

Composite Structures of Steel and Concrete

Beams, Slabs, Columns and Frames for Buildings

Fourth Edition

Roger P. Johnson

University of Warwick, UK

with Fire Resistance chapter contributed by

Yong C. Wang

University of Manchester, UK

WILEY Blackwell

Contents

Preface	<i>xi</i>
Symbols, Terminology and Units	<i>xv</i>
1 Introduction	1
1.1 Composite beams and slabs	1
1.2 Composite columns and frames	2
1.3 Design philosophy and the Eurocodes	3
1.3.1 Background	3
1.3.2 Limit state design philosophy	4
1.4 Properties of materials	8
1.4.1 Concrete	9
1.4.2 Reinforcing steel	10
1.4.3 Structural steel	10
1.4.4 Profiled steel sheeting	10
1.4.5 Shear connectors	11
1.5 Direct actions (loading)	11
1.6 Methods of analysis and design	12
1.6.1 Typical analyses	13
1.6.2 Non-linear global analysis	17
2 Shear Connection	19
2.1 Introduction	19
2.2 Simply-supported beam of rectangular cross-section	20
2.2.1 No shear connection	20
2.2.2 Full interaction	22
2.3 Uplift	24
2.4 Methods of shear connection	25
2.4.1 Bond	25
2.4.2 Shear connectors	25
2.4.3 Shear connection for profiled steel sheeting	29
2.5 Properties of shear connectors	29
2.5.1 Stud connectors used with profiled steel sheeting	33
2.5.2 Stud connectors in a 'lying' position	38
2.5.3 Example: stud connectors in a 'lying' position	39

2.6	Partial interaction	41
2.7	Effect of degree of shear connection on stresses and deflections	43
2.8	Longitudinal shear in composite slabs	44
2.8.1	The shear-bond test	45
2.8.2	Design by the $m-k$ method	47
2.8.3	Defects of the $m-k$ method	47
3	Simply-supported Composite Slabs and Beams	49
3.1	Introduction	49
3.2	Example: layout, materials and loadings	49
3.2.1	Properties of concrete	50
3.2.2	Properties of other materials	50
3.2.3	Resistance of the shear connectors	51
3.2.4	Permanent actions	51
3.2.5	Variable actions	51
3.3	Composite floor slabs	51
3.3.1	Resistance of composite slabs to sagging bending	54
3.3.2	Resistance of composite slabs to longitudinal shear by the partial-interaction method	56
3.3.3	Resistance of composite slabs to vertical shear	58
3.3.4	Punching shear	59
3.3.5	Bending moments from concentrated point and line loads	60
3.3.6	Serviceability limit states for composite slabs	62
3.4	Example: composite slab	63
3.4.1	Profiled steel sheeting as formwork	64
3.4.2	Composite slab – flexure and vertical shear	65
3.4.3	Composite slab – longitudinal shear	66
3.4.4	Local effects of point load	68
3.4.5	Composite slab – serviceability	69
3.4.6	Example: composite slab for a shallow floor using deep decking	70
3.4.7	Comments on the designs of the composite slab	73
3.5	Composite beams – sagging bending and vertical shear	73
3.5.1	Effective cross-section	73
3.5.2	Classification of steel elements in compression	74
3.5.3	Resistance to sagging bending	76
3.5.4	Resistance to vertical shear	84
3.5.5	Resistance of beams to bending combined with axial force	85
3.6	Composite beams – longitudinal shear	86
3.6.1	Critical lengths and cross-sections	86
3.6.2	Non-ductile, ductile and super-ductile stud shear connectors	87
3.6.3	Transverse reinforcement	90
3.6.4	Detailing rules	94
3.7	Stresses, deflections and cracking in service	95
3.7.1	Elastic analysis of composite sections in sagging bending	96
3.7.2	The use of limiting span-to-depth ratios	98
3.8	Effects of shrinkage of concrete and of temperature	99

3.9	Vibration of composite floor structures	99
3.9.1	Prediction of fundamental natural frequency	101
3.9.2	Response of a composite floor to pedestrian traffic	103
3.10	Hollow-core and solid precast floor slabs	104
3.10.1	Joints, longitudinal shear and transverse reinforcement	105
3.10.2	Design of composite beams that support precast slabs	105
3.11	Example: simply-supported composite beam	107
3.11.1	Composite beam – full-interaction flexure and vertical shear	108
3.11.2	Composite beam – partial shear connection, non-ductile connectors and transverse reinforcement	110
3.11.3	Composite beam – deflection and vibration	113
3.12	Shallow floor construction	117
3.13	Example: composite beam for a shallow floor using deep decking	119
3.14	Composite beams with large web openings	122
4	Continuous Beams and Slabs, and Beams in Frames	129
4.1	Types of global analysis and of beam-to-column joint	129
4.2	Hogging moment regions of continuous composite beams	133
4.2.1	Resistance to bending	133
4.2.2	Vertical shear, and moment-shear interaction	137
4.2.3	Longitudinal shear	138
4.2.4	Lateral buckling	139
4.2.5	Cracking of concrete	144
4.3	Global analysis of continuous beams	149
4.3.1	General	149
4.3.2	Elastic analysis	150
4.3.3	Rigid-plastic analysis	154
4.4	Stresses and deflections in continuous beams	156
4.5	Design strategies for continuous beams	157
4.6	Example: continuous composite beam	158
4.6.1	Data	158
4.6.2	Flexure and vertical shear	160
4.6.3	Lateral buckling	162
4.6.4	Shear connection and transverse reinforcement	164
4.6.5	Check on deflections	165
4.6.6	Control of cracking	168
4.7	Continuous composite slabs	169
5	Composite Columns and Frames	171
5.1	Introduction	171
5.2	Composite columns	173
5.3	Beam-to-column joints	173
5.3.1	Properties of joints	173
5.3.2	Classification of joints	179
5.4	Design of non-sway composite frames	180
5.4.1	Imperfections	180
5.4.2	Elastic stiffnesses of members	182

5.4.3	Methods of global analysis	183
5.4.4	First-order global analysis of braced frames	184
5.4.5	Outline sequence for design of a composite braced frame	186
5.5	Example: composite frame	187
5.5.1	Data	187
5.5.2	Design action effects and load arrangements	188
5.6	Simplified design method of EN 1994-1-1, for columns	189
5.6.1	Introduction	189
5.6.2	Detailing rules, and resistance to fire	190
5.6.3	Properties of column lengths	191
5.6.4	Resistance of a cross-section to combined compression and uniaxial bending	192
5.6.5	Verification of a column length	193
5.6.6	Transverse and longitudinal shear	195
5.6.7	Concrete-filled steel tubes	196
5.7	Example (continued): external column	197
5.7.1	Action effects	197
5.7.2	Properties of the cross-section, and y-axis slenderness	198
5.7.3	Resistance of the column length, for major-axis bending	201
5.7.4	Resistance of the column length, for minor-axis bending	202
5.7.5	Checks on shear, and closing comment	204
5.8	Example (continued): internal column	205
5.8.1	Global analysis	205
5.8.2	Resistance of an internal column	207
5.8.3	Comment on column design	207
5.9	Example (continued): design of frame for horizontal forces	207
5.9.1	Design loadings, ultimate limit state	208
5.9.2	Stresses and stiffness	209
5.10	Example (continued): joints between beams and columns	209
5.10.1	Nominally-pinned joint at external column	209
5.10.2	End-plate joint at internal column	210
5.11	Example: concrete-filled steel tube with high-strength materials	216
5.11.1	Loading	216
5.11.2	Action effects for the column length	216
5.11.3	Effect of creep	217
5.11.4	Slenderness	218
5.11.5	Bending moment	218
5.11.6	Interaction polygon, and resistance	218
5.11.7	Discussion	219
6	Fire Resistance	223
	<i>Yong C. Wang</i>	
6.1	General introduction and additional symbols	223
6.1.1	Fire resistance requirements	224
6.1.2	Fire resistance design procedure	225
6.1.3	Partial safety factors and material properties	226

6.2	Composite slabs	226
6.2.1	General calculation method	226
6.2.2	Tabulated data	227
6.2.3	Tensile membrane action	227
6.3	Composite beams	229
6.3.1	Critical temperature method	229
6.3.2	Temperature of protected steel	232
6.3.3	Load-carrying capacity calculation method	234
6.3.4	Appraisal of different calculation methods for composite beams	238
6.3.5	Shear resistance	238
6.4	Composite columns	239
6.4.1	General calculation method and methods for different types of columns	240
6.4.2	Concrete-filled tubes	241
6.4.3	Worked example for concrete-filled tubes with eccentric loading	244
A	Partial-interaction theory	247
A.1	Theory for simply-supported beam	247
A.2	Example: partial interaction	250

References 253

Index 259