Study on Partially Restrained Connections of Cold Form Steel Structures

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Abstract— The study of connections in any structure is of primary importance because, it is always desirable the structural member to fail first instead of the connection. If the structural connection fails before the failure of the member it is always a brittle failure and catastrophic. Present study is focused out to determine the structural performances of various beam–columns with bolted moment connections on cold formed light gauge steel sections by analytical, FEM analysis and experimental tests. The analysis included four types of beam column connections with gusset plate. The number of bolts required for basic connection are determined from BS 5950-5 1998.Based on proposed four types of connection configuration, they are modeled in pro-e. Further, this modeled connection is analyzed in hypermesh, then experimental test have been carried out on the same connections. The relations between moment-rotation, moment resistance, model factor and various modes of failure were observed. From the experimental and FEM analysis it has been observed that there is always torsional buckling failure of beam section and distortion of gusset plate and from result model factor of proposed model is 0.731 and moment resistance of connection archives 32% to that of moment resistance of cold form steel section.

Key words: Cold Form Steel Structures, flushed gusset plate

I. INTRODUCTION

Cold form light gauge steel is steel with very small thickness varying from 0.8 mm to 4 mm with yield strength of 280 MPa, 350 MPa and 450 MPa. The idiom “cold form light gauge steel connection” refers to the connection which is developed by using cold form light gauge steel structural members [4].

Cold form is a thin steel product which is now days used extensively in the building construction, ranging from purlins and lintels to roof sheeting and flour decking. These thin sections are cold formed by rolling or bending from steel strips and are given the generic title of cold form steel sections. The thin sheets of steel can be moulded into any enviable shapes. For example ‘C’ section, ‘Z’ section, ’T’ section, Hat section, Sigma section with or without lips, Rectangular hollow sections (RHS), Circular hollow sections etc.

The chief reason to use cold form steel is their strength, light weight, versatility, non-combustibility and ease of production has given confidence to the architects, engineers and contractor [9-10].

Cold form steel industry is fast building in usage of low to medium habitation. There are miniature guidelines given for the study of cold form steel connections for a practical usage when judged against hot rolled steel. Hence, it is vital to broaden study of cold form steel structural connections.

In the direction to widen the successful use of cold form steel in building relevance. It is extremely required to build safe and sound desirable moment frames and thus design information on bolted moment connections in beam-column sub-frames with practical connection configurations should be provided [3].

The design rules for the connection of cold formed steel sections apprehension the load carrying ability of individual fasteners such as screws, bolts, rivets and welding. Diminutive information is available on bolted moment connection of cold formed steel sections to determine the structural behavior. So it is vital to bring out experimental study to determine use of moment connection of cold formed steel in building industry [3].

A. *Objective of the Study*

The main purpose to study the cold form steel connection is to increase the percentage of application of cold form steel in the structures. The aim of this work is to study on semi rigid connections of cold formed steel section with different connection configuration. Due to semi rigid connection the consumption of steel is minimized and construction can be made effective. This study attempts to broaden the load carrying capacity of the cold formed steel with various connection configurations between beam and column. Limited data is available on the FEM analysis of cold formed steel connections. For this reason the project, with help of theoretical and experimental analysis will be followed by FEM analysis and result between these will be compared.

The design is followed by using the British code BS 5950-5:1998 (Part 5. Code of practice for design of cold formed thin gauge sections). The design of connections is based on the semi-rigid criteria.[1]

B. *Proposed Types of Connection*

1) *Connection with flushed gusset plate (C1)*

In this type of connection the beam and column is connected to the gusset plate without any extra angles.

2) *Connection with extended gusset plate (C2)*

This connection is similar as the flushed gusset plate connection but pitch distance of bolt in column and gusset plate joint is increased.

3) *Connection with gusset plate and column stiffeners (C3)*

This connection is similar that of extended gusset plate with column stiffeners.

4) *Connection with gusset plate and web, flange angles (C4)*

This connection is similar as that of extended gusset plate connection with angle connecting to flange of column and web of beam on one side and on opposite side angle connecting flange of column and gusset plate.

Based on the design criteria of the semi-rigid connection mentioned in the British standards BS 5950-5:1998 the beam is designed from which the number of bolts was obtained for the basic connection. In the other two types of connections cold-formed steel angles are used and are placed differently in each of two different connections at the beam-column in order to stiffen the connection. The pattern of these four types of connections is referred from the reference [2-7]. And modified as per our proposed connections.

All these four types of connections are modeled in the modeling software PRO-E and the finite element analysis of the connections is done in the (FEM) software HYPERMESH for fem analysis. And same connections are tested experimentally.

In the present investigation, all the test specimens are constructed according to the proposed basic configuration. All bolts are 16mm in diameter and of Grade 8.8. A double section of two lipped C sections Back-to-back with a section depth of 100 mm, a flange width of 50 mm and a thickness of 1.05 mm is used in all tests The yield strength of the sections is 550 N/mm^2 which is designated as G450. The moment capacity of the double section is 7.132 kN m which obtained from theoretical calculation where it is based on yield strength and moment of inertia of the section. In C1, beam column connection pitch on column section is 32 mm and end distance is 35mm. In other three connections C2, C3 and C4 pitch distance on column section is 80mm and end distance is 35mm. and thickness of gusset plate is 3mm in all connection configurations.

II. Experimental Analysis Details

The beam column connection configuration is fabricated by using "C" section of web depth 100mm, flange width 50mm, gusset plate of 3 mm thickness and angles of suitable size. The bolts used for connection are 8 mm in diameter and grade of 8.8 with 1mm clearance. The C-sections are interconnected by using tapping screws of 5mm diameter.

The external beam column connection configuration is then fixed into frame by using cup and collar arrangement. This frame with connection configuration fixed in to UTM machine and load is applied at free end of beam by using hydraulic jack with pressure gauge. As shown in figure 1. Both the applied load And the displacements of each member of the test specimens were measured during the entire deformation history Displacement of connection is measured by using dial gauge.. The tests were terminated when there is no further more increase in displacement of beam even for increasing load [2-5]

Fig. 1: Experimental Step-up

III. Finite Element Analysis Details

After the connections were modeled in the software PRO-E, they were analyzed in the FEA software Hypermesh v9.0 for FEM analysis. In Hypermesh all the four types of connections were meshed with 2-D quadrilateral elements having Global size 6 mm, Minimum length 1.5 mm, Jacobian 0.6, Warpage 0.5 and Aspect ratio is 5:1. As the thickness of the sections is very small i.e. 1.05 mm only, the meshing is carried out on the mid-surface of the sections. The load is applied as a point load at the free end of the beam as shown in figure 2. Top and bottom side of column is fixed in all directions. The meshed model is then analyzed by assigning them the respective material and sectional properties. The results were viewed in the software HYPERVIEW which is the post-processor of Hypermesh [7-8].

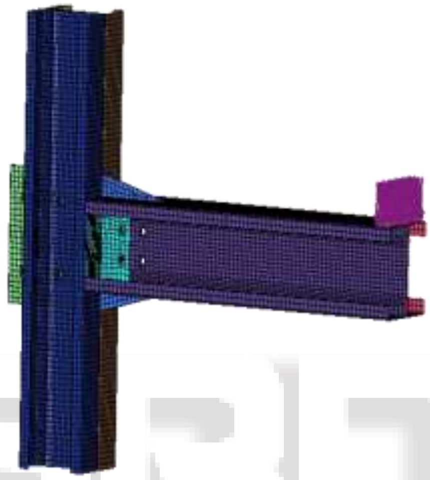

Fig. 2: FEM Model

IV. Results and Discusion

The results include the experimental and FEM analysis output for all the four types of connections with their respective tabulations and graphs. The tabulation consists of load, deflection, moment and rotation at the connection as shown in table 1 and table 2.

The initial stiffness is obtained by taking the slope of the plot of moment v/s rotation as shown in the figure 3.

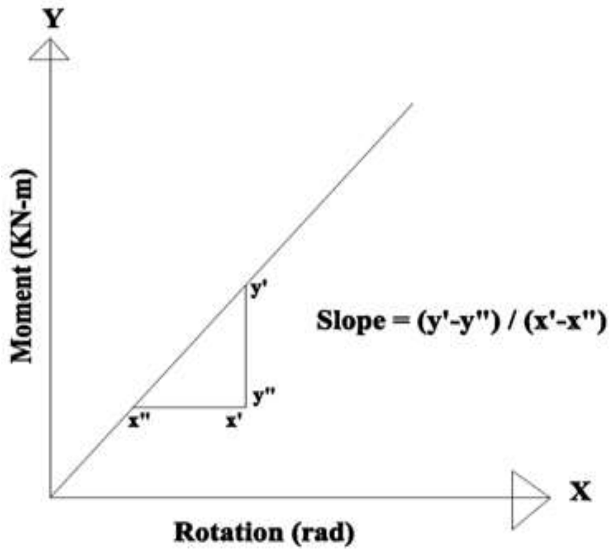

Fig. 3: Plot of Moment v/s Rotation Curve

The torsional buckling failure of C4 type of beam-column connection and failure of column flange of C3 type of beam column connection based on experimental analysis is shown in figure 4 and figure 5. And stress at connection based on FEM analysis is presented in figure 6.

Fig. 4. Failure of Experimental Connections C4

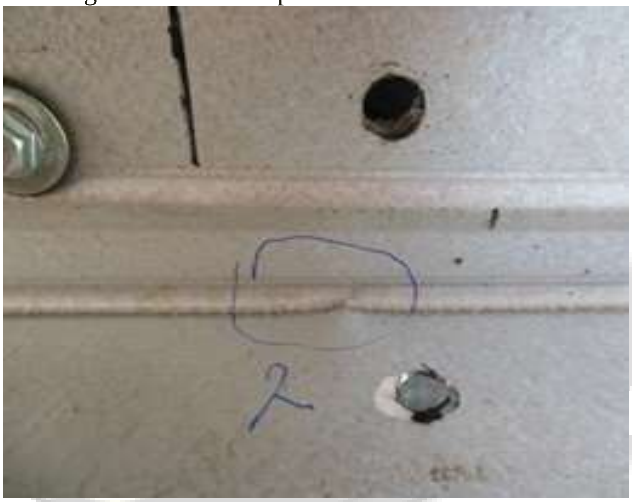

Fig. 5. Failure of Experimental Connections C3

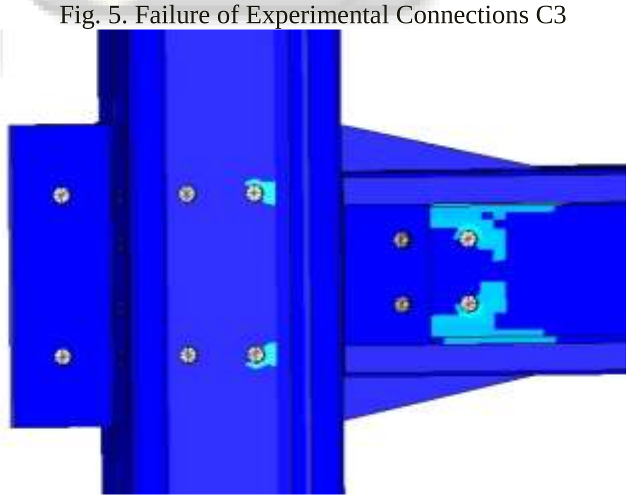

Fig. 6. Stress at a Connection from FEM Analysis

Type of connection	Load (kN)	Displacement (mm)	Ultimate Moment (kN-m)	Rotational stiffness (rad)
C1	2.80	109.8	1.374	6.107
C2	3.73	120.4	1.830	6.381
C3	4.20	130.2	2.058	6.897
C4	4.90	138.4	2.402	8.360

Table 1: Summary of Experimental Results

Type of connection	Load (kN)	Displacement (mm)	Ultimate Moment (kN-m)	Rotational stiffness (rad)
C1	1.5	12.6	0.735	28.58
C2	2.0	15.8	0.980	30.33
C3	2.5	17.0	1.223	35.24
C4	3.5	18.7	1.715	44.92

Table 2: Summary of FEM Results

Type of connection	M_{EXP} (kN-m)	M_{FEM} (kN-m)	M_d (kN-m)	Moment ratio(φ_R)
C1	1.374	0.735	7.312	0.18
C2	1.830	0.980	7.312	0.25
C3	2.058	1.223	7.312	0.28
C4	2.402	1.715	7.312	0.32

Table 3: Summary of Moment Resistance Ratio

M_{EXP} :- Moment resistance from experimental results

M_{FEM}:- Moment resistance from FEM results

M_d:- Moment resistance from theoretical results

Type of connection	M_{rEXP} (kNm)	M_{rFEM} (kNm)	Model factor (φ_m)
C1	1.374	0.735	0.5346
C2	1.830	0.980	0.5354
C3	2.058	1.223	0.5928
C4	2.402	1.715	0.7138

Table 4: Summary of Model Factor

After the experimental and FEM analysis, the moment rotation curves of the external beam-column sub frames are presented in Figure 7 and figure 8. In order to assess the effectiveness of the bolted moment connections a moment resistance ratio, φ_R, is presented in table 3 and which is defined as follows:

$$\varphi_R = \frac{\text{moment resistance of connection from experimental analysis}}{\text{moment resistance of section from therotical analysis}}$$

In order to establish the adequacy of proposed analysis, results obtained from the experimental and FEM analysis model factor (φ_m) is found and presented in table 4.model factor is defined as it is ratio of moment resistance measured from FEM analysis to moment resistance measured from experimental analysis. The adequacy of proposed model is shown in figure 9.

$$\varphi_m = \frac{\text{moment resistance by FEM analysis}}{\text{moment resistance by experimental analysis}}$$

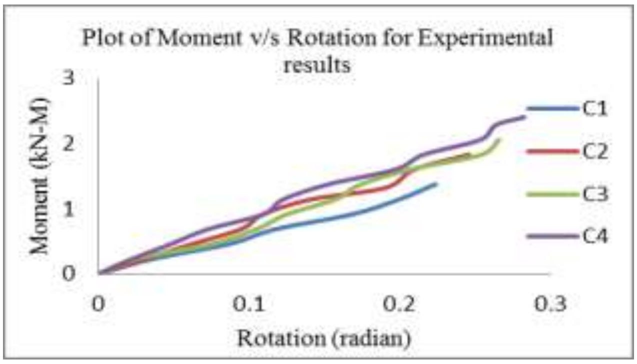

Fig. 7: Plot of Moment v/s Rotation Curve of connections for all experimental results

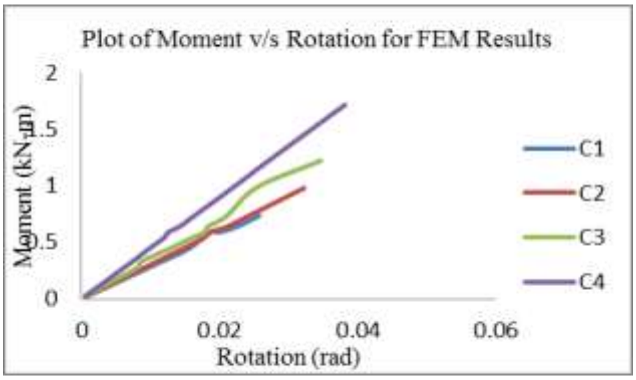

Fig. 8. Plot of Moment v/s Rotation Curve of connections for all FEM results

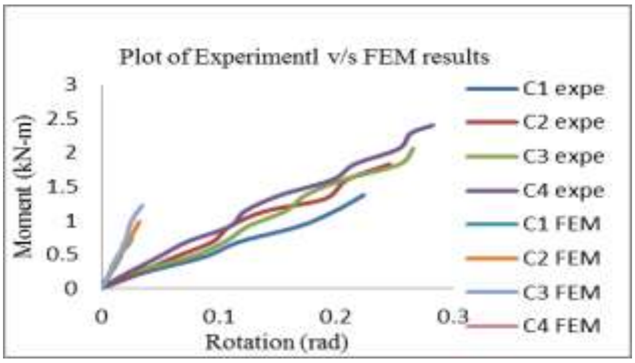

Fig. 9. Plot of Moment v/s Rotation Curve for all experimental and FEM Connections

Moment v/s rotation curves of each connection are plotted on bases of experimental and FEM analysis because they reveal the characteristic behavior of a connection. In FEM analysis the failure of the sections is recognized when the stress in the section crosses its yield value or the grade of steel. In this case the grade of steel used is 550 which mean the yield strength of the sections is 550 N/mm2. In experimental analysis failure of section is recognized when there is further no more increment in displacement even though for increased loading.

As per the FEM analysis all of the connections have failed by buckling of the flange of the beam at a point where the load was applied. From experimental analysis it is observed that there is a torsional buckling failure of beam web in all type of connections and due to distortion of gusset plate bearing failure of cold form section is visible. The torsional buckling failure of C4 and C3 type of connection is initiated at higher load case as compared to C1 and C2 type of connection. More amount of flexure failure of the column flange is observed in C1 type of connection and distortion of gusset plate is comparatively high in C1 type of connection.
As per experimental analysis flexure failure of column flange is less in C3 and C4 type of connection compared to C2 and C1, this implies that with proper use of angle flexure failure of column flange is avoided. Sign of bearing failure of gusset plate is observed when angle are provided inside and outside of column sections.

The graph has been plotted as shown in figure 7 and figure 8. it has been found that, ultimate moment capacity of C4 type connection is more compared to other type of connection. Initial stiffness of C1 type of connection is less compared to other three type of connection. As the initial stiffness of C4 type of connection is more hence it is stiffer relative to other type of connection. Connection C1 is rotating excessively when compared to other three type of connection ultimately leading to lesser stiffness.

There is increase in initial stiffness of connection when we move from connection C1 to C4, there is a drastic increase in initial stiffness of connection, and this implies that as increase in the angle in connection with gusset plate rotation at the connection decreases ultimately. When bolt pitch distance in column to gusset plate interconnection is increased then it has been observed that there is increase in load carrying capacity of the connection. C4 type of connection has more load carrying capacity as compared with C1, C2 and C3 type of connection.

From the test result it has been observed that, the moment resistance of C4 type connection attains 32 % of moment capacity of connected cold form steel sections. It shows that as we increase the initial stiffness of connection, moment resistance can increases.

From the table 4 and figure 9 it has been found that, the model factor for the finite element model of beam column connection is increased as increasing the initial stiffness of connection and with accurate meshing.

V. CONCLUSION

1) Connection C1 is rotating excessively compared to all other connections, which is not recommendable.
2) In case of FEM analysis, connections failed by buckling of the bottom flange where the load was applied and in case of experimental analysis, connection failed by torsional buckling of beam.
3) Due to distortion of gusset plate bearing failure of cold form is visible flexure failure of the column flange is observed in C1 type of connection and distortion of gusset plate is comparatively high than in other types of connection.
4) The inclusion of web angles to beam in the connection does affect the load carrying capacity and the connection initial stiffness.
5) Ultimate moment capacity of C4 type connection is more compared to other type of connection.
6) It was observed from both analyses that, In C4 type of connection moment resistance ratio is 32.28% which is more than the other type of connection.
7) It is found that the Adequacy of FEM Model factor is 0.735.

VI. SCOPE FOR FURTHER WORK

1) New connections can be designed by studying different connection configurations.
2) The same connections as studied in this project can be analyzed again by using hot-rolled angles in place of cold-formed steel angles.
3) Connections using other connectors in place of bolts can also be tried
4) More studies on model factor can be carried out in order to increase the adequacy.

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