Journal of Constructional Steel Research 76 (2012) 75–82

Contents lists available at SciVerse ScienceDirect

Journal of Constructional Steel Research

Slenderness limits for cold-formed channel sections in bending by experimental methods

S. Maduliat [a,*], M.R. Bambach [b], X.L. Zhao [a]

[a] Dept. of Civil Engineering, Monash University, Australia
[b] IRMRC, Faculty of Science, University of New South Wales, Australia

ARTICLE INFO

Article history:
Received 17 October 2011
Accepted 12 March 2012
Available online 26 April 2012

Keywords:
Cold-formed steel
Channels
Plastic capacity
Hot-rolled steel

ABSTRACT

Inelastic design methods allow for larger application of loads on sections than elastic design methods, due to the redistribution of yield stress through the depth of the section. Sections that can reach the full plastic capacity and maintain it for sufficient rotation are considered applicable for plastic mechanism design, resulting in more economical structural solutions. Cold-formed steel channel sections are used extensively in portal frame structures in agricultural and light industrial/commercial applications, structures well suited to plastic design, however may currently only be designed elastically. To address this limitation in design standards, experimental and numerical analyses on the inelastic bending capacity of cold-formed channel sections are performed, and design rules to account for such behaviour are developed. Design rules are prepared using the hot-rolled steel specification methodology of classifying a section as compact, non-compact or slender (according to the Australian Standards) and Classes 1, 2, 3 and 4 (according to the European Standards). Proposals for the Australian standard are shown to provide accurate and reliable capacity predictions for cold-formed steel channel sections whose bending capacity exceeds the elastic limit.

1. Introduction

If a beam or portal frame member reaches its plastic moment, a plastic hinge will develop at that stage. If that plastic hinge can rotate sufficiently to redistribute the moment along the member, additional load can be resisted by the structural assembly which can be up to 70% greater than the first yield capacity. Therefore, the plastic design method is more economical compared to the traditional elastic design method. In Australia, hot-rolled sections are designed under the Australian Standard for Steel Structures [1] and cold-formed sections under the Australian/New Zealand Standard for Cold-formed Steel Structures [2]. While the hot-rolled standard allows full plastic design, the cold-formed standard does not. Additionally, cold-formed sections typically do not satisfy the conditions for plastic design in the hot-rolled standard [1]: the yield stress must not exceed 450 MPa; the ratio of the ultimate tensile stress to the yield stress must not be less than 1.2; and the steel must exhibit a strain hardening capacity. However, a number of authors have demonstrated that cold-formed sections that do not satisfy these conditions may be suitable for full plastic design [3–6], or partially plastic design (inelastic design) [7–10]. This is due to the local plastic mechanism development of the cold-formed (thin-walled) sections which causes an inelastic behaviour of the section ([19]). For such sections the elastic design approach is unduly conservative. For example, the tests of portal frames manufactured from cold-formed channels in [9] demonstrated a capacity of 25% to 70% greater than the first yield capacity.

The Australian standard [1] classifies hot-rolled sections into different classes according to their slenderness ratio, and the approach and equations are similar in the European and North American hot-rolled standards. The ultimate moment capacity is calculated using the following equations:

$$M_S = F_y Z_e \tag{1}$$

where Z_e is the effective section modulus.

For compact sections:

$$Z_e = Min(S, 1.5Z). \tag{2}$$

For non-compact sections:

$$Z_e = Z + \left[\left(\frac{\lambda_{sy}-\lambda_s}{\lambda_{sy}-\lambda_{sp}}\right)(S-Z)\right]. \tag{3}$$

For slender sections:

$$Z_e = Z\left(\frac{\lambda_{sy}}{\lambda_s}\right) \text{for plate element in uniform compression} \tag{4}$$

* Corresponding author at: Dept. Civil Engineering, Building 60, Clayton Campus, Monash University, VIC 3800, Australia. Tel.: +61 3 990 51956; fax: +613 9905 4944.
E-mail addresses: smaduliat@hotmail.com (S. Maduliat), mikebambach@gmail.com (M.R. Bambach), zhao.xiao.ling@monash.edu (X.L. Zhao).

0143-974X/$ – see front matter. Crown Copyright © 2012 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.jcsr.2012.03.009

Table 1
Tensile coupon test results.

Coupons	Thickness t (mm)	Yield stress Fy (MPa)	Average yield stress Fy for each steel sheet	Elongation %eu	Young's modulus E (MPa)	Tensile stress Fu (MPa)
G1	1.54	535.0	528.5	11%	194198.0	561.8
G2	1.57	522.0		10%	177338.0	563.5
H1	1.53	541.0	542.5	10%	176938.0	565.4
H2	1.53	544.0		12%	187905.0	581.0
I1	1.5	557.0	541.0	12%	196506.0	584.3
I2	1.51	525.0		12%	191620.0	559.3
J1	1.49	543.0	552.0	12%	198834.0	568.4
J2	1.49	561.0		12%	197997.0	595.7
Mean	1.52	541.00		11.4%	190167.0	572.2
		>450.0		<15%		

$$Z_e = Z\left(\frac{\lambda_{sy}}{\lambda_s}\right)^2 \text{ for plate element with maximum compression at an unsupported edge and zero or tension at the other} \quad (5)$$

where Z is the elastic section modulus, S is the plastic section modulus, λ_{sy} is the elastic slenderness limit and λ_{sp} is the plastic slenderness limit. λ_s is the value of either the web or flange slenderness ratio with the greatest value of λ_e/λ_{ey}. The slenderness ratio of each element, λ_e, is calculated according to Eq. (6);

$$\lambda_e = \left(\frac{b}{t}\right)\sqrt{\frac{f_y}{250}} \quad (6)$$

where t is the element thickness and b is the clear width of the element between the face of supporting elements.

Table 2
Section properties.

Sections	b4 (mm)	b3 (mm)	b2 (mm)	b1 (mm)	Thickness t (mm)	Length Leff (mm)	Yield stress Fy (Mpa)	My kN-m	Mp kN-m
1			47.40	161.22	1.54	500	541.00	9.52	11.39
2			66.45	121.68	1.57	500	541.00	8.53	9.67
3	12.32	15.94	44.92	122.14	1.57	500	528.50	7.80	9.24
4	14.20	14.94	62.75	79.85	1.56	500	552.00	5.75	6.62
5	12.62	21.67	41.49	111.16	1.57	500	528.50	6.66	8.07
6	12.51	16.29	41.27	129.03	1.57	500	528.50	8.05	9.63
7	12.39	15.78	34.99	139.88	1.58	500	528.50	8.32	10.09
8	11.82	17.66	48.23	110.04	1.59	500	528.50	7.15	8.45
9	9.78	18.06	56.65	99.00	1.56	500	552.00	6.98	8.10
10	17.12	17.98	49.36	99.83	1.54	500	541.00	6.50	7.73
11	10.85	16.19	60.10	94.21	1.54	500	552.00	6.73	7.75
12	10.85	16.50	50.93	113.76	1.53	500	541.00	7.55	8.84
13	9.98	14.27	58.18	102.90	1.57	500	541.00	7.29	8.38
14		22.74	47.59	121.10	1.58	500	542.50	7.98	9.42
15		13.34	42.49	141.02	1.58	500	542.50	8.59	10.19
16		18.67	31.40	159.19	1.57	500	542.50	9.08	11.17
17		12.44	37.01	161.69	1.54	500	542.50	9.31	11.29
18		17.34	62.09	102.68	1.56	500	541.00	7.33	8.34
19		12.45	47.50	141.42	1.55	500	542.50	8.98	10.55
20		14.53	55.88	121.20	1.56	500	542.50	8.31	9.57
21		12.88	65.86	103.61	1.57	500	541.00	7.58	8.54
22		20.00	39.99	89.00	1.50	500	541.00	4.41	5.22
23		19.96	45.00	89.98	1.50	500	541.00	4.83	5.65
24		19.96	49.99	89.96	1.50	500	541.00	5.18	6.01
25		19.97	35.00	79.80	1.55	500	541.00	3.60	4.30
26		20.00	40.20	79.99	1.50	500	541.00	3.82	4.52
27		19.97	45.00	79.98	1.52	500	541.00	4.18	4.88
28		19.96	29.97	70.05	1.50	500	541.00	2.63	3.20
29		19.95	34.99	70.10	1.55	500	541.00	3.00	3.59
30		19.99	39.97	70.00	1.50	500	541.00	3.18	3.75
31		20.00	25.00	58.90	1.50	300	541.00	1.83	2.27
32		19.97	29.96	60.80	1.55	400	541.00	2.22	2.70
33		19.97	35.00	60.40	1.55	500	541.00	2.44	2.92
34		14.80	19.90	49.50	1.55	190	541.00	1.24	1.54
35		14.96	24.99	50.10	1.50	285	541.00	1.42	1.73
36		14.95	29.97	50.10	1.50	290	541.00	1.61	1.92
37		9.75	14.78	38.20	1.55	170	541.00	0.67	0.84
38		9.63	19.75	39.40	1.55	210	541.00	0.85	1.03
39		9.83	24.68	38.50	1.55	240	541.00	0.97	1.15
40		9.20	10.45	28.10	1.55	85	541.00	0.33	0.43
41		9.70	14.50	29.50	1.55	155	541.00	0.45	0.56
42		9.73	19.55	29.00	1.55	145	541.00	0.54	0.67