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Parametric behaviour beam-to-column composite connection using CFS section

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Abstract

Recently, cold-formed steel (CFS) has become a popular material for low- and medium-rise building structural elements. Where the CFS section assembles the beam and column parts. The merits of CFS might make the construction lighter and more effective to field modifications. In regions prone to earthquakes, the structure's mass is crucial. The combination of CFS and lightweight concrete is proposed to reduce the structure's weight and reduce the seismic activity of the building. This paper investigates the parametric behavior of beam-to-column composite connection using the CFS section, where the slab component is a lightweight concrete material. The CFS was constructed using a double-lipped channel (DLC) section that was arranged in a back-to-back arrangement. In contrast, the beam is made of DLC250 and the column is built of DLC300. In this research, a 5 mm gusset plate with a haunched gusset plate structure was presented. The isolated joint test of lightweight concrete (IJLW) with parametric method is carried out based on the Eurocode Standard to calculate the connection moment resistance, connection stiffness, and connection classification. According to the results of the parametric calculation, the connection's moment resistance was 67.28 kNm, and its stiffness was 1464.39 kNm/rad. The failure mode shows that the connection fails at beam bolt hole in bearing. The results show that the connection is classified as semi-rigid, partial strength, and ductile behavior.

Keywords

***Cold-formed steel, Composite connection, Lghtweight concrete, Haunched gusset plate, Parametric study*.**

1.Introduction

Steel is a series of iron–carbon alloys with well-defined component ratios. [1]. Steel has several advantages over other materials like concrete and wood. The steel quality could be controlled, produced massively, has high strength in tension, high ductility, and very homogenous and uniform material. Steel is divided into cold-formed steel (CFS) and hot-rolled steel (HRS) [2]. CFS has advantages over HRS, such as lightweight, could be formed for unusual sectional configuration, efficient structural application, and is relatively easy to be modified in the field [3]. Due to its lighter weight, the CFS is beneficial in reducing the weight of the building to reduce seismic activity. Connections are an important part of a steel structure, where a proper design and treatment are necessary to make the structure safe and economic [4].

The load transfer mechanism is vital in connection. CFS has a problem in connection due to the thickness, so a proper connection design for the CFS has to be suitable for the application. The bolt connection is recommended for the beam-column connection with CFS material rather than the screw connection. The connection studies for beam-column are divided into two areas: composite and non-composite study.

A composite connection is a combination of materials utilized in the connection, such as steel and concrete. The composite study [5−9] has slab components with concrete material. Shear connectors are used to connect the concrete material to the CFS beam to prevent shear failure. All of the concrete utilized in those tests was conventional concrete. The studies utilized the slip-in gusset plate with a rectangular gusset plate [5, 6] and a haunched gusset plate [7]. Yu et al. [8] conducted a composite connection study

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using HRS material for the beam and the column with a steel-reinforced concrete configuration.

Saggaff, et al. [9] studied about CFS composite beam. The specimen consisted of CFS as the beam and self-compacting concrete as the slab material. The study is conducted with a full-scale experimental test with a four-point load system. The results show that CFS with 4 mm thickness has a high value of ultimate moment compared to CFS with 2 mm and 3 mm thickness. The CFS could be an alternative material for the roofs and floors building.

The studies of composite connection [7] have been conducted by investigating the effect of beam dimension and the seat angles' influence. The study shows that the seat angle does not influence the connection significantly. Adding the seat angles could cause a rigid behavior in the connection and prevent the local buckling on the bottom flange of the beam [7]. Sulaiman et al. [5] studied a composite connection of cold-formed sections. The results show that a composite connection had a better load-carrying capacity than a non-composite connection.
Non-composite connections mean that just a single material is used in this study. The study of non-composite connections [10−15] is very various. All of the studies used the bolted connection and a slip-in gusset plate. Other non-composite connections discussed a portal frame [16−19], improvised connection for industrial structure [11], and welded connection in HRS beam-column [20].

For the composite studies about the beam, the component utilizes ultra-high-performance concrete (UHPC) for the slab [21], and steel fiber reinforced concrete is utilized for the composite beam [22]. Parastesh et al. [23] improved an anti-symmetrical CFS beam or column component profile.

Based on the studies above, no study has discussed the behaviour of composite CFS connection utilizing lightweight concrete for the slab. This paper investigated beam-to-column composite connection's parametric behaviour, where the slab material is lightweight concrete. The parametric study investigates the moment resistance, stiffness, and classification of the connection within the proposed connection configuration. This study refers to Yu et al. [8] research using bolted and haunched gusset plate connections. It is hoped that this type of structural configuration could reduce the structural weight and make it more economical. This study shows lightweight structures that combine a lightweight material in steel and concrete, which is still rare.

In this paper, section 1 describes the background and objective. Section 2 shows the literature review on CFS as a structural member and connection. Section 3 explains the methodology that was carried out in this study. Section 4 shows the results of this study. Then, Section 5 discusses the obtained results. Last, Section 6 concludes the discussed results.

2.Literature review

Utilization of the CFS section as the structural component is still rare. It is due to a lack of stability in the CFS profile. CFS has a slender profile rather than HRS. Furthermore, some studies have discussed CFS as a structural component, such as beam component [23−33], flooring system [34], column component [35−38], portal frame[16-19, 39], apex and eaves connection [40−43] and a connection between beam-column components [5−7, 10−15, 44−51] had already investigated in the previous study. Also, a study about the connection in HRS has been conducted [52−58].

Zhao et al. [24] have studied the influence of web holes on the flexural behavior of CFS channel beams and assessed the reliability of the direct strength method (DSM) following North American Specification (NAS). Under four-point bending, 10 examples with varying web hole diameters and lips were tested. Local buckling and distortional buckling are dominant failure modes. It has been discovered that the DSM in NAS provides an inappropriate estimation for CFS channel beams with web holes. Chen et al. [25] have carried out an experimental study for CFS with elliptical hollow section (EHS) for beam-columns element. Some variation of eccentricities is utilized to evaluate the load-moment relationship. The result shows that the experimental results and the prediction by analytical design are quite conservative and reliable for CFS with EHS type.

The research about CFS beam for the modular building was conducted by Gathesshgar et al. [26]. The use of CFS in modular systems demonstrated the possibility for lighter modules and more sustainable constructions by lowering their carbon footprint. The researchers reach the conclusion that improving the CFS section with super sigma sections improves structural performance and brings the shear center closer to the outside web. Shi et al. [27] carried out the study about composite CFS beams. It has six full-scale specimens to investigate the flexural behavior and the CFS composite slab capacity. There are a variety of shear transfer mechanisms and different slab materials. The results show that the shear buckling of the joist web commonly occurs, different behavior of each specimen due to different types of sections, and the CFS joist's strength influence the composite beams' flexural behavior. Recently, a study on constraint optimization for anti-symmetric CFS in beam-column elements was conducted [23]. The study intended to increase the load-bearing capacity of beam-column components to make them more efficient and cost-effective. There are 132 specimens with three different lengths and eleven cross-sections subjected to concentric compression stresses. Additionally, a variety of load eccentricities are implemented. The findings indicate that the optimization of CFS constraint enhances the strength of beam-column elements by 62%, 92%, and 188%, respectively, compared to the standard sections for short, medium, and long elements. Saggaff, et al. [9] studied about CFS composite beam. The specimen consisted of CFS as the beam and self-compacting concrete as the slab material. The study uses a full-scale experimental test with a four-point load system. The results show that CFS with 4 mm thickness has a high value of ultimate moment compared to CFS with 2 mm and 3 mm thickness. The CFS could be an alternative material for the roofs and floors of the building. Another investigation on CFS composite beam presented a beam with a rectangular shape, packed with various lightweight packing materials, which resulted in a novel lightweight CFS beam [30]. The lightweight material was hollow PVC, cardboard, and timber for the flange and web variation. The results show that cardboard and timber packing shows a good resistance, especially against CFS's distortional buckling.

An HRS study about square hollow section connection is conducted by Tafsirojjaman et al. [58]. The connection tests are conducted under monotonic and cyclic loading. The composite joint test for a residential structure was carried out by Zhang et al. [53] using a U-shaped steel composite beam and a concrete-filled square steel tube column as the components. The welded connection was applied in the experiment. The connection strengthening studies of simple shear connection has conducted by Alrubaidi et al. [57]. The results show that the peak load of the specimen was significantly increased throughout the flexural and catenary action phases after shear connections were strengthened using pre-tensioned high-strength hot-rolled steel bars inside the connection zone.

Mojtabaei et al. [38] studied the apex and eaves connection subjected to axial compression, shear, and bending moment from AISI and Eurocode Standard. Rinchen and Rasmussen [19] performed full-scale tests of portal frames with a single C-Section, and the ultimate load is predicted with the Direct Strength Method. The experiments were performed on six portal frames with a center-to-center span of 13.6 meters, an eaves height of 5.7 meters, and an apex height of 6.8 meters.

The study of beam-column connection with finite element method analysis is conducted by Venghiac et al. [59]. The results indicate that the bolt's diameter influences the stress level. When the diameter of the bolt increases from 10 mm to 16 mm, the stress level decreases to 46.15%. A cyclic and monotonic loading test of cold-formed steel has been conducted [14, 15, 50, 60] with a haunched gusset plate configuration. The beam-column connection of encased CFS Beams to concrete-filled steel tube columns has been carried out [48]. The experimental test was conducted with the static load. The study showed that the designed specimen has a higher load-bearing capacity and more resilience than the beam-column connection shown in conventional reinforced concrete. The concrete prevented the CFS from buckling, and the composite action contributed to improving the flexural capacity.

The studies of composite connection in CFS [7] have been conducted by investigating the effect of beam dimension and the seat angles' influence. It stated that the seat angles influence the connection resistance. Adding the seat angles could cause a rigid behaviour in the connection and prevent the local buckling on the bottom flange of the beam [7]. Sulaiman et al. [5] studied a composite connection of cold-formed sections. The result shows that a composite connection had a better load-carrying capacity than a non-composite connection.

Previous studies have indicated that the topic of CFS research has advanced. Structures such as beams, columns, composite beams, and connections were utilized. Especially for connection, studies have been performed on screw, weld, and bolt connections. Bolted beam-column connections indicate the limitations of the research in composite connections. According to the overall composite connection study, there is no research on the composite connection that uses lightweight concrete as the slab component. The behavior of lightweight concrete used as the slab component in composite connections is discussed in this study.

3.Methodology

The study attempts to evaluate the moment capacity of a composite connection using lightweight concrete. This study was conducted using a parametric approach following the Eurocode Standard. The specimen for the current study is called isolated joint test of lightweight concrete (IJLW). The isometric view of the IJLW specimen can be seen in *Figure 1*.

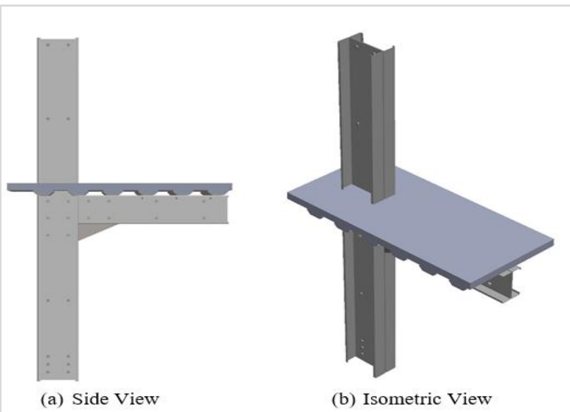

Figure 1 (a) Side View and (b) Isometric view of IJLW specimen

3.1Material properties

This study has two CFS types: C250 for beam components and C300 for column components. The CFS yield strength was 450 MPa and the ultimate strength was 480 MPa. The specification of the CFS is shown in *Figure 2* and *Table 1*. The back-to-back system of the double-lipped channel (DLC) was applied in this study.

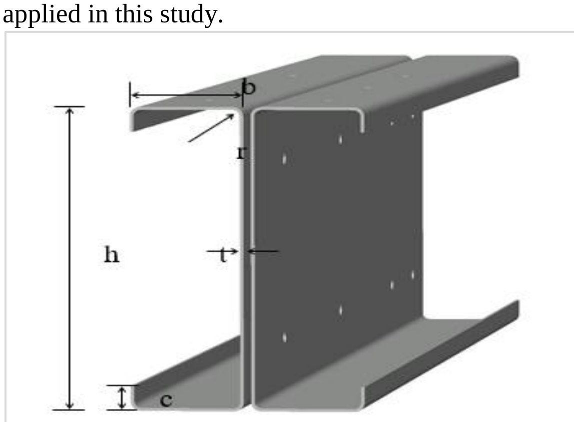

Figure 2 CFS section

Table 1 The dimension of CFS section

Section	b (mm)	h (mm)	t (mm)	r (mm)	c (mm)
DLC250	75	250	2.4	5	20
DLC300	100	300	2.4	5	25

The gusset plates were haunched gusset plates with the configuration same as previous research [7]. An HRS type was used for the gusset plate, which had a yield strength of 321 MPa and an ultimate strength of 465 MPa. The gusset plate has a thickness of 5 millimetres all the way through. The *Figure 3* of the gusset plate may be seen in the following illustration.

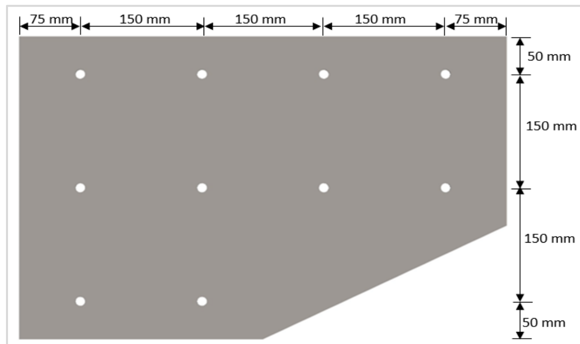

Figure 3 The shape of gusset plate

Concrete has been cast into a slab that is 750 millimetres wide and has a thickness of 100 millimetres. This lightweight concrete had a compressive strength of 20 MPa when it was analyzed. There are a rebar ϕ6-200 and ϕ12 for the anchorage component. The slab was supported by a metal deck, while M12 shear connections make the composite actions between the concrete slab and CFS beam. The bolt yield strength was 758 MPa and 834 MPa for ultimate strength based on Lawan [61]. The rebar and the anchorage are shown in the isometric and top view (*Figure 4* and *Figure 5*).

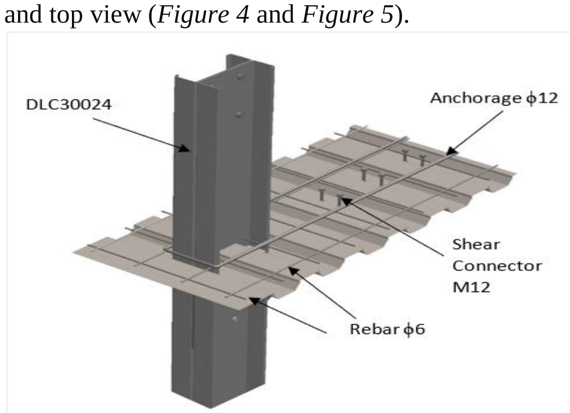

Figure 4 Isometric view of IJLW rebar and anchorage

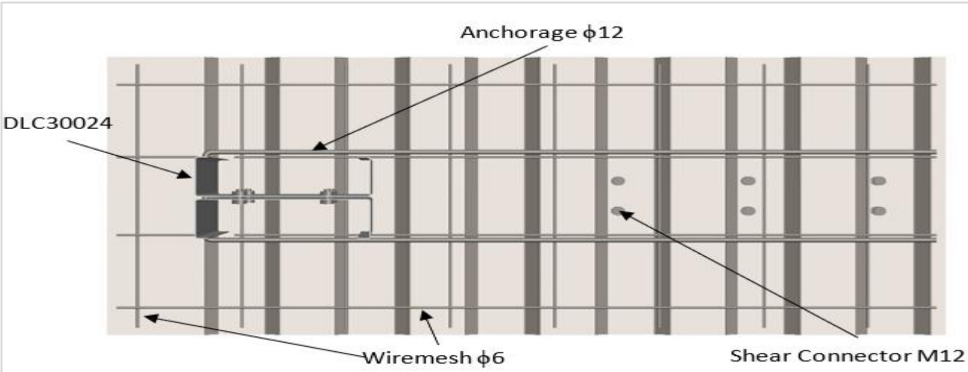

Figure 5 Top view of IJLW

In this study, *Figure 6* presents the study's flowchart. It described how to assess the connection's moment resistance and stiffness in accordance with Eurocode 3 specifications. The cross-section characteristics were previously described in *Table 1*, and the material parameters, such as yield strength and ultimate strength, of CFS, HRS, and the bolt, were previously described. The flowchart allowed us to compute the moment resistance and stiffness of the connection. After the moment resistance and stiffness have been calculated, the connection may be categorized into strength, stiffness, and ductility.

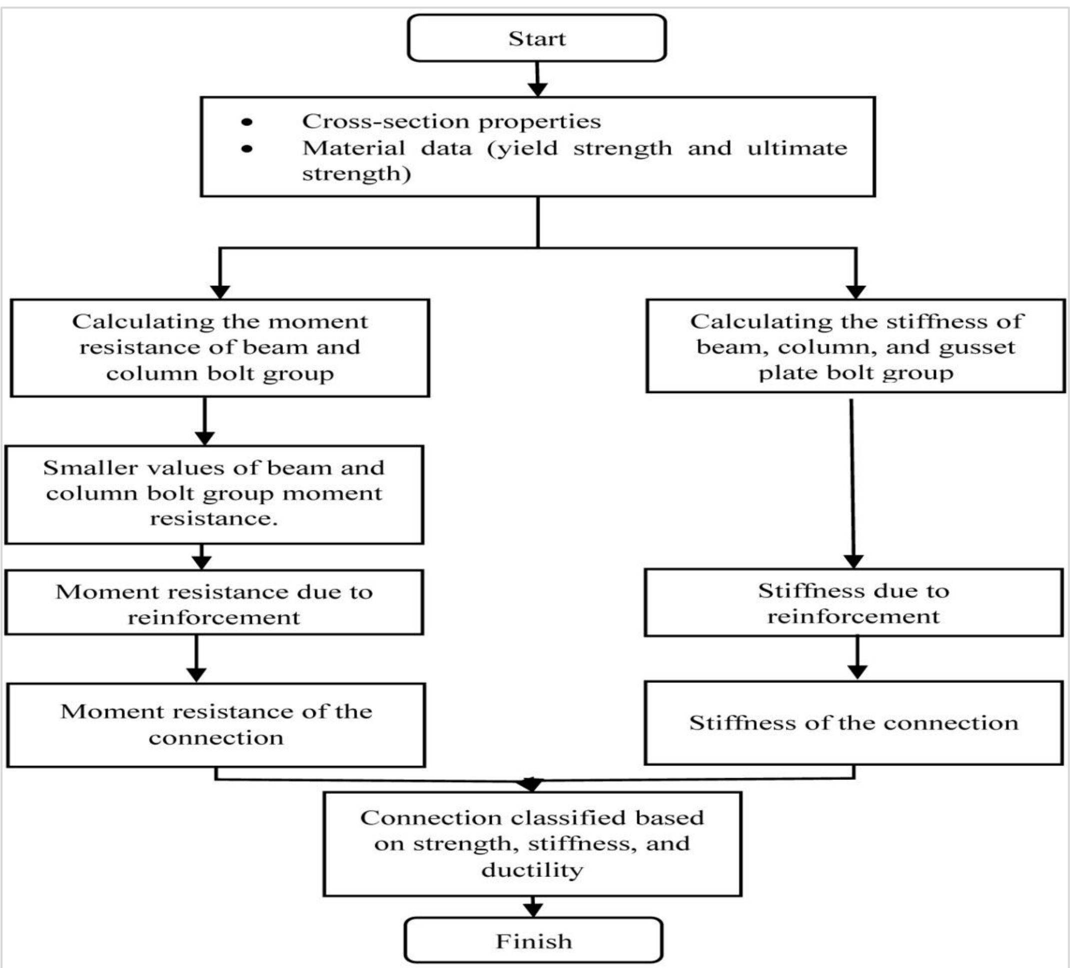

Figure 6 Study flowchart

In BS EN 1993 1-8: 2005, some calculations about bolt group resistance in gusset plate exist. There are shear resistance and bearing resistance that governs the joint capacity. The shear and bearing resistance formulation are shown in Equation 1 and 2, respectively.

$$F_{v,Rd} = \frac{\alpha_v f_{u,bolt}\quad_{s,bolt}}{\gamma m_2} \tag{1}$$

$$F_{b,Rd} = \frac{k_1 \alpha_d f_u t}{\gamma m_2} \tag{2}$$

$F_{v,Rd}$ stands for the bolt's shear resistance and $F_{b,Rd}$ for the bolt's bearing resistance. α_v is a coefficient of shear plane on the unthreaded portion. $f_{u,bolt}$ is a ultimate tensile strength of the bolt. $A_{s,bolt}$ is the bolt area. γ_{M2} shows the partial safety factor with a 1.25 value. The smallest value of $f_{u,bolt}/f_u$ or 1 is shown by α_d. The thickness of the connected part is represented by t. f_u is the ultimate tensile strength of connected material.

The connection resistance and reinforcement resistance influence the moment resistance of composite connections. The connection's moment resistance is classified into beam bolt group and column bolt group. There are two cases for the reinforcement moment resistance where the compression and tension value is determined in the next step of the calculation. The first case was when the compression value was higher than the tension value and the second case was when the compression value was lower than the tension value.

For the connection stiffness, there are some considerations of bolt conditions. The bolt in shear condition and the bolt in bearing condition. The formulation is shown in Equation 3 and Equation 4.

$$k_{11} = \frac{8\, n_b\, d^2 f_{ub}}{E\, d_{M16}} \tag{3}$$

$$k_{12} = \frac{12\, n_b\, k_b\, k_t\, d\, f_u}{E} \tag{4}$$

k_{11} means the bolt in shear condition and k_{12} means the bolt in bearing condition. n_b stands for the number of bolts. d is the diameter of the bolt. f_{ub} is the ultimate strength of the bolt. E is the modulus elasticity of the component. d_{M16} is the diameter of M16 bolt. k_b is a coefficient that influenced by the bolt spacing and bolt diameter. k_t is the coefficient affected by the component thickness and M16 diameter.

The equation to calculate the stiffness of the bolt group in beam and column components is shown below.

$$S_{j,ini} = \frac{E_s\, z^2}{(\frac{1}{\Sigma k})} \tag{5}$$

$$\frac{1}{\Sigma k} = \frac{1}{k11,j} + \frac{1}{k12,j} + \frac{1}{k12,gj} \tag{6}$$

$$\Sigma k = \frac{1}{\frac{1}{k11,j} + \frac{1}{k12,j} + \frac{1}{k12,gj}} \tag{7}$$

Where E_s is the modulus elasticity of the steel, z is the lever of the arm, and k is the stiffness coefficient for the basic joint component.

There are three rotation that needs to be considered in the calculation. The ϕ_1 and ϕ_2 are for horizontal rotation and ϕ_3 for vertical rotation. The calculation of the rotations is based on Equations (8-10).

$$\phi_1 = \frac{P\, L_a^2}{(E_s\, I_{yb,eff})} \tag{8}$$

$$\phi_2 = \frac{M_b L_a}{E_s\, I_{yb,eff}} \tag{9}$$

$$\phi_3 = \frac{M_c L_b}{L_c\, E_s\, I_{yc,eff}} \tag{10}$$

So for the gusset plate stiffness the calculation was.

$$S_{gp,ini} = \frac{M_c}{\phi_1 + \phi_2 + \phi_3} \tag{11}$$

The composite action between concrete and steel had an impact on connection stiffness. There is an additional stiffness from the reinforcement with the following Equation 12.

$$S_{j,reinf} = \frac{E_s\, z_{eq}^2}{\Sigma \frac{1}{k_i}} \tag{12}$$

So, the total connection stiffness was a summary between the gusset plate and reinforcement stiffness. Then, the result is affected by the modification stiffness from BS EN 1993-1-8. The modification factor was $\eta = 2$ (Equation 13 and 14).

$$S_{j,conn} = S_{j,gp} + S_{j,reinf} \tag{13}$$

$$S_{j,Rd} = \frac{S_{j,conn}}{\eta} \tag{14}$$

$S_{j,conn}$ means a stiffness of the connection between the gusset plate ($S_{j,gp}$) and reinforcement contribution ($S_{j,reinf}$). $S_{j,Rd}$ is the stiffness that occurred in the joint.

4.Results

The connection's moment resistance calculation is explained in *Table 2*. The calculation shows a beam bolt group and column bolt group calculation. The calculation is referred to Equation 1 and Equation 2. The shear and bearing resistance is governed in *Table 2*. The moment resistance of shear and bearing is affected by the lever of arm of each bolt group.

After calculating the moment resistance on the connection. The moment resistance due to reinforcement is calculated too. The calculation is explained in *Table 3.*

Table 2 Calculation of moment resistance

Equation	Result	Units
Moment Resistance of Beam Bolt Group		
Shear Resistance $F_{v,Rd,b} = \frac{\alpha_v f_{u,bolt} A_{s,bolt}}{\gamma m_2}\ x\ 2$	67.49	kN
Bearing resistance of Cold-Formed Steel		
$F_{b,Rd,bc} = \frac{k_1 \alpha_d f_u t}{\gamma m_2}\ x\ 2$	54.37	kN
Bearing resistance of Gusset Plate		
$F_{b,Rd,bg} = \frac{k_1 \alpha_d f_u t}{\gamma m_2}$	200.16	kN
Moment Resistance in Beam $M_{j,b} = \sum f_{i,b}\ x\ L_{i,b}$	23.07	kNm
Moment Resistance of Column Bolt Group		
Shear Resistance $F_{v,Rd,b} = \frac{\alpha_v f_{u,bolt} A_{s,bolt}}{\gamma m_2}\ x\ 2$	67.49	kN
Bearing resistance of Cold-Formed Steel		
$F_{b,Rd,bc} = \frac{k_1 \alpha_d f_u t}{\gamma m_2}\ x\ 2$	54.37	kN
Bearing resistance of Gusset Plate		
$F_{b,Rd,bg} = \frac{k_1 \alpha_d f_u t}{\gamma m_2}$	200.16	kN
Moment Resistance in Column $M_{j,c} = \sum f_{i,c}\ x\ L_{i,c}$	44.63	kNm
The moment resistance of connection (M_{jg}) is the smallest value due to bearing failure in the beam bolt hole.	23.07	kNm

Table 3 Calculation of moment resistance due to reinforcement

Equation	Result	Units
The value of F_c	101.64	kN
The value of F_t	139.38	kN
So from the value above, $F_c < F_t$		
$y_c = \frac{F_t - F_c}{t_{w,b} f_{y,b}}$	17.77	mm
$y_w = 0.5\ x\ y_c$	8.88	mm
$F_w = y_c\ x\ t_{w,b}\ x\ f_{y,b}$	37.74	kN
$M_{j,reinf} = F_t\ x\ h_{reinf} - (F_w\ y_w)$	44.21	kNm
So, the composite connection moment resistance is		
$M_{j,Rd} = M_{jg} + M_{j,reinf}$	67.28	kNm

Stiffness is calculated for column, beam, and gusset plate bolt groups. The results of the stiffness calculation reveal how rigid the structural component is. *Table 4* presents the results of the calculation about the stiffness. The number of bolts and the lever of arm of each bolt demonstrate that the column part has a larger stiffness value than the beam part. There is another additional stiffness due to the reinforcement. Due to composite action, reinforcement has an impact to the connection stiffness. The calculation of the connection stiffness is explained in *Table 5*. In total, the connection stiffness was 2928.79 kNm/Rad.

Table 4 Stiffness on column bolt group and beam bolt group

Equation	Result	Units
Stiffness of beam bolt group		
$k_{11,c} = \frac{8\, n_b\, d^2 f_{ub}}{E\, d_{M16}}$	0.572	
$k_{12,c} = \frac{12\, n_b\, k_b\, k_t\, d\, f_u}{E}$	0.364	
$k_{12,gc} = \frac{12\, n_b\, k_b\, k_t\, d\, f_u}{E}$	0.374	
$S_{c,bg,ini} = \frac{E_s\, z^2}{(\frac{1}{\sum k})}$	1317.77	kNm/Rad
Stiffness of column bolt group		
$k_{11,b} = \frac{8\, n_b\, d^2 f_{ub}}{E\, d_{M16}}$	0.572	
$k_{12,b} = \frac{12\, n_b\, k_b\, k_t\, d\, f_u}{E}$	0.364	
$k_{12,gb} = \frac{12\, n_b\, k_b\, k_t\, d\, f_u}{E}$	0.374	
$S_{b,bg,ini} = \frac{E_s\, z^2}{(\frac{1}{\sum k})}$	3623.86	kNm/rad
Stiffness of gusset plate bolt group		
$\phi_1 = \frac{P\, L_a^2}{(E_s\, I_{yb,eff})}$	0.000386816	Rad
$\phi_2 = \frac{M_b L_a}{E_s\, I_{yb,eff}}$	0.002191959	Rad
$\phi_3 = \frac{M_c L_b}{L_c\, E_s\, I_{yc,eff}}$	0.000407629	Rad
$S_{gp,ini} = \frac{M_c}{\phi_1 + \phi_2 + \phi_3}$	11552.35	kNm/Rad
Stiffness of connection		
$S_{j,gp} = \frac{1}{\frac{1}{S_{c,bg,ini}} + \frac{1}{S_{b,bg,ini}} + \frac{1}{S_{gp,ini}}}$	891.77	kNm/rad

Table 5 Calculation of stiffness due to reinforcement

Equation	Result	Units
$S_{j,reinf} = \frac{E_s\, z_{eq}^2}{\sum \frac{1}{k_i}}$	2037.02	kNm/rad
$S_{j,conn} = S_{j,gp} + S_{j,reinf}$	2928.79	kNm/rad
$S_{j,Rd} = S_{j,conn}/\eta$	1464.39	kNm/rad

Table 6 compares moment resistance between the current and the latest studies. It shows that the current study connection has moment resistance higher than the non-composite connection [13, 62]. The utilization of bolted connection in this study has a

significant influence rather than the screw connection [13].

In depth, the current study compared to previous research in Firdaus et al. [7] for specimen IJT-02 with a parametric method with a similar connection configuration but different gusset plate thickness. The comparison is shown in *Table 7*. Based on *Table 7*. It can be seen from here that the connection's moment resistance and connection stiffness are almost similar, with a ratio of 0.95 for moment resistance and a connection stiffness by 0.97. The IJLW has less moment resistance and stiffness than the previous study's connection. It occurs because it has a different gusset plate thickness and without an angle stiffener. Another factor was that the type of concrete utilized in this study differed from the previous one. Therefore, it results in a reduction in the connection's moment resistance as well as its stiffness.

Table 6 The moment resistance comparison with another study

Moment resistance			
kNm			
Composite		Non-Composite	
Recent study	Firdaus et al. [7]	Amsyar et al. [13]	Wang et al. [62]
67.28	70.312	22.94	33.6

Table 7 The comparison between IJLW and IJT-02 [7]

Moment Resistance ($M_{j,Rd}$) kNm		**Moment resistance ratio**	**Connection stiffness ($S_{j,conn}$) kNm/Rad**		**Connection stiffness ratio**
IJLW	IJT-02	IJLW/IJT-02	IJLW	IJT-02	IJLW/IJT-02
67.28	70.312	0.95	1464.39	1513.2	0.97

5. Discussion

The moment resistance of the gusset plate connection show from *Table 2* is 23.07 kNm due to the bearing failure of the beam bolt hole at CFS. The thickness of the cold-formed steel and the lever arm in the beam section affect the failure mode. Since the beam section has a shorter lever of arm than the column section does, the beam section has a lower moment resistance as a direct consequence of this design feature.

The composite action at the connection had an additional moment resistance due to reinforcement. The reinforcement contributed 44.21 kNm and the composite connection was 67.28 kNm. From the calculation, it shows that the contribution of the reinforcement is significant.

Table 4 shows that gusset plate has a high contribution in connection stiffness because it has a higher stiffness value than the column and beam bolt groups. The column has a higher stiffness due to number of bolts with 6 bolts rather than in beam with 4 bolts. The lever of arm at the column was longer than the lever of arm at the beam. In total, the stiffness of the connection was 891.77 kNm/rad. Then, there is an influence of reinforcement to the connection stiffness that show in *Table 5*. It shows that the reinforcement contributes 2037.02 kNm/rad, so reinforcement significantly influences the connection stiffness.

In *Figure 7* there is a comparison of the moment rotation graph from recent and previous studies. The IJT-02 [7] shows as full strength category and IJLW as the partial strength category. Full strength is occurred due to the moment resistance value being more than the bending moment in bending, following BS EN 1993-1-8:2005 part 5.2. Section 5.2.3.3. IJLW and IJT-02 [7] had a similar semi-rigid category in the stiffness category, according to BS EN 1993-1-8:2005 part 5.2. Section 5.2.2.5. *Figure 7* also shows that the rotation of the connection is more than 0.03 rad. So, the ductile type of connection is presented. According to the connection classification found in the Eurocode, it can be stated that the suggested composite connection is appropriate for use as the structural system.

This study is limited to predicted moment resistance, stiffness, and failure in the connection. Compared with the previous study, the utilization of lightweight concrete has a lesser moment resistance and rigidity of the connection but still in the semi-rigid and partial strength classification. A complete list of abbreviations is shown in *Appendix I.*

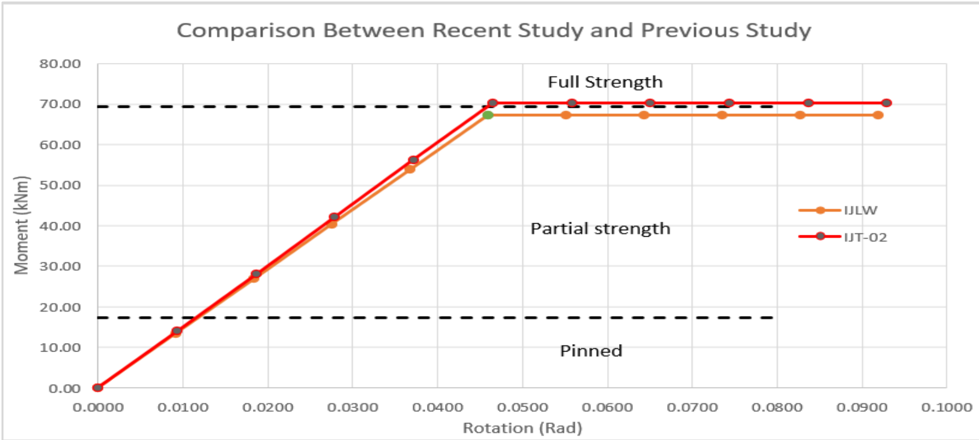

Figure 7 Moment Rotation between recent study and previous study [7]

6.Conclusion and future work

From the result and discussion above, the recent studies with less thickness gusset plate and lightweight concrete as a slab material had almost similar behavior in the parametric method to the previous study [7]. The ratio between moment resistance and stiffness on both studies is close, 0.95 and 0.97, respectively. The recent studies connection has a behavior that the connection was in semi-rigid connection and partial strength connection, while the previous study [7] shows a semi-rigid connection with a full-strength connection category. The proposed connection also shows a ductile connection behavior. The results show that the composite connection with lightweight concrete as the slab material is suitable for the lightweight structure system.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

R.M. Fadel Satria Albimanzura: Does conceptual framework, method, analysis, and writing. **Anis Saggaff**: is contributed by monitoring and information evaluation. **Mahmood Md Tahir:** Review of data and supervision. **Kiagus Muhammad Aminuddin:** Review of data and supervision.

References

[1] Bernuzzi C, Cordova B. Structural steel design to Eurocode 3 and AISC specifications. John Wiley & Sons; 2016.
[2] Yu C. Recent trends in cold-formed steel construction. Woodhead Publishing; 2016.
[3] Yu WW, Laboube RA, Chen H. Cold-formed steel design. John Wiley & Sons; 2019.
[4] Tamboli A. Handbook of structural steel connection design and details. McGraw-Hill Education; 2010.
[5] Sulaiman A, Salleh NM, Sukardi N, Siang TC, Saggaff A. Experimental evaluation of composite beam-to-column joint using cold-formed steel sections. In conference series: materials science and engineering 2019 (pp.1-13). IOP Publishing.
[6] Amsyar F, Siang TC, Sulaiman A, Khun MC. Numerical and experimental study of semi-rigid beam-to-column composite connections in cold-formed steel. In AIP conference proceedings 2020. AIP Publishing LLC.
[7] Firdaus M, Saggaff A, Tahir MM, Aghlara R, Sulaiman A, Aminuddin K, et al. Influence of seat angles on the behaviour of cold-formed steel concrete composite joints. Journal of Constructional Steel Research. 2020.
[8] Yu S, Wu C, Zhou F, Wang P, Zhao K, Liu J. Experimental study and numerical simulation of a new prefabricated SRC column to steel beam composite joint. Structures 2020; 27:999-1010. Elsevier.
[9] Saggaff A, Tahir MM, Azimi M, Alhajri TM. Structural aspects of cold-formed steel section designed as U-shape composite beam. In AIP conference proceedings 2017 (pp. 1-11). AIP Publishing LLC.
[10] Desmaliana E, Herbudiman B, Ulfayani AM, Gunawan FA. Study of cold formed steel beam column joint to resist lateral load. In MATEC web of conferences 2019 (pp. 1-6). EDP Sciences.
[11] Bishay-girges NW. Improved steel beam-column connections in industrial structures. Engineering, Technology & Applied Science Research. 2020; 10(1):5126-31.
[12] Fahmy AS, Swelem SM, Mussttaf HH. Beam-column connections behavior of cold-formed steel members: New experimental configuration. KSCE Journal of Civil Engineering. 2020; 24(7):2147-59.

[13] Amsyar F, Tan CS, Mohammad S, Tahir MM, Hamid HA. Partial strength beam-to-column connection of cold-formed single channel section: numerical and experimental study. ASM Journal. 2021.
[14] Vipin.V, Nair DS. Behaviour of cold-formed steel moment connections under cyclic loading. International Journal of Engineering Research and Technology. 2021; 9(6):17-21.
[15] Abaszadeh A, Rousta AM, Golsoorat PA, Beiranvand P. Behavior of connections in cold-formed steel frames under cycling loading. Practice Periodical on Structural Design and Construction. 2021; 26(2):1-11.
[16] Blum HB, Rasmussen KJ. Experimental investigation of long-span cold-formed steel double channel portal frames. Journal of Constructional Steel Research. 2019; 155:316-30.
[17] Cardoso FS, Zhang H, Rasmussen KJ, Yan S. Reliability calibrations for the design of cold-formed steel portal frames by advanced analysis. Engineering Structures. 2019; 182:164-71.
[18] Mccrum DP, Simon J, Grimes M, Broderick BM, Lim JB, Wrzesien AM. Experimental cyclic performance of cold-formed steel bolted moment resisting frames. Engineering Structures. 2019; 181:1-14.
[19] Rinchen R, Rasmussen KJ. Experiments on long-span cold-formed steel single C-section portal frames. Journal of Structural Engineering. 2020; 146(1).
[20] Chen Y, Huo J, Chen W, Hao H, Elghazouli AY. Experimental and numerical assessment of welded steel beam-column connections under impact loading. Journal of Constructional Steel Research. 2020.
[21] Wang Z, Nie X, Fan JS, Lu XY, Ding R. Experimental and numerical investigation of the interfacial properties of non-steam-cured UHPC-steel composite beams. Construction and Building Materials. 2019; 195:323-39.
[22] Zhang Y, Liu A, Chen B, Zhang J, Pi YL, Bradford MA. Experimental and numerical study of shear connection in composite beams of steel and steel-fibre reinforced concrete. Engineering Structures. 2020.
[23] Parastesh H, Mojtabaei SM, Taji H, Hajirasouliha I, Sabbagh AB. Constrained optimization of anti-symmetric cold-formed steel beam-column sections. Engineering Structures. 2021.
[24] Zhao J, Sun K, Yu C, Wang J. Tests and direct strength design on cold-formed steel channel beams with web holes. Engineering Structures. 2019; 184:434-46.
[25] Chen MT, Young B. Beam-column tests of cold-formed steel elliptical hollow sections. Engineering Structures. 2020.
[26] Gatheeshgar P, Poologanathan K, Gunalan S, Tsavdaridis KD, Nagaratnam B, Iacovidou E. Optimised cold-formed steel beams in modular building applications. Journal of Building Engineering. 2020.
[27] Shi Y, Yang K, Guan Y, Yao X, Xu L, Zhang H. The flexural behavior of cold-formed steel composite beams. Engineering Structures. 2020.
[28] Taheri E, Firouzianhaji A, Mehrabi P, Vosough HB, Samali B. Experimental and numerical investigation of a method for strengthening cold-formed steel profiles in bending. Applied Sciences. 2020; 10(11):1-31.
[29] Puluhulawa I. Behavior of shear connector variations on strengthened reinforced concrete slabs using cold formed steel. In conference series: earth and environmental science 2020 (pp. 1-8). IOP Publishing.
[30] Dar AR. An experimental study on the flexural behavior of cold-formed steel composite beams. Materials Today: Proceedings. 2020; 27:340-3.
[31] Roy K, Lau HH, Ting TC, Chen B, Lim JB. Flexural capacity of gapped built-up cold-formed steel channel sections including web stiffeners. Journal of Constructional Steel Research. 2020.
[32] Chen B, Roy K, Uzzaman A, Lim JB. Moment capacity of cold-formed channel beams with edge-stiffened web holes, un-stiffened web holes and plain webs. Thin-Walled Structures. 2020.
[33] Chen B, Roy K, Fang Z, Uzzaman A, Pham C, Raftery G, et al. Shear capacity of cold-formed steel channels with edge-stiffened web holes, un-stiffened web holes and plain webs. Journal of Structural Engineering. 2022; 148(2).
[34] Karki D, Far H. State of the art on composite cold-formed steel flooring systems. Steel Construction. 2021; 14(2):117-27.
[35] Dubina D, Ungureanu V, Kotelko M. Post-elastic capacity of thin-walled cold-formed steel members. In proceedings of the cold-formed steel research consortium colloquium 2020 (pp. 1-8).
[36] Chen B, Roy K, Uzzaman A, Raftery G, Lim JB. Axial strength of back-to-back cold-formed steel channels with edge-stiffened holes, un-stiffened holes and plain webs. Journal of Constructional Steel Research. 2020.
[37] Roy K, Ting TC, Lau HH, Masood R, Alyousef R, Alabduljabbar H, et al. Cold-formed steel lipped channel section columns undergoing local-overall buckling interaction. International Journal of Steel Structures. 2021; 21(2):408-29.
[38] Mojtabaei SM, Becque J, Hajirasouliha I. Behavior and design of cold-formed steel bolted connections subjected to combined actions. Journal of Structural Engineering. 2021; 147(4).
[39] Senapati S, Sangle KK. Nonlinear static analysis of cold-formed steel frame with rigid connections. Results in Engineering. 2022.
[40] Mojtabaei SM, Becque J, Hajirasouliha I. Local buckling in cold-formed steel moment-resisting bolted connections: behavior, capacity and design. Journal of Structural Engineering. 2020; 146(9).
[41] Phan DT, Mojtabaei SM, Hajirasouliha I, Lau TL, Lim JB. Design and optimization of cold-formed steel sections in bolted moment connections considering bimoment. Journal of Structural Engineering. 2020; 146(8).
[42] Chen X, Blum HB, Roy K, Pouladi P, Uzzaman A, Lim JB. Cold-formed steel portal frame moment-

resisting joints: behaviour, capacity and design. Journal of Constructional Steel Research. 2021.
[43] Phan DT, Mojtabaei SM, Hajirasouliha I, Ye J, Lim JB. Coupled element and structural level optimisation framework for cold-formed steel frames. Journal of Constructional Steel Research. 2020.
[44] Hanisha CS, Kishore IS. Experimental and finite element analysis of cold formed steel beam-column joint. Materials Today: Proceedings. 2020; 33:480-3.
[45] Alemdar F, Geleta H, Algaadi F. Moment-rotation characteristics and finite element analysis of cold formed steel connections. Journal of Uludag University Faculty of Engineering. 2021; 26(1):29-46.
[46] El AM, Amoush E, Soliman M. Numerical study of bolted moment connections in cold-formed steel frames. Future Engineering Journal. 2020; 1(1):1-12.
[47] Wang X, Liu F, Li X, Li T, Xu X, Shui Z, et al. Static bearing capacity investigation of a novel prefabricated light-steel beam–column connection. Applied Sciences. 2022; 12(9):1-22.
[48] Mosheer KA, Dawood MB, Ghalib MH. Experimental study on beam-column connections of concrete encased cold-formed steel beams to concrete-filled steel tube columns. In IOP conference series: materials science and engineering 2021 (pp. 1-9). IOP Publishing.
[49] Jiang L, Zhang X, Ye J, Jiang L, Zhou L. Seismic behavior and damage assessment of mid-rise cold-formed steel-framed buildings with normal and reinforced beam-column joints. Archives of Civil and Mechanical Engineering. 2021; 21(3):1-16.
[50] Papargyriou I, Mojtabaei SM, Hajirasouliha I, Becque J. Cyclic and monotonic moment-rotation behaviour of CFS web-connected beam-to-column joints. 1st Croatian conference on earthquake engineering 2021 (pp. 1067-77).
[51] Mojtabaei SM, Hajirasouliha I, Ye J. Optimisation of cold-formed steel beams for best seismic performance in bolted moment connections. Journal of Constructional Steel Research. 2021.
[52] Bai Y, Wang S, Mou B, Wang Y, Skalomenos KA. Bi-directional seismic behavior of steel beam-column connections with outer annular stiffener. Engineering Structures. 2021.
[53] Zhang Z, Mao G, He R, Xiao A, Liu Z. Bearing capacity of composite joints of u-shaped steel composite beams and concrete-filled square steel tubular columns based on channel steel connection. Journal of Engineering Science & Technology Review. 2021; 14(4):40-52.
[54] Jiang ZQ, Yang XF, Dou C, Pi YL, Li R. Design theory of earthquake-resilient prefabricated beam-column steel joint with double flange cover plates. Engineering Structures. 2020.
[55] Ye M, Jiang J, Chen HM, Zhou HY, Song DD. Seismic behavior of an innovative hybrid beam-column connection for precast concrete structures. Engineering Structures. 2021.
[56] Yang H. Performance analysis of semi-rigid connections in prefabricated high-rise steel structures. Structures. 2020; 28:837-46. Elsevier.
[57] Alrubaidi M, Abbas H, Elsanadedy H, Almusallam T, Iqbal R, Al-salloum Y. Experimental and FE study on strengthened steel beam-column joints for progressive collapse robustness under column-loss event. Engineering Structures. 2022.
[58] Tafsirojjaman T, Fawzia S, Thambiratnam DP, Zhao XL. FRP strengthened SHS beam-column connection under monotonic and large-deformation cyclic loading. Thin-Walled Structures. 2021.
[59] Venghiac VM, Olteanu-donțov I, Alexa-stratulat MS, Țăranu G, Băetu SA, Toma IO. FEM analyses on beam-to-column connection for a thin-walled cold-formed steel frame. In IOP conference series: materials science and engineering 2021 (pp. 1-9). IOP Publishing.
[60] Chen M, Huo JH, Xing YW. Seismic behavior of cold-formed steel frames with bolted moment connections. Journal of Structural Engineering. 2020; 146(3).
[61] Lawan MM. Structural pereormance of cold-formed steel with self-compacting concrete in a composite beam system (Doctoral Dissertation, Universiti Teknologi Malaysia). 2015.
[62] Wang F, Han Y, Yang J. Nonlinear FE analysis on stiffness and resistance of bolted cold-formed steel built-up joints. Structures. 2021; 33:2520-33. Elsevier.

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Appendix I

S. No.	Abbreviation	Description
1	CFS	Cold-formed Steel
2	DLC	Double-Lipped Channel
3	DSM	Direct Strength Method
4	EHS	Elliptical Hollow Section
5	HRS	Hot-Rolled Steel
6	IJLW	Isolated Joint Test of Lightweight Concrete
7	NAS	North American Specification
8	UHPC	Ultra-high-performance Concrete