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Experimental investigation on cold-formed steel structural frame made with lipped channel column and beam elements subjected to lateral loading

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ABSTRACT

This study examines the structural performance of a cold-formed steel (CFS) structural frame subjected to lateral loading. An experimental investigation was conducted on cold-formed steel frame. Structural building frames made of cold-formed steel structural members. The structural members (beams and columns) were selected for building the structural frame on the basis of optimized design considering factors such as ease of availability of section and adequate testing conditions. In this way, the channel section is used for columns provided with and without lips. Parameters such as load-carrying capacity, stiffness, and the load– deflection relationship were examined. Based on the results and discussion, the structural frame made with a lipped channel section was found to have high load carrying capacity and high stiffness compared with the other models.

Keywords: Cold-formed steel (CFS); Steel structure; Lateral loading; Finite element analysis (FEA); Light-gauge steel structure; Structural Building Frame; Stiffness.

1. INTRODUCTION

Since CFS structures have several benefits, such as a high strength-to-weight ratio, exceptional durability, and flexibility in fabrication and construction, they have become increasingly popular in the construction industry for low-rise buildings DIAS *et al.* [1] LAÍM *et al*. [2]. In lightweight and prefabricated buildings, LGS members such as columns, beams, and roof truss members are frequently used as load-bearing elements LEE *et al.* [3]. In LGS construction, a variety of specific structural framing member shapes are frequently used, such as angles, channels (C-sections), hat sections, I-sections, T-sections, Z-sections, and tubular members RATHORE *et al*. [4]. This study's goal is to investigate how CFS frames respond to lateral loads DERVENI *et al.* [5]. Four distinct specimens are subjected to finite element (FE) analysis, which takes into account differences in the cross-section columns and member thickness employed in the frame. LGS beams and columns frequently use Lipped C and Sections, with column section thicknesses varying from 1.2 mm to 3.2 mm JAVED *et al*. [6], AYHAN and SCHAFER [7], and BATISTA ABREU [8]. The lips on the edges of the channel section add additional material at critical locations, increasing the section's moment of inertia. This improves the overall strength and stiffness of the member, allowing it to carry greater loads and resist deflection more effectively. The study's main objectives are to assess CFS frames' stiffness, failure mechanisms, load-displacement curves, and lateral load-resisting ability ANBARASU *et al.* [9]. A great deal of research has been done on perforated LGS members, including a study of lipped channel sections XIANG *et al.* [10]. Present study focuses experimental investigation on cold-formed steel made frame specimens. Based on this investigation significant factor that influences the lateral strength and resistance against the lateral force were examined.

1.1. Literature review

Some recent research explained the CFS structural element's performance by conducting several physical tests, involving conducting experiments with the appropriate test setup, or by conducting the analytical investigation such as finite element analysis, and theoretical assessment by handling the reference of standards codes that have equations and formulas. Similarly, here the essence of some studies is discussed in this section.

IYER [11] conducted theoretical and analytical investigations on the maximum load-carrying capacity and the behaviour of light gauge un-lipped channel sections with ends being fixed and then subjected to axial

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compression. The comparison is being done with the design strengths as predicted by using the North American Standards. ELKERSH [12] studied the behaviour of bolted cold-formed steel frame apex connections under a pure moment. The study was performed on a portal frame rafter with double C cold-formed sections. A total of 10 rafter sections as part of portal frames were used in the study. The study aimed to investigate the effect of different factors on both the frame capacity and connection failure mode. The effects of variable bolt pitches, the thickness of gusset plates, and the effect of bearing or hole deformation around the bolt were investigated. ROY [13], This paper has proposed the improved version design rules and its accuracy by FEA using ABAQUS and ANSYS software and the test results for the back-to-back CFS built-up channel sections which are subjected to the axial compression. The FE model will include the modelling of the material's non-linearity, web fasteners, and geometric imperfections.

Priyadarshini *et al.* [14]. The project aims to study the behavior of cold-formed steel frames made using channel sections. From the review of literature, it has been found that much work has not been done on cold-formed steel hollow section frames. Therefore, this study on cold-formed steel channel section frames is undertaken. The study involves hollow section tests on cold-formed steel frames are two specimens of single bayed two-story frames of 3 mm thickness are tested along both the major and minor axis. Cold-formed steel hollow section frames connected along to major and minor axes connections are tested experimentally under concentrated loading. Stress-strain curves are plotted and compared with that of hot-rolled steel. It was found that frames connected along the major axis exhibit 38% higher load carrying capacity than the frames connected along the minor axis.

In this study, such investigations are selected and observed about a cold-formed steel frame subjected to lateral loads. Some researchers investigated the behaviour of cold-formed steel subjected to axial compression, as well as subjected to lateral loading. Researchers had made their investigation via physical experiments or analytical investigation they found good results in frame capacity and connection failure mode, displacement mode of the frame while it is subjected to static and dynamic loadings based on results they had conducted different parameter analyses. Likewise, in this study, the investigation has been made to examine the behaviour of cold-formed steel frames under lateral loading via physical test, load-displacement relation, frame load carrying capacity, and stiffness have been discussed.

2. MATERIALS AND METHODS

The sectional properties of the selected sections for frame were obtained from IS811 specification for cold-formed light gauge structural steel sections. The cross dimensions were fixed, based on the AISI specification for cold-formed steel constructions and covered the practical range of channel section for beams and columns presently utilized in the industry to minimize the local failure. Figure 1 depicts geometry details of frame specimen. Cold cast steel frames are fabricated in the steel factory as per the design. The frame design was carried out based on AISI specification and industry practice specification. Angle cleats and mild steel bolts were used for beam-column joint connection, as well as base plate and column bottom connection. The frame specimen consist of components like columns, beams and base plate. For the column part, channels are arranged in a back-to-back orientation that forms a likewise H-shaped cross-section of the column. The working column is made by bolting the two sections of a column using a self-driven screw with effective spacing and distance. Similarly, another column has been formed. The beams that have only one channel section was positioned between the columns. The beams that have only one channel section had been positioned between the columns. The beam-columns connection is done. Connection is made using a connecting device that is Angle cleat strong bolting arrangement is introduced between column and beam, Angle cleat has a size of 60 × 80 × 5 mm which has been seated on beam and column. It is provided on the end of the beam and also semi-rigid connection condition is ensured. A base plate has been introduced between the ends of the column for the column base. The base plate size is decided to accommodate the column end portion and avoidance of the occurrence of shear failure and bearing failure while deciding the size of the base plate were taken into account.

2.1. Material properties

Material properties play a crucial role in the performance of structural steel members. The primary mechanical property of steel that is used to describe its behavior is the stress-strain graph Cold-formed steel shows gradual yielding, a rounded knee is formed after the elastic region, and as there is no well-defined yield stress, the 0.2% proof stress is generally used to define a value of its yield stress. Generally, cold-formed steel doesn't show any plastic region, and strain hardening occurs immediately after yielding. The yield stress of cold-formed steel increases with the amount of cold work executed to produce the section shape. The mechanical properties of the steel sections are mostly affected by the cold forming work, particularly in the regions of bends. Therefore mechanical properties of cold formed steel material obtained by conducting physical test on cold formed steel and hot rolled section specimen. In the present investigation, tensile coupon test specimens were prepared

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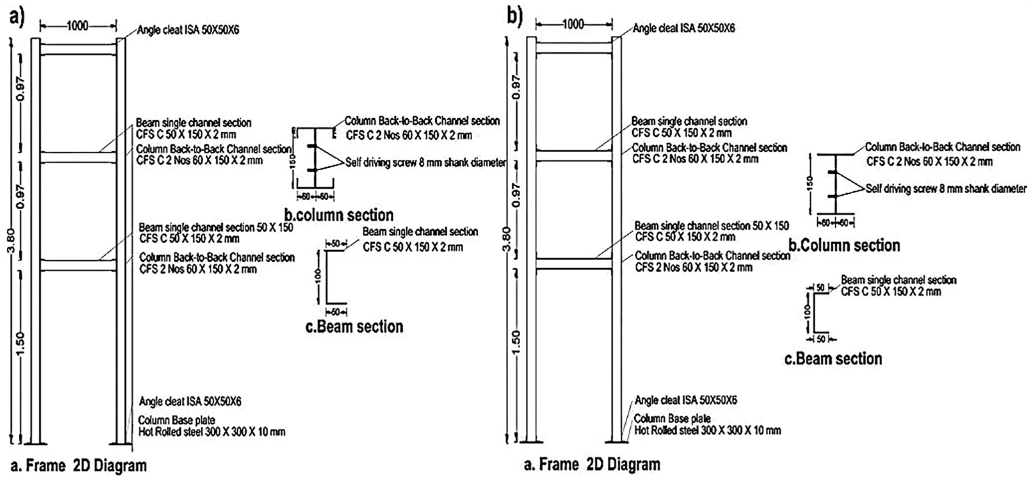

Figure 1: a. Geometry details of cold-formed steel frame with lips - 2D view. b. Geometry details of cold-formed steel frame without lips - 2D view.

Table 1: Mechanical properties of cold-formed steel and hot rolled steel.

MATERIAL	YIELD STRENGTH (N/mm^2)	ULTIMATE STRENGTH (N/mm^2)	ELASTIC MODULUS (N/mm^2)	ELONGATION (mm)
Cold-formed steel	385	429	2.02×10^5	17
Hot rolled steel	250	412	2.00×10^5	11

from cold-formed sheets available thickness. Tensile test on prepared specimen was conducted. Results were obtained. Table 1 shows the mechanical properties of cold-form steel section and hot rolled section used.

2.2. Experiment investigation

Experiment investigations were conducted on cold–formed steel structural frame in a structural testing laboratory. Table 2 presents geometric details of structural frame. Figure 2 presents diagram CFS structural frame specimen. The load points were at the top-storey levels in line with the beams. The load frame used to apply loadings. The arrangement was made similar to the structural frame specimen stand in position and fixed rigidly at the soffit with the floor. Loading jacks of 20 Ton capacity were placed at each storey level. Lateral load was applied through hydraulic jacks, and the corresponding lateral displacement was measured using linear variable differential transducers (LVDTs). Special Arrangements to avoid displacements due to the rotation of the frame from the test floor and the rigid welded base-to-floor connection with the test floor to arrest the rotation of the frame. The loading proceeded with an equal interval of 1 kN via push and pull operation the deflection values were noted. Linear variable differential transducers were connected at the opposite end of the frame loading point to measure the displacement. LVDTs were used at the beam column joint in line with the beam member. The test setup for bare frame is shown in Figure 3. Two LVDTs were used to measure the lateral deflection at bottom and top floors for push and pull lateral loading conditions. Figure 4 presents experiment test setup.

2.3. Interpretation of experiment results

From the part of the experiment program, lateral load applying progression was continued until the structural element in the frame specimen exhibit out of control of lateral deflection exist. In between the time the loads increased gradually at regular interval of 1 KN through push ward and pull ward. Initially the load transferred to the frame voyaged in load – deflection was in the linear progression. At one stage, buckling of element in the frame was observed. At the stage, it was recorded and it was informed such that the respective maximum load observed was the maximum load holdup by the corresponding frame type. The hydraulic jack was allowed transfer the load to the frame with the control rate of 1kN and pull back with the same procedure. At the same time the deflection was measured at every push and pull by using LVDT in the respective storey levels. As the result, on comparing response of all type of tested frames. It was found that the frame made of lipped channel column CFSF2WL-II hold up maximum load of 13 kN. Corresponding maximum lateral deflection was found as 64.38 mm. In the other end, it was found that frame made without lipped channel column CFSF2WOL-I hold up maximum load of 11 kN. The corresponding maximum lateral deflection was found as 72.36 mm. Table 3 shows the

Table 2: Geometry details of cold-formed steel frame models.

SL. NO	FRAME MODEL DESIGNATION	THICKNESS OF SECTION	COLUMN SECTION	BEAM SECTION	LIP/WITHOUT LIP LENGTH
1.	CFSF2WOL-I	2	2 × 150 × 60 × 2	100 × 50 × 2	–
2.	CFS2WOL-II	2	2 × 150 × 60 × 2	100 × 50 × 2	–
3.	CFSF2WL-I	2	2 × 150 × 60 × 2	100 × 50 × 2	25
4.	CFSF2WL-II	2	2 × 150 × 60 × 2	100 × 50 × 2	25

Figure 2: Cold-formed steel structural frame specimen.

loads and corresponding displacement, maximum strain were recorded. It was found that in all specimen in the final phase of loadings, the maximum uncontrolled deflection was occurred accompanied with buckling failure occurred in the beam present respective levels in the frame specimen. Finally, it was observed and recorded as local buckling failure. It was observed the specimen CFSF2WOL-II reached maximum deflection and buckling failure experienced ahead compared to other specimens.

3. RESULT AND DISCUSSION

3.1. Load-deflection curve

The load-deflection curve characterizes how a structure deforms under increasing lateral loads. Buckling failure is an important factor that can have a significant impact on load-carrying capacity and frame deflection. Likewise, it was observed important consequence existed in the test.

From the test results, it found that the displacement value also increased while the load increased in all the frame models. Likewise, the lipped channel frame resulted slow rate increment of displacement compared to lipped channel frame. The lipped channel frame has acquired high the lateral load resistance capacity because of the reason the gross section area of column in the frame is so quite high compared to unlipped channel frame. So it facilitates to counteract the external forces by its virtue of its section and its connection provided. Figure 5 presents load – displacement curve resulted. The specimen CFSF2WOL-I acquired maximum load carrying capacity of 11 KN, the corresponding deflection measured was 72.36 mm. Likewise the specimen CFSF2WOL-II acquired maximum load carrying capacity of 10.5 kN, the corresponding deflection measured was 70.37 mm. The specimen CFSF2WL-I and CFSF2WL-I acquired maximum load carrying capacity of 13 kN, the corresponding deflection measured 66.39 and 64.45 mm respectively.

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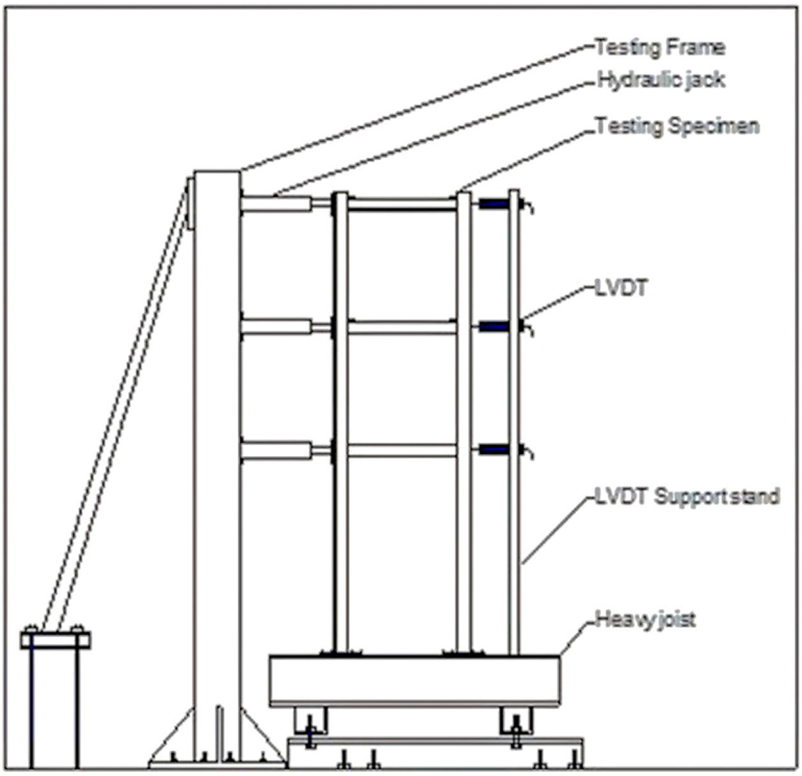

Figure 3: Test setup for cold-formed steel structural frame.

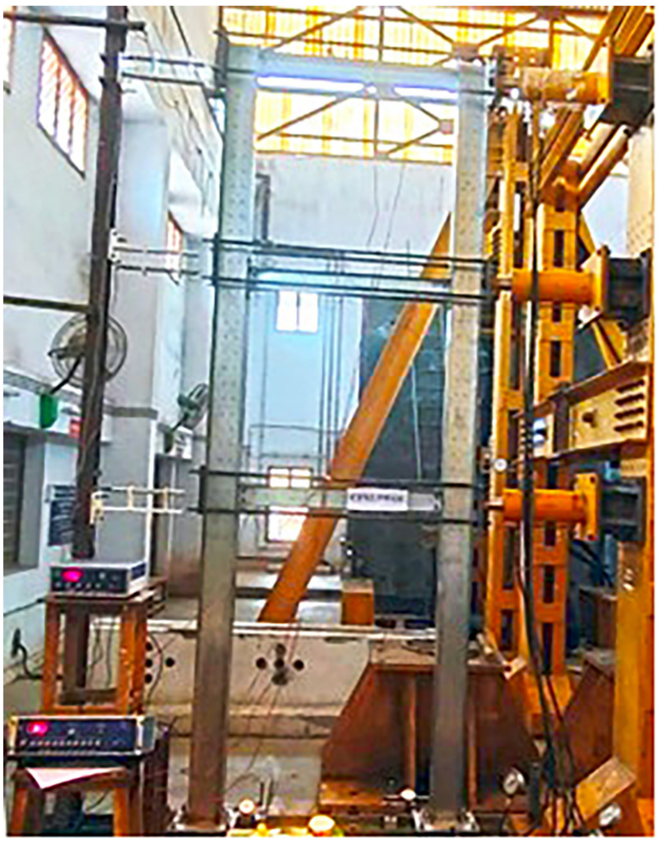

Figure 4: Experiment test setup for test specimen (Ex. CFSF2WL).

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Table 3: Experiment results.

SL. NO	FRAME MODEL DESIGNATION	MAXIMUM LOAD (kN)		MAXIMUM DEFLECTION (mm)		MAXIMUM STRAIN (mm/mm)	
		PUSH (kN)	PULL (kN)	PUSH (mm)	PULL (mm)	PUSH (mm/mm)	PULL (mm/mm)
1.	CFSF2WOL-I	11	11	72.31	72.36	0.0042	0.0041
2.	CFSF2WOL-II	10.5	10.5	70.29	70.37	0.0041	0.0040
3.	CFSF2WL-I	13	13	66.35	66.39	0.0046	0.0044
4.	CFSF2WL-II	13	12.5	64.36	64.45	0.0053	0.0054

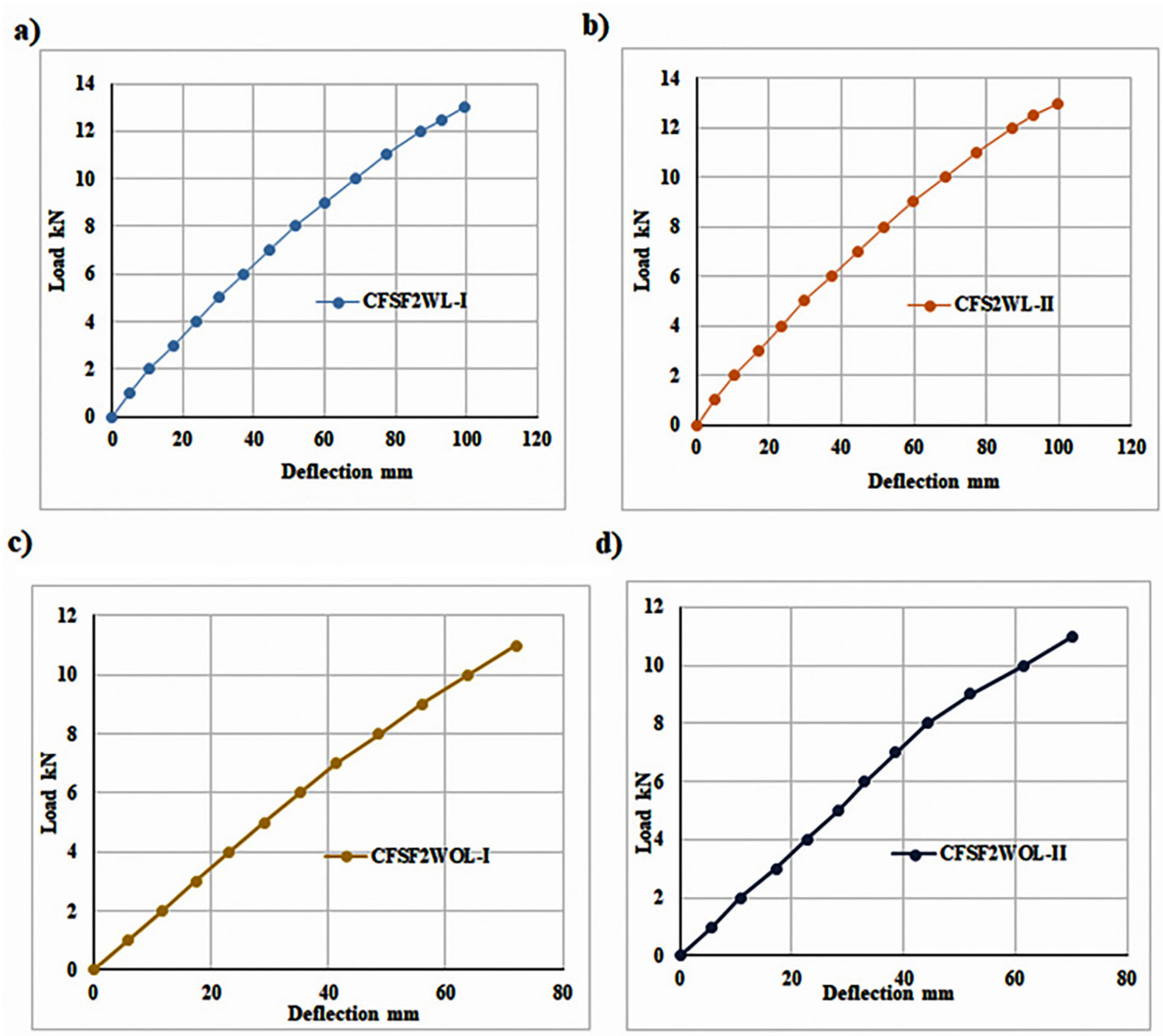

Figure 5: Load-deflection curve.

3.2. Stiffness

The stiffness of all frame models is calculated from the load-displacement curve in the elastic region, where the slope of the curve is predicted from the best-fitting linear elastic line. Generally the stiffness value reflects the strength of the structural elements while the structure subjected to any external loads. By this way lipped channel column frame CFSF2WL exhibited valuable stiffness value compared to unlipped channel column frame. Main reason for the difference is lipped channel have high moment of inertia and radius of gryartion compared to unlipped channel column frame. Table 4 presents stiffness value obtained in the experiment test.

Table 4: Stiffness result.

SL. NO	FRAME MODEL DESIGNATION	STIFFNESS (N/mm)	MAXIMUM DEFLECTION (mm)
1.	CFSF2WOL-I	167.82	72.36
2.	CFSF2WOL-II	166.18	70.37
3.	CFSF2WL-I	192.42	66.39
4.	CFS2WL-II	189.24	64.45

Table 5: Maximum load carrying capacity.

SL. NO	FRAME MODEL DESIGNATION	GROSS SECTION AREA OF COLUMN SECTION (mm^2)	MAXIMUM LOAD CARRYING CAPACITY (LATERAL) (kN)
1.	CFSF2WOL-I	1064	11
2.	CFSF2WOL-II	1064	10.5
3.	CFSF2WL-I	1164	13
4.	CFSF2WL-II	1164	13

3.3. Maximum load carrying capacity

The response of cold-formed steel frame subjected to lateral loading was observed in the experiment test. noticeably the resistance offered by the structural elements being considered important parameters than other parameters. It was observed the cold-formed frame consisted of lipped channel column experienced high resistance compared to unlipped channel column frame. It was observed reason for this increment is the column have high cross sectional area that factor proportional to increase of moment of inertia. The factors that governs the maximum resistance are second moment of inertia and radius of gyration. This factors significant play important role in increase of resistance capacity of cold-formed steel frames. The Table 5 presents the maximum resistance of cold-formed steel frames.

4. CONCLUSIONS

The analysis revealed several significant findings, highlighting important aspects of the frame's performance. Initially, the analysis showed that the connections provided in both the beam-column junctions and the column-base plate demonstrated excellent performance without any slip or reduction in connectivity when subjected to applied forces.

It was observed that the frame model included lipped channel columns exhibited superior load-carrying capacity compared to other frame model. This leads and suggests that the use of lipped channel columns enhances the frame's overall strength and ability to meet serviceability requirements.

It was observed that the frame model utilizing 2 mm thick channel columns exhibited higher stiffness in this case stiffness found 192.42 N/mm compared to other frame model stiffness found 167.82 N/mm.

It was observed that increases of thickness and cross sectional area of the column sections positively influences the frame's rigidity, which can contribute to improved structural stability and reduced deformations under lateral loading conditions.

Future research could focus on optimizing the connection details between members in CFS bare frames. This involves exploring various types of connectors, such as screws, bolts, and welds, as well as their arrangements and spacing. Enhanced connection details could potentially improve the overall stability and load-carrying capacity of CFS frames under lateral loading.

Future research is the influence of initial imperfections and residual stresses on the behavior of CFS bare frames under lateral loads. Investigating how these factors affect the buckling and post-buckling response, as well as the overall structural performance, can lead to more accurate predictive models and safer design guidelines.

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