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EFFECTS OF THE PLATE SLENDERNESS RATIO ON BUILT-UP BACK-TO-BACK CHANNELS STUB COLUMNS

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The purpose of this paper is to investigate the influence of plate slenderness ratio on the compression capacity and the performance of cold-formed steel built-up back-to-back C-channels sections. For stub columns, the overall slenderness ratio (KL/r) of the column has little effect on the load carrying capacity of the section. However, the plate element slenderness plays a major role in determining the performance of stub columns. The plate element slenderness for web or flanges needs to be less than the yield slenderness limit to be fully effective. Otherwise, only proportion of the web or flanges can be considered as effective. The study of the effects of plate element slenderness was carried out on the cold formed steel built-up columns fabricated by connecting two lipped C-channel columns back-to-back using self-drilling screws. Experimental results are compared with the calculated design results from the NAS specifications. Finite element model was created using commercial software LUSAS v14.4 to simulate the deformation curves and also to predict the load carrying capacities. Finite element results are validated by the test results. This study on the stub column shows that the plate element slenderness plays an important role in determining the compressive capacity and behavior of the stub column.

Keywords: Cold-formed Steel, Stub Column, Built-up, Slenderness, Finite Element, Compression Test.

1 Introduction

Built-up back-to-back channels sections are members composed of two identical C-channels connected at their webs by using self-drilling screws (Figure 1). Structural viability and installation requirements in construction projects made built-up section a highly used element in many low- and mid-rise residential and commercial buildings.

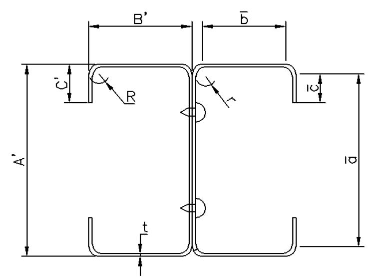

Figure 1. Failure Modes for BU90S50L300-1

Built-up sections are gaining popularity in the industry, thus, the factors that govern the strength and behavior of built-up sections are of interest to many researchers. One of the important factors is the plate element slenderness. The slenderness of the plate elements affects the effectiveness of the cross section of the column, thus, affecting its strength and behavior.

When designing stub columns, the overall slenderness ratio (KL/r) of the column has little effect on the load carrying capacity of the section. Design codes and specifications introduced dimensional limitations to restrict the width-thickness ratio for cold-formed steel sections.

Thus this research's focus is to study the influences of the width-thickness ratio of the built-up back-to-back channels stub columns.

2 Literature Review

In Rasmussen and Hancock (1992), the applicability of the plate slenderness rules to high strength steel was assessed. The tests were performed on 18 stub columns of square box section, cruciform section and I-section. For each type of cross-section, three different sizes were selected in the vicinity of the yield slenderness limit.

The tests on I-section columns confirmed that the compressive strength of a cross-section can be determined by considering the plates individually. This shows that the plate slenderness limit is important design factor for stub columns. They also concluded that stocky plates are less affected by residual stress than slender plates because the cross-section of a stocky plate is almost fully plastic at the ultimate load.

Gao et al. (2009) also shows that the buckling capacity and behavior of a built-up stub column is affected by the slenderness of the plate elements of the section. In their research on box built-up stub columns, they found that the ultimate load-carrying capacity of stub columns with square cross sections (smaller web-flange ratio) is always much larger than that of columns with rectangular cross sections (larger web-flange ratio). The failure mode changed from material strength failure to buckling failure as the web-flange ratio becomes larger. However, the variation is not obvious for columns with small width-thickness ratio.

In North American Specification (AISI 2002), the web-thickness ratio is accounted for by calculating the elastic local buckling stresses of cold-formed steel members as stated in section B1.2. Its importance can be shown in the equation below.

$$f_{ol} = \frac{k\pi^2 E}{12\left(1-\upsilon^2\right)\left(\frac{b}{t}\right)^2} \quad (1)$$

Elastic local buckling stress, f_{ol} is inversely proportional to the square of width-thickness ratio $(b/t)^2$. To prevent a plate from buckling before it reaches its yields (i.e. to avoid elastic local buckling), the yield stress must be less than the local buckling stress ($f_y<f_{ol}$).

In AS4100 (AS/NZS 1998), width-thickness ratio is also being accounted for in the element slenderness equation as shown below.

$$\lambda_e = \frac{b}{t}\sqrt{\frac{f_y}{250}} \quad (2)$$

This equation limits the web or flange slenderness to be less than the yield slenderness limit specified in table 6.2.4 of AS4100, so that the cross section is fully effective as a compression member. Otherwise, only a portion of the web or flange with slenderness less than yield slenderness limit can be considered as effective.

3 Experimental Analysis

Compression tests were conducted on six stub columns which are brake-pressed from aluminum/zinc-coated Grade G550 structural steel sheet of 1.2mm thickness. Dimensions of the specimens are tabulated in Table 1. The test setup is detailed in previous publication (Ting & Lau, 2011b).

Table 1. Specimens' Measured Dimension

Built-up	Web, A'	Flange, B'	Lip, C'	Thickness, t	Length, L
	mm	Mm	mm	mm	Mm
BU75S50L300-1	73.14	19.81	11.13	1.2	263
BU75S50L300-2	73.06	19.82	11.20	1.2	280
BU75S50L300-3	72.71	19.47	10.82	1.2	280
BU90S50L300-1	91.31	49.81	14.56	1.2	274
BU90S50L300-2	91.78	49.70	14.54	1.2	272
BU90S50L300-3	92.88	49.44	14.52	1.2	272

4 Finite Element Analysis

Finite element model was created using LUSAS v14.4 (FEA, 2010) to simulate the deformation curves and to predict the load carrying capacities. A detailed description of the model can be found in author's previous publication (Ting & Lau, 2011a).

5 Results & Discussion

5.1 *Failure Modes*

Result for BU90 shows that local buckling occurs near to the end of the specimens (Figure 2 to 4). With smaller web-flange ratio (A'/B'), column failed with yielding of the whole section. This is because cross section with smaller web-flange ratio (A'/B)' is more effective. This gives BU90 higher capacity to resist the axial load. Thus failure mainly occurs with plastic deformation near the end of the specimen.

As for BU75, local buckling occurs near to mid length (Figure 5 to 7). This is because BU75 with larger web-flange ratio (A'/B') ratio has small flange and is less effective to stiffen the web. Therefore, failure is governed by buckling failure.

5.2 *Axial Capacity*

Table 2 compares the ultimate loads predicted by finite element models to the results obtained from experiments and theoretical calculations. The theoretical results were calculated using Effective Width Method (EWM) and Direct Strength Method (DSM) based on North American Specification. The study shows that finite element model predicts the stub column capacity well with (P_{EXP}/P_{FEM}) of ~~1.08~~ 0.97. The axial capacity calculated using EWM gave results which are close to the ultimate test strength with (P_{EXP}/P_{EWM}) of 0.96. The strength predictions by DSM are also close to the ultimate test strength with (P_{EXP}/P_{DSM}) of 1.07 but lesser than EWM. This is because the EWM takes the effectiveness of elements into account. The effectiveness of elements is important for stub columns because local buckling dominates the failure. Although distortional buckling and buckling interaction are adequately considered by DSM, they are not the major failure modes for stub columns.

For BU90, the carrying capacity of the column decreases rapidly after the ultimate load and sudden failure occurs. Soon after, visible deformation occurred after the ultimate load and the weakened effective section of the column accelerate the failure. Compression stiffness of the stub column is greater with larger flanges. This is shown in Figure 8 to Figure 10 that the initial slope of axial load versus shortening curve is steeper for BU90 with larger flange-thickness ratio (B'/t).

For BU75 with smaller flange-thickness ratio (B'/t), there is no sudden rupture during testing. This is because with smaller flange, the web is not stiffened. Deformation of the elements occurred before reaching the ultimate load. The deformation becomes greater as the loading increases after the ultimate load.

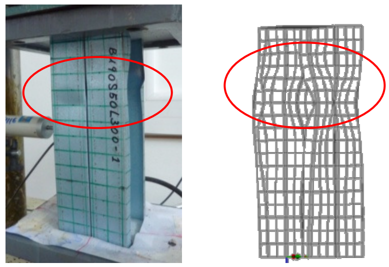

Figure 2. Failure Modes for BU90S50L300-1

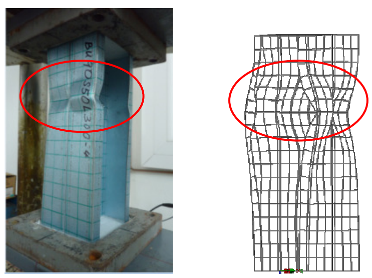

Figure 3. Failure Modes for BU90S50L300-2

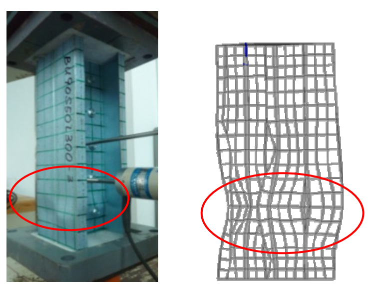

Figure 4. Failure Modes for BU90S50L300-3

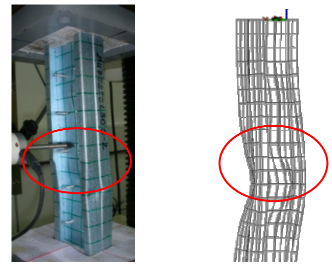

Figure 5. Failure Modes for BU75S50L300-1

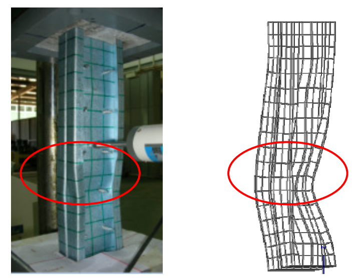

Figure 6. Failure Modes for BU75S50L300-2

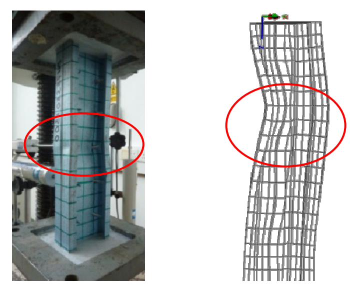

Figure 7. Failure Modes for BU75S50L300-3

Table 2. Comparison of the Axial Capacity of Back-to-back Built-up Stub Columns

Built-up	P_{DSM}	P_{EWM}	P_{FEM}	P_{EXP}	P_{EXP}/P_{DSM}	P_{EXP}/P_{EWM}	P_{EXP}/P_{FEM}
	kN	kN	kN	kN	-	-	-
BU75S50L300-1	114.45	127.05	119.18 ~~114.97~~	120.66	1.05	0.95	1.01 ~~1.05~~
BU75S50L300-2	114.40	127.00	120.78 ~~116.44~~	118.87	1.04	0.94	0.98 ~~1.02~~
BU75S50L300-3	113.12	124.90	118.54 ~~114.50~~	118.65	1.05	0.95	1.00 ~~1.04~~
BU90S50L300-1	156.67	174.86	183.10 ~~151.98~~	172.49	1.10	0.99	0.94 ~~1.13~~
BU90S50L300-2	156.36	174.56	182.31 ~~152.88~~	171.61	1.10	0.98	0.94 ~~1.12~~
BU90S50L300-3	155.64	174.49	182.00 ~~153.09~~	167.56	1.08	0.96	0.92 ~~1.09~~

Average	1.07	0.96	0.97 ~~1.08~~

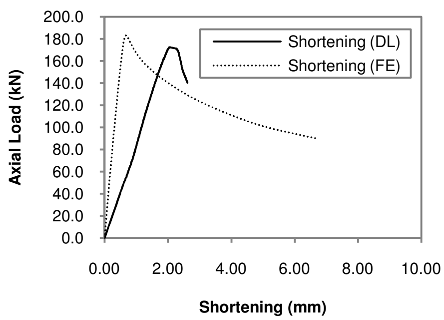

Figure 8. Graph of Axial Load vs Shortening BU90S50L300-1

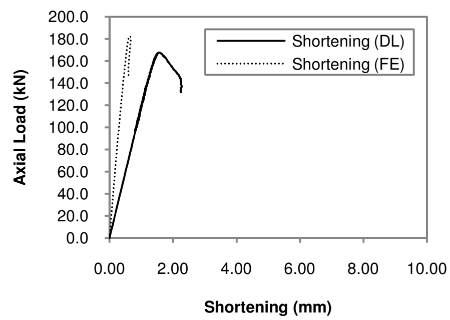

Figure 10. Graph of Axial Load vs Shortening BU90S50L300-3

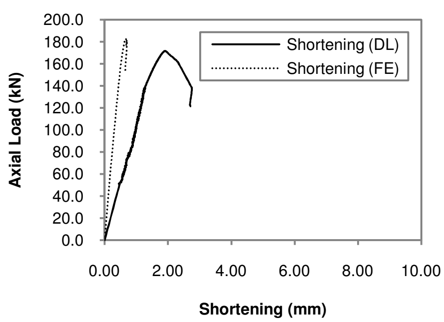

Figure 9. Graph of Axial Load vs Shortening BU90S50L300-2

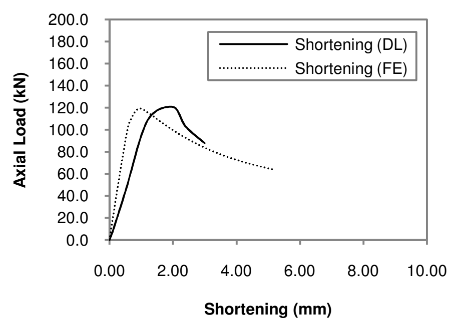

Figure 11. Graph of Axial Load vs Shortening BU75S50L300-1

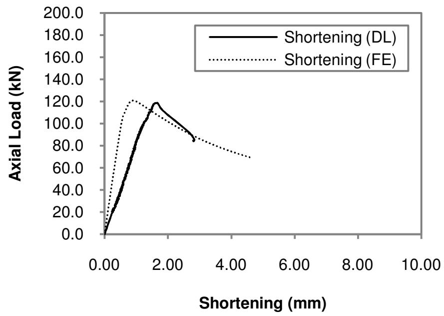

Figure 12. Graph of Axial Load vs Shortening BU75S50L300-2

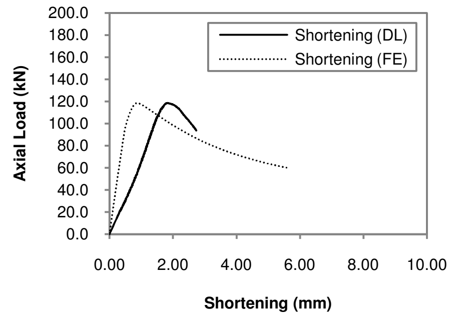

Figure 13. Graph of Axial Load vs Shortening BU75S50L300-3

7 Conclusion

The buckling behaviours of thin-walled back-to-back stub columns fabricated by high strength steel were studied by compression tests. Test data shows that the failure of stub columns is generally resulted from local and distortional buckling.

Numerical simulations carried out using LUSAS shows good correlation with the experimental results. The finite element model used in this paper can simulate the behavior of the stub columns closely.

Result shows that plate element slenderness plays a major role to determine the compressive capacity of the stub column. At large flange-thickness ratio (B'/t), local buckling governs the failure. At small flange-thickness ratio (B'/t), overall buckling tends to govern the failure. It was also shown that for columns with larger web-flange ratio (A'/B') the buckling failure is dominant, while the material yielding failure is dominant for columns with smaller web-flange ratio (A'/B').

Acknowledgments

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References

AS/NZS, Steel structures, Australian Standard/ New Zealand Standards 4100:1998, Standards Australia, Sydney, Australia, 1998.

AS/NZS, Cold-formed steel structures, Australian Standard/ New Zealand Standards 4600:1998, Standards Australia, Sydney, Australia, 1998.

AISI, AISI Manual – cold-formed steel design, American Iron and Steel Institute, Washington DC, 2002.

AISI, North American Specification for the design of cold-formed steel structural members, American Iron and Steel Institute, Washington DC, 2001.

FEA Co., Ltd, Lusas element reference manual and user's manual, United Kingdom, 2010.

K.J.R. Rasmussen, G.J. Hancock, Plate slenderness limits for high strength steel sections in *Journal of Constructional Steel Research*, issue 23, 73-96, 1992.

L. Gao, H. Sun, F. Jin, H. Fan, Load-carrying capacity of high-strength steel box-sections I - stub columns in *Journal of Constructional Steel Research*, issue 65, 918-924, 2009.

T.C.H. Ting, H.H. Lau, A Numerical Investigation on Cold-formed Steel Built-up Back-to-back Channel Stub Columns in *7th International Conference on Steel & Aluminium Structures*, Kuching, Sarawak, Malaysia, 2011a.

T.C.H. Ting, H.H. Lau, Compression Test on Cold-formed Steel Built-up Back-to-back Channels Stub Columns in *Advanced*

Materials Research, Vols. 201-203, 2900-2903, 2011b.