

CHAPTER 5 BEAMS, PURLINS AND BRACING

5.1 General

The design of beams for strength is usually governed by one of the following limit states:

- (a) yielding of the most heavily loaded cross section in bending including local and post-local buckling of the thin plates forming the cross-section, or
- (b) elastic or inelastic buckling of the whole beam in a flexural-torsional (commonly called lateral) mode, or
- (c) elastic or inelastic buckling of a length of beam in a distortional mode, or
- (d) yielding and/or buckling of the web subjected to shear, or combined shear and bending, or
- (e) yielding and/or buckling of the web subjected to bearing (web crippling) or combined bearing and bending.

The design for (a) determines the nominal section moment capacity (M_s) given by Eq. (5.1).

$$M_s = Z_e f_y \quad (5.1)$$

where Z_e is the effective section modulus about a given axis computed at the yield stress (f_y). Calculation of the effective section modulus at yield is described in Chapter 4 of this book. As specified in Table 1.6 of AS/NZS 4600, the capacity reduction factor (ϕ_b) for computing the design section moment capacity is 0.95 for sections with stiffened or partially stiffened compression flanges and 0.90 for sections with unstiffened compression flanges.

The design for (b) and (c) determines the nominal member moment capacity (M_b) given by Eq. (5.2).

$$M_b = Z_c f_c \quad (5.2)$$

where

$$f_c = \frac{M_c}{Z_f} \quad (5.3)$$

M_c is the critical moment for lateral or distortional buckling. Z_c is the effective section modulus for the extreme compression fibre computed at the critical stress (f_c) and Z_f is the full unreduced section modulus for the extreme compression fibre. Equation 5.2 allows for the interaction effect of local buckling on lateral or distortional buckling. The use of the effective section modulus computed at the critical stress (f_c) rather than the yield stress (f_y) allows for the fact that the section may not be fully stressed when the critical moment is reached and hence the effective section modulus is not reduced to its value at yield. The method is called the unified approach and is described in detail in Ref. 4.10. For the specific case of distortional buckling where the flange locally buckles before the web, interaction buckling does not occur and the full section modulus (Z_f) is used in place of the effective section modulus (Z_c) as described in Clause 3.3.3.3 of AS/NZS 4600. Hence M_b is simply M_c in this case. As specified in Table 1.6 of AS/NZS 4600, the capacity reduction factor (ϕ_b) for computing the design member moment capacity is 0.90.

Clause 3.3.3.2 of AS/NZS 4600 gives design rules for laterally unbraced and intermediately braced beams including box, I-beams, T-beams, C- and Z-section beams when cross-sectional distortion does not occur. The basis of the design rules for lateral buckling is described in the following Section 5.2 of this book.

Clause 3.3.3.3 of AS/NZS 4600 gives design rules for beams which undergo distortional buckling, as shown in Fig. 1.18, rather than lateral buckling. This usually occurs when the compression flange of a beam is laterally restrained but the flange and lip are free to rotate about the flange/web junction as shown in Fig. 3.12 and this is specified in Clause 3.3.3.3(a) of



AS/NZS 4600. This mode is sometimes called ‘Flange Distortional’ and is described in Section 5.3.1 of this book. In some cases, such as for the Hollow Flange Beam and the LiteSteel beam subject to bending, distortional buckling may involve transverse flexure of the web as shown in Fig. 3.15 and 3.16 and this is specified in Clause 3.3.3.3(b) of AS/NZS 4600. This mode is sometimes called ‘Lateral Distortional’ and is described in Section 5.3.2 of this book.

The basic behaviour of purlins is described in Section 5.4, and design methods for purlins are described in Section 5.5. These include the R-factor design approach in Clause 3.3.3.4 of AS/NZS 4600 which allows for the restraint from sheeting attached by screw-fastening to one flange. Methods for bracing beams against lateral and torsional deformation are described in Clause 4.3 of AS/NZS 4600 and are described in Section 5.6 of this book. Allowance for inelastic reserve capacity of flexural members is included as Clause 3.3.2.3 of AS/NZS 4600 as an alternative to initial yielding described by Clause 3.3.2.2 and specified by Eq 5.1. Inelastic reserve capacity is described in Section 5.7 of this book.

The design for (d) requires computation of the nominal shear capacity (V_v) of the beam and is fully described in Chapter 6 (Webs) of this book. The design for (e) requires computation of the nominal capacity for concentrated load (R_b) (bearing) and is also described in Chapter 6 (Webs) of this book. The interaction of both shear and bearing with section moment is also described in Chapter 6.

5.2 Flexural-Torsional (Lateral) Buckling

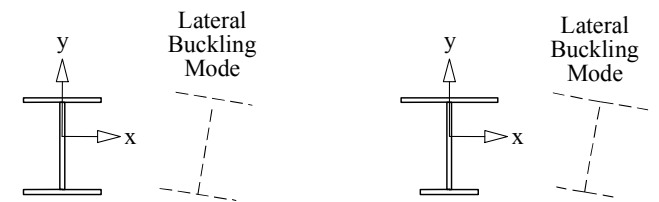
5.2.1 Elastic Buckling of Unbraced Simply Supported Beams

The elastic buckling moment (M_o) of a simply supported and I-beam, monosymmetric I-beam or T-beam bent about the x -axis perpendicular to the web as shown in Fig. 5.1(a) with equal and opposite end moments and of unbraced length (l) is given in Refs 5.1 and 5.2 and is equal to:

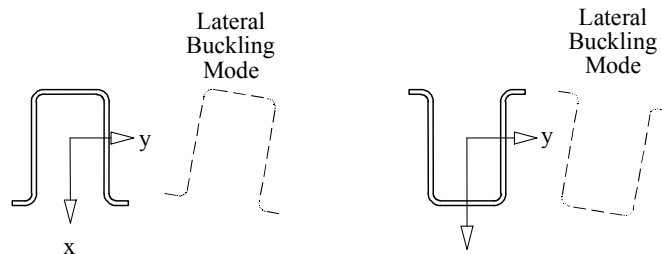
$$M_o = \frac{\pi\sqrt{EI_yGJ}}{l} \left[\frac{\pi\delta}{2} + \sqrt{\left(\frac{\pi\delta}{2}\right)^2 + \left(1 + \frac{\pi^2 EI_w}{GJ^2}\right)} \right] \quad (5.4)$$

where

$$\delta = \frac{\pm \beta_x}{l} \sqrt{\frac{EI_y}{GJ}} \quad (5.5)$$



(a) I-section and Monosymmetric I-section bent about x -axis



(b) Hat and Inverted Hat Sections bent about y -axis

Fig. 5.1 Lateral buckling modes and axes

The value of δ is positive when the larger flange is in compression, is zero for doubly symmetric beams, and is negative when the larger flange is in tension.



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

