Behaviour of rectangular gusset plate with angle cleat connections for cold-formed steel section

KM Aminuddin[1], Anis Saggaff[2], Mahmood Md Tahir[3*], Shek Poi Ngian[4], Arizu Sulaiman[4], Muhammad Firdaus[5], Musab N A Salih[4]

[1] Ph.D. Student, Civil Engineering Department, Faculty of Engineering, Universitas Sriwijaya, Inderalaya, 30862, Indonesia.
[2] Professor, Civil Engineering Department, Faculty of Engineering, Universitas Sriwijaya, Inderalaya, 30862, Indonesia.
[3*] UTM Construction Research Centre, Professor, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia.
[4] UTM Construction Research Centre, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia.
[5] Universitas PGRI, Faculty of Engineering, Department of Civil Engineering, Lr. Gotong Royong, 9/10 Ulu, Seberang Ulu I, Kota Palembang, Sumatera Selatan 30116.

Email: km_aminuddin@student.pps.unsri.ac.id

Abstract. Cold-formed steel (CFS) members designed with proper stiffener can significantly increase the loading capacity of the connected member even though they are thin and slender. Design recommendations of connections especially for CFS sections are mostly related to the load-carrying capacities of individual fasteners such as bolts, screws, and rivets. The proposed bolted top-seat flange cleat joint in this paper should be able to categorize as semi-rigid that can further enhance the use of CFS in structural steel. This paper aims to investigate the behaviour of cold-formed steel section with gusset plate integrated with angle cleats. The full-scale isolated joint test was conducted on three specimens where the size of column size is C30024, and the size of beams is C20024, C25024, and C30024. All sections are 2.4mm thick. The connections were stiffened with a rectangular gusset plate of 10mm thick and angle cleat of 6 mm thick, respectively. The result of the test showed that the moment resistance (M_j) of the connection for beam sections C20024, C25024 and C30024 were 45.3 kNm, 48,8 kNm, and 52.5 kNm respectively. The initial stiffness ($S_{j,ini}$) of the connections for beam section C20024, C25024 and C30024 were 510 kNm/rad, 650 kNm/rad and 610 kNm/rad respectively. The experimental results showed that the ratio of the moment resistance ranged from 1.00 to 1.16, and the ratio of initial stiffness ranged 1.00 to 1.35 as compared to the numerical analysis adopted from EC3 code.

1. Introduction

Due to their high structural performance and durability, cold-formed steel (CFS) sections are well suited for building construction, and their lightweight is a significant advantage [1]**.** Typical cold-formed steel members such as studs, track, purlins, girts, and angles are mainly used for carrying loads while panels and decks such as floors, roofs, and walls are only functioned to resist in-plane and out-of-plane surface loads [2]. The use of cold-formed steel members should be able to provide a good alternative in steel construction as they are light in weight as compared to hot-rolled steel [3]. Above all, CFS sections offer flexibility and versatility in producing a variety of cross-sectional shapes, which are obtained by bending relatively thin metal sheets using either a cold rolling or a press braking process at room temperature [4]. Design recommendations of connections especially for CFS sections are mostly related to the load-carrying capacities of individual fasteners such as bolts, screws, rivets and spot welds [13][1]. The connection is an essential element in structural steelwork construction. The significant mechanical properties of connections are strength (load capacity), stiffness (rotation rigidity) and ductility (deformation capacity) [5]. Connections also should be able to resist high stress-strain formation developed from dynamic redistribution of moments and tension loads which means they require high ductility to dissipate energy and undergo deformation without failure [8]

The proposed joints should be simple, strong, durable, fast, and easy to install. One of the most practical ways to connect joint elements is by using gusset plates and bolts [4]. The use of gusset plate can be further enhanced by integrating the use of bolted flange-cleat beam-to-column joints in order to achieve a connection considered as simple, fast, cost-effective, and of high quality [9].

The bolted top-seat flange cleat joints should be able to achieve a semi-rigid connection that has the potential to address the cost-effective issue. This joint profile offers simple configuration in fabrication and installation and requires no welding [10]. Research on CFS connections using gusset plate has been done by Tan [12]. From these experimental results, it is observed that the ratio of moment resistance of joint to the moment resistance of the connected beam increased within the range between 0.46 to 0.70 more than 0.25 as suggested by EC3. The rotational capacities of the joints exceeded 30 mRad which can be considered as ductile connection. The rotational stiffness was recorded as 511 kNm/rad to 1671 kNm/rad. From these tests results, it was concluded that the use of gusset plate can enhance the CFS connection as partial strength connection.

Bucmys has proposed a bolted gusset-plate joint for CFS section since it is one of the easiest ways for a beam-to-column connection [2]. The specimen's joint under analysis consists of a double C-channel of back-to-back lipped sections bolted to gusset plate designed as T shape. The strength capacity shows similar values in analytical calculations and experimental results. In 2017, Bucmys also investigated the behavior of rectangular gusset plates in CFS connections for beam-to-column connection with double C-channel arranged back-to-back [2]. The experimental results are compared with the numerical analysis calculated from EC3 formulation. The comparison showed satisfactory agreement with the proposed connections were categorized as semi-rigid connection. Based on previous research, if the gusset plate connection on CFS is combined with flange-cleat, it has the potential to increase the connection capacity such as moment and rotational stiffness. However, despite the above advantages, lack of knowledge concerning the actual behavior of semi-rigid flange cleat joints has resulted in avoiding this type of joints in current practice [9]. Therefore, this study proposed the use of CFS of double lipped channel cross-section installed back-to-back for beam-to-column connection. This paper aims to investigate the behavior of the proposed isolated joint of beam-to-column by carried out full-scale testing and compare with the numerical analysis established from EC3.

2. Geometrical configuration of the specimens

The geometrical configuration of the specimens for beam and column was listed in Table 1. The column was used only one profile of C300 whereas, for beams C200, C250 and C300 with steel of grade 450 N/mm^2 were proposed.

Table 1. Cross-section of specimen

Profile	Dimension (mm)				
	Web	Flange	Lip	Thickness	Radius
C20024	200	75	16	2.4	5
C25024	250	75	20	2.4	5
C30024	300	100	25	2.4	5

IOP Conf. Series: Materials Science and Engineering **849** (2020) 012068 doi:10.1088/1757-899X/849/1/012068

The arrangement of bolts configuration was in accordance with Eurocode 3 rules, as shown in Fig. 1 and Fig. 2. All bolts used in this connection were of M12 Grade 8.8. In order for smooth installation of bolts, a 13 mm bolt's hole was drilled on the rectangular gusset plate of 10mm thick (see Fig. 1) and flange cleat of 6 mm thick (see Fig. 2). Each of the specimens was named IJT-BGJ-4, IJT-BGJ-5, and IJT-BGJ-6 as shown in Table 2 and Table 3.

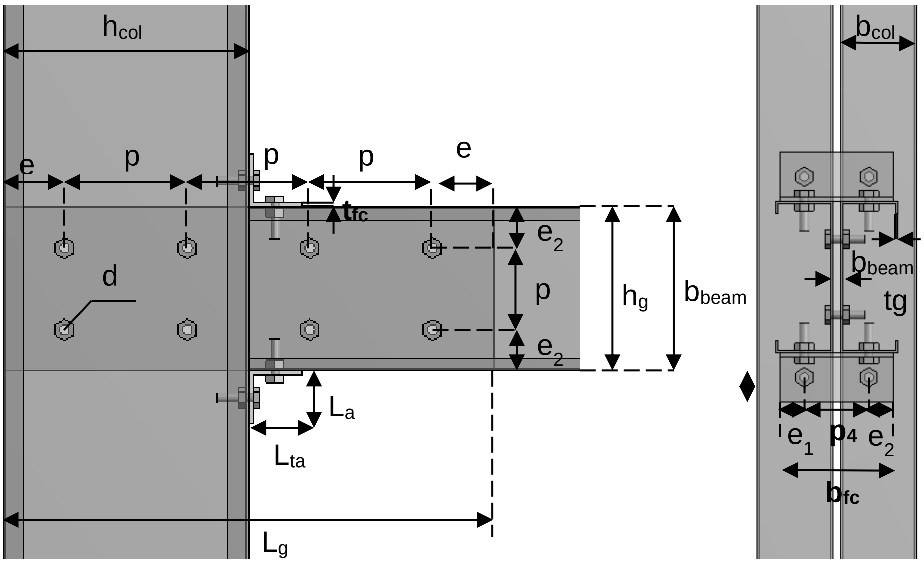

Figure 1. Detail of specimen

Table 2. Configuration detail of gusset plate connection

Label	Beam	Column	Detail of Connection (mm)								Number of Bolts
			t_g	h_g	L_g	e_1	e_2	p_1	p_2	p_3	
IJT-BGJ-4	C20024	C30024	10	200	600	75	50	150	100	150	8
IJT-BGJ-5	C25024		10	250	600	75	50	150	150	150	8
IJT-BGJ-6	C30024		10	300	600	75	75	200	150	150	8

Table 3. Configuration detail of flange cleat connection

Label	Beam	Column	Detail of Connection (mm)							Number of Bolts
			t_{fc}	r_{fc}	L_a	L_{ta}	e_{1a}	e_{2a}	p_2	
IJT-BGJ-4	C20024	C30024	6	5	65	65	32.5	32.5	85	4
IJT-BGJ-5	C25024		6	5	65	65	32.5	32.5	85	4
IJT-BGJ-6	C30024		6	5	65	65	32.5	32.5	85	4

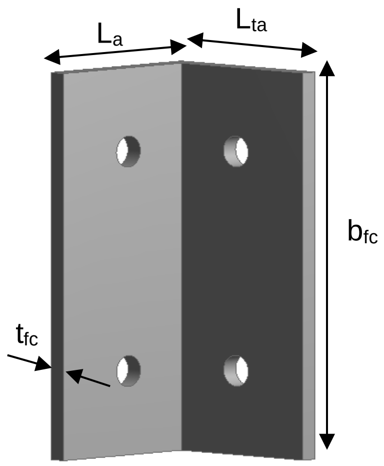

Figure 2. Dimension of flange cleat

Table 4. Configuration detail of flange cleat connection

IJT-BGJ-4	IJT-BGJ-5	IJT-BGJ-6
L_a = 65 mm	L_a = 65 mm	L_a = 65 mm
L_{ta} = 65 mm	L_{ta} = 65 mm	L_{ta} = 65 mm
b_{fc} = 162 mm	b_{fc} = 162 mm	b_{fc} = 202 mm
t_{fc} = 6 mm	t_{fc} = 6 mm	t_{fc} = 6 mm

3. Experimental test

The specimens were tested at Constructions Research Center (CRC) Universiti Teknologi Malaysia (UTM) that assembled as full scale isolated joint test (FSIJ) on Magnus frame, as shown in Fig. 3.

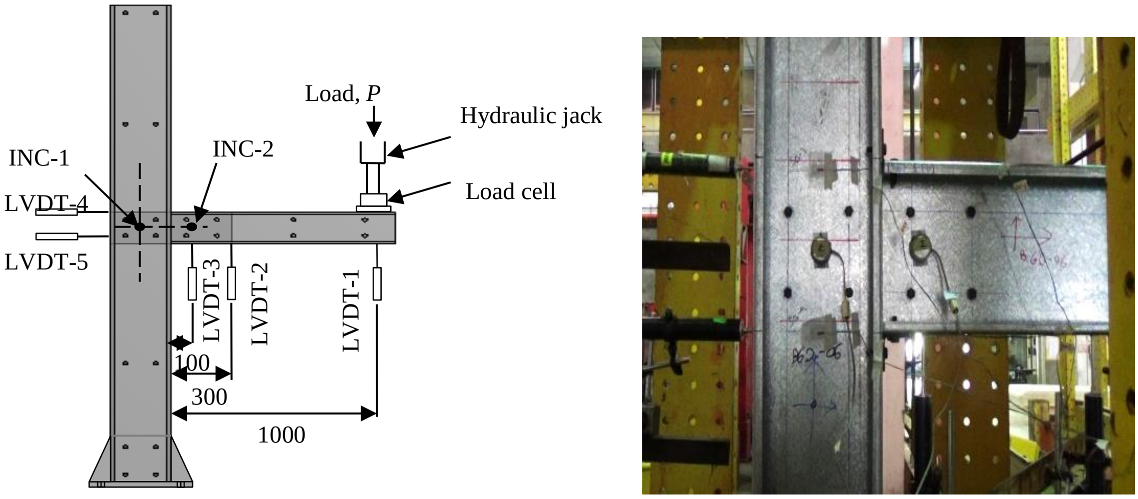

Figure 3. Testing of Specimen with Isolated Joint Test (IJT)

The equipment used in the tests and method of assemblage are listed as follows:-

a. Lateral restraint was installed to avoid excessive torsion of the beam
b. An inclinometer was installed at the centre of the beam and column to measure the rotation of the connection

c. Five units of LVDT (Linear Variable Differential Transformer) located as shown in Fig. 3 to measure deflection. LVDT 1 (under load cell); LVDT 2 (500 mm from flange column); LVDT 3 (100 mm from flange column) and LVDT 4-5 (web column).

The test results data such as the load, deflection, and the rotation of connection were recorded by the data logger.

4. Result and discussion

4.1. Failure mode

Three specimens of isolated joint test have been tested. The typical failure modes of the specimens are shown in Fig. 4 represented by specimen IJT-BGJ-4. Fig. 4 show that the deformation occurred at the compression zone of the column where the column web of the beam deformed when the 45 kN of loads were applied. At the same time, the top angle cleat was also pulled apart from the column flange. Typical failure of this type of connection is more on the local buckling of the compression zone of the column web before any failure of the top column can be noticed. However, the use of top and bottom cleat has increased the resistance of the proposed connection.

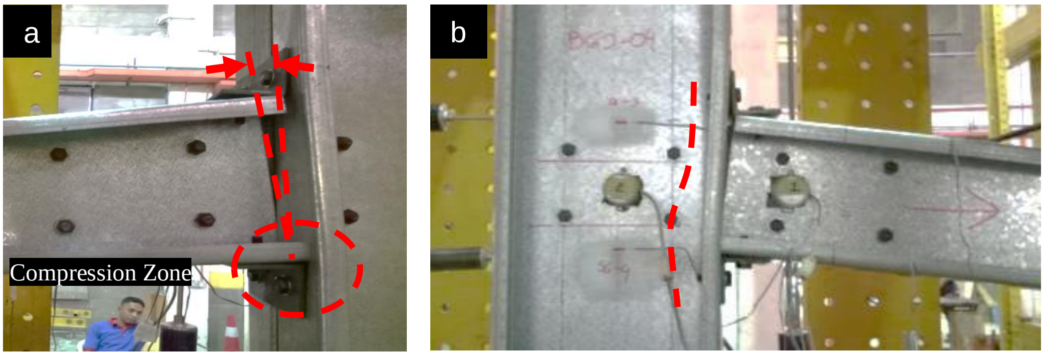

Figure 4. Deformation of specimen IJT-BGJ-4

The results of observations from the three specimens can be summarized as shown in Table 5. The IJT-BGJ-4 specimens were stopped at the load of 45 kN, IJT-BGJ-5 at load of 40 kN, and IJT-BGJ-6 at load of 20 kN. The flange column of each specimen has identified the same buckling failure pattern in the compression zone; only in the IJT-BGJ-4 section has the buckling flange beam, and the lower flange cleat was bending too. The bearing of the CFS bolt hole, gusset plate, and flange cleat also occurred on all specimens.

Table 5. Modes of failure on each specimen

Specimen	Failure mode identification
IJT-BGJ-4	1. Bending on the lower flange cleat 2. The bearing of bolt hole on CFS, gusset plate and flange cleat 3. Column flange was buckling in the compression zone 4. Beam flange was bending in the compression zone 5. The bolt hole of the upper column flange and upper beam flange were bending in the compression zone
IJT-BGJ-5	1. The bearing of bolt hole CFS, gusset plate and flange cleat 2. Column flange was buckling in the compression zone 3. The bolt hole of the upper column flange and upper beam flange were bending in the compression zone
IJT-BGJ-6	1. The bearing of bolt hole CFS, gusset plate and flange cleat

2. The bolt hole of the upper column flange and upper beam flange were bending in the compression zone
3. Column flange was buckling in the compression zone

4.2. Moment-rotation curve

Figure 5 - Figure 7 shows the moment rotation curve for the tested specimens. Fig. 5 shows that the moment joint capacity ($M_{j,u,exp}$) for IJT-BGJ-4, which is 45.3 kNm, the initial stiffness value ($S_{j,ini}$) drawn from straight line of linear iteration is 510 kNm / rad and rotation ($Ø_{j,u,exp}$) is 0.087 Rad.

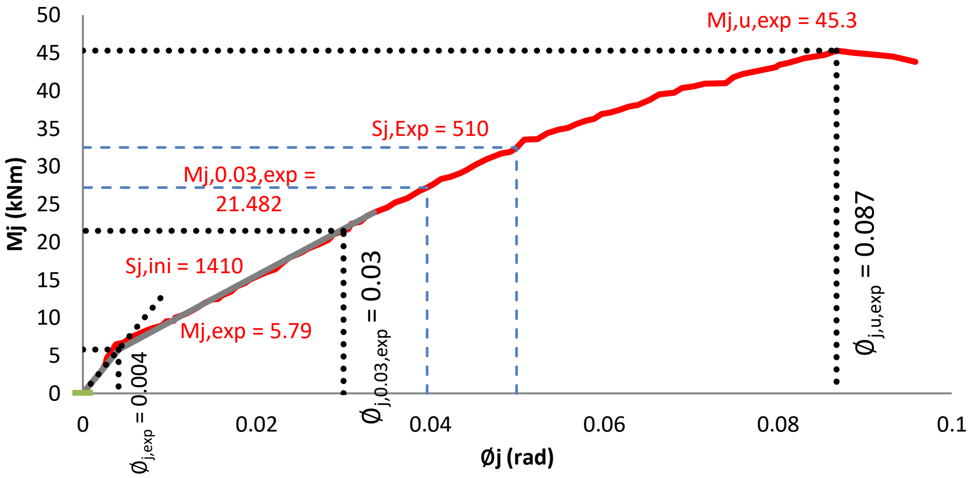

Figure 5. Moment - rotation curve (M-Øcurve) IJT-BGJ-4 (beam C20024)

The moment vs rotation curve from Fig. 6 has shown that moment connection capacity ($M_{j,u,exp}$) for IJT-BGJ-5 is recorded as 48.87 kNm with initial stiffness ($S_{j,ini}$) as 650 kNm / rad and rotation value ($Ø_{j,u,exp}$) as 0.056 Rad.

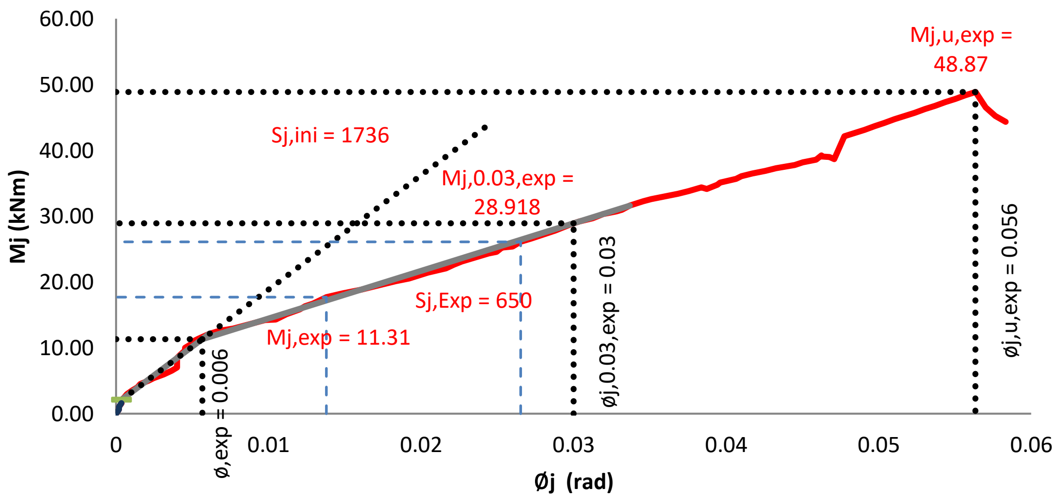

Figure 6. Moment - rotation curve (M-Øcurve) IJT-BGJ-5 (beam C25024)

The moment vs rotation curve in Fig. 7 of the connection has recorded moment capacity ($M_{j,u,exp}$) for IJT-BGJ-6 as 52.5 kNm, initial stiffness ($S_{j,ini}$) as 690 kNm / rad and rotation ($Ø_{j,u,exp}$) as 0.054 Rad

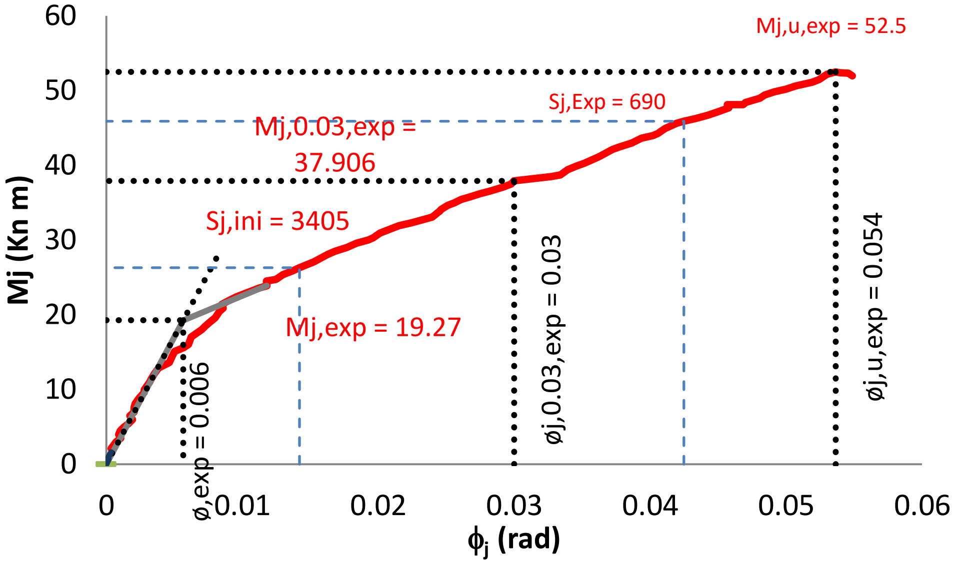

Figure 7. Moment - rotation curve (M-Øcurve) IJT-BGJ-6 (beam C30024)

The results in Fig. 5 to 7 show that the moment resistance and initial stiffness increases as the depth of the beam increased. Table 6 presented that the ratio of moment resistance ranged from 1.00 to 1.16, and the ratio of initial stiffness ranged from 1.00 to 1.35 as compared to the moment resistance calculated by numerical analysis based on EC3 code. The use of rectangular gusset plate and flange cleat has increased both the stiffness and the moment resistance of the proposed connection [14-16].

Table 6. Experimental Result

Specimen	Beam	$M_{j,u,exp}$ (kNm)	Ratio $M_{j,u,exp}$	$Ø_{j,u,exp}$ (rad)	$S_{j,ini}$ (kNm/rad)	Ratio $S_{j,ini}$
IJT-BGJ-4	C20024	45.3	1.00	0.087	510	1.00
IJT-BGJ-5	C25024	48.87	1.08	0.056	650	1.28
IJT-BGJ-6	C30024	52.5	1.16	0.054	690	1.35

5. Conclusion

The proposed isolated joint test was carried out, where the CFS section was combined with a rectangular gusset plate and flange cleat. From this paper the following conclusions are drawn:

1. The failure mode for all specimens was almost the same where the top angle cleat yield and the bottom beam flanged developed a local deformation on the column flange.
2. The full-scale test results on the moment resistance (M_j) of the proposed connections for beam section C20024, C25024, and C30024 were 45.3 kNm, 48.87 kNm and 52.5 kNm respectively. The initial stiffness ($S_{j,ini}$) of the connections for beam section C20024, C25024 and C30024 were 510 kNm/rad, 650 kNm/rad and 610 kNm/rad respectively. These resulted showed that as the depth of the beam increases, the moment and the initial stiffness also increased.
3. The experimental result showed that the ratio of the moment resistance ranged from 1.00 to 1.16, and the ratio of initial stiffness ranged from 1.00 to 1.35 as compared to the numerical analysis established by adopting formula given in EC3 code. These results showed that the connection could be defined as full strength and rigid connection as the ratio is equal or more than one by EC3.

Acknowledgement

This research was funded by Sriwijaya University, and Construction Research Centre, Universiti Teknologi Malaysia (UTM-CRC) grant No (Q.J130000.2409.04G50 and RJv130000.7309.4B235). The author would like to express the utmost gratitude to his supervisors, Professor Anis Saggaf and Professor Mahmood Md Tahir for his guidance and assistance throughout the study.

References

[1] Ahamed H and M Mahendran 2010 Bolted beam-column moment connections between cold-formed steel members *21st Australasian Conf. on the Mechanics of Structures and Materials* (ACMSM 21)

[2] Pisarek Z 2018 Approximated Method for Determining Moment Resistance and Stiffness of Bolted Beam to Column Joints Made with Angle Web and Flange Cleats *J. Czasopismo Inżynierii Lądowej, Środowiska i Architektury* **65** 197

[3] Bučmys Ž and Daniūnas A 2017 Rectangular gusset plate behaviour in cold-formed I-type steel connections *J. Archives of Civil Engineering* **63(2)** 3

[4] Ye J, Hajirasouliha I, Becque J and Pilakoutas K 2016 Development of more efficient cold-formed steel channel sections in bending. *J. Thin-Walled Structures* **101** 1

[5] Bučmys Ž and A Daniūnas 2015 Analytical and experimental investigation of cold-formed steel beam-to-column bolted gusset-plate joints *J. Civil Engineering and Management* **21(8)** 1061

[6] Lee Y H, Tan C S, Mohammad S, Lim J B P and Johnston R 2015 Numerical study of joint behaviour for top-seat flange cleat connection in cold-formed steel structures *J. Scientia Iranica. Transaction B Mechanical Engineering* **22(4)** 1554

[7] Lee Y H, Tan C S, Mohammad S and Lee Y L 2015 Mechanical Properties Prediction for Cold-formed Steel Angle Connection with Various Flange Cleat Thickness. *J. Teknologi* **74(4)** 51

[8] Mohammadhosseini, H. and Tahir, M.M., 2018. Production of sustainable fibre-reinforced concrete incorporating waste chopped metallic film fibres and palm oil fuel ash. *Sadhana*, 43(10), p.156.

[9] Rahbari R, Tyas A, Davison J B and Stoddart E P 2014 Web shear failure of angle-cleat connections loaded at high rates *J. Constructional Steel Research* **103** 37

[10] Skejic D, Dujmovic D and Beg D 2014 Behaviour of stiffened flange cleat joints *J. Constructional Steel Research* **103** 61

[11] Tan C S, Lee Y H, Lee Y L, Mohammad S, Sulaiman A, Tahir M Md and Shek P N 2013 Numerical simulation of cold-formed steel top-seat flange cleat connection *J. Teknologi* **61(3)** 63

[12] Haidarali M R and Nethercot D A 2012 Local and distortional buckling of cold-formed steel beams with edge-stiffened flanges *J.Constructional Steel Research* **73** 31

[13] Tan C S, Tahir M Md, Shek P N and Kueh A 2011 Experimental Investigation on Slip-In Connection for Cold-Formed Steel Double Channel Sections *J. Advanced Materials Research* **250-253** 1038

[14] Tahir, M M, Mohammadhosseini, H, Alyousef, R, Leong, W K. and Salih, M N, 2019. Performance Evaluation of Pre-fabricated Footing Using Cold-Formed Steel of Lipped C-Channel Section. *Arabian Journal for Science and Engineering*, 44(10), pp.8225-8238

[15] Tahir, M M., Mohammadhosseini, H , Ngian, S P. and Effendi, M K., 2018. I-beam to square hollow column blind bolted moment connection: Experimental and numerical study. *Journal of Constructional Steel Research*, 148, pp.383-398

[16] Mohammadhosseini, H., Tahir, M.M. and Sayyed, M.I., 2018. Strength and transport properties of concrete composites incorporating waste carpet fibres and palm oil fuel ash. *Journal of Building Engineering*, 20, pp.156-165.