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Study on seismic performance of cold-formed steel bolted and welded moment connections

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ABSTRACT: *Cold-formed steel (CFS), also known as thin-walled structure, is a structural and non-structural material used in structural engineering. Building structures from cold-formed steel members are now widely popular due to their economy and efficiency in using light weight structural members. This form of construction is now known as the industrialized building system (IBS) and it has become a common mode of construction for low-to medium-rise structures and residential houses. This is because the cold formed steel possesses high strength to weight ratio. Scope of this paper is to investigate the effect of seismic load on moment caring capacity of cold formed moment connections with varying gusset plate thickness. The beam-column connection consists of two back to back hot rolled channel column section and two back to back cold formed channel beam section. In this project, six numbers of connections were analysed by varying the gusset plate thickness using ANSYS 19.0. The behavior of both bolted cold formed beam-column connection and welded cold formed beam-column connections were studied and compared. The result of the analysis showed that bolted beam-column connections possess higher moment carrying capacity than welded beam-column connection. Three different through plate thickness such as 2mm, 4mm and 6mm were considered for the analysis of beam-column connection.*

KEYWORDS - *Bolted connection connections, Cold-formed steel, finite element analysis, moment resisting connections, welded connections.*

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I. INTRODUCTION

In steel structures, mainly there are two types of steel that used to make structural members, sections and plates: hot- rolled steel (HRS) and cold-formed steel (CFS). Cold formed steel sections are produced by cold working process, that means rolling or pressing of thin-walled steel sheets to form open cross sectional shapes at ambient temperature. cold formed steel sections are lightweight materials with great structural performance and durability, making them ideal for building construction. Lipped C-sections and lipped Z-sections are the most common cold-formed steel sections, and the thickness typically ranges from 0.35 mm to 6.35 mm having yield strength of 230 to 420 Mpa.

Because of their thin-walled parts, conventional CFS sections are prone to premature local failures. The mobilisation of bolt slip and bearing action while beams and columns remain elastic is one strategy for avoiding early local failures and providing ductility in bolted CFS connections (1). According to study, in CFS double back-to-back channel sections, reasonably high moment resistance can be generated by adopting appropriate connection details for CFS beam-column connections, such as gusset plates. (2,3).

Traditional double back to back channel beam sections integrated into topping concrete were demonstrated to have a degree of ductile capacity in dissipating seismic energy by reaching rotations more than 0.04 rad in a recent study by the authors (4), meeting the requirements for special moment frames (7). The through plate type of CFS beam-to-column connections showed promising results in this study as well (4). If CFS beams are to be used as the primary energy dissipation components in seismic resistant MRFs, the ductility capacity of the thin-walled elements in the beams must be increased. To allow plastic deformations, the initial step is to delay local buckling as much as feasible. The authors created curved flange beam sections by adding extra bends to the flanges (8-9), a step by- step process that ultimately led to significant increase in moment resistance, stiffness and ductility, compared with flat flange beams.

The aim of this study is to propose efficient design configurations for moment-resisting CFS welded and bolted beam-to-column connections in order to improve their moment bearing capacity and ductility, and so make them more feasible for use in earthquake resistant frames. Detailed nonlinear FE models are developed by taking into account, gusset plate thickness and connections which are known to affect the moment carrying capacity of the connection.

II. BEAM – COLUMN CONNECTION

For CFS beam-column connections, a web bolted moment resistant type of connection is adopted in this analysis. Hot rolled steel C sections are used for columns, while cold formed steel C sections are used as beams, in the beam column connections under analysis. gusset plates are used to join the columns and beams here. The gusset plates are the connection's essential components, distributing forces in-plane to both the near and far sides of the column.by varying the gusset plate thickness the moment carrying capacity of the connections also increasing, it was shown by FE analysis.

III. STUDY ON BOLTED BEAM-COLUMN CONNECTION

A total of three different gusset plate thickness connections were considered for the analysis. The thickness of plates is varying in the order of 2mm, 4mm and 6mm. Columns were made of hot rolled steel back to back channel sections, and beams were made of cold formed steel back to back channel sections is shown in fig 3. The geometrical specification of cold formed beam and hot rolled column are shown in Table-1. A gusset plate with dimensions of 720mmx 550mm was chosen. Bolts with a diameter of 18 mm were chosen for the column to gusset plate interface, while bolts with a diameter of 20 mm were chosen for the beam to gusset plate connection. For moment connection, ANSYS workbench 19.0 software was used to do a nonlinear cyclic analysis. SOLID 186 was used to design the hot rolled steel, cold formed beam, gusset plate, and bolts, with hexahedron meshes. The geometrical model of beam sections is shown in Fig 1.

TABLE 1 Geometrical specification of model

Channel sections	Thickness of flange (tf) (mm)	Thickness of Web, (tw) (mm)	Width of flange (mm)	Height (mm)
Beam	4	4	100	200
column	16	10	100	300

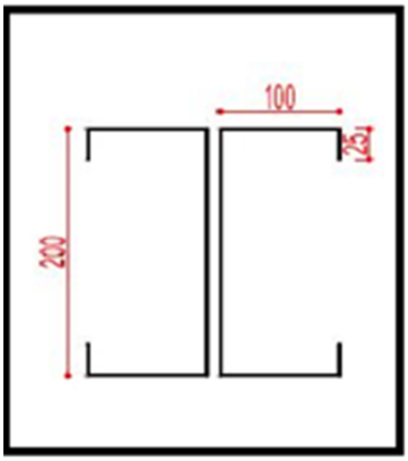


Fig 1 Flat flanged beam

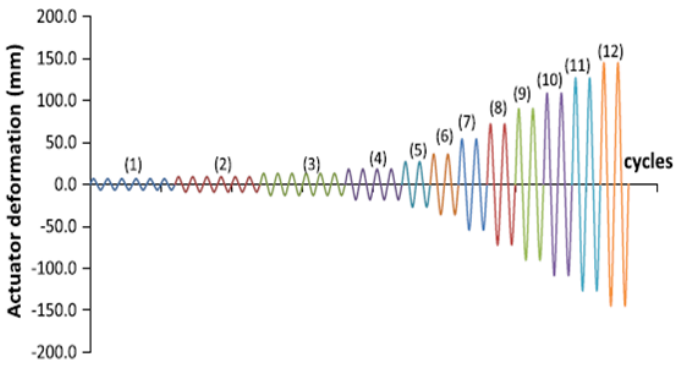


Fig 2 loading cycle

3.1. Geometry, boundary conditions and element types

SOLID 186 was used to represent the hot rolled steel, cold formed beam, through plate, and bolts, with hexahedron meshes. The mesh size of 10 mm was chosen to strike a compromise between precision and computational efficiency. The top of the back-to-back channel column's translational degrees of freedom UX and UY are constrained, whereas the bottom of the column is considered pinned.

3.2. Loading protocol

A loading protocol (Fig. 2) described in section S6.2 of AISC Seismic Provisions [7] for qualifying beam-column moment connections in special and intermediate moment frames was used to apply cyclic loading through a hinge connection at the end of the beam. The end of the gusset plate is considered to be the center of the plastic hinge area, which is utilised to calculate the bending moment, M, and rotation, ɵ, of the beams.

IV. STUDY ON WELDED BEAM-COLUMN CONNECTION

Here also hot rolled steel back to back channel sections were used for columns and cold formed steel back to back channel sections were used for beams. The geometrical specification of cold formed beam and hot rolled column are same as that of the bolted beam-column connection. For the welded beam column connection, ANSYS workbench 19.0 software was used to evaluate the nonlinear cyclic analysis. SOLID 186 is used to represent the hot rolled steel, cold formed beam, gusset plate, and welds. Fig 4 shows the view of weld beam column section.

V. FINITE ELEMENT ANALYSIS OF THE CONNECTION

The models were used to analyse the cyclic loading behaviour by studying the moment carrying capacity and ductility of the connection. The FEMA model is based on the cyclic moment-rotation envelope, which may take into account both positive and negative post-yield slopes, and is used to characterise the cyclic behaviour of the specified bolted and welded moment connections. The yield rotation (y1) is calculated if the secant slope crosses the actual envelope curve at 60% of the notional yield moment (My1), and the area enclosed by the bilinear curve is equal to the area contained by the original curve restricted by the target displacement (θt), as shown in figure 5. Tables 2 and 3 provide the characteristic parameter values of the FEMA models corresponding to the various bolted and welded moment CFS connections.

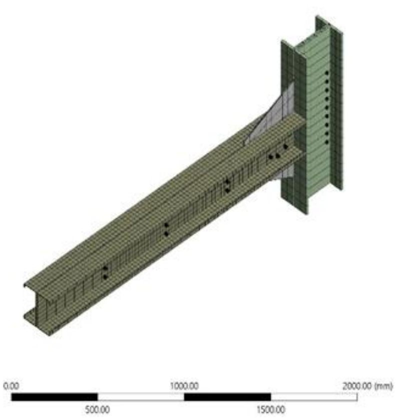


Fig 3 CFS flat flanged bolted connections with 2mm plate thickness

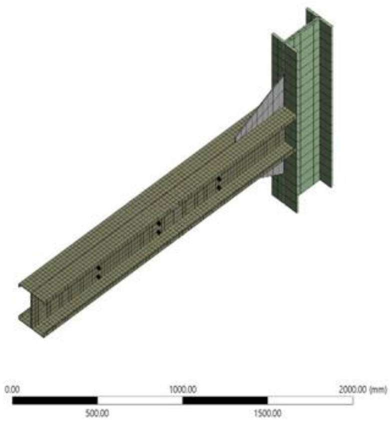
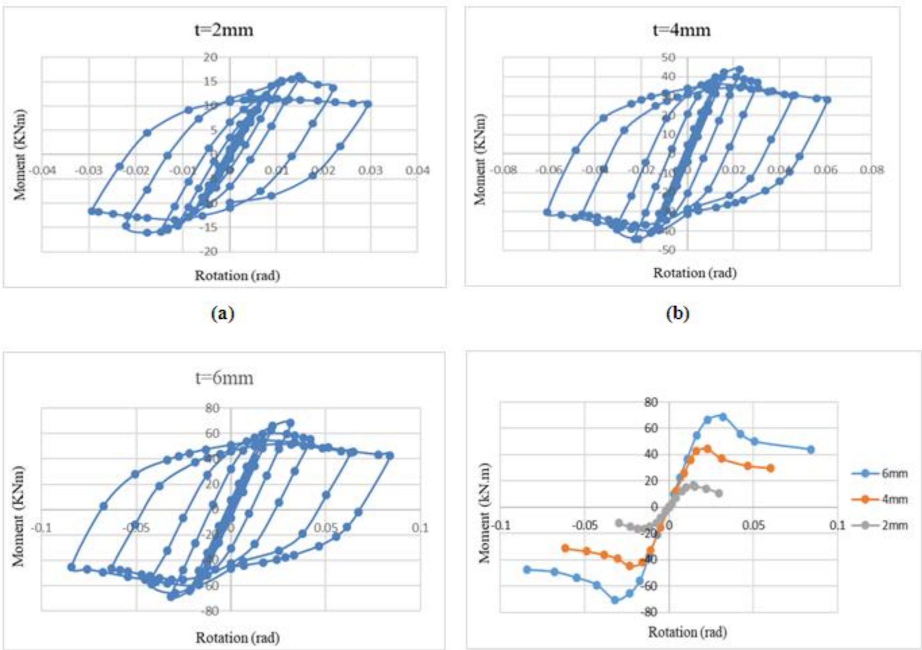


Fig 4 CFS flat flanged welded connections with 2mm plate thickness

VI. RESULTS AND DISCUSSIONS



(a) (b) (c) (d)

Fig 5 a, **b** and **c** are Cyclic moment-rotation relationship curves of the bolted beam section with varying gusset plate thickness and **d** is the effect of gusset plate thickness on the moment-rotation behavior of CFS bolted connections

TABLE 2 Characteristic parameters of the CFS bolted connections with varying plate thickness.

Plate thickness t(mm)	Yield moment My1(kN.m)	Maximum moment My2(kN.m)	Yield rotation θy (rad)	Ultimate rotation θu (rad)	Ductility μ
2	12.34	15.1	0.0084	0.03	3.57
4	36.28	43.86	0.013	0.06	4.61
6	50.97	68.48	0.014	0.085	6.07

TABLE 3 Characteristic parameters of the CFS welded connections with varying plate thickness.

Plate thickness t(mm)	Yield moment My1(kN.m)	Maximum moment My2(kN.m)	Yield rotation θy (rad)	Ultimate rotation θu (rad)	Ductility μ
2	11.36	13.48	0.0095	0.035	3.68
4	33.82	39.87	0.015	0.063	4.2
6	47.63	63.78	0.015	0.081	5.4

6.1. Moment capacity of the connection

The moment-rotation results are used to determine different performance parameters such as moment capacity, yield moment, ductility and ultimate rotation in the above sections.

Moment rotation graph of connections with three different thickness of gusset plate is shown in Fig 3. Here the moment carrying capacity bolted beam connection increases with increase in thickness of through pate from 2mm to 6mm. On analysing the graph (fig 6), it shows that the moment carrying capacity of bolted beam connection is higher as compared to welded beam column connection. Also the moment capacity depends on the variation in gusset plate thickness of the connection. Bolted beam connection with plate thickness 6mm shows the highest moment carrying capacity.

6.2. Ductility ratio of the connections

Moment resisting connections in seismic-resistant systems should be ductile enough to withstand and redistribute seismic loads. The ductility ratio (μ) is defined as the ratio of the ultimate rotation (θu) to the yield rotation (θy), as follows:

$$\mu = (\theta u)/(\theta y)$$

The results of the FEA models are used to calculate the ductility ratio of the CFS connections in this study. It indicates that plate thickness has an effect on the ductility of the connection, with ductility increasing as plate thickness increases. Bolted beam column connections have a higher ductility than welded connections.

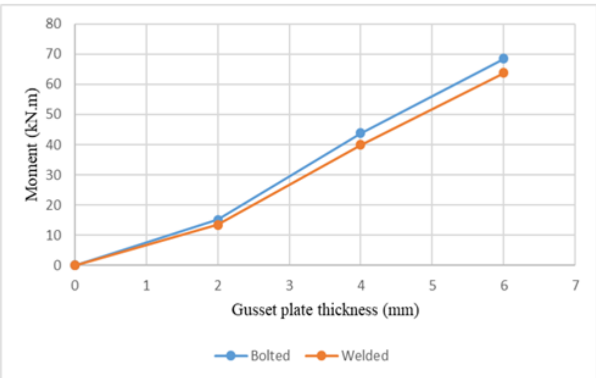


Fig 6 Effect of stiffeners on the moment-rotation behavior of CFS bolted and welded connections

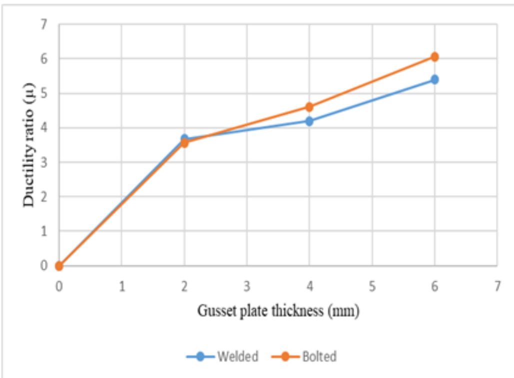


Fig 7 Effect of ductility on the gusset plate thickness of CFS bolted and welded connections

VII. Conclusions

The purpose of this study was to look at the seismic behaviour of bolted and welded moment connections with varying gusset plate thicknesses. The following conclusions were drawn based on the results of the finite element analysis performed on the moment connection:

- The moment carrying capacity of bolted beam column connection is higher than that of welded beam column connection. using bolted beam column connections can increase the moment capacity of the connections by up to 7% as compared to welded connections.
- The moment capacity of the connection is influenced by the thickness of the gusset plate; the thicker the gusset plate, the higher the moment resistance of the connection. The beam column connection with 6mm gusset plate shows higher moment carrying capacity (above 65%) compared to other connections.

- The ductility of the connections is also governed by type of connection and thickness of gusset plate. Bolted beam-column connection results shows up to 11% higher ductility level as compared to welded connection.in general, using the 6mm gusset plate can increase the ductility of the connections (up to 41%) compared to the other connection arrangements.

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