FLEXURAL STRENGTH OF LIP CHANNELS COLD-FORMED STEEL BEAM IN BACK-TO-BACK ARRANGEMENT WITH A VARIETY OF LENGTHS

[1]Nindyawati, [2]M. Mirza Abdillah Pratama, dan [3]Husnik Maulidya Tungga Dewi

[1]Civil Engineering Department, Universitas Negeri Malang, email: nindyawati.ft@um.ac.id
[2]Civil Engineering Department, Universitas Negeri Malang, email: mirza.abdillah.ft@um.ac.id
[3]Civil Engineering Department, Universitas Negeri Malang, email: husnik.maulidya.1805236@students.um.ac.id

Abstrak: Optimization of cold-formed steel construction materials in the form of merging two individual channel into built up back-to-back channel. The use of cold-formed steel is increasingly applicable with varying lengths used. Therefore, it is necessary to research the effect of variations in beam span length affect the flexural strength of cold-formed steel beams arranged back to back. This study aims to determine the load, deflection, and failure mode of back-to-back C channel beam with variations in beam span length. The research uses quantitative methods through a laboratory experimental approach. The results of the study can be concluded as follows: (1) A load of back-to-back cold-formed steel beams has decreased with an increase in the length of the beam span in each variation code test specimen. The decrease in load compared to the shortest span length of 90 cm for the lengths of 120, 210, 240 cm are 10,90%, 51,12%, and 62,39% respectively. The decrease in actual load is caused by a reduction of flexural rigidity, the presence of stress concentrations at the loading point that prevent the load from being properly distributed to the support, and the instability of the back-to-back or open sections, which increases as the length of the beam span increase. (2) Deflection of the beam due to transverse loads which act on back-to-back cold-formed steel beams increases as the span length increases for each variation code test spesimen. The beam deflection compared to the shortest span length of 90 cm for the lengths of 120, 210, and 240 cm increased by 17,26%, 73,11% dan 103,3% respectively. The decrease in beam stiffness due to increased length of the beam span with a constant spreader beam size, which results in increased distance between the loading point and the support, is what causes the rise in vertical deflection of the beam. The deflection that occurs in each length variation code exceeds the maximum deflection limit, so it is necessary to take into consideration of the load applied to the back to back cold-formed steel beam. (3) The failure modes that occured in the back-to-back cold-formed steel beam in each variation of the span length during the flexural test had the same failure, namely flange local buckling, distortional buckling, and lateral torsional buckling. The difference in failure modes among C channels in the back-to-back beam was observed and there is an interaction of local buckling, distortional, and lateral torsional buckling failure modes in one of C channel, while the other C channel only experiences lateral torsional buckling.

Keywords: flexural strength, cold-formed steel, back-to-back c channel beam, variety of length

1. PRELIMINARY

Material construction as the support of the construction sector has a significant influence on the quality of construction. To maximize its wider use and support the development of the construction industry, innovation and optimization of materials need to be carried out to maximize their wider use. Cold-formed steel is a thin-walled steel material that has unique properties and advantages so that it is widely applied as beams, columns, roof truss systems, wall panels, and so on. Some of the advantages of cold-formed steel are that it can vary, is relatively lightweight compared to conventional steel with a self-weight reduction of 32.03%, an increase in strength with a yield stress of 280-550 MPa, ease of installation, and corrosive resistance so that it is classified as a sustainable material (Alhaddad et al., 2020; Ashokbhai et al., 2017; Dar et al., 2019; Ting & Huon, 2013)

Cold-formed steel profiles commonly used in construction, especially in beams, are channel or C-sections. However, this type is classified as a thin-walled material and has a mono-symmetrical shape, so that lateral torsional buckling is easy due to differences in the location of the shear center and the centroid of the cross-section, local buckling, and distortion buckling (Kang et al., 2017; Ye et al., 2018). Efforts to develop the required cold-formed steel material are in line with increasing use. One method is a built-up member or the joining of two or more sections applied to a double profile using fastenings such as bolts, screws, and others. The types of joining include the built-up back-to-back profile, which has several advantages, namely higher axial and flexural capacity than a single cold-formed steel profile, can increase the moment of inertia possessed, and the resistance to lateral torsional buckling increases due to the position of the shear center, and the center of gravity of the cross-section coincides (Fratamico et al., 2018; Kang et al., 2017; Mahar & Sanjeevi, 2021; Ting & Huon, 2013)

Previous research on cold-formed steel beams has been carried out several times. Testing the flexural behavior of cold-formed sigma steel profiles towards variations in the cross-sectional arrangement of profiles, namely single and alternating, by Laim et al. (2015). he test results obtained show that the maximum back-to-back profile load is 2.9 times greater than the single profile. This shows that the shape of the section arrangement plays a role in flexural strength. The investigation carried out by Kang et al. (2017) on the flexural behavior of alternating C-profile cold-formed steel against variations in thickness and connection distance using bolts The maximum load increases along with the increase in thickness, which is 3–98% with a connection distance of every L/2–L/6 span. The experimental study of the behavioral profile of the C rolled steel beam rearranged against variations in body thickness increased the load by 10–20% (Fitrah & Melinda, 2020).

From the various research results above, each variation of the experiment carried out has an influence on the load and failure pattern that occur in cold-formed steel beams arranged back-to-back. Therefore, experimental research on C-profile cold-formed steel beams arranged back-to-back with varying span lengths is necessary. In this study, C-profile cold-formed steel beams with various beam span lengths were arranged back-to-back using a self-drilling screw connection type. This study aims to determine the load, deflection, and failure mode produced by the back-to-back cross-section of cold-formed C-profile steel beams with variations in the length of the beam span.

2. METHOD

This study uses a quantitative method with a laboratory experimental approach with the aim of analyzing the effect of variations in length of cold-formed steel beams with canal or C-section arranged back-to-back on the magnitude of the load, deflection, and failure mode that occurs.

Research Sample

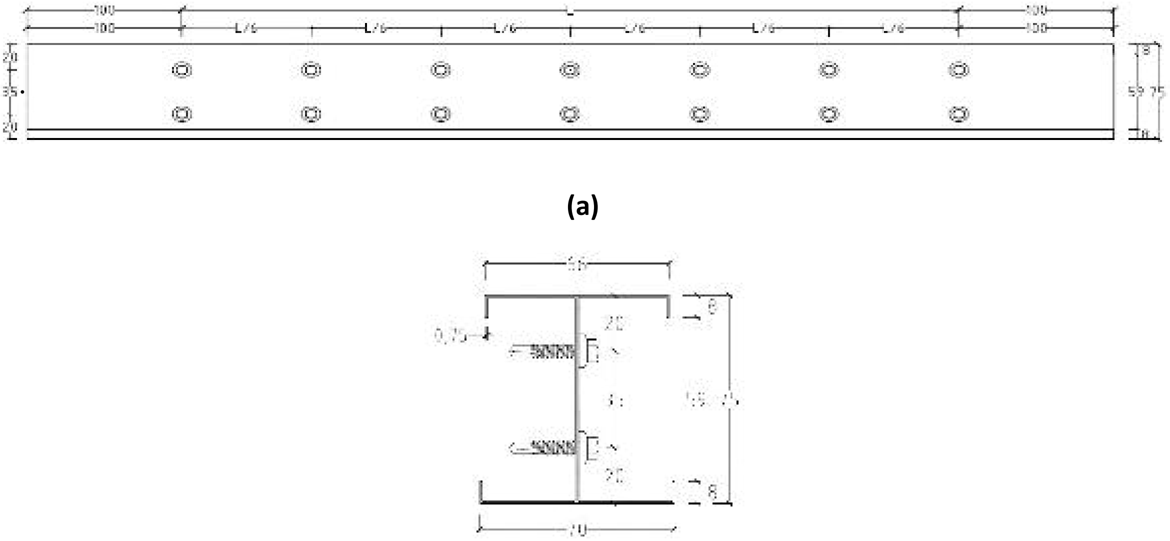
The research sample used was a cold-formed steel beam with a C section of 75 x 33 x 35 x 8 x 0.75 arranged back to back. Connection of profiles using self-drilling screws (SDS) No. 12 x 5 mm. The joining distance of the two cold-formed steel profiles is based on SNI 7971 of 2013 and is an L/6 beam span. The variation in the length of the specimens is shown in **Table 1**. Details of the specimens are shown in **Figure 1.**

Table 1. The Length Variation of The Specimens

Variant Code	Variation of Length, (cm)	Specimens Code	Specimens Total
BB90	90	BB90-1	1
		BB90-2	1
		BB90-3	1
BB120	120	BB120-1	1
		BB120-2	1
		BB120-3	1
BB210	210	BB210-1	1
		BB210-2	1
		BB210-3	1
BB240	240	BB240-1	1
		BB240-2	1
		BB240-3	1

Note:

Specimen code "BB90-1" is interpreted as follows: BB is back to back, 90 is the length of the beam span, and number 1 is the number that states the sequence of repetitions of the test specimen.



(a)

(b)

Figure 1. Details of The Cross-Section of The Specimen with A Predetermined L: (a) Front View, and (b) Side View

Beam Flexural Strength Test Procedure

Back-to-back flexural strength testing of cold-formed steel beams was carried out to obtain the amount of load possessed by the beam, the resulting deflection, and the type of failure pattern that occurred. The equipment used in testing the flexural strength of steel beams includes loading frames, pinned and rolled supports, hydraulic jacks, pumps, load cells (capacity 100 kN), spreader beams (l = 20 cm), data logger, dial gauge, and strain gauge. A strain gauge serves as a measuring tool for secondary analysis, namely the strain that occurs in the beam when the bending test is carried out.

The loading frame is used as a place to install steel beam test objects and other testing equipment. Hydraulic jacks and pumps are used to produce a concentrated load that will be applied to the beam during the test. The load cell is used as a measuring instrument for the magnitude of the load received by the beam and as a distributor of the load from the hydraulic jack to the spreader beam during the flexural strength test. A spreader beam is used as a centralized load divider, obtained from the hydraulic jack and channeled by the load cell into a load with two loading points. The dial gauge is used for measuring vertical deflection, horizontal deflection, and torsion angle that occur in the beam manually at mid-span. This study uses three dial gauges placed in the middle of the beam span, with the first dial gauge to measure vertical deflection and the second and third dial gauges to measure horizontal deflection and torsion angle. The second dial gauge is placed 22.5 cm from the first dial gauge, and the third dial gauge is placed 7.5 cm from the second dial gauge. The amount of load the beam can accept is obtained from the load cell recorded in the data logger. The beam flexural strength test setting is shown in **Figure 2.**

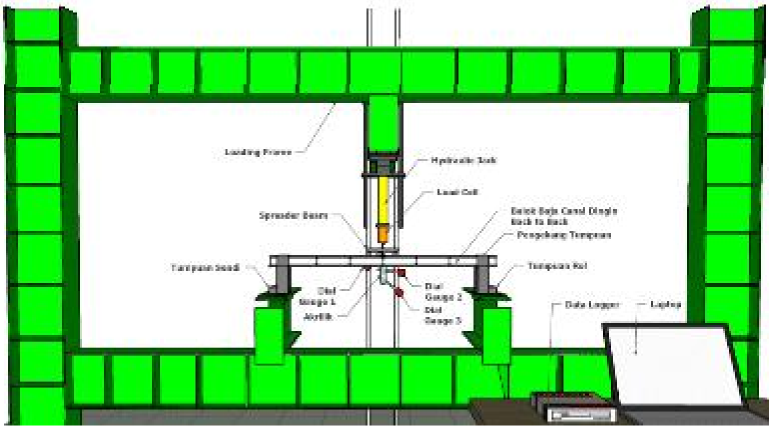


Figure 2. Illustration of Flexural Strength Test of Cold-formed steel Beams Back To Back

3. RESULTS

Tensile Strength Test Data

The tensile strength test of cold-formed steel is carried out using a Universal Testing Machine (UTM). The dimensions of the cold-formed steel tensile strength test specimens are based on SNI 07-0371-1998 with test rod number No. 13 B. The number of specimens used was three with the test object code, namely TSS-1, TSS-2, and TSS-3. After testing the tensile strength, the elastic modulus data for TSS-1 has a different elastic modulus value from the other specimen codes. According to Han and Kamber (2012), data that does not behave in general according to the model of a data set is called outlier data. According to Suliyanto (2011), the step to creating normality in the data distribution to produce data that is close to the average value is to eliminate outlier data. The results of data processing on the tensile strength of cold-formed steel material with outlier data selection are shown in **Figure 3** and **Table 2.**

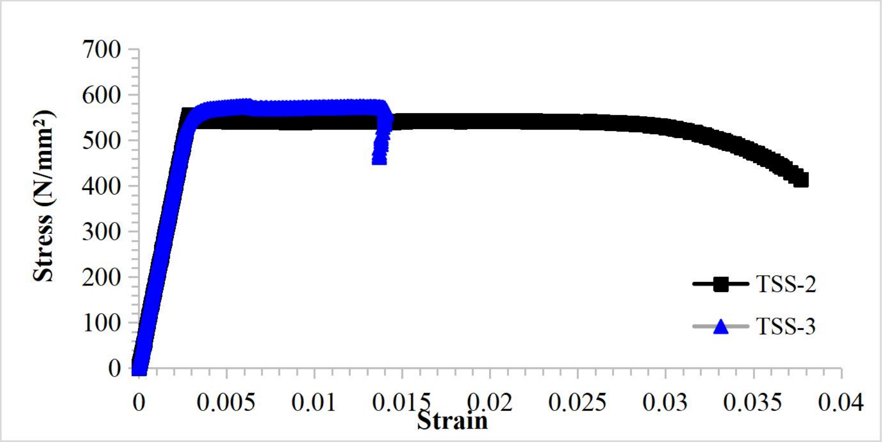


Figure 3. Stress-Strain Curves of Cold-formed steel

Table 2. Results of Data Processing for Testing Tensile Strength of Cold-formed steel Materials

Test Specimen Code	**Yield Stress (f_y)**	**Ultimate Stress (f_u)**	**Strain (*e*)**	**Modulus of Elasticity**
	(N/mm^2)	**(N/mm^2)**		**(N/mm^2)**
TSS-2	541,227	556,480	0,00275	196.809,818
TSS-3	571,200	575,893	0,00287	199.024,390
Average	**556,214**	**566,187**	**0,00281**	**197.917,104**

Load and Vertical Deflection Data

The load gain that can be received by cold-formed steel beams back-to-back is obtained from four-point bending loading using a load cell and a spreader beam as a centralized load divider. The load increment reading interval is 0.1 kN. The vertical deflection of cold-formed steel beams back-to-back is obtained by reading a dial gauge placed in the centre of the beam span.

Based on the results of testing the flexural strength of back-to-back cold-formed steel beams, the maximum load and vertical deflection of BB90-3 are 4.525 kN and 14.02 mm, BB120-3 is 3.678 kN and 12.61 mm, BB210-1 is 2.311 kN and 13.70 mm, and BB240-1 of 1.530 kN and 27.30 mm have values that are different from the maximum vertical load and deflection in the other test object codes in each variant code. The data from the outlier data selection on the load data and maximum vertical deflection of back-to-back cold-formed steel beams with variations in span length are shown in **Table 3.**

Table 3. Results of Maximum Load and Vertical Deflection Maximum Data After Outlier Data Selection

No.	**Variant Code**	**Specimens Code**	**Maximum Load**	**Maximum Load Average**	**Vertical Deflection Maximum**	**Vertical Deflection Maximum Average**
			(kN)	**(kN)**	**(mm)**	**(mm)**
1.	BB90	BB90-1	4,329	4,329	11,50	11,53
		BB90-2	4,329		11,55	

2.	BB120	BB120-1	3,808	3,857	13,88	13,52
		BB120-2	3,906		13,15	
3.	BB210	BB210-2	2,116	2,116	20,32	19,96
		BB210-3	2,116		19,60	
4.	BB240	BB240-2	1,628	1,628	22,04	23,44
		BB240-3	1,628		24,83	

Failure Mode Data

Back-to-back cold-formed steel beams with variations in span length tested for flexural strength are known to experience several failure patterns. The results of observations on the tested beam specimens are shown in Table 4. Illustrations of the failure pattern that occurs are shown in **Figures 4** to **7.**

Tabel 4. Result of Failure Mode Data

No	Variant Code	Specimens Code	Failure Mode
1	BB90 (Figure 4)	BB90-1	Local buckling of the flange, distortion buckling, and later torsional buckling
		BB90-2	Local buckling of the flange, distortion buckling, and lateral torsional buckling
2	BB120 (Figure 5)	BB120-1	Local buckling of the flange, distortion buckling, and lateral torsional buckling
		BB120-2	Local buckling of the flange, distortion buckling, and lateral torsional buckling
3	BB210 (Figure 6)	BB210-2	Local buckling of the flange, distortion buckling, and lateral torsional buckling
		BB210-3	Local buckling of the flange, distortion buckling, and lateral torsional buckling
4	BB240 (Figure 7)	BB240-2	Local buckling of the flange, distortion buckling, and lateral torsional buckling
		BB240-3	Local buckling of the flange, distortion buckling, and lateral torsional buckling

The pattern of failure that occurs in the entire specimen of cold-formed steel beam back-to-back with variations in span length is local buckling in the flange area, distortion buckling, and lateral torsional buckling. When the beam reaches the lateral torsional buckling failure pattern, the beam experiences a torsion which can be determined by the torsional angle and the resulting horizontal or lateral deflection. The results of processing the torsional angle data and horizontal deflection when the maximum load conditions have been selected for outlier data are shown in Table 5.

Table 5. Results of Torsional Angle and Horizontal Deflection in Maximum Load Condition

No.	Variant Code	Specimens Code	Torsional Angel	Torsional Angel Average	Horizontal Deflection	Horizontal Deflection Average
			(°)	(°)	(mm)	(mm)
1.	BB90	BB90-1	9,19	9,10	34,24	32,76
		BB90-2	9,01		31,27	
2.	BB120	BB120-1	11,74	12,31	44,22	46,08

		BB120-2	12,87		47,94	
3.	BB210	BB210-2 BB210-3	18,24 18,67	18,46	63,12 64,59	63,86
4.	BB240	BB240-2 BB240-3	22,50 22,85	22,68	77,21 78,60	77,90

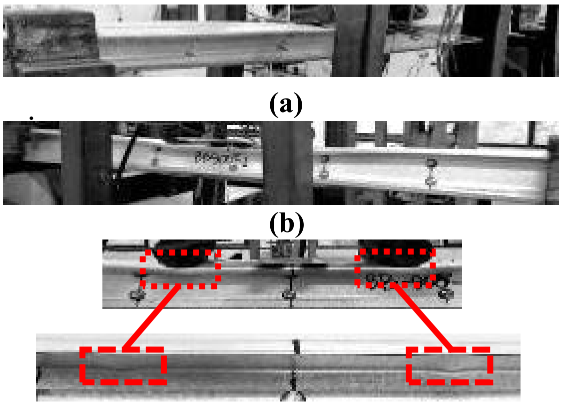

(a)
(b)
(c)

Figure 4. Failure Mode BB90: (a) Lateral - torsional buckling, (b) Distortional buckling, dan (c) Local buckling of the flange

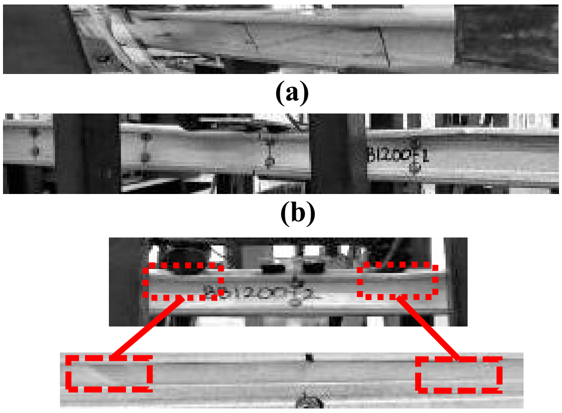

(a)
(b)
(c)

Figure 5. Failure Mode BB120: (a) Lateral - torsional buckling, (b) Distortional buckling, dan (c) Local buckling of the flange

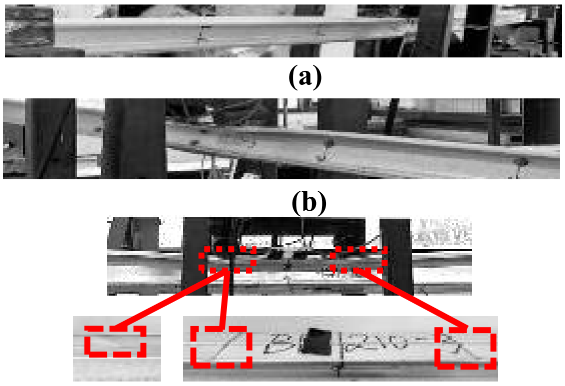

(a)
(b)
(c)

Figure 6. Failure Mode BB210: (a) Lateral - torsional buckling, (b) Distortional buckling, dan (c) Local buckling of the flange

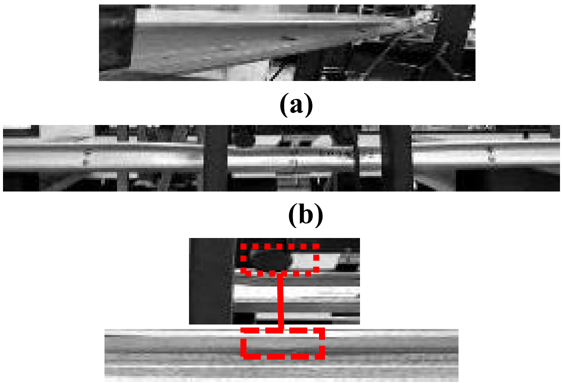

(a)
(b)
(c)

Figure 7. Failure Mode BB240: (a) Lateral -torsional buckling, (b) Distortional buckling, dan (c) Local

4. DISCUSSION

Load Analysis

The flexural strength test on cold-formed steel beams back-to-back produces a load for each variation of the span length that can be received by the beam as shown in **Table 3**. Based on the table, it can be concluded that the greater the dimensions of the variation in length applied to the beam, the smaller the load that can be received by the beam, as shown in **Figure 8.**

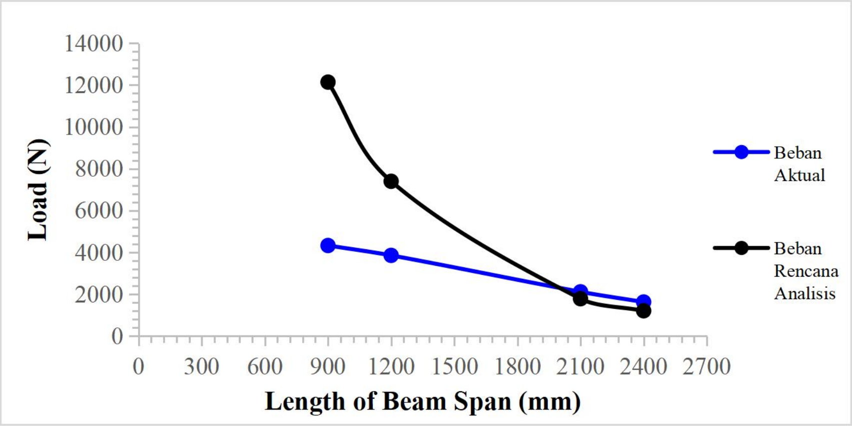


Figure 8. Actual Load and Design Load Results of Cold-formed steel Beams Back-to-Back Profile C

Based on **Figure 8**, the decrease in actual load performance on back-to-back profile C cold-formed steel beams when compared between the length variation codes BB90 (l = 90 cm) with BB120 (l = 120 cm), BB210 (l = 210 cm), and BB240 (l = 240 cm), respectively 10.90%, 51.12% and 62.39%. Several factors causing the length of beam span variation can affect the actual load that can be accepted due to several factors, among others.

Based on **Figure 8**, it is known that the actual load achievement of the BB90 and BB120 variation codes has decreased, while the actual load of the BB210 and BB240 variation codes has increased compared to the design load results. This can be caused by the large length of the span owned by the beam. The factor of the span length of the beam contained in the calculation of the nominal structural moment capacity (M_b) can affect the value of the non-dimensional slenderness ratio of structural members experiencing lateral buckling (λ_b) in the beam. This can cause the critical moment (M_c) which is used to calculate the moment capacity of the component that receives lateral buckling (M_b) using a different equation to obtain M_c which is adjusted to the acquisition of the value of λ_b so that it can affect the magnitude of the load achievement of the design analysis.

The dimensions of a structural member, especially the length that is varied in this study, affect the rigidity it has so that it determines the ability of the beam to accept the load. Based on Hooke's Law equation in **Equation 1**, the formula for stress and strain is translated so that **Equation 2**. is obtained. Therefore, changes in the dimensions of the length of the beam that are getting bigger cause a decrease in the rigidity of the beam so that the load performance decreases.

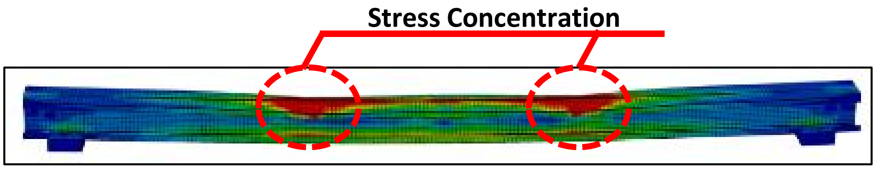
$$E = \frac{\sigma}{\varepsilon} \tag{1}$$

$$P = \frac{EI\,.\,\Delta l}{a\,.\,y\,.\,l} \tag{2}$$

where:

P : beam transverse load, kN
EI : rigidity, kNmm^2
Δl : deformation, mm
l : length of the beam span, mm
a : distance between loading point and support, mm
y : distance from neutral to edge, mm

The four-point bending applied to this flexural test also has an effect on the distribution of the load in each variation of the length applied to the beam. Variations in the length of the beam span that is getting bigger with the use of a fixed spreader beam size cause stress concentrations to occur in the area of loading points below the spreader beam. Based on Gere dan Timoshenko (1996), the stress concentration indicates that the concentrated load (which in this study is a concentrated load at two points or four-point bending) has not been evenly distributed across the beam cross-section. It can be understood that the length of the span has an influence on the distribution of the load to the support so that it results in a decrease in the load that can be resisted by the back-to-back cold-formed steel beam type C profile when experimental testing is carried out. According to research conducted by Roy et al (2021) through finite element analysis (FEA) on the flexural strength behavior of cold-formed steel beams arranged back to back, stress concentration also occurs just below the four-point bending loading point in the bending test of rolled steel beams. cold back-to-back profile C. The results of the analysis of previous studies with FEA can be seen in **Figure 9.**



(a)

Figure 9. Stress Concentration Occurs Below the Loading Point of Four-point Bending: Research Results of FEA Numerical Analysis by Roy et al (2021)

The characteristics of cold-formed steel have a slender section, and thin walls, and the back-to-back C profile has an open cross-section so that there is a risk of structural instability. Structural instability that occurs in back-to-back cold-formed steel beams can also be known based on the comparison of load gain with cold-formed steel beams with other structured cross sections, namely the closed section (face to face) performed by Alvyonika (2022) shown in **Figure 10**. The percentage of decrease for the shortest span length variation is BB90 with FF70 is 32,37%. The percentage reduction in load performance for variations in length BB120, BB210 and BB240 with FF130 were 15,40%, 53,60%, and 64,30%. This indicates that the instability of the cold-formed steel beam structure arranged back-to-back is more dominant than the face-to-face structure. Therefore, the open cross-sectional shape of the back-to-back beam can cause a decrease in the load performance that can be received by cold-rolled steel beams arranged back-to-back compared to those arranged face-to-face which have a closed cross-sectional shape.

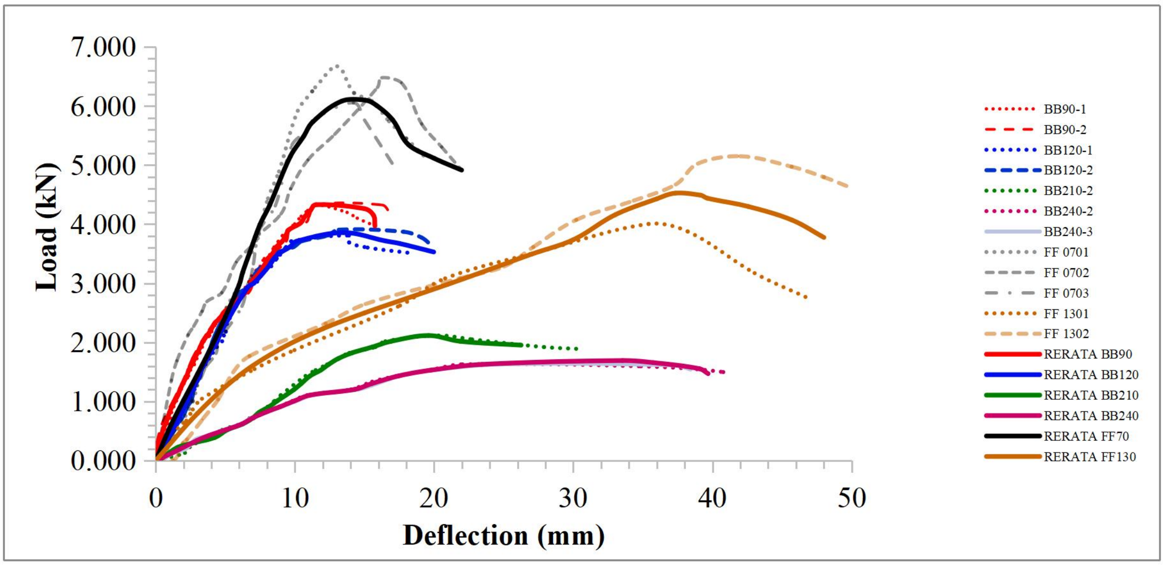


Figure 10. Comparison of Load-Deflection Curve of Cold-formed Steel Beams Back-to-Back (BB90, BB120, BB210, and BB240) and Face to Face (FF70 and FF130)

One of the forms of cross-sectional instability encountered is lateral torsional buckling where the beam deflects in the horizontal direction along with torsion to the longitudinal axis. The torsion in the beam is also caused by the eccentricity of the transverse loading applied to the beam due to the hydraulic jack not being able to keep up with changes in the movement of the beam which also deflects horizontally. The magnitude of the torsion angle and lateral or horizontal deflection that occurs is presented in **Table 5**. Based on the table, it is known that the torsion angle and horizontal deflection have increased along with the increase in beam span length variations and caused a decrease in the acceptable load gain. Thus, the occurrence of greater instability along with the increase in the length of the beam span plays a role in causing a decrease in the actual load performance.

Vertical Deflection Analysis

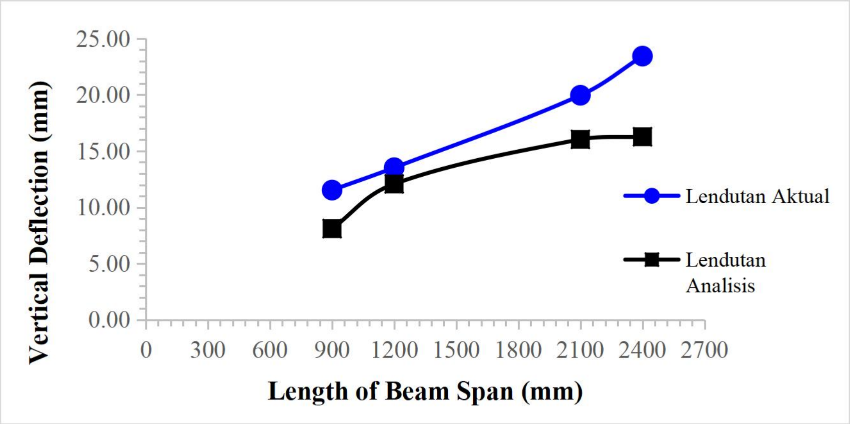


Figure 11. Actual Vertical Deflection and Deflection Design Analysis of Cold-formed Steel Beams Back-to-Back Profile C

The results of the cold-formed steel beam back-to-back flexural test results in the vertical direction are shown in **Table 3**. Based on the table, shows that the greater the dimensions of the variation in length applied to the beam, the greater the results obtained from the calculation of the vertical direction deflection. The large increase in deflection resulting from the length variation codes BB90, BB120, and BB210 to BB240 is shown in **Figure 11**. Based on **Figure 11**, the increase in the actual deflection achievement of the back-to-back profile C cold-formed steel beam when compared between the length variation code BB90 (l = 90 cm) with BB120 (l = 120 cm), BB210 (l = 210 cm), and BB240 (l = 240 cm) respectively at 17.26%, 73.11% and 103.3%. Factors that cause variations in the length of beam spans that can affect the actual vertical deflection that occurs will be discussed in this section.

Based on **Figure 11**, it is known that the actual deflection of the vertical direction of each variation code is greater than the calculated vertical direction of the analysis. This can be caused by the analysis of the vertical deflection equation used, namely **Equation 4** which does not take into account the instability conditions of cold-formed steel beams with slender and open cross sections. Instability in the form of horizontal deflection and torsion due to lateral torsional buckling occurs simultaneously with vertical deflection so the longer the beam span is varied, the greater the instability. Therefore, it can affect the actual vertical deflection achieved greater than the analysis of vertical deflection.

The deflection of the beam affects by load that the beam can accept. Based on Kamelia et al., (2021) the relationship between deflection and load referring to stiffness is shown in **Equation 3**. The beam deflection is also influenced by the length of the beam owned by the beam. Based on **Equation 4**, according to Gere and Timoshenko (1996), the magnitude of the resulting deflection is also influenced by the length of the span and the distance between the loading point and the support. Based on **Equation 3**, it is known that a large beam deflection can cause a decrease in stiffness. So, it can be concluded that the greater the span length of the beam and the distance between the loading point and the support can cause the resulting deflection to be greater and the beam stiffness decrease.

$$k = \frac{P}{\delta} \tag{3}$$

Where:
P : beam transverse load, kN
δ : deflection, mm
k : stiffness, kN/mm

$$\delta = \frac{Pa[3l^2 - 4a^2]}{24EI} \tag{4}$$

Where:
δ : deflection, mm
P : beam transverse load, kN
l : length of beam span, mm
a : distance between loading point and support, mm
EI : rigidity, kNmm2

Failure Mode Analysis

Local buckling in the flange occurs just below the load point of the spreader beam. The level of beam damage due to local buckling is clearly visible at both points of loading in the span variation codes BB90 and BB120. However, this does not occur in the span variation codes BB210, and BB240 where the damage due to local buckling is not clearly visible or only one part is still clearly marked, resulting in an indentation on the lower surface of the compression flange. Local buckling in the variation of the code span BB240 also found indentations in the lip cross-section. This can be caused by the occurrence of lateral torsional buckling damage that is more dominant in the BB210 and BB240 variation codes where the torsion angle increases with increasing length. Also, the rest of the footing from the point of the spreader beam where the local buckling of the flange occurs does not show a large increase.

The longer the span applied to the beam, the more visible distortion buckling occurs. The compression wing part of the BB90 span length variation code to the BB120 code begins to bend more and more inward. The degree of bending of the compression flange is greater in the BB210 and BB240 codes, followed by the tensile flange, which also experiences an increase in bending.

The greater the variation in length applied to the beam span, the greater the level of damage due to lateral torsional buckling. This increased level of damage can be seen especially clearly in the changes in the horizontal or lateral deflection and the greater the torsion angle.

Different failure patterns between back-to-back cold-formed C profiles were found in this study. The failure pattern of one section of profile C experienced an interaction of local buckling failure pattern, distortion buckling, and lateral torsional buckling, while the other C profile section only experienced a lateral torsional buckling failure pattern. The interaction between the failure patterns in this study in each code of variation in the length of the beam span This interaction occurs when local buckling in the beam occurs, then, when the load approaches its maximum state, distortion buckling occurs on the flange, which is rotated inward and accompanied by lateral torsional buckling, which is increasing and causing the beam to experience greater torque. so that the resulting buckling distortion is also more visible with increasing inward bending of the profile flange. The interaction that occurs in the C profile cold-formed steel beam also occurs in the research of Chen et al. (2021) , namely the interaction between local buckling failure patterns and distortion, and Niu et al. (2014), namely the interaction between distortion buckling and lateral torsional buckling failure patterns.

Based on several failure patterns that occur, it can be concluded that the greater the variation in length applied to cold-formed steel beams back-to-back, the more changes in the form of distortion buckling damage and lateral torsional buckling will increase.

5. CONCLUSION

The results of the research on "Bending Strength of Double Cold-formed Steel Beams Profile C Arranged Back-to-Back with Length Variations" are in the form of loads, deflections, and failure mode, and the conclusion is that the load achievement that can be accepted by cold-formed steel beams back to back with the addition of the length of the beam span on each variation code decreases. The decrease in actual load performance is caused by a decrease in the flexural rigidity of the beam, the concentration of stress at the loading point, and the increasing instability of the back-to-back cross section marked by an increase in the torsion angle and horizontal deflection. Investigations into the load-carrying capacity of the beam did not take into account the effects of screw connections.

The achievement of vertical deflection that occurs due to transverse loads acting on back-to-back cold-formed steel beams along with the addition of span length for each variation code has increased. The increase in actual vertical deflection was caused by a decrease in beam stiffness resulting from the length of the span being varied in the larger beam. The deflection that occurs in each length variation code exceeds the maximum deflection limit, so it is necessary to pay attention to the application of the design load on the cold-rolled steel beams arranged back-to-back.

The type of failure pattern that occurs in back-to-back cold-formed steel beams in every variation of span length during flexural testing has the same failure, namely local buckling on the flange, distortion buckling, and lateral torsional buckling. The greater the length of the span that is varied on the beam, the more visible changes in damage that occur, especially distortion buckling and lateral torsional buckling. The pattern of lateral torsional buckling damage has increased, which is supported by an increase in the torsion angle and the resulting horizontal or lateral deflection.

6. REFERENCES

Alhaddad, W., Halabi, Y., Jian, Z., & Honggang, L. (2020). Manufacturing, Applications, Analysis and Design of Cold-Formed Steel in Engineering Structures: A Review. *International Journal of Advanced Engineering Research and Science*, *7*(2). https://doi.org/10.22161/ijaers.72.3

Alvyonika, C. (2022). *Studi Eksperimental Batang Lentur Baja Canai Dingin Ganda Berhadapan (face to face) dengan Variasi Panjang*. Universitas Negeri Malang.

Ashokbhai, S. F., Thakkar, K. R., & Nimodiya, P. N. (2017). Comparative Study of Hot Rolled Steel Sections and Cold-formed steel Sections for Industrial Shed. *International Journal of Engineering Research And*, *6*(04), 191–193. https://doi.org/10.17577/ijertv6is040279

Chen, M. T., Young, B., Martins, A. D., Camotim, D., & Dinis, P. B. (2021). Experimental investigation on cold-formed steel lipped channel beams affected by local-distortional interaction under non-uniform bending. *Thin-Walled Structures*, *161*(October), 1–20. https://doi.org/10.1016/j.tws.2021.107494

Dar, M. A., Subramanian, N., Dar, A. R., Anbarasu, M., Lim, J. B. P., & Atif, M. (2019). Behaviour of Partly Stiffened Cold-Formed Steel Built-Up Beams: Experimental Investigation and Numerical Validation. *Advances in Structural Engineering*, *22*(1), 172–186. https://doi.org/10.1177/1369433218782767

Fitrah, R. A., & Melinda, A. P. (2020). Behaviour of Cold-formed Steel Back-to-Back Channel Built-Up Sections under Bending. *I O P Conference Series: Materials Science and Engineering*. https://doi.org/10.1088/1757-899X/1041/1/012006

Fratamico, D. C., Torabian, S., Zhao, X., Rasmussen, K. J. R., & Schafer, B. W. (2018). Experiments on The Global Buckling and Collapse of Built-Up Cold-Formed Steel Columns. *Journal of Constructional Steel Research*, *144*, 65–80. https://doi.org/10.1016/j.jcsr.2018.01.007

Gere, J. M., & Timoshenko, S. P. (1996). *Mekanika Bahan* (H. W. Hardani (ed.); Keempat). Penerbit Erlangga.

Kamelia, N., Romey Sitompul, I., & Suryanita, R. (2021). Analisis Numerik Lendutan Balok Baja dengan Penambahan Pengaku (Stiffener). *Siklus*, *7*(1), 43–52. https://journal.unilak.ac.id/index.php/SIKLUS

Kang, K., Chaisomphob, T., Patwichaichote, W., & Yamaguchi, E. (2017). Experimental and Numerical Investigation on Cold-formed Steel C Back-to-Back Beams. *IPTEK Journal of Proceedings Series*, *3*(6). https://doi.org/10.12962/j23546026.y2017i6.3281

Laím, L., Paulo, J. C. R., & Craveiro, H. D. (2015). Flexural behaviour of beams made of cold-formed steel sigma-shaped sections at ambient and fire conditions. *Thin Walled Structures*, *87*, 53–65. https://doi.org/10.1016/j.tws.2014.11.004

Mahar, A. M., & Sanjeevi, A. J. (2021). A Computational Study on Buckling Behavior of Cold-Formed Steel Built-Up Columns Using Compound Spline Finite Strip Method. *International Journal of Structural Stability and Dynamics*, *21*(05).

Niu, S., Rasmussen, K. J. R., & Fan, F. (2014). Distortional-global interaction buckling of stainless steel C-beams: Part i - Experimental investigation. *Journal of Constructional Steel Research*, *96*, 127–139. https://doi.org/10.1016/j.jcsr.2014.01.007

Roy, K., Ho, H., Chui, T., Ting, H., Chen, B., & Lim, J. B. P. (2021). Flexural Behaviour of Back-To-Back Built-Up Cold-Formed Steel Channel Beams : Experiments and Finite Element Modelling. *Structures*, *29*(October 2020), 235–253. https://doi.org/10.1016/j.istruc.2020.10.052

Ting, T., & Huon, C. (2013). *The Behaviour of Axially Loaded Cold-formed Steel Back-to-back C-channel Built-up Columns* (Issue September).

Ye, J., Hajirasouliha, I., & Becque, J. (2018). Experimental investigation of local-flexural interactive buckling of cold- formed steel channel columns. *Thin Walled Structures*, *125*(February), 245–258. https://doi.org/10.1016/j.tws.2018.01.020