Nonlinear analysis of joint between square and rectangular hollow steel section members for cyclic loading condition using FE software ABAQUS

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Abstract - 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 rectangular hollow beam to square hollow column connection was selected and modelled in commercial finite element software ABAQUS. This model was analysed for nonlinear static analysis considering a number of connection details. Following three alternative types of connection details were selected for this study: (i) using end-plate, (ii) using angle section and (iii) using channel sections. The base model (rectangular hollow beam welded to one face of the square hollow column). The performance of the selected connection details are compared and the best performing connection details is recommended for rectangular hollow beam-to- square hollow column joints.

Key Words: Box sections, steel material, connection designs and modelling, nonlinear static analysis, FE software ABAQUS, capacity curve, formation of plastic hinges.

1. INTRODUCTION

Now a days, steel hollow sections (such as square, rectangular and circular) are gaining popularities. These sections are manufactured and supply to nationwide for a variety of applications including mechanical engineering for example, manufacturing of booms, frames and other vehicle components. Especially for applications where high strength combined with excellent usability is needed, with high torsion rigidity and compressive strength, these hollow sections are comparably more efficient than conventional steel sections (such as angle, channel and beam) which were designed by conventional working stress method.. The excellent distribution of material around the axis of the square and rectangular steel hollow sections allows for remarkable strength qualities and thus offers decisive advantages in its applications. The smooth and uniform profile of the sections minimizes corrosion and facilitates easy, onsite fabrication to significantly enhance the aesthetics of structures. A higher strength to weight ratio credits these sections with nearly 30% reduction in the use of steel.

1.1 Advantages & Applications of Hollow Steel Sections

Various advantages of these sections are listed below:

Cost effective, corrosion resistance, concentric strength, convenience of fabrication and creativity.

These sections can be applicable for various fields like: Architectural, Infrastructure, Industrial, and General Engineering.

1.2 Motivation of Study

This development has brought attention of researchers to 'the connection design' which is a very important aspect of steel design and construction. Unlike the conventional steel sections these hollow sections do not have standard connection details available in design code or in published literature Sufficient research works have been done on the connections between conventional beams and columns (especially I-beam, I-column), but very little information are available on the connections between hollow beams to hollow columns. Direct extensions from connections detailing between the conventional sections are also not feasible as there are certain differences in geometry between hollow and conventional sections. As the thickness of the walls in hollow box sections are usually very small (2-10 mm) the possibility of local failure is very high if connection is designed without proper analysis. According to the current practice, full penetration of welds are used in joints involving smaller hollow sections and for large hollow sections diaphragms are inserted in columns at beam flange level. However this is not fully capable of resisting the fracture under cyclic loading and also involves a lot of fabrication works resulting the hike in cost of the structure. The use of bolts can be an alternative as it would give considerable tolerances in fabrication but for tightening of nuts the access on the inside for the conventional bolts cannot be provided everywhere. To overcome these problems a suitable and economic connection detail should be designed between two hollow sections which should be easy to fabricate and should be capable enough to resist loading. This is the primary motivation of the present study.

2. Problem Identification

Main objective of the present study is identified as to develop improved beam-to-column connection detail for rectangular hollow beam to square hollow column ensuring smooth flow of forces. Followings are the scopes and limitation of the present study.

- Instead of CHS only RHS and SHS are to be considered in this study in which RHS is used for beam and SHS is used for column.
- Sometime hollow columns are filled with concrete or other materials for improving compressive force capacity. This type of concrete filled hollow sections (CFHS) are however kept outside the scope of the present study.
- Only welded connection are to be considered.
- Since, the purpose of this study is to find a suitable connection between hollow beam and hollow column so, failure is allowed only at the joint of beam and column.

3. Methodology

To achieve the objective of the study following methodology have been worked out:

- Select the geometry of the hollow steel sections for connection of rectangular hollow beam to square hollow column.
- Model the selected connection in finite element software ABAQUS.
- Simulate the model with standard results.
- Plan for possible alternative connection details for the selected beam-to-column connection and model in FE software ABAQUS.
- Analyse the selected beam-to-column connection for nonlinear static analysis considering all the selected connection detail for cyclic loading condition.
- Arrive at the most suitable connection detail for the selected beam-to-column connection considering the capacity curve of the joint.

3.1 Type of Connections for Modelling

3.1.1 Type 1: Basic connection

Two hollow sections in which one is rectangular is used as beam section and other is square which is used as column section are modelled with the help of ABAQUS and the connection is done by tie. The dimension of the beam section is 120x180 mm, thickness 8 mm and length is having 1500 mm, whereas column section is having dimension of 180x180 mm, thickness 10 mm and length of 3000mm. Mesh size of column and beam are kept as 20 mm square. Boundary condition are kept at the column ends as both side pinned.

3.1.2 Type 2: Connection detail using end plate

An end plate is welded over the column surface at beam column joint of the basic connection. Dimension of the end plate is 180x420 mm and thickness is kept as 10 mm. Mesh size of the plate is equal to 20 mm square.

3.1.3 Type 3: Connection detail using angle section

In this type of connection detail two angle sections are welded with both of the box section at beam column junction. The mesh size of the angle sections are kept as 10 mm square. The dimension of each angle section is 120x120x10 mm.

3.1.4 Type 4: Connection detail using angle section

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 100x200 mm, length 420 mm and 10 mm thick. Both of the channel sections are welded together to form a box section. Mesh size of the channel section is equal to 10 mm square.

3.2 Capacity curve

In static nonlinear procedure magnitude of the structure loading (or displacement) is incrementally increase in a certain predefined pattern. In the present study point load is applied at the tip end of the cantilever beam and load will incrementally increase in displacement control approach. With the increase in magnitude of the displacement, weak links and the failure modes of the beam to column joint will be found. Local nonlinear effects will modelled through specifying nonlinear stress-strain behavior and tip end of the beam will be pushed until collapse mechanism is formed. At each step with increase in the magnitude of every rising applied force the deflection of the free end of the cantilever beam will be plotted for all four type of connections and compared to achieve a final conclusion.

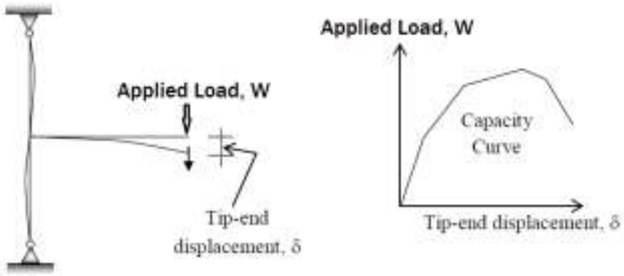

Fig. 1: Capacity curve of nonlinear analysis

4. Result and Discussion

A finite element analysis is done for the model consisting two box sections with the help of ABAQUS software up to failure. Then analyzing 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 modelled 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. Capacity curve is the main parameter to compare the most suitable connection among all connection types.

The Chart-1 and the Table-1 shows that the load carrying capacity of the joint and the maximum deformation capacity is highly sensitive to the type of connection used. It also shows that maximum load carrying capacity of the joint may vary 33 kN in model Type-1 to 60 kN in Type-4 (an increment of almost 82%). Similarly the deformation at collapse is varying from 83 mm to 125 mm (an increment of about 50%).

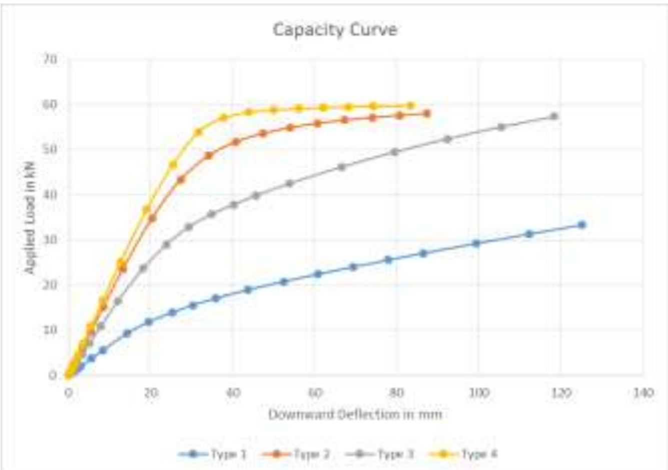

Chart -1: Capacity Curves of different types of connections

Table -1: Important characteristic of the result of analysis

Connection Type	Maximum Strength	Yield Deformation	Location of Plastic Hinge at
Type-1	33	125	Beam-column joint
Type-2	58	87	Beam-column joint
Type-3	57	118	Beam-column joint
Type-4	60	83	Beam

The results shows in the above chart clearly represents that the performance of the connection Type-4 is best among the other models with respect to the maximum load carrying capacity and the deformation at collapse. The location of the formation of plastic hinge during the inelastic deformation are represents in Table-1. These data confirms the effectiveness of Type-4 as the plastic hinge form in this connection type at the beam end away from beam-to-column joint whereas, in all other cases the formation of plastic hinge occurs in the beam to column joint.

5. CONCLUSIONS

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

1) Load carrying capacity of the joint and the maximum deflection capacity is highly sensitive to the type of connection used.
2) Reaction forces, SF, BM and deflection values are matched with FE software values. So, the model is simulated.
3) Maximum load carrying capacity of the joint found to vary from 33 kN in basic connection model Type-1 to 60 kN in connection Type-4 (using box section) with an increase of almost 82%. Similarly the deformation at collapse is varying from 83 mm to 125 mm (an increment of about 50%).
4) The formation of plastic hinge is usually found to occur at the beam-to-column joint for all different types of connection except Type-4 which is away from the joint.
5) Performance of the joint with Type-4 (connection details using channel sections) performs best among others with respect to the maximum load, deformation at collapse and formation of plastic hinges.

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