

Fig. 3.10 Finite strip buckling analyses

3.3 Purlin Section Study

3.3.1 Channel Section

To demonstrate the different ways in which a channel purlin may buckle when subjected to major axis bending moment as shown in Fig. 3.11, a finite strip buckling analysis of a channel purlin of depth 150 mm, flange width 65 mm, lip size 14 mm, and plate thickness 1.5 mm has been performed and the results are shown in Fig. 3.12. This graph is similar to that for the lip-stiffened channel in Fig. 3.6 except for the shape of the buckling modes and their nomenclature.

The first minimum point (A) is again a LOCAL buckling mode which now involves the web, the compression flange and its lip stiffener. The second minimum point (B) is associated with a mode of buckling where the compression flange and lip rotate about the flange web junction with some elastic restraint to rotation provided by the web. This mode of buckling is called a FLANGE DISTORTIONAL buckling mode and is shown in a test specimen of a Z-section in Fig. 3.13. The value of the stiffener buckling stress is highly dependent upon the size of the lip stiffener.

At long wavelengths (point C) where the purlin is unrestrained, a flexural-torsional buckle occurs which is often called a LATERAL buckle. However if the tension flange is subjected to a torsional restraint such as may be provided by sheeting screw fastened to the tension flange, then a LATERAL DISTORTIONAL buckle will occur at a minimum half-wavelength of approximately 4000 mm as shown at point D in Fig. 3.12. The value of the minimum buckling stress and its half-wavelength depend upon the degree of torsional restraint provided to the tension flange.

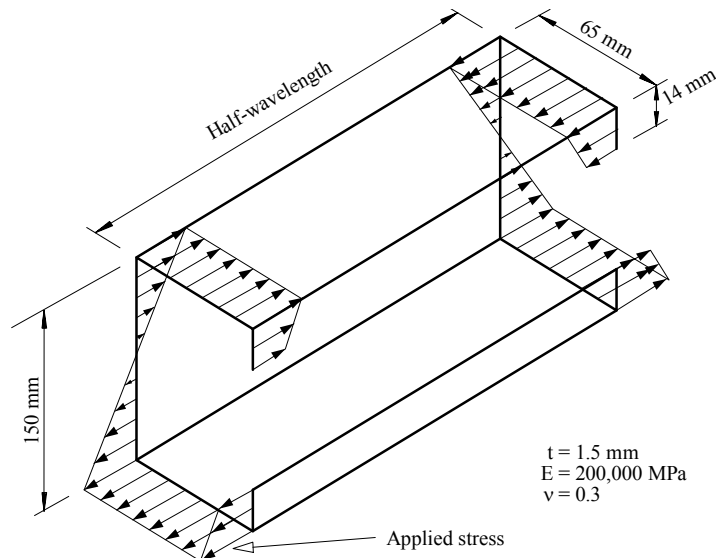


Fig. 3.11 Channel section purlin subjected to major axis bending moment



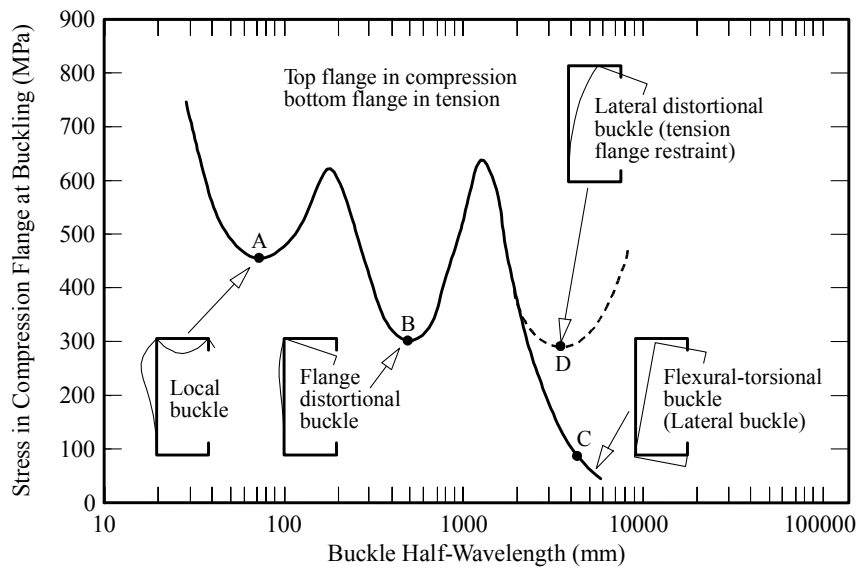


Fig. 3.12 Channel section purlin buckling stress versus half-wavelength for major axis bending



Fig. 3.13 Purlin flexural-torsional buckle with distortional buckle (foreground) and local buckle (background)

3.3.2 Z-Section

A similar study to that of the channel section in bending has been performed for the two Z-sections shown in Fig. 3.14. The first section contains a lip stiffener which is perpendicular to the flange and the second has a lip stiffener which is located at an angle of 45 degrees to the flange. In Fig. 3.14, the buckling stresses have been computed for buckle half-wavelengths up to 1000 mm so that only the local and stiffener buckling modes have been investigated.

As for the channel section study described above, the distortional buckling stresses are significantly lower than the local buckling stresses for both Z-sections. For the lip stiffener turned at 45 degrees to the flange, the flange distortional buckling stress is reduced by 19 percent compared with the value for the lip stiffener perpendicular to the flange thus indicating a potential failure mode of purlins with sloping lip stiffeners.



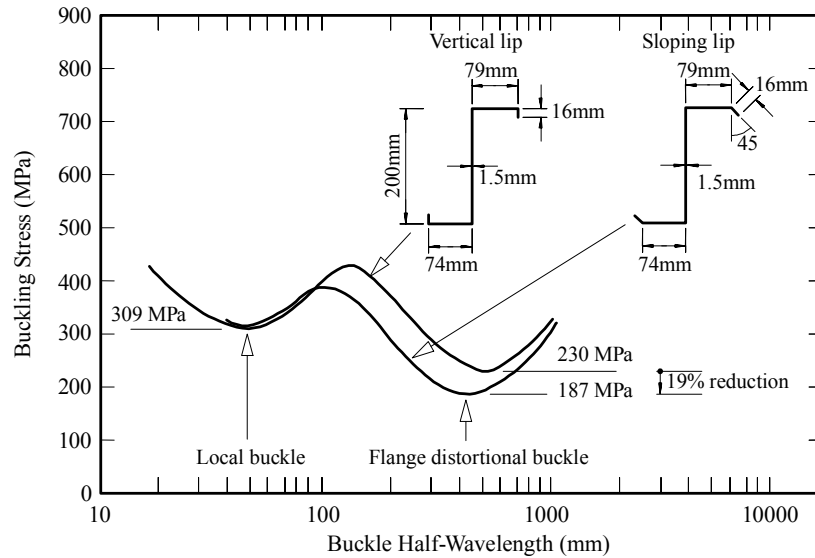


Fig. 3.14 Z-Section purlin - buckling stress versus half-wavelength for bending about a horizontal axis

3.4 Tubular Flange Sections

3.4.1 Hollow Flange Beam in Bending

The Hollow Flange Beam (HFB) section in Fig. 1.13 has been investigated using the semi-analytical finite strip buckling analysis. Two sections have been analysed to demonstrate the effect of the ERW weld on the section buckling behaviour. These are the section with closed flanges called ("HBS1"), and the section with open flanges (called "HBS2"). Fig. 3.15 shows graphs of buckling stress versus buckle half-wavelengths for the two sections subjected to pure bending about their major principal axes so that their top flanges are in compression and their bottom flanges are in tension as in a conventional beam. The buckling stress is the value of the stress in the compression flange farthest away from the bending axis when the section undergoes elastic buckling.

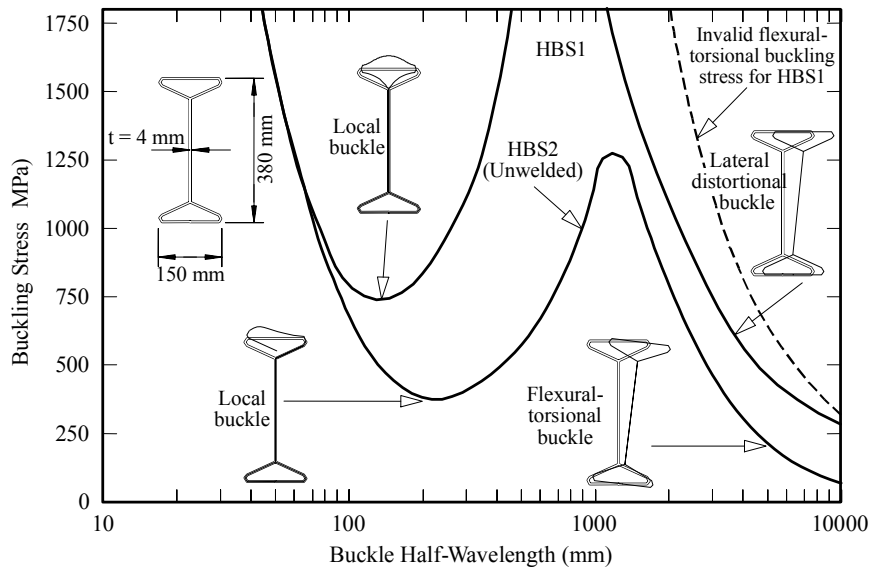


Fig. 3.15 Hollow flange beam - buckling stress versus half-wavelength for major axis bending

At short half-wavelengths (50 mm - 500 mm in Fig. 3.15), the effect of welding the flange to the abutting web clearly demonstrates the changed buckling mode from LOCAL BUCKLING in the unattached flange for HBS2 to LOCAL BUCKLING of the top flange at a higher stress for HBS1.

At long half-wavelengths (2000 mm - 10000 mm in Fig. 3.15), the increased torsional rigidity of



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

