

CHAPTER 7 COMPRESSION MEMBERS

7.1 General

The design of cold-formed members in compression is generally more complex than conventional hot-rolled steel members. This is a result of the additional modes of buckling deformation which commonly occur in thin-walled structural members. These are:

- local buckling and post-local buckling of stiffened and unstiffened compression elements, as described in Chapter 4,
- flexural, torsional and flexural-torsional modes of buckling of the whole compression member as shown in Fig. 1.17(b), and
- distortional buckling as shown in Fig. 1.18(a).

The design for (a) determines the nominal section compression capacity (N_s) described in Section 7.3 of this book. The design for (b) and (c) gives the nominal member compression capacity (N_c) given in Section 7.4 of this book. As specified in Table 1.6 of AS/NZS 4600, the capacity reduction factor (ϕ_c) for computing the design section or member capacity from N_s or N_c is 0.85.

The elastic buckling stress for flexural, torsional and flexural-torsional buckling of members in compression is discussed in Section 7.2.1 of this book. The elastic distortional buckling stress of members in compression was discussed in Section 5.3.1.1 of this book.

Section 3.4 of AS/NZS 4600 includes rules which enable the designer to account for these additional buckling modes as well as the normal failure modes of flexural buckling and yielding commonly considered for doubly-symmetric hot-rolled compression members.

7.2 Elastic Member Buckling

7.2.1 Flexural, Torsional and Flexural-Torsional Buckling

The elastic critical load for flexural, torsional and flexural-torsional buckling of a thin-walled member of general cross-section, as shown in Fig. 7.1(a), was derived by Timoshenko and is explained in detail in Timoshenko and Gere (Ref. 3.6) and also by Trahair in Ref. 5.2. For a member subjected to uniform compression and restrained at its ends by simple supports which prevent lateral displacement of the section perpendicular to its longitudinal axis, as well as twisting rotation, the elastic critical load (N_{oc}) is given by solution of the following three simultaneous equations in the displacement amplitudes A_1 , A_2 in the x -, y -directions respectively and twist angle A_3 as follows:

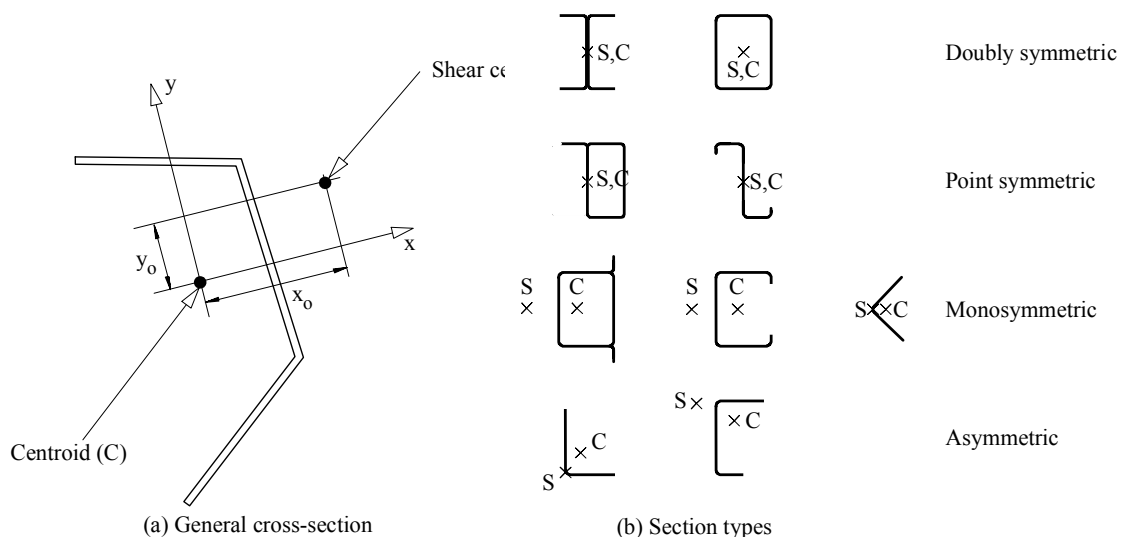


Fig. 7.1 Thin-walled sections



$$(N_{oy} - N_{oc})A_1 - N_{oc}y_o A_3 = 0 \quad (7.1)$$

$$(N_{ox} - N_{oc})A_2 + N_{oc}x_o A_3 = 0 \quad (7.2)$$

$$-N_{oc}y_o A_1 + N_{oc}x_o A_2 + (r_{o1})^2 (N_{oz} - N_{oc})A_3 = 0 \quad (7.3)$$

where

$$N_{ox} = \pi^2 \frac{EI_x}{l^2} \quad (7.4)$$

$$N_{oy} = \pi^2 \frac{EI_y}{l^2} \quad (7.5)$$

$$N_{oz} = \frac{GJ}{r_{o1}^2} \left(1 + \frac{\pi^2 EI_w}{GJl^2} \right) \quad (7.6)$$

$$r_{o1}^2 = \frac{(I_x + I_y)}{A} + x_o^2 + y_o^2 \quad (7.7)$$

The terms x_o and y_o are the shear centre coordinates shown in Fig. 7.1(a). The modes of buckling for flexure about both principal axes, and twist angle are sinusoidal with amplitudes of A_1 , A_2 and A_3 respectively.

Two solutions to Eqs (7.1) - (7.3) exist. Either the column does not buckle and $A_1 = A_2 = A_3 = 0$, or the column buckles and the determinant of the matrix of coefficients of A_1 , A_2 and A_3 in Eqs (7.1) - (7.3) is zero. In this case, the resulting cubic equation to be solved for the critical load (N_{oc}) is:

$$N_{oc}^3 (r_{o1}^2 - x_o^2 - y_o^2) - N_{oc}^2 [(N_{ox} + N_{oy} + N_{oz})r_{o1}^2 - (N_{oy}x_o^2 + N_{ox}y_o^2)] + N_{oc}r_{o1}^2 (N_{ox}N_{oy} + N_{oy}N_{oz} + N_{oz}N_{ox}) - N_{ox}N_{oy}N_{oz}r_{o1}^2 = 0 \quad (7.8)$$

For general asymmetric sections of the type shown in Fig. 7.1(b), the solution of Eq. (7.8) in its general form is necessary. Eq. (7.8) is given in Clause 3.4.5 of AS/NZS 4600 such that it has been divided by the gross sectional area cubed to convert it to a buckling stress (f_{oc}).

For monosymmetric sections of the type shown in Fig. 7.1(b), for which either x_o or y_o are zero, then simpler solutions exist. In the case of the x-axis as the axis of symmetry, then y_o is zero and hence:

$$(N_{oc})_1 = N_{oy} \quad (7.9)$$

$$(N_{oc})_{2,3} = \frac{(N_{ox} + N_{oz}) \pm \sqrt{(N_{ox} - N_{oz})^2 + 4N_{ox}N_{oz} \left(\frac{x_o}{r_{o1}} \right)^2}}{2 \left[1 - \left(\frac{x_o}{r_{o1}} \right)^2 \right]} \quad (7.10)$$

Eq. (7.9) gives the flexural buckling load about the y-axis and the smaller of the two values computed using Eq. (7.10) gives the flexural-torsional buckling load. Eqs (7.9) and (7.10), converted to buckling stresses (f_{oc}) by dividing by the gross area (A) form the basis of Clause 3.4.3 of AS/NZS 4600.

Eq. (7.9) for the unlippped channel section in Fig. 3.2 produces identical results with the curve through C in Fig. 3.3 for column lengths greater than 1000 mm where local buckling effects have no influence. Similarly evaluation of Eq. (7.10) for the channel section in Fig. 3.2 produces identical results with the curve through D in Fig. 3.3 for column lengths greater than 1000 mm.



In Figs 3.6, 3.7 and 3.9, the curves shown as the dashed line labelled "Timoshenko flexural-torsional buckling formula" were calculated using the lower root of Eq. (7.10).

For doubly symmetric or point symmetric sections where x_o and y_o are both zero, then the three solutions of Eq. (7.8) are simply

$$(N_{oc})_1 = N_{ox} \quad (7.11)$$

$$(N_{oc})_2 = N_{oy} \quad (7.12)$$

$$(N_{oc})_3 = N_{oz} \quad (7.13)$$

For doubly-symmetric sections, closed cross-sections and any other sections that can be shown not to be subject to torsional or flexural-torsional buckling, Clause 3.4.2 of AS/NZS 4600 uses the lesser N_{oc} derived from Eqs (7.11) and (7.12) divided by the gross area (A) to give the flexural buckling stress (f_{oc}) (Eq. 3.4.2(1) of AS/NZS 4600). For point symmetric sections, where torsional buckling can also occur, Clause 3.4.4 of AS/NZS 4600 uses N_{oc} derived from Eq. 7.13 divided by the gross area (A) to give the torsional buckling stress (f_{oz}). The lesser of f_{oc} from Clause 3.4.2 and f_{oz} from Clause 3.4.4 must be used for the design of point symmetric sections.

In Eqs (7.4) - (7.6), the length (l) is the unbraced length between the simply supported ends of the column. However the length (l) in Eqs (7.4), (7.5) and (7.6) has been replaced by l_{ex} , l_{ey} and l_{ez} respectively in Clause 3.3.3.2.1 of AS/NZS 4600. The lengths l_{ex} , l_{ey} and l_{ez} are the effective lengths about the x-, y- and z-axes respectively as defined in Clause 3.3.3.2.1. The use of different lengths in the computation of the flexural-torsional buckling load by Eqs (7.8) or (7.10) is not theoretically justifiable. However it usually produces a conservative estimate of the flexural-torsional buckling load of columns which have different flexural and torsional effective lengths. This procedure has been justified experimentally for the uprights of steel storage rack columns as described in Ref. 7.1.

In Section 5 of the Australian Steel Storage Racking Standard (Ref. 1.21), effective length factors are specified for flexural buckling in the direction perpendicular to the upright frame (typically $l_{ez} / l = 1.7$ for racking not braced against side sway), for flexural buckling in the plane of the upright frame (typically $l_{ey} / l = 1.0$) and for torsional buckling (typically $l_{ez} / l = 0.8$) provided twisting of the upright is prevented at the brace points.

For the design of studs in the walls of steel framed housing, effective lengths have been suggested in Section 5.3.2.1(ii) of Ref. 7.2. The torsional effective length (l_{ez}) is recommended as 0.8 times the noggin space where bracing is provided at the noggin and the ends according to Clause 4.4(a) of AS/NZS 4600. The effective length for flexure (l_{ex}) is recommended as 0.65 times the height of the stud for flat-ended wall studs restrained from flexure normal to the wall at both ends.

7.2.2 Distortional Buckling

The calculation of the elastic distortional buckling stress (f_{od}) for flange distortional buckling was discussed in detail in Section 5.3.1.1 of this book as an introduction to flange distortional buckling in flexure described in Section 5.3.1.2. Detailed formulations for computing the elastic distortional buckling stress (f_{od}) are given for a general channel in compression in Appendix D1 of AS/NZS 4600, and for a simple lipped channel in compression in Appendix D2 of AS/NZS 4600.

7.3 Section Capacity in Compression

The strength of short length columns compressed between rigid end platens is governed mainly by the yield strength of the material and the slenderness of the plate elements forming the cross-section. For sections with stocky plate elements, the strength is simply equal to the



Design of Cold-Formed Steel Structures
(To Australian/New Zealand Standard
AS/NZS 4600:2005)

by

Gregory J. Hancock BSc BE PhD DEng

Bluescope Steel Professor of Steel Structures

Dean

Faculty of Engineering & Information Technologies

University of Sydney

fourth edition - 2007



CONTENTS

	Page
PREFACE TO THE 4 th EDITION	viii
CHAPTER 1 INTRODUCTION	1
1.1 Design Standards and Specifications for Cold-Formed Steel	1
1.1.1 General	1
1.1.2 History of Australian Cold-Formed Steel Structures Standards and USA Specifications	1
1.1.3 New Developments in the 2005 Edition	2
1.2 Common Section Profiles and Applications of Cold-Formed Steel	4
1.3 Manufacturing Processes	10
1.4 Special Problems in the Design of Cold-Formed Sections	12
1.4.1 Local Buckling and Post-local Buckling of Thin Plate Elements	12
1.4.2 Propensity for Twisting	13
1.4.3 Distortional Buckling	14
1.4.4 Cold Work of Forming	14
1.4.5 Web Crippling under Bearing	15
1.4.6 Connections	15
1.4.7 Corrosion Protection	16
1.4.8 Inelastic Reserve Capacity	16
1.4.9 Fatigue	16
1.5 Loading Combinations	17
1.6 Limit States Design	17
1.7 Computer Analysis	19
1.8 References	20
CHAPTER 2 MATERIALS AND COLD WORK OF FORMING	22
2.1 Steel Standards	22
2.2 Typical Stress-Strain Curves	23
2.3 Ductility	25
2.4 Effects of Cold Work on Structural Steels	29
2.5 Corner Properties of Cold-Formed Sections	30
2.6 Fracture Toughness	32
2.6.1 Background	32
2.6.2 Measurement of Critical Stress Intensity Factors	32
2.6.3 Evaluation of the Critical Stress Intensity Factors for Perforated Coupon Specimens	34
2.6.4 Evaluation of the Critical Stress Intensity Factors for Triple Bolted Specimens	35
2.7 References	36
CHAPTER 3 BUCKLING MODES OF THIN-WALLED MEMBERS IN COMPRESSION AND BENDING	37
3.1 Introduction to the Finite Strip Method	37
3.2 Monosymmetric Column Study	38
3.2.1 Unlipped Channel	38
3.2.2 Lipped Channel	41
3.2.3 Lipped Channel (Fixed Ended)	44
3.3 Purlin Section Study	45
3.3.1 Channel Section	45
3.3.2 Z-Section	46



3.4	Tubular Flange Sections	47
3.4.1	Hollow Flange Beam in Bending	47
3.4.2	LiteSteel Beam Section in Bending	48
3.5	References	49
CHAPTER 4 STIFFENED AND UNSTIFFENED COMPRESSION ELEMENTS		50
4.1	Local Buckling	50
4.2	Postbuckling of Plate Elements in Compression	51
4.3	Effective Width Formulae for Imperfect Elements in Pure Compression	52
4.4	Effective Width Formulae for Imperfect Elements under Stress Gradient	56
4.4.1	Stiffened Elements	56
4.4.2	Unstiffened Elements	56
4.5	Effective Width Formulae for Elements with Stiffeners	57
4.5.1	Edge Stiffened Elements	57
4.5.2	Intermediate Stiffened Elements with One Intermediate Stiffener	58
4.5.3	Edge Stiffened Elements with Intermediate Stiffeners, and Stiffened Elements with more than One Intermediate Stiffener	58
4.5.4	Uniformly Compressed Edge Stiffened Elements with Intermediate Stiffeners	59
4.6	Examples	59
4.6.1	Hat Section in Bending	59
4.6.2	Hat Section in Bending with Intermediate Stiffener in Compression Flange	63
4.6.3	C-Section Purlin in Bending	68
4.7	References	75
CHAPTER 5 BEAMS, PURLINS AND BRACING		76
5.1	General	76
5.2	Flexural-Torsional (Lateral) Buckling	77
5.2.1	Elastic Buckling of Unbraced Simply Supported Beams	77
5.2.2	Continuous Beams and Braced Simply Supported Beams	81
5.2.3	Bending Strength Design Equations	85
5.3	Distortional Buckling	86
5.3.1	Flange Distortional Buckling	86
5.3.2	Lateral-Distortional Buckling	89
5.4	Basic Behaviour of Purlins	89
5.4.1	Linear Response of Channel and Z-sections	89
5.4.2	Stability Considerations	92
5.4.3	Sheeting and Connection Types	94
5.5	Design Methods for Purlins	95
5.5.1	No Lateral and Torsional Restraint Provided by the Sheeting	95
5.5.2	Lateral Restraint but No Torsional Restraint	95
5.5.3	Lateral and Torsional Restraint	96
5.6	Bracing	98
5.7	Inelastic Reserve Capacity	101
5.7.1	Sections with Flat Elements	101
5.7.2	Cylindrical Tubular Members	102
5.8	Examples	102
5.8.1	Simply Supported C-Section Purlin	102
5.8.2	Distortional Buckling Stress for C-Section	107
5.8.3	Continuous Lapped Z-Section Purlin	108
5.8.4	Z-Section Purlin in Bending	116
5.9	References	122



CHAPTER 6	WEBS	125
6.1	General	125
6.2	Webs in Shear	125
6.2.1	Shear Buckling	125
6.2.2	Shear Yielding	127
6.3	Webs in Bending	127
6.4	Webs in Combined Bending and Shear	129
6.5	Web Stiffeners	130
6.6	Web Crippling (Bearing) of Open Sections	130
6.6.1	Edge Loading Alone	130
6.6.2	Combined Bending and Edge Loading	133
6.7	Webs with Holes	134
6.8	Examples	136
6.8.1	Combined Bending and Shear at the End of the Lap of a Continuous Z-Section Purlin	136
6.8.2	Combined Bearing and Bending of Hat Section	138
6.9	References	139
CHAPTER 7	COMPRESSION MEMBERS	141
7.1	General	141
7.2	Elastic Member Buckling	141
7.2.1	Flexural, Torsional and Flexural-Torsional Buckling	141
7.2.2	Distortional Buckling	143
7.3	Section Capacity in Compression	143
7.4	Member Capacity in Compression	144
7.4.1	Flexural, Torsional and Flexural-Torsional Buckling	144
7.4.2	Distortional Buckling	146
7.5	Effect of Local Buckling	147
7.5.1	Monosymmetric Sections	147
7.5.2	High Strength Steel Box Sections	149
7.6	Examples	151
7.6.1	Square Hollow Section Column	151
7.6.2	Unlipped Channel Column	153
7.6.3	Lipped Channel Column	157
7.7	References	164
CHAPTER 8	MEMBERS IN COMBINED AXIAL LOAD AND BENDING	165
8.1	Combined Axial Compressive Load and Bending - General	165
8.2	Interaction Equations for Combined Axial Compressive Load and Bending	166
8.3	Monosymmetric Sections under Combined Axial Compressive Load and Bending	167
8.3.1	Sections Bent in a Plane of Symmetry	167
8.3.2	Sections Bent about an Axis of Symmetry	169
8.4	Combined Axial Tensile Load and Bending	170
8.5	Examples	171
8.5.1	Unlipped Channel Section Beam-Column Bent in Plane of Symmetry	171
8.5.2	Unlipped Channel Section Beam-Column Bent about Plane of Symmetry	174
8.5.3	Lipped Channel Section Beam-Column Bent in Plane of Symmetry	176
8.6	References	180



CHAPTER 9	CONNECTIONS	182
9.1	Introduction to Welded Connections	182
9.2	Fusion Welds	184
9.2.1	Butt Welds	184
9.2.2	Fillet Welds subject to Transverse Loading	184
9.2.3	Fillet Welds subject to Longitudinal Loading	185
9.2.4	Combined Longitudinal and Transverse Fillet Welds	186
9.2.5	Flare Welds	186
9.2.6	Arc Spot Welds (Puddle Welds)	187
9.2.7	Arc Seam Welds	190
9.3	Resistance Welds	190
9.4	Introduction to Bolted Connections	190
9.5	Design Formulae and Failure Modes for Bolted Connections	192
9.5.1	Tearout Failure of Sheet (Type I)	193
9.5.2	Bearing Failure of Sheet (Type II)	193
9.5.3	Net Section Tension Failure (Type III)	194
9.5.4	Shear Failure of Bolt (Type IV)	196
9.6	Screw Fasteners and Blind Rivets	196
9.7	Rupture	200
9.8	Examples	201
9.8.1	Welded Connection Design Example	201
9.8.2	Bolted Connection Design Example	205
9.9	References	208
CHAPTER 10	DIRECT STRENGTH METHOD	209
10.1	Introduction	209
10.2	Elastic Buckling Solutions	209
10.3	Strength Design Curves	210
10.3.1	Local Buckling	210
10.3.2	Flange-distortional buckling	212
10.3.3	Overall buckling	213
10.4	Direct Strength Equations	213
10.5	Examples	215
10.5.1	Lipped Channel Column (Direct Strength Method)	215
10.5.2	Simply Supported C-Section Beam	216
10.6	References	218
CHAPTER 11	STEEL STORAGE RACKING	219
11.1	Introduction	219
11.2	Loads	220
11.3	Methods of Structural Analysis	221
11.3.1	Upright Frames - First Order	222
11.3.2	Upright Frames - Second Order	223
11.3.3	Beams	223
11.4	Effects of Perforations (Slots)	224
11.4.1	Section Modulus of Net Section	224
11.4.2	Minimum Net Cross-Sectional Area	225
11.4.3	Form Factor (Q)	225
11.5	Member Design Rules	225
11.5.1	Flexural Design Curves	225
11.5.2	Column Design Curves	226



11.5.3	Distortional Buckling	227
11.6	Example	227
11.7	References	235
SUBJECT INDEX BY SECTION		236

