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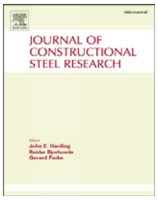

Failure modes and buckling coefficient of partially stiffened cold-formed sections in bending

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ABSTRACT

Flange edge stiffeners increase the ultimate moment capacity of cold-formed channel sections. At the same time, they cause complexity to the buckling failure mode of the section. There is a lack of experimental research on the failure mode of sections with a partially stiffened element, such as channel sections with edge stiffeners, in which a distortional buckling mode can be observed. The focus of recent studies is mainly on the behaviour of the whole section as one member under bending without any concern about the relationship between the web and flange ratio.

In this study, an extensive experimental analysis of 42 cold-formed channel sections was used to explore the failure behaviour of cold-formed channel sections under pure bending. The sections were made from cold-formed G450 steel with a nominal thickness of 1.6 mm. The results of the pure bending experimental investigations are used to describe the relationship between the web and flange ratio and the failure deformations. It is also shown that the current international cold-formed steel specifications over-predict the buckling coefficient of partially stiffened elements with high aspect ratio values. The experimental results are used to propose revisions to current international cold-formed steel specifications.

1. Introduction

Cold-formed section strength is not only controlled by material yielding but also by lateral, lateral–torsional, local and distortional buckling. In lateral buckling the whole section deflects laterally. In lateral–torsional buckling, the whole section twists and bends without any changes in the section's shape. In local buckling, the plate element buckles without any deformation of the web-flange juncture. In distortional buckling, the shape of the cross-section is changed and the flange element rotates around the web-flange intersection.

A compression element with an edge stiffener is called a partially stiffened element, and is susceptible to distortional buckling failure mode. The buckling behaviour of a partially stiffened element, depending on the edge stiffener size, varies between unstiffened and stiffened elements. Therefore, the plate buckling coefficient, k, of a partially stiffened element varies between 0.43 and 4. Desmond et al. [8] conducted analytical and experimental studies on partially stiffened elements. They concluded that the buckling behaviour of an element with an adequate size of stiffener (and therefore its effective width), is similar to a stiffened element that has the same material and dimensions. The outcome of the research by Desmond et al. [8] led to the design rules for calculating the buckling coefficients of uniformly compressed partially stiffened elements in AS/NZS 4600 [2] and AISI-S100 [1].

Schafer et al. [14] studied the effect of complex edge stiffeners on the distortional buckling behaviour of thin-walled members. They concluded that Open thin-walled members benefit substantially from the use of edge stiffeners. However, an increase in the length of the stiffener could cause local instability for the section.

Bambach [6] illustrated that if the lip-to-flange ratio for an element with a simple stiffener exceeds 0.16, the element will behave as a stiffened element. Bambach also concluded that the lip-to-flange ratio should not exceed 0.25. This is due to the fact that a large stiffener initiates buckling itself and will reduce the theoretical buckling stress of the whole element.

It is to be noted that the AISI-S100 [1] and AS/NZS 4600 [2] calculations are based on the Winter equation. To verify the Winter equation for partially stiffened elements, Kwon and Hancock [9] have performed compression tests on cold-formed channel sections with edge stiffeners. Their test results indicated that sections without adequate edge stiffeners, and a flange buckling coefficient of less than 4, will fail due to distortional buckling. Therefore, the critical value of an element's theoretical buckling stress (f_{cr}) should be equal to the theoretical distortional buckling stress. Based on distortional buckling failure, Kwon and Hancock [9] compared their test results with the Winter equation results and concluded that the Winter equation provides an un-conservative design capacity for partially stiffened elements.

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Bambach [6] modified the Winter equation for edge-stiffened elements. Bambach's modification was purely based on an empirical approach using finite element analysis, and his modified equations are as follows:

$$\text{For } 0.43 < k < 4.0 : \rho = \left[\frac{1-0.22/\lambda}{\lambda}\right]^{4/3} \tag{1}$$

$$\text{For } k = 4.0 \text{ or } k = 0.43 : \rho = \left[\frac{1-0.22/\lambda}{\lambda}\right] \tag{2}$$

where λ is the slenderness ratio and is determined using Eq. (9).

From Kwon and Hancock [9] and Bambach [6], it can be concluded that distortional buckling failure is not clearly addressed in the effective width method (EWM). Bambach [5] verified Eqs. (1) and (2) by testing 30 plates, which were simply supported on three sides, with the remaining (longitudinal) edge stiffened with an edge stiffener.

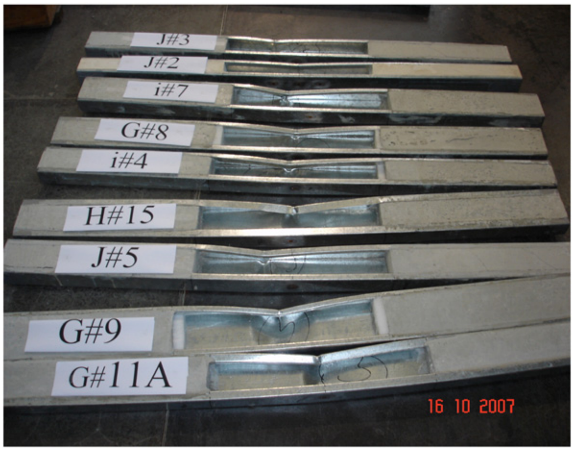

Fig. 1. Sample tested sections.

Table 1
Section properties.

Sections	b_4 (mm)	b_3 (mm)	b_2 (mm)	b_1 (mm)	Thickness t (mm)	Width/depth b_2/b_1	Length L_{eff} (mm)	Aspect ratio	I_s/width	α_1 Deg	α_d Deg	Yield stress F_y (Mpa)
1			47.40	161.22	1.54	0.29	500	10.55	0.00	7.20	21.60	541.00
2			66.45	121.68	1.57	0.55	500	7.52	0.00	8.60	18.10	541.00
3	12.32	15.94	44.92	122.14	1.57	0.37	500	11.13	13.58	12.60	27.30	528.50
4	14.20	14.94	62.75	79.85	1.56	0.79	500	7.97	8.05	9.10	8.20	552.00
5	12.62	21.67	41.49	111.16	1.57	0.37	500	12.05	13.55	13.60	27.90	528.50
6	12.51	16.29	41.27	129.03	1.57	0.32	500	12.12	13.24	13.60	/	528.50
7	12.39	15.78	34.99	139.88	1.58	0.25	500	14.29	5.93	15.95	/	528.50
8	11.82	17.66	48.23	110.04	1.59	0.44	500	10.37	17.54	11.70	20.40	528.50
9	9.78	18.06	56.65	99.00	1.56	0.57	500	8.83	15.06	10.00	13.90	552.00
10	17.12	17.98	49.36	99.83	1.54	0.49	500	10.13	15.79	11.50	20.60	541.00
11	10.85	16.19	60.10	94.21	1.54	0.64	500	8.32	10.15	11.30	13.40	552.00
12	10.85	16.50	50.93	113.76	1.53	0.45	500	9.82	12.70	11.10	23.20	541.00
13	9.98	14.27	58.18	102.90	1.57	0.57	500	8.59	6.72	9.80	/	541.00
14		22.74	47.59	121.10	1.58	0.39	500	10.51	17.54	11.90	28.70	542.50
15		13.34	42.49	141.02	1.58	0.30	500	11.77	3.43	13.20	/	542.50
16		18.67	31.40	159.19	1.57	0.20	500	15.92	3.64	12.60	25.10	542.50
17		12.44	37.01	161.69	1.54	0.23	500	13.51	2.92	12.20	40.80	542.50
18		17.34	62.09	102.68	1.56	0.60	500	8.05	6.17	10.90	14.70	541.00
19		12.45	47.50	141.42	1.55	0.34	500	10.53	2.29	11.90	32.50	542.50
20		14.53	55.88	121.20	1.56	0.46	500	8.95	3.57	/	/	542.50
21		12.88	65.86	103.61	1.57	0.64	500	7.59	1.92	8.60	16.80	541.00
22		20.00	39.99	89.00	1.50	0.45	500	12.50	11.83	12.70	25.30	541.00
23		19.96	45.00	89.98	1.50	0.50	500	11.11	13.55	12.50	14.00	541.00
24		19.96	49.99	89.96	1.50	0.56	500	10.00	12.19	10.20	13.00	541.00
25		19.97	35.00	79.80	1.55	0.44	500	14.29	6.06	8.10	18.60	541.00
26		20.00	40.20	79.99	1.50	0.50	500	12.44	12.10	8.50	19.10	541.00
27		19.97	45.00	79.98	1.52	0.56	500	11.11	13.76	10.10	13.40	541.00
28		19.96	29.97	70.05	1.50	0.43	500	16.68	2.60	/	/	541.00
29		19.95	34.99	70.10	1.55	0.50	500	14.29	6.06	8.10	19.50	541.00
30		19.99	39.97	70.00	1.50	0.57	500	12.51	11.80	7.10	9.80	541.00
31		20.00	25.00	58.90	1.50	0.42	300	12.00	0.65	/	/	541.00
32		19.97	29.96	60.80	1.55	0.49	400	13.35	2.43	7.60	25.10	541.00
33		19.97	35.00	60.40	1.55	0.58	500	14.29	6.06	8.10	19.00	541.00
34		14.80	19.90	49.50	1.55	0.40	190	9.55	0.01	/	18.00	541.00
35		14.96	24.99	50.10	1.50	0.50	285	11.40	0.64	0.00	25.60	541.00
36		14.95	29.97	50.10	1.50	0.60	290	9.68	2.60	7.60	25.10	541.00
37		9.75	14.78	38.20	1.55	0.39	170	11.50	0.00	0.00	11.80	541.00
38		9.63	19.75	39.40	1.55	0.50	210	10.63	0.01	0.00	24.30	541.00
39		9.83	24.68	38.50	1.55	0.64	240	9.72	0.49	0.00	26.30	541.00
40		9.20	10.45	28.10	1.55	0.37	85	8.13	0.00	0.00	69.60	541.00
41		9.70	14.50	29.50	1.55	0.49	155	10.69	0.00	0.00	12.40	541.00
42		9.73	19.55	29.00	1.55	0.67	145	7.42	0.01	0.00	16.10	541.00