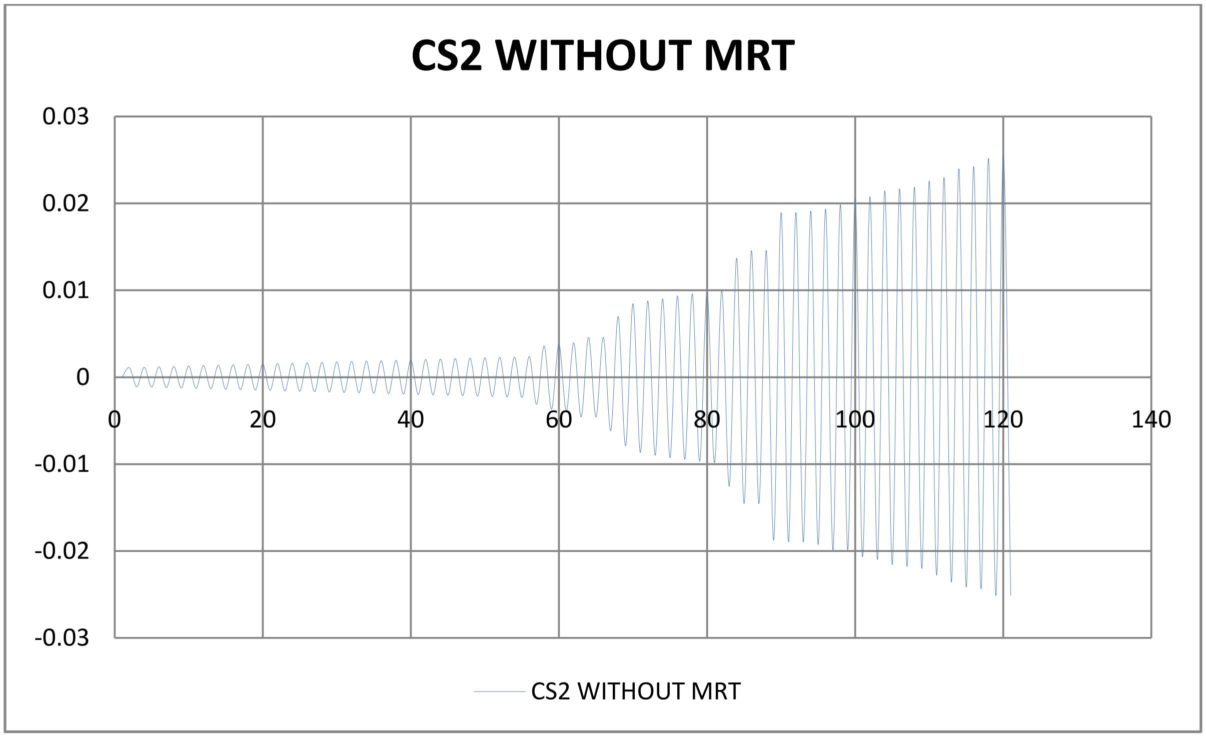


Fig. 6.3.3 Displacement Time history for CS2

Exterior joint with Two beams (SS2): -

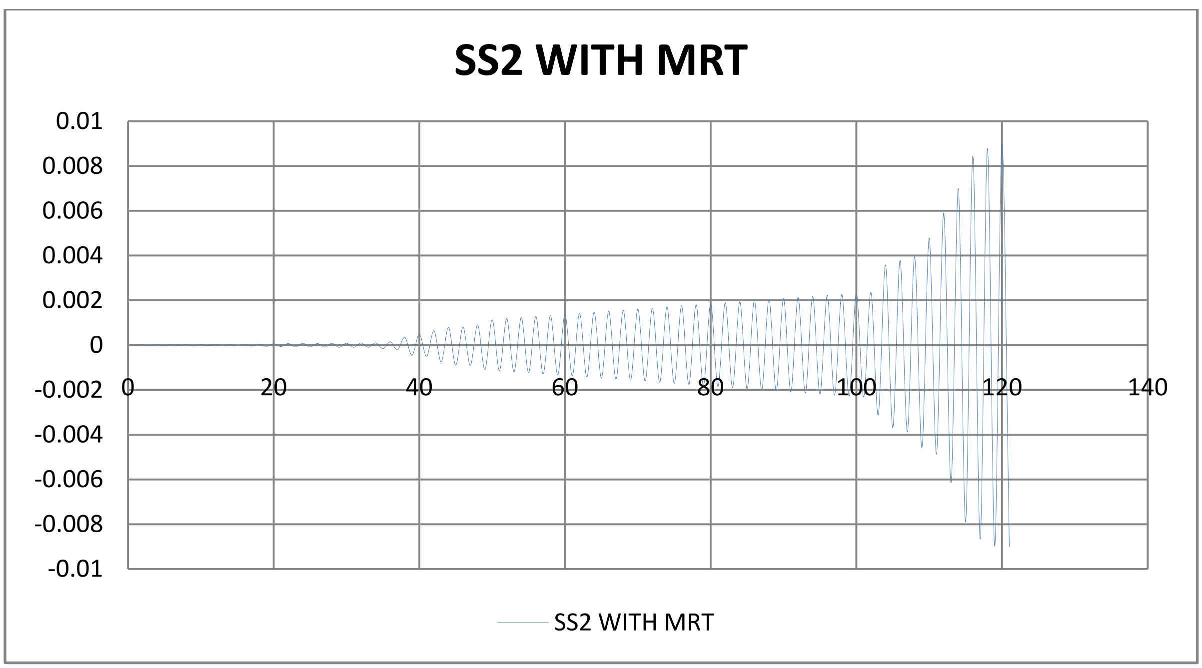


Fig. 6.3.4 Displacement Time history forSS2

Exterior joint with Three beams (CS3): -

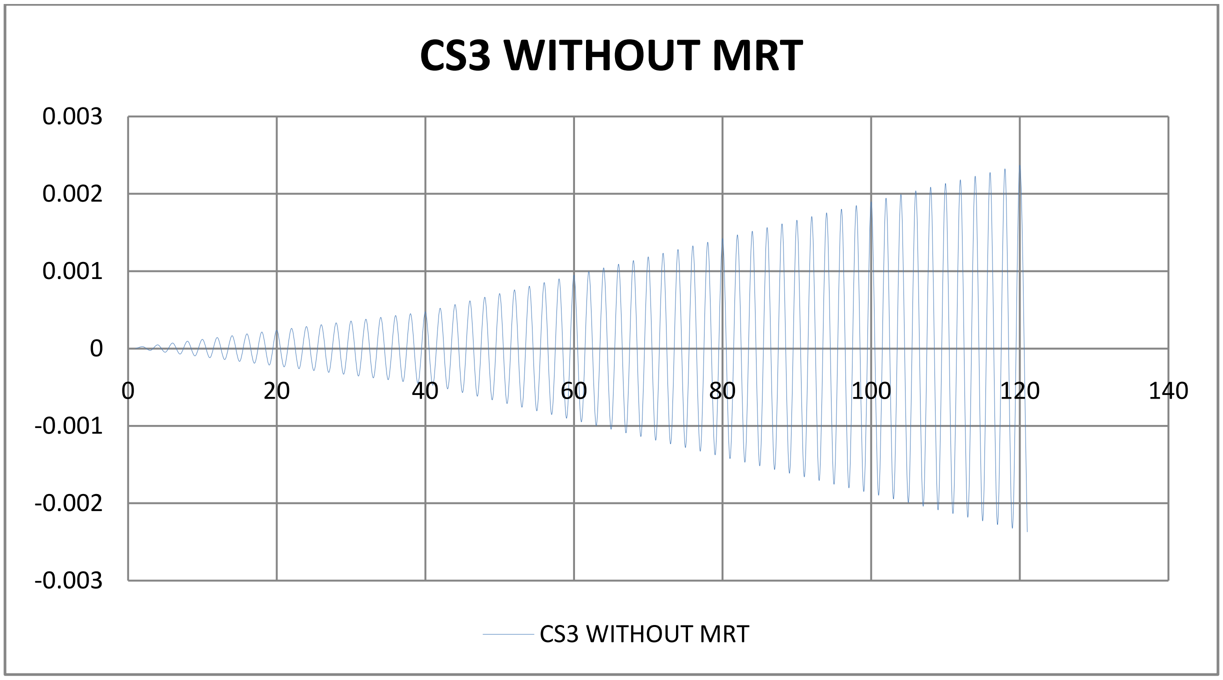


Fig. 6.3.5 Displacement Time history for CS3

Exterior joint with Three beams (SS3): -

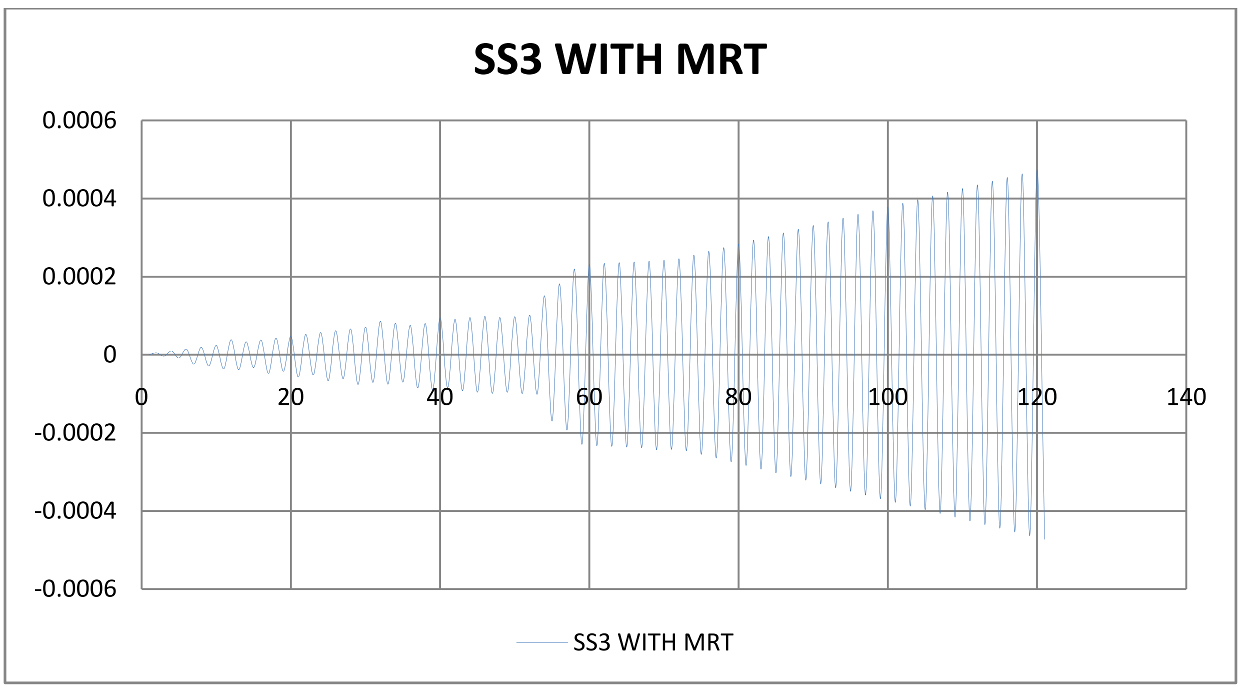


Fig. 6.3.6 Displacement Time history for SS3

Interior joint with Four beams (CS4): -

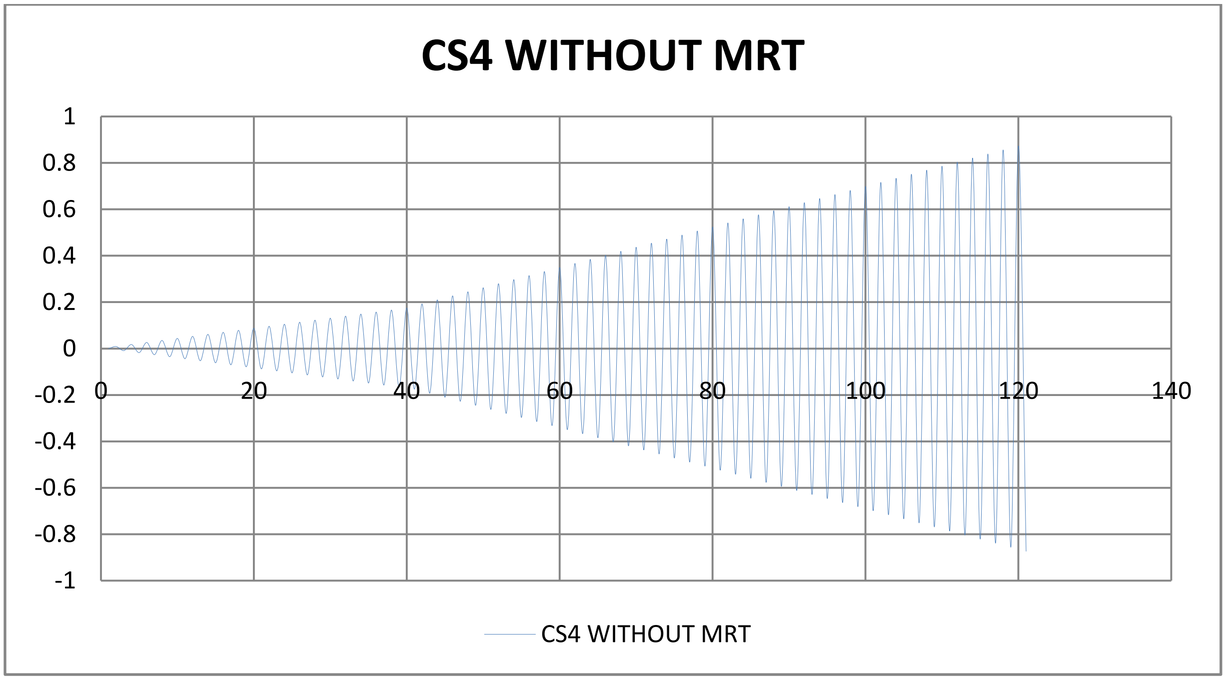


Fig. 6.3.7 Displacement Time history for CS4

Interior joint with Four beams (SS4): -

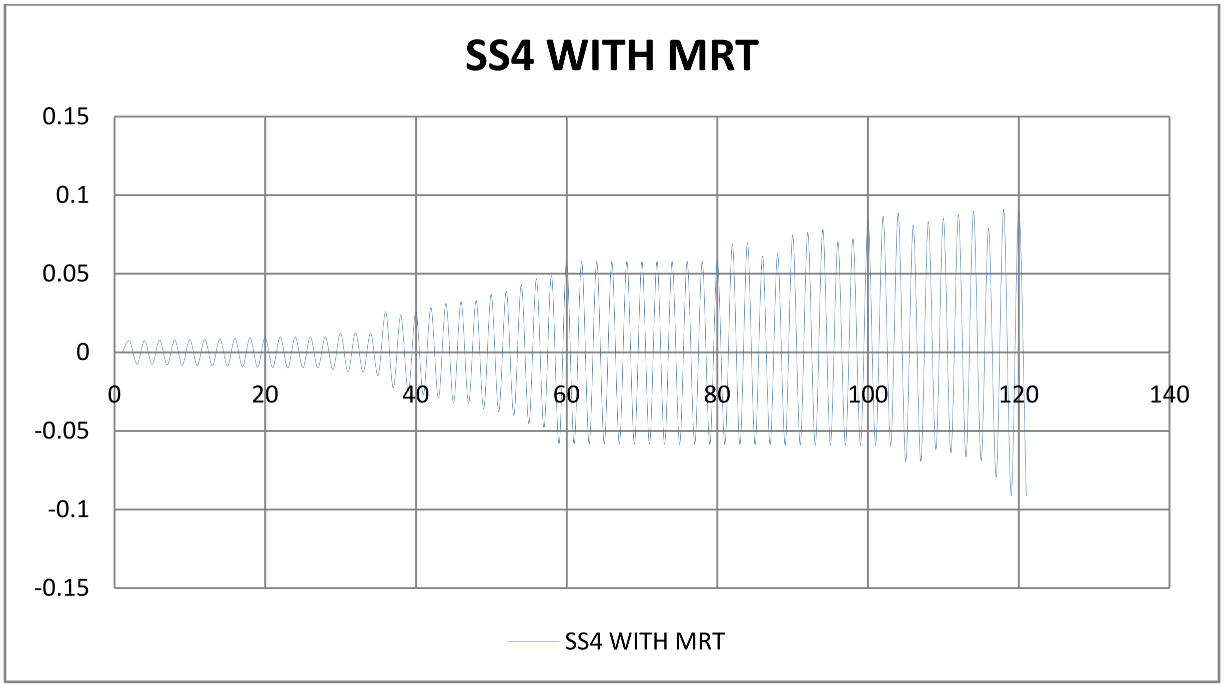


Fig. 6.3.8 Displacement Time history for SS4

Corner joint (CS5): -

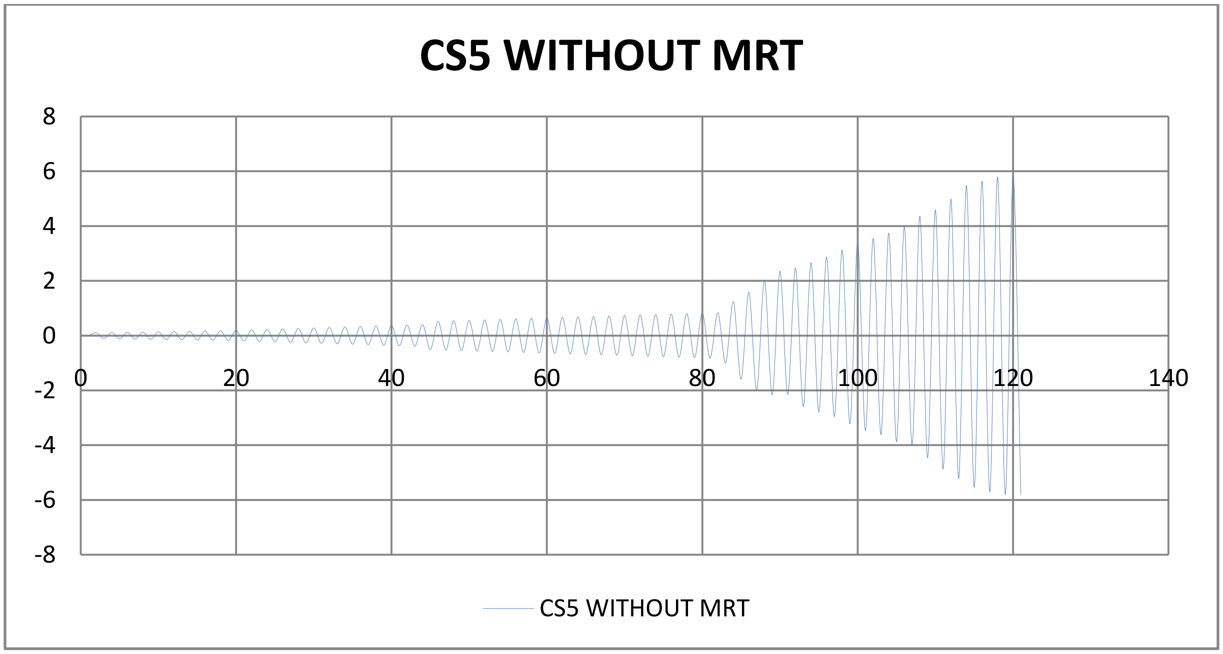


Fig. 6.3.9 Displacement Time history for CS5

Corner joint (SS5): -

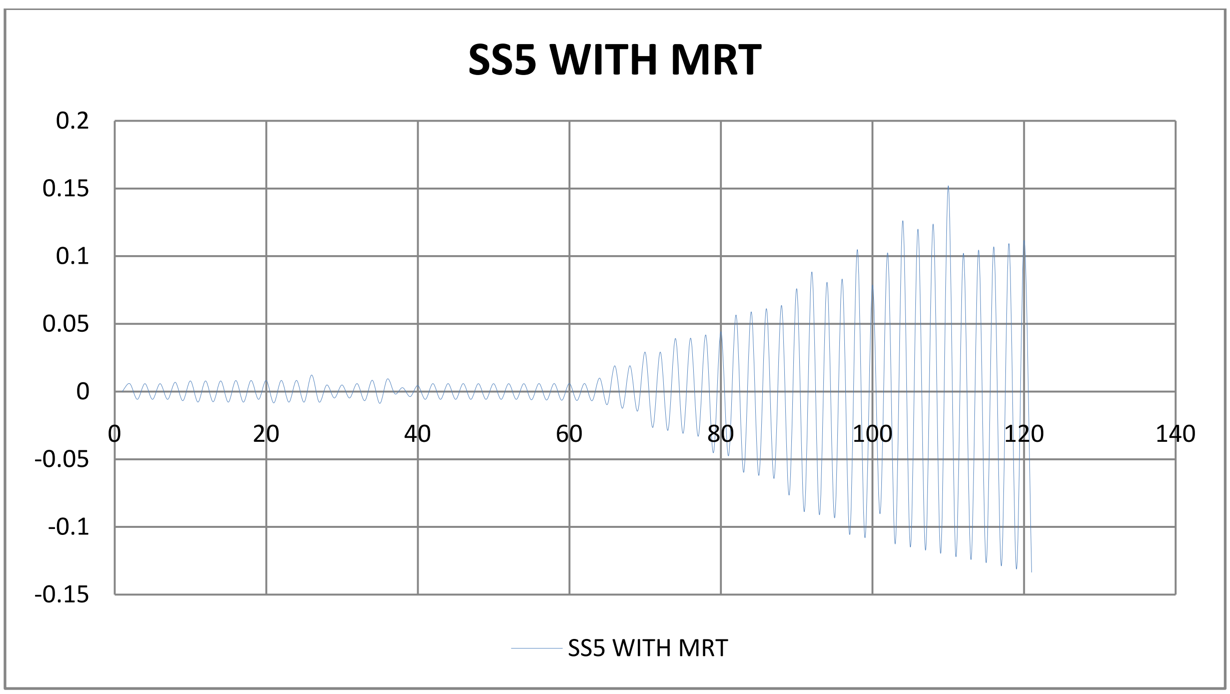


Fig. 6.3.10 Displacement Time history for SS5

6.4 Load-Displacement Behavior for Bean-Column Joints

The finite-element results for control and strengthened specimens were compared through load-displacement behavior shown in Fig. 6.3.1-6.3.5. The load-displacement behavior obtained from analysis concludes that the strengthened specimen with implementation of cross bars at joint shows better results as compared to the control specimens. From Fig. 6.3.1-6.3.5, it is observed that the total deformation is control in beam-column joints and increases the ultimate load carrying capacity of joints by introducing cross inclined bars at joints.

Exterior joint with one beam (CS1 & SS1): -

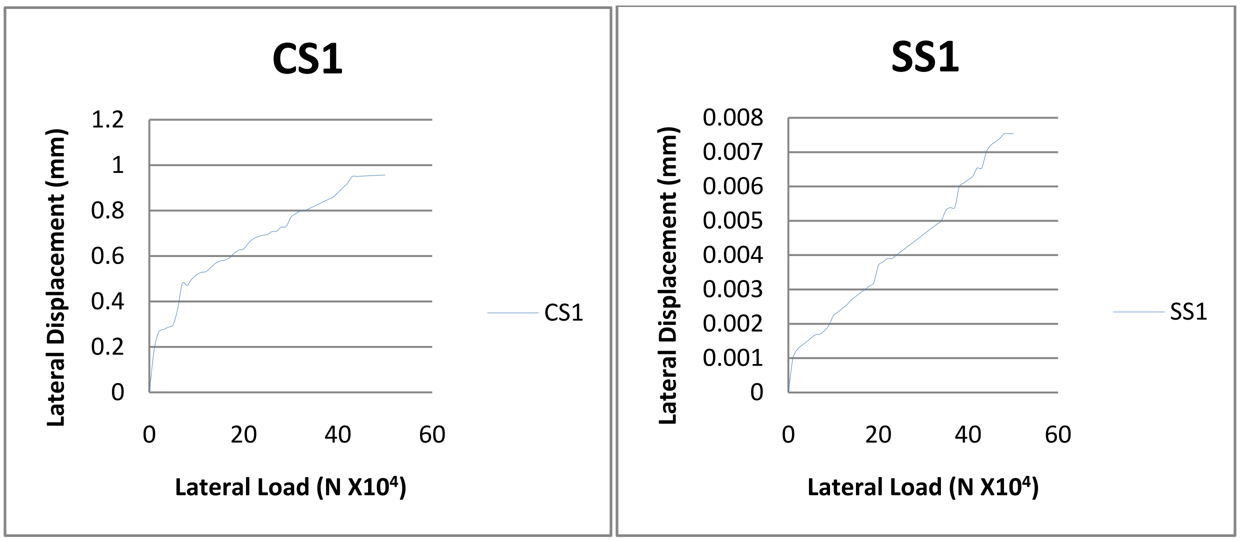


Fig. 6.4.1 Load displacement response for CS1& SS1 beam-column joints

Exterior joint with Two beams (CS2 & SS2): -

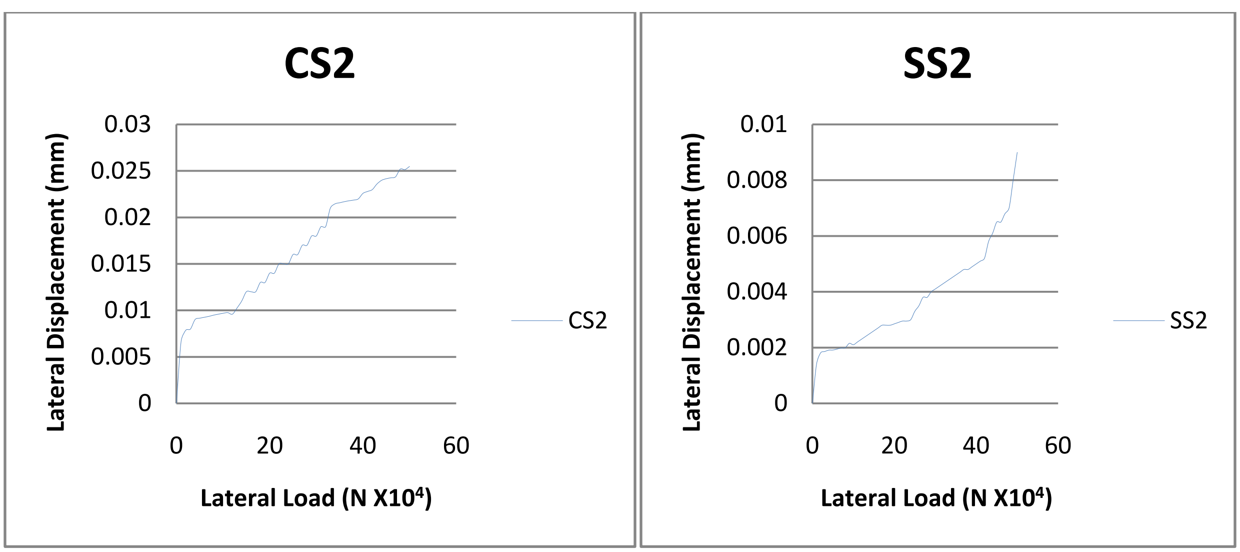


Fig. 6.4.2 Load displacement response for CS2 & SS2 beam-column joints

Exterior joint with Three beams (CS3 & SS3): -

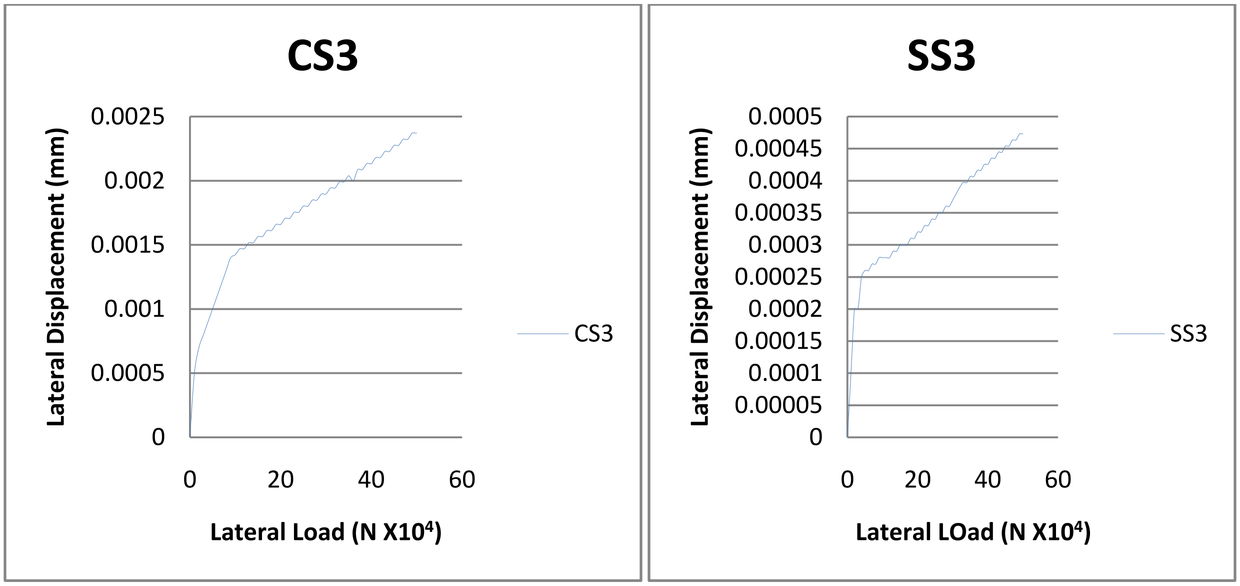


Fig. 6.4.3 Load displacement response for CS3 & SS3 beam-column joints

Interior joint with Four beams (CS4 & SS4): -

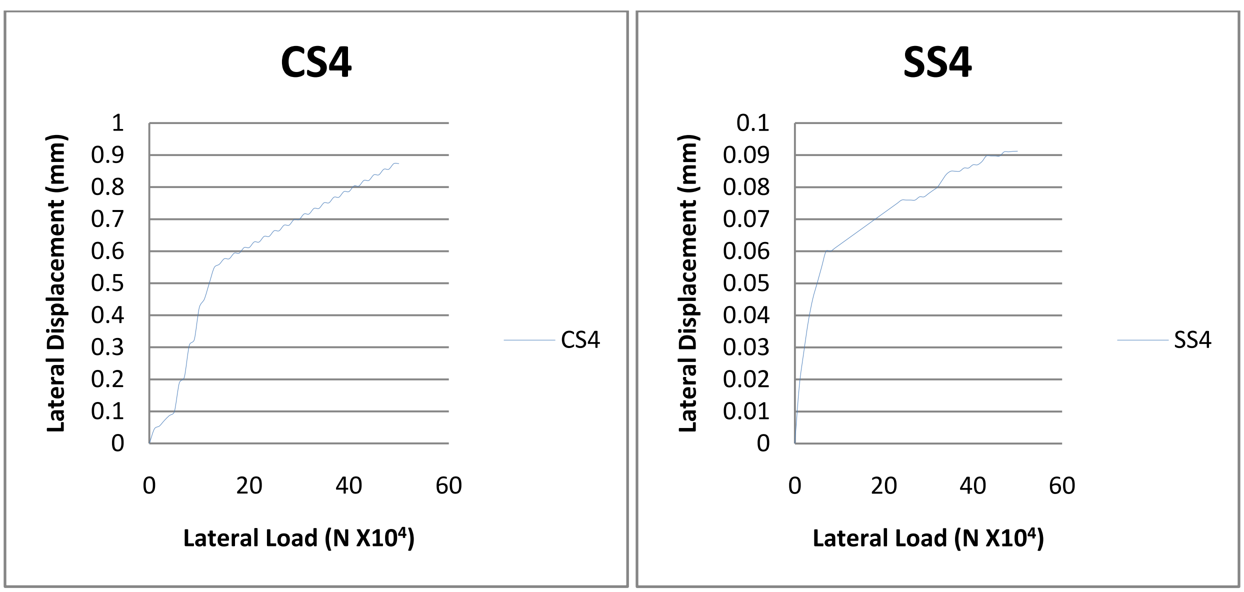


Fig. 6.4.4 Load displacement response for CS4 & SS4 beam-column joints

Corner joints (CS5 & SS5): -

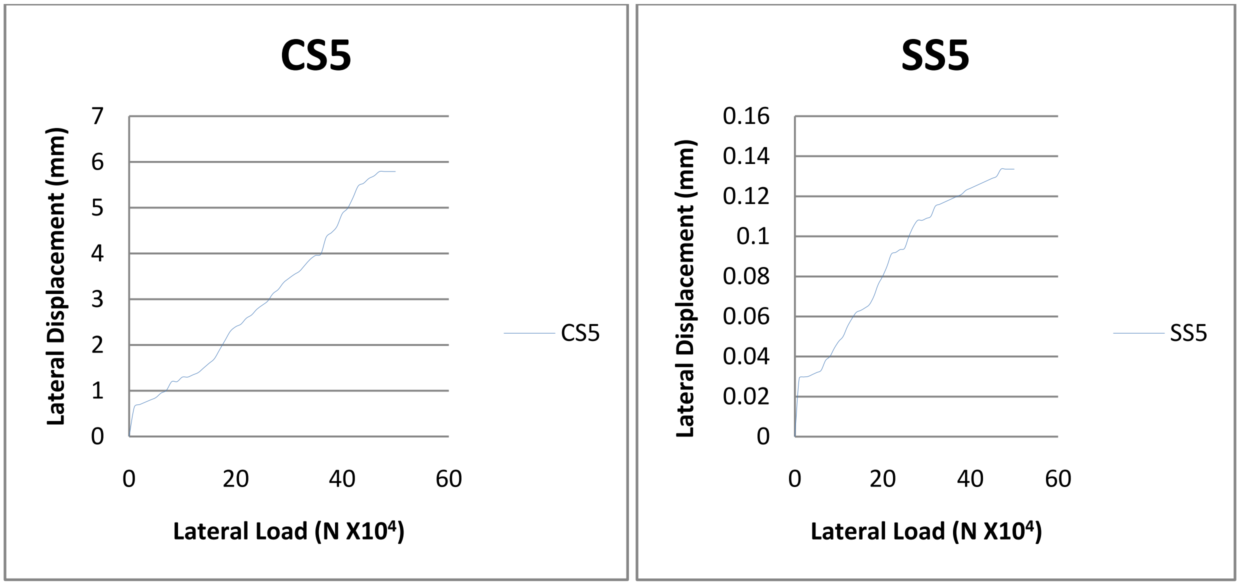


Fig. 6.4.5 Load displacement response for CS5 & SS5 beam-column joints

CHAPTER 7

CONCLUSIONS AND FUTURE SCOPE

The present study is aimed at understanding the influence of different parameters on the shear strength of cyclically loaded beam-column joints. The most important factor affecting the shear capacity of joints are the concrete compressive strength, joint aspect ratio, anchorage of beam longitudinal reinforcement and amount of stirrups inside the joint.The results obtained from the Finite-Element model were compared with the control specimens to the strengthened specimens through load-displacement hysteretic curves, displacement time history curves, cyclic load Vs shear stress and load displacement response, and it was observed that the implementation of cross inclined bars at the joint region predict better results as compared to control specimens. The all joints are analyzed for the same loading with same arrangement of reinforcement for control and strengthened specimen and it was observed that the higher deformation and stress obtained in the corner joints as compare to the other joints.Unsafe design and detailing within the joint region jeopardizes the entire structure, even if other structural members conform to the design requirements. The beam moment which induced during earthquake motion on the beam can produce high shear forces and bond breakdown into the joint resulting in cracking of the joints. Modified reinforcement technique using crossed inclined bars at beam column junction is a feasible solution for increasing the shear capacity of the cyclically loaded exterior beam-column joints. The cross inclined bars aids in creating an additional mechanism for shear transfer. The beam-column joint reinforcement modified with crossed inclined bars modeled in ANSYS Workbench v12 showed high strength under cyclic loading. From analytical result done via ANSYS concludes that the specimen with diagonal cross bar at joint shows better performance under the cyclic loading and it is a feasible solution for increasing the shear capacity of exterior and interior beam-column joints.The reinforcement details of all joints though conform to the general construction code of practice may not adhere to the modern seismic provisions. A beam column joint becomes structurally less efficient when subject to large lateral loads, such as strong wind. One of the solutions to meet the requirement of strength, stiffness and ductility is by providing high percentages of transverse hoops in the core of joints. Another which can be proposed is the modified reinforcement technique as studied in present study in which the provision of cross diagonal reinforcement increased the ultimate load carrying capacity, stiffness and ductility of joints in the both upward and downward loading conditions.

Future Research Scope: -

The current work can be extended for studying,

- The variation of stresses in reinforcing bars of column and beam.
- The beam-column joints with variations of diameter of cross bars.
- The behaviors of joints with variations of length of cross bars.
- The behaviors of joints with different arrangement of cross bars.
- The joints analysis with change of reinforcement detailing.
- The joints analysis with change of grade of concrete.

REFERENCES

BOOK:

1. Park and paulay, *"Design of concrete structure"* Page no. 716-751.

JOURNAL:

1. S.H.Alsayed, Y.A.Al-Salloum, N.A. Siddiqui and T.H.Almusallam, 2010, "Seismic response of FRP-upgraded exterior RC beam column Joints", *Journal of composites for construction ASCE/MARCH/APRIL, 2010*, page no.195-208.
2. K.R.Bindhu Department of Civil Engineering, College of Engineering, Thiruvananthapuram, India, and K.P. Jaya Structural Engineering Division, Anna University, Chennai, India,2010. *"Strength and Behavior of Exterior Beam Column Joints with Diagonal Cross Bracing Bars" ASIAN JOURNAL OF CIVIL ENGINEERING (BUILDING AND HOUSING) VOL. 11, NO. 3(2010)* page no. 397-410.
3. Suhasini M Kulkarni (Civil Engineering Department, Parul Institute of Engineering & Technology, India), Yogesh D Patil (Applied Mechanics Department, Sardar Vallabhbhai Patel National Institute of Technology, India). *"Cyclic Behavior of Exterior Reinforced Beam-Column Joint with Cross-Inclined Column Bars" IOSR-JMCE VOL. 11, Issue 4, JUL-AUG, 2014*, page no. 09-17.
4. C.D.Vecchio, M.D.Ludovico, Albeeto Balsamo, Andrea Prota, Gaetano Manfredi, and Mauro Dolce,2014, *"Experimental Investigation of Exterior RC Beam-Column Joints Retrofitted With FRP system"journal of composites for construction ASCE/JANUARY/, 2014*, page no.01-13.
5. S. H. Alsayed, Y. A. Al-Salloum, T. H. Almusallam, and N.A. Siddiqui, 2010, *"Seismic Rehabilitation of Corner RC Beam-Column Joints Using CFRP Composites"journal of composites for construction ASCE/NOVEMBER/DECEMBER , 2010*, page no.681-692.
6. Tarek H. Almusallam, Yousef A. Al-salloum, and M.sc student, dept. of civil engineering, king saud university, Riyadh, Saudi Arabia, 2007, *"seismic response of interior RC beam-column joints upgraded with FRP sheets. II: Analysis and Parametric Study" journal of composites for construction ASCE/NOVEMBER/DECEMBER, 2007*, page no.590-600.

7. Tarek H. Almusallam, Yousef A. Al-salloum, and M.sc student, dept. of civil engineering, king saud university, Riyadh, Saudi Arabia,2007, *"Numerical Investigations on the seismic Behavior of FRP and TRM Upgraded RC Exterior Beam-column Joints I" journal of composites for construction ASCE/MAY/JUNE, 2012*, page no.308-321
8. Mukherjee, A., and Joshi, M. 2005. *"FRPC reinforced concrete beam column joints under cyclic excitation." Compos.Struct*, page no.185–199.
9. Hakuto, S. Park, R., and Tanaka, H. 2000. *"Seismic load tests on interior and exterior beam-column joints with substandard reinforcing details."ACI Struct. J.*, page no. 11–25.
10. Hanson, N. W., and Connor, H. W. 1967. *"Seismic resistance of reinforced concrete beam-column joints." J. Struct. Div.*, page no. 553–560.
11. Hwang, S.and Lee, H. 2000. *"Analytical model for predicting shear strengths of interior reinforced concrete beam-column joints for seismic resistance."ACI Struct. J.*, page no. 35–44.
12. Kam, W. Y.and Pampanin, S. 2008. *"Selective weakening techniques for retrofit of existing reinforced concrete structures."Proc., 14th World Conf. on Earthquake Engineering (14WCEE).*
13. American Concrete Institute (ACI). (2011). *"Guide for seismic rehabilitation of existing concrete frame buildings and commentary."* ACI 369R-11, Farmington Hills, MI.
14. Jack Moehle University of California, Berkeley, ppt on Beam Column Connection.
15. Martin Alberto Masuelli, *"Introduction of Fibre-Reinforced Polymers – Polymers and Composites: Concepts, Properties and Processes"*, 2014.
16. Prota, A. Nanni, A., Manfredi, G., and Cosenza, E. (2004). *"Selective upgrade of under-designed reinforced concrete beam-column joints using carbon fiber-reinforced polymers."* ACI Struct. J., 101(S69), page no. 699–707.
17. IS 13920:1993, *Indian Standard Code on Criteria for Earthquake Resistant Design of Structures*, (Bureau of Indian Standards), New Delhi, India, 2002.
18. IS 456:2000, *Indian Standard Plain and Reinforced Concrete Code of Practice*, (Bureau of Indian Standards), New Delhi, India, 2000.
19. SP 34:1987, *Indian Standard Handbook on Concrete Reinforcement and Detailing*, (Bureau of Indian Standards), New Delhi, India, 1987.