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Technical Specification of Extension-Connection for Axial Tension C-Section Cold-Formed Steel (CFS)

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Abstract

Cold-Formed Steel (CFS) structures are increasingly used in construction due to their light weight, cost-effectiveness, and ease of fabrication. However, limitations in design standards for CFS connections hinder further structural optimization. This study examines the tensile performance of four C-section connection types Face-to-Face Web (FTF-W), Face-to-Face Flange (FTF-F), Back-to-Back (BTB), and Sleeve Flange (SF) subjected to axial tension. A total of 48 samples were tested using two CFS thicknesses (0.75mm and 1.00mm) and two screw configurations (2 and 4 number of screws), in accordance with AISI S100 (2016) and ASTM E8 (2022). Analytical resistances were calculated based on Eurocode 3 (2006), covering net tension, bearing, and shear. BTB connections consistently demonstrated the best performance, with experimental-to-design resistance ratios exceeding 1.0 across most failure modes. At 0.75mm thickness with four screws, BTB's bearing resistance exceeded design estimates by over 135%. In contrast, FTF-W showed the weakest performance, with a net tension ratio as low as 0.12 approximately 87% lower than BTB due to eccentric loading and poor screw engagement. Increasing material thickness improved net tension ratios by 20–50% in stronger configurations (BTB, FTF-F, SF), while adding more screws enhanced tensile strength but often reduced shear resistance by 20–25% due to over-constraint. Failure modes included bearing deformation, screw tilting, and snapping, each influenced by geometry and fastener configuration. The findings highlight BTB's structural reliability and emphasize the need for improved design in FTF-W connections.

1. Introduction

Cold-formed steel has gained popularity within the construction industry due to its favorable properties, including high strength-to-weight ratio, easy fabrication, and affordability [1]. Cold-rolled or bent ways of producing this material can be used in a wide spectrum of structural elements. CFS has a better strength-to-weight ratio, and it is well suitable for structural applications, such as wall studs, roof trusses, and frameworks [2][3]. Furthermore, the ease of fabrication and assembly leads to faster construction timelines and lower labor costs, making CFS a financially attractive option for builders [4].

A critical aspect of cold-formed steel construction is the performance of connections, as they play a crucial role in the overall structural integrity of the system. Screw connections are widely favored in construction due to their simplicity in design, ease of installation, and cost-effectiveness. They are also technically advantageous, as they reduce labor and installation time while providing reliable shear transfer, particularly in multi-ply connections where screws distribute loads efficiently [5]. Different screw patterns can lead to various failure modes such as bearing, tilting, pull-out, and shear failure [6][7]. According to Wu et al. [8], increasing the number of screws and optimizing their pattern enhances shear capacity and stiffness. However, as screw quantity rises, strength per screw decreases due to uneven load distribution and stress concentration [9].

Tensile testing is a critical method for assessing the performance of CFS connections under various loading conditions. The shear performance of CFS screw connections is a critical factor in the structural integrity of CFS shear walls. The arrangement of screws, including the number of screws and their pattern, significantly influences the shear strength of these connections. Furthermore, the spacing of screws has a notable impact on shear resistance. When the spacing exceeds a certain threshold, further increases have a minimal effect on shear resistance [10]. The edge distance has a stronger effect on shear capacity compared to other factors like screw diameter and stud thickness. Increasing the edge distance improves shear capacity, particularly under tension [11]. End distance also influences shear resistance, but its effect diminishes beyond a certain point.

This study focuses on investigating the tensile performance of four type of CFS connection which are face-to-face web (FTF-W), face-to-face flange (FTF-F), back-o-back (BTB), and sleeve flange (SF) connection. The thickness of CFS sample for all type of connections that have been used are C-sections with thickness of 1.00mm connected using self-drilling Hex Metal M5.5 screws. The key difference between these four connections lies in what part they attached to (web/flange), and the condition of the CFS plate that attached to the other plate. The FTF web connection joins directly to the web of another element, while the FTF flange connection attaches to the flange of another element. BTB connection joins directly to the web that facing back of another element, while SF connection joint when the sleeve is properly aligned with other members. Moreover, the study is focusing on the behaviour of all type of connections under tensile test. All 12 samples for each connection type had been conducted under tensile test to evaluate the ultimate tensile load and displacement of each sample. In this research, the mechanical properties of the CFS C-Section and self-drilling screws were also tested. Besides, the mode of failures of each connection was also reported as part of observation made from the outcomes of the laboratory testing.

2. Methodology

2.1 Analytical Work

The design requirements all types of connections were evaluated in accordance with the American Iron and Steel Institute (AISI S100 2016) [12] and Eurocode 3 (EN 1993-1-3) [13].

2.1.1 Calculation Parameters

Table 1 indicates the key parameter used in the calculation for the shear, tensile and bearing resistances. Some of the values were extracted from EN 1993-1-3, and mill certificate of the CFS sample.

Table 1 *Analytical parameter for design resistance*

Parameter		Value
Ultimate stress of CFS sample, f_u (from tensile test)	Thickness 0.75mm	581.79N/mm^2
	Thickness 1.00mm	636.27N/mm^2
Effective length of the screw in the direction of the tensile force, α (taken from EN 1993-1-3, Table 8.2)	Thickness 0.75mm	1.182mm
	Thickness 1.00mm	1.364mm
Area cross-section of screw, A_s		20.1mm^2
Diameter of the screw, d		5.5mm
Ultimate stress of screw, f_u (from tensile test)		727.50N/mm^2
The partial safety factor for resistance of cross-sections, Υ_{M0} (taken from EN 1993-1-3)		1.0
Resistance of net sections at fastener holes, Υ_{M2} (taken from EN 1993-1-3)		1.25

2.1.2 Shear Resistance of Screw Fastener

In accordance with Eurocode 3 (EN 1993-1-3) [13], the shear resistance of self-drilling screws can be determined using the Equation (1) provided below. The characteristic shear strength of the screw, denoted as $\mathbf{F_{v,Rk}}$ can be obtained from the mill certificate associated with the screw. Nonetheless, the prevailing industry practice for assessing the shear strengths of fasteners is to utilize 60% of the minimum ultimate tensile strength of the fastener when evaluating single shear joints [14].

$$F_{v,Rd} = \frac{F_{v,Rk}}{\gamma_{M2}}$$

$$F_{v,Rk} = \frac{0.6 \times Pu_{screw} \times A_S}{\gamma_{M2}} \tag{1}$$

2.1.3 Net Tension Resistance of Cold Formed Steel

The design resistance of a cross-section subjected to uniform tension, denoted as $F_{n,Rd}$, can be calculated using Equation (2) as specified in Clause 6.1.2 of Eurocode 3 (EN 1993-1-3).

$$F_{n,Rd} = \frac{A_{net} f_u}{\gamma_{M2}} \tag{2}$$

The mechanical properties (f_y, f_u) and geometric properties (A_{net}) shall be validated through mill certificates or direct coupon testing.

2.1.4 Bearing Resistance of Screw Fastener

According to the Eurocode 3 (EN 1993-1-3), the bearing resistance of self-drilling screw can be calculated by using the Equation (3) below.

$$F_{b,Rd} = \frac{\alpha f_u dt}{\gamma_{M2}} \tag{3}$$

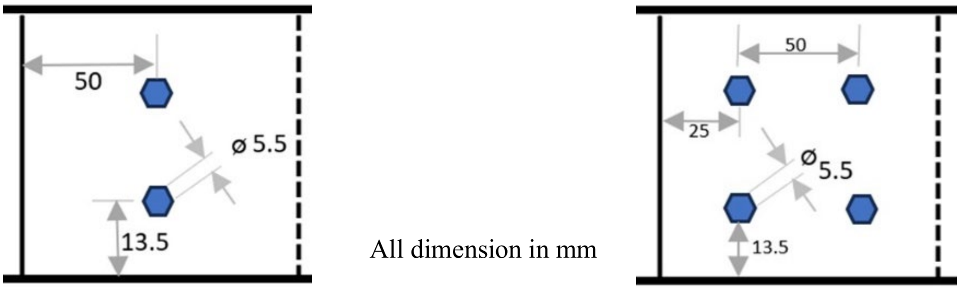
In the equation above, α is an effective length of the screw in the direction of the tensile force, f_u is tensile strength of the screw material, and dt is the nominal diameter of the screw.

2.1.5 Spacing, Edge and End Distances

The screw spacing was designed to comply with the AISI S100 (2016) [12] standards. Table 2 summarizes the spacing requirements used in this research with the illustrations given in Fig. 1.

Table 2 *Spacing requirement for screws*

No.	Item	Formula	Required	At Web		At Flange	
				2nos	4nos	2nos	4nos
1	Fastener Spacing	Not less than 3*d*	16.5mm	50mm	50mm	50mm	50mm
2	Edge Distance	Not less than 1.5*d*	8.25mm	13.5mm	13.5mm	15mm	15mm
3	End Distance	Not less than 1.5*d*	8.25mm	50mm	25mm	50mm	25mm



(a) Spacing for 2nos **(b) Spacing for 4nos**

Fig. 1 *Fastener spacing illustrations; (a) Spacing for 2nos; (b) Spacing for 4nos*

2.2 Experimental Work

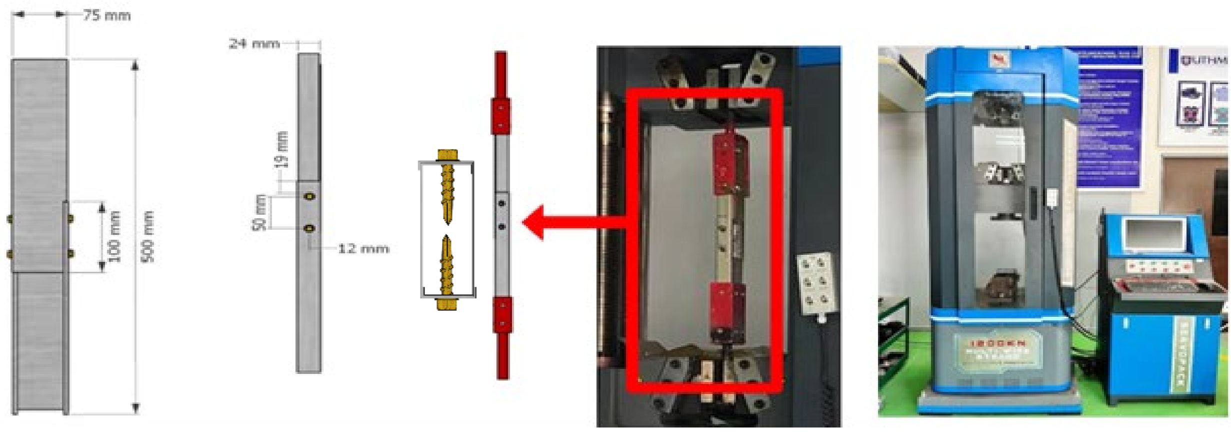
The distribution of sample for the tensile testing is tabulated in Table 3. A total of 12 samples for each connection type were prepared for tensile testing. The fastener utilized was a Hex M5.5 carbon steel self-drilling screw, with lengths of 20mm for flange connections and 50mm for web connections. In this laboratory, the primary testing parameters were the thicknesses (0.75mm and 1.00mm), and the number of screws employed (2nos and 4nos).

Table 3 *Distribution of the FTF web/flange connection*

Type	Thickness of CFS C-Section	No. of Screw (nos)	No. of Samples	Samples Label
FTF-F	1.00mm	2	3	F1-C100-2, F2-C100-2, F3-C100-2
		4	3	F1-C100-4, F2-C100-4, F3-C100-4
FTF-W	1.00mm	2	3	W1-C100-2, W2-C100-2, W3-C100-2
		4	3	W1-C100-4, W2-C100-4, W3-C100-4
BTB	1.00mm	2	3	B1-C100-2, B2-C100-2, B3-C100-2
		4	3	B1-C100-4, B2-C100-4, B3-C100-4
SL	1.00mm	2	3	S1-C100-2, S2-C100-2, S3-C100-2
		4	3	S1-C100-4, S2-C100-4, S3-C100-4

2.2.1 Tensile Testing Setup

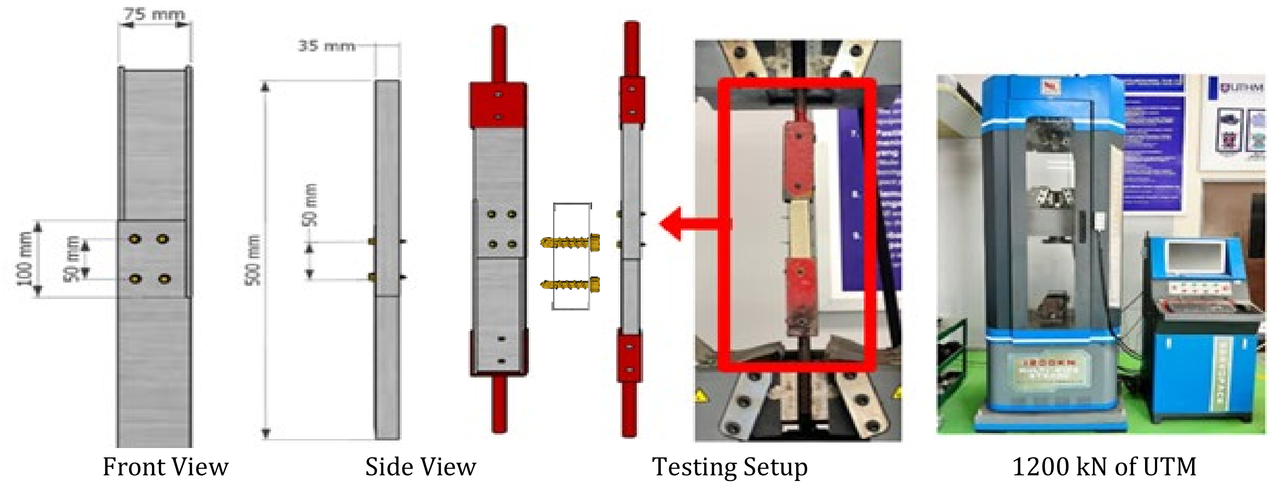
A tensile test of the materials was performed in accordance with ASTM F606 [15] for self-drilling screws, and ASTM E8 [16] for the CFS C-Section plate using a 100kN Universal Testing Machine (UTM) to assess the mechanical properties of tensile stress. The screw fasteners were evaluated for their yield and ultimate tensile stress. Similarly, the CFS plate underwent testing, with the plate being cut into coupon shapes based on the requirement of ASTM E8 [16]. The testing setup for the CFS connections is illustrated in Fig. 2, utilizes a UTM machine with a 1200kN capacity, at testing rate of 5mm/min.



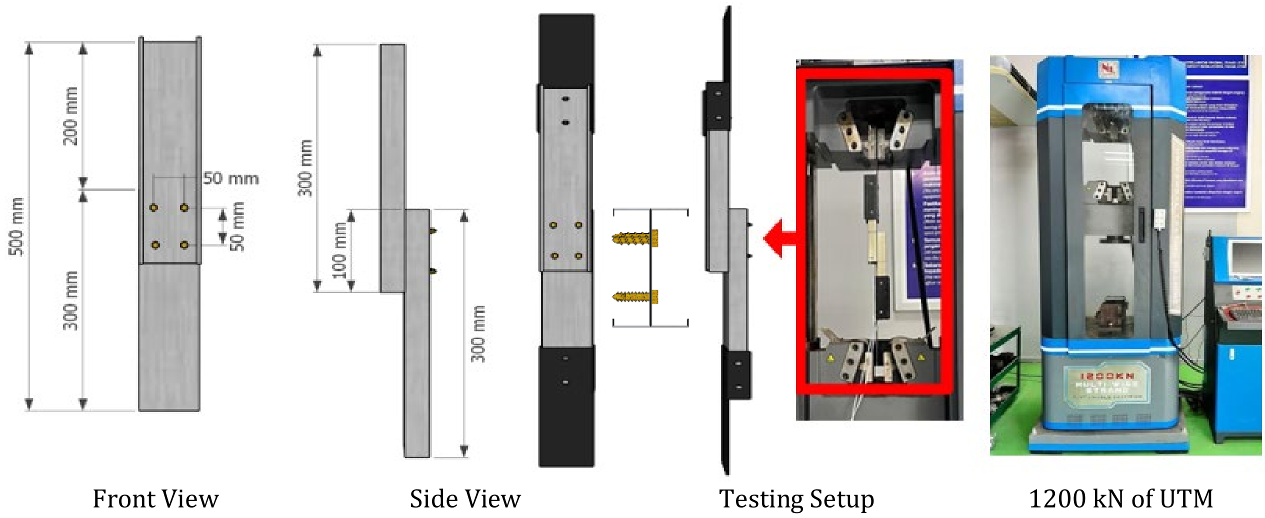
Front View Side View Testing Setup 1200 kN of UTM

(a) FTF flange connection

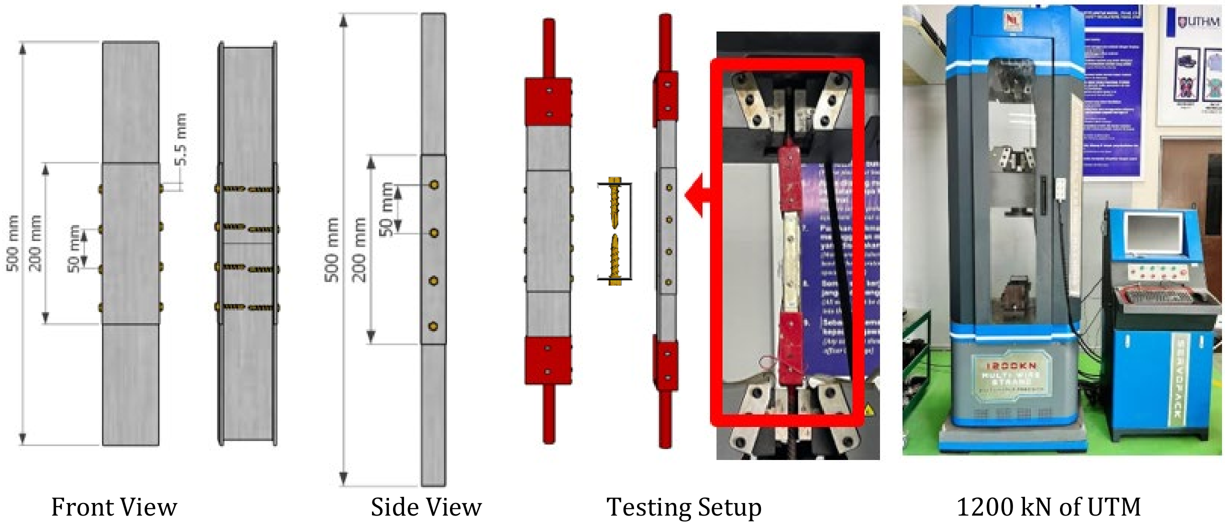
Int. Journal of Integrated Engineering Vol. 17 No. 3 (2025) p. 266-278



(b) FTF web connection



(c) BTB connection



(d) SF connection

Fig. 2 *Testing setup of the tensile test (a) FTF flange connection; (b) FTF web connection; (c) BTB connection; (d) SF connection*

2.2.2 Experimental and Analytical Ratio (Exp/Dsg)

The experimental-to-design resistance ratios (N_{Exp}/N_{Dsg}) were used as an indicator to evaluate the adequacy of each connection type relative to analytical predictions. For all configurations, a ratio greater than 1.0 was considered satisfactory, indicating that the experimental axial force exceeded the design resistance. This ratio was assessed against the net tension ($F_{n,Rd}$), bearing ($F_{b,Rd}$), and shear ($F_{v,Rd}$) resistances for each test. These calculated ratios are further detailed and discussed alongside the analytical resistances in Table 9 which provides a complete breakdown by thickness, connection type, and screw quantity.

3. Results and Discussion

3.1 Laboratory Result for CFS Connections with 2 nos

Fig. 3 and Table 4 show the ultimate load-carrying capacity from the tensile test of CFS connection with 2nos for both thicknesses of CFS connections. A thickness of 1.00mm generally attains higher peak loads compared to 0.75mm, where BTB configuration dominated the highest load capacity. In contrast, the FTF-W configuration records the lowest load capacity.

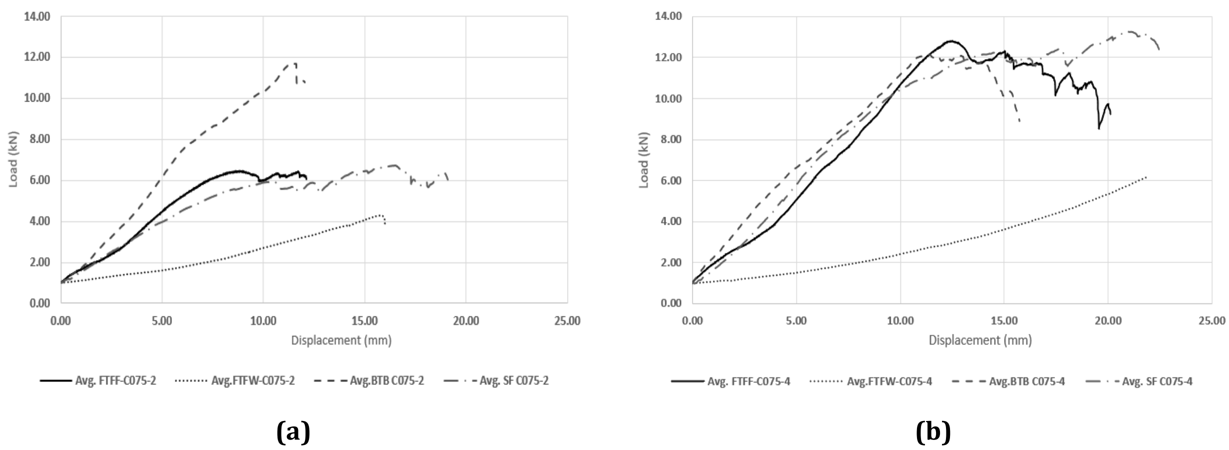


Fig. 3 *Comparison for load vs displacement (a) Connections with thickness of 0.75mm and 2nos; (b) Connection with thickness of 1.00mm and 2nos*

A clear relationship between material thickness and load capacity, with 1.00mm thick connections generally performing better than those with 0.75mm thickness. At the connections with a 1.00mm thickness generally achieve higher peak loads compared to those with 0.75mm, indicating the positive effect of increased material thickness on load-carrying capacity. Among the different connection types, the BTB configuration exhibits the highest load capacity (refer to Table 4). In contrast, the FTF-W configuration records the lowest load capacity.

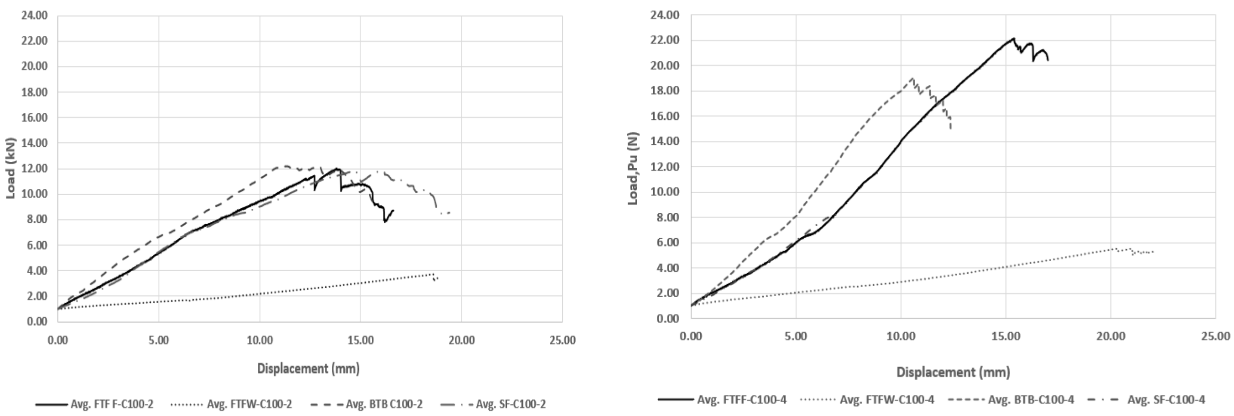
Table 4 *P_u for 0.75 mm and 1.00 thicknesses of CFS C-section connected by 2nos*

Thickness CFS	Type of Extension Styles	P_u (kN)
0.75 mm	FTF-F	6.44
	FTF-W	4.29
	SF	6.74
	BTB	11.67
1.00 mm	FTF-F	11.99
	FTF-W	3.74
	SF	11.81
	BTB	12.16

Int. Journal of Integrated Engineering Vol. 17 No. 3 (2025) p. 266-278

3.2 Laboratory Result for CFS Connections with 4nos

The result of tensile test of CFS connection with 4nos is summarized in the Fig. 4 and Table 5 below provide a comparative analysis of the ultimate load-carrying capacity and the displacement behavior for each connection type and thickness under 2 and 4 screws.



(a) **(b)**

Fig. 4 *Comparison for load vs displacement (a) Connections with thickness of 0.75mm and 4nos; (b) Connection with thickness of 1.00mm and 4nos*

The load-displacement curves for 4nos connections demonstrate that specimens with a 1.00mm thickness consistently reach higher ultimate loads compared to those with a 0.75mm thickness, exhibiting a similar trend as samples with 2nos. This laboratory outcome indicates that an increase in material thickness, in combination with 4nos, enhances the connection capacity. These observations underscore the importance of both material thickness and screw quantity in improving the overall strength and deformation capacity of cold-formed steel connections.

Table 5 *P_u for 0.75mm and 1.00mm thicknesses of CFS C-section connected by 4nos*

Thickness CFS	Type of Extension Styles	P_u (kN)
0.75mm	FTF-F	12.67
	FTF-W	6.23
	SF	13.26
	BTB	12.16
1.00mm	FTF-F	22.11
	FTF-W	5.51
	SF	16.43
	BTB	19.08

3.3 Observation from Both Laboratory Findings

Laboratory findings on the CFS connection styles under tensile loading reveal that the FTF-F, BTB, and SF configurations exhibit consistent trend of P_u vs displacement curves, unlike the FTF-W configuration. These trends highlight the significant roles of both material thickness and connection geometry influencing the structural behavior of CFS connections. This suggests that merely increasing material thickness is insufficient to enhance load capacity if the connection design is unstable and inadequately to resist external loads due to inappropriate fastener positioning. An increase in material dimensions in term of the thickness enhances the strength due to a larger cross-sectional area, allowing the structure to better withstand applied loads.

Additionally, the FTF-F, BTB and SF connections demonstrate higher load-carrying capacities compared to the FTF-W, emphasizing the significant impact of connection design on structural integrity and performance. These observations highlight the importance of optimizing both material thickness and connection design in to improve the overall strength and deformation capacity of CFS connections.

3.4 Connection Capacity Between Laboratory and Analytical Calculation

Based on Table 6 and Table 7 below, a ratio of $N_{Exp.}/N_{Dsg.} \geq 1$ indicates that the experimental capacity exceeds the design resistances requirement for satisfactory application. This comparative analysis serves to evaluate the reliability of analytical predictions in capturing the actual behaviour of the CFS connections under axial loading and identifies any discrepancies between the laboratory and theoretical results from the tensile, bearing and shear resistances requirement.

Table 6 *Analytical design resistances for net tension resistance*

Thickness (mm)	Net tension resistance (kN)	
	Flange	Web
0.75	$f_{n,Rd} = \frac{A_{net} \cdot f_u}{\gamma M_2}$ Net width: dnet = dh + 0.2mm = 5.7mm (clearance) Net area: $A_{net} = t(b - n \times d_0)$ 2nos: bnet = t (b - 2 x dnet) = 0.75(35.5 – 2 x 5.7) = 18.075mm^2 Design resistances: $N_{u,Rd} = \frac{18.075 \times 581.79}{1.25} = 8.41kN$	$f_{n,Rd} = \frac{A_{net} \cdot f_u}{\gamma M_2}$ Net width: dnet = dh + 0.2mm = 5.7mm (clearance) Net area: $A_{net} = t(b - n \times d_0)$ 2nos: bnet = t (b - 2 x dnet) = 0.75(75 – 2 x 5.7) = 47.70mm^2 Design resistances: $N_{u,Rd} = \frac{47.70 \times 581.79}{1.25} = 22.20kN$
1.00	$f_{n,Rd} = \frac{A_{net} \cdot f_u}{\gamma M_2}$ Net width: dnet = dh + 0.2mm = 5.7mm (clearance) Net area: $A_{net} = t(b - n \times d_0)$ 2 nos: bnet = t (b - 2 x dnet) = 1.00(35.5 – 2 x 5.7) = 24.1mm^2 Design resistances: $N_{u,Rd} = \frac{24.1 \times 636.27}{1.25} = 12.27kN$	$f_{n,Rd} = \frac{A_{net} \cdot f_u}{\gamma M_2}$ Net width: dnet = dh + 0.2mm = 5.7mm (clearance) Net area: $A_{net} = t(b - n \times d_0)$ 2 nos: bnet = t (b - 2 x dnet) = 1.00(75 – 2 x 5.7) = 63.60mm^2 Design resistances: $N_{u,Rd} = \frac{63.60 \times 636.27}{1.25} = 32.37kN$

Note: 0.2mm is a standard allowance added to the nominal hole diameter (d_h) to account for manufacturing tolerances and potential hole enlargement during drilling.

Table 7 *Analytical design resistances for shear and bearing*

Thickness (mm)	Bearing resistance (kN)	Shear resistance (kN)
0.75	$F_{b,Rd} = \frac{\alpha f_u dt}{\gamma_{M2}}$ $F_{b,Rd} = \frac{1.182(581.79)(5.50)(0.75)}{1.25}$ $F_{b,Rd} = 2.27\ kN$	$F_{v,Rd} = \frac{F_{v,Rk}}{\gamma_{M2}}$ $F_{v,Rk} = 0.6(f_u screw)(A_s)$ $= \frac{(60/100)(727.50)(20.1)}{1.25}$ $F_{v,Rd} = 7.02kN$ per screw
1.00	$F_{b,Rd} = \frac{\alpha f_u dt}{\gamma_{M2}}$ $F_{b,Rd} = \frac{1.364(636.27)(5.50)(1.0)}{1.25}$ $F_{b,Rd} = 3.82kN$	

The analytical design calculations for net tension, shear, and bearing resistance summarized in Tables 6 and 7 were carried out using the provisions in Eurocode 3 (EN 1993-1-3) and the relevant parameters for self-drilling screws and cold-formed steel (CFS) materials. Table 8 below summarize all the design resistance value.

Table 8 *Analytical design resistances summary*

Design Resistance		Thickness (mm)	Value (kN)
Net tension resistance	Flange connection	0.75	8.41kN
		1.00	12.27kN
	Web connection	0.75	22.20kN
		1.00	32.37kN
Bearing resistance		0.75	2.27kN
		1.00	3.82kN
Shear resistance (per screw)		-	7.02kN

The calculations consider variables such as material thickness, net section area, screw diameter, and ultimate tensile strength. In terms of net tension resistance ($F_{n,Rd}$), the design values increase with thickness due to the proportional increase in net cross-sectional area. For instance, the net tension resistance for 1.00mm CFS was significantly higher than that of the 0.75mm specimens, confirming the theoretical advantage of increased material thickness. Bearing resistance calculations reflect the interaction between the screw and the connected steel plate. These values also scale with thickness and effective screw bearing area.

At 1.00mm thickness, the bearing resistance was noticeably higher, supporting the observed enhancement in load-carrying capacity with thicker materials. Shear resistance of the screws was estimated using 60% of the ultimate tensile strength, as per common practice for single-shear conditions. Since this resistance is dependent on the screw material and not the plate thickness, it remained constant per screw, though the total shear resistance scaled with the number of screws used. Table 9 below presents a comparative analysis between experimental tensile capacities and analytically calculated design resistances for various CFS connection configurations, highlighting the influence of geometry, material thickness, and screw quantity on structural performance.

Table 9 *Connection capacity between laboratory versus design resistance obtained from analytical calculations*

Thickness (mm)	(Analytical) Design Resistance, N_{Dsg} (kN)	(Experimental) Axial Forces, N_{exp} (kN)		Ratio ($N_{Exp.}$/ $N_{Dsg.}$) satisfactory when ≥ 1		
				N_{Exp} / $N_{t, Rd}$	N_{Exp} / $F_{b, Rd}$	N_{Exp} / $F_{v, Rd}$
0.75	$F_{n, Rd(flange)}$ = 8.41 $F_{n, Rd(web)}$ = 22.20 $F_{b, Rd}$ = 2.27 $F_{v, Rd}$ = 7.02/screw	FTF-F	2 screws	0.77	2.84	0.46
			4 screws	1.51	5.58	0.79
		FTF-W	2 screws	0.19	1.89	0.31
			4 screws	0.28	2.74	0.22
		SF	2 screws	0.80	2.97	0.48
			4 screws	1.58	5.84	0.47
		BTB	2 screws	0.52	5.14	0.83
			4 screws	0.55	5.36	0.43
1.00	$F_{n, Rd(flange)}$ = 12.27 $F_{n, Rd(web)}$ = 32.37 $F_{b, Rd}$ = 3.82 $F_{v,Rd}$ = 7.02/screw	FTF-F	2 screws	0.98	3.14	0.85
			4 screws	1.80	5.79	0.79
		FTF-W	2 screws	0.12	0.98	0.27
			4 screws	0.17	1.44	0.20
		SF	2 screws	0.96	3.09	0.84
			4 screws	1.34	4.30	0.58
		BTB	2 screws	0.38	3.18	0.87
			4 screws	0.59	4.99	0.68

Based on the result from Table 9 above, the BTB connection consistently performed the best among all tested configurations, especially in terms of bearing and net tension capacities [20]. For example, at 0.75mm thickness with four screws, BTB achieved a high bearing resistance ratio of 5.36. Even with 1.00mm thickness, the net tension ratio was 0.59, showing that this setup transfers loads efficiently and aligns well with design predictions. These results highlight BTB as a reliable and practical choice for structural applications.

On the other hand, the FTF-W connection showed the poorest performance, especially when it came to tension and shear resistance. With just two screws and 1.00mm thickness, its net tension ratio dropped as low as 0.12, and shear resistance stayed below 0.31, even when material thickness or the number of screws was increased. This underperformance is likely due to eccentric loading and weak screw engagement, making FTF-W the least suitable configuration without further design improvements [6].

SF and FTF-F connections showed promising results especially when using thicker material and more screws. For example, the SF connection at 1.00mm with four screws reached a tension ratio of 1.34, while the FTF-F setup reached 1.80 under the same conditions indicating a clear improvement from better geometry and additional fasteners. However, shear resistance remained low across the board, never exceeding 0.87. In this study, experimental shear resistance ratios consistently exceeded unity in bearing but remained below unity in shear, suggesting a possible gap between the conservative analytical model and observed behavior.

Increasing the number of screws from two to four improved performance in tension-dominated cases but sometimes resulted in a reduction in shear ratios. For example, the BTB shear ratio decreased from 0.87 to 0.68 when the screw count was doubled. This trend may reflect non-uniform load distribution and potential over-constraint in connections with multiple fasteners, leading to premature local failures [17]. In contrast, bearing resistance ratios across all configurations significantly exceeded unity, ranging from 1.44 to 5.84, reinforcing the adequacy of the Eurocode bearing provisions under the tested conditions.

Overall, the results suggest that while BTB connections perform reliably and closely align with analytical predictions, the FTF-W configuration is structurally inefficient and may require substantial redesign potentially through improved web detailing or alternative screw arrangements as proposed by Feng et al. [10].

3.5 Mode of Failures

Fig. 5 illustrates the failure modes of all tested samples. It offers valuable insights into the structural performance and integrity of the materials under investigation, with the goal of enhancing the behavior of connections under tension, bearing, and shear resistance for optimized design of CFS connections. Bearing failure emerged as the dominant mode. This finding highlights the significance of bearing capacity in determining the tensile strength of the connections, which is influenced by several factors, including screw diameter, material properties, and the geometry of the connection. Bearing failure occurs when the compressive stress exerted between the contact area to the screw, and the connected material surpasses the yield strength of the material, resulting in deformation.

Meanwhile, screw tilting was frequently observed, particularly in connections utilizing two screws. This failure mode is likely attributed to the eccentric application of tensile loads or imperfections present in the connection geometry. The occurrence of screw tilting can diminish the effective bearing area and amplify stress concentrations at the interface between the screw and the material, which may lead to premature failure of the connection. According to the Minh Toan Huynh *et al.* [18], tilting can lead to increased stress and potential failure modes such as bearing, tilting, pull-out, and shear failure in CFS connections.

Finally, screw snapping was observed in certain instances, especially in connections employing four screws. Having only two screws may result in concentrated tension at each connection, resulting to early failure [19]. This failure mode arises when the tensile stress experienced by the screw surpasses its ultimate tensile strength. Such failures are often attributed to the rigidity of the connection between the screw and the thicker plate, which may have been overly constrained, leaving insufficient tolerance for the screw to tilt. Consequently, this rigidity can lead to the complete snapping of all screws involved [20].

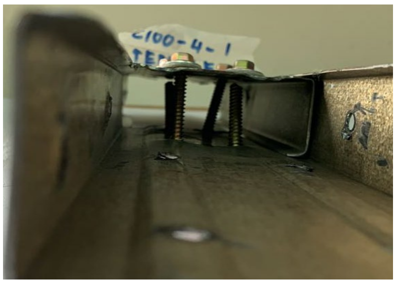
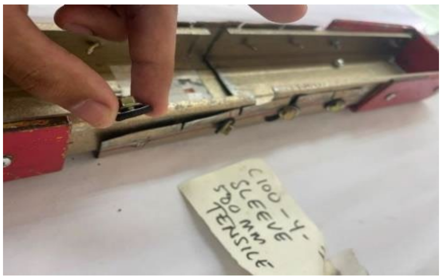
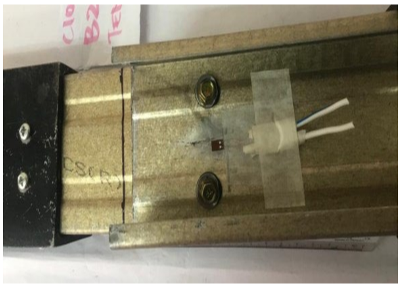
No.	Sample Details	Failures Images		Type of Failures
(a)	FTF-F			• Screw tilting • Bearing failure • Screw snapped
(b)	FTF-W			
(c)	SF			
(d)	BTB			

Fig. 5 *Mode of failure for each type of CFS connection, (a) FTF flange connection; (b) FTF web connection; (c) SF connection; (d) BTB connection*

Conclusion

This study provided a detailed evaluation of the tensile behavior of four CFS connection types FTF-W, FTF-F, BTB, and SF subjected to axial loading. Among these, BTB connections consistently demonstrated superior structural performance, with experimental-to-design resistance ratios above 1.0 for net tension, bearing, and shear, attributed to effective load distribution. Enhancements such as increasing material thickness from 0.75 mm to 1.00 mm and using four screws instead of two resulted in 20–50% gains in load capacity for well-performing configurations like FTF-F, BTB, and SF. However, FTF-W connections remained the least effective, with net tension ratios falling below 0.30, primarily due to eccentric loading and inadequate screw engagement. The observed failure mechanisms bearing deformation (driven by geometry and material characteristics), screw tilting (common in two-screw configurations), and screws snapped (noted in four-screw assemblies with high rigidity) expose key design vulnerabilities.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

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