Initial Structural Characteristics of Built-up I-section Cold-formed Steel with Oriented Strand Board Short Column

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GRAPHICAL ABSTRACT

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Roof truss systems and wall panels are two examples of popular structural components made by cold-formed steel (CFS) which is classified as a steel-based building material available in a wide range of shapes, and thicknesses. The use of CFS is increasing due to its many desirable properties, including a high strength-to-weight ratio, low weight, resistance to corrosion, and fast installation. In contrast, the thin-surfaced and opened section of CFS buckles easily when utilised as a beam or column. When the load is applied directly, the CFS section fails in modes such as web crippling, torsion, and buckling. As a result, the new I-section with top and bottom flange elements was produced by using CFS channel section, and timber board from the type of oriented strand board (OSB) as a web element. The study aimed to determine the initial structural characteristics of the built-up I-section CFS with OSB short column. A single or double web element made by yellow and dark brown OSB was used to construct the I-section for determining the initial structural characteristics. The I-section with a double web of yellow OSB showed the highest value of ultimate load and compressive strength as compared to other specimens in the range of 8.00% to 14.00%.

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Keywords: Built-up I-section; Cold-formed steel; Oriented strand board; Composite Short Column; Structural Characteristic

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INTRODUCTION

Cold-formed steel (CFS) is often used in civil engineering applications where weight saving is preferred and where safety, stability, and strength are maintained. The selection of CFS depends on the specific requirements of the application, such as cost, structural performance, weight, environmental considerations, material efficiency, manufacturability, and thermal properties. The CFS, while having various advantages, is exposed to structural integrity challenges, such as buckling, instability, and plastic deformation. Thus, numerous researchers are studying ways to produce the built-up CFS section or a composite section from the utilisation of an individual CFS section. In general, CFS either as a column element or beam element is critically susceptible to buckling failure and it depends on the length, end support condition, and cross-sectional shape. There are four categories of buckling failure of the CFS column or beam including local buckling, distortional buckling, global buckling, and lateral buckling.

The study of the production or modification of the individual CFS section, which is in the open section and unsymmetrical section to the built-up CFS or composite section, has been considered as a way to minimise buckling failure. Many studies propose the built-up CFS section from the combination of two or more individual sections and introduce the basic built-up section including a back-to-back and face-to-face section by using fasteners, for example a back-to-back section by using an angle section (Ananthi *et al.* 2021), a face-to-face section by using angle section (Ananthi *et al.* 2023), a face-to-face section by using channel section (Roy *et al.* 2019), and a back-to-back section by using channel section (Roy *et al.* 2018). However, the CFS section is still not completely stable and strong. In addition, there are many studies that combine CFS with other materials, such as timber, engineered timber products, concrete, and mortar. There are examples of previous studies on CFS with timber or engineered timber products, such as CFS rectangular section with timber (Song *et al.* 2024), three CFS channel sections with timber (Dar *et al.* 2023), two CFS channel sections with OSB (Mohd Sani *et al.* 2019, 2023), two channel sections with glued laminated timber (Glulam) (Yang *et al.* 2023), CFS plate which taken from a web element in channel section with solid timber (Yoresta and Nugroho 2023), and CFS Z-section with timber (Awaludin *et al.* 2015). Additionally, there are several studies of the combination of CFS with timber and engineered timber products for composite flooring systems, for example, CFS channel with particleboards (Kyvelou *et al.* 2017), CFS channel with plywood panels (Karki *et al.* 2024), CFS channel with OSB (Zhou *et al.* 2019), and CFS channel with cross-laminated timber (Navaratnam *et al.* 2021). A combination of CFS and timber or engineered timber products in wall systems is becoming popular, such as CFS with OSB (Xu *et al.* 2021; Yilmaz *et al.* 2023a), CFS with fibre cement board (Derveni *et al.* 2020), CFS with straw board (Zhang *et al.* 2023), and CFS with integrated board made by basalt fibre and biobased-basic magnesium sulphate cement (Liu *et al.* 2024). Yilmaz *et al.* (2023a) stated that the OSB thickness is an important factor to determine the load-deformation behaviour of CFS wall panels and reported that the use of thicker OSB significantly enhanced both the initial stiffness and lateral capacity of CFS wall panels in a nearly proportionate means. Consequently, the study involved and focused on column elements that proposed composite structures by using CFS with engineered timber products is introduced. Oriented strand board (OSB) is considered a type of engineered timber product or known as a structural timber panel. The OSB is manufactured by using irregularly shaped thin timber strands which are arranged in cross-oriented layers and waterproof heat-cured glue that is stronger than plywood.

Song *et al.* (2024) mentioned that CFS with timber structure possesses its own role. For example, the steel section is used as the core load-bearing component and timber is used to prevent the buckling of the steel, to improve the insulation and seismic performance of the building and to increase the decoration outcome. Moritani *et al.* (2021) stated that CFS with timber structure provides many advantages, such as facilitating advanced industrial construction, minimising environmental effects, ensuring structural stability within a plane, and possessing a high ratio of capacity to self-weight. There is limited information and insufficient knowledge in designing CFS with timber structures in the present and available codes of practice (Moritani *et al.* 2021). Yilmaz *et al.* (2023b) stated that the bending strength of the stud wall sheathed with OSB increased 33% when the thickness of OSB is doubled to 18 mm, and the bending strength of the stud wall increased 86% when the thickness of CFS is increased from 1.2 mm to 2.0 mm. The OSB panel would be tensioned, and the CFS section would be compressed under the adverse load scenario of uplift loading for the flexural test (Kyvelou *et al.* 2021). Abreu *et al.* (2020) reported that the structural performance of CFS is decreased when the temperature is increased, and OSB is burnt when the temperature is in the range of 2,000 to 4,000 °C with the loss of the sheathing restraint.

Generally, the combination of CFS with timber or engineered timber product is used for specific fasteners for instance bolts and nuts, screws, and glue. The fasteners between CFS and OSB are classified as critical issues to determine the structural performance of the overall building (Abreu *et al.* 2021). Overall, the study of CFS with OSB as a main structural component either beam or column, is limited. However, the study of the CFS section with OSB acting as sheathing material in the wall or OSB acting as flooring system material, is classified as still under research to this day. There is also no information about CFS with OSB as a structural component in the design code or standard. Hopefully, the combination of CFS and OSB can reduce the production and maintenance costs, help to protect the environment by minimising the usage of traditional materials, to propose the permanent formwork by reducing the waste product on site, and to support the sustainable development goals and green technology in construction and to reduce the problem of structural integrity.

In summary, the lack of knowledge and understanding of particular design rules and criteria in the development of the built-up I-section CFS with the OSB section is classified as a significant approach to determining the structural characteristics of the column. The novelty of the study offers the unique advantages of combining the CFS and OSB, and introduces opportunities for innovation in built-up I-section with different types of material of the flange and web element as a column. The development of the column is able to improve structural performance, introduce material synergy, promote sustainability and cost efficiency, produce architectural flexibility and stimulate emerging applications. Thus, the main objective of the study is to determine the initial structural characteristic of the built-up I-section CFS with OSB column, especially for the short column.

EXPERIMENTAL MATERIAL AND SETUP

The CFS channel section with lipped and double intermediate web stiffeners was selected, cleaned, and cut according to the height of the column. The CFS channel section with section dimension and properties of 75 mm of web element (D), 34 mm of flange element (F), 8 mm of lipped element (L), 1 mm of thickness (t), 148 mm^2 of cross-section area (A), and 550 MPa of yield strength (f_y) was selected because of its availability at the Malaysian construction market and it is often used in buildings and residential houses for roof truss structures. The function of the double intermediate web stiffeners and lipped element is to minimise the initial buckling of the section, particularly the local buckling. The example diagram of the CFS channel section is illustrated in Fig. 1, and the section properties of the CFS channel section are tabulated in Table 1. The section dimension ratio of flange to thickness element is 34.00 and flange to lipped element is 4.25. The section dimension ratio of 2.21 and 9.38 is recorded for the ratio of web to flange element and web to lipped element, respectively. The ratio is important to ensure the section with suitable cross-section and dimension for the proposal as a structural component. For example, the web to thickness ratio of 75.00 is vital to measure the ability of the section to control the initial local buckling when subjected to compression load. From the analysis of the ratio, the CFS channel section is classified as a suitable section for proposing a structural component. The CFS channel section was cleaned and cut at the flange and web element in the longitudinal direction that was categorised as a flat element into a coupon tensile shape according to BS EN10002-1 (2001). The initial geometric imperfection and the additional strength of the CFS channel section were ignored.

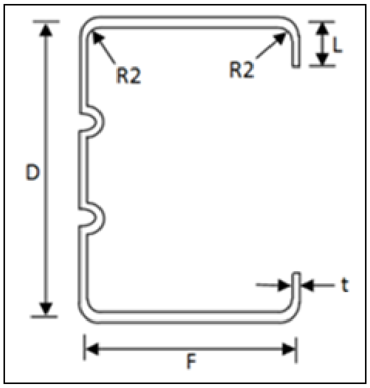
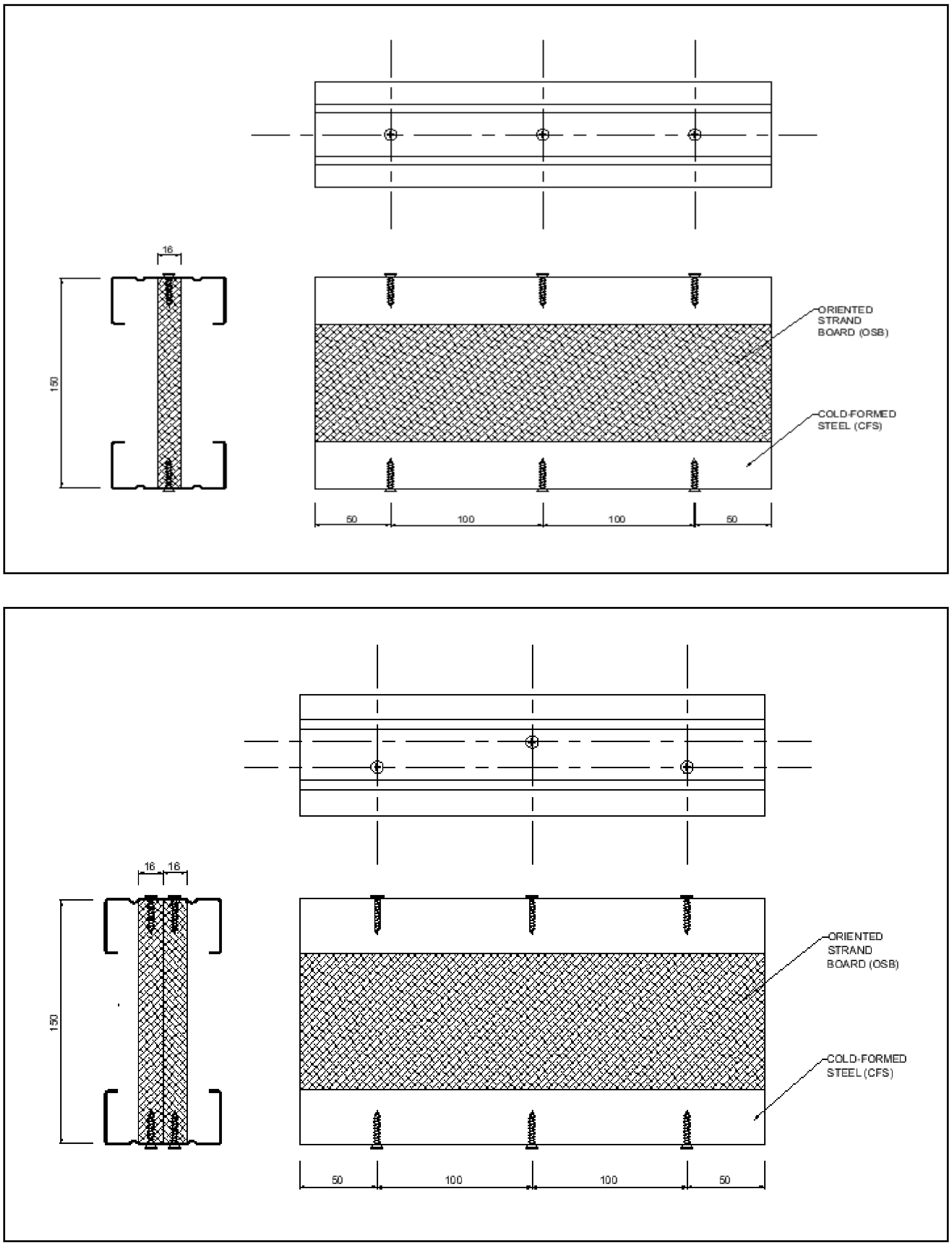


Fig. 1. The diagram of the CFS channel section with cross-section and dimension

Table 1. Section Properties and Section Dimension Ratio of the CFS Channel Section

Section Properties			
I_{xx}	0.135×10^6 mm^4	I_{yy}	0.025×10^6 mm^4
Z_{xx}	3.605×10^3 mm^3	Z_{yy}	2.240×10^3 mm^3
R_x	30.22 mm	R_y	12.94 mm
Mass/unit length	1.19 kg/m	Centroid, X	11.07 mm
Section Dimension Ratio			
F/t	34.00	F/L	4.25
D/F	2.21	D/L	9.38
D/t	75.00	L/t	8.00

Oriented strand board (OSB), which is available in the Malaysian construction market with a thickness of 16 mm and width of 150 mm, was used and cut according to the height of the column. The OSB was attached to the CFS channel section by using a screw, and OSB acted as a web element and CFS acted as a flange element. The combination of OSB and CFS in the study is illustrated as a composite I-section, as shown in Fig. 2. The figure shows the front view, side view, and top view of a composite I-section and illustrated the size of OSB and screw spacing. There were two types of composite I-sections that included a single web and double web, and there were also two types of OSB that were categorised by colour used (yellow and dark brown). The screw position was 50 mm of end spacing and 100 mm of mid spacing, referring to the study of Ananthi *et al.* 2023 and Sang *et al.* 2023, respectively. For the single web, the screw position is situated in one row, and for the double web, the screw position is situated in two rows in a zig-zag position according to the study of Aruna *et al.* 2015. For the double web, the timber glue is used to join between the two OSBs. The concept of the screw is in two rows but in a zig-zag position is to minimise the screw usage and minimise the localised failure issue. Additionally, the zig-zag position of the screw is able to help distribute loads more evenly across the joint, reduce the stress concentrations, increase the effective area of the screw which provides shear and tension resistance, and reduce timber splitting risk. The target height of the column in the study was fixed to 300 mm. The explanation of the specimen is tabulated in Table 2. From Table 2, the percentage difference of the mass between single web and double web for yellow OSB is 26.78%, and for dark brown OSB is 26.84%. The percentage difference between the single web for yellow OSB and dark brown OSB is 1.15%. A 1.22% percentage difference was reported as a comparison between the composite I-section with double web for yellow OSB and double web for dark brown OSB. In conclusion, the dark brown OSB is heavier as compared to the yellow OSB.



(a)

(b)

Fig. 2. The schematic diagram of the composite I-section for (a) single web, and (b) double web (all dimensions in mm)

Table 2. Description and Symbols of the Specimen

Specimen Symbols	Description	OSB Types	Mass (kg)
SOSBY	CFS channel section located on top and bottom of composite I-section with a single web of OSB	Yellow	1.121
DOSBY	CFS channel section located on top and bottom of composite I-section with a double web of OSB	Yellow	1.531
SOSBDB	CFS channel section located on top and bottom of composite I-section with a single web of OSB	Dark Brown	1.134
DOSBDB	CFS channel section located on top and bottom of composite I-section with a double web of OSB	Dark Brown	1.550

The experimental setup of the study is focused on the determination of the material properties of CFS channel section and structural characteristics of the composite I-section column when subjected to axial load. The universal testing machine (UTM) with a load capacity of 100 kN and compression speed of 1.0 mm/min and extensometer with a length of 50 mm were used to measure the material properties of CFS channel section, especially the ultimate load, ultimate strength, yield strength, deformation at ultimate load, modulus of elasticity and ductility. The arrangement of the coupon tensile specimen and extensometer in UTM is represented in Fig. 3. The automatic compressive strength machine with a load capacity of 2,000 kN and compression speed of 0.5 kN/s was used for determining the column structural characteristic. The arrangement of the column is situated on the middle part of the steel plate of the machine jig and is considered pin-ended on the top and bottom sides. Then, the result data of the ultimate load and compressive strength of the short column was recorded. Lastly, the failure mode of all specimens was observed and classified as the type of failure.

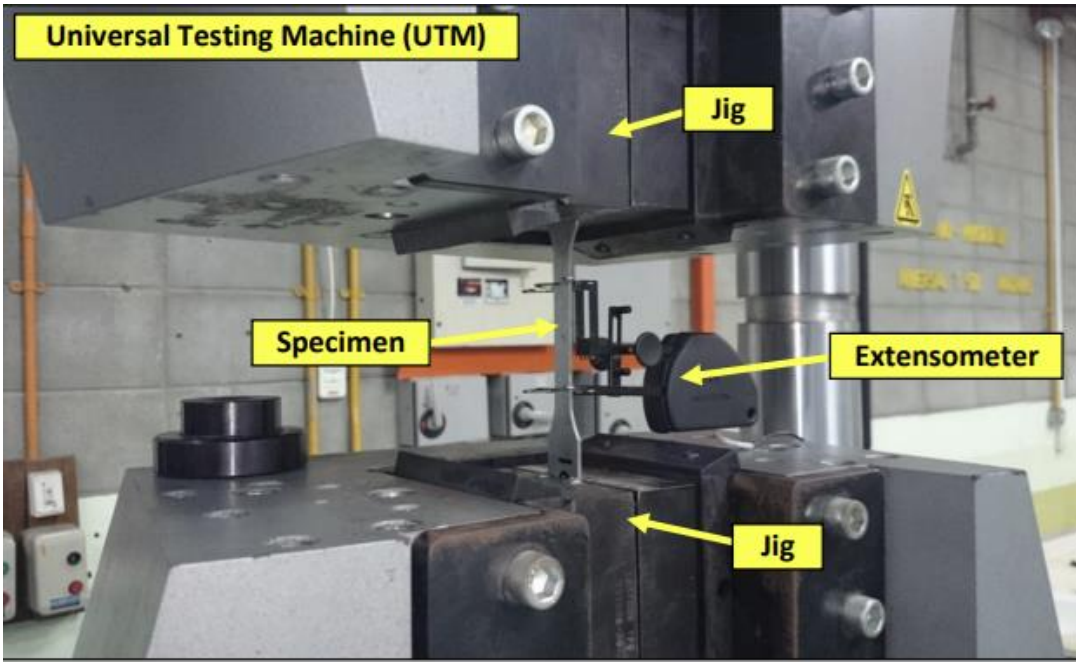


Fig. 3. The arrangement of the specimen attached to the extensometer in the universal testing machine

RESULTS AND DISCUSSION

The results of the material properties of CFS channel section and structural characteristics of the composite I-section column are analysed and discussed here. All studies, especially in forming the structural components either columns or beams or other applications, normally start with material properties testing. The test obtains the modulus of elasticity and yield strength data of the material, which is later to be used for further analysis.

Material Properties of the Cold-formed Steel

Table 3 shows the result of the material properties testing. It is apparent that the failure of all specimens was within the extensometer length range. From Table 3, the element with the lowest value of ultimate load and strength was the web element with 6,710 N and 537 MPa, respectively, and the highest value of ultimate load and strength was the flange element with 7,130 N and 570 MPa, respectively. The percentage difference of ultimate load and strength between the web and flange element is reported as 5.88%. The ultimate load and strength of the flange element were more than the web element because the flange element went through a lot of processes, such as cold-bending, cold-curving, and cold-shaping, with indirect additional strength. In conclusion, the ultimate load and strength of the CFS section increased with the addition of the process of cold-bending and cold-curving. The percentage difference of the yield strength between the web and flange element was 6.49% and it is reported that the value of the experiment yield strength is similar to the factory yield strength (factory data). Deformation at ultimate load for web element and flange element is reported to be approximately more than 4.00 mm and noted to be 3.99% as compared to web and flange elements. Lastly, the modulus of elasticity of the web and flange element was recorded as more than 200 GPa and categorised in the section as purely steel-based material. The modulus of elasticity of the web element was higher than the flange element with 2.15%. The ultimate strength for web and flange elements according to tensile test data is shown in Fig. 4.

Table 3. The Material Properties of CFS Channel Section

Element	Ultimate Load	Ultimate Strength, f_u	Yield Strength, f_y	Deformation at Ultimate Load	Modulus of Elasticity
Web	6,707.86 N	536.63 MPa	524.07 MPa	4.432 mm	205.22 GPa
Flange	7,126.75 N	570.14 MPa	560.42 MPa	4.255 mm	200.80 GPa

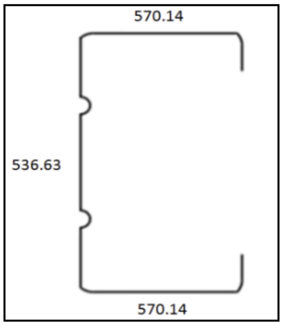


Fig. 4. The ultimate strength of web and flange elements for the CFS channel section (all dimensions in MPa)

The effect of the cold-working condition of the CFS channel section is dependent on the ductility which is calculated by the ratio of ultimate strength over yield strength (f_u/f_y). The f_u/f_y ratio of the web element was 1.023 and the flange element was 1.017. The factory yield strength (f_{yf}) of the CFS channel section was 550 MPa. The ratio of f_u/f_{yf} for the web element and flange element was 0.976 and 1.037, respectively. From the calculation, the CFS channel section with a ratio near 1.10 was reported to be classified as possessing good ductility. In conclusion, the CFS channel section with good ductility and material properties was judged to be appropriate to continue the study by proposing a structural component. In general, the ductility of the CFS significantly influences the structural characteristics of built-up CFS columns to redistribute stresses during deformation or buckling and also to ensure the column becomes more stable and efficient in structural applications.

Structural Characteristic of the Built-up I-section Cold-formed Steel with Oriented Strand Board Short Column

Secondly, the built-up I-section CFS with OSB short column was tested to determine the structural characteristic, and the result is tabulated in Table 4.

Table 4. Result of the Built-up I-section CFS with OSB Short Column

Specimen	Ultimate Load	Compressive Strength - CFS	Compressive Strength - OSB
SOSBY	116.1 kN	350.00 MPa	5.196 MPa
DOSBY	134.2 kN	365.61 MPa	5.410 MPa
SOSBDB	116.0 kN	350.00 MPa	5.180 MPa
DOSBDB	121.0 kN	329.70 MPa	4.880 MPa

From Table 4, the highest value of the ultimate load is the DOSBY specimen and the lowest value of the ultimate load is the SOSBDB specimen. Comparing the ultimate load between single web, the SOSBY specimen with yellow OSB showed the highest value but is slightly higher than the SOSBDB specimen with dark brown OSB. The percentage difference between SOSBY and SOSBDB specimens is 0.086%. In conclusion, the ultimate load of the column with a single web is not affected when the type of OSB is not similar but with similar thickness. However, for the column with double web, the DOSBY specimen is illustrated to have the highest value of ultimate load than the DOSBDB specimen. The percentage difference between both specimens was recorded at approximately 9.84%. The percentage difference of 13.49% and 4.13% were recorded for columns with a single web as compared to a double web for yellow OSB and dark brown OSB, respectively. The built-up I-section CFS either with a single web OSB or double web OSB for the short column was classified as not important if the ultimate load was less than 10%. Figure 5 illustrates the ultimate load for all specimens. Thus, the web element of the built-up I-section CFS with OSB short column was not influenced directly by the ultimate load but the flange element played an important role. DOSBY double web CFS specimen was the highest compressive strength while the single web CFS compressive strength was markedly the same value. The highest value of the compressive strength of OSB for all specimens was recorded at 5.410 MPa, which was noted for the DOSBY specimen. From the structural characteristic result, the built-up I-section CFS with oriented strand board is suitable to be used as a residential framing such as a vertical support section in sheathing or partition walls. It also can be used as a temporary support during construction, used as architectural features which need aesthetic benefits, used as a light storage structure, and used as an open-web columns. However, the key considerations for designing the column are buckling condition, connection details and also moisture sensitivity. The structural characteristic of the column also depends on the flange element material and the stability of the web element.

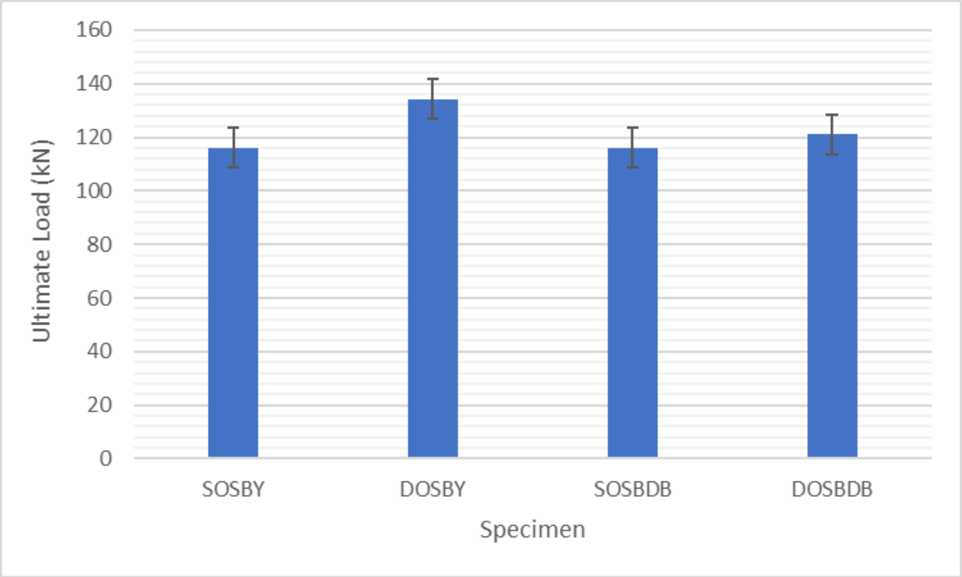


Fig. 5. The ultimate load of all column specimens

The failure mode of all specimens was observed and classified according to buckling type. All specimens were observed to fail at the OSB part near to attachment between OSB and CFS, and the flange of the CFS channel section. There was no failure at the screw connection between CFS and OSB. The failure mode of the SOSBY specimen is illustrated in Fig. 6. The OSB on the specimen showed a long crack at the middle part and CFS, which is located on the top and bottom and was reported to have distortional buckling of the flange element of the CFS channel section. Figure 7 illustrates the failure mode of the DOSBY specimen and observed failure at the flange element of the CFS channel section at the middle part and end part. The OSB developed a long crack on one side of the double web and there was no failure in the connection between two OSB. The use of screws, particularly the number and position of the screws to join the CFS and OSB, are deemed appropriate when subjected to compression load. The failure mode of SOSBDB and DOSBDB specimens is shown in Figs. 8 and 9, respectively. Figure 8 shows the specimen failure at the middle and end part of the CFS channel section flange element. However, OSB did not display critical crack failure as SOSBY and DOSBY specimens. Figure 9 shows failure at the end part of the CFS channel section. However, OSB did not show any critical crack or failure. Dark brown OSB with the highest value of mass is illustrated as more stable and did not show any critical crack when subjected to compression load. Galewska *et al.* (2016) stated that the CFS with intricate analysis and calculation, and unpredictable failure mode, with the use of CFS justified due to their overall variety, adaptability and flexibility. Lastly, the web element with double OSB can effectively resist the initial local buckling, help maintain a balanced distribution of stresses across the section, and provide greater stability.

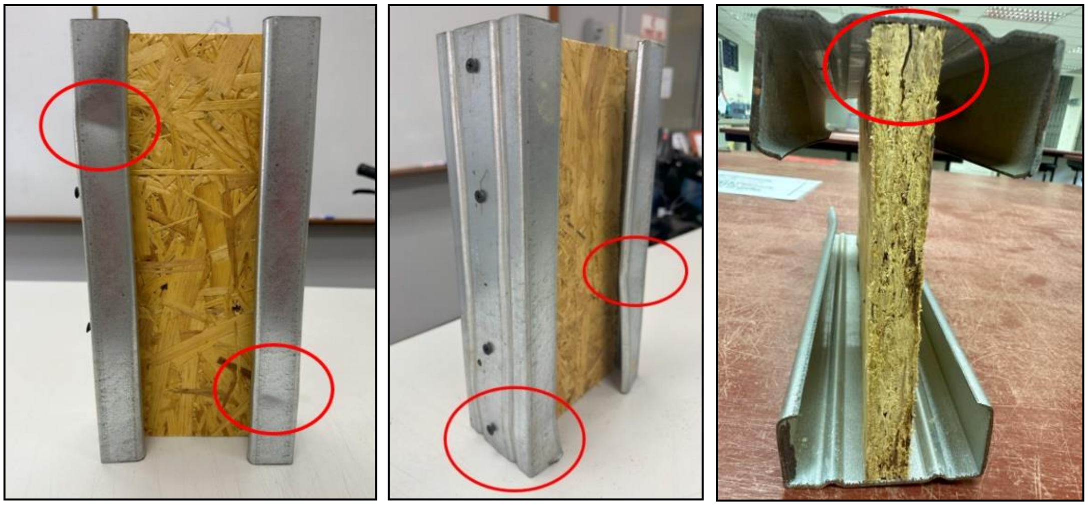


Fig. 6. The failure mode of the SOSBY specimen

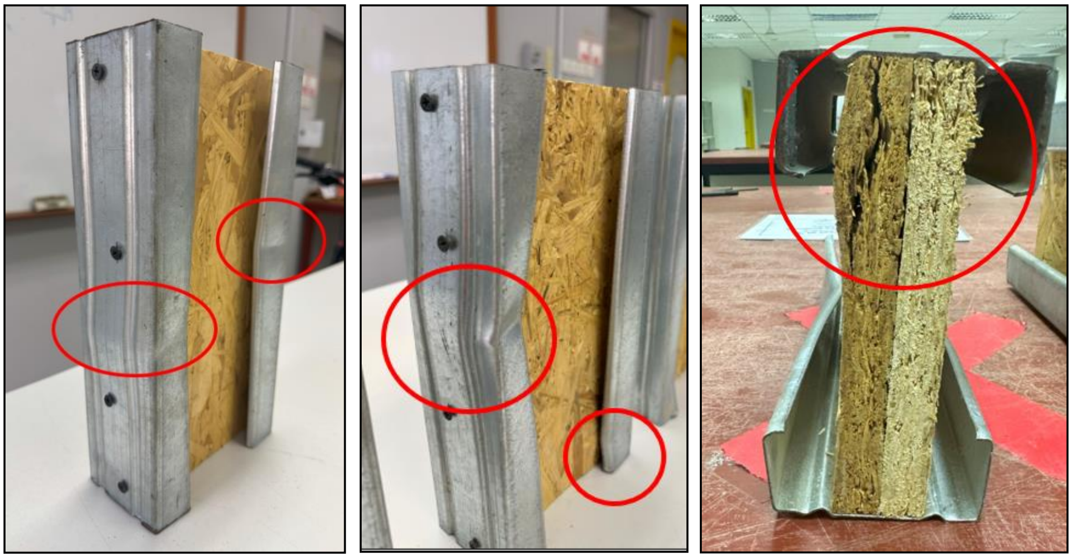


Fig. 7. The failure mode of the DOSBY specimen

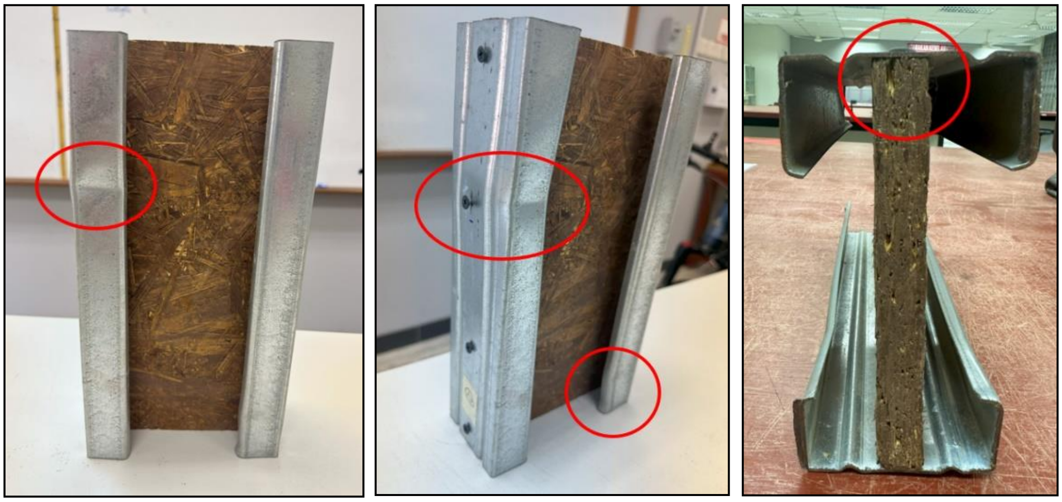


Fig. 8. The failure mode of the SOSBDB specimen

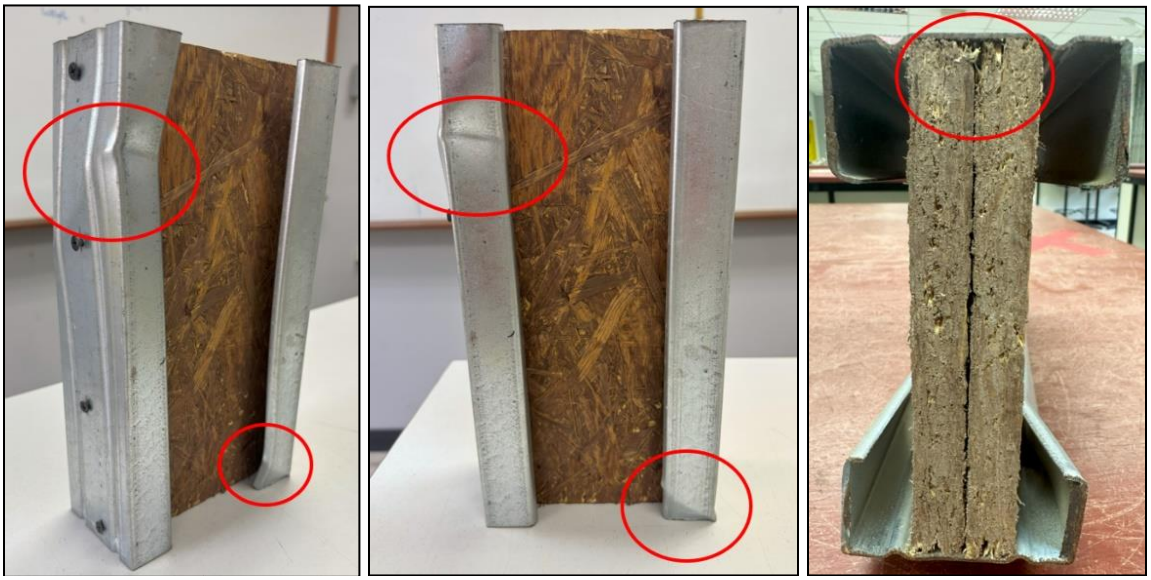


Fig. 9. The failure mode of the DOSBDB specimen

CONCLUSIONS

In this study, the experimental activity analysis was conducted and supported with data results of the material properties of cold-formed steel (CFS) and structural characteristics of built-up I-section CFS with oriented strand board (OSB) short column. Several conclusions and recommendations are made from the analysis of these two experimental activities as represented here.

1. The material properties of the CFS channel section can be classified as appropriate data as compared to the factory information data. The ultimate load of the flange was 7,130 N and is considered higher than the ultimate load of the web element at 6,710 N because of the additional strength from the cold-bending and cold-curving processes. The ductility of the CFS channel section is considered in good condition by referring to the ultimate strength over yield strength ratio.
2. The structural characteristic of the built-up I-section CFS with OSB short column is determined by referring to the value of the ultimate load and compressive strength, and the failure mode. There was a similar value of the ultimate load and compressive strength of the I-section column for a single web. However, the highest value of the ultimate load and compressive strength of the I-section column for a double web was observed for the DOSBY specimen. The web of the I-section did not affect the determination of the ultimate load and compressive strength. The data of the ultimate load and compressive strength result could be used for designing the short composite column. Additionally, the design procedure according to material ductility, screw position, and geometry properties could be proposed in the design codes. Besides, the result shows that the CFS is suitable to combine with OSB in producing composite I-sections due to efficiency, performance, and sustainability. The screw is also appropriate to use in combining CFS with OSB for the purpose of construction times and cost-effectiveness. From the observation, the failure mode for all specimens is

shown to have similar failure at the flange element of the CFS channel section and OSB. However, dark brown OSB did not show serious crack failure relative to yellow OSB.

For future work, the length of the column should be designed according to the slenderness ratio, especially intermediate and slender columns. The thickness of OSB should be varied to further optimise the structural characteristics of the composite column section. Then, the result of the structural characteristic of this column will be compared with numerical analysis by using finite element modelling. Lastly, the study should be extended for proposing and designing the specimen to become a beam component.

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