LOAD CARRYING CAPACITY OF HIGH STRENGTH COLD-FORMED STEEL BUILT-UP BOX SECTIONS

H.H. LAU[1], T.C.H. TING[2]

[1] *Department of Civil & Construction Engineering, Curtin University Technology Sarawak Campus, Miri, Sarawak, Malaysia <lau.hieng.ho@curtin.edu.my>*
[2] *Department of Civil & Construction Engineering, Curtin University Technology Sarawak Campus, Miri, Sarawak, Malaysia <tina.ting@stud.curtin.edu.my>*

ABSTRACT
This paper presents an experimental study of the cold-formed steel built-up box sections in compression. The built-up box sections are formed by two identical simple C-lipped channels connected at their flanges with self-drilling screws. The specimens were compressed between fixed end conditions for stub columns and also for intermediate columns. The column test strengths were compared with the theoretical design strengths, which were calculated using the Effective Width Method (EWM) and also the Direct Strength Method (DSM). Three analytical models were proposed for the compressive strength prediction of the built-up box section. Results from the study show that Effective Width Method predicts the compressive strength of built-up box sections better than Direct Strength Method. Proposed analytical model 1 results for stub columns and model 2 results for intermediate columns correlates well with the experimental results.

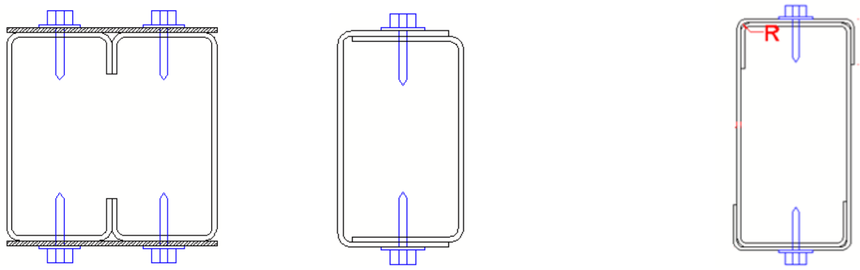
1. INTRODUCTION

Common built-up box sections are made of two identical C-Channels connected together face to face by means of mechanical fasteners such as screws or bolts. These sections are generally used in cold-formed steel construction to resist loads induced in a structural member when a single section is insufficient to carry the applied load. These applications of built-up box sections have been used extensively in low- and mid-rise residential and commercial buildings. Due to its popularity in construction projects, the industry has come up with a few ways to form these built-up box sections. They are two C-Channels connected face to face (i) at flange with C-channels of the same size using batten plates, or (ii) at flange with one C-Channel larger than the other as shown in Figure 1(i). The box section in Figure 1**Error! Reference source not found.**(i) can be less stable in terms of shearing between individual sections because the two C-Channels are connected using batten plates. The second option in 1(i) would generally be more structurally stable but connecting two C-Channels of different sizes would require different sizes of the sections which are inconvenient in production. Thus, the local industry has created a new configuration for the built-up box section by connecting two C-Channels of the same size face to face and pushing them into position as shown in Figure 1(ii). The current North American Specification (NAS) [1] for the Design of Cold-Formed Steel Structural Members does not provide any

Steel & Composite Structures—Proceedings of the 4th International Conference
Edited by Brian Uy, Zhong Tao, Fidelis Mashiri, Xinqun Zhu, Olivia Mirza & Ee Loon Tan

doi:10.3850/978-981-08-6218-3_SS-Th016

specific guidelines for this built-up box section configuration. The stress distribution in the elements of the box section might be affected during the production process, especially when the sections are pushed into position. This can potentially lead to a change in behaviour and also carrying capacity of the built-up box section compared to the sum of the capacities of the individual members that make up the assembly. To address these problems, the behaviour of this type of built-up box sections under compression needs to be understood.



(i) Currently Available (ii) New Configuration

Figure 1: Built-up Box Sections

2. LITERATURE REVIEW

A lot of research has been performed on cold-formed steel open section columns and individual C-channel, but not much research is done on cold-formed steel built-up closed section columns [2]. Young and Chen [3] performed a series of studies, both analytical and experimental, on built-up closed section columns with intermediate stiffeners. They proposed three different analytical sections i.e. single section; single section restrained at the flanges and double section with the flange thickness two times the web thickness to calculate the buckling stress and compared them to the experimental results. They concluded that the direct strength method, using a single section to calculate the buckling stress, is conservative. They also stated that an accurate model to calculate the compressive strength of the built-up box section is currently unavailable. Furthermore, there is limited research on the built-up sections, thus little test data reported especially for cold formed steel built up box section columns. This paper aims to present an experimental study on the local innovative cold formed steel built-up box section in compression and to compare the experimental results with the design strengths obtained using the Effective Width Method and Direct Strength Method in the North America Specification (NAS) [1], [4] and also Australian/New Zealand standard (AS/NZS) [5].

3. ANALYTICAL MODELS

In this study, the theoretical axial compressive strengths of the cold-formed steel sections are determined using the Effective Width Method (EWM) and Direct Strength Method (DSM). Direct Strength Method (DSM I) carried out in this paper used manual elastic buckling calculation instead of other numerical methods. Three analytical models are proposed with different thicknesses at certain areas to simulate the different degree of restraint among the box sections. There is some degree of restraint in the flanges and possibly in the lips of the built-up sections by connecting the two identical C-Channels together in this study. The three analytical models are built-up box section with lips (Model 1), built-up box section without lips (Model 2) and box section with double the thickness (Model 3). The nomenclature is

"Doubled Flange Lip" (DFL) for model 1, "Doubled Flange" (DF) for model 2 and "Doubled" (D) for model 3. The three analytical models are as shown in Figure 2.

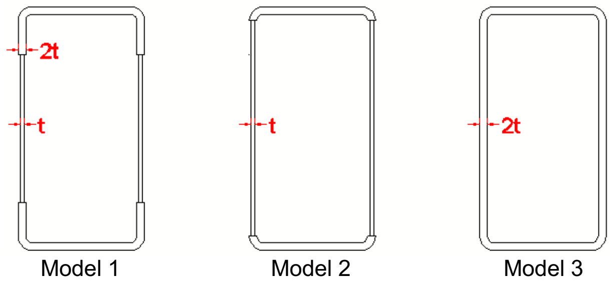


Figure 2: Proposed Analytical Models

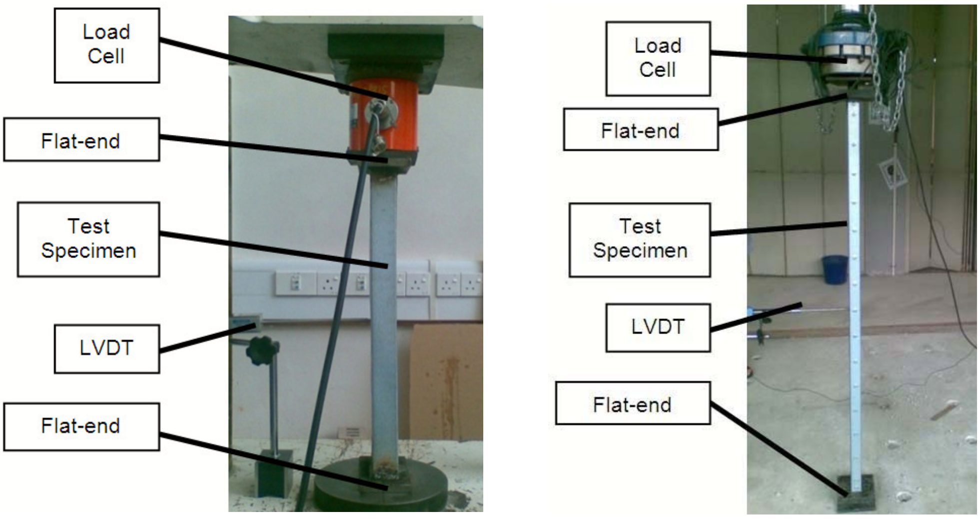
4. TEST SPECIMENS

Test specimens were made from two simple C-lipped channels connected at their flanges, using self-drilling screws spaced at 100mm, to form the built-up box sections. Each section was cut to lengths of 450mm and 1500mm. For 450mm length specimens, the ends of the specimens were welded to steel plates of 12.5mm thick to provide full contact to the end bearing of the testing machine. For stub column series, the specimens are of 450mm length for both simple C-lipped channel and built-up box sections. The stub column length of 450mm is sufficiently short to eliminate overall column buckling effects and also sufficiently long to minimize the end effects during the loading [6]. For intermediate column series, the specimen length is 1500mm.

Each specimen is measured individually and nominal sizes for the c-lipped channels and built-up box section are 75mm for web, 38mm for flange and 14mm for lip. The thickness of the specimen is 1mm. A total number of 16 specimens were tested in this study. The specimens are categorised into four series, according to their length and the type of sections. The four series were labelled as C75L450, C75L1500, for simple C-lipped channel and B75L450, B75L1500 for built-up box section. The "75" refers to nominal width of the web. In this paper, the material's properties used for EWM and DSM calculation are based on the average yield stress, f_y of 550MPa and the Young's Modulus, E of 205GPa.

5. TEST SETUP

The test setup for stub and intermediate columns are as shown in Figure 3. The stub column compression test was carried out using the GOTECH, GT-7001-LC60 Universal Testing Machine (UTM) with a capacity of 600kN. Two 12.5mm end thick plates were welded to the ends of the specimen. The rigid flat end of the specimen was considered fixed. One Linear Variable Differential Transducer (LVDT) was positioned at the mid-span of the specimen. A data logger was used to record the applied load and displacement at the mid span of the specimen. An average loading rate of <3.5kN/min was applied for both simple C-lipped channel and built-up box section specimens. The intermediate column compression test was carried out using a 500kN capacity hydraulic jack. A small pre-load is applied to the specimen to ensure the endplates are in full contact with the specimen end plates. Two LVDT's were positioned at mid span and at the top of the specimen for mid span deflection and axial shortening. A constant loading flow rate was applied to both simple C-lipped channels and built-up box sections specimens.



(i) Stub Column (ii) Intermediate Column

Figure 3: Test Setup for Stub and Intermediate Column Compression Test

6. RESULTS AND DISCUSSIONS

The theoretical strength calculated using EWM (P_{EWM}), and DSM I (P_{DSMI}) are compared to the experimental compressive strength (P_{TEST}). Analysis of each design approach was carried out using the three proposed analysed models of DFL, DF, and D. For intermediate columns, the experimental local buckling load was determined by using the method by K.R. Venkataramaiah and J. Roorda [6]. Applied load (P) was plotted against square of the mid-span web deformation. Then, a tangent straight line is drawn to the imperfect curve. The tangent curve will intersect with the applied load axis and the value of the intersection is approximated to be the experiment local buckling load of the specimen.

6.1. C75L450 series

The experimental results and theoretical results are summarised in Table 1. The experimental results range from 54 to 58kN. From Table 1, the experimental results correlate well with the strength prediction by EWM with mean P_{TEST}/P_{EWM} ratio of 0.96. The strength prediction by DSM I is relatively conservative.

Specimens	P_{TEST}	P_{EWM}	P_{DSMI}	P_{TEST} / P_{EWM}	P_{TEST} / P_{DSMI}
C75L450-1	57.54	60.41	48.03	0.95	1.20
C75L450-2	55.50	58.32	48.56	0.95	1.14
C75L450-3	54.20	58.11	47.43	0.93	1.14
C75L450-4	57.74	58.11	47.43	0.99	1.22
Mean				0.96	1.18

Table 1: Result of C75L450 Series

6.2. B75L450 series

The experimental results and theoretical results are summarised in Table 2 to Table 3. These tables show a comparison of the experimental results with theoretical analysis of the two proposed analytical models using EWM and DSM I respectively. The experimental results range from 124 to about 131kN. From Table 2 shows that results of EWM based using models 2 predicts the experimental results well. Whereas, from Table 3, the experimental results correlate well with DSM I prediction based on model 1. The DSM I prediction based on model 1 is not conservative. As for model 3, all strength predictions are not conservative for both EWM and DSM I design approaches.

Specimens	P_{TEST}	$P_{EWM-DFL}$ (Model 1)	P_{EWM-DF} (Model 2)	P_{EWM-D} (Model 3)	P_{TEST} / $P_{EWM-DFL}$	P_{TEST} / P_{EWM-DF}	P_{TEST} / P_{EWM-D}
B75L450-1	124.80	166.27	122.55	209.76	0.75	*1.02*	0.59
B75L450-2	127.52				0.77	*1.04*	0.61
B75L450-3	130.50				0.78	*1.06*	0.62
B75L450-4	129.70				0.78	*1.06*	0.62
Mean					0.77	*1.05*	0.61

Table 2: Result of B75L450 Series (EWM)

Specimens	P_{TEST}	$P_{DSMI-DFL}$ (Model 1)	$P_{DSMI-DF}$ (Model 2)	P_{DSMI-D} (Model 3)	P_{TEST} / $P_{DSMI-DFL}$	P_{TEST} / $P_{DSMI-DF}$	P_{TEST} / P_{DSMI-D}
B75L450-1	124.80	133.34	85.00	201.25	*0.94*	1.47	0.62
B75L450-2	127.52				*0.96*	1.50	0.63
B75L450-3	130.50				*0.98*	1.54	0.65
B75L450-4	129.70				*0.97*	1.53	0.64
Mean					*0.96*	1.51	0.64

Table 3: Result of B75L450 Series (DSM I)

6.3. C75L1500 series

The experimental results and theoretical results for single C channel series are summarized in Table 4. From Table 4, the experimental results correlate well to the strength prediction by EWM with mean P_{TEST}/P_{EWM} ratio of 0.92. Again, the strength prediction by DSM I is relatively conservative.

Specimens	P_{TEST}	P_{EWM}	P_{DSMI}	P_{TEST} / P_{EWM}	P_{TEST} / P_{DSMI}
C75L1500-1	39.00	45.29	36.66	0.86	*1.06*
C75L1500-2	40.50	46.07	37.07	0.88	*1.09*
C75L1500-3	42.00	44.84	35.75	0.94	*1.17*
C75L1500-4	45.50	44.84	35.75	1.01	*1.27*
Mean				0.92	*1.15*

Table 4: Result of C75L1500 Series (FIX-FIX)

6.4. B75L1500 series

The experimental results and theoretical results are summarised in Table 5 to Table 6. Table 5 shows that the experimental results correlate well with model 2 for EWM design approach. However, all 3 model results are non conservative. Whereas Table 6 shows that the experimental results correlate well with Model 2 also for DSM I prediction. Model 2 results are conservative compare to other model predictions.

Specimens	P_{TEST}	$P_{EWM-DFL}$ (Model 1)	P_{EWM-DF} (Model 2)	P_{EWM-D} (Model 3)	P_{TEST} / $P_{EWM-DFL}$	P_{TEST} / P_{EWM-DF}	P_{TEST} / P_{EWM-D}
B75L1500-1	84	134.40	98.88	176.91	0.63	0.85	0.47
B75L1500-2	81				0.60	0.82	0.46
B75L1500-3	92				0.68	0.93	0.52
B75L1500-4	91				0.68	0.92	0.51
Mean					0.65	0.88	0.49

Table 5: Result of B75L1500 Series (EWM) (FIX-FIX)

Specimens	P_{TEST}	$P_{DSMI-DFL}$ (Model 1)	$P_{DSMI-DF}$ (Model 2)	P_{DSMI-D} (Model 3)	P_{TEST} / $P_{DSMI-DFL}$	P_{TEST} / $P_{DSMI-DF}$	P_{TEST} / P_{DSMI-D}
B75L1500-1	84	114.48	72.62	174.42	0.73	1.16	0.48
B75L1500-2	81				0.71	1.12	0.46
B75L1500-3	92				0.80	1.27	0.53
B75L1500-4	91				0.79	1.25	0.52
Mean					0.76	1.20	0.50

Table 6: Result of B75L1500 Series (DSM I) (FIX-FIX)

Overall, model 2 predicts the compressive strength better than the other two models. Among the three proposed models, model 1 predicts the stub columns well whereas model 2 predicts the intermediate columns better. For stub columns, local buckling at web governs the failure. Thus, model 1 which doubled the flange and lip better represents the actual box section with over-lapping flange and lip and non-lapping web. For intermediate columns, model 2 better predicts because global buckling governs the failure mode of slender columns. By slotting the two C-Channels together, the doubled flange thickness in model 2 represents better degree of restraint. Model 3 predictions are generally too conservative.

7. CONCLUSIONS

The study found that Effective Width Method predicts the compressive strength of built-up box sections better compared to Direct Strength Method. In addition, the strength predictions based on Model 1 for stub columns and the strength predictions of built-up box section using Model 2 for intermediate columns correlate well to the experimental results. The carrying capacity of the built-up box section is more than the sum of the capacities of the individual members that make up the assembly in both stud and intermediate columns.

8. REFERENCES

[1] NAS. North American Specification for Design of Cold-formed Steel Structure Members, American Iron and Steel Institute, Washington, D.C., 2001.

[2] Schafer B.W.. Review: The Direct Strength Method of cold-formed steel member design, Journal of Constructional Steel Research, pp. 766-778, (2008).

[3] Young B., Chen J.. Design of cold-formed steel built-up closed sections with intermediate stiffeners, Journal of Structural Engineering, Vol. 134, pp. 727-737 (2008).

[4] NAS. Cold Formed Steel Design, American Iron and Steel Institute, Washington DC, 2002.

[5] AS/NZS:4600. Cold-formed steel structures, Australian Standard/New Zealand Standards:4600:1996, Standards Australia, Sydney, Australia, 1996.

[6] Roorda J., Venkataramaiah K.R.. Analysis of local plate buckling experimental data, *Sixth International Specialty Conference on Cold-Formed Steel Structure*, US, 1982.