

Contents

<i>Preface to the fourth edition</i>	xvii
<i>Preface to the third edition</i>	xix
<i>Preface to the second edition</i>	xxi
<i>Preface to the first edition</i>	xxiii
1 Introduction to structural design: The meaning, the purpose and the limits of structural design – general	1
1.1 <i>Introduction</i> 1	
1.2 <i>Phases of structural design</i> 1	
1.2.1 <i>Basic considerations concerning the structural design process</i> 3	
1.3 <i>The meanings of structural design</i> 3	
1.4 <i>Can structural design be taught?</i> 4	
1.5 <i>Databases and expert systems in structural design</i> 5	
1.6 <i>The importance of the computer modelling process</i> 5	
2 Steel structures – structural engineering	9
2.1 <i>Need for and use of structures</i> 9	
2.2 <i>Structural materials – types and uses</i> 10	
2.3 <i>Types of structures</i> 11	
2.3.1 <i>General types of structures</i> 11	
2.3.2 <i>Steel structures</i> 12	
2.4 <i>Foundations</i> 14	
2.5 <i>Structural engineering</i> 15	
2.5.1 <i>Scope of structural engineering</i> 15	
2.5.2 <i>Structural designer's work</i> 16	
2.6 <i>Conceptual design, innovation and planning</i> 17	
2.7 <i>Comparative design and optimization</i> 19	
2.7.1 <i>General considerations</i> 19	

2.7.2	<i>Aims and factors considered in design comparison</i>	20
2.7.3	<i>Specific basis of comparisons for common structures</i>	21
2.8	<i>Load paths, structural idealization and modelling</i>	24
2.8.1	<i>Load paths</i>	24
2.8.2	<i>Structural idealization</i>	25
2.8.3	<i>Modelling</i>	25
2.9	<i>Drawings, specifications and quantities</i>	27
2.9.1	<i>Steelwork drawings</i>	27
2.9.2	<i>Specification</i>	28
2.9.3	<i>Quantities</i>	29
2.10	<i>Fabrication</i>	30
2.11	<i>Transport and erection</i>	30

3 Structural steel design 33

3.1	<i>Design theories</i>	33
3.1.1	<i>Development of design</i>	33
3.1.2	<i>Design from experience</i>	33
3.1.3	<i>Elastic theory</i>	33
3.1.4	<i>Plastic theory</i>	36
3.1.5	<i>Limit state theory and design codes</i>	36
3.2	<i>Limit states and design basis</i>	37
3.3	<i>Loads, actions and partial safety factors</i>	38
3.3.1	<i>Loads</i>	38
3.3.2	<i>Partial factors for loads/partial safety factors and design loads</i>	39
3.4	<i>Structural steels – partial safety factors for materials</i>	40
3.5	<i>Design methods from codes – ultimate limit state</i>	40
3.5.1	<i>Design methods from BS 5950</i>	40
3.5.2	<i>Analysis of structures – EC3</i>	42
3.5.3	<i>Member and joint design</i>	43
3.6	<i>Stability limit state</i>	44
3.7	<i>Design for accidental damage</i>	45
3.7.1	<i>Progressive collapse and robustness</i>	45
3.7.2	<i>Building Regulations 1991</i>	45
3.7.3	<i>BS 5950 requirements for structural integrity</i>	46
3.8	<i>Serviceability limit states</i>	47
3.8.1	<i>Deflection limits</i>	47
3.8.2	<i>Vibration</i>	48

3.9	<i>Design considerations</i>	48
3.9.1	<i>Fatigue</i>	48
3.9.2	<i>Brittle fracture</i>	49
3.9.3	<i>Corrosion protection</i>	50
3.9.4	<i>Fire protection</i>	52
4	Preliminary design	57
4.1	<i>General considerations</i>	57
4.2	<i>Need for and scope of preliminary design methods</i>	57
4.3	<i>Design concept, modelling and load estimation</i>	58
4.3.1	<i>Design concept</i>	58
4.3.2	<i>Modelling</i>	59
4.3.3	<i>Load estimation</i>	59
4.4	<i>Analysis</i>	60
4.4.1	<i>Statically determinate structures</i>	60
4.4.2	<i>Statically indeterminate structures</i>	62
4.5	<i>Element design</i>	66
4.5.1	<i>General comments</i>	66
4.5.2	<i>Ties and struts</i>	67
4.5.3	<i>Beams and girders</i>	69
4.5.4	<i>Beam–columns</i>	72
4.5.5	<i>Members in portal frames</i>	72
4.6	<i>Examples</i>	73
4.6.1	<i>Ribbed dome structure</i>	73
4.6.2	<i>Two-pinned portal – plastic design</i>	75
5	Single-storey, one-way-spanning buildings	77
5.1	<i>Types of structures</i>	77
5.2	<i>Pinned-base portal – plastic design</i>	78
5.2.1	<i>Specification and framing plans</i>	78
5.2.2	<i>Dead and imposed loads</i>	79
5.2.3	<i>Wind loads</i>	80
5.2.4	<i>Design load cases</i>	84
5.2.5	<i>Plastic analysis and design</i>	86
5.2.6	<i>Dead and wind loads</i>	87
5.2.7	<i>Plastic design – checks</i>	87
5.2.8	<i>Rafter under wind uplift</i>	97
5.2.9	<i>Portal joints</i>	99
5.2.10	<i>Serviceability check</i>	102

5.3	<i>Built-up tapered member portal</i>	103
5.3.1	<i>General comments</i>	103
5.3.2	<i>Design process</i>	104
5.4	<i>Two-pinned arch</i>	104
5.4.1	<i>General considerations</i>	104
5.4.2	<i>Specification</i>	105
5.4.3	<i>Loading</i>	105
5.4.4	<i>Analysis</i>	108
5.4.5	<i>Design</i>	108
5.4.6	<i>Construction</i>	111
5.4.7	<i>Lattice arch</i>	111
6	Single-storey, one-way-spanning pinned-base portal-plastic design to EC3	117
6.1	<i>Type of structure</i>	117
6.2	<i>Sway stability</i>	117
6.2.1	<i>For dead and imposed load</i>	117
6.3	<i>Arching stability check-rafter, snap through</i>	118
6.4	<i>Check the column</i>	119
6.4.1	<i>Section classification</i>	119
6.4.2	<i>Moment of resistance</i>	121
6.4.3	<i>Column buckling between intermediate restraints</i>	121
6.4.4	<i>Column buckling between torsional restraints</i>	123
6.5	<i>Stability of the rafter</i>	127
6.5.1	<i>Section classification</i>	127
6.5.2	<i>Moment of resistance</i>	128
6.5.3	<i>Rafter check buckling between intermediate restraints</i>	129
6.5.4	<i>Rafter check buckling between torsional restraints (stays)</i>	132
7	Multistorey buildings	137
7.1	<i>Outline of designs covered</i>	137
7.1.1	<i>Aims of study</i>	137
7.1.2	<i>Design to BS 5950</i>	137
7.2	<i>Building and loads</i>	137
7.2.1	<i>Specification</i>	137
7.2.2	<i>Loads</i>	138
7.2.3	<i>Materials</i>	140

7.3	<i>Simple design centre frame</i>	140
7.3.1	<i>Slabs</i>	140
7.3.2	<i>Roof beam</i>	140
7.3.3	<i>Floor beam</i>	141
7.3.4	<i>Outer column – upper length 7–10–13</i>	141
7.3.5	<i>Outer column – lower length 1–4–7</i>	143
7.3.6	<i>Centre column – upper length 8–11–14</i>	144
7.3.7	<i>Centre column – lower length 2–5–8</i>	144
7.3.8	<i>Joint design</i>	145
7.3.9	<i>Baseplate – centre column</i>	146
7.4	<i>Braced rigid elastic design</i>	146
7.4.1	<i>Computer analysis</i>	146
7.4.2	<i>Beam design</i>	149
7.4.3	<i>Column design</i>	151
7.4.4	<i>Joint design</i>	154
7.5	<i>Braced rigid plastic design</i>	157
7.5.1	<i>Design procedure</i>	157
7.5.2	<i>Design loads and moments</i>	157
7.5.3	<i>Frame design</i>	159
7.6	<i>Semirigid design</i>	167
7.6.1	<i>Code requirements</i>	167
7.6.2	<i>Joint types and performance</i>	169
7.6.3	<i>Frame analysis</i>	170
7.6.4	<i>Frame design</i>	173
7.7	<i>Summary of designs</i>	182
8	Multistorey buildings, simple design to EC3	183
8.1	<i>Outline of design covered</i>	183
8.1.1	<i>Aims of study</i>	183
8.1.2	<i>Design to EC3</i>	183
8.2	<i>Simple design centre frame</i>	184
8.2.1	<i>Roof beam with full lateral restraints</i>	184
8.2.2	<i>Floor beam – full lateral restraints</i>	188
8.3	<i>Braced rigid elastic design/floor beam 10–11–12</i>	190
8.3.1	<i>Check buckling resistance of beam $M_{b,Rd} > M_{F,d}$</i>	190
8.4	<i>Column – upper length 7–10–13, design and checking using EC3</i>	192
8.4.1	<i>Check resistance of cross-sections, bending and axial force (Clause 5.4.8 EC3)</i>	193

8.4.2	<i>Resistance of member: Combined bending and axial compression (Clause 5.5.4 EC3)</i>	193
8.5	<i>Outer column – lower length 1–4–7</i>	195
8.5.1	<i>Check column below 1st floor at joint 4</i>	195
8.6	<i>Base plate (EC Annex L, Clause L1 EC3)</i>	198
8.6.1	<i>Check bearing pressure and strength $N_{sd}/A_{ef} \leq f_i$</i>	198
8.6.2	<i>Check resisting moment $M_{Ed} < M_{Rd}$</i>	200
8.7	<i>Joint design (Figure 5.4 EC3)</i>	200
8.7.1	<i>Check positioning for holes for bolts</i>	200
8.7.2	<i>Check shear resistance of bolt group (Clause 6.5.5 and Table 3.3 EC3)</i>	202
8.7.3	<i>Check bearing resistance</i>	202
8.7.4	<i>Shear resistance of leg of cleat</i>	203

9 Floor systems 205

9.1	<i>Functions of floor systems</i>	205
9.2	<i>Layouts and framing systems</i>	205
9.3	<i>Types of floor construction</i>	207
9.4	<i>Composite floor slabs</i>	207
9.4.1	<i>General comments</i>	207
9.4.2	<i>Design procedure</i>	209
9.5	<i>Composite beam design</i>	210
9.5.1	<i>Design basis</i>	210
9.5.2	<i>Effective section</i>	210
9.5.3	<i>Plastic moment capacity</i>	212
9.5.4	<i>Construction</i>	212
9.5.5	<i>Continuous beam analysis</i>	212
9.5.6	<i>Design of members</i>	213
9.5.7	<i>Shear connectors (Section 5.4 of code)</i>	213
9.5.8	<i>Longitudinal shear (Section 5.6 of code)</i>	214
9.5.9	<i>Deflection (Section 6 of code)</i>	215
9.6	<i>Simply supported composite beam</i>	215
9.6.1	<i>Specification</i>	215
9.6.2	<i>Moment capacity (Section 4.4 of code)</i>	216
9.6.3	<i>Shear (Section 5.3.4 of code)</i>	217
9.6.4	<i>Shear connectors (Section 5.4 of code)</i>	217
9.6.5	<i>Longitudinal shear</i>	217
9.6.6	<i>Deflection (Section 6.1 of code)</i>	218
9.7	<i>Continuous composite beam</i>	219
9.7.1	<i>Specification</i>	219
9.7.2	<i>Floor loads</i>	219

9.7.3	<i>Elastic analysis and redistribution</i>	221
9.7.4	<i>Section design checks</i>	225
9.7.5	<i>Shear connectors</i>	229
9.7.6	<i>Longitudinal shear</i>	230
9.7.7	<i>Deflection (Clause 6.1.1)</i>	232
10	Composite floor system to EC4	235
10.1	<i>Composite floor and composite beams</i>	235
10.1.1	<i>The method of construction</i>	237
10.1.2	<i>Effective width of the concrete flange (BS EN 1994-1-1 2004(E), Clause 5.4.1.2 (3-9))</i>	237
10.1.3	<i>General comments on design</i>	238
10.2	<i>Initial selection of the steel beam size</i>	239
10.2.1	<i>Design case study</i>	239
10.2.2	<i>Design data</i>	240
10.2.3	<i>Initial selection of beam size</i>	240
10.2.4	<i>Construction stage design</i>	241
10.3	<i>Plastic analysis of composite section</i>	241
10.3.1	<i>Composite stage design, $M_{pl,d}$</i>	244
10.3.2	<i>Compression resistance of concrete slab, R_c</i>	244
10.3.3	<i>Compression resistance of steel section, R_s</i>	244
10.3.4	<i>Moment resistance of the composite beam, $M_{pl,Rd}$</i>	244
10.3.5	<i>Location of neutral axis</i>	245
10.4	<i>The shear resistance of the composite section</i>	245
10.5	<i>Case study – shear connectors resistance</i>	248
10.5.1	<i>Partial shear connection</i>	248
10.5.2	<i>Longitudinal shear force transfer, R_q</i>	250
10.5.3	<i>Degree of shear connection, N/N_f (Clause 6.2.13): For $R_s < R_c$</i>	250
10.5.4	<i>Composite steel section with partial shear connection: Moment resistance</i>	250
10.6	<i>Checks for serviceability limit state</i>	251
10.6.1	<i>Deflection for non-composite stage</i>	251
10.6.2	<i>Deflection for composite, at service</i>	252
10.6.3	<i>Composite beam total deflection</i>	253
10.7	<i>Check transverse reinforcement</i>	253
10.8	<i>Check shear per unit length, v</i>	254
10.9	<i>Check vibration</i>	254

11	Tall buildings	257
11.1	<i>General considerations</i>	257
11.2	<i>Structural design considerations</i>	258
11.3	<i>Structural systems</i>	259
11.3.1	<i>All-steel braced structure</i>	259
11.3.2	<i>Rigid frame and mixed systems</i>	260
11.3.3	<i>All-steel outrigger and belt truss system</i>	262
11.3.4	<i>Composite structures</i>	262
11.3.5	<i>Suspended structures</i>	265
11.3.6	<i>Tube structures</i>	266
11.3.7	<i>SWMB structures</i>	268
11.4	<i>Construction details</i>	268
11.4.1	<i>Roofs and floors</i>	268
11.4.2	<i>Walls</i>	269
11.4.3	<i>Steel members</i>	270
11.5	<i>Multistorey building – preliminary design</i>	270
11.5.1	<i>Specification</i>	270
11.5.2	<i>Dead and imposed loads</i>	274
11.5.3	<i>Beam loads and design</i>	274
11.5.4	<i>Design of perimeter column PC1</i>	278
11.5.5	<i>Braced core wall – vertical loads</i>	281
11.5.6	<i>Wind loads</i>	283
11.5.7	<i>Stability, foundations and bracing</i>	287
12	Wide-span buildings	289
12.1	<i>Types and characteristics</i>	289
12.2	<i>Tie-stayed roof – preliminary design</i>	292
12.2.1	<i>Specification</i>	292
12.2.2	<i>Preliminary design</i>	292
12.2.3	<i>Stability and wind load</i>	300
12.3	<i>Space decks</i>	302
12.3.1	<i>Two-way spanning roofs</i>	302
12.3.2	<i>Space decks</i>	302
12.3.3	<i>Space deck analyses and design</i>	305
12.4	<i>Preliminary design for a space deck</i>	306
12.4.1	<i>Specification</i>	306
12.4.2	<i>Arrangement of space deck</i>	306
12.4.3	<i>Approximate analysis and design</i>	306
12.4.4	<i>Computer analysis</i>	309

12.4.5	<i>Computer results</i>	312
12.4.6	<i>Member design</i>	312
12.5	<i>Framed domes</i>	313
12.5.1	<i>Types</i>	313
12.5.2	<i>Dome construction</i>	316
12.5.3	<i>Loading</i>	316
12.5.4	<i>Analysis</i>	317
12.5.5	<i>Stability</i>	318
12.6	<i>Schwedler dome</i>	318
12.6.1	<i>Specification</i>	318
12.6.2	<i>Loading for statical analysis</i>	320
12.6.3	<i>Statrical analysis</i>	320
12.6.4	<i>Member design</i>	324
12.6.5	<i>Membrane analysis</i>	325
12.7	<i>Retractable roof stadium</i>	326
12.7.1	<i>Introduction</i>	326
12.7.2	<i>Proposed structure</i>	327
12.7.3	<i>Preliminary section sizes</i>	328
12.7.4	<i>Problems in design and operation</i>	330
13	Composite steel columns to EC3 and EC4: Theory, uses and practical design studies	331
13.1	<i>Theory and general requirements</i>	331
13.2	<i>Design notes, partially or totally encased universal columns</i>	331
13.3	<i>Column symmetric about both axes. General requirement of BS EC EN 1994-1-1</i>	333
13.3.1	<i>The steel contribution ratio δ satisfies the following limits</i>	333
13.3.2	<i>The relative slenderness $\bar{\lambda}$ for relevant plane of bending</i>	334
13.4	<i>Axial compression resistance of composite column cross section: Design resistance ($\chi N_{pl,Rd}$)</i>	335
13.5	<i>Resistance of composite column cross section in combined compression and bending</i>	335
13.6	<i>Case study 1: Composite column: Compression resistance of cross section</i>	336
13.6.1	<i>Check h/t (actual) < 52e (allowable), Clause 9.7.9, Table 6.3 BS EN 1994-1-1 2004(E)</i>	337
13.6.2	<i>Plastic resistance of cross section, $N_{pl,Rd}$</i>	337

13.7	<i>Case study 2: Resistance of composite column in combined compression and bending about the major axis</i>	338
13.7.1	<i>Section properties</i>	338
13.7.2	<i>Plastic compression resistance, $N_{pl,Rd}$</i>	339
13.7.3	<i>Steel contribution ratio, δ</i>	339
13.7.4	<i>Maximum moment capacity, $M_{max,Rd}$</i>	339
13.7.5	<i>Resistance of concrete to compression normal force, $N_{pm,Rd}$</i>	339
13.7.6	<i>Neutral axis position, h_n</i>	340
13.7.7	<i>Calculate W_{pcn}, $M_{n,Rd}$, $M_{pl,Rd}$</i>	340
13.7.8	<i>Resistance of composite column for axial buckling about the major axis</i>	341
13.7.9	<i>Compression and bending resistance of column based on second-order linear elastic analysis</i>	342
13.8	<i>Case study 3: Combined compression and biaxial bending</i>	343
13.8.1	<i>Interaction diagrams for y-y axis and z-z axis</i>	343
13.8.2	<i>Resistance to axial buckling about the minor axis z-z</i>	345
13.8.3	<i>Second-order effects (major y-y axis) – based on second-order linear elastic analysis</i>	345
13.8.4	<i>Second-order effects (minor z-z axis) – based on second-order linear elastic analysis</i>	346
13.8.4.1	<i>Major axis, M_{350}, minor axis, M_{350}</i>	346
13.8.4.2	<i>Compression and bending resistance of column based on second-order linear elastic analysis</i>	347
14	Steel plate girders: Design to EC3	349
14.1	<i>General theory, uses and practical examples/applications</i>	349
14.2	<i>Design of plate girder</i>	352
14.2.1	<i>Critical h_w/t_w ratio for a girder with no web stiffeners</i>	352
14.2.2	<i>Design methods</i>	355
14.2.3	<i>Plate girder bending moment resistance</i>	355
14.2.4	<i>Plate girder cross section classification</i>	355
14.2.5	<i>Design of the plate girder web sectional dimensions</i>	356
14.2.6	<i>Nondimensional slenderness ration ($\bar{\lambda}_w$)</i>	358
14.2.7	<i>Shear capacity of web</i>	359
14.2.7.1	<i>Nonrigid end post</i>	359
14.2.7.2	<i>Rigid end post</i>	360

14.2.8	<i>Design shear resistance $V_{b,Rd}$</i>	361
14.2.9	<i>Design of stiffeners</i>	363
14.2.9.1	<i>Rigid end post (see cl. 9.3.1, EN 1993-1-5)</i>	363
14.2.9.2	<i>Minimum cross-sectional area of stiffener of rigid end post, A_{min}</i>	363
14.2.9.3	<i>Nonrigid end post spacing between stiffeners</i>	366
14.2.9.4	<i>Intermediate transverse stiffeners</i>	367
14.2.10	<i>Buckling resistance of the stiffener (cl. 9.1, EN 1993-1-3)</i>	368
14.2.10.1	<i>Buckling resistance of intermediate stiffener</i>	368
14.2.10.2	<i>Buckling resistance of the end stiffener</i>	369
14.2.11	<i>Web to flange welds</i>	369
15	Plate girder: Practical design studies	371
15.1	<i>Total design loads acting on the plate girder</i>	371
15.2	<i>Maximum bending moment acting on the plate girder</i>	371
15.3	<i>Web critical slenderness ratio</i>	371
15.4	<i>Plate girder: Dimensions of cross-section</i>	372
15.4.1	<i>Web thickness t_w and web depth h_w</i>	372
15.4.2	<i>Deciding plate girder flange thickness</i>	372
15.5	<i>Check that actual h_w/t_w ratio < allowable h_w/t_w</i>	373
15.6	<i>Plate girder cross-section classification</i>	373
15.6.1	<i>Web classification</i>	373
15.6.2	<i>Classification of the flanges</i>	374
15.7	<i>Check plastic moment of resistance of the flanges $M_{pl,Rd}$</i>	374
15.8	<i>Maximum shear force</i>	374
15.9	<i>Web design</i>	374
15.9.1	<i>Determination of χ_v</i>	374
15.10	<i>Plate girder with nonrigid end post</i>	375
15.10.1	<i>The shear capacity $V_{b,Rd}$ of the first panel from the support is given by</i>	375
15.10.2	<i>Intermediate stiffeners—strength check</i>	377
15.10.2.1	<i>First intermediate stiffener</i>	377
15.10.2.2	<i>Second intermediate stiffener</i>	378
15.10.3	<i>Dimensions of stiffeners: The minimum stiffness requirement</i>	380
15.11	<i>Intermediate stiffener: Buckling check</i>	380
15.12	<i>Plate girder: End stiffener – nonrigid end post</i>	381

15.1.3 Welding between flange and webs, Clause 9.3.5-BS EN 1993-1-5 2006(E)	384
15.14 Plate girder with rigid end post	384
15.14.1 Intermediate stiffener	384
15.15 Rigid end post	387
16 Sustainable steel buildings and energy saving	391
16.1 Sustainable steel buildings	391
16.2 Energy saving and thermal insulation	392
16.3 The U-value	394
16.4 Resistances of surfaces	395
16.5 Resistances of air spaces	395
16.6 Example calculation	395
16.7 Some maximum U-values	396
16.7.1 Example calculation 1	396
16.7.2 Example calculation 2	396
16.7.3 Example calculation 3	397
16.7.4 Example calculation 4	397
16.7.5 Example calculation 5	398
16.7.6 Example calculation 6	398
16.8 Thermal conductivities of commonly used insulating materials	399
16.9 Some typical k-values (W/m K)	399
16.10 Thermal insulation	401
16.11 Acoustic insulation	403
<i>Bibliography</i>	405
<i>Index</i>	413