"Investigation Of Structural Behaviour Of RCC Beam-Column Joint Using Finite Element Modelling"

A PROJECT

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

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

Mr. Bibhas Paul
Assistant Professor (Grade – II)

By

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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

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TABLE OF CONTENTS

TOPICS **PAGE NUMBER**

CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"Investigation Of Structural Behaviour Of RCC Beam-Column Joint Using Finite Element Modelling"** in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by Samarth Aggarwal (141603), Mohd. Nehan Rehman (141609) and Deepak Chhugani (141610) during a period from July 2017 to June 2018 under the supervision of **Mr. Bibhas Paul** Assistant Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat

Theabovestatementmadeiscorrecttothebestofourknowledge.

Date: - ………………………

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DECLARATION

We do here by declare that the work reported in the B.TECH thesis entitled **"Investigation Of Structural Behaviour Of RCC Beam-Column Joint Using Finite Element Modelling"**submitted at **Jaypee University of Information Technology, Waknaghat, India** is an authentic record of our work carried out under the supervision of **Mr. Bibhas Paul.** We have not
submitted this work elsewhere for any other degree or diploma.

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ACKNOWLEDGEMENT

We take upon this opportunity endowed upon us by grace of the almighty, to thank all those who have been part of this endeavor.

We also want to thank my supervisor “Mr. Bibhas Paul” for giving me the correct heading and legitimate direction in regards to the subject. Without their dynamic association and the correct direction this would not have been conceivable.

We earnestly thank our Head of Department 'Prof. (Dr.) Ashok Kumar Gupta' for giving me the shot and the support for all the time being.

Last however not the minimum, we generously welcome each one of those individuals who have helped me straightforwardly or in a roundabout way in making this seminar project a win. In this unique situation, we might want to thank the various staff individuals, both educating and non-instructing, which have developed their convenient help and facilitated my undertaking.

Abstract

In the recent past, there were many buildings which were not fully implemented for seismic resistance in many countries, including Portugal. Thus, the RC Beam-Column Joint buildings which were designed in 1960s had less amount of reinforcing steel than the buildings designed in accordance with recent codes. Thus, the adequacy of old RC Beam-Column joints is essential to determine the eventual need to retrofit and the targets of the intervention.

So, in order to put a value to the current modelling techniques for the evaluation of existing jerry-built RC Beam-Column joints, a structure is considered as representative of the stock built in 1960s in Lisbon, Portugal.

For determining the critical joints here of the building SAP 2000 is used. As it is an old building and it requires rehabilitation work so pushover analysis is performed. As the name say "Push - over", push the building until the point that you achieve its most extreme ability to disfigure. It helps in understanding the disfigurement and breaking of a structure in the event of an earthquake and gives a kind of fair understanding of the deformation of building and development of plastic hinges in the structure.

Then the structure is modelled in STAAD.Pro as per IS standards. The structure is modelled to calculate the forces on the crtical beam column joints that are obtianed from the analysis in SAP 2000.

Then finally the rectification of critical beam- column joints is carried out using retrofit method like FRP wrapping in Abaqus and then the graphs are plotted which indicated that if the retrofitting were done in time it could have prevented the beam-column joint failure.

List of Figures

List of Tables

List of Graphs

CHAPTER 1

INTRODUCTION

1.1 Background

Earthquake can cause collapse of reinforced concrete structures, loss of lives and also loss of capital. Most of the structures around the world,which are planned utilizing non-seismic code of practice, are not able to resist even slight earthquake loading. Under seismic conditions,it is important that the RC building have lateral resistancestrength against brittle failure. Since destroying and reconstructing such RC buildings are very expensive, so retrofitting the critical structural components may offer economic solution to ensure the safety of the building and people.

These early established RC structures may have non-ductile reinforcement detailing in the beam-column joint regioneither with inadequate or even no shear reinforcement, and short anchor length of bottom steel bars running alongthe longitudinal beam. In addition, the joint may also be bearing high resistance due to a strong beam design. A bond slip failure or joint shear failure reduces the overall strength of the structure up to a great extent.

1.2 Case Study: Building

The building taken into consideration is aneight-storey building (ground floor plus seven storeys) located in Lisbon (Portugal). The dimensions of the building are 36.80m in X-direction and 10.85m in Y-direction. Height of the building is 27m. The building was designed and built in the 1960’s.

Fig.1 :Building in Lisbon(Portugal)

1.3 Project Objective

The purpose of this project involves identification of critical beam-column joint using the pushover analysis. The behavior of critical beam-column joint is observed for total deformation, and stress using finite element method. Thereafter the joints are rectified and the behavior of such joints is compared in terms of total deformation and stress. The pushover analysis has been done by using SAP2000. In addition the Finite Element analysis is performed using ABAQUS vs 6.13.

1.4 Literature Review

1. Naveen Hooda, Jyoti Narwal, Bhupinder Singh, Vivek Verma, Parveen Singh**"An Experimental Investigation on Structural Behavior of Beam Column"** Standard concrete loses its resistance after the development of cracks in the structure. The ultimate strength of concrete is significantly increased by the use of fibers which helps in resisting the formation of cracks and the ultimate tensile strength is also increased because extra amount of energy is required to cause failure of the fiber reinforcing the concrete. Beam-column joint is an importantintegral part of the whole structural complexity of the buildings. Because of this reason they must be provided with adequate strength so that they can bear the loads transmitted between beam and columns. The studycomparesthe behavior of such a joint with different detailing of reinforcement, different spacing of

connecting ties and with different percentage of steel fibers. Increment in the deflection and curvature was observed with the decrease in spacing of hoops/tie.

2. Prakash Panjwani , Dr. S.K. Dubey, "**Study of Reinforced Concrete Beam-Column Joint**" The beam column joint forms an important integral part of the moment resisting structure. It must be designed to handle large forces during seismic activity and its detailing has a significant roleto play on the responsebehavior of the structure. The shear failure of joint is not an acceptable structural response especially during seismic conditions. The paper discusses some theories associated with the behavior and response of joints under critical conditions. Understanding the behavior of joint in seismic conditions is essential for proper design of joints.

3. S.V.Chaudhari, K.A.Mukane, M.A.Chakrabarti, "**Comparative study on Exterior RCC Beam Column Joint Subjected to Monotonic Loading**" This paperdiscusses the use of ABAQUS to develop a finite element model of the joint that can be used in investigating the response of RC exterior beam-column connections. Model development includes investigation and characterizing of the behaviors of standard concrete and reinforcing bars. Comparing results of computed and observed response of structural elements indicated that the model used to represent the local response mechanisms, determines global behaviour correctly. Comparison of load displacement diagram of RCC exterior beam column joint subjected to monotonic loading by using ABAQUS and ANSYSnonlinear modelling is studied. It is observed that the ABAQUS gives morepractical and accurate results than ANSYS software.

4. A.Ghobarah and A. Said, "**SEISMIC REHABILITATION OF BEAM-COLUMNJOINTS USING FRP LAMINATES**" Aconventional and practical rehabilitationtechnique for the improvement of beam-column joints is the use ofcarbon fiber reinforced polymers (FRP). The purpose is to increase thestrength of the joint and thus allowing the formation of flexural hinge to form in the beam. An

experimentinvolving rehabilitation of an external beam-column joint from a moment resisting frame that is designed to earlier non seismic code and is tested under axial column load and cyclic load. The suggested retrofittingmethod was then applied to the tested specimen. The polymer usedwas successful inincreasing the shear strength of the nonductile beam-column joint. The paper represents a comparison study between the structural behaviour of the specimen before and after the use of rehabilitation technique. A design methodology involving steelfibre jacketing to increase the shear resisting capacity of joint in moment resisting frames is proposed.

5. A.Ghobarah and A. Said, "**SHEAR STRENGTHENING OF BEAM-COLUMN JOINT**" The paper discusses ways to develop effective rehabilitation techniques for reinforced concrete beam-column joints using advanced composite materials namely polymers. Many reinforced concrete beam-column joints were designed according to detailing of pre-seismic code and constructed. The specimens were subjected to cyclic loading and they showed joint shear failure at the beam tip. Different fibre-wrap rehabilitation techniques were then applied to the joint and the joints were tested again under the same loading. The tested rehabilitation techniques showedincrement in the shear resistance of the joint.

6. A.K.H. Kwan, "**IMPROVED WIDE-COLUMN-FRAME ANALOGY FOR SHEAR/CORE WALL ANALYSIS**" This is a popular design method offered for the analysis of shear/core beam column joint. Basically the method treats the nonplaner shear/core walls assemblies of 2-D planer wall units connected at their vertical wall joints and modeling the planer wall units individually as discrete column members residing at the centroidal axis of the wall units.

7. N.M.Nikam and L.G.Kalukar, "**PUSHOVER ANALYSIS OF BUILDING WITH SHEAR WALL**" Use of nonlinear static pushover analysis is carried out by either using user-defined nonlinear hinge properties or default-hinge properties, based on the FEMA-356 and FEMA-440 guidelines. This paper shows the results ofapushover analysis (non-linear static analysis) of RC building. The non-linear static analysis of a RCC structureprovidesus with better understanding

and more accurate seismic response of the buildings which will help us to study the failure element of the structural building.

8. Y,M.Fahjan, J. Kubin and M.T. Tan, "**PUSHOVER ANALYSIS OF A 19 STORY CONCRETE SHEAR WALL BUILDING**" Modeling of the shear walls is very important in designing of any structure for both linear and nonlinear analyses. In linear analyses of structures, modeling of shear wall can be done using different methods either using combination of frame elements or shell elements. In the nonlinear analyses, the nonlinear model frame is based on plastic hinge concept.Plastic hinges are located on the plastic zones of the structural elements. In this paper, different techniques for modeling of linear and nonlinear shear walls in structural analyses of buildings are studied. The overall results in terms of overall behaviorusing different approaches are compared.

9. S.Prakash, L.Prabha and V.Sharmila, "**STUDY OF EXTERIORREINFORCED CONCRETE BEAM COLUMN JOINT**" Beam–column joints being an important integral part of a reinforced concrete framed structure should have proper anchorage detailing. One of the most effective way to increase the strength of a joint is by the use of crossed inclined bars in the joint region. Beam column joint should be designed and detailed properly, especially when the frame is subjected to seismic loading. Non linear analysis is carried out in STAAD Pro software.

10. N. H. Hamid, N. D. Hadi, K. D. Ghani, "**RETROFITTING OF BEAM-COLUMN JOINT USING CFRP NAD STEEL PLATE"** This paper represents the rehabilitation of beam-column joint using steel plate and CFRP (Carbon Fiber Reinforced Polymer). A specimen joint was considered which developed diagonal cracks attheupperside of the column. CFRP were wrapped around the joint. Steel plates with bonding were attached to the two connected beams and the jointing system. This retrofitted specimen is tested again under lateral cyclic loading up 1.75% drift. Visual observations show that the cracks started at joint when 0.5% drift applied at top of column. Damage of retrofitted beam-column joint occurred inside the CFRP and it cannot be seen from outside. Analysis of elastic stiffness, lateral strength, ductility, hysteresis loops and equivalent viscous damping shows that these values are higher than before retrofitting. Therefore, it

is recommended to use this type of retrofitting method for beam-column joint with corbel which suffers severe damage after the earthquake.

CHAPTER 2

BEAM-COLUMN JOINT

The point of interconnection of beams and columns in a reinforced concrete structure is termed as a beam-column joint. They are critical regionsin a reinforced concrete moment resisting frame due to themovement of large amount of forces between them (i.e. beams and columns Design check for beam-column joints is not taken into consideration in standard design of practice. But, the failure of such frames during the past earthquakes all over the world has demonstrated the importance of stresses in joints.Shear in the joints culminate in the collapse of the structure. Detailed studies of joints for such buildings have been undertaken only in the past few decades. The basic `requirement for the adequate performance of a joint in a reinforced concrete structure is:

1. A joint should display a service load performance equal in quality to that of the member it joins.
2. A joint should possess strength that should be equal to or more than at least with the most adverse load combination that the adjoining member could possibly resist, several times if necessary.
3. Strength of the structure should not be governed by the strength of the joint, and its behavior should not hamper to the development of the full strength capacity of the adjoining member.

2.1Types of Joints in a Frame

There are basically three types of beam-column joint-

1. Interior Beam-Column joint –Interior joint is the joint in which four beam are connected to one column.
2. Exterior Beam-Column joint –Exterior joint is the joint in which three beam, all perpendicular to each other are connected the vertical face of a single column.

3. Corner Beam-Column joint –Corner joints are the joints that can be seen on the corner edges of a frame. Corner joint is the joint in which two beams are connected to vertical face of a single column.

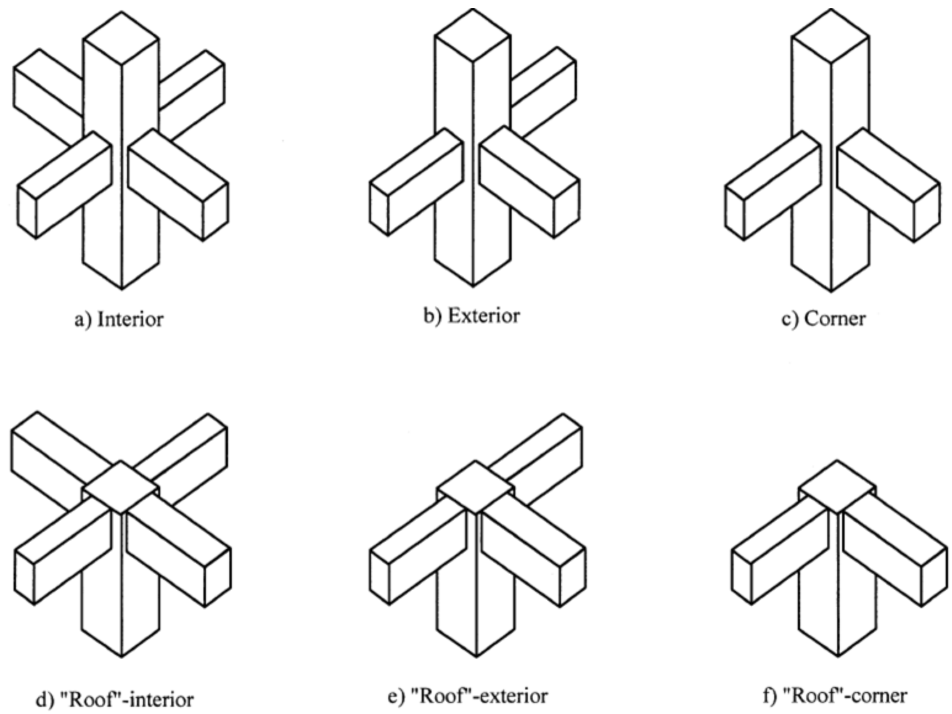


Fig.2 :Types of beam-column Joints in frames

2.2 Joint Mechanisms

During shaking of ground (earthquake), the beams connecting a joint are exposed to moments whose magnitude are large and direction is same either in clockwise or anti-clockwise. Under these conditions, the top reinforcing bars ofthe joints are pulled in one direction and the bottom one in the opposite direction. Thisdifference in magnitude forces are balanced by bond stress that isdeveloped between steel and concrete. If the column is not wide enough or if the grade of the concrete used is not adequate enough, then there is weak gripof concrete on the steel bars. In such condition there is slippage ofreinforcement bar under the joint region and ultimately the beam lossesitsstrength to carry load. Under these forces of opposite nature at top and bottom joint ends, joint undergo deformation that is, one end of the joint expands and the other compresses and if the cross-sectional areaof the column is not adequate, then the concrete member in the joint develops cracks. These pull-push forces on joint cause two problems i.e. slip ofreinforcing bars in joint region and deformation of joints causing diagonal cracks and crushing of concrete.

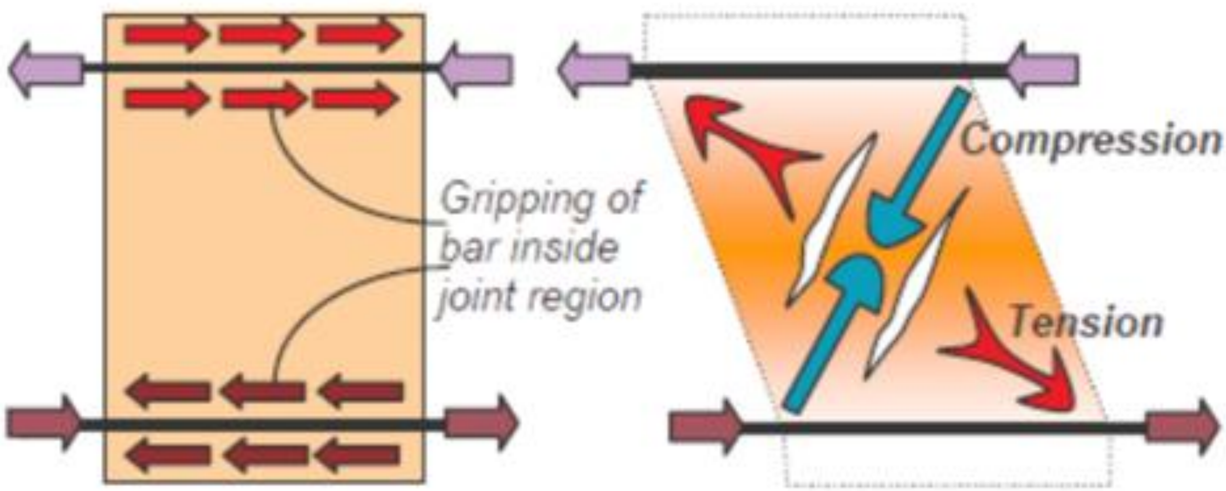


Fig. 3 :Pull-Push Forces on joints

In strong column-weak beam design, plastic hinges develops at the beam. The high internal forces accumulated at plastic hinges causes critical bond-slip conditions in the joint reinforcing bars and also impose high shear demand in the joint region. The joint behavior exhibits a complex connection between bond and shear. The strong the bond strength of the bars anchored in thejoint,the stronger is the shear resisting mechanism of the structure.

Fig. 4 :Failure of beam-column joint

2.3 Exterior Joint

In exterior joints the reinforcement bars of the beamterminates within the joint core. After a few repetition of inelastic loading, the bond between concrete and reinforcing bars starts to deteriorateat the face of the column due to formation of cracks which progresses towards the joint core. Repetition of loading evenworsens the case and a complete loss of bond of the entire bent region of the bar may take place. The beam reinforcement baris pulled by a massive amount of tensile force due to progressive loss of bond. Tensile failure of the longitudinal reinforcing beam bars results in complete loss of flexural strength. This kind of failure is undesirable at any stage. Hence, proper ductile detailingof the reinforcement bars in the joint core is of most importance. The pull out-failure of bars in exterior joints can be prevented by the providing hooks or by modified reinforcement techniques. Modified reinforcement technique, can be used to provide adequate anchorage when accommodated with adequate horizontal development length and the additional mechanism of shear transfer at joints. The development length that is to be considered should be adequate from the critical section beyond the region of yield penetration. Thus, the length of the member should include the development length considering the probability of yield penetration.

2.4 Interior Joint

Many RC framed structure that were destroyed in the past earthquakes and which were not build according to seismic code have been studied and in most of the cases, the failure of interior beam-column joints initiated the collapse process of structures. Therefore, interior beam-column jointisconsidered as the weakest joint in any existing RC moment-resisting frames. The reason of failure of interior joint is inadequate shear strength of the joint. Inadequate joint shear strength is because of insufficient and inadequately reinforcement detailing in the joint region. Due to inadequate detailing particularly in transverse reinforcement in the joint, joint brittleness increases, which, in turn, adds significantly to the collapse of the structure. Modified reinforcement technique, is helpful in the shear transfer or additional mechanism to shear transfer at joint region.

2.5 Corner Joint

Corner joints are the joints that are generally found at the roof level of a RC framed structure. These joints, if not designed safely, may suffer substantial damage during earthquakes due to generation of shear reinforcement in the joint region. The internal forces generated at this joint may result in failure of the joint before the strength of the beam or column, whichever weaker, is attained. Several techniques of retrofitting such of RC joints, damaged by earthquakes, have been going on in earthquake prone countries such as Japan, Mexico, and China.

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

1. The reinforcing steel is continuous around the corner of the joint (i.e. it is not lapped within the joint).
2. The tension reinforcing bars are bent to a sufficient length to prevent grip failure under the bars. Nominal transverse bars placed under the bent bars.

CHAPTER 3

FINITE ELEMENT ANALYSIS

For some engineering complications, analytical solutions are not feasible, in perspective of the unpredictability of the material properties, the limit conditions and the structure itself. Finite Element Method also assigned as Finite Element Analysis is used to locate the approximate solutions of various boundary value problems or field value problems as called sometimes.The essential idea of FEM is that it divides or represents the structure into small elements called finite elements. It divides the domain of problem into collection of sub domain.

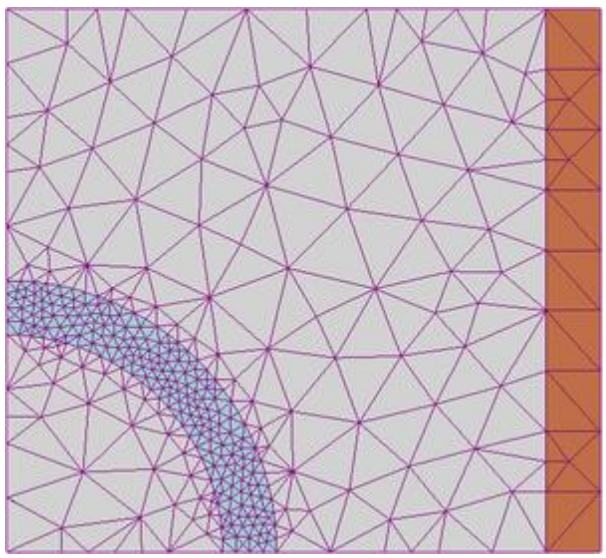


Fig. 5 :Meshing in the FEM

Overall, this is a surmised strategy and result must be approved before utilize. At the point when alluded to the examination of structures the FEM is an intense strategy for figuring the relocations, stresses and strains in a structure under the arrangement of burdens.The Finite Element Method changes over the elliptic fractional differential condition into an arrangement of arithmetical conditions which are anything but easy to tackle. The initial value problems which comprise of an illustrative or hyperbolic differential condition and the underlying conditions (other than the limit conditions), can not be totally illuminated by the finite element method. The parabolic or hyperbolic differential equations contain the time as one of the independent variables. There is a requirement of both Finite Element Method and Finite Difference Method to solve an initial value problem.

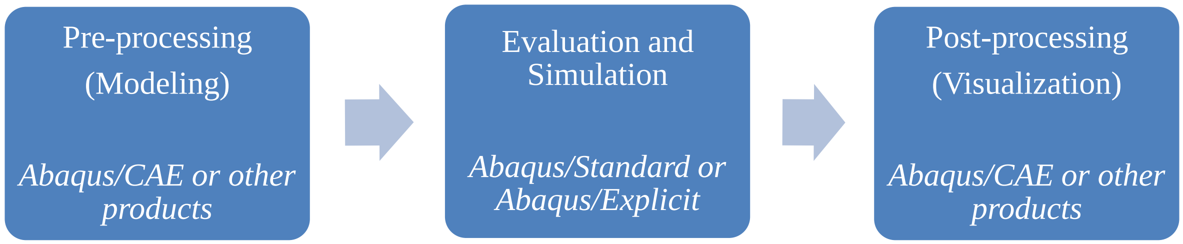


Fig. 6 :ABAQUS software order of use

Every finite-element analysis comprises of 3isloate stages:

1. Pre-processing or modeling: This stage includes making an input file or information document which contains a designer's plan for a finite-element analyzer (also called "solver").

2. Processing or finite element analysis: An output visual file is made in this stage.

3. Post-processing or generating report, image, animation, etc. from the output file: a visual rendering stage.

Each software has some features and other has another which is making one superior over another. Like Abaqus is capable of doing the above mentioned processes of the solver; in any case, the main stage should likewise be possible by other CAD software, or even a text editor.

CHAPTER 4

METHODOLOGY

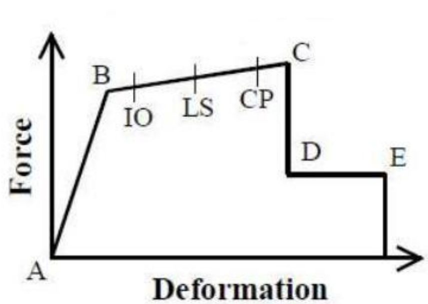
The procedure is divided into three different phases namely

1. SAP2000 - for finding critical beam-column joints.
2. STAAD.Pro - for determining the forces in the critical beam column joints.
3. Abaqus – for modeling of joint and carrying out the required rectification process.

4.1 – SAP2000

In first phase, the structure is modeled and designed in SAP 2000 and critical beam-column joints are identified using the Pushover Analysis.SAP2000 is a broadly useful structural buildingprogram perfect for the investigation and plan of an auxiliary framework. Fundamental and propelled frameworks, going from 2D to 3D, of basic geometry to complex, might be demonstrated, dissected, composed, and advanced utilizing a down to earth and natural protest based displaying condition that rearranges and streamlines the engineering process.For determining the critical joints here of the building SAP 2000 is used. As it is an old building and it requires rehabilitation work so pushover analysis is performed.

As the name say "Push - over", push the building until the point that you achieve its most extreme ability to disfigure.It helps in understanding the disfigurement and breaking of a structure in the event of an earthquake and gives a kind of fair understanding of the deformation of building and development of plastic hinges in the structure.



IO- Immediate Occupancy

LS- Life Safety

CP- Collapse Prevention

Fig. 7 :Force Deformation for Pushover Hinge

As shown in the above figure, there are five points that are labelled as A, B, C, D, E, these are used to define the force- deformation pattern of the hinge, and the three points in between B and C (IO, LS, and CP) determines the acceptance criteria for the hinge. The values allocated to each one of these focuses depends on the member classification and on numerous different parameters defined in ATC-40.

The modelling of structure is carried out and the section properties are defined. Applying the different load cases, different load combinations the result is obtained in the three axes ('+x', '-y', '+y') that is the critical joints. In total the critical joints obtained after the Pushover analysis are Eight (x = two, y+= zero, y-= six).

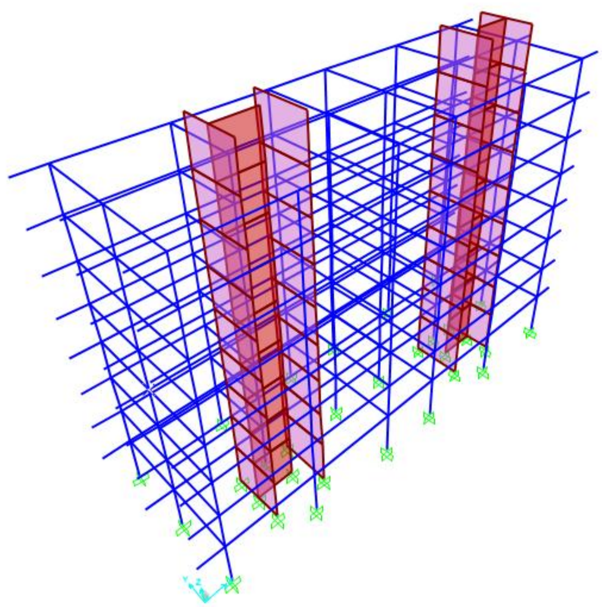


Fig. 8 :3D view of the structure

Grids are define on the three axes and given above is the 3D view of the structure consisting of Beams, Columns and Shear Wall.

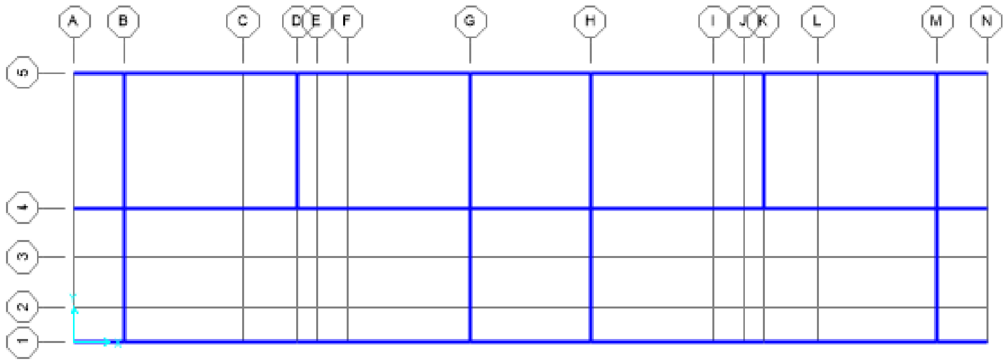


Fig. 9 :XY plane view of the structure.

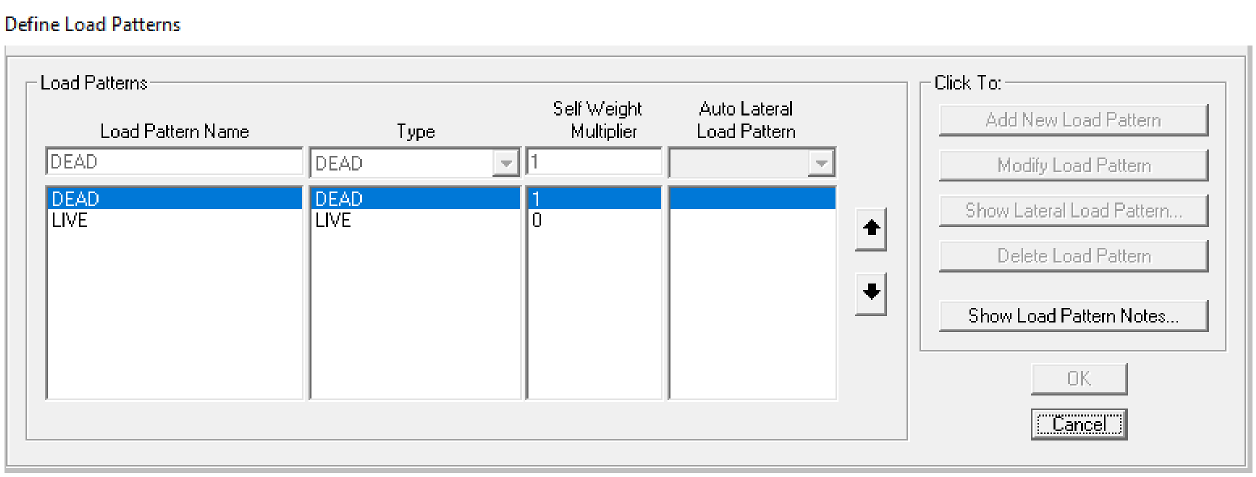


Fig. 10 :Dead and Live Load Patterns

A different load pattern that is Dead and Live is assigned.

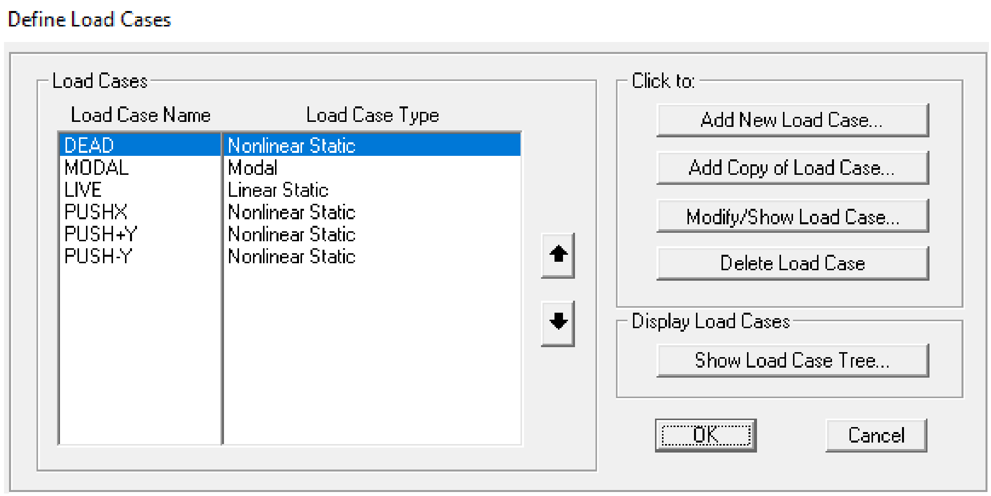


Fig. 11 :Different Load Cases

After assigning the load patterns, load cases are introduce. The main point, which is considered, is that Dead load is Nonlinear Static. Then the Pushover Load case is assign, which is assigned to the three different directions as stated above (+x, -y, +y).

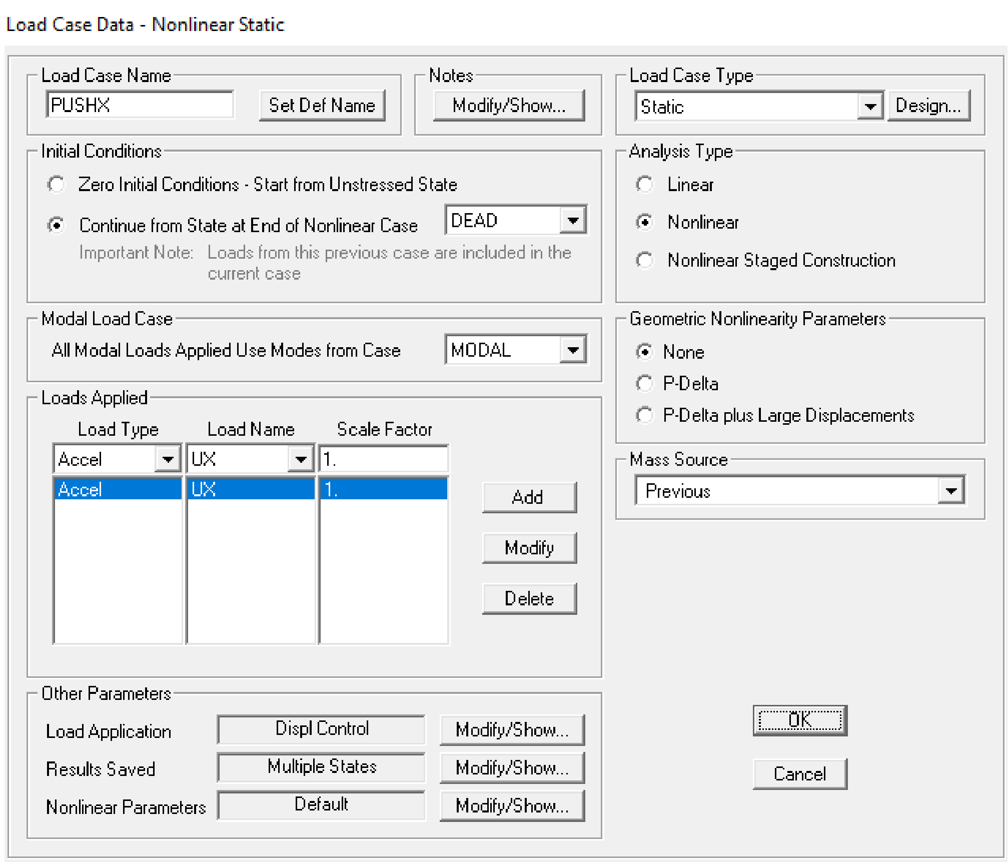


Fig. 12 :Pushover Analysis (X direction)

Consider the figure above where the Pushover analysis is Static Nonlinear. The Load Case PUSHX is (continued from State at End of Nonlinear case) which means that the Pushover load is applied only after the application of the Dead load and also with the Load Type acceleration and Scale Factor 1.

Similarly the Load case is done for PUSH (Y) and PUSH (-Y) with the Load Type acceleration and Scale Factor 1 and -1 respectively.

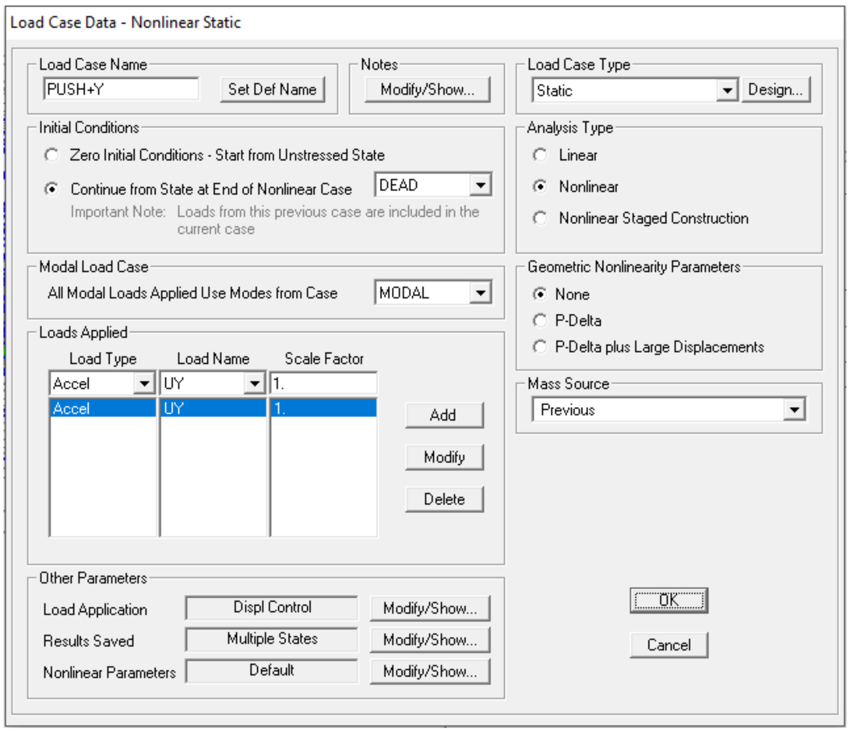


Fig. 13 :Load case for PUSH(Y)

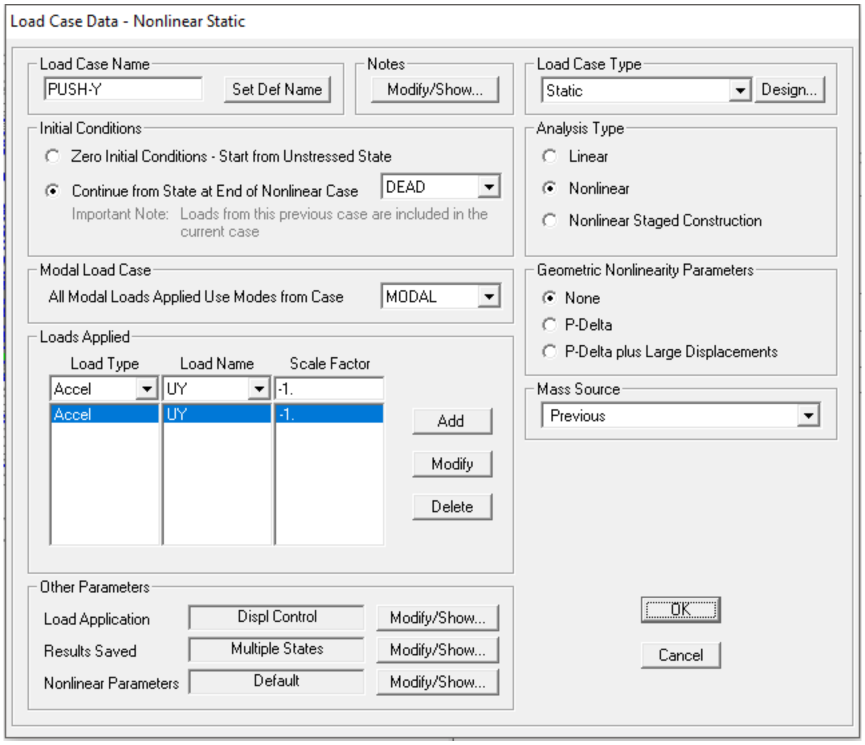


Fig. 14 :Load case for PUSH(-Y)

After the load cases, the hinge properties of the frame building were assigned.

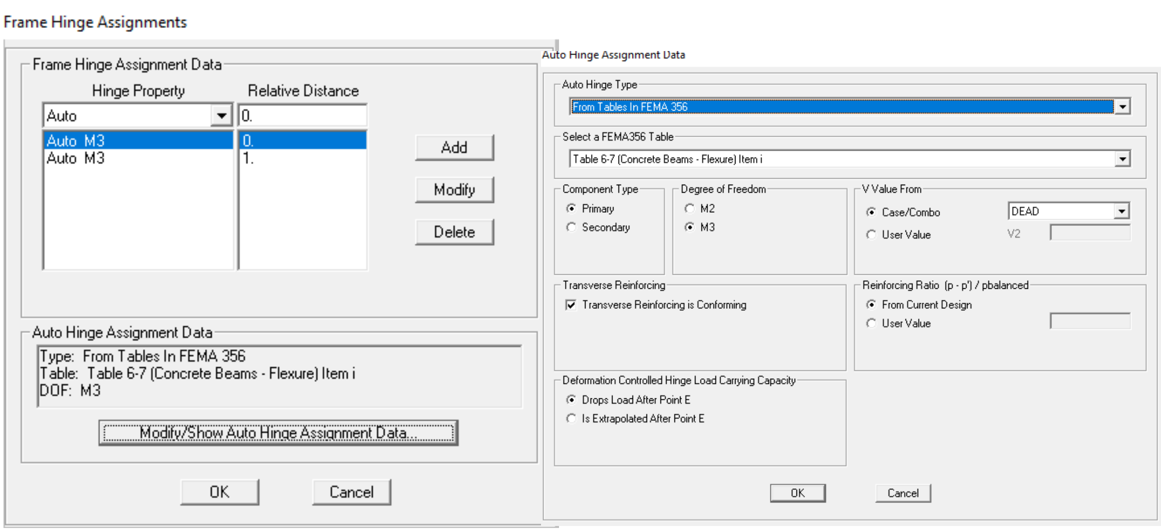


Fig. 15 :Hinge Properties of Beam

The above pictures portray the hinge properties that are assign in the Beams. The M3 degree of freedom and the Dead Load Case Combo is assigned.

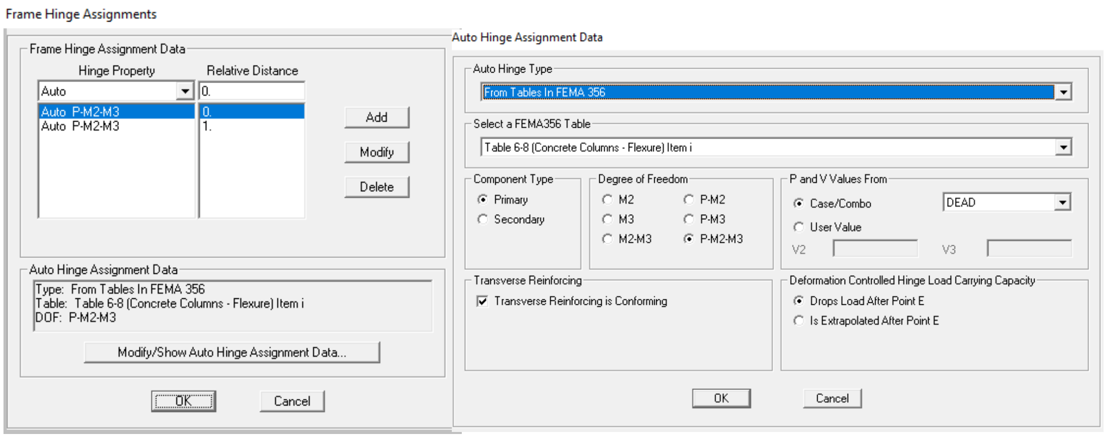


Fig. 16 :Hinge properties of Column

Similarly for Columns the Hinge properties are assign and P-M2-M3 degree of freedom is applied asthe P-M2-M3 hinge is best suited for nonlinear static pushover and the Case Combo Dead Load is applied. The relative distance is basically applied as to jump over to the next structural member that is Beam or Column.Then the Analysis of the building is performed.

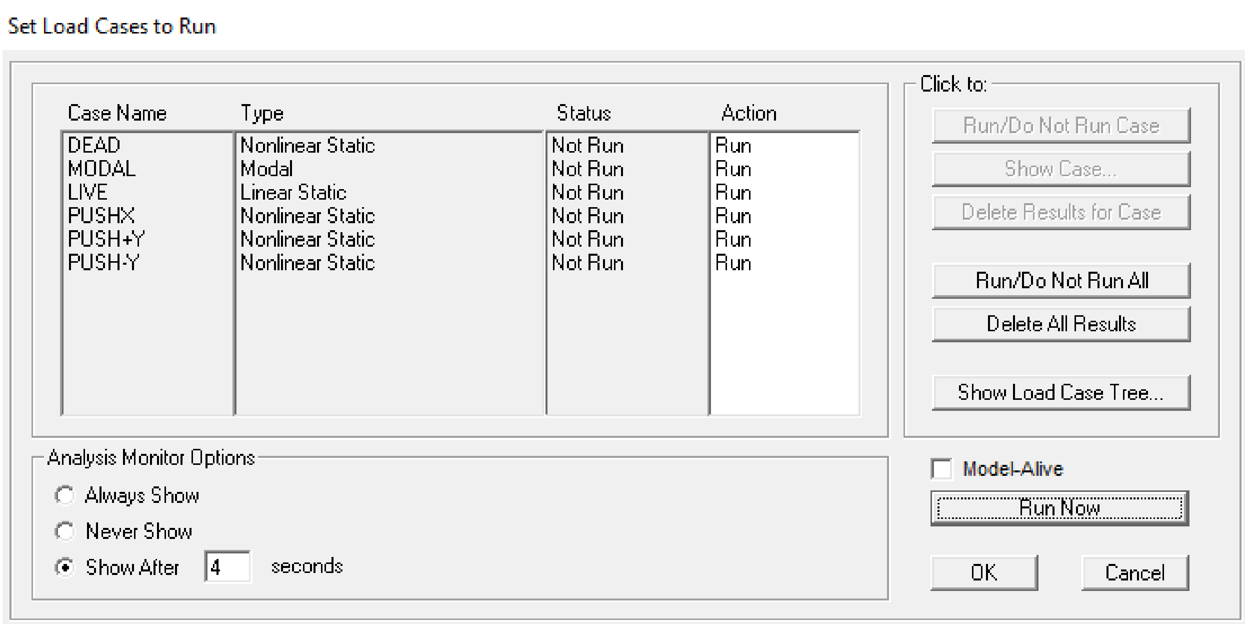


Fig. 17 :Different Load Cases

Taking all the Cases into consideration the analysis is performed.

In second phase, the structure is modelled in STAAD.Pro as per IS standards. The structure is modelled to calculate the forces on the crtical beam column joints that are obtianed from the analysis in SAP 2000.

4.2 STAAD.Pro

STAAD.Pro can make use of various forms of analysis from the traditional 1st order static analysis, 2nd order p-delta analysis, geometric non-linear analysis, Pushover analysis (Static-Non Linear Analysis) or a buckling analysis. It can also make use of various forms of dynamic analysis from modal extraction to time history and response spectrum analysis.

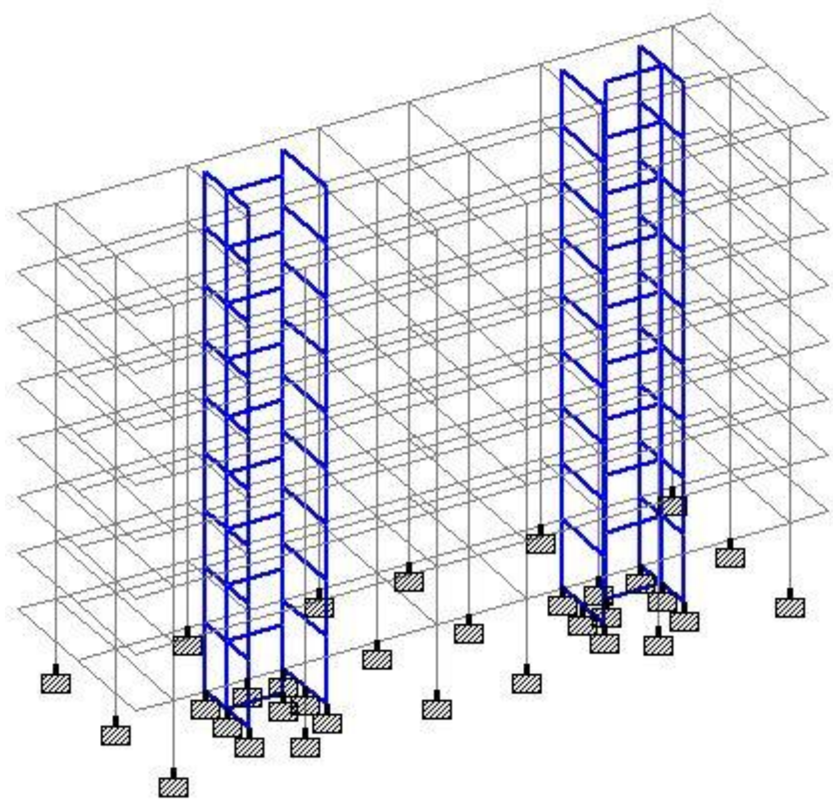


Fig. 18 :3D view of structure in STAAD.Pro

The building structure is designed in STAAD.Pro

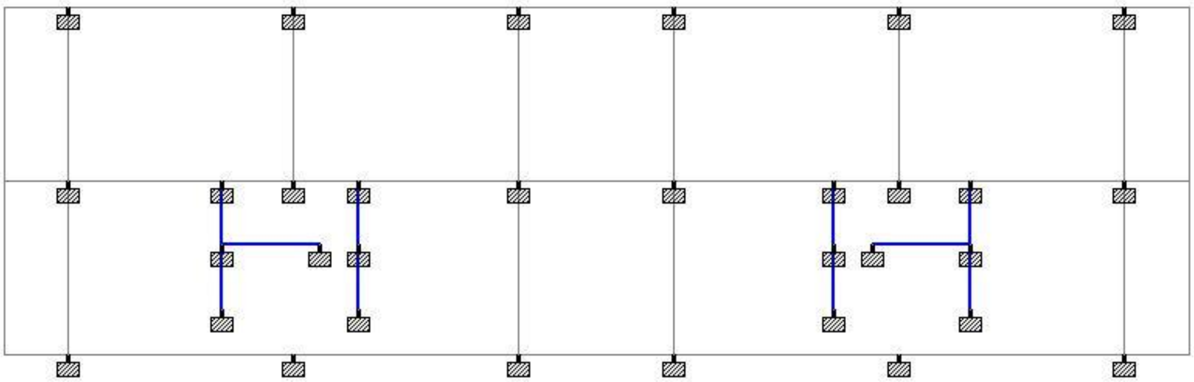


Fig. 19 :Plan view of structure in STAAD.Pro

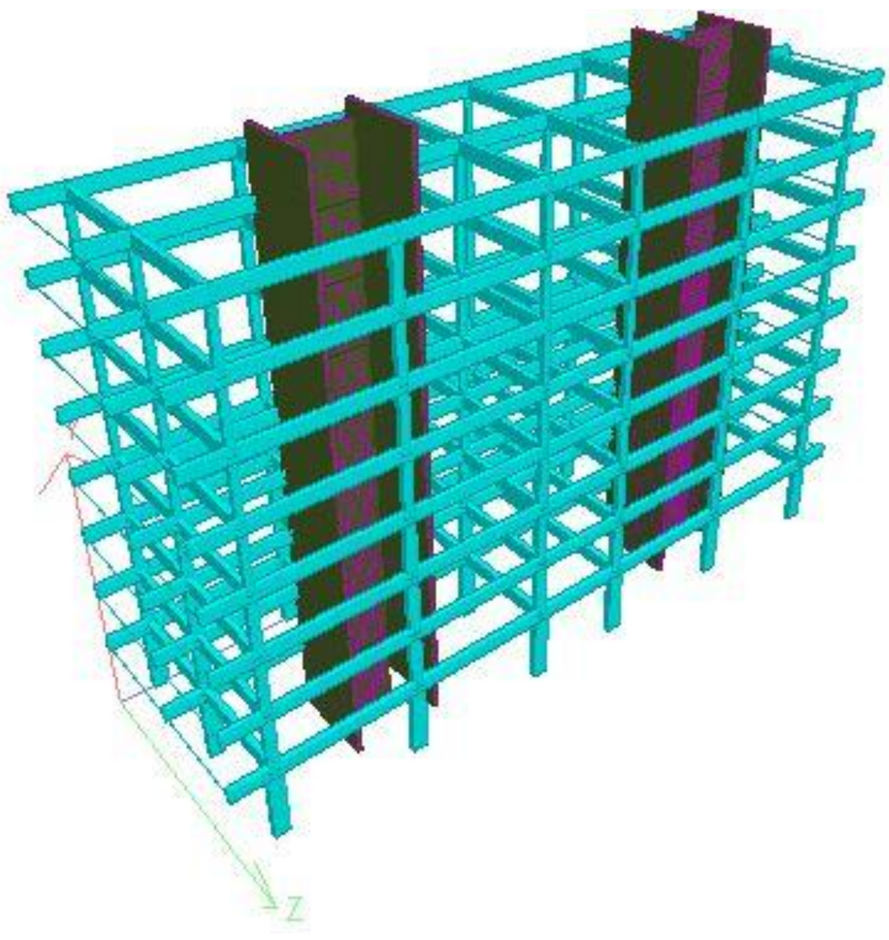


Fig. 20 :3D rendered view of structure showing shear walls and other members in STAAD.Pro

To easily identify the nodes, a simple notation is developed to know the exact coordinates of the beam and columns attached to that specific node.

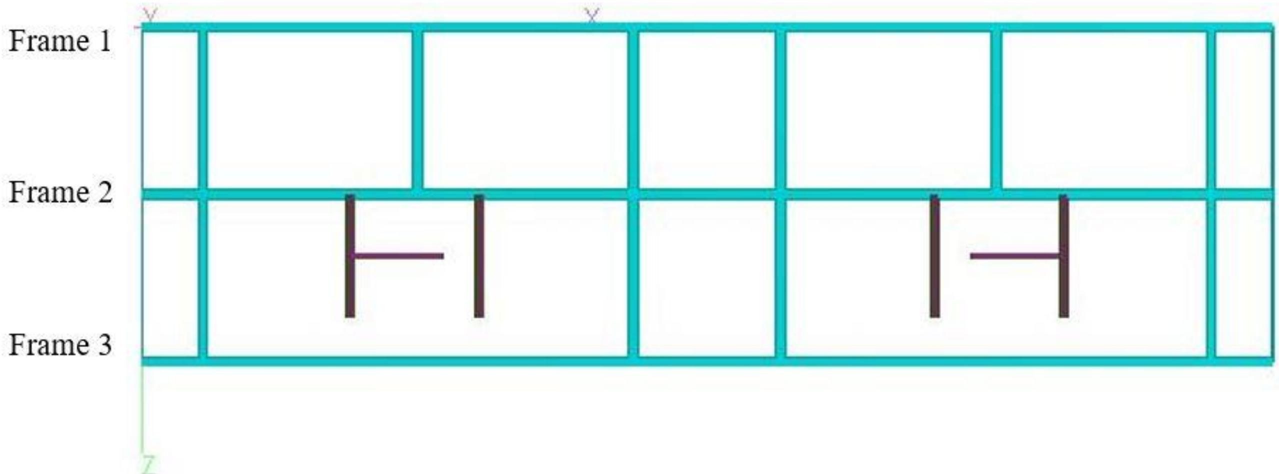


Fig. 21 :Identification of Reinforced Concrete frames in the building.

Each frame in the above figure represents the beams on the different floors of the building. By knowing the frame number, the exact node can be located in the building.The frames are along the XY-plane.The frame numbers are denoted by using numbers 1, 2 and 3 for further simplicity in identifying the location of nodes and easy understanding of the structure and results regarding the analysis of the structure.

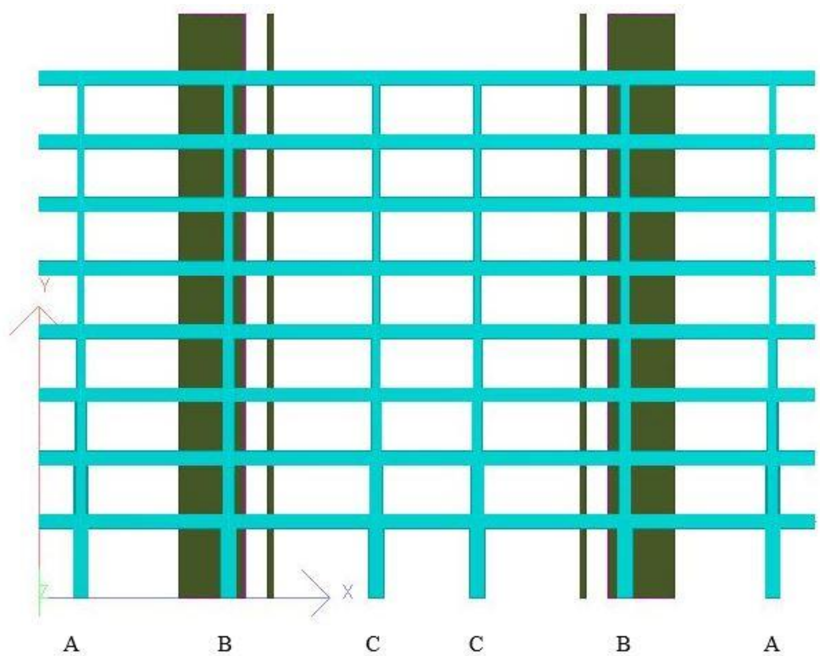


Fig. 22 :Identification of Reinforced Concrete columns in the building.

The above figure denotes the labeling of columns in the building. The notations used are A, B and C only because of the mirror image of the building plan along its centre line along Y-axis.

Example: a member placed at third floor along column-C in Frame-1 is represented by (C,1,3).

The types of loadings applied in STAAD.Pro are:

1. Dead load: Self weight and 6kN/m UDL on each member
2. Live load: 3 kN/m^2 pressure as floor load
3. Wind load: Loading from to directions namely +z and –z directions.
4. Time history: Time history seismic loading applied using ElCentro acceleration data along the North-South direction.

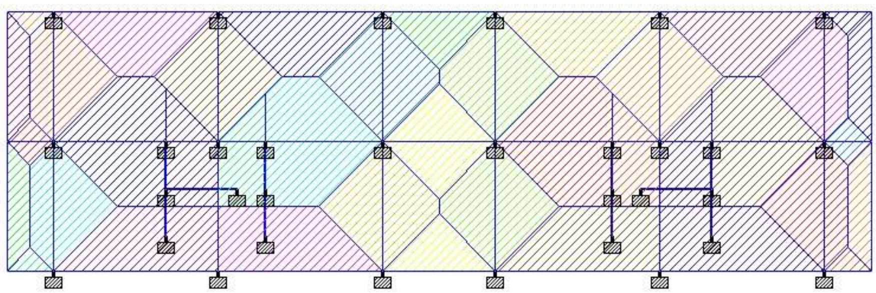


Fig. 23 :Live load in STAAD.Pro

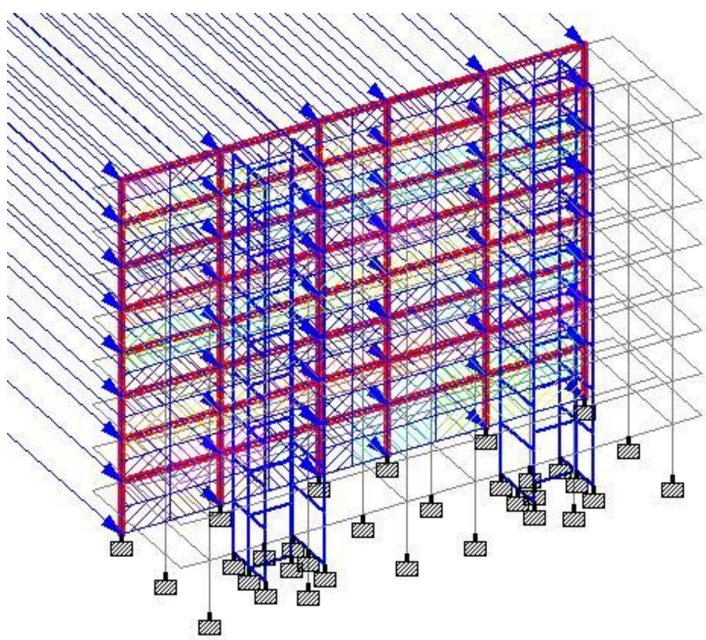


Fig. 24 :Wind load along +z direction in STAAD.Pro

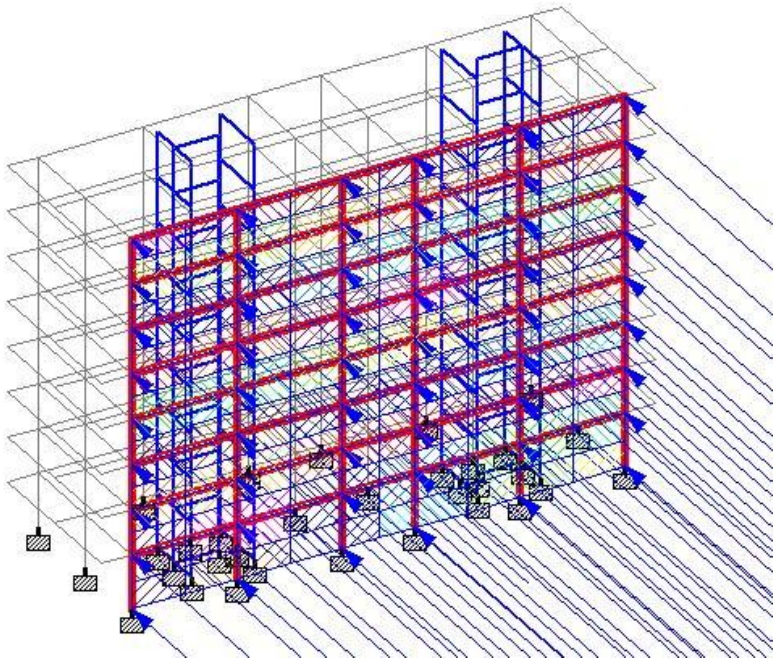


Fig. 25 :Wind load along -z direction in STAAD.Pro

The load combinations used in STAAD.Pro are as in the following table:

Load Combination no.	Multiplying factor of Loads				
	DL	LL	WL (+Z)	WL (-Z)	TH
1	1.5	1.5	0	0	0
2	1.2	1.2	1.2	0	0
3	1.2	1.2	0	1.2	0
4	1.2	1.2	-1.2	0	0
5	1.2	1.2	0	-1.2	0
6	1.2	1.2	0	0	1.2
7	1.2	1.2	0	0	-1.2
8	1.5	0	1.5	0	0
9	1.5	0	0	1.5	0
10	1.5	0	-1.5	0	0
11	1.5	0	0	-1.5	0
12	1.5	0	0	0	1.5
13	1.5	0	0	0	-1.5
14	0.9	0	0	0	1.5
15	0.9	0	0	0	-1.5

The dimensions of members used in the structure are as follows:

1. 700mm x 300mm Columns
2. 500mm x 250mm Columns
3. 400mm x 250mm Columns
4. 300mm x 250mm Columns
5. 600mm x 250mm Columns
6. 650mm x 250mm Beams
7. 650mm x 300mm Beams

The Concrete grade used in the structure is M30.The steel grade used in the structure is Fe415.

The results in the STAAD.Pro are obtained and taking the forces into consideration the critical beam column joints are modeled in ABAQUS and the results are observed.

4.3 ABAQUS

Finite-Element analyzer that employs explicit integration scheme to solve highly nonlinear systems with many complex contacts under transient loads.ABAQUS main job is to design and analyze the critical beam-column joints of the building structure. The results from SAP 2000 are used to simulate the actual deflections and forces in the joints. ABAQUS is mainly taken into consideration for analysis of Beam-column joints because of Finite Element modeling which gives more accurate results than other software’s and also has an aspect to provide more detailing to the model designed.

4.3.1 Constraints

In ABAQUS, the methodology followed is, firstly the constraints are defined. Two Constraints are taken into account: Tie and Embedded. Tie Constraint is used to join the materials of similar properties like Concrete members whereas Embedded constraints are used to join the materials of varying properties like Concrete and Steel.

4.3.2 Boundary Conditions

These conditions are defined in such a way that the length of the members are considered upto a point where moment is zero. This gives the benefit of directly applying the Fixed End Moment boundary condition at the end of each member.

4.3.3 Meshing

Meshing is done on the members. Meshing is of four types. Tetrahedral Meshing is consideredto be most effective among all four because sometimes the structure is too complex or geometry of the structure is too disoriented that it is difficult to solve or to model the whole structure and that is where tetrahedral meshing is taken into account. Therefore, if the geometry is simple it is ideal to mesh with Hex. The current working structure is not that complex or the geometry of the structure is not distorted so therefore the meshing, which is done on the members is hexahedral meshing.

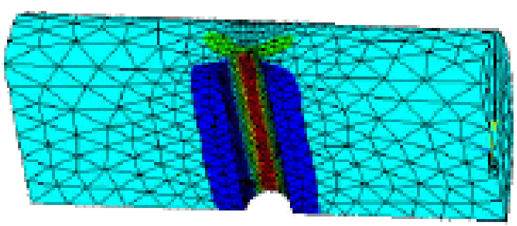


Fig. 26:Tetrahedral Meshing

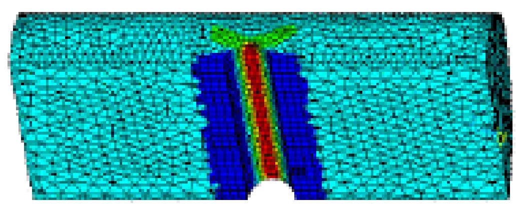


Fig. 27 : Hexahedral Meshing

CHAPTER 5

RESULTS

1. <u>SAP 2000 results</u>

The modelling of structure is carried out and the section properties are defined. Applying the different load cases, different load combinations the result is obtained in the three axes ('+x', '-y', '+y') that is the critical joints.

Below is the figure obtained after applying the Dead Load.

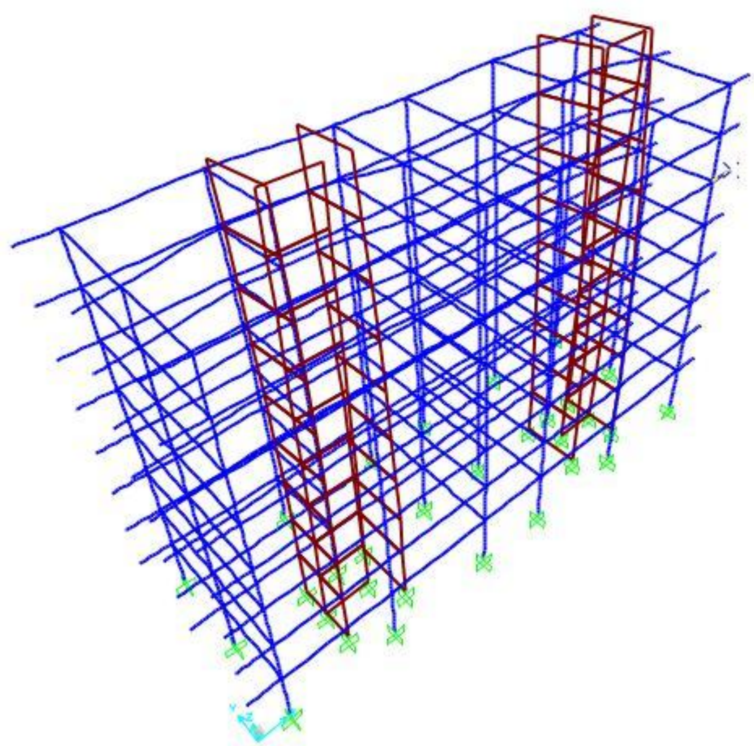


Fig.28: Distortion after the application of Dead Load

As stated in methodology, Dead Load is Nonlinear Static and value is 6 kN/m^2.

Then the Pushover Load case is assign, which is allocated to the three different directions as stated above (+x, -y, +y).

Result of SAP 2000 after application of pushover load in (X) direction.

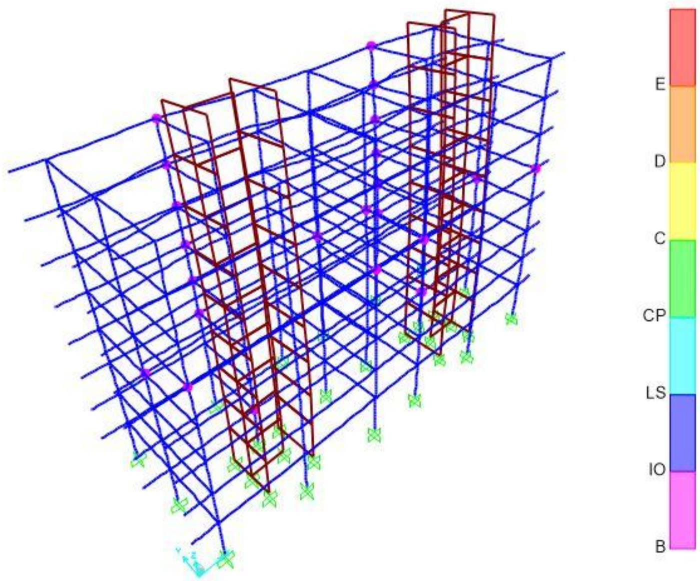


Fig. 29 : 3D representation of the structure

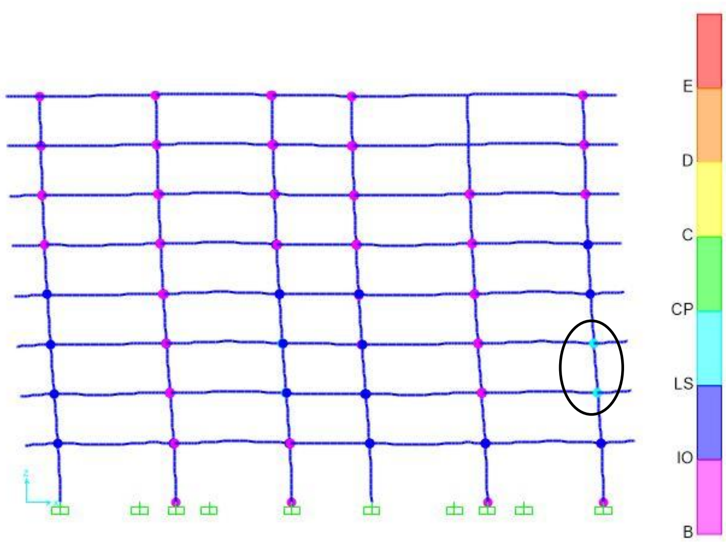


Fig. 30 : Critical Nodes

As seen in the above figure, the Pushover Analysis is done and the structure is deformed therefore the hinges are formed. The side bar which is given is bascially the hinge deformation graph which tells about the hinge formation. The point CP is maximum and above that faliure is observed.

The circled ones in the below figure are the most critical nodes among all, as they lie in the (LS-CP zone) which is the highest of all the other node zones.

Similarly, the pushover load case is assigned in the +Y and –Y directions.

Result of SAP 2000 after application of pushover load in (Y) direction

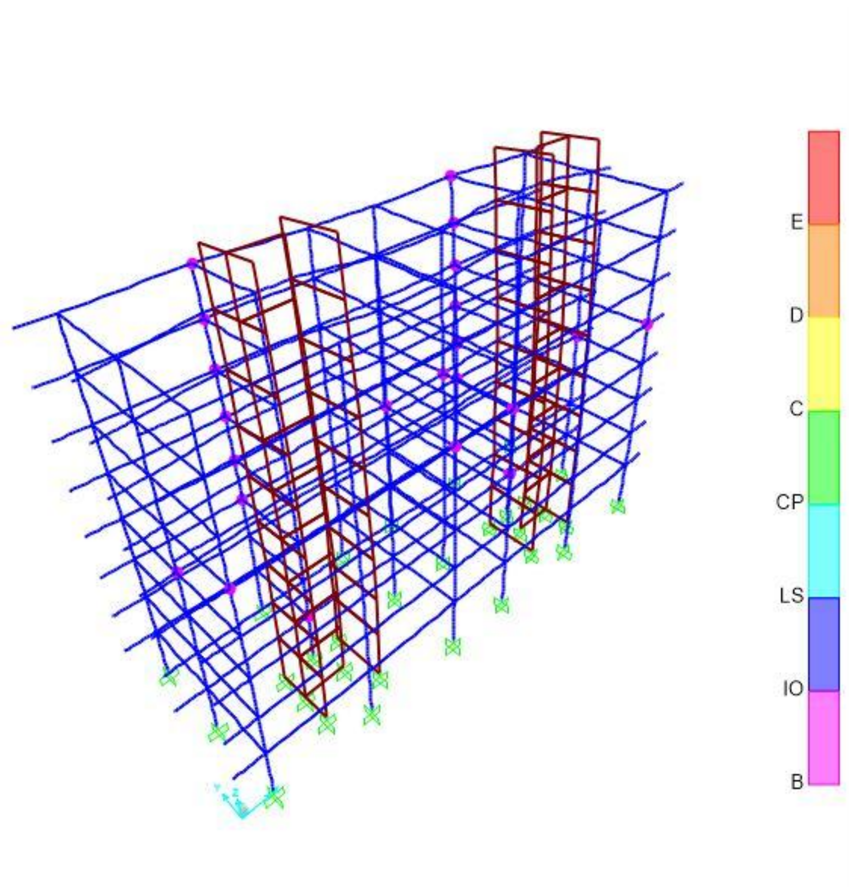


Fig. 31 : 3D representation of the structure

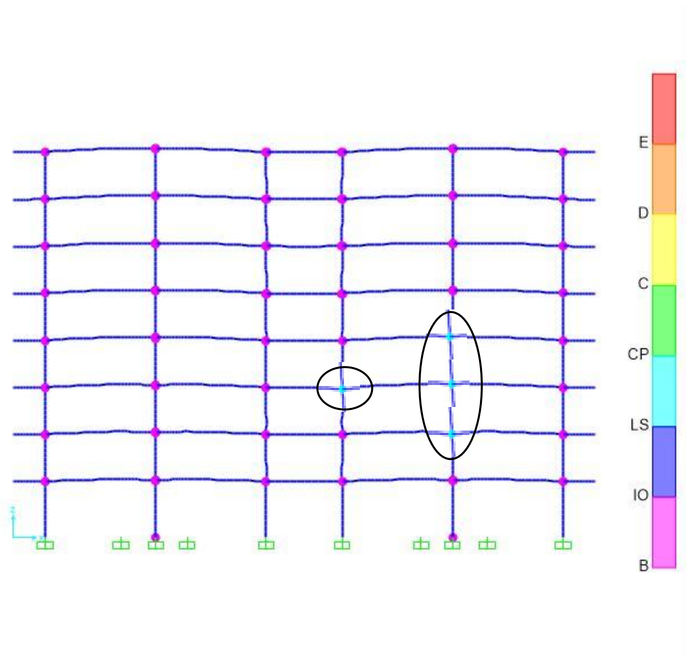


Fig. 32 : Critical Nodes

Result of SAP 2000 after application of pushover load in (–Y) direction

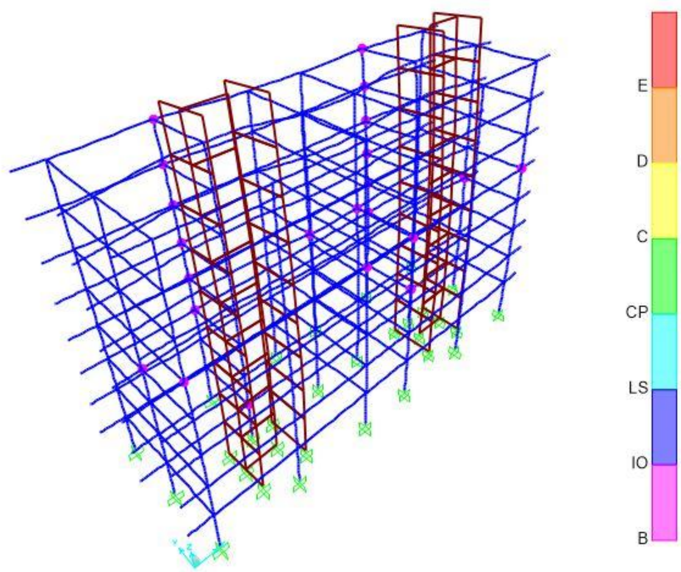


Fig. 33: 3D representation of the structure

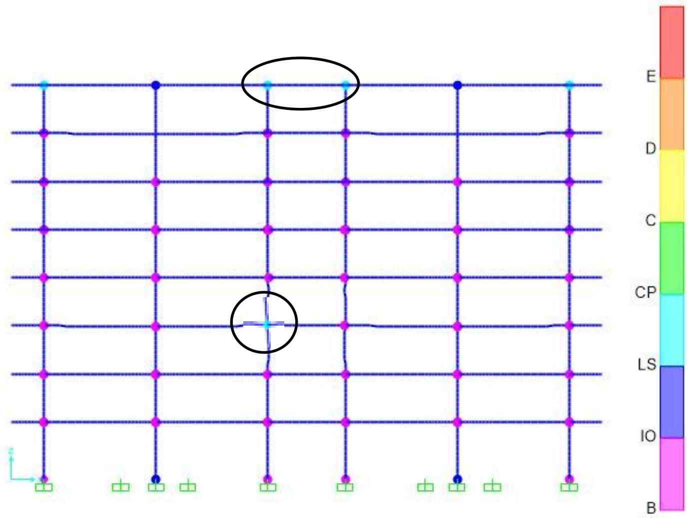


Fig. 34 : Critical Nodes

+X

- Node - (A,2,2)
- Node - (A,2,3)

+Y

- Node - (B,2,2)
- Node - (B,2,3)
- Node - (B,2,4)
- Node - (C,2,3)

-Y

- Node - (A,2,8)
- Node - (C,2,8)
- Node - (C,2,2)

These are the critical nodes obtained by the Static Pushover analysis in SAP 2000 in three axes that are +X, +Y and –Y.

2. STAAD.Pro Results

There are 9 critical nodes from the analysis done in SAP2000 along different push axis.

Critical node details:

Node no.	Location	Connected Members	Reinforcement
1	A,2,2	Beam-63	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-79	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-80	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-101	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Column-92	Main: 6# 25ø; Ties: 6ø @ 250mm c/c
		Column-145	Main: 6# 25ø; Ties: 6ø @ 250mm c/c
2	A,2,3	Beam-116	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-132	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-133	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-154	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Column-145	Main: 6# 25ø; Ties: 6ø @ 250mm c/c
		Column-198	Main: 6# 25ø; Ties: 6ø @ 250mm c/c
3	B,2,2	Beam-59	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-73	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-99	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Column-88	Main: 6# 16ø; Ties: 6ø @ 250mm c/c
		Column-141	Main: 6# 16ø; Ties: 6ø @ 250mm c/c
4	C,2,2	Beam-60	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-74	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-75	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-100	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c

		Column-89	Main: 6# 25ø; Ties: 6ø @ 250mm c/c
		Column-142	Main: 6# 25ø; Ties: 6ø @ 250mm c/c
5	B,2,3	Beam-112	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-126	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-152	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Column-141	Main: 6# 16ø; Ties: 6ø @ 250mm c/c
		Column-194	Main: 6# 16ø; Ties: 6ø @ 250mm c/c
6	C,2,3	Beam-113	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-127	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-128	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-153	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Column-142	Main: 6# 25ø; Ties: 6ø @ 250mm c/c
		Column-195	Main: 6# 25ø; Ties: 6ø @ 250mm c/c
7	B,2,4	Beam-165	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-179	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-205	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Column-194	Main: 6# 16ø; Ties: 6ø @ 250mm c/c
		Column-247	Main: 6# 16ø; Ties: 6ø @ 250mm c/c
8	A,2,8	Beam-375	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-376	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-389	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-390	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Column-405	Main: 6# 16ø; Ties: 6ø @ 250mm c/c
9	C,2,8	Beam-378	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-392	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c

		Beam-393	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Beam-418	Top: 3# 16ø; Bottom: 3# 16ø; Stirrups: 2 legged 6ø @300mm c/c
		Column-407	Main: 6# 16ø; Ties: 6ø @ 250mm c/c

There are 2 critical nodes in +X axis analysis.

Node (A,2,2) and Node (A,2,3)

<u>Results for node (A,2,2):</u>

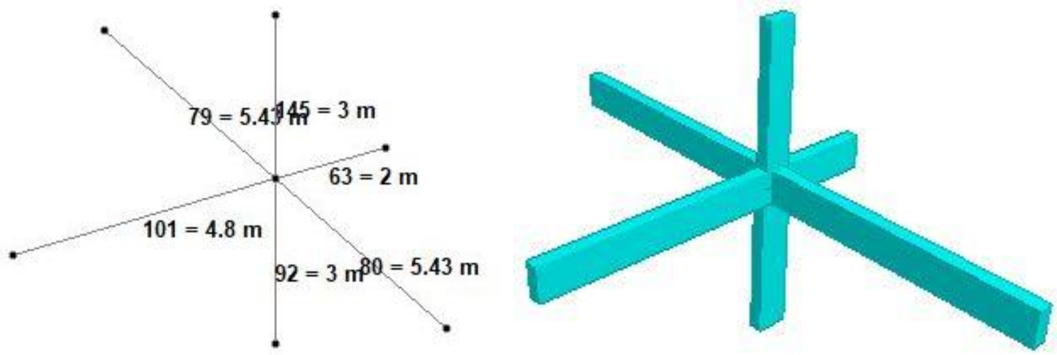


Fig. 35 :Node(A,2,2) and connected members.

Beam 63:

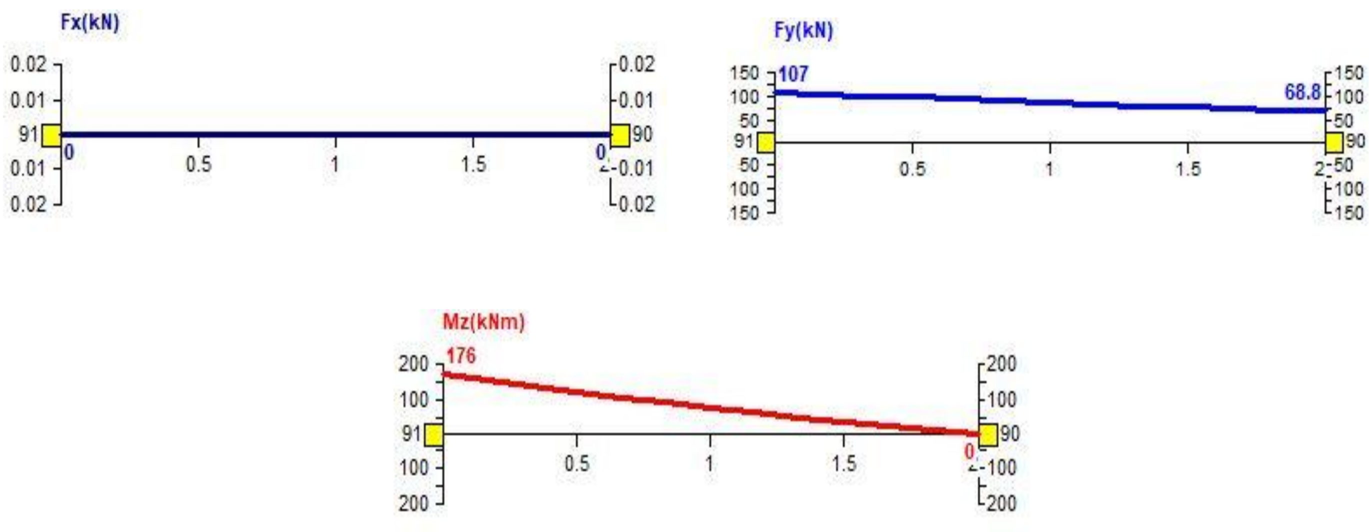


Fig. 36 :Shear forces and moments of beam-63

Beam-79:

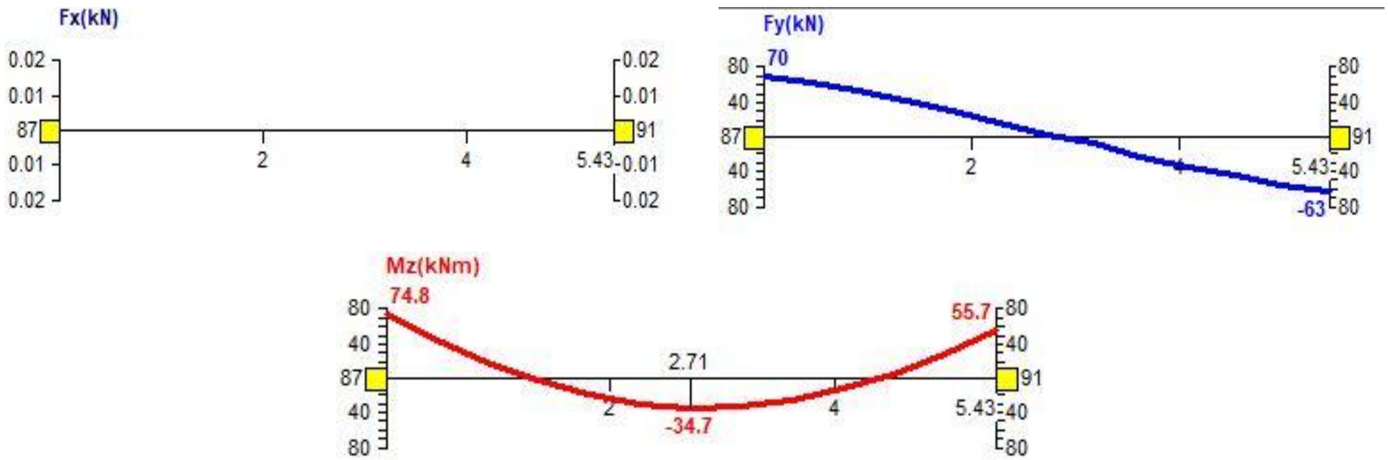


Fig. 37 :Shear forces and moments of beam-79

Beam-80:

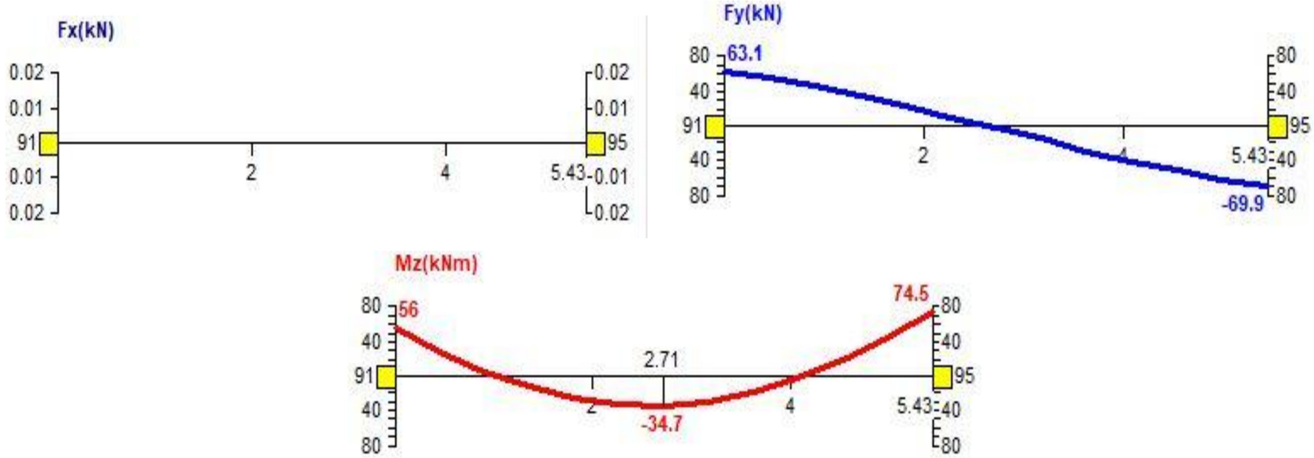


Fig. 38 :Shear forces and moments of beam-80

Beam-101:

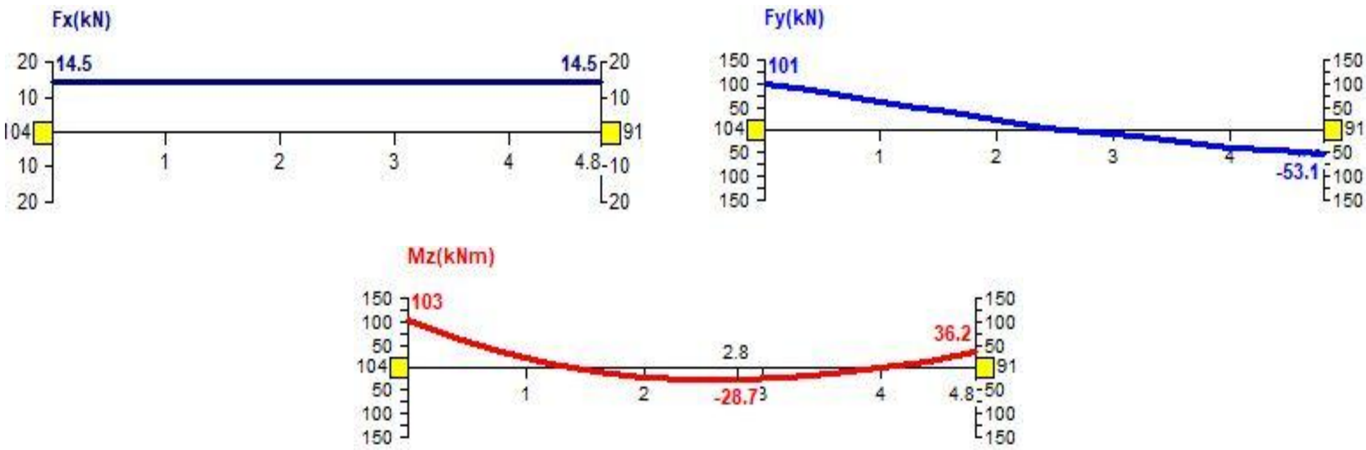


Fig. 39 :Shear forces and moments of beam-101.

Column-92

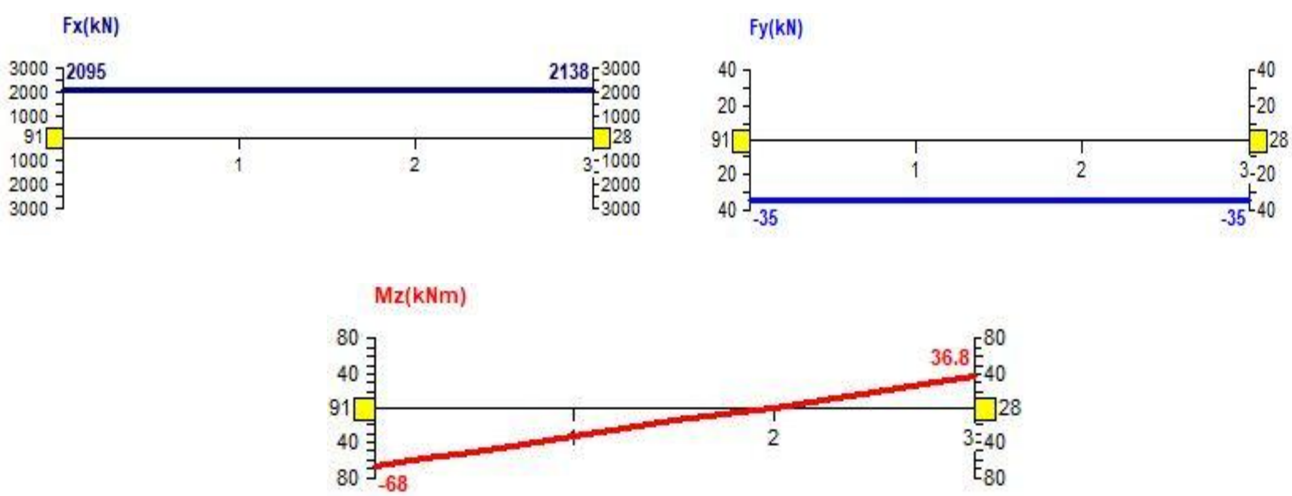


Fig. 40 :Shear forces and moments of column-92.

<u>Results for Node (A,2,3):</u>

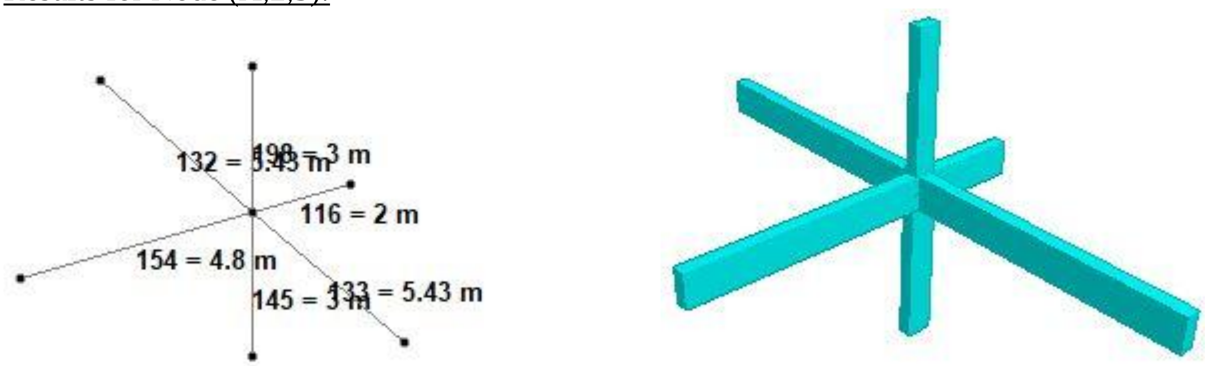


Fig. 41 : Node (A,2,3) and connected members

Column 145:

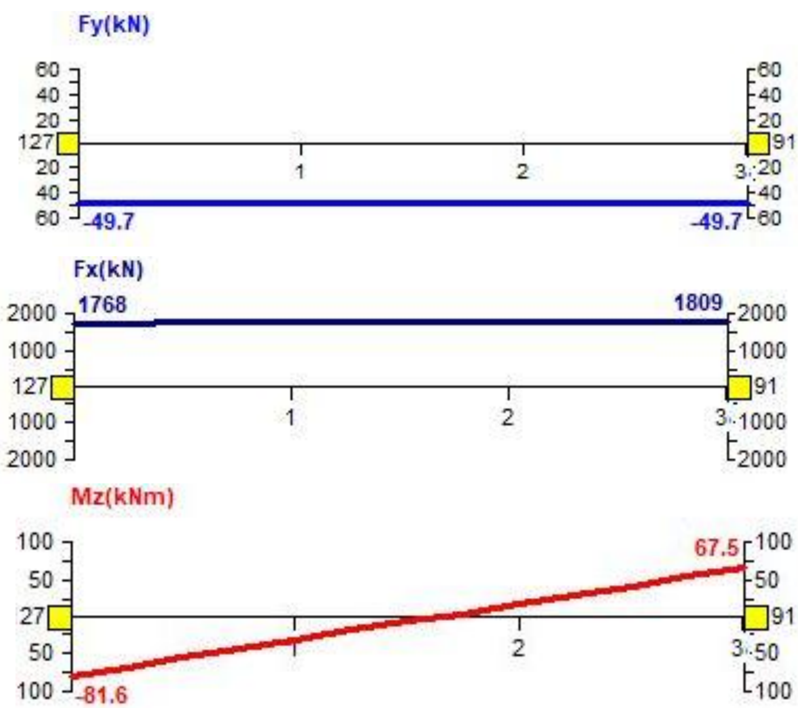


Fig. 42 : Shear force and Moment of Column 145

Beam 116 :

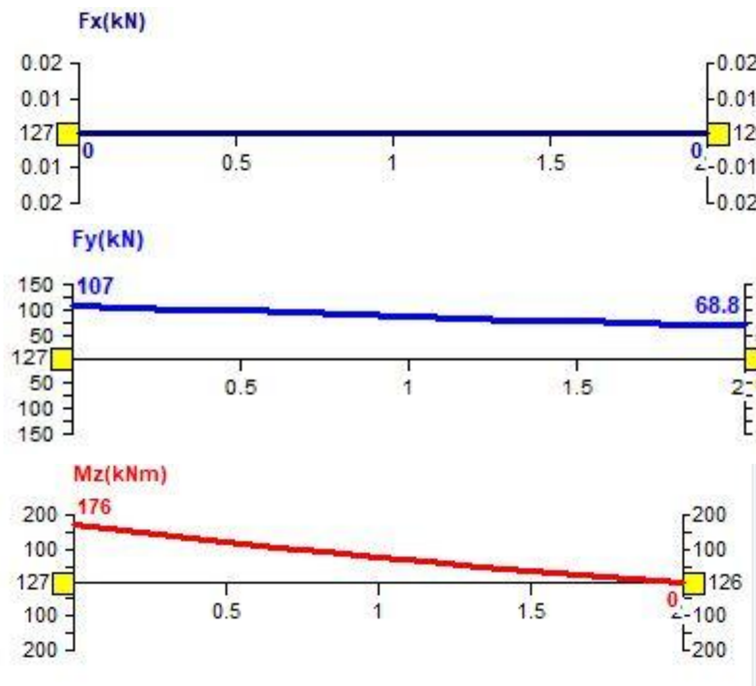


Fig. 43 : Shear force and Moment of Beam 116

Beam 132:

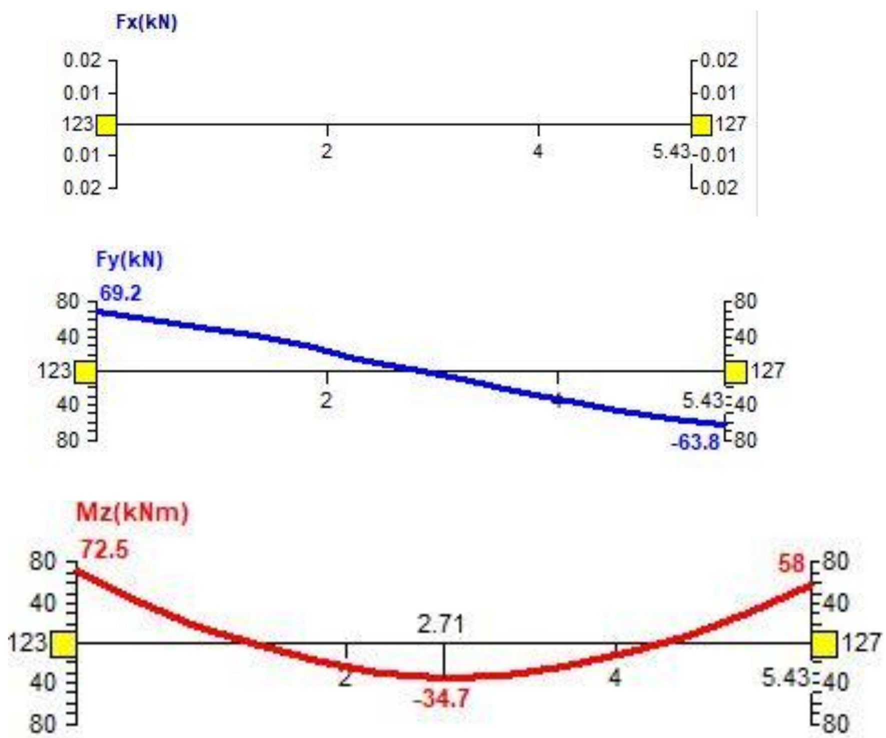


Fig. 44 : Shear force and Moment of Beam 132

Beam 133:

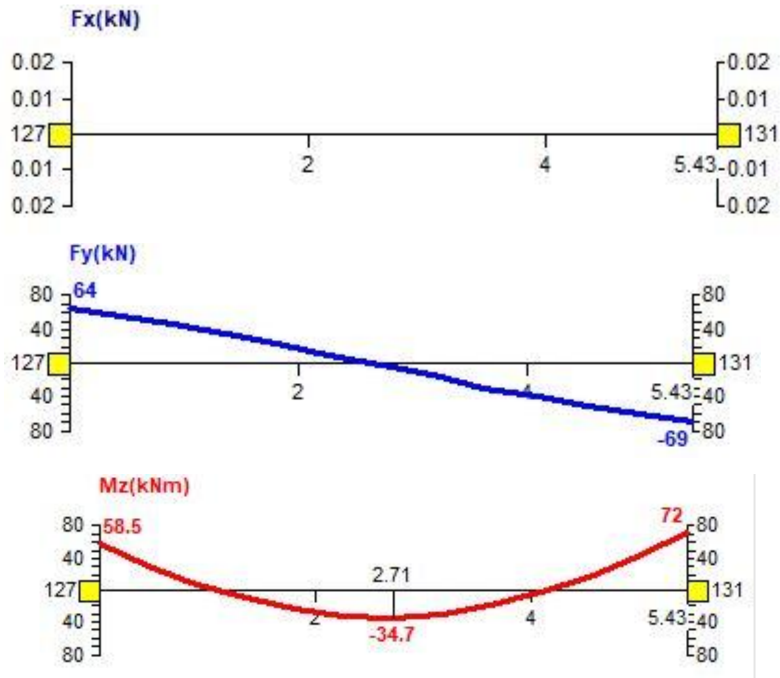


Fig. 45 : Shear force and Moment of Beam 133

Beam 154:

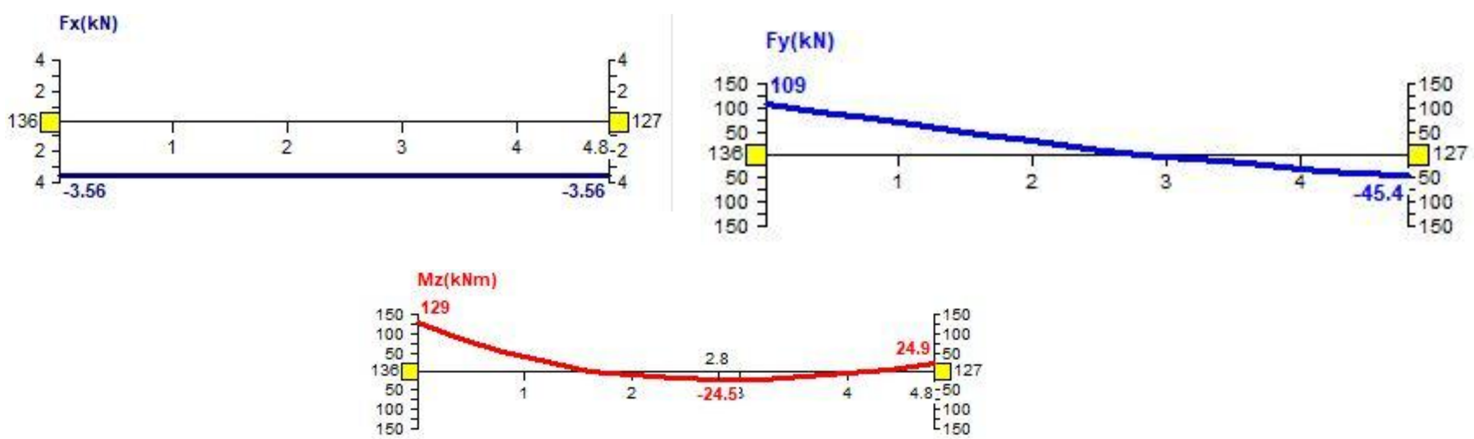


Fig. 46 : Shear force and Moment of Beam 154

Column 198:

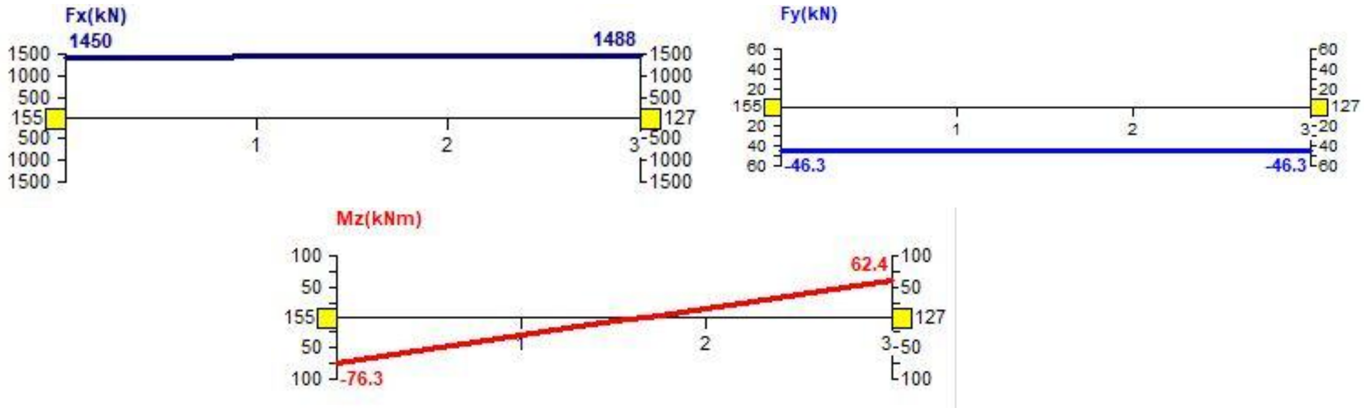


Fig. 47 : Shear force and Moment of Column 198

<u>Results for node-(B,2,2):</u>

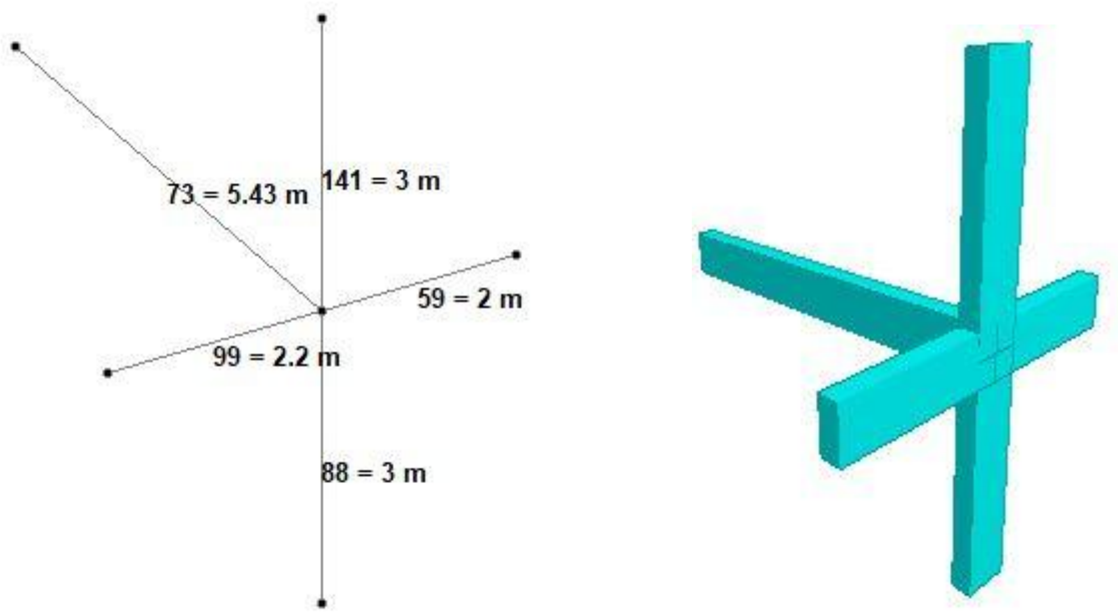


Fig. 48 : Node-(B,2,2) and connected members.

Beam-59:

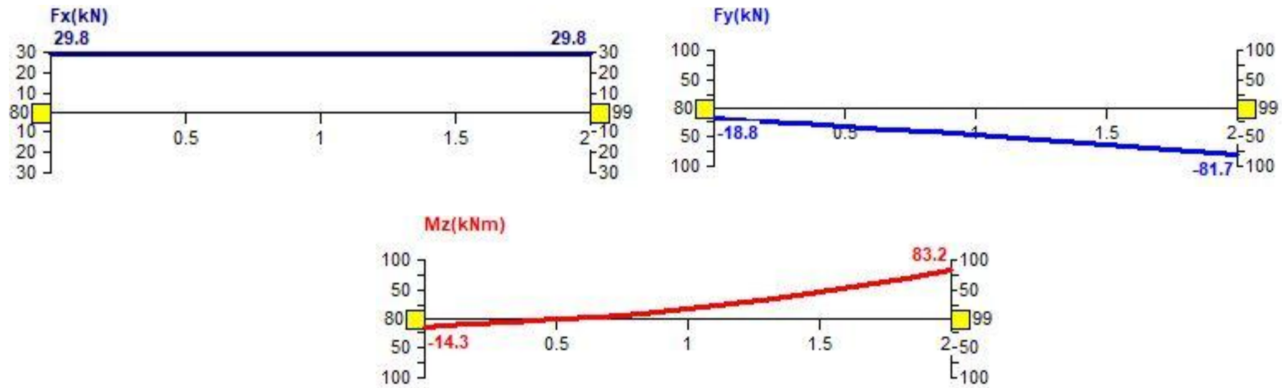


Fig. 49 : Shear force and Moment of Beam 59

Beam 73:

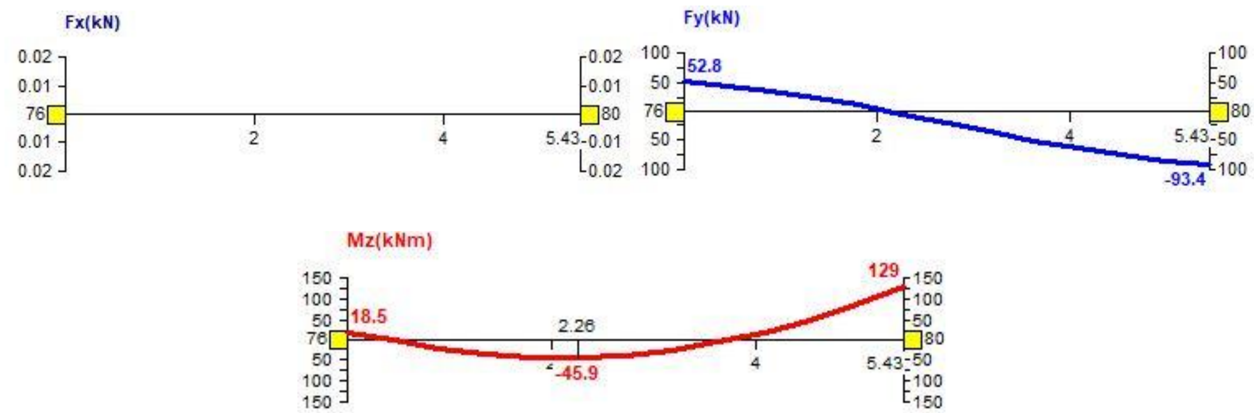


Fig. 50 : Shear force and Moment of Beam 73

Beam 99:

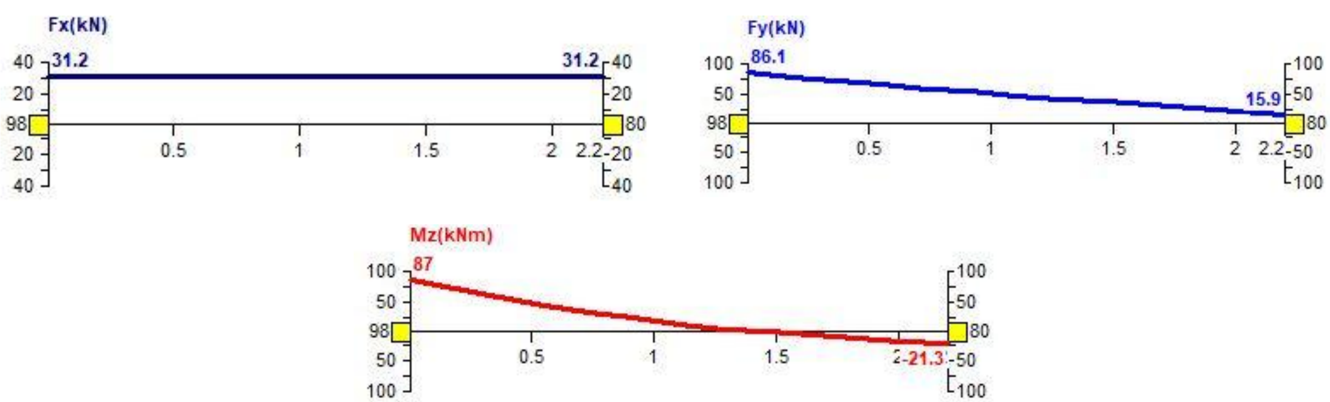


Fig. 51 : Shear force and Moment of Beam 99

Column 88:

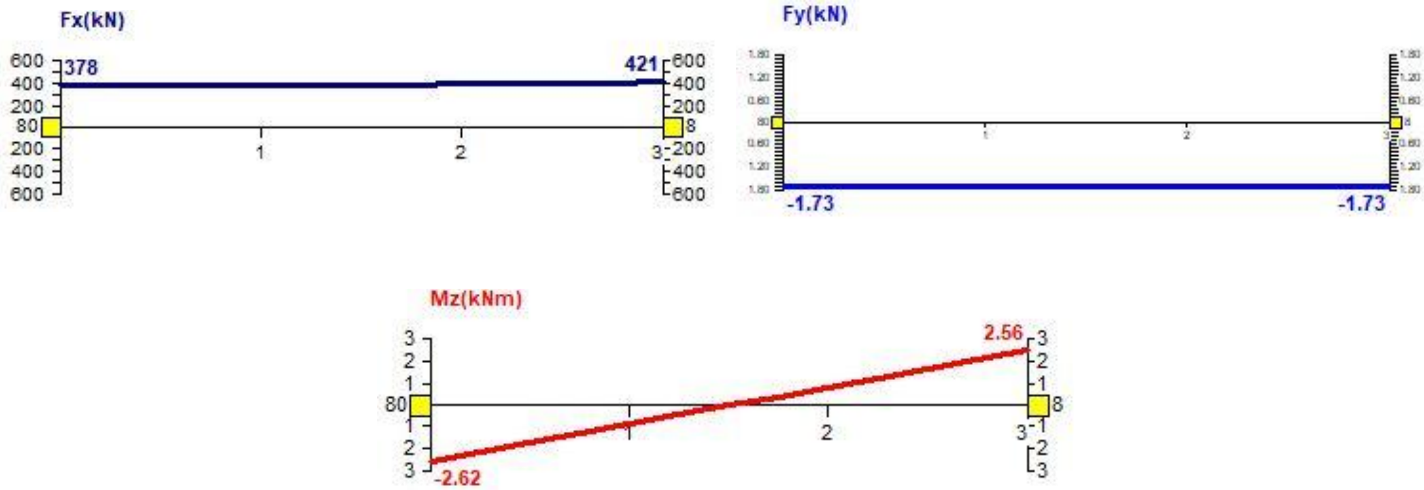


Fig. 52 :Shear force and Moment of Column 88

Column 141:

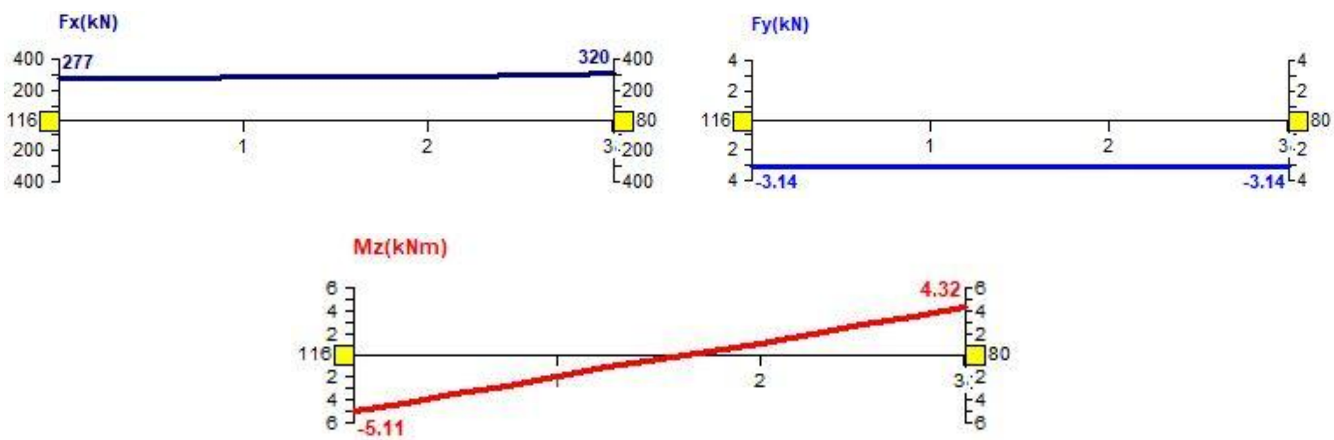


Fig. 53 :Shear force and Moment of Column 141

Results for node-(C,2,2):

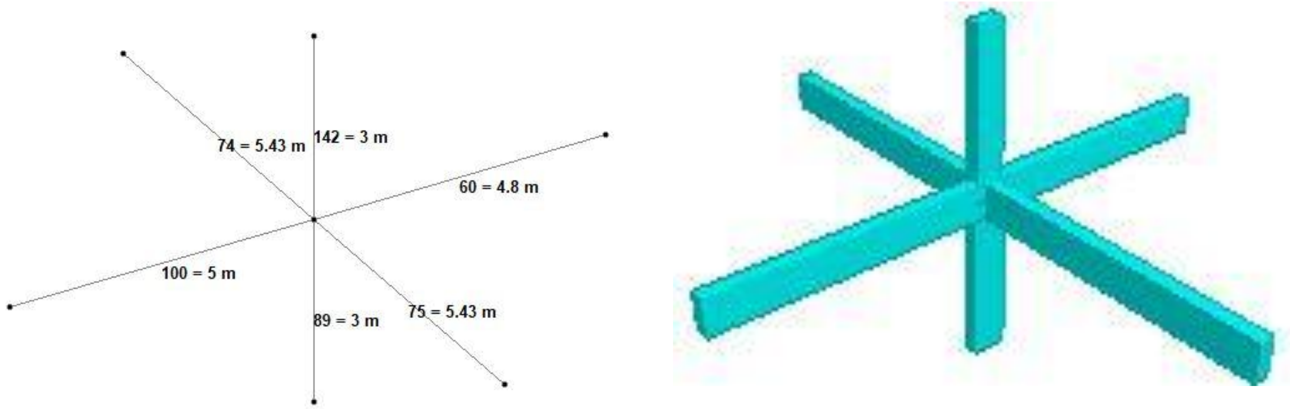


Fig. 54 :Node-(C,2,2) and connected members

Beam 60:

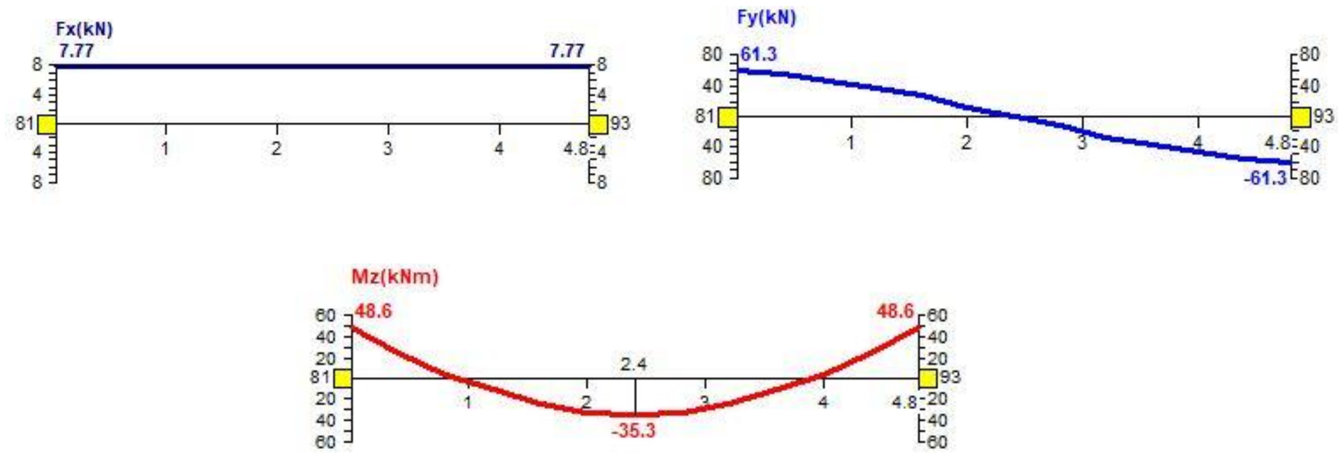


Fig. 55 :Shear force and Moment of Beam 60

Beam 74:

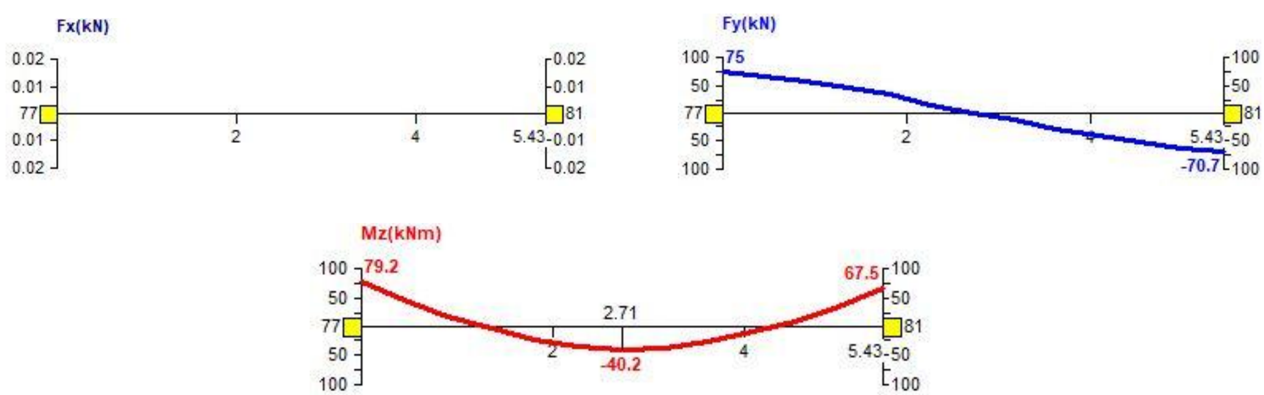


Fig. 56 :Shear force and Moment of Beam 74

Beam 75:

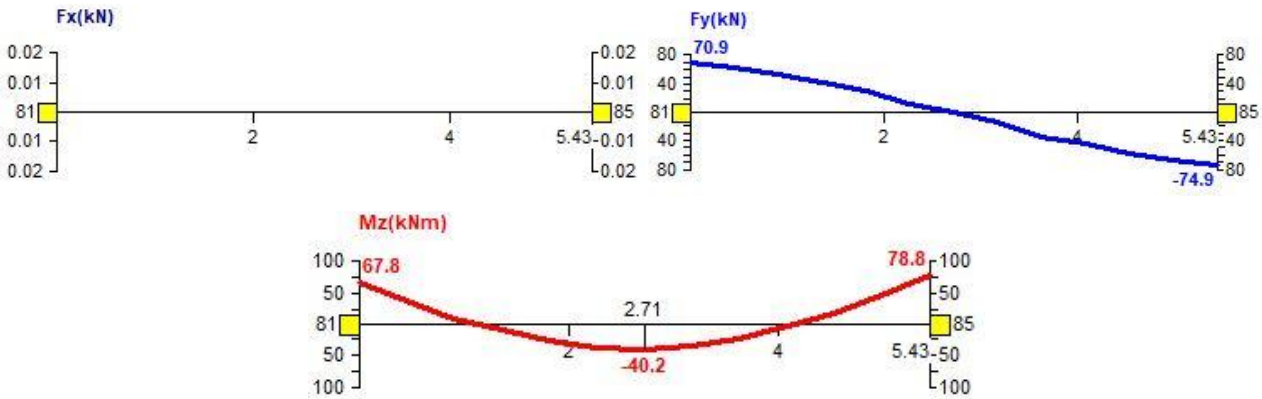


Fig. 57 :Shear force and Moment of Beam 75

Beam 100:

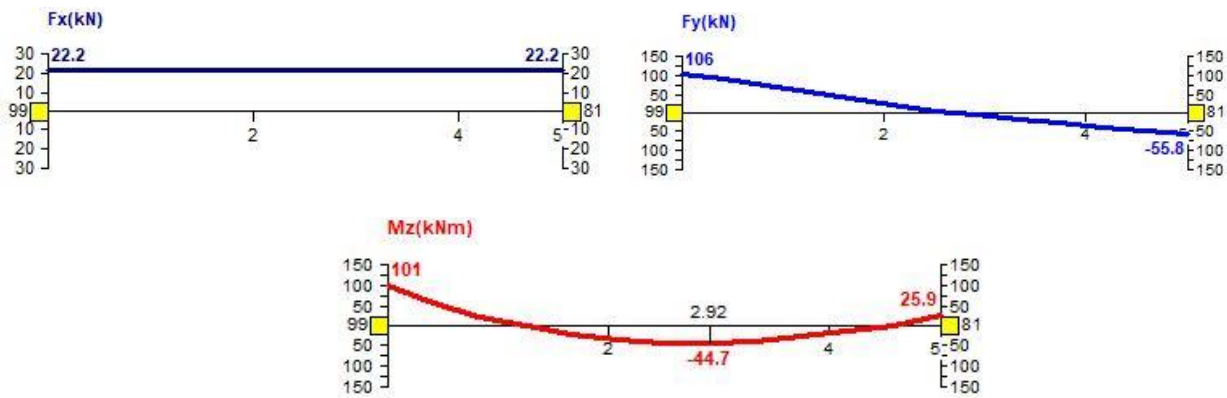


Fig. 58 :Shear force and Moment of Beam 100

Column 89:

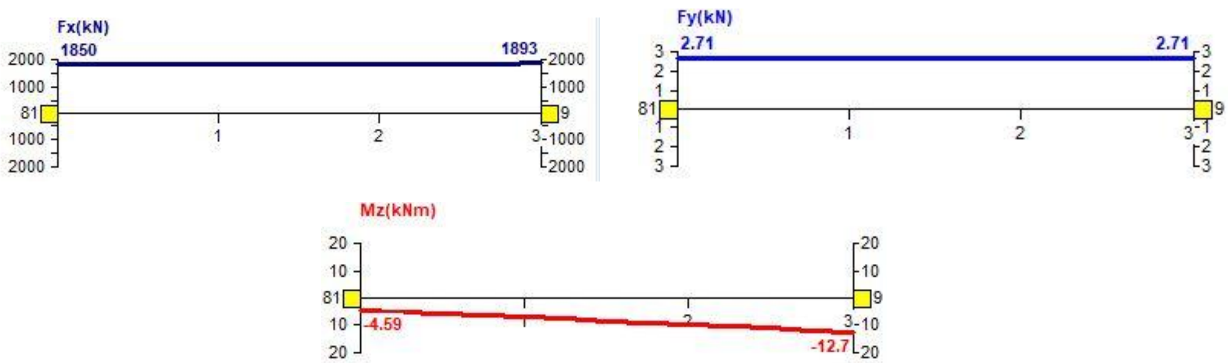


Fig. 59 :Shear force and Moment of Column 89

Column 142:

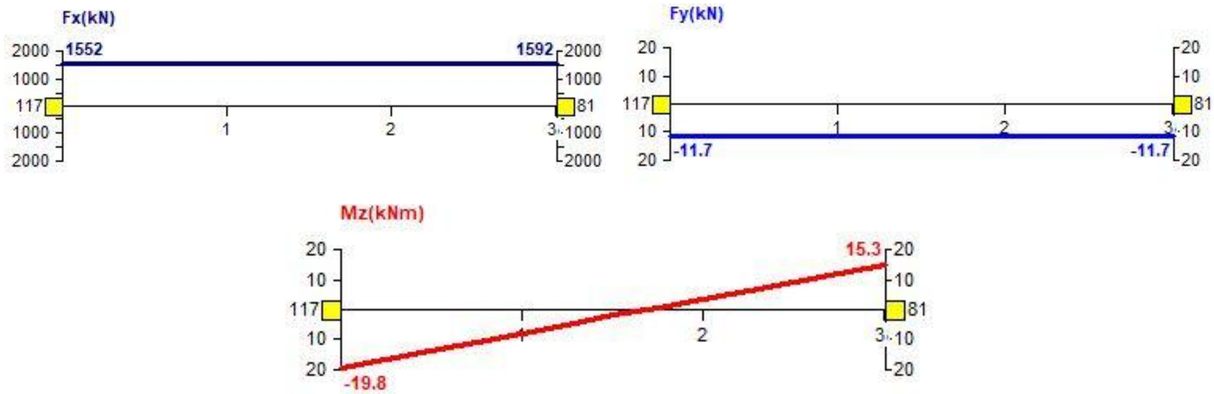


Fig. 60 :Shear force and Moment of Column 142

<u>Results for node (B,2,3):</u>

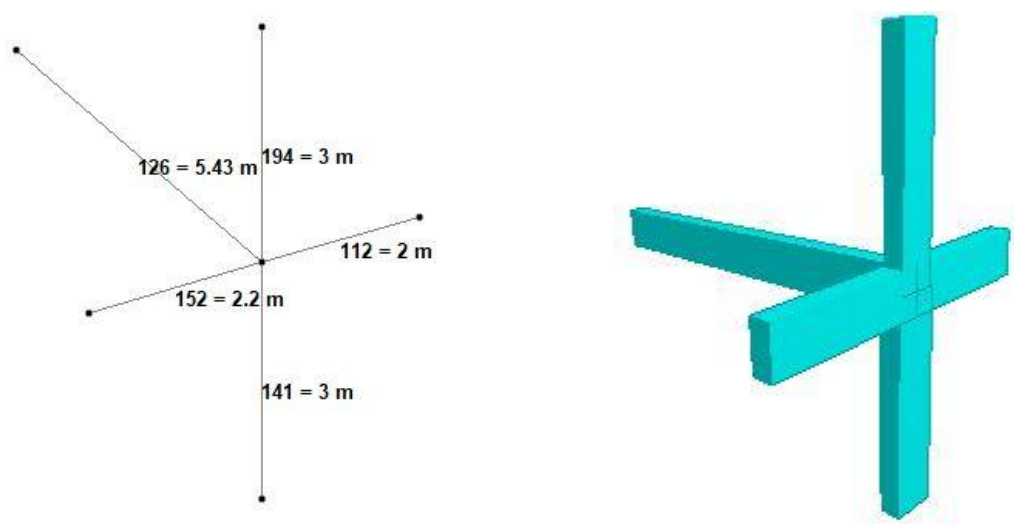


Fig. 61 :Node-(B,2,3) and connected members.

Beam 112:

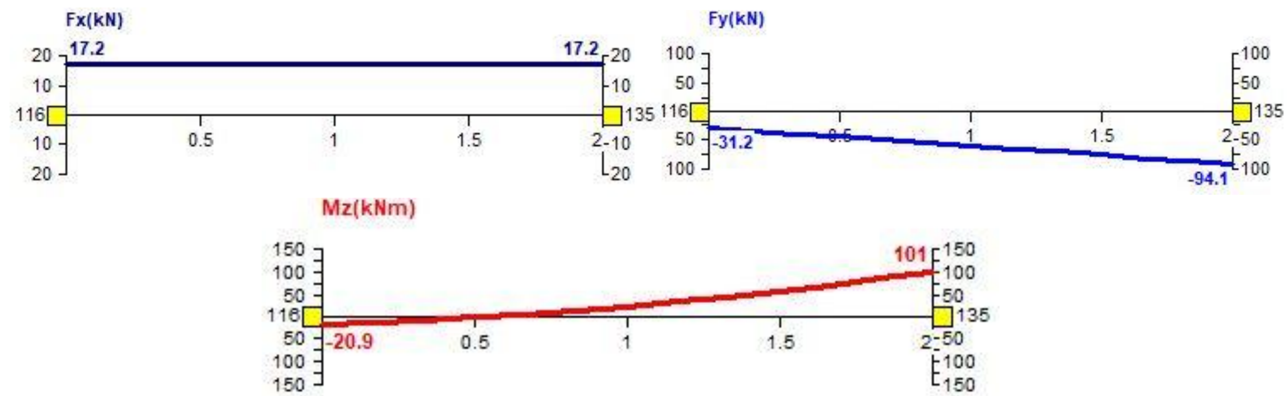


Fig. 62 :Shear force and Moment of Beam112

Beam 126:

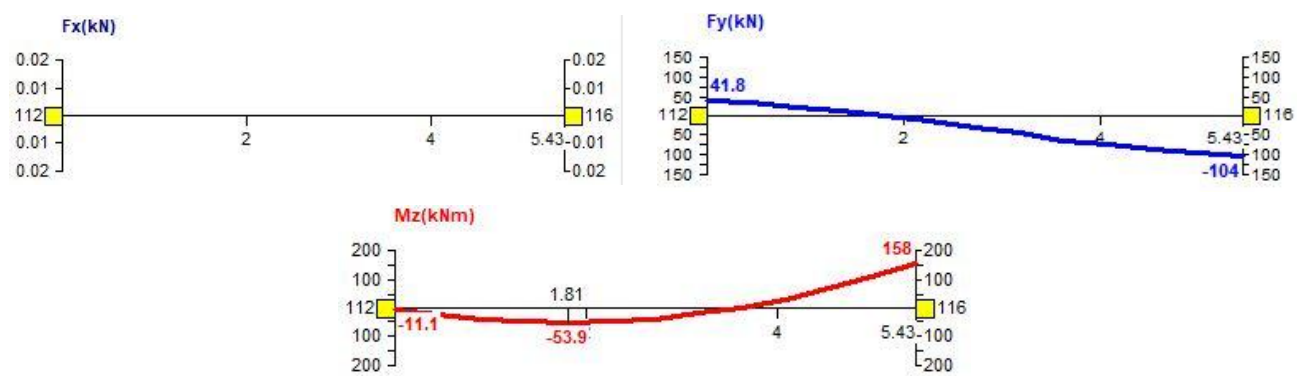


Fig. 63 :Shear force and Moment of Beam 126

Beam 152:

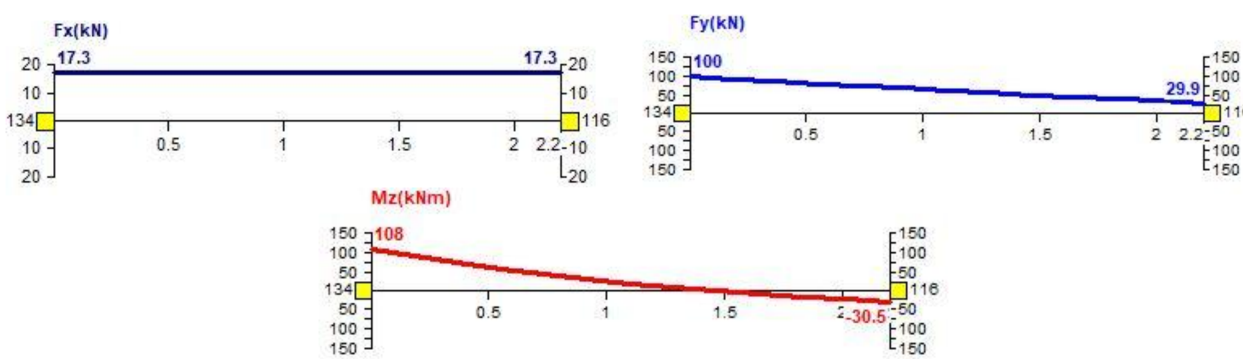


Fig. 64 :Shear force and Moment of Beam 152

Column 141:

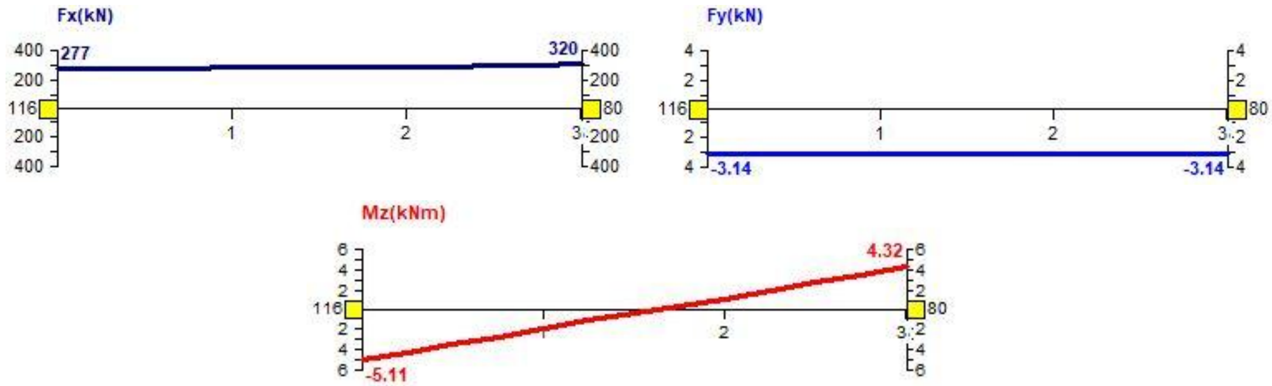


Fig. 65 :Shear force and Moment of Column 141

Column 194:

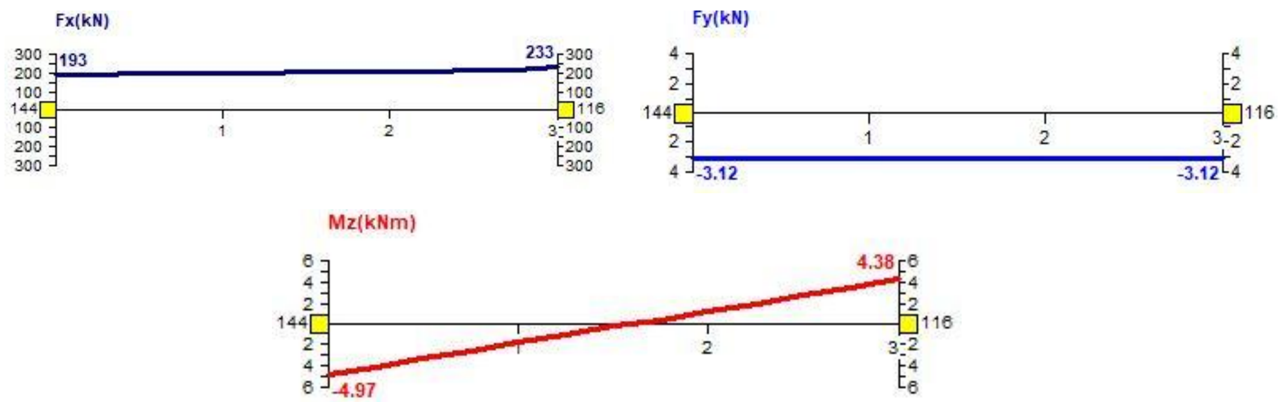


Fig. 66 :Shear force and Moment of Column 194

Results for Node (C,2,3):

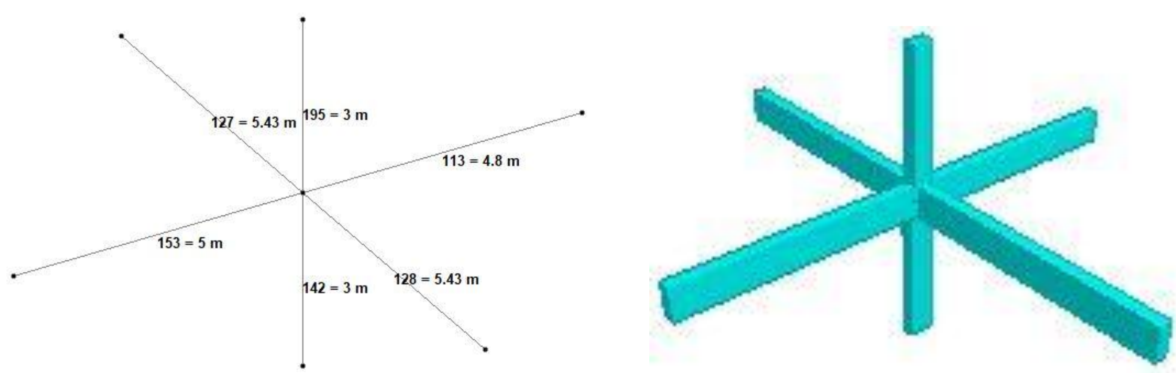


Fig. 67 :Node(C,2,3) and its connected members

Beam 113:

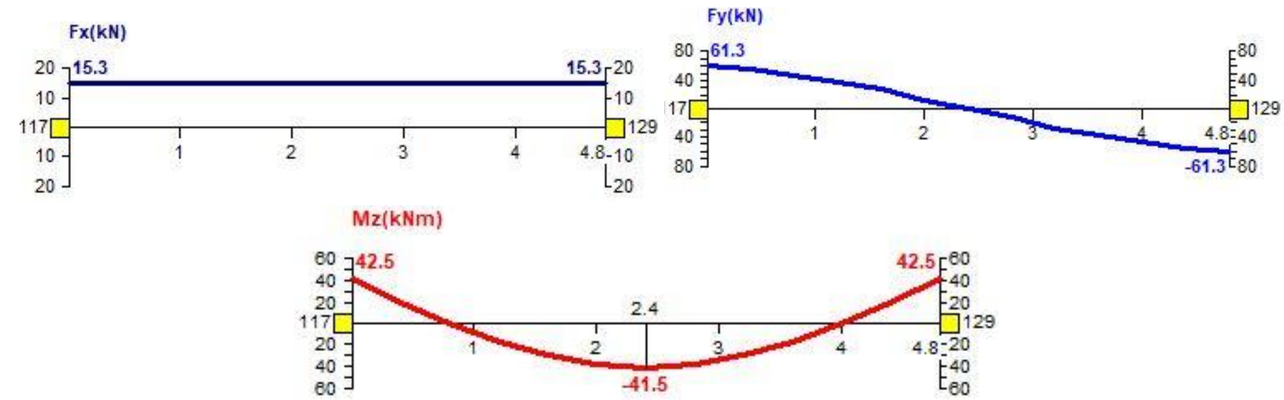


Fig. 68 :Shear force and Moment of Beam 113

Beam 127:

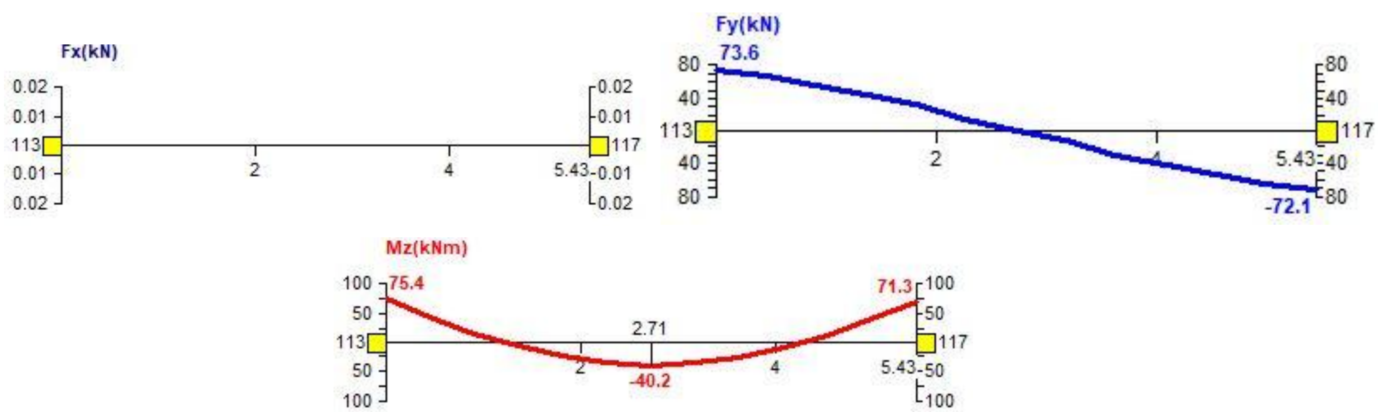


Fig. 69 :Shear force and Moment of Beam 127

Beam 128:

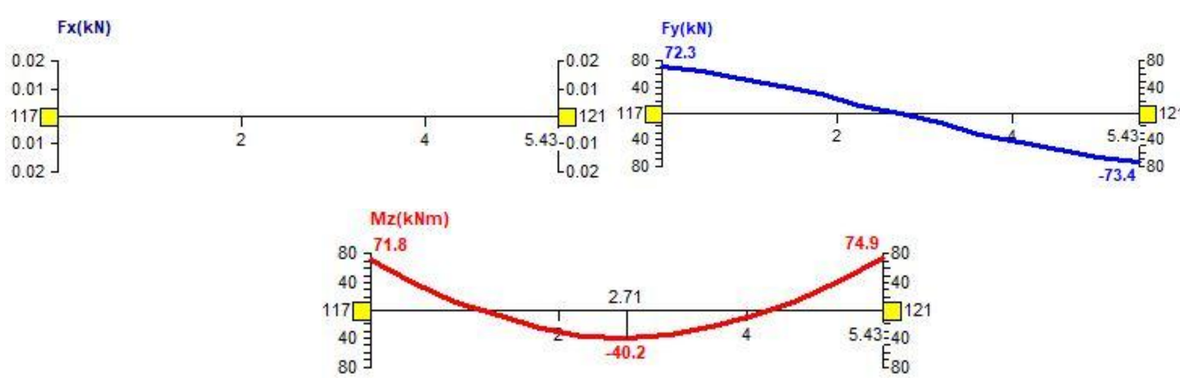


Fig. 70 :Shear force and Moment of Beam 128

Beam 153:

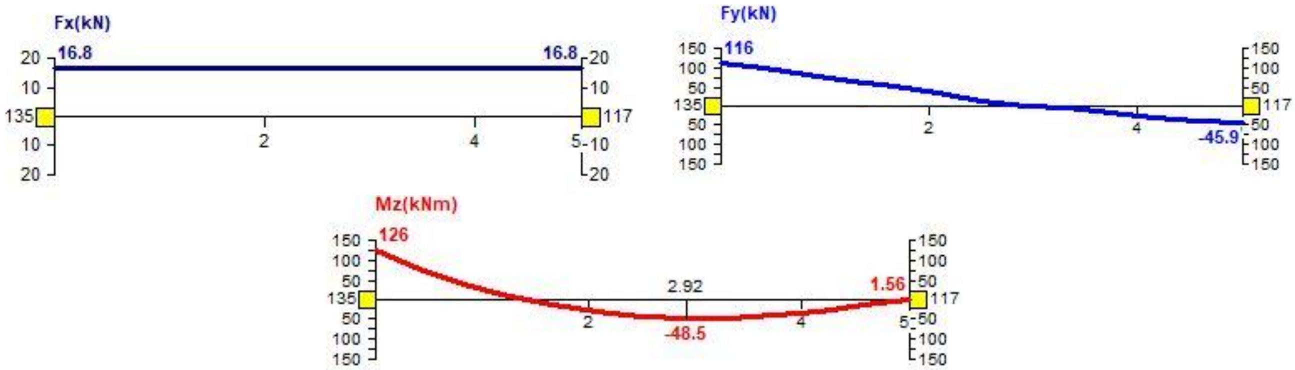


Fig. 70 :Shear force and Moment of Beam 153

Column 142:

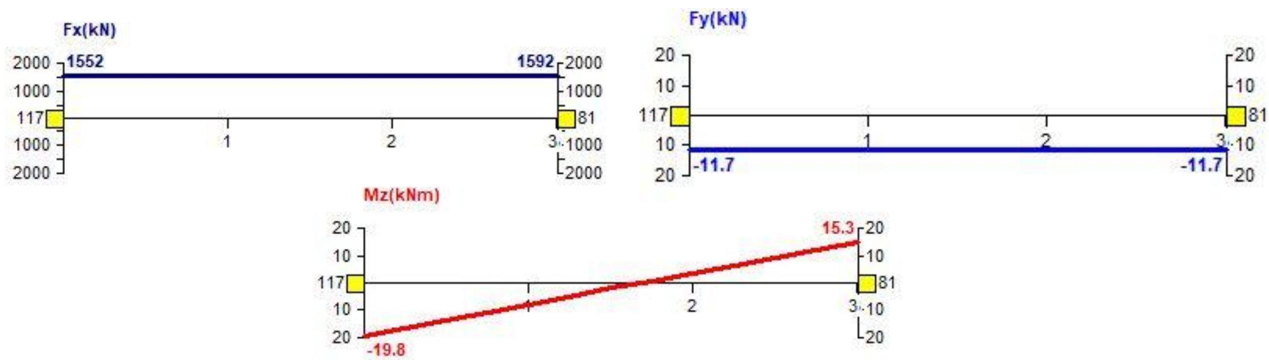


Fig. 71 :Shear force and Moment of Column 142

Column 195:

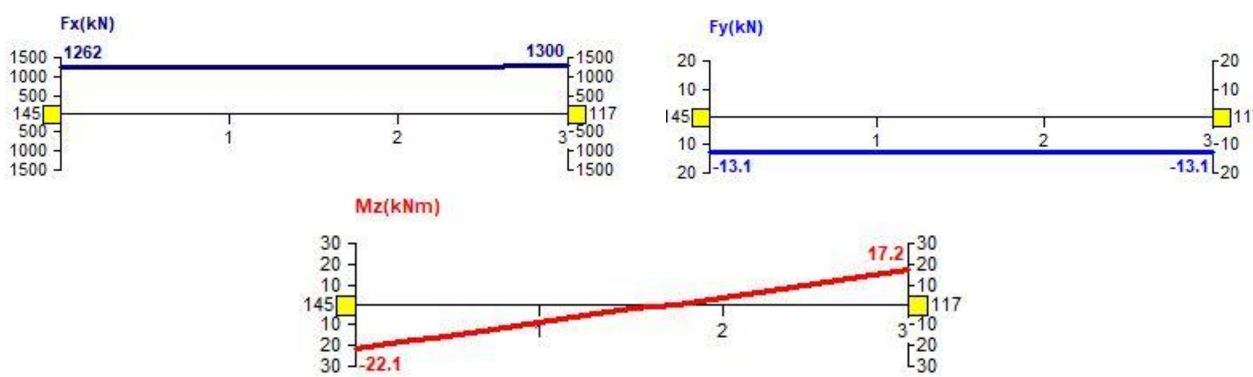


Fig. 72 :Shear force and Moment of Column 195

Results for node (B,2,4):

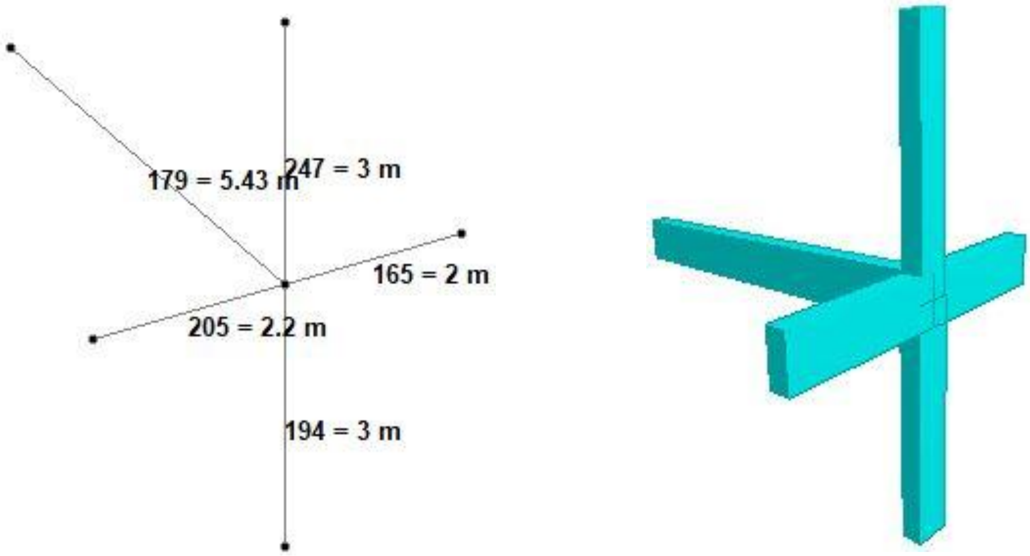


Fig. 73 :Node(B,2,4) and its connected members

Beam 165:

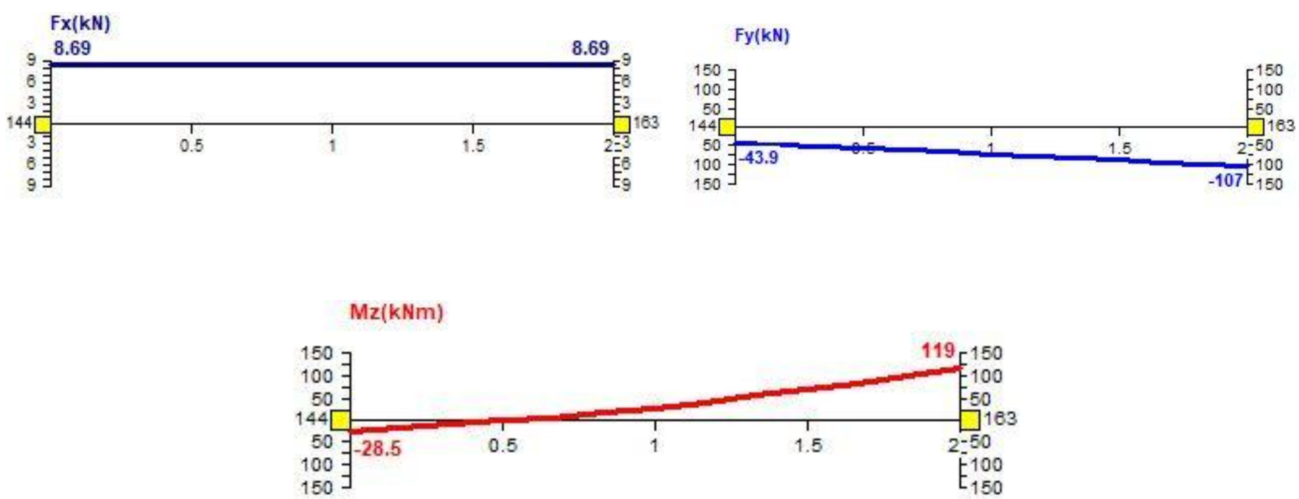


Fig. 74 :Shear force and Moment of Beam 165

Beam 179:

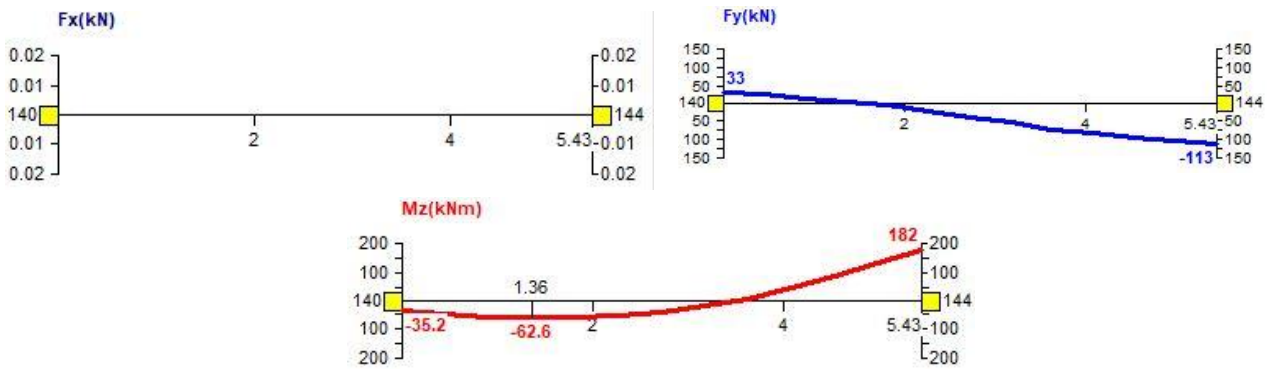


Fig. 75 :Shear force and Moment of Beam 179

Beam 205:

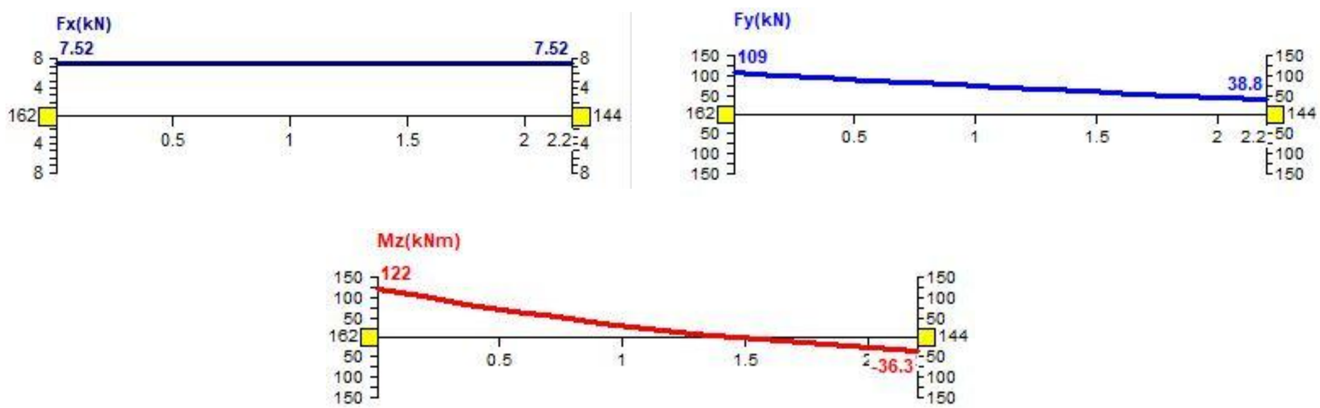


Fig. 76 :Shear force and Moment of Beam 205

Column 194:

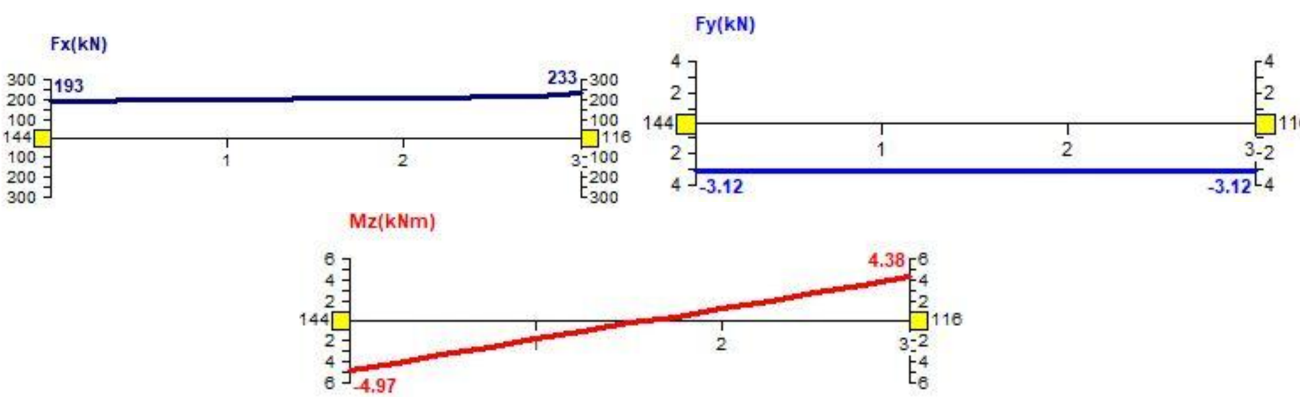


Fig. 77 :Shear force and Moment of Column 194

Column 247:

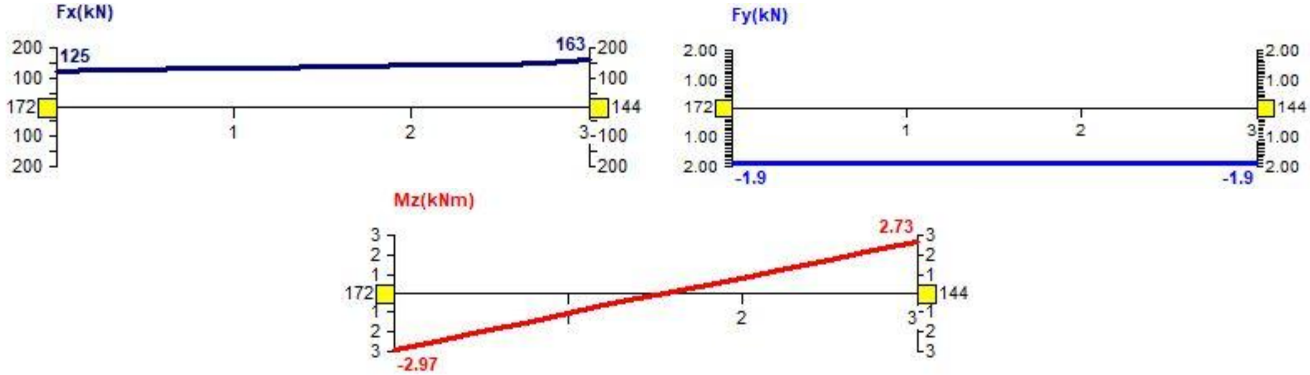


Fig. 78 :Shear force and Moment of Column 247

<u>Results for node (A,2,8):</u>

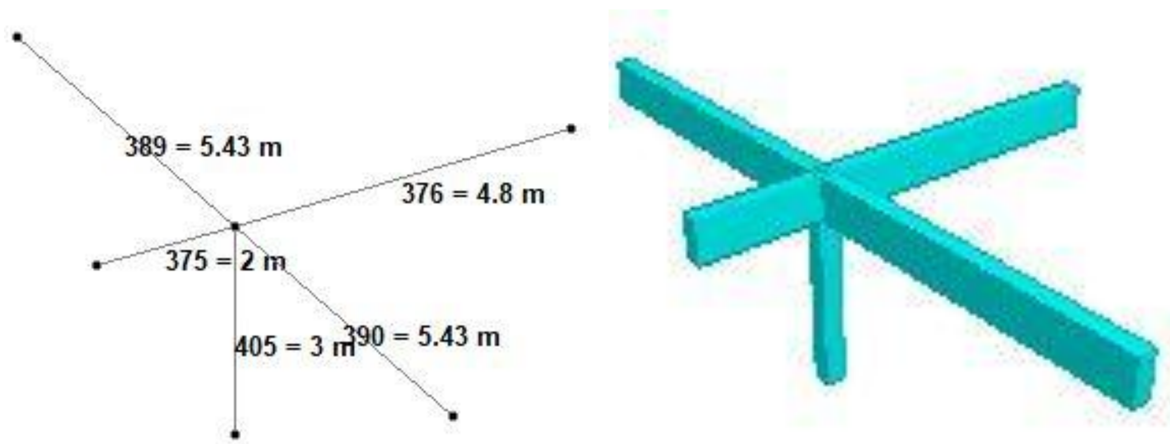


Fig. 79 :Node(A,2,8) and its connected members

Beam 375:

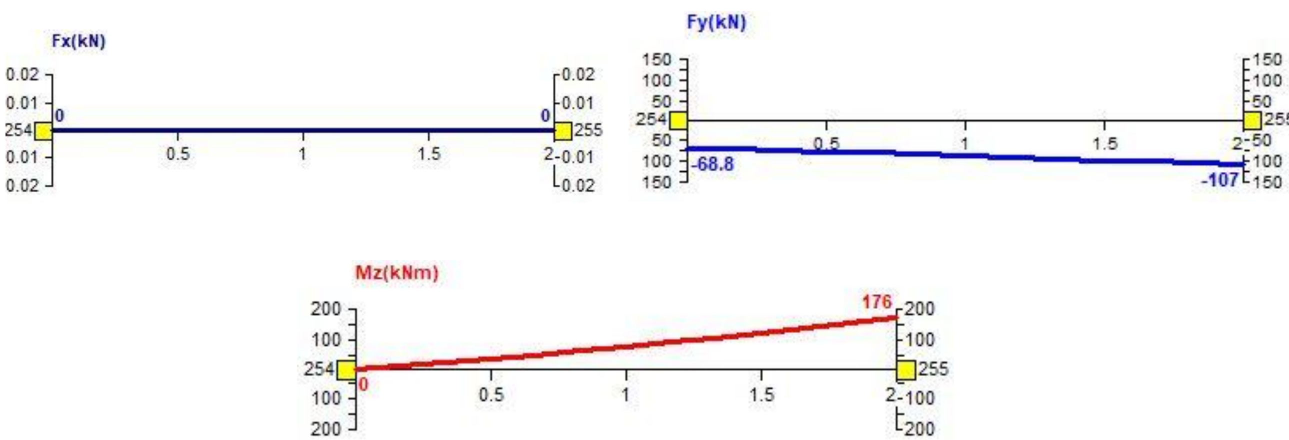


Fig. 80 :Shear force and Moment of Beam 375

Beam 376:

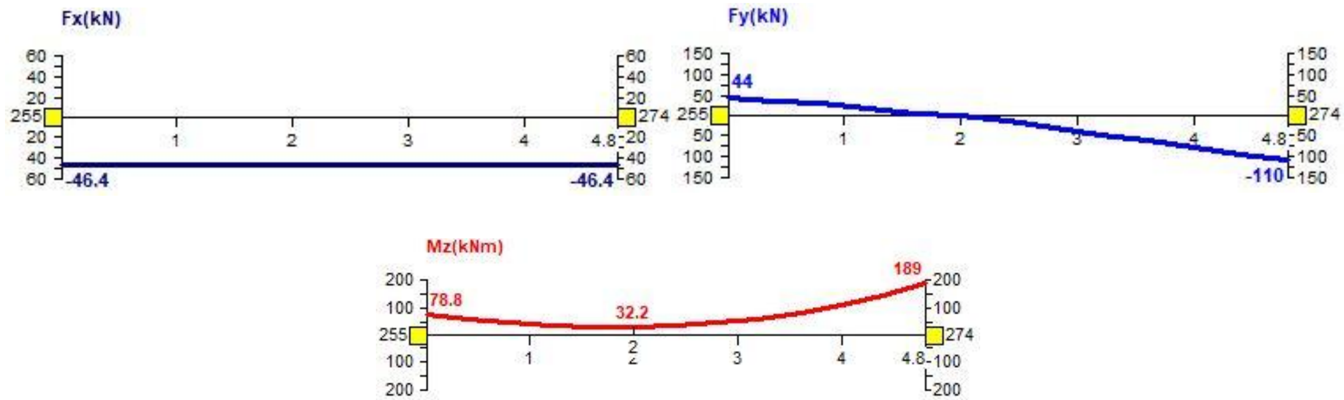


Fig. 81 :Shear force and Moment of Beam 376

Beam 389:

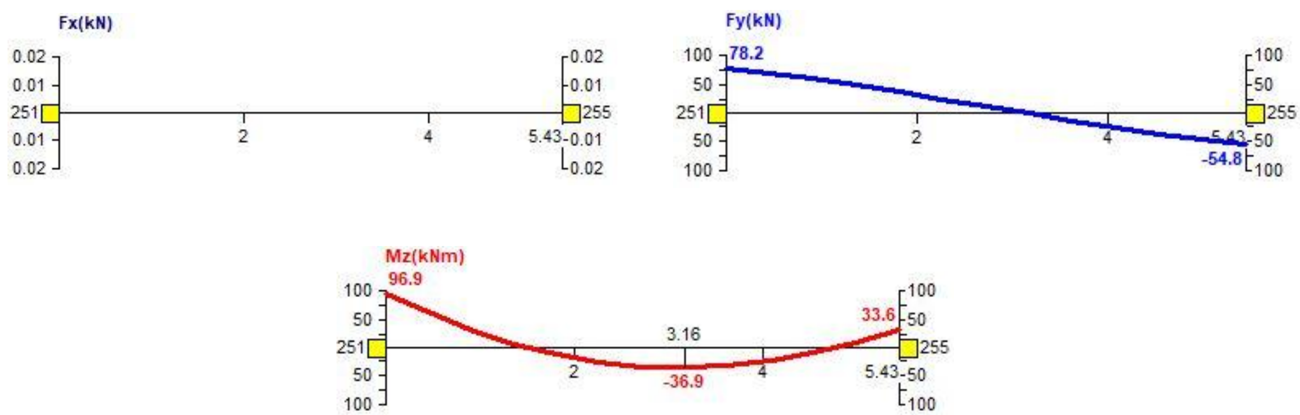


Fig. 82 :Shear force and Moment of Beam 389

Beam 390:

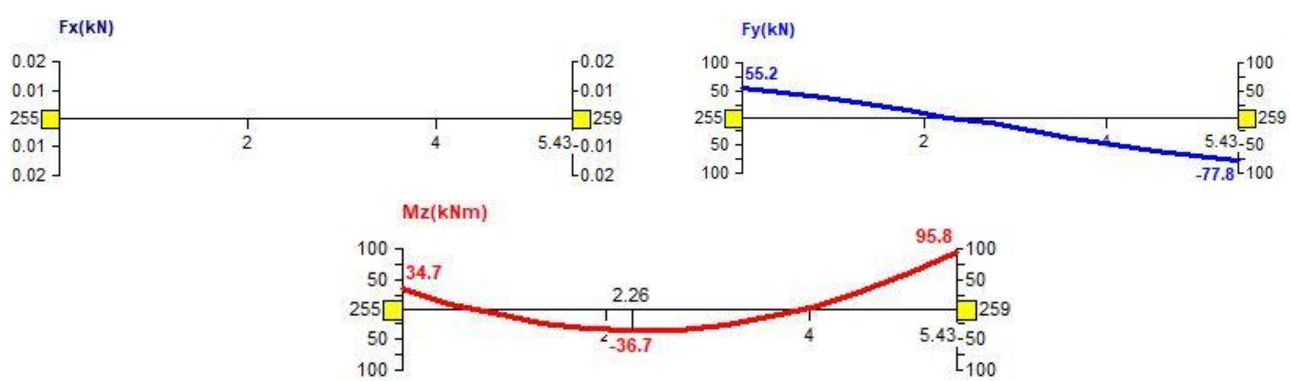


Fig. 83 :Shear force and Moment of Beam 390

Column 405:

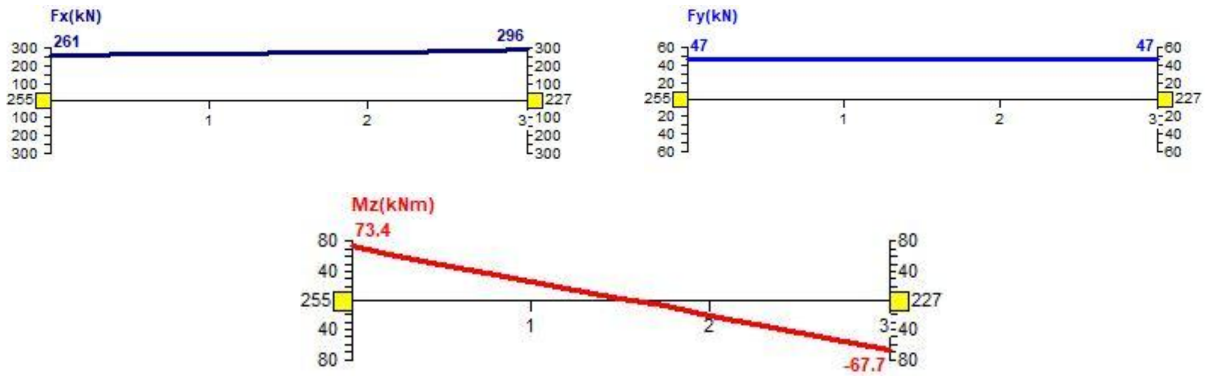


Fig. 84 :Shear force and Moment of Column 405

Results for Node (C,2,8):

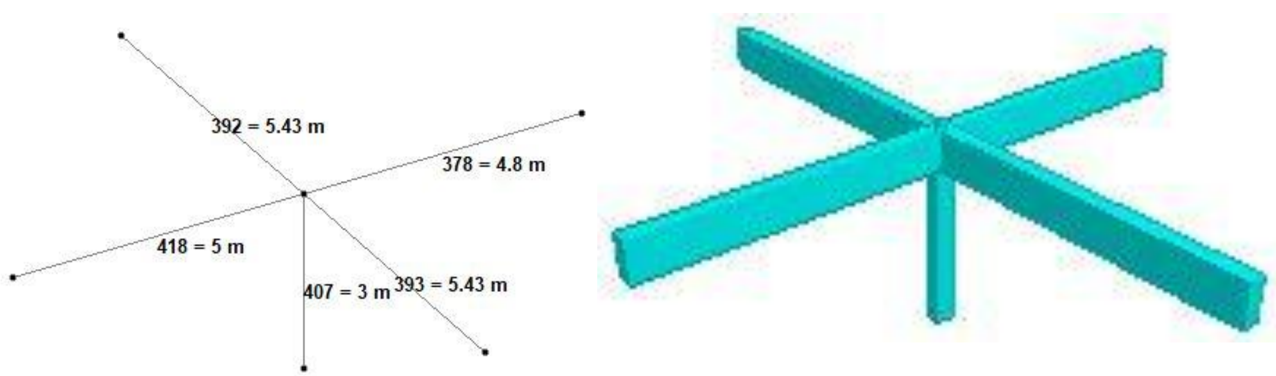


Fig. 85 :Node(C,2,8) and its connected members

Beam 378:

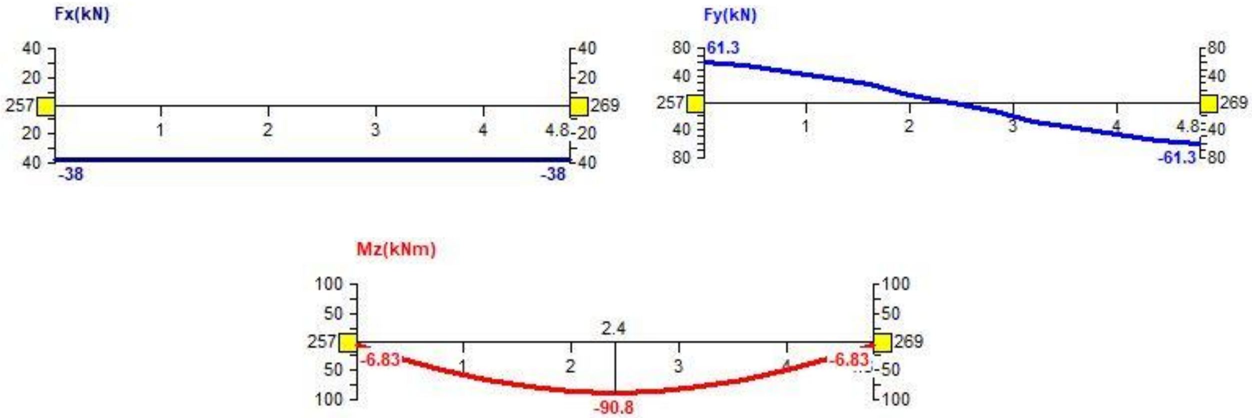


Fig. 86 :Shear force and Moment of Beam 378

Beam 392:

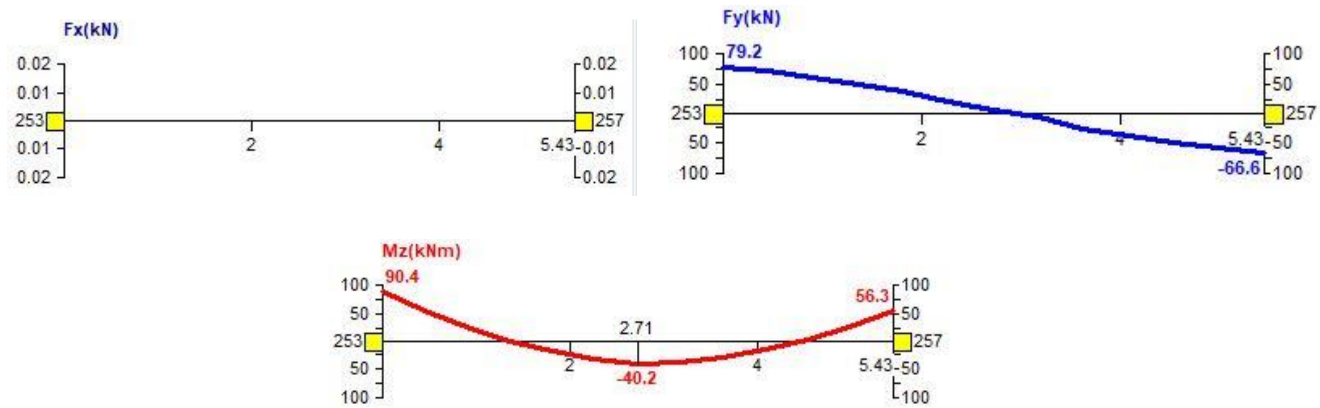


Fig. 87 :Shear force and Moment of Beam 392

Beam 393:

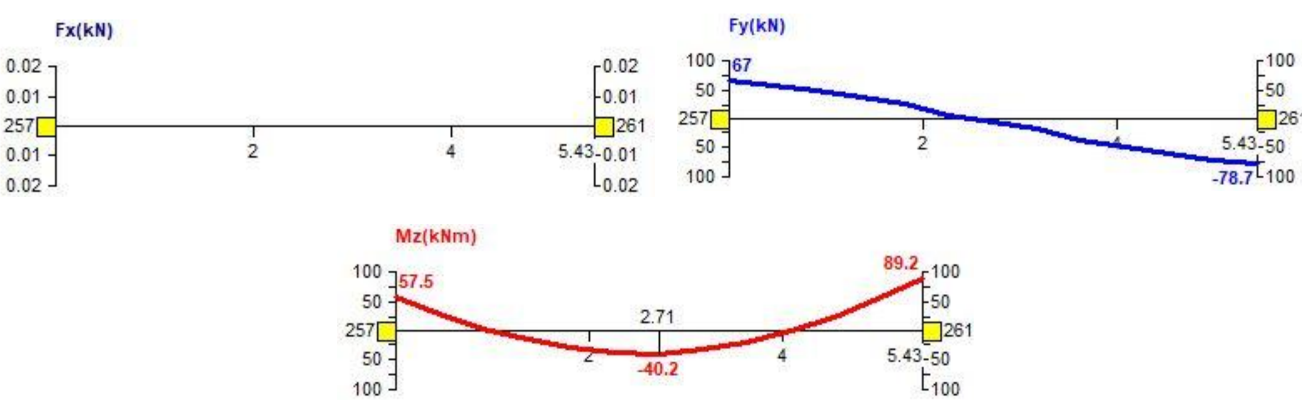


Fig. 88 :Shear force and Moment of Beam 393

Beam 418:

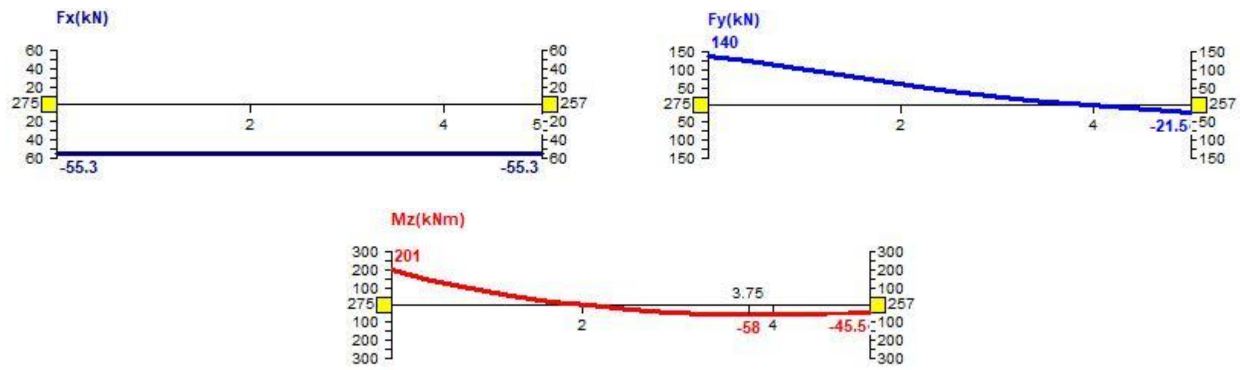


Fig. 89 :Shear force and Moment of Beam 418

Column 407:

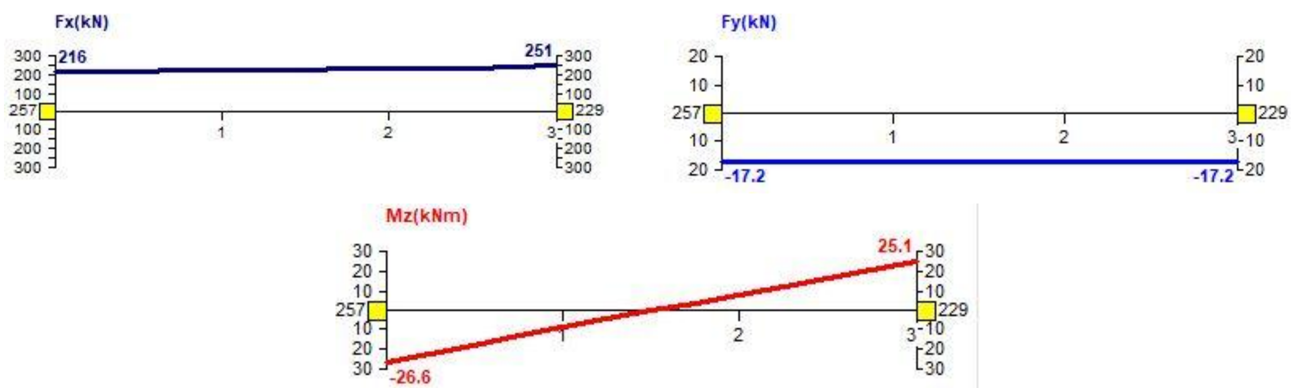


Fig. 90 :Shear force and Moment of Column 407

1.3 ABAQUS results-

ABAQUS main job is to design and analyze the critical beam-column joints of the building structure. The results from SAP 2000 and STAAD.Pro used to simulate the actual deflections and forces in the joints.

Critical Node – (C,2,3)

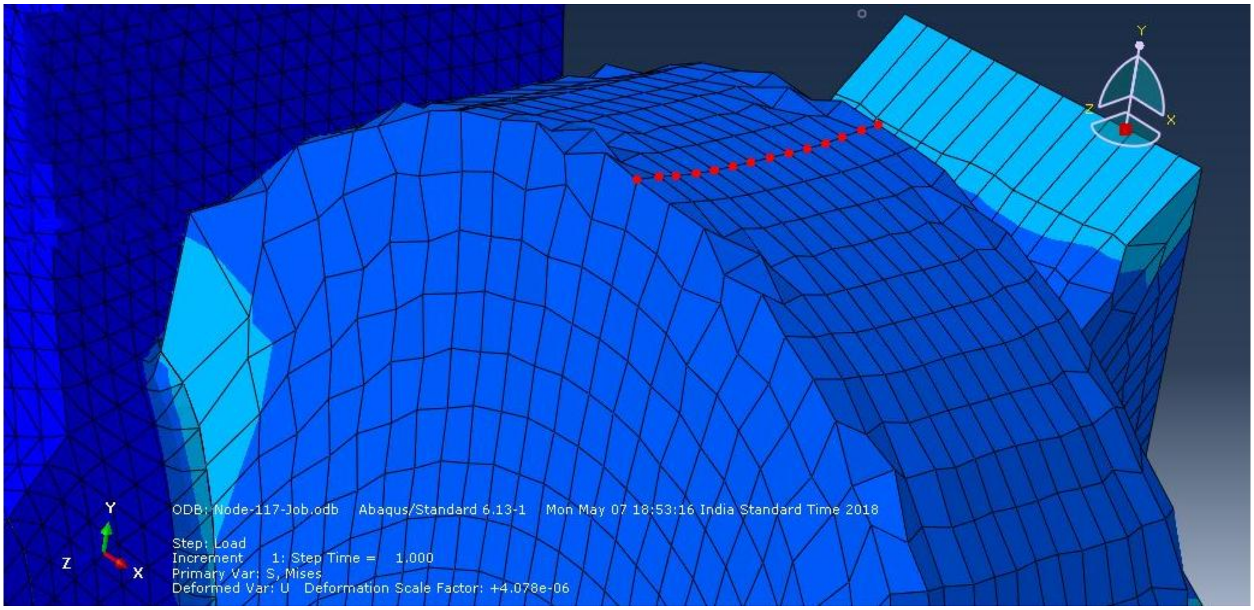


Fig. 91 : Zoomed in view of the points chosen

In the above figure the meshing is done and the points are chosen in the pattern as shown above.

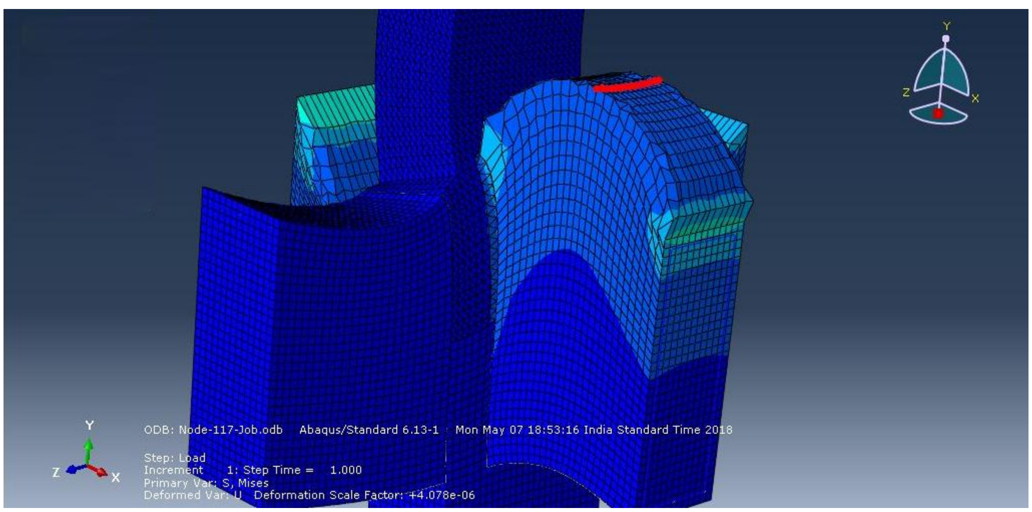


Fig. 92 : Zoomed out view of the points chosen

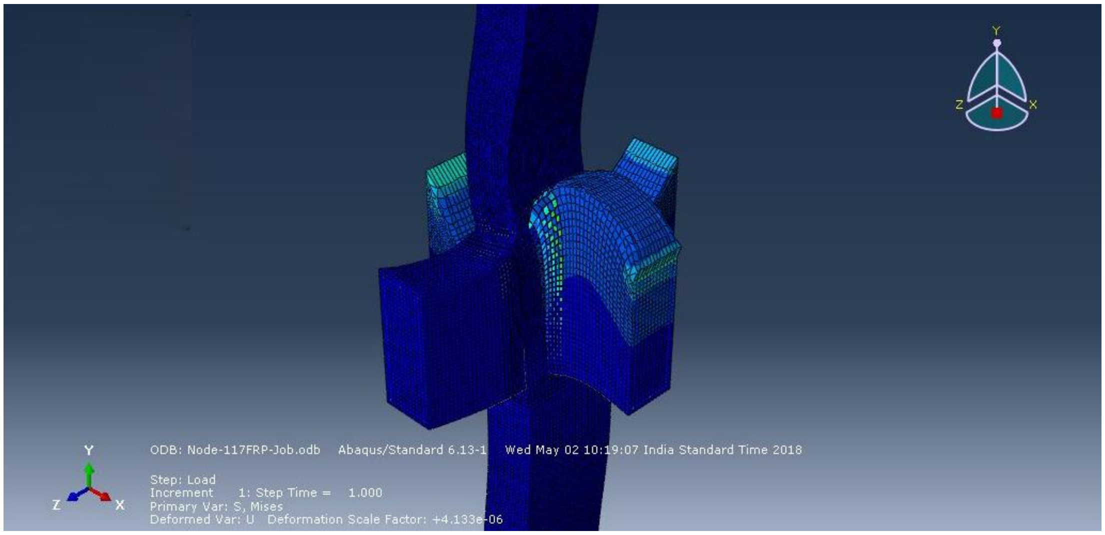


Fig. 93 : Deformation after FRP Wrapping

The beam column joint is wrapped in FRP and rectangle meshing is done, thereby increasing the strength and load bearing capacity of the beam column joint and thereby rectifying it.

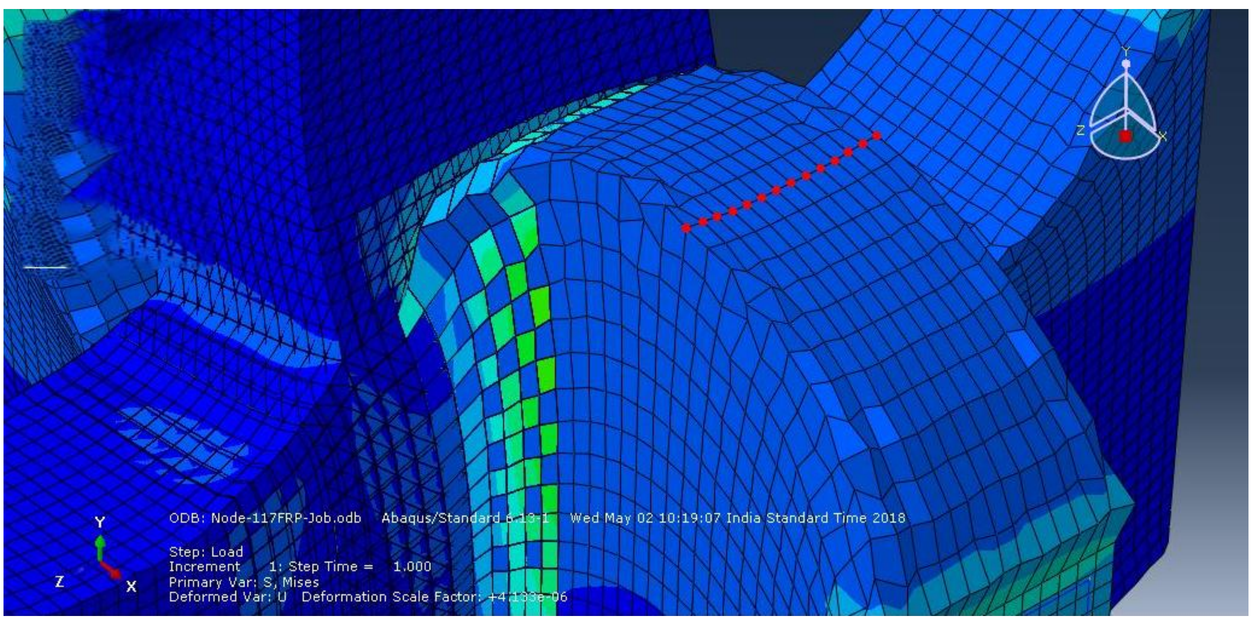
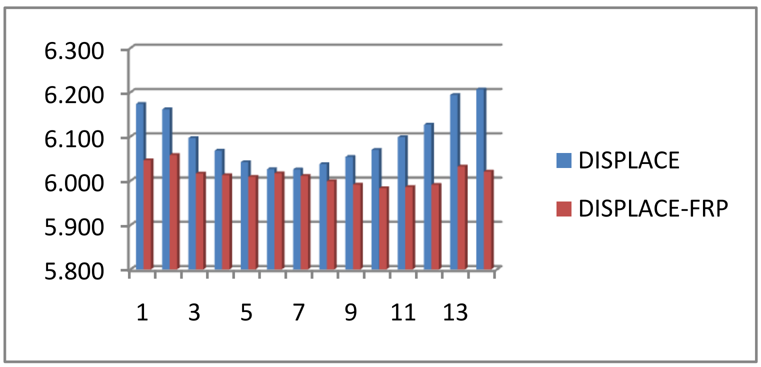
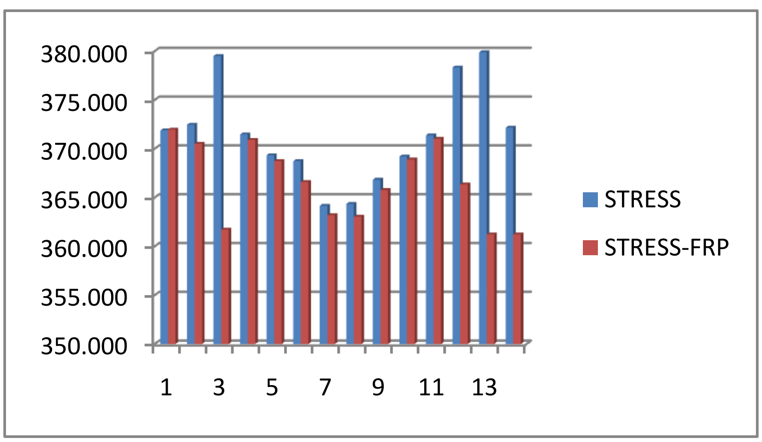


Fig. 94 : Zoomed in view of the points after FRP Wrapping

TABLE-1			
STANDARD		FRP	
STRESS(N)	DISPLACE(mm)	STRESS-FRP(N)	DISPLACE-FRP(mm)
371.882	6.174	371.975	6.046
372.459	6.162	370.503	6.058
379.508	6.097	361.714	6.017
371.466	6.068	370.907	6.013
369.326	6.042	368.732	6.009
368.732	6.026	366.587	6.017
364.153	6.026	363.199	6.011
364.345	6.038	363.038	5.999
366.828	6.054	365.768	5.991
369.211	6.070	368.897	5.983
371.377	6.099	371.021	5.986
378.330	6.127	366.350	5.991
379.892	6.194	361.215	6.032
372.152	6.207	361.215	6.021



Graph 1 : Graphical Portrayal of Stress Values with and without FRP



Graph 2 : Graphical Portrayal of Displacement Values with and without FRP

The table above shows the stress and displacement values with and without FRP Wrapping. Below them are the graphs which clearly shows the reduction in the amount of stress and displacements after the rectification.

Critical Node – (B,2,4)

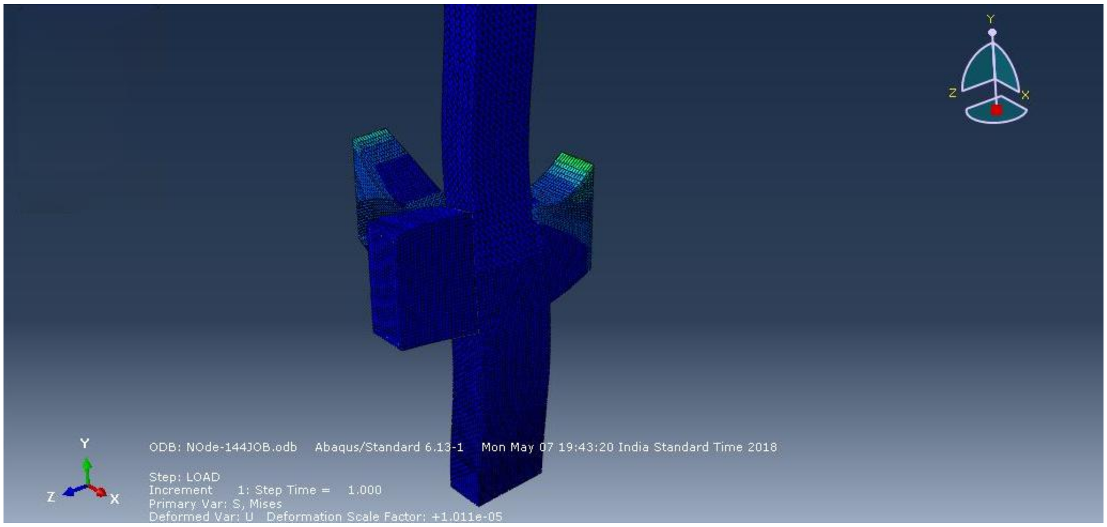


Fig. 95 : Critical Node (B,2,4) after analysis

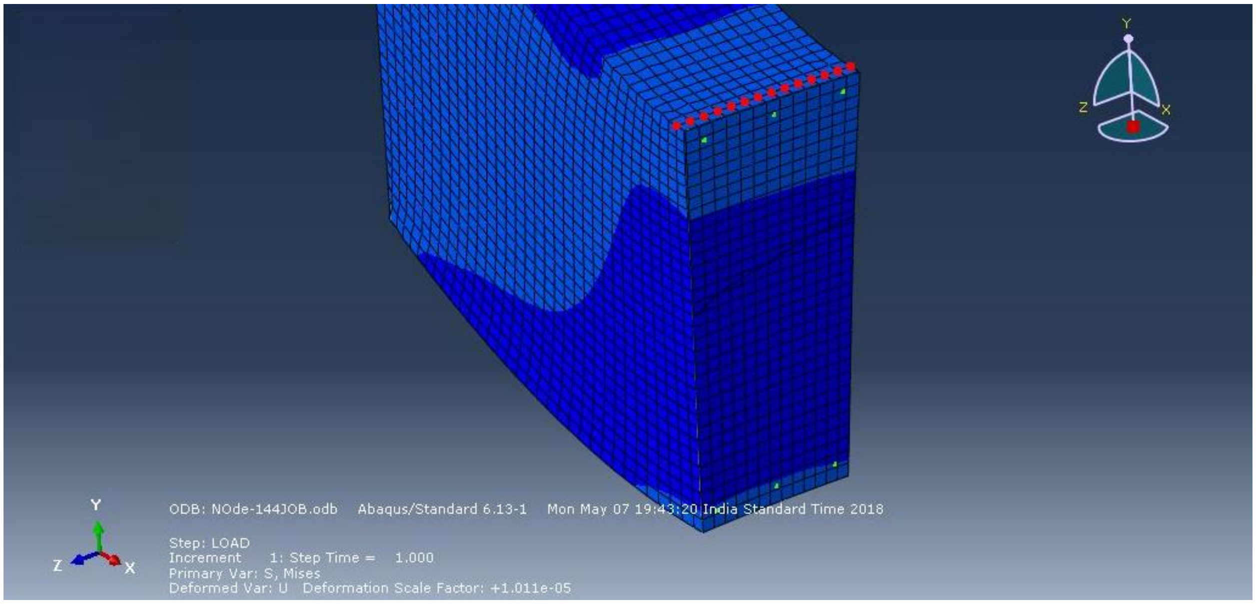


Fig. 96 : Zoomed in view of the points chosen

In the above picture the section is cut and the following points are chosen.

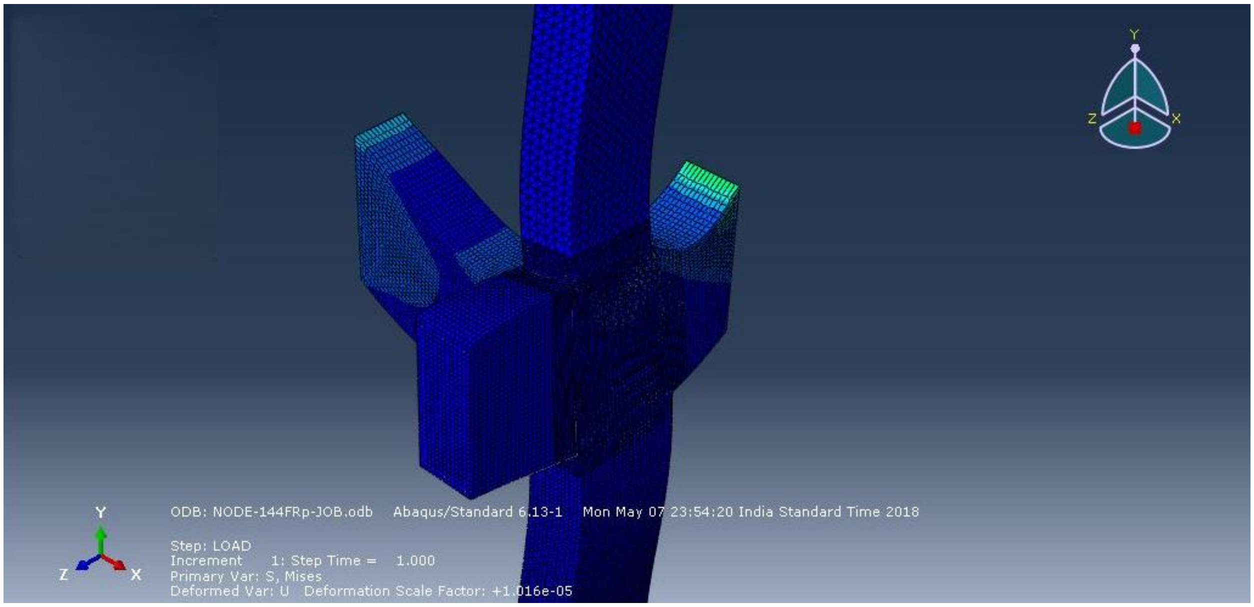


Fig. 97 : FRP Wrapped Beam Column Joint

The beam column joint is wrapped in FRP and rectangle meshing is done, thereby increasing the strength and load bearing capacity of the beam column joint and thereby rectifying it.

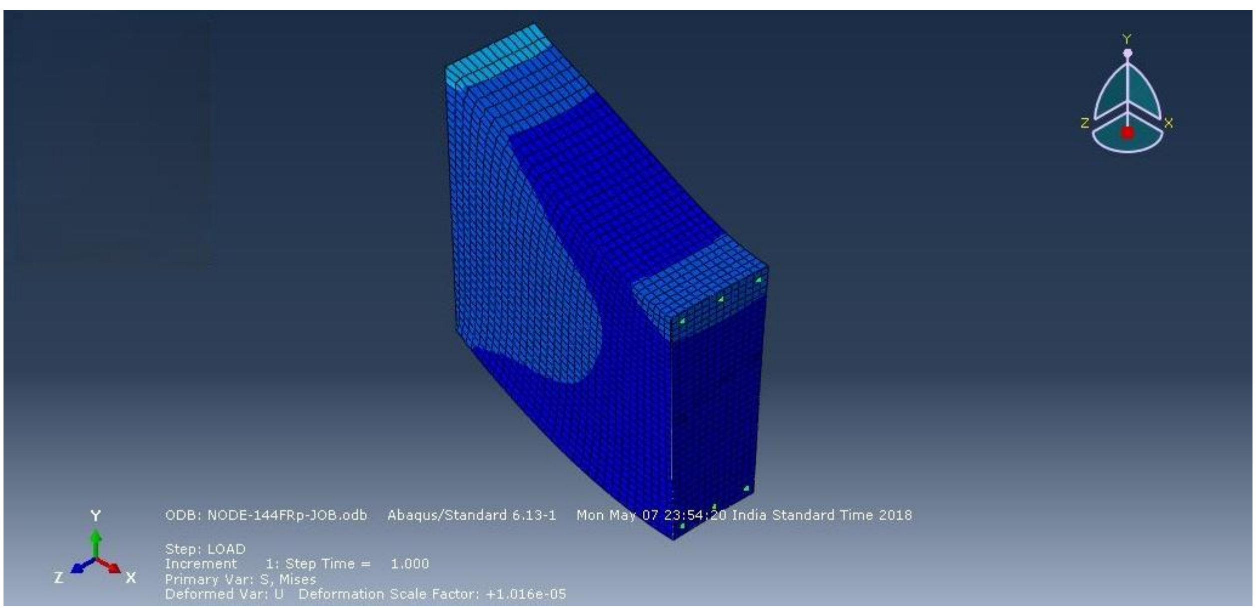


Fig. 98 : Zoomed in view of the section that is cut after the application of FRP Wrapping

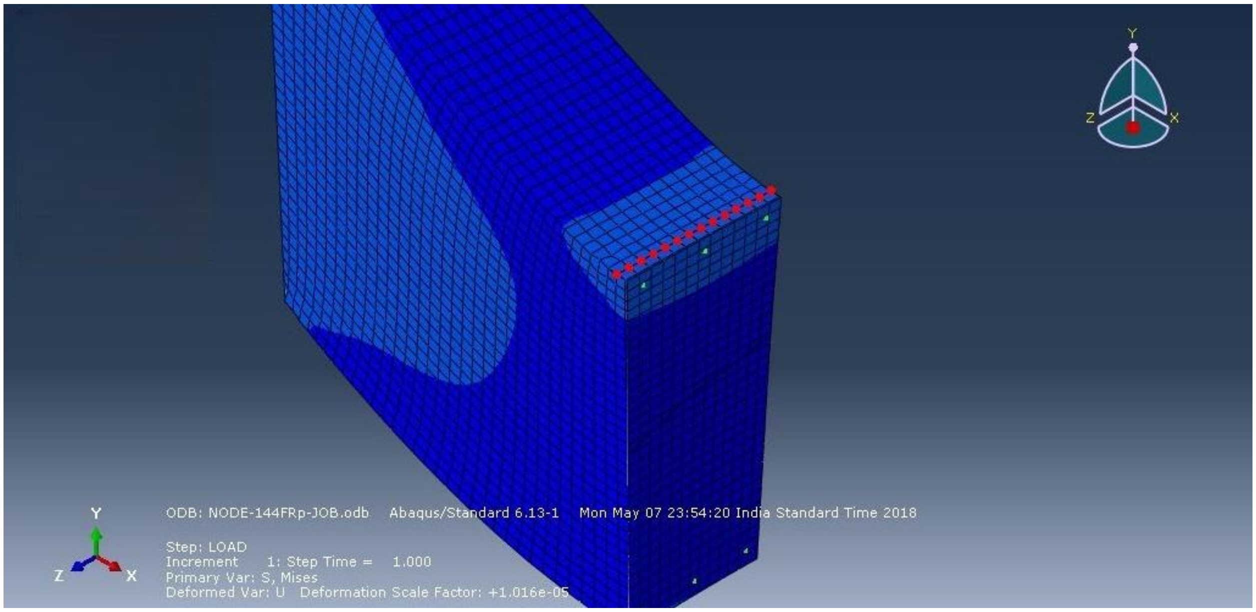
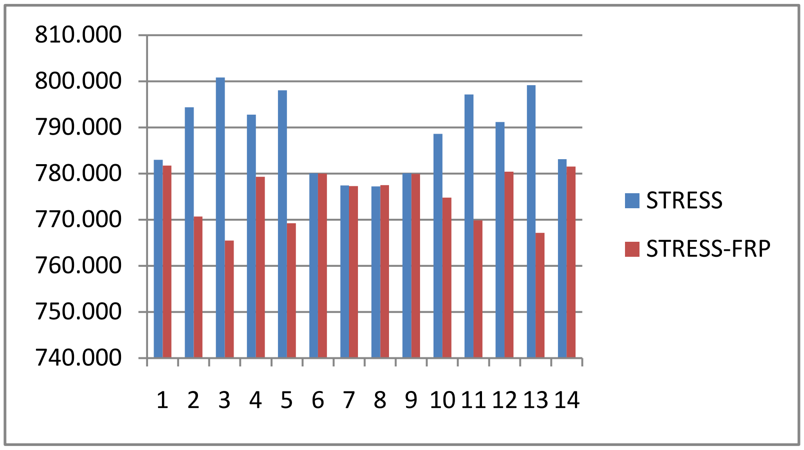
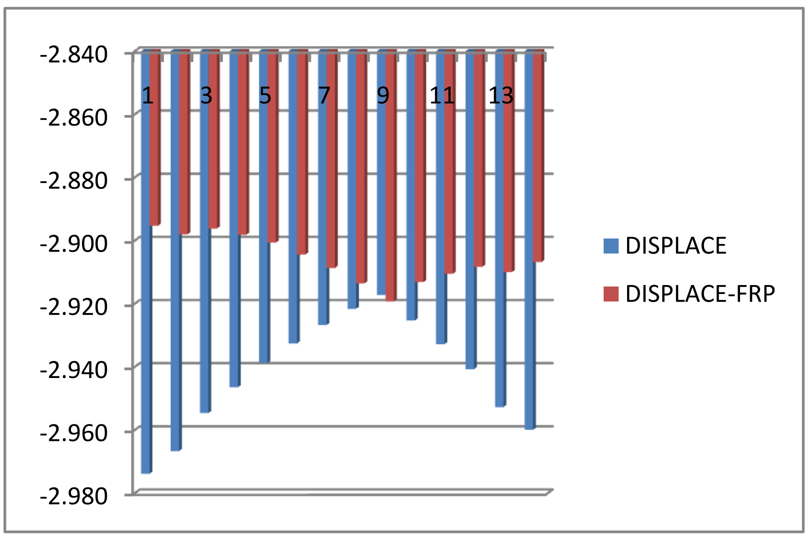


Fig. 99 : Zoomed in view of the points after rectification

TABLE-2			
STANDARD		FRP	
STRESS(N)	DISPLACE(mm)	STRESS-FRP(N)	DISPLACE-FRP(mm)
782.997	-2.974	781.720	-2.895
794.351	-2.967	770.675	-2.898
800.803	-2.955	765.462	-2.896
792.800	-2.946	779.332	-2.898
798.074	-2.939	769.223	-2.901
780.088	-2.933	779.979	-2.904
777.459	-2.927	777.263	-2.909
777.233	-2.922	777.473	-2.914
780.102	-2.917	779.945	-2.919
788.641	-2.925	774.774	-2.913
797.177	-2.933	769.874	-2.910
791.185	-2.941	780.414	-2.908
799.161	-2.953	767.175	-2.910
783.124	-2.960	781.562	-2.907



Graph 3 : Graphical Portrayal of Stress Values with and without FRP



Graph 4 : Graphical Portrayal of Displacement Values with and without FRP

The two tables above shows the stress and displacement values with and without FRP Wrapping. Next to them are the graphs which clearly shows the reduction in the amount of stress and displacements after the rectification.

Critical Node –(C,2,8)

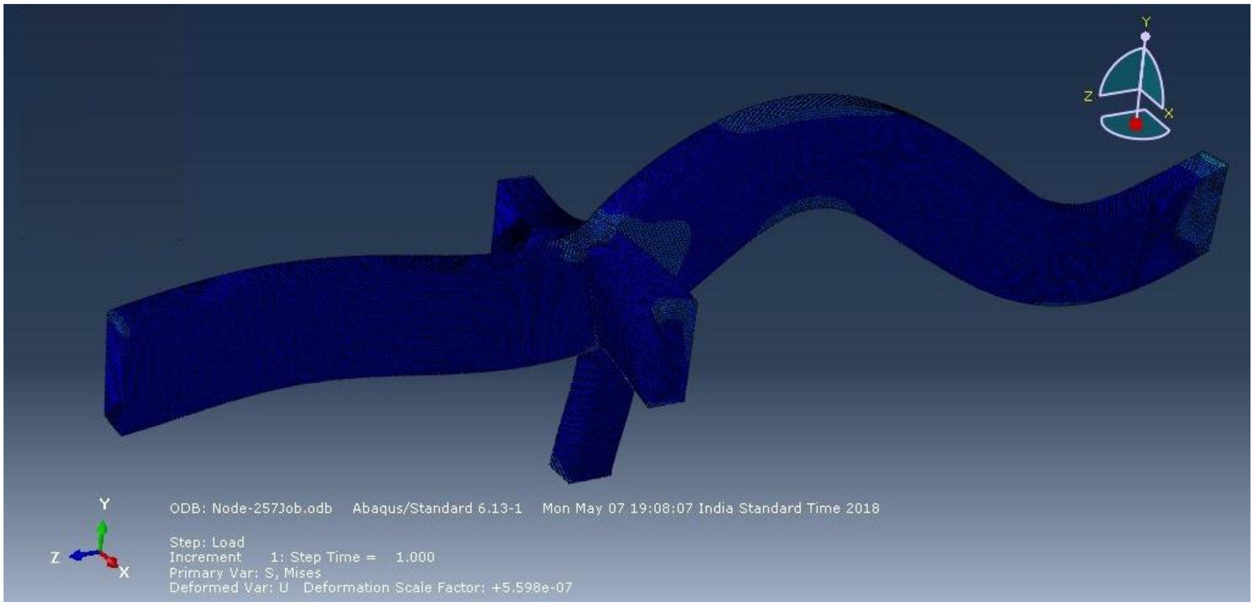


Fig.100 : Critical Node (C,2,8) after analysis

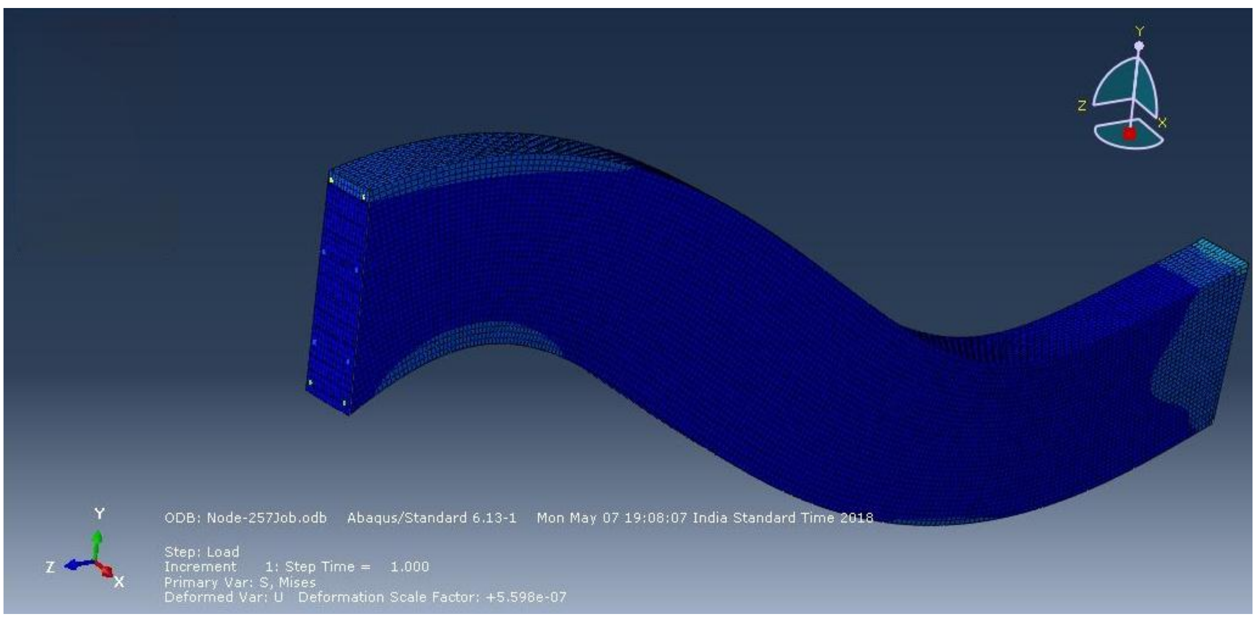


Fig. 101 : Section is cut for further steps

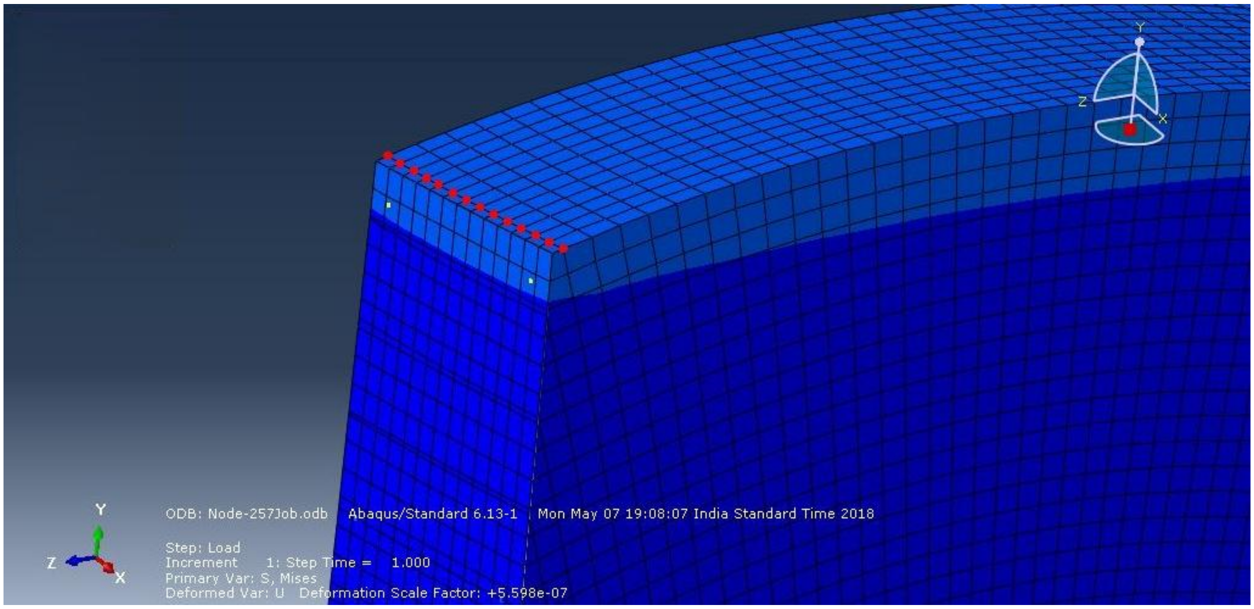


Fig. 102 :Zoomed in view of the points chosen

In the above picture the section is cut and the following points are chosen.

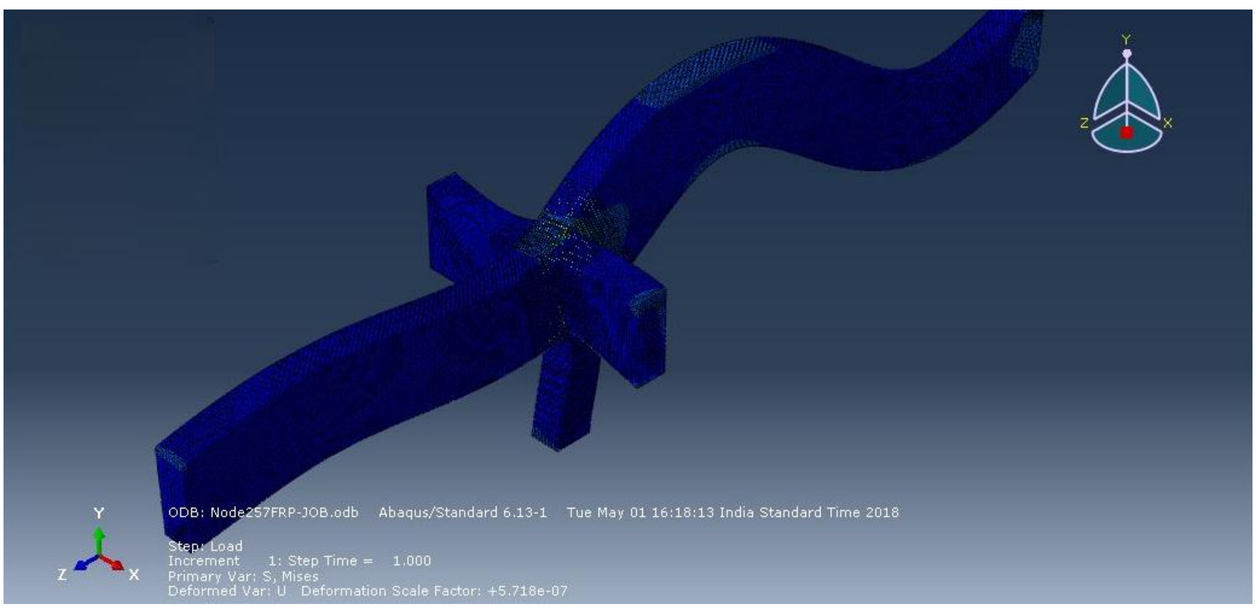


Fig. 103 : FRP Wrapped Beam Column Joint

The beam column joint is wrapped in FRP and rectangle meshing is done, thereby increasing the strength and load bearing capacity of the beam column joint and thereby rectifying it.

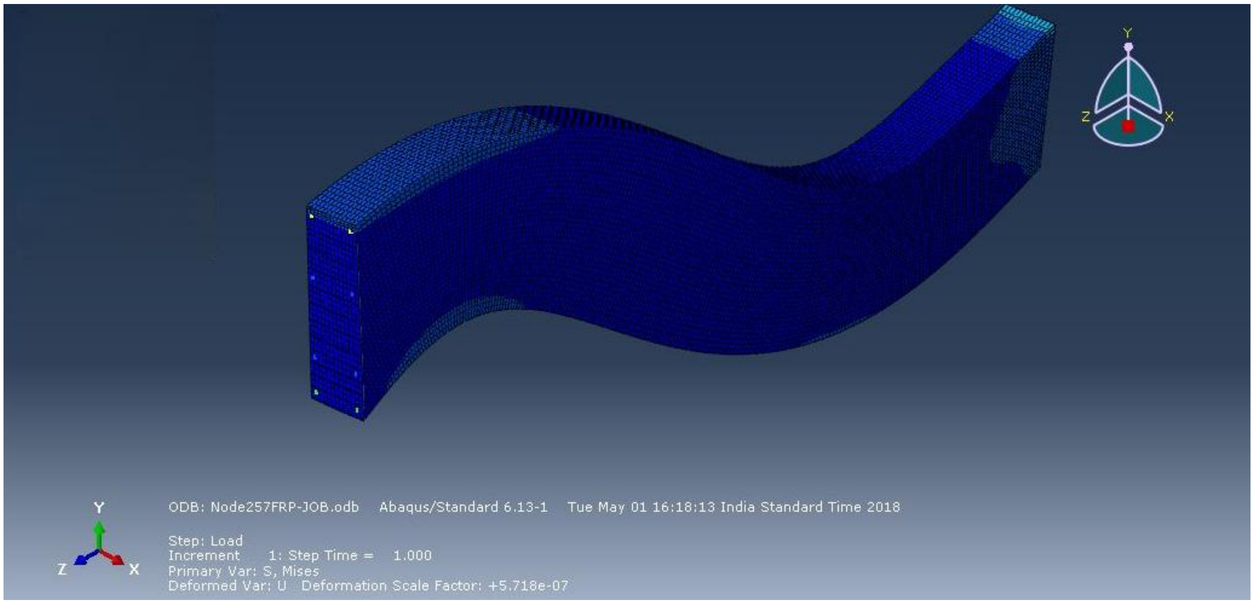


Fig. 104 : Same section is cut out after the application of the FRP Wrapping

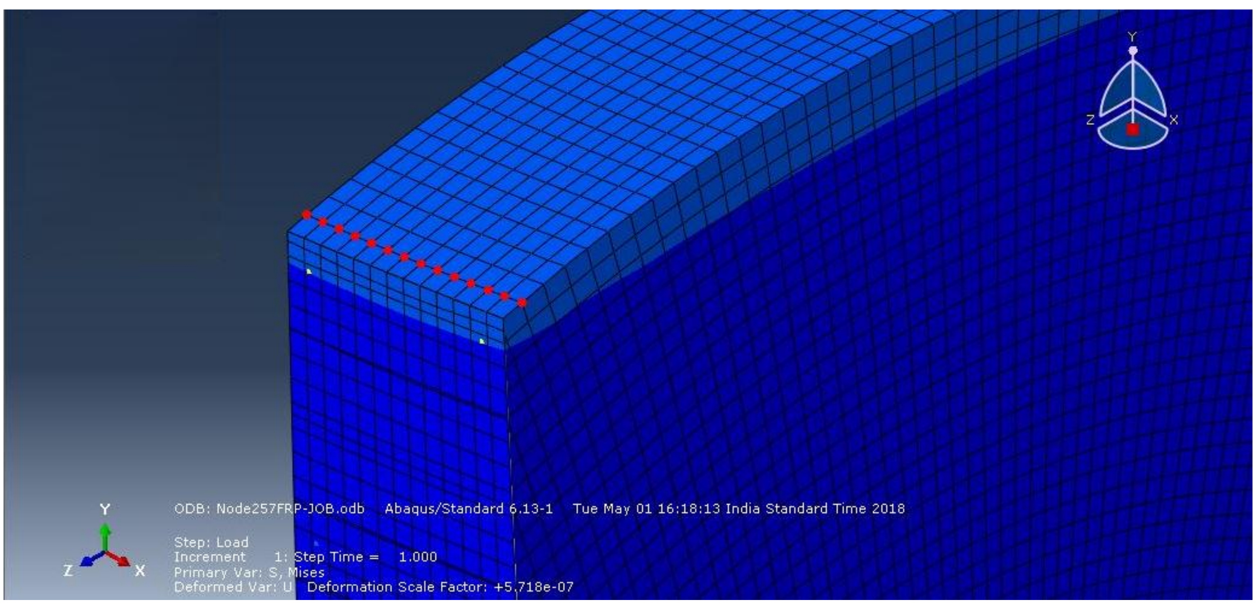
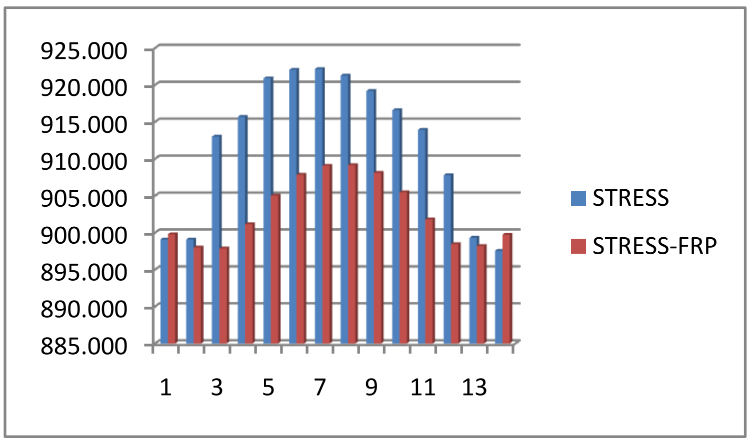


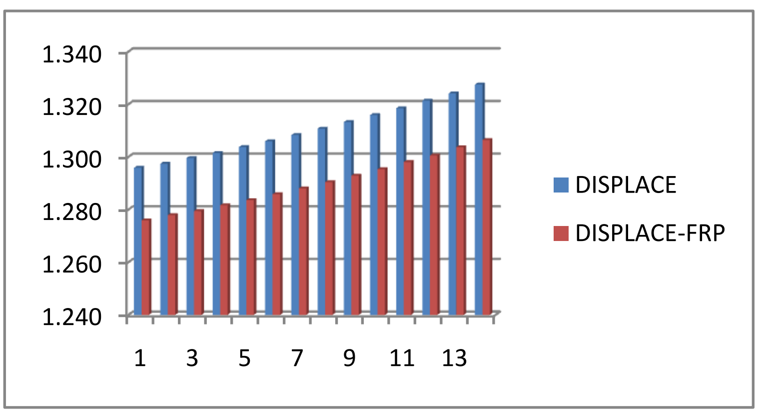
Fig. 105 : Zoomed in view of the cut out section

The points are marked again after the application of FRP Wrapping on the member.

TABLE-3			
STANDARD		FRP	
STRESS(N)	DISPLACE(mm)	STRESS-FRP(N)	DISPLACE-FRP(mm)
899.087	1.296	899.794	1.276
899.087	1.297	898.013	1.278
913.016	1.300	897.863	1.279
915.673	1.302	901.161	1.282
920.905	1.304	905.012	1.284
922.049	1.306	907.838	1.286
922.173	1.308	909.072	1.288
921.288	1.311	909.164	1.290
919.194	1.313	908.118	1.293
916.590	1.316	905.490	1.295
913.917	1.319	901.818	1.298
907.798	1.321	898.443	1.301
899.328	1.324	898.193	1.304
897.559	1.328	899.730	1.306



Graph 5 : Graphical Portrayal of Stress Values with and without FRP



Graph 6 : Graphical Portrayal of Displacement Values with and without FRP

The table above shows the stress and displacement values with and without FRP Wrapping. Below them are the graphs which clearly shows the reduction in the amount of stress and displacements after the rectification.

CHAPTER-6

Conclusion

1. The failure of beam-column joint could have been prevented if they were retrofitted and rectified in time. The loads in the structure were higher than the bearing capacity of the members which lead to the state called 'Weak column, strong beam'.
2. The use of Carbon Fiber Reinforced Polymer or CFRP reduced the stresses in the members by nearly an average of 10% which is a significant value considering the previous state of the members
3. The values of displacement were also reduced significantly by reduction around 10-15% from the non-retrofitted members compared to the member with CFRP wrapping.
4. Carbon Fiber Reinforced Polymer or CFRP is an economical choice as well because the mass to be used per beam-column joint is very less and the reduction in the stresses and displacement values is relatively good in comparison retrofitting measures.
5. The retrofitting by use of CFRP would have saved the building from facing 'Soft Storey' failure along the ground and first floors. Thus, making the building available for use in the future as well at a low cost rectification.

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