

TABLE OF CONTENTS

FOREWORD	xiii
PREFACE	xv
NOTATIONS	xix

Chapter 1

INTRODUCTION	1
1.1. Relations between different Eurocodes	1
1.2. Scope of EN 1993-1-2	3
1.3. Layout of the book	3

Chapter 2

MECHANICAL LOADING	7
2.1. General	7
2.1.1. General rule	7
2.1.2. Simplification 1	10
2.1.3. Simplification 2	10
2.1.4. Simplification 3	12
2.2. Examples	13
2.3. Indirect actions	14

Chapter 3

THERMAL ACTION	17
3.1. General	17
3.2. Nominal temperature-time curves	18
3.3. Parametric temperature-time curves	21
3.4. Zone models	29
3.5. CFD models	31
3.6. Localised fires	32
3.7. External members	39

Chapter 4

TEMPERATURE IN STEEL SECTIONS	45
4.1. Introduction	45
4.2. The heat conduction equation and its boundary conditions	45
4.3. Advanced calculation model. Finite element solution of the heat conduction equation	47
4.3.1. Temperature field using the finite element method	48
4.4. Section factor	51
4.5. Temperature of unprotected steelwork exposed to fire	54
4.6. Temperature of protected steelwork exposed to fire	61
4.7. Internal steelwork in a void protected by heat screens	76
4.8. External steelwork	78
4.8.1. General principles	78
4.8.2. Example	80
4.9. View factors in the concave part of a steel profile	88
4.10. Temperature in steel members subjected to localised fires	92
4.10.1. Unprotected steel members	92
4.10.2. Protected steel members	93
4.10.3. Thermal response of steel members in case of multiple localised fires	95
<i>4.10.3.1. Multiple localised fires due to simultaneously burning cars: an example of a car park</i>	95
<i>4.10.3.1.1. Characterization of the fire and definition of the fire scenarios</i>	95
<i>4.10.3.1.2. Temperature of the main beam</i>	98
4.11. Temperature in stainless steel members	101
4.11.1. Example	104

Chapter 5

MECHANICAL ANALYSIS	105
5.1. Basic principles	105
5.2. Mechanical properties of carbon steel	110
5.3. Classification of cross sections	115

5.3.1. Cross section under combined bending and axial-compression at normal temperature	120
5.3.1.1. <i>First methodology for Class 1 and Class 2 cross sections</i>	123
5.3.1.2. <i>Second methodology for the case of Class 1 and Class 2 cross sections</i>	125
5.3.1.3. <i>First methodology for Class 3 cross sections</i>	127
5.3.1.4. <i>Second methodology for Class 3 cross sections</i>	128
5.3.1.5. <i>Advantages and disadvantages of the two presented methodologies</i>	130
5.3.2. Cross section under combined bending and tension at normal temperature	132
5.3.3. Classification under fire conditions	132
5.4. Effective cross section	134
5.5. Fire resistance of structural members	136
5.5.1. General	136
5.5.2. Members with Class 4 cross sections	138
5.5.3. Tension members	139
5.5.4. Compression members	140
5.5.5. Shear resistance	143
5.5.6. Laterally restrained beams	145
5.5.6.1. <i>Uniform temperature distribution</i>	145
5.5.6.2. <i>Non-uniform temperature distribution</i>	147
5.5.6.3. <i>Bending and shear</i>	150
5.5.7. Laterally unrestrained beams	152
5.5.7.1. <i>The elastic critical moment for lateral-torsional buckling</i>	152
5.5.7.2. <i>Resistance to lateral-torsional buckling</i>	156
5.5.8. Members subjected to combined bending and axial compression	159
5.5.9. Some verifications of the fire resistance not covered by EN 1993-1-2	163
5.5.9.1. <i>Shear buckling resistance for web without intermediate stiffeners</i>	163
5.5.9.2. <i>Cross section verification of a member subjected to combined bending and axial force (compression or tension)</i>	164

TABLE OF CONTENTS

5.5.9.2.1. Class 1 and 2 rectangular solid sections	165
5.5.9.2.2. Class 1 and 2 doubly symmetric I- and H-sections	166
5.5.9.2.3. Class 3 doubly symmetric I- and H-sections	168
5.5.9.2.4. Class 4 cross sections	169
5.5.9.3. Bending, shear and axial force	169
5.6. Design in the temperature domain. Critical temperature	170
5.7. Design of continuous beams	180
5.7.1. General	180
5.7.2. Continuous beams at room temperature	181
5.7.3. Continuous beams under fire conditions	184
5.8. Fire resistance of structural stainless steel members	186
5.9. Design examples	193

Chapter 6

ADVANCED CALCULATION MODELS **273**

6.1. General	273
6.2. Thermal response model	275
6.3. Mechanical response model	282
6.4. Some comparisons between the simple and the advanced calculation models	288
6.4.1. Shadow factor	289
6.4.2. Buckling curves	293
6.4.3. Factor κ_2	295
6.4.4. Factor κ_1	296

Chapter 7

JOINTS **299**

7.1. General	299
7.2. Strength of bolts and welds at elevated temperature	300
7.3. Temperature of joints in fire	301
7.4. Bolted connections	302
7.4.1. Design fire resistance of bolts in shear	303

7.4.1.1. <i>Category A: Bearing type</i>	303
7.4.1.2. <i>Category B (slip resistance at serviceability) and Category C (slip resistance at ultimate state)</i>	303
7.4.2. Design fire resistance of bolts in tension	303
7.4.2.1. <i>Category D and E: Non-preloaded and preloaded bolts</i>	303
7.5. Design fire resistance of welds	304
7.5.1. Butt welds	304
7.5.2. Fillet welds	304
7.6. Design examples	304

Chapter 8

THE COMPUTER PROGRAM “ELEFIR-EN”	315
8.1. General	315
8.2. Brief description of the program	316
8.2.1. Available thermal calculations	316
8.2.2. Available mechanical calculations	322
8.3. Default constants used in the program	329
8.4. Design example	329

Chapter 9

CASE STUDY	343
9.1. Description of the case study	343
9.2. Fire resistance under standard fire	344
9.2.1. Thermal calculations	344
9.2.2. Structural calculation	345
9.2.2.1. <i>Loading</i>	345
9.2.2.2. <i>Fire resistance by the simple calculation model</i>	349
9.2.2.3. <i>Fire resistance by the general calculation model</i>	351
9.3. Fire resistance under natural fire	353
9.3.1. Temperature development in the compartment	353

REFERENCES	359
-------------------	------------

Annex A**THERMAL DATA FOR CARBON STEEL AND STAINLESS
STEEL SECTIONS**

	369
A.1. Thermal properties of carbon steel	369
A.1.1. Specific heat	369
A.1.2. Thermal conductivity	370
A.1.3. Thermal elongation	371
A.2. Section factor A_m/V [m^{-1}] for unprotected steel members	372
A.3. Section factor A_p/V [m^{-1}] for protected steel members	374
A.4. Tables and nomograms for evaluating the temperature in unprotected steel members subjected to the standard fire curve ISO 834	375
A.5. Tables and nomograms for evaluating the temperature in protected steel members subjected to the standard fire curve ISO 834	380
A.6. Thermal properties of some fire protection materials	384
A.7. Thermal properties of stainless steel	385
A.7.1. Specific heat	385
A.7.2. Thermal conductivity	385
A.7.3. Thermal elongation	386
A.8. Tables and nomograms for evaluating the temperature in unprotected stainless steel members subjected to the standard fire curve ISO 834	387
A.9. Thermal properties of some fire compartment lining materials	394

Annex B**INPUT DATA FOR NATURAL FIRE MODELS**

B.1. Introduction	395
B.2. Fire load density	395
B.3. Rate of heat release density	398
B.4. Ventilation control	403
B.5. Flash-over	406

Annex C

**MECHANICAL PROPERTIES OF CARBON STEEL AND
STAINLESS STEEL**

407

C.1 Mechanical properties of carbon steel	407
C.1.1. Mechanical properties of carbon steel at room temperature (20°C)	407
C.1.2. Stress-strain relationship for carbon steel at elevated temperatures (without strain-hardening)	410
C.1.3. Stress-strain relationship for carbon steel at elevated temperatures (with strain-hardening)	418
C.1.4. Mechanical properties to be used with Class 4 cross sections and simple calculation models	419
C.2. Mechanical properties of stainless steel	421

Annex D

**TABLES FOR SECTION CLASSIFICATION AND
EFFECTIVE WIDTH EVALUATION**

429

Annex E

**SECTION FACTORS OF EUROPEAN HOT ROLLED
IPE AND HE PROFILES**

435

Annex F

**CROSS SECTIONAL CLASSIFICATION OF THE EUROPEAN
HOT ROLLED IPE AND HE PROFILES**

443

F.1. Cross sectional classification for pure compression and pure bending	443
F.2. Cross sectional classification for combined compression and bending moment	450