

# TABLE OF CONTENTS

<b>FOREWORD</b>	<b>xiii</b>
<b>PREFACE</b>	<b>xvii</b>
<b>Chapter 1</b>	
<b>SEISMIC DESIGN PRINCIPLES IN STRUCTURAL CODES</b>	<b>1</b>
1.1 Introduction	1
1.2 Fundamentals of seismic design	2
1.2.1 Capacity design	2
1.2.2 Seismic design concepts	6
1.3 Codification of seismic design	11
1.3.1 Evolution of seismic design codes	11
1.3.2 New perspectives and trends in seismic codification	19
<b>Chapter 2</b>	
<b>EN 1998-1: GENERAL AND MATERIAL INDEPENDENT PARTS</b>	<b>25</b>
2.1 Introduction	25
2.2 Performance requirements and compliance criteria	27
2.2.1 Fundamental requirements	27
2.2.2 Ultimate limit state	32
2.2.3 Damage limitation state	34
2.2.4 Specific measures	35
2.3 Seismic action	36
2.3.1 The fundamentals of the dynamic model	36
2.3.2 Basic representation of the seismic action	40
2.3.3 The seismic action according to EN 1998-1	46
2.3.4 Alternative representations of the seismic action	52
2.3.5 Design spectrum for elastic analysis	54
2.3.6 Combinations of the seismic action with other types of actions	56
2.4 Characteristics of earthquake resistant buildings	58
2.4.1 Basic principles of conceptual design	58
2.4.2 Primary and secondary seismic members	60

## TABLE OF CONTENTS

---

2.4.3	Criteria for structural regularity	61
2.5	Methods of structural seismic analysis	70
2.5.1	Introduction	70
2.5.2	Lateral force method	72
2.5.3	Linear modal response spectrum analysis	75
2.5.4	Nonlinear static pushover analysis	84
2.5.5	Nonlinear time-history dynamic analysis	90
2.6	Structural modelling	94
2.6.1	Introduction	94
2.6.2	Modelling of masses	96
2.6.3	Modelling of damping	98
2.6.4	Modelling of structural mechanical properties	101
2.7	Accidental torsional effects	107
2.7.1	Accidental eccentricity	107
2.7.2	Accidental torsional effects in the lateral force method of analysis	109
2.7.3	Accidental torsional effects in modal response spectrum analysis	110
2.7.4	Accidental torsional effects in nonlinear static pushover analysis	111
2.7.5	Accidental torsional effects in linear and nonlinear dynamic time history analysis	114
2.8	Combination of effects induced by different components of the seismic action	114
2.9	Calculation of structural displacements	117
2.10	Second order effects in seismic linear elastic analysis	118
2.11	Design verifications	121
2.11.1	Safety verifications	121
2.11.2	Damage limitation	126
 <b>Chapter 3</b>		
<b>EN 1998-1: DESIGN PROVISIONS FOR STEEL STRUCTURES 129</b>		
3.1	Design concepts for steel buildings	129
3.2	Requirements for steel mechanical properties	133
3.2.1	Strength and ductility	133
3.2.2	Toughness	135

---

3.3	Structural typologies and behaviour factors	137
3.3.1	Structural types	137
3.3.2	Behaviour factors	141
3.4	Design criteria and detailing rules for dissipative structural behaviour common to all structural types	145
3.4.1	Introduction	145
3.4.2	Design rules for cross sections in dissipative members	145
3.4.3	Design rules for non-dissipative connections	147
3.4.4	Design rules and requirements for dissipative connections	148
3.4.5	Design rules and requirements for non-dissipative members	148
3.5	Design criteria and detailing rules for moment resisting frames	149
3.5.1	Code requirements for beams	149
3.5.2	Code requirements for columns	152
3.5.3	Code requirements for beam-to-column joints	153
3.6	Design criteria and detailing rules for concentrically braced frames	158
3.6.1	Code requirements for braces	158
3.6.2	Code requirements for beams and columns	162
3.7	Design criteria and detailing rules for eccentrically braced frames	164
3.7.1	Code requirements for seismic links	164
3.7.2	Code requirements for members not containing seismic links	171
3.7.3	Code requirements for connections of the seismic links	172

## Chapter 4

<b>DESIGN RECOMMENDATIONS FOR DUCTILE DETAILS</b>	<b>173</b>	
4.1	Introduction	173
4.2	Seismic design and detailing of composite steel-concrete slabs	174
4.3	Ductile details for moment resisting frames	182
4.3.1	Detailing of beams	182
4.3.2	Detailing of beam-to-column joints	186
4.3.3	Detailing of column bases	210
4.4	Ductile details for concentrically braced frames	215
4.4.1	Introduction	215
4.4.2	Detailing of brace-to-beam/column joints	216
4.4.3	Detailing of brace-to-beam midspan connections	228
4.4.4	Detailing of brace-to-brace connections	230
4.4.5	Detailing of brace-to-column base connections	235

## TABLE OF CONTENTS

---

4.4.6	Optimal slope, constructional tolerances and local details for braces	236
4.5	Ductile details for eccentrically braced frames	239
4.5.1	Detailing of links	239
4.5.2	Detailing of link lateral torsional restraints	241
4.5.3	Detailing of diagonal brace-to-link connections	244
4.5.4	Detailing of link-to-column connections	245

### Chapter 5

#### **DESIGN ASSISTED BY TESTING** **247**

---

5.1	Introduction	247
5.2	Design assisted by testing according to EN 1990	248
5.2.1	Introduction	248
5.2.2	General overview of EN 1990	250
5.2.3	Testing	252
5.2.4	Derivation of design values	254
5.3	Testing of seismic components and devices	262
5.3.1	Introduction	262
5.3.2	Quasi-static monotonic and cyclic testing	262
5.3.3	Pseudo-dynamic testing	275
5.3.4	Dynamic testing	277
5.4	Application: experimental qualification of buckling restrained braces	278
5.4.1	Introduction and scope	278
5.4.2	Test specifications	279
5.4.3	Test specimens	280
5.4.4	Test setup and loading protocol for ITT	280
5.4.5	Results	281
5.4.6	Fabrication Production Control tests	283

### Chapter 6

#### **MULTI-STOUREY BUILDING WITH MOMENT RESISTING FRAMES** **285**

---

6.1	Building description and design assumptions	285
6.1.1	Building description	285
6.1.2	Normative references	287
6.1.3	Materials	288

---

6.1.4	Actions	289
6.1.5	Pre-design	292
6.2	Structural analysis and calculation models	293
6.2.1	General features	293
6.2.2	Modelling assumptions	296
6.2.3	Numerical models and method of analysis	297
6.2.4	Imperfections for global analysis of frames	301
6.2.5	Frame stability and second order effects	303
6.3	Design and verification of structural members	304
6.3.1	Design and verification of beams	304
6.3.2	Design and verification of columns	310
6.3.3	Panel zone of beam-to-column joints	316
6.4	Damage limitation	319
6.5	Pushover analysis and assessment of seismic performance	320
6.5.1	Introduction	320
6.5.2	Modelling assumptions	321
6.5.3	Pushover analysis	328
6.5.4	Transformation to an equivalent SDOF system	331
6.5.5	Evaluation of the seismic demand	333
6.5.6	Evaluation of the structural performance	334

**Chapter 7**

**MULTI-STOREY BUILDING WITH CONCENTRICALLY BRACED FRAMES**

		<b>335</b>
7.1	Building description and design assumptions	335
7.1.1	Building description	335
7.1.2	Normative references	337
7.1.3	Materials	337
7.1.4	Actions	338
7.1.5	Pre-design	340
7.2	Structural analysis and calculation models	342
7.2.1	General features	342
7.2.2	Modelling assumptions	342
7.2.3	Numerical models and method of analysis	344
7.2.4	Imperfections for global analysis of frames	348
7.2.5	Frame stability and second order effects	349

## TABLE OF CONTENTS

---

7.3	Design and verification of structural members	350
7.3.1	Design and verification of X-CBFs	350
7.3.2	Design and verification of inverted V-CBFs	357
7.4	Damage limitation	365

## Chapter 8

### MULTI-STOREY BUILDING WITH ECCENTRICALLY BRACED

#### FRAMES 369

---

8.1	Building description and design assumptions	369
8.1.1	Building description	369
8.1.2	Normative references	371
8.1.3	Materials	371
8.1.4	Actions	372
8.2	Structural analysis and calculation models	374
8.2.1	General features	374
8.2.2	Modelling assumptions	375
8.2.3	Numerical models and method of analysis	376
8.2.4	Imperfections for global analysis of frames	380
8.2.5	Frame stability and second order effects	380
8.3	Design and verification of structural members	381
8.3.1	Design and verification of shear links	381
8.3.2	Design and verification of beam segments outside the link	384
8.3.3	Design and verification of braces	384
8.3.4	Design and verification of columns	385
8.4	Damage limitation	388

## Chapter 9

### CASE STUDIES 391

---

9.1	Introduction	391
9.2	The Bucharest Tower Centre International	393
9.2.1	General description	393
9.2.2	Design considerations	397
9.2.3	Detailing	421
9.2.4	Construction	422
9.3	Single storey Industrial Warehouse in Bucharest	432
9.3.1	General description	432

---

9.3.2	Design considerations	435
9.4	The Fire Station of Naples	449
9.4.1	General description	449
9.4.2	Design considerations and constructional details	456
9.4.3	The anti-seismic devices	467
<b>REFERENCES</b>		<b>475</b>

---

