

BENDING TEST ON COLD-FORMED STEEL BOX BEAMS WITH LARGE CROSS-SECTION

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Abstract

This research studies a bending test of cold-formed steel box beams with large cross-sections. Torsional rigidity of an open single C-section is weak since a cold-formed steel cross-section usually consists of thin elements. With this lack of thickness, buckling in the compression elements is introduced including local, distortional, and lateral-torsional buckling. To improve torsional rigidity and extend further investigation, flexural tests on a built-up box beam assembled with 2 C-sections were conducted in this study. C30024 was selected as the large cross-section, and stiffening plates and self-drilling screws were used as fasteners on both the top and bottom flanges of each C-section. A 4-point bending test and simply supported condition were employed as specimens to achieve a series of bending tests under pure moment. In addition, the influence of the connection spacing on the flexural behavior was investigated at $L/2$, $L/3$, $L/4$, and $L/6$. The maximum loads and failure modes are examined and presented, and it was observed that there was no failure of the stiffening plates and self-drilling screws.

Keywords: Bending test, cold-formed steel, box beam, buckling mode

Introduction

The use of cold-formed steel in the construction industry has become more and more popular. It is used for columns, beams, joists, studs, floor decking, built-up sections, and other components. Since cold-formed steel sections normally have a large width-to-thickness ratio, buckling, such as local, distortional, and

lateral-torsional buckling, usually occurs when the element or elements of the members are subjected to compression. The use of 2 or more profiles of cold-formed steel increases its torsional rigidity and is expected to improve its flexural behavior. Research in this field has gained interest and has been carried out since

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there is a lack of design specification. For instance, in the North American specification for the design of a cold-formed steel structural member (American Iron and Steel Institute *et al.*, 2016), the specification that is provided for a built-up box beam is unclear. Only flexural members of a built-up back-to-back composed of 2 C-sections and connection spacing of $L/6$ were provided. Thanh *et al.* (2015) studied a cold-formed steel built-up C-section beam with an overall height of 150 mm. They introduced connection spacing for a series of flexural tests. The results showed that using connection spacing of $L/6$ increases the ultimate load in the range of 10% to 18% as compared to that of $L/2$. It was observed that specimens C15019 with connection spacings of $L/4$ and $L/6$ were likely to appear with an equal ultimate load. Chea and Chaisomphob (2016) studied a cold-formed steel built-up box beam by C-section with an overall height of 100 mm, but studies on other larger sections have not yet been conducted. The results showed that the failure load increased, and the vertical deflection decreased when the thickness increased and the connection spacing decreased. Kang and Chaisomphob (2016) studied built-up back-to-back I-beams consisting of 2 C-sections. Wang and Young's (2016) research was on an experimental study of a built-up box beam with intermediate stiffeners. Laím *et al.* (2013) studied the structural behavior of cold-formed steel beams with C-, I-, R-, and 2R-shapes comprising C (lipped channel) and U (channel) profiles. Twelve quasi-static bending tests were conducted. The results showed that cold-formed steel beams are very sensitive to local-distortional interaction. The use of 2 or more cold-formed steel sections and the decrease of

connection spacing might improve the flexural behavior of the beams.

This research focused on a cold-formed steel built-up box beam with a large cross-section consisting of 2 C-sections. The aim of this study was to investigate the behavior of flexural tests on a built-up box beam including the failure loads, failure modes, deflections (vertical and horizontal), strains, and the influences of connection spacing. Stiffening plates and self-drilling screws were used as fasteners to form a specimen. Four different types of connection spacing were applied to the specimen and were marked as $L/2$, $L/3$, $L/4$, and $L/6$. Four beams were placed under the simply supported condition and subjected to a 4-point bending test.

Experimental Study

Test Specimens

C-sections with a lipped channel named as C30024 with an actual length of 4,000 mm were used in these experiments. The yield stress $F_y = 476$ MPa and the tensile strength $F_u = 497$ MPa were obtained from tensile coupon tests. The inside bend radius r is 5 mm and the other dimensions are given in Table 1. Two C-sections were positioned face-to-face and stiffening plates with self-drilling screws were used to fasten the box beam as shown in Figure 1. The position of the stiffening plates depended on 4 types of connection spacing and were marked as $L/2$, $L/3$, $L/4$, and $L/6$. The stiffening plate was 120 mm square and 2.4 mm thick. Four self-drilling screws with a physical radius of 1.95 mm were employed in the connection.

Table 1. Geometric properties and connection spacing

Specimen	t	h	w	l	Connection Spacing
	mm	mm	mm	mm	mm
C30024-L/2	2.4	300	96	27.5	1,710
C30024-L/3	2.4	300	96	27.5	1,140
C30024-L/4	2.4	300	96	27.5	855
C30024-L/6	2.4	300	96	27.5	570

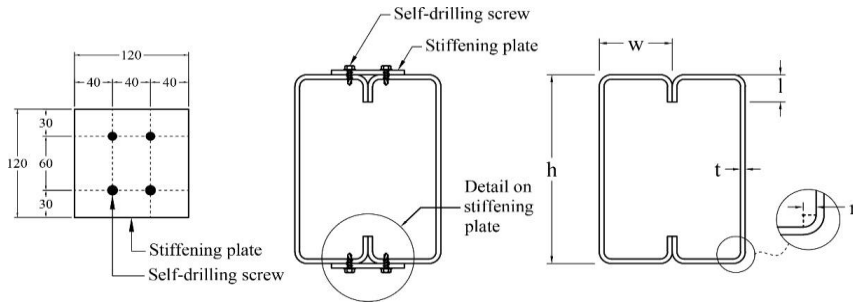


Figure 1. Box beam cross-section, geometric properties, and detail on stiffening plate

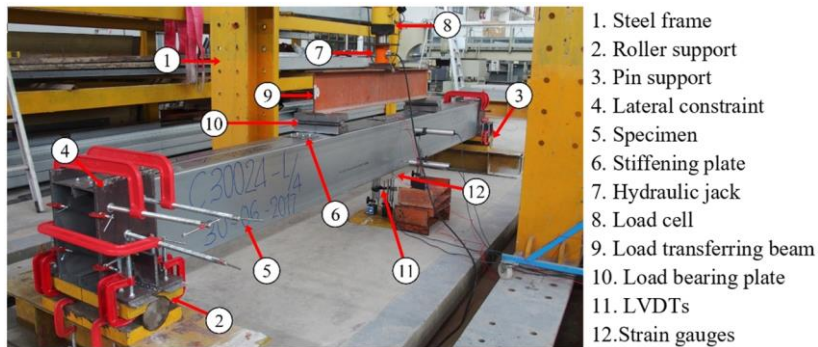


Figure 2. Overview on test set-up

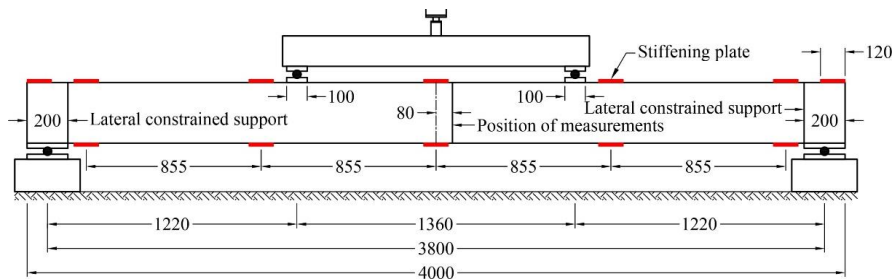


Figure 3. Example of 4,000 mm tested specimen with connection spacing $L/4$

Test Set-up and Test Procedure

An overview of the test set-up is shown in Figures 2 and 3. The width dimension of both end supports was 200 mm. Lateral constrained supports were provided to ensure that failure does not occur at either end supports. A hydraulic jack with maximum capacity of 700 bars and a load cell with a capacity of 300 kN was used. In this test, vertical and

horizontal displacements were accounted for, and special devices known as linear variable displacement transducers (LVDTs) were used. Three strain gauges were attached with the same longitudinal position of vertical LVDTs. Load was applied statically by using the hydraulic jack and increased gradually until the beam reached its failure load, and its failure modes were observed.

Results and Discussions

The position of the measurements are illustrated in Figure 4. A summary of the results of the experimental study are presented in Table 2.

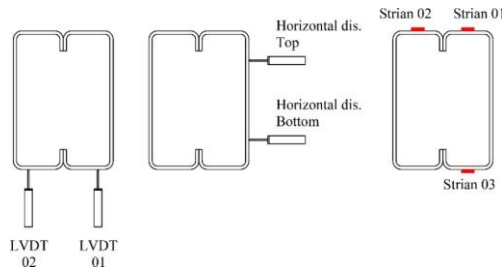


Figure 4. Position of measurements

Load and Vertical Displacement

Figure 5 shows the load and vertical displacement curves. The load in kN is plotted in the vertical axis of the graph and the vertical displacement in mm is plotted in the horizontal axis. Two vertical deflections were obtained from each C-section named as LVDT 01 and LVDT 02. As mentioned above, the position of these 2 vertical deflections were at 80 mm from the center of the beam specimens, since there was a stiffening plate at the midspan for L/2, L/4, and L/6.

Influences of Connection Spacing

The built-up box beam C30024 had failure loads of 86.27 kN, 87.47 kN, 84.55 kN, and 86.19 kN for the connection spacings L/2, L/3, L/4, and L/6, respectively. The decrease of the

connection spacing from L/2 to L/3 made an increase of the maximum load of 1.39%. In contrast, the failure loads decreased when the connection spacing decreased from L/2 to L/4 and L/6. It was observed that there was little difference in the failure load when the connection spacing changed. It might be that the connection spacing did not control the ultimate load of the built-up box beams. On the other hand, the connection spacing controlled the failure mode of the specimens as shown in the failure mode section.

Load and Horizontal Displacement

One horizontal displacement was set 50 mm from the very top surface of the flange and named as Top, while another one was set 50

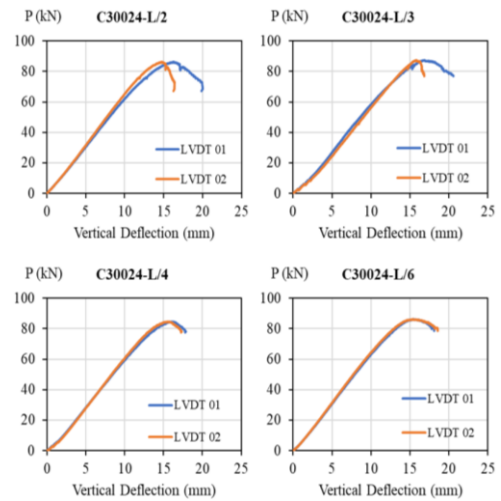


Figure 5. Load and vertical displacement curves

Table 2. Experimental results

Specimen C30024	Failure Mode	Failure Load	Vertical Displacement		Horizontal Displacement		Compression Strain		Tension Strain
		kN	LVDT01	LVDT02	Top	Bottom	01	02	03
			mm	mm	mm	mm	10 ⁻⁶	10 ⁻⁶	10 ⁻⁶
L/2	LB	86.27	16.31	14.17	4.45	0.45	-823	-923	1254
L/3	LB+DB	87.47	16.85	15.85	4.29	0.83	-945	-1037	1187
L/4	LB	84.55	16.04	15.51	2.63	0.22	-941	-855	1161
L/6	LB	86.19	15.48	15.39	0.31	0.16	-1041	-1054	1080

mm from the bottom surface of the flange and named as Bottom. Both horizontal displacements reached values in the range of 0.31 mm to 4.45 mm. It was observed that the top horizontal displacements decreased when the connection spacing decreased. The bottom horizontal displacement also decreased as the connection spacing decreased, except spacing $L/3$. Another important result can be drawn from the top horizontal displacements being always bigger than the bottom horizontal displacements, as shown in Figure 6.

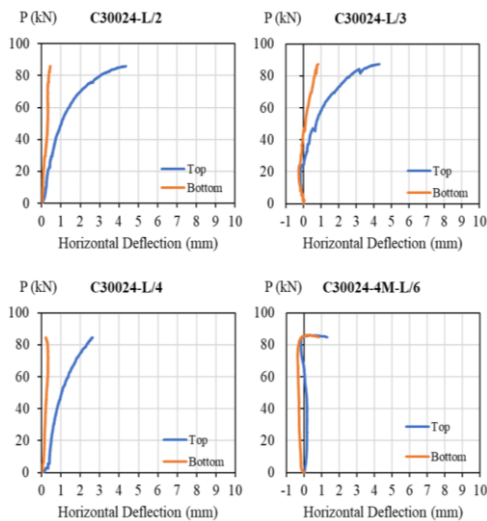


Figure 6. Load and horizontal displacement curves

Load and Strain

Three strain values were obtained, 2 compression strains and 1 tension strain. The compression and tension strains were expected to be the same since the beam specimen was subjected to pure moment, which distributed an equal opposite stress on the top and the bottom flanges in the elastic range. As can be seen in Figure 7, it was observed that the compressive strains and tension strain likely appeared to be symmetric in the elastic range and even at the failure part. This means that the neutral axis did not change its position too much from the center of the beams. Another

investigation showed that all the compressive strains were slightly smaller than the tension strains.

Failure Mode

Failure modes were observed during the test procedure when the beam reached its maximum load. Two types of failure mode were identified, local buckling (LB) and the combination between local buckling and distortional buckling (LB+DB), as shown in Figure 8. It was observed that, for C30024, the failure mode of the specimens with connection spacings $L/2$, $L/4$, and $L/6$ was local buckling at the loading point. Local buckling at the loading point and distortional buckling at the mid-span were found in specimens with connection spacing $L/3$. There was no stiffening plate at the mid-span which allowed the deformation of the cold-formed steel at that point. Consequently, the distortional buckling occurred at the mid-span of the beam.

Conclusions

The experimental study on 4 built-up box beams with a large cross-section, lipped channel C30024, was conducted with variation of

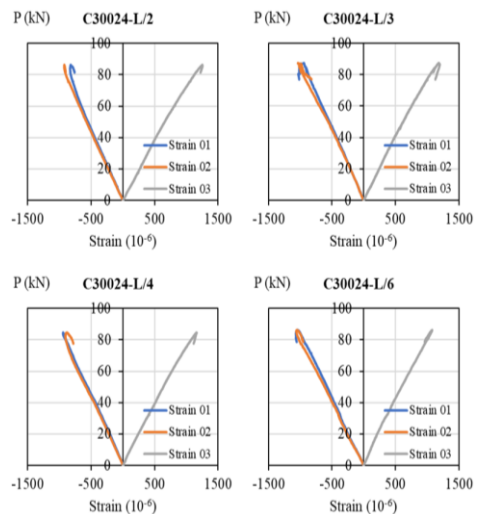


Figure 7. Load and strain curves

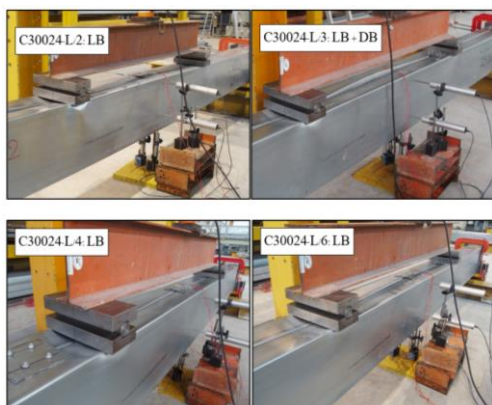


Figure 8. Buckling modes

connection spacings $L/2$, $L/3$, $L/4$, and $L/6$. To form a built-up box beam, stiffening plates and self-drilling screws were used. It should be mentioned that there was no failure of the stiffening plates and self-drilling screws in these 4 specimens. It was likely to appear that there was little influence of the connection spacing to the flexural strength of the built-up box beams of large sections. The highest different percentage in terms of the maximum load was 3.45%. On the other hand, the connection spacing controlled the failure mode of the specimens. The horizontal displacements, compressive strain, and tensile strain were presented. Finally, numerical studies should be conducted to investigate and be compared with the experimental results. Another parametric study, such as for the variation of the span length, influences of thickness, and influence of height, should also be conducted to extend further research.

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