International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 7 Issue 4, July-August 2023 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Analysis and Modeling of Steel Square Hollow Beam-to-Square Hollow Column Joint

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ABSTRACT

Most of the steel structures in India are made of conventional steel sections (such as angle, channel and beam sections). However, new hollow steel sections (such as square and rectangular hollow sections) are gaining popularity in recent steel constructions due to a number of advantages such as its higher strength to weight ratio, better fire resistance properties, higher radius of gyration, lesser surface area, etc. This type of hollow sections can save cost up to 30 to 50% over the conventional steel sections. But unlike the conventional steel sections these hollow sections do not have standard connection details available in design code or in published literature. To overcome this problem the objective of the present study was identified to develop a suitable and economic connection detail between two square hollow sections which should be capable of transmitting forces smoothly and easy to be fabricated To achieve the above objective, a square hollow beam to square hollow column connection was selected and modeled in commercial finite element software ABAQUS.

This model was analyzed for nonlinear static (pushover) analysis considering a number of connection details. Following four alternative scheme of connection details were selected for this study: (i) using end-plate, (ii) using angle section, (iii) using channel sections, and (iv) using collar plates. The base model (rectangular hollow beam welded to one face of the rectangular hollow column) is also studied for reference. The performance of the selected connection details are compared and the best performing connection details is recommended for rectangular hollow beam-to- rectangular hollow column joints. The result shows that the load carrying capacity of the joint and the maximum deformation capacity is highly sensitive to the type of connection used. Also, the location of formation of plastic hinges in the structure (which can be at joint or at beam) depends highly on the type of connection used.

How to cite this paper: Md Faisal Iqbal | Prof. Afzal Khan "Analysis and Modeling of Steel Square Hollow Beam-to-Square Hollow Column Joint" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-7 | Issue-4, August 2023, pp.433-445, URL: www.ijtsrd.com/papers/ijtsrd59706.pdf

IJTSRD59706

KEYWORDS: *hollow sections, non linear (pushover) analysis, capacity curve, plastic hinge*

1. INTRODUCTION

1.1. BACKGROUND AND MOTIVATION

Most of the steel structures in India are made of conventional steel sections (such as angle, channel and beam sections) and were designed by conventional working stress methods. However, new hollow steel sections (such as square and rectangular hollow sections) are gaining popularity in recent steel constructions due to a number of advantages. Not only the hollow sections make the entire structure light weighted as they possess high strength to weight ratio, also they have higher efficiencies in resisting forces in comparison to conventional steel sections. The hollow sections also have better fire resistance properties. Higher radius of gyration, lesser surface area of the sections result savings in transportation, fabrication and painting costs. According to a recent study (Tata Steel Hollow section brochure), up to 30 to 50% saving in cost can be achieved by using hollow steel sections over the conventional steel sections. The steel industry in India started producing such hollow sections and making them available to the builders in regular basis. Fig. 1 presents photograph of typical rectangular hollow section (RHS) available in India

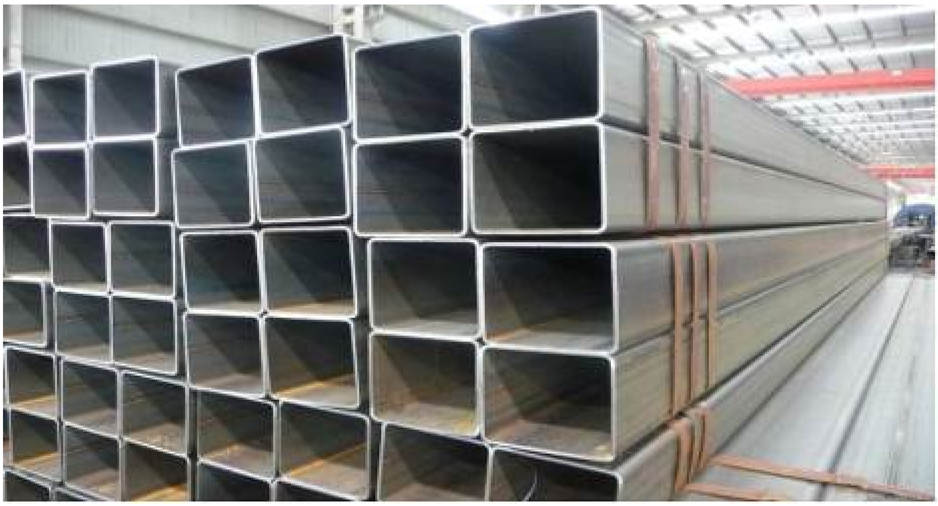


FIG. 1.1 TYPICAL RECTANGULAR HOLLOW SECTION (RHS)

2. PROBLEM IDENTIFICATION AND RESEARCH OBJECTIVES

2.1. PROBLEM IDENTIFICATION

- Only RHS or SHS sections are to be considered in this study for both column and beams.
- Sometime hollow columns are filled with concrete or other materials for improving compressive force capacity. This type of concrete filled hollow sections (CFHS) is however kept outside the scope of the present study.
- Only welded connections are to be considered.

2.2. RESEARCH OBJECTIVE

- Analyze the selected beam-to-column connection for nonlinear static analysis considering all the selected connection detail
- Model the selected connection in commercial finite element software ABAQUS

Arrive at the most suitable connection detail for the selected beam-to-column connection considering flow of the stresses or forces, load carrying capacity of the joint and the associated ductility achieved.

3. METHODOLOGY

3.1. INTRODUCTION

Different methods can be utilized to study the responses of beam-to-column joints. Experimental testing would be the most effective out of all possible methods. However, experimental methods are very costly with respect to time and money. Therefore, finite element analysis technique has been used to analyze the joint in the present study. The finite element analysis has been increased in recent days due to progressive knowledge and capabilities of computer software and hardware. The use of computer software to model components is very much faster and also very cost effective. Acceptable conclusions can be drawn by analyzing the structures through finite element analysis.

Modeling is a very important aspect in finite element analysis; accuracy of the results depend on the accuracy in modelling. For the purpose of modeling and analyzing a beam column joint involving two box sections, it is necessary to know about the element type and about their features and behaviors. It is also very important to have an idea about the different types of elements being used in FE software ABAQUS. A clear knowledge should be present on which element is better in 2D approximation and which is better for 3D approximation in ABAQUS. Therefore this chapter deals with finite element modeling including material modeling used in the present study.

This research is based on nonlinear static (pushover) analysis of selected beam to column joints. This chapter presents brief discussions on the pushover analysis procedure used in the present study.

3.2. GEOMETRIC MODELLING

As the elements required for modeling in the FE software have already been discussed in the above, now another important thing required to proceed in this research topic is the modeling of the geometry of the problem. As it has been already stated that the main objective of this work is to design a suitable connection between two box sections, the modeling part should contain box sections and other suitable sections (like angle, plate) to design a beam column connection. This part consists of the different types of proposed connection details modeled with the help of ABAQUS, their physical and FE characteristics, Boundary conditions.

3.2.1. Basic Connection

Two exactly similar square hollow sections are modelled with the help of ABAQUS and the connection is done by tie. No welding or bolting is done in this connection. The dimension of both the sections are 200×200×8 mm. Length of both the sections are 3000 mm. Boundary conditions are kept at the column ends as both sides hinged. The connection is shown in the below.

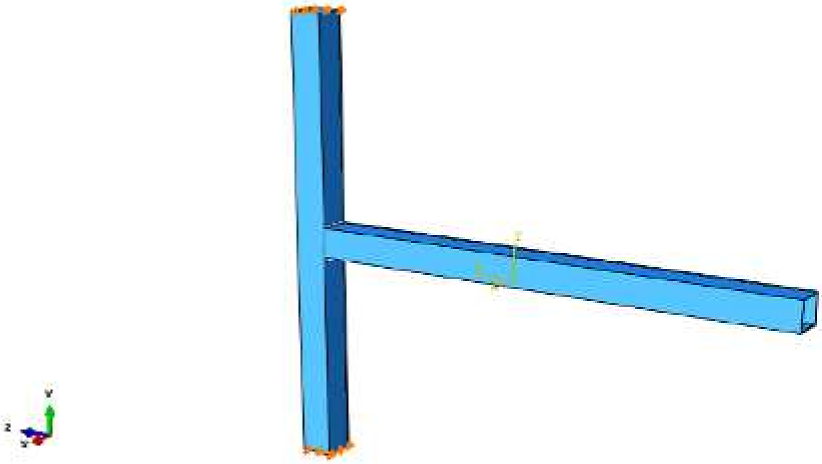


FIG 3.1: BASIC CONNECTION DETAIL

3.2.2. Connection Detail using End-plate

An end plate is connected at the beam column joint of the basic connection which is shown above. The thickness of the end plate is 10 mm. The mesh size of the end plate is kept 40mm square. The dimension of the plate is 200×1000×8.

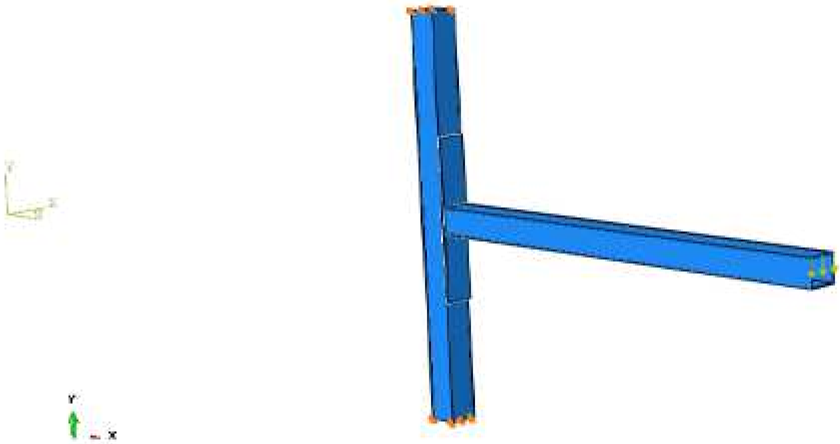


FIG 3.2 CONNECTION DETAIL USING END PLATE

3.2.3. Connection Detail using Angle Section

In this type of connection detail four angle sections are connected with the box sections at the beam column junction. The mesh size of the angle sections are kept as 45 mm square. The dimension of each angle section is 100×100×10 mm.

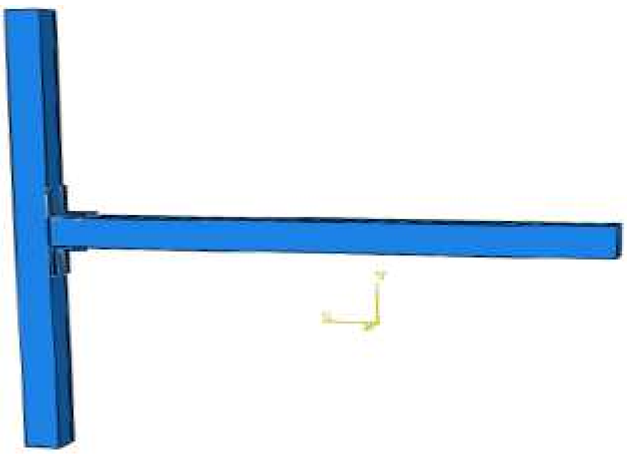


FIG 3.3: CONNECTION DETAIL USING ANGLE SECTIONS

3.2.4. Connection Detail using Channel Sections

Two channel sections are used in this type of connection detailing. They are basically used for jacketing the column section at beam column junction. The dimension of each channel section is 200×500×6 mm. The mesh size of the channel section is 40 mm square.

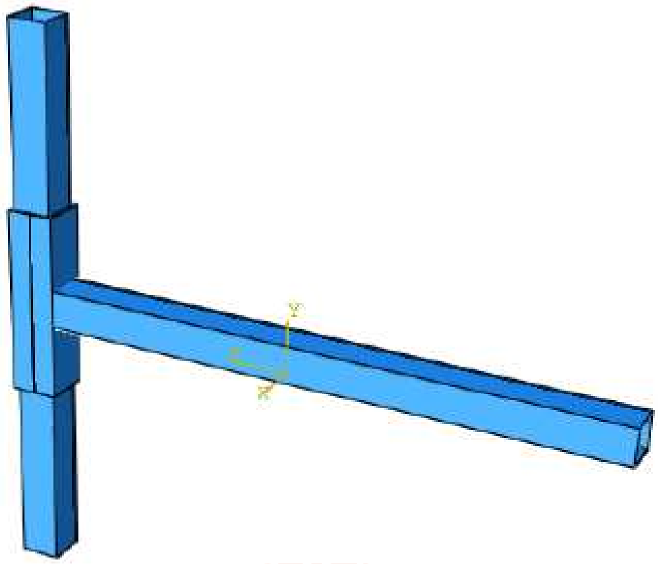


FIG 3.4: CONNECTION DETAIL USING CHANNEL SECTIONS

3.2.5. Connection Details using Collar Plate:

This type of connection consists of two collar plates and twelve triangular plates. The collar plate is made by connecting two 'C' shaped plate of thickness 10 mm welding face to face.

The collar plates thus formed is then welded at the column at the upper and lower part of the beam column junction. The triangular plates are the welded between the column face and the collar plates to make a rigid connection. The dimension of the triangular plates is taken as 200×100×8 mm. The mesh size is taken as 40 mm square.

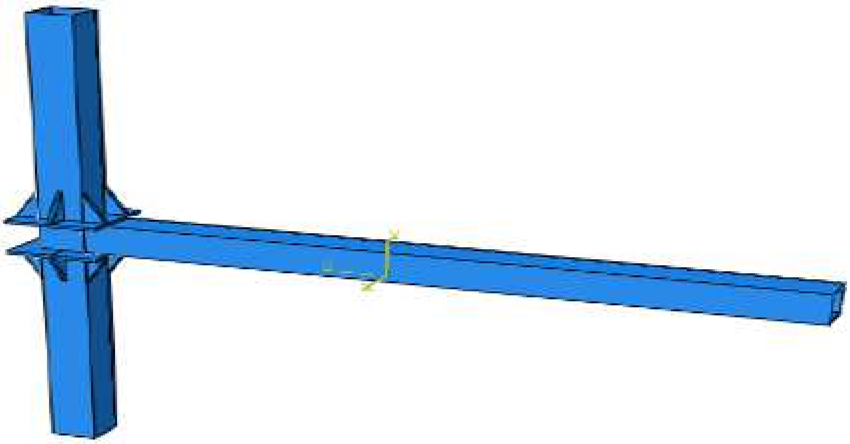


FIG 3.5: CONNECTION DETAIL USING COLLAR PLATES

3.3. MATERIAL MODELLING

Linear elastic analysis does not reflect the true behavior of structure under ultimate loads, and it becomes necessary to model the material non-linearity when the structure is subjected to large deformations (due to forces like earthquake). To model the material nonlinearity in the present study stress strain curve of steel is considered as per. the stress-strain relation of mild steel used in the present study. The characteristic strength of steel in tension and compression is assumed to be same as 250 MPa. The slope of the strain hardening portion of the curve is after removal of elastic curvature component. This stress strain relationship curve of mild steel has also been used in the research work titled use of external t-stiffeners in box-column to I-beam connections.

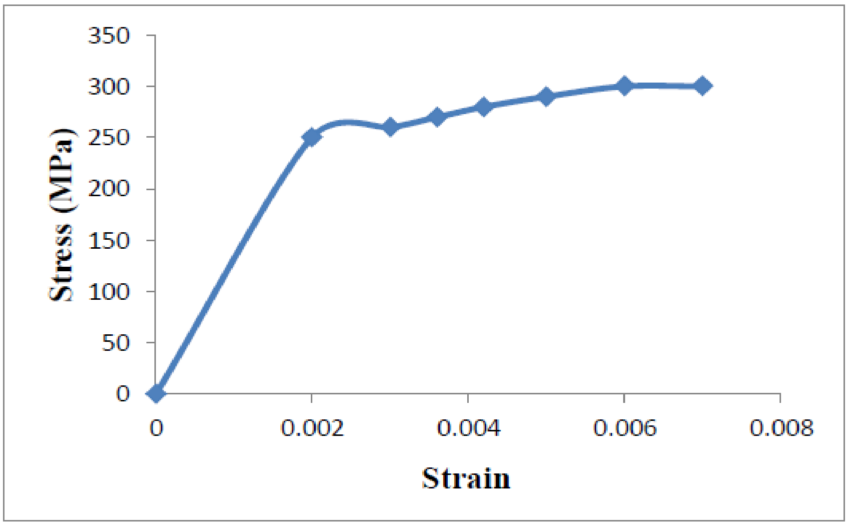


FIG 3.6: STRESS STRAIN CURVE FOR MILD STEEL USED IN PRESENT STUDY

3.4. NON LINEAR PUSH OVER ANALYSIS

Pushover analysis is a static, nonlinear procedure in which the magnitude of the structural loading (or displacement) is incrementally increased in accordance with a certain predefined pattern. In the present study a point load is applied at the tip-end of the beam and the load is incrementally increase using displacement controlled approach. With the increase in the magnitude of the displacement, weak links and failure modes of the beam-to-column joints are found. Local nonlinear effects are modelled through specifying nonlinear stress-strain behaviour and the tip end of the beam is pushed until collapse mechanism is formed. At each step, the total shear force reaction at the fixed end of the beam and the displacement of the free tip-end of the beam are plotted (Capacity Curve).

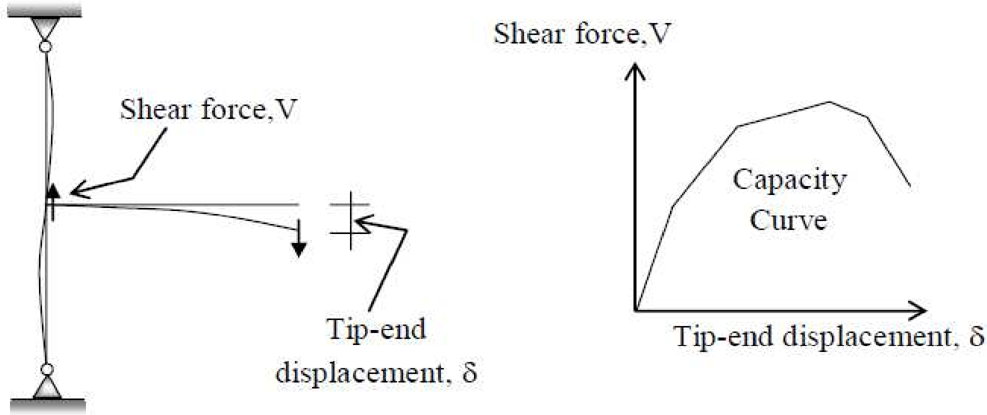


FIG. 3.7: PUSHOVER ANALYSIS

4. RESULT AND DISCUSSION

4.1. INTRODUCTION

As discussed in the previous chapter, the main objective of this research work is to develop a suitable connection between two box sections considering welding connective. To achieve this objective, the first thing to be considered is the parameters required to accomplish this work. From the extensive literature review which has been done for this research work, some inherent difficulties have been found out while designing a suitable connection between two hollow sections. The main difficulty is that the works which have done previously are basically between one hollow section and one conventional section. So direct extensions from that connection details is not feasible due to geometric differences. For this some new parameters should also be considered. So in this chapter firstly a Fe analysis is done for the model consisting two Square Hollow sections with the help of ABAQUS software up to failure. Then analysing the results the main parameters like flow of forces, location of the formation of plastic hinge are sorted out and then some proposed connection details have been modeled fulfilling the criteria. Then a thorough comparative analysis has been done among the proposed connection details to select the best connection detail for the problem in all aspects.

So this chapter consists of modeling and analysis of the proposed connection details fulfilling the criteria of designing a suitable connection detail and selection of the best possible connection detail among the proposed ones.

4.2. BASIC CONNECTION DETAIL

To proceed in the current research work two suitable hollow sections have been chosen from the Indian Steel table. In this case two square hollow sections are chosen which are identical. Dimensions of the sections are 200×200 8 mm. The length of both the sections is taken as 3000mm. The modeling part and the mesh sizes have been stated in the previous chapter. Then the sections are assembled as abeam column structure. The assembled structure has been shown in figure 4.1. Boundary conditions at both the ends of the column are kept as hinged and load is applied at the tip of the beam.

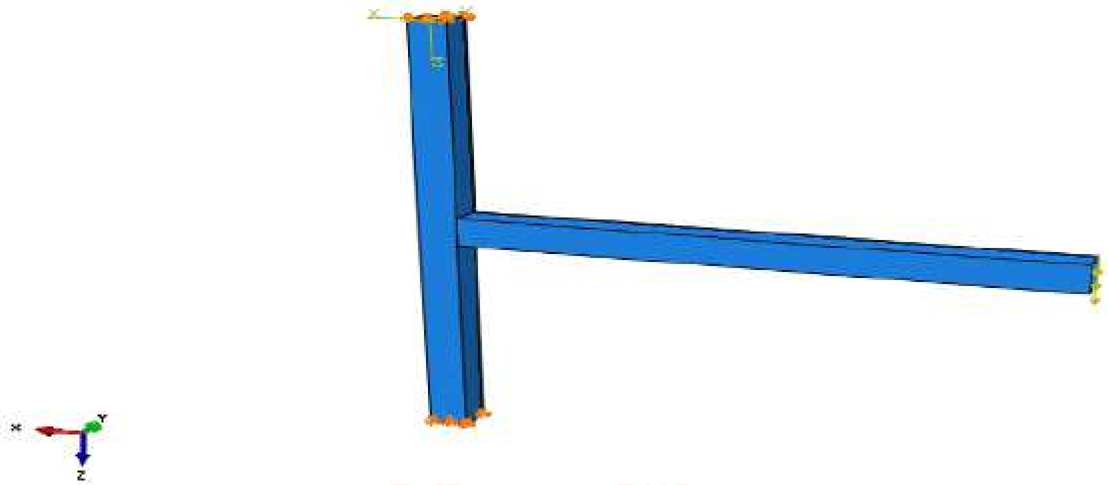


FIG 4.1 BASIC CONNECTION DETAIL

Applying the load at the tip of beam the structure is analysed with the help of ABAQUS software till the failure occurs. After the analysis it is seen that the major stress concentration is found at the beam column joint of the structure which has been shown in figure 4.2 which means that plastic hinge is formed at the column which is not good for a seismic connection. For a seismic connection the formation of plastic hinge should be away from the beam column joint. The other basic observation made form the analysis is that the flow of maximum principle force is from the beam centreline to the column web.

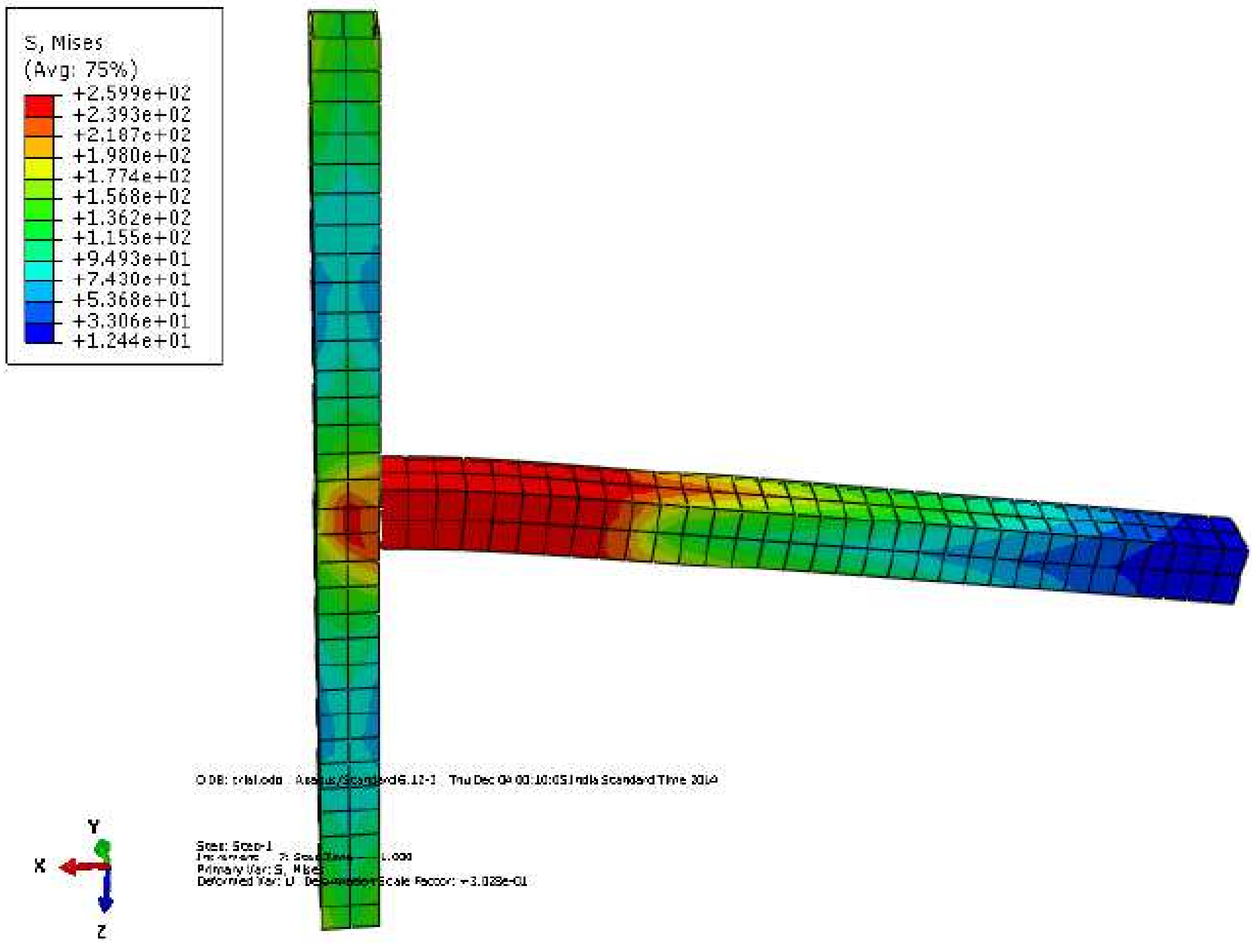


FIG 4.2 STRESS DISTRIBUTION AT FAILURE

4.3. PROPOSED CONNECTION DETAILS

As the observations from the analysis of the basic connection detail show that formation of plastic hinge and the path of the force flow is not good for a suitable seismic connection, some new connection details between the existing structures have been proposed to overcome the above mentioned difficulties. The basis of selections of the appropriate connection details are as follows.

- The connection detail should reduce stress intensity at the column face and push the location of energy dissipating plastic hinge away from the column face
- It should allow a smooth transfer of beam shear to column webs
- It should be capable of resisting larger deformations without fracture
- Strength and stiffness are to be sufficiently large.

Keeping the above points in mind some alternative connection details have been proposed. The descriptions, analysis and results of those proposed connection details are given in the below.

4.3.1. Scheme 1: Using End-plate:

In this type of connection detail a plate of thickness 8 mm is welded at the beam column junction of the structure as shown in figure 4.3. The dimension of the plate provided is 200×1000×8 mm. The main objective of providing the plate between the beam section and the column section is to reduce stress intensity at the column face and push the location of energy dissipating plastic hinge away from the column face.

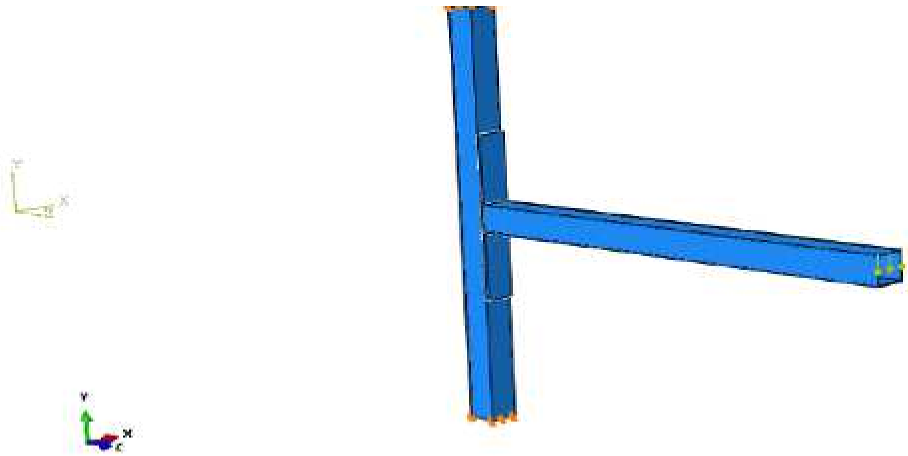


FIG 4.3 CONNECTION DETAIL USING END PLATE

The structure is then analysed by FE software ABAQUS after applying downward deflection at the tip of the beam. Deflection at the tip is gradually increased till it fails. The stress distribution of the structure at failure is shown in figure 4.4.

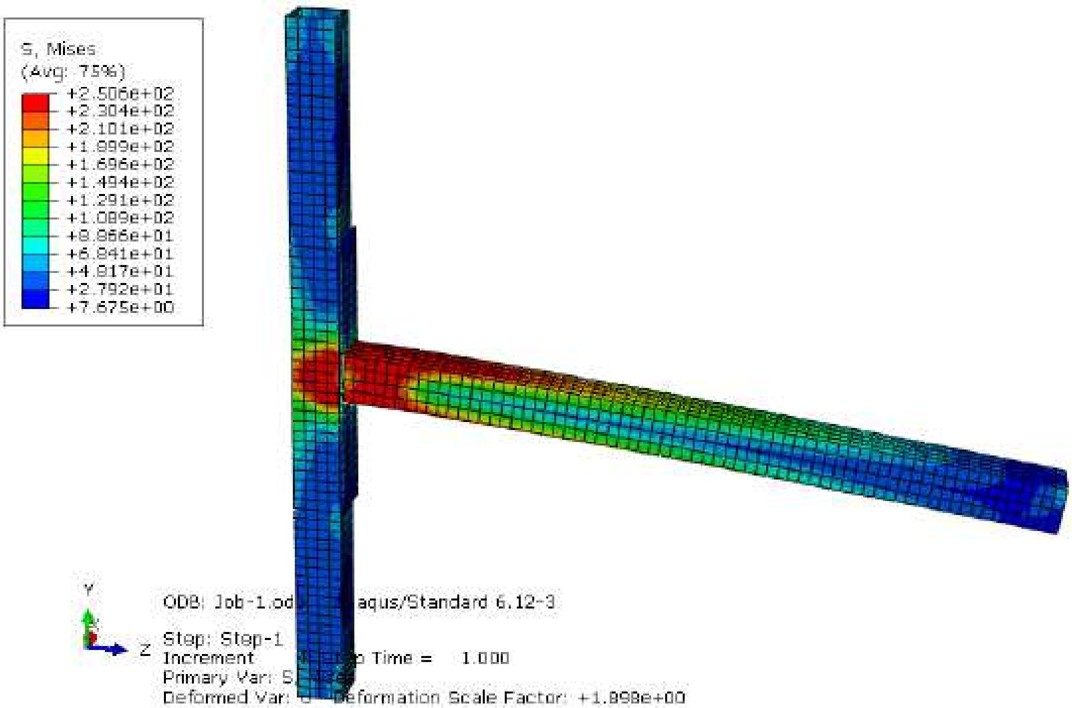


FIG 4.4 STRESS DISTRIBUTION AT FAILURE

The results show that ultimate load carrying capacity of this connection is moderate but the displacement ductility is not up to the mark. The stress distribution also shows that maximum stress is concentrated at column face of the beam column junction. So, the purpose of trying to shift the formation plastic hinge away from the column face is also not satisfied.

4.3.2. Scheme 2: Using Angle Sections:

This type of connection consists of four equal angle sections welded at four corners of the beam column joint. The dimension of each angle section is 100×100×10 mm. The main purpose of providing the angle sections at the joint is to reduce the stress intensity at the column face and to achieve a moderate ductility. The connection detail is shown in figure 4.5.

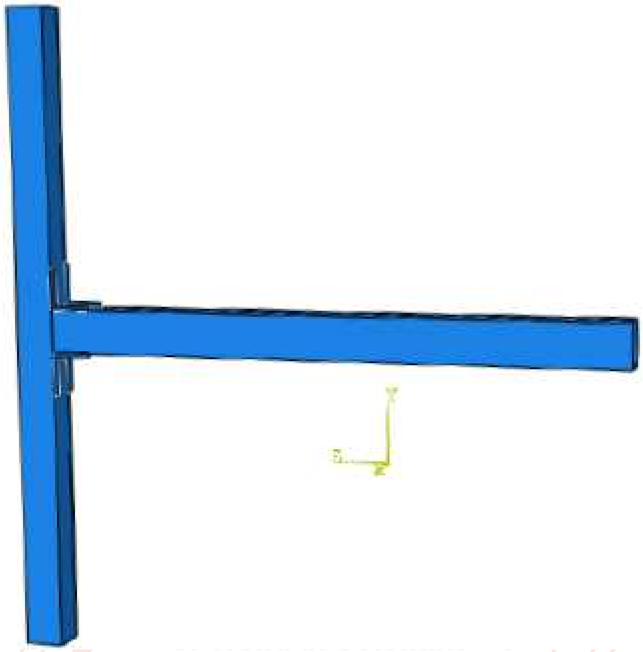


FIG 4.5: CONNECTION DETAIL USING ANGLE SECTIONS

The structure is then analysed by FE software ABAQUS after applying downward deflection at the tip of the beam. Deflection at the tip is gradually increased till it fails. The stress distribution of the structure at failure is shown in figure 4.6.

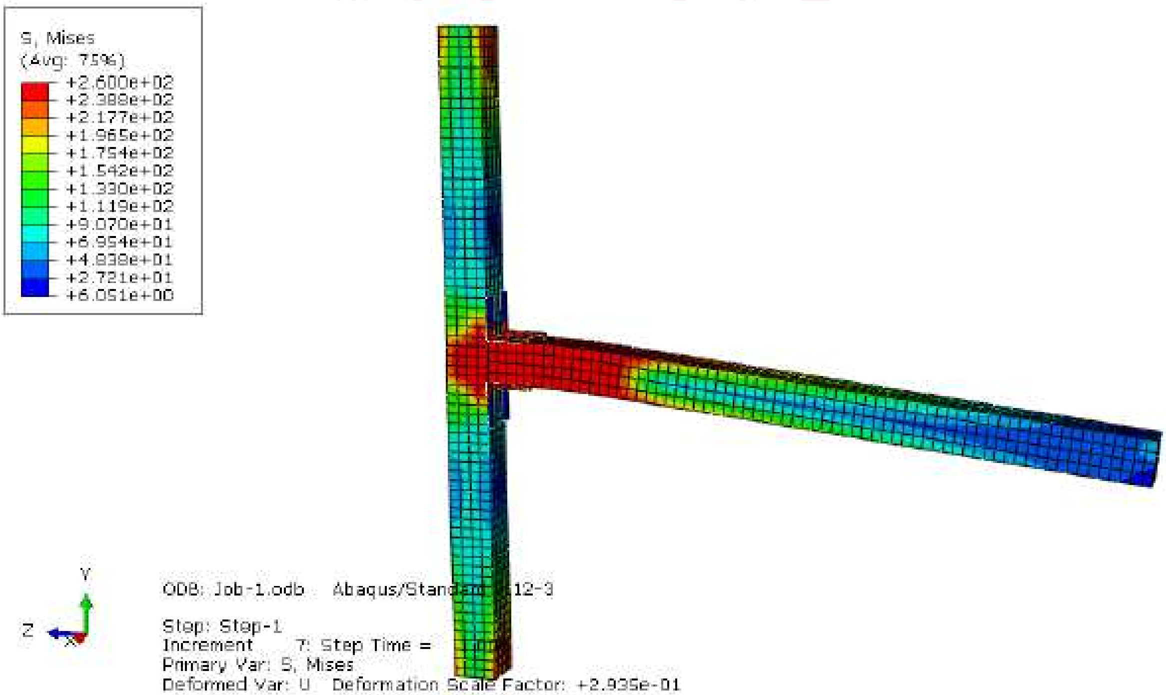


FIG 4.6 STRESS DISTRIBUTION AT FAILURE

The result shows that the ultimate carrying capacity of this type connection is greater than the previous connection detail and the ductility is also better. But this connection is also not capable enough to reduce the stress intensity at the column face as it is shown in figure 4.6.

4.3.3. Scheme 3: Using Channel Section:

In this type of connection steel jacketing is used. Two equal channel sections are used to jacket the column at the beam column junction. The dimension of each channel section is taken as 200×500×6 mm. This type of connection detail is used to achieve a higher ultimate load and to reduce the stress at the column face by thickening the column. The connection detail is shown in figure 4.7.

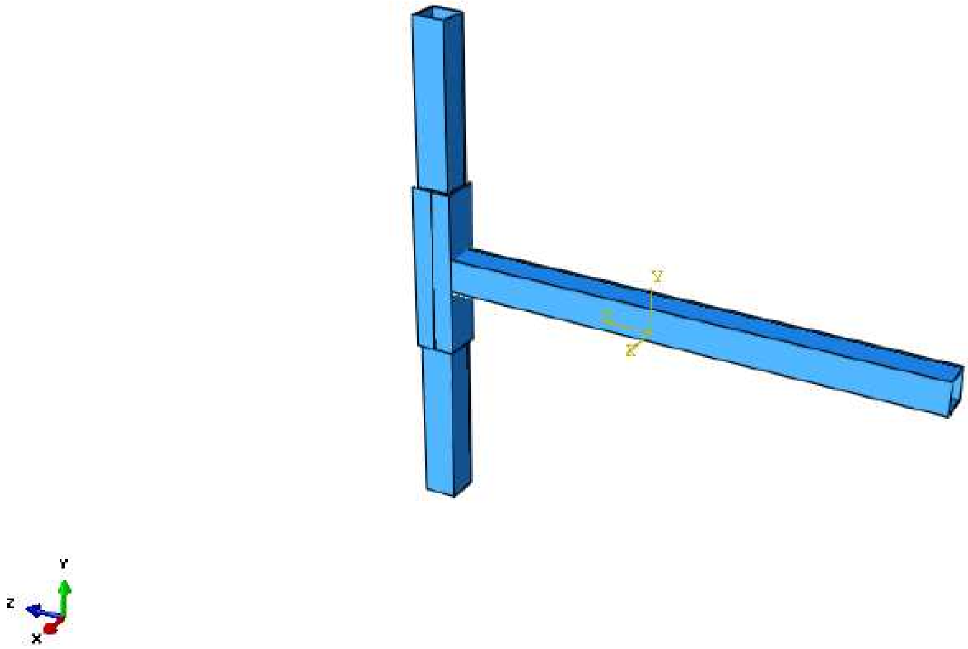
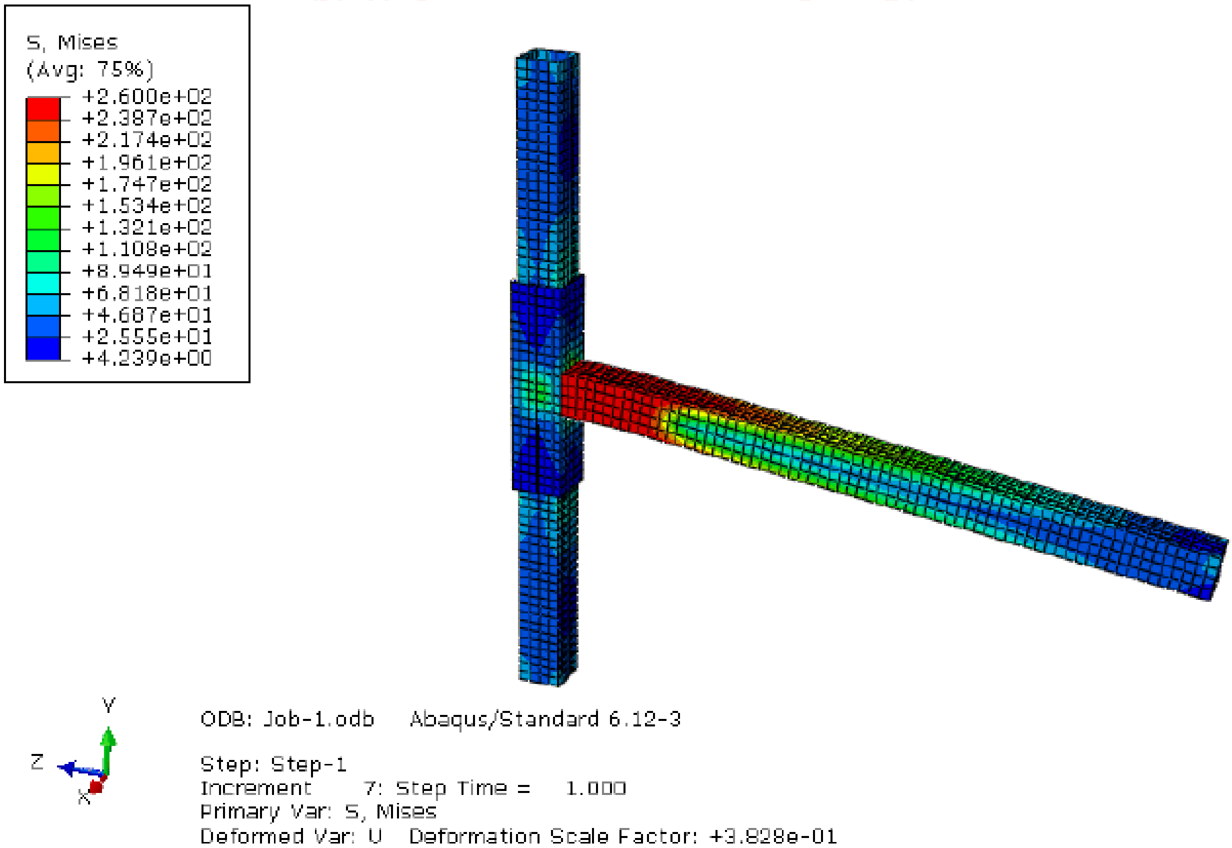


FIG 4.7: CONNECTION DETAIL USING CHANNEL SECTIONS

The structure is then analysed by FE software ABAQUS after applying downward deflection at the tip of the beam. Deflection at the tip is gradually increased till it fails. The stress distribution of the structure at failure is shown in figure 4.8.



The result shows that the ultimate load carrying capacity is very much higher than the previous two connections. From the figure 4.8 it can be also seen that at failure the stress intensity at the column face is very less. So the objective of reducing the stress intensity at the column is achieved. But the main drawback of this type of connection is displacement ductility is not that much high.

4.3.4. Scheme 4: Using Collar Plate:

This type of connection consists of two collar plates and twelve triangular plates. The collar plate is made by connecting two 'C' shaped plate of thickness 10 mm welding face to face.

The collar plates thus formed is then welded at the column at the upper and lower part of the beam column junction. The triangular plates are the welded between the column face and the collar plates to make a rigid connection. The dimension of the triangular plates is taken as 200×100×8 mm. The connection detail is shown is figure 4.9. The main objective for designing this type connection is to achieve a higher ductility value and a greater ultimate load at failure.

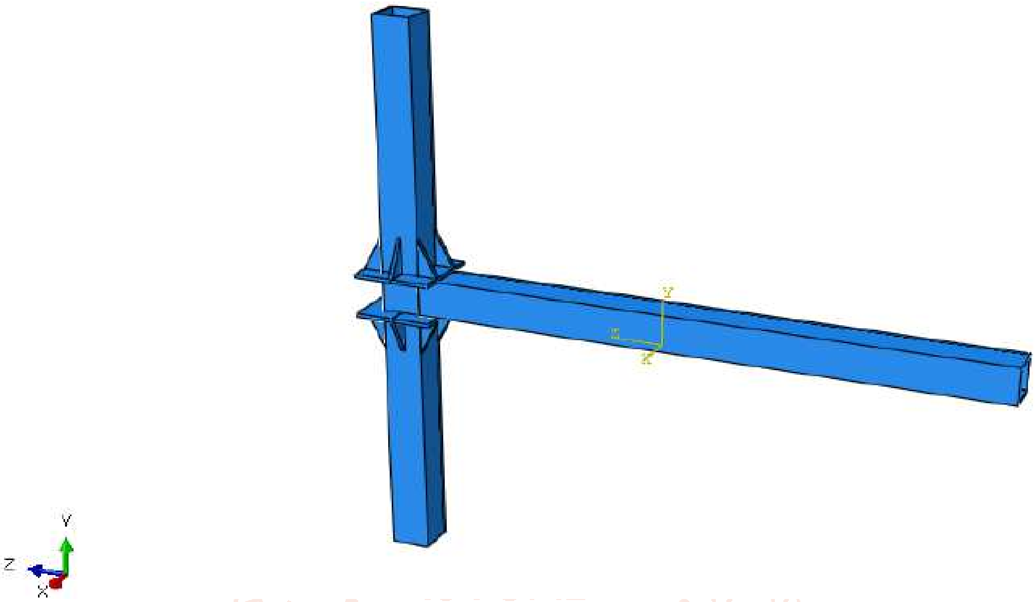
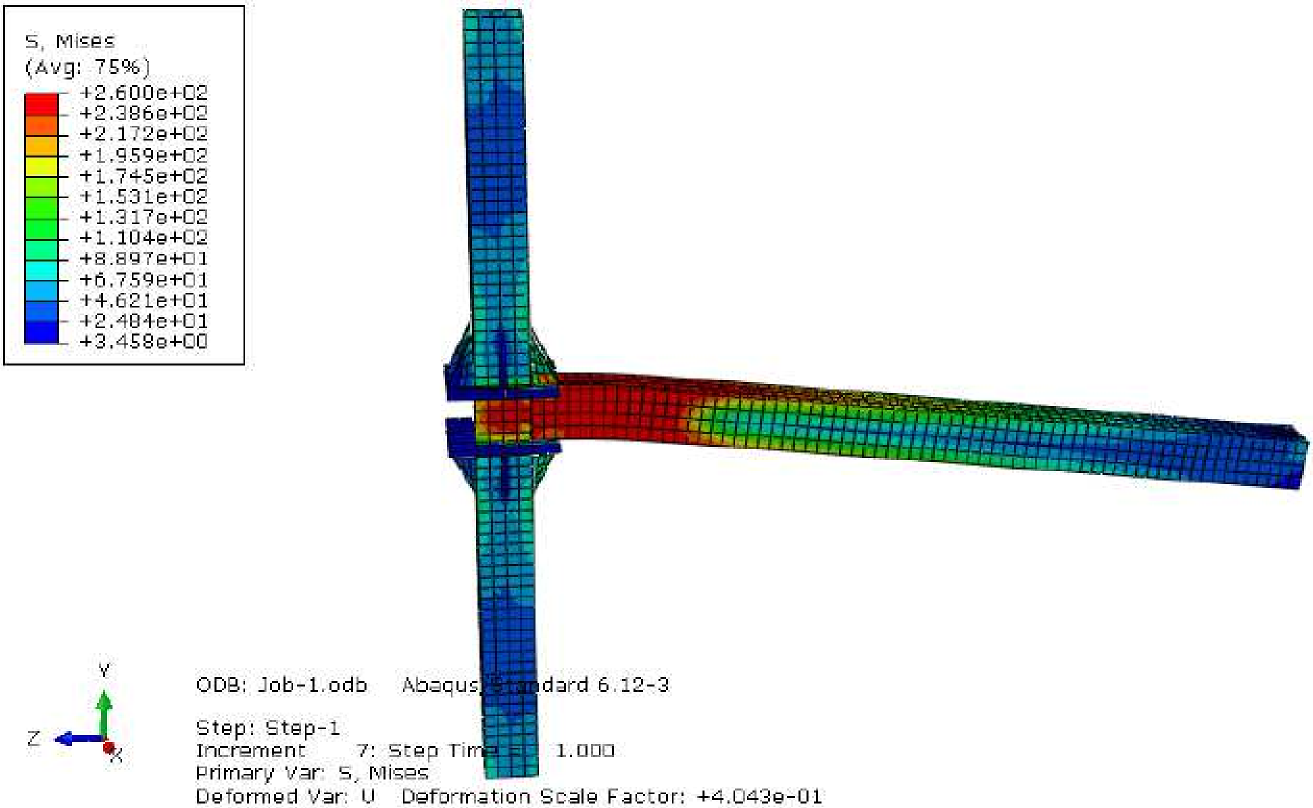


FIG 4.9: CONNECTION DETAIL USING COLLAR PLATES

The structure is then analysed by FE software ABAQUS after applying downward deflection at the tip of the beam. Deflection at the tip is gradually increased till it fails. The stress distribution of the structure at failure is shown in figure 4.10.



The result shows that though the ductility value is satisfactory but ultimate load carrying capacity is not greater the previous connection detail. From figure 4.10 it is also seen that the connection is not capable to reduce the stress at the column face of the beam column joint.

4.4. CAPACITY CURVES

This section presents the comparison of the capacity curves obtained from pushover analysis of the joint for different schemes of connection details. Fig. 4.11 compares the performance of selected connection details through the resulting capacity curves of the joint. The important characteristics of these curves are presented in Table 4.1. This figure (and the table) shows that the load carrying capacity of the joint and the maximum deformation capacity is highly sensitive to the type of connection used. The table shows that ultimate shear force capacity of the joint may vary 267 kN in basic model (welded) to 506 kN in Scheme 3 (an increase of almost 90%). Similarly, the deformation at collapse is varying from 306 mm in basic model to 627 mm in Scheme 3 (an increase of about 105%).

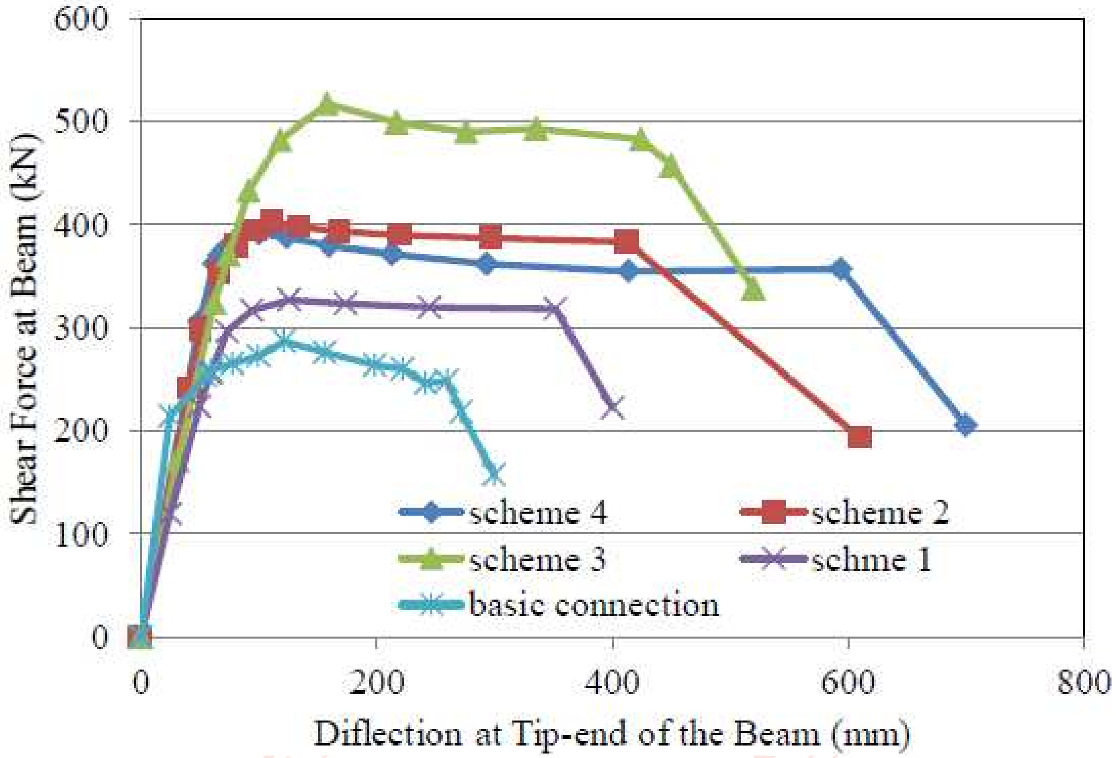


FIG. 4.11: COMPARISON OF CAPACITY CURVES FOR DIFFERENT SCHEME OF CONNECTIONS

TABLE 4.1: PUSHOVER ANALYSIS RESULTS OF THE JOINT FOR DIFFERENT SCHEME OF CONNECTIONS

Connection Scheme	Maximum Strength (kN)	Yield Deformation (mm)	Ultimate Deformation (mm)	Ductility Factor	Formation of Plastic Hinge at
Basic	267	76	306	3.98	Beam-to-Column Joint
Scheme-1	315	104	413	3.97	Beam-to-Column Joint
Scheme-2	404	100	592	5.92	Beam-to-Column Joint
Scheme-3	**506**	**152**	**627**	**4.20**	**Beam**
Scheme-4	398	98	587	5.99	Beam-to-Column Joint

The results presented in Table 4.1 clearly shows that the performance of the joint with connection details of Scheme 3 performs best among others with respect to the ultimate load and deformation at collapse. Table 4.1 also presents the location of the formation of plastic hinge during the inelastic deformation. This data confirms the effectiveness of Scheme 3 as the plastic hinge form in this scheme in the beam-end away from beam-to-column joint whereas in all other cases the formation of plastic hinges occur in the beam-to-column joint.

5. CONCLUSION AND FUTURE SCOPE

5.1. SUMMARY

New hollow steel sections (such as square and rectangular hollow sections) are gaining popularity in recent steel constructions in India due to a number of advantages (such as: high strength to weight ratio, higher efficiencies in resisting forces, better fire resistance properties, Higher radius of gyration, lesser surface area). Unlike the conventional steel sections these hollow sections do not have standard connection details available in design code or in published literature. To overcome this problem the objective of the present study was identified to develop a suitable and economic connection detail between two hollow sections which should be capable of transmitting forces smoothly and easy to be fabricated.

To achieve the above objective, a square hollow beam to square hollow column connection was selected and modeled in commercial finite element software ABAQUS. This model was analysed for nonlinear static (pushover) analysis considering a number of connection details. Following four alternative scheme of connection details were selected for this study: (i) using end-plate, (ii) using angle section, (iii) using channel sections, and (iv) using collar plates. The base model (rectangular hollow beam welded to one face of the rectangular hollow column)

The performance of the selected connection details are compared and the best performing connection details is recommended for rectangular hollow beam-to- rectangular hollow column joints.

5.2. CONCLUSIONS

The important conclusions drawn from the present study are listed as follows:

A. Load carrying capacity of the joint and the maximum deformation capacity is highly sensitive to the type of connection used.

B. Ultimate shear force capacity of the joint found to vary from 267 kN in basic model (welded) to 506 kN in Scheme 3 (using channel) with an increase of almost 90%. Similarly, the deformation at collapse is varying from 306 mm in basic model to 627 mm in Scheme 3 (an increase of about 105%).

C. The formation of the plastic hinge is usually found to occur at the beam-to-column joint for all the different schemes of connection details except Scheme 3. Scheme 3 results the plastic hinge in the beam end away from joint.

D. Performance of the joint with connection details of Scheme 3 (columns jacketed with two channel sections and connected with beam by welding) performs best among others with respect to the ultimate load, deformation at collapse and formation of plastic hinges.

5.3. FUTURE SCOPE

This study can be further extended as follows:

A. Present study is based on exterior beam-to-column joints. Similar study can be executed for interior beam-to column joints

B. This study considers equal beam and column sections in the selected joints. It will be interesting to study the responses of the joint with varying dimensions of beam and column sections.

C. Results in this study are based on nonlinear static (pushover analysis). This can be extended to include nonlinear dynamic analyses.

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