# Table of Contents

**Contributors**  XVII  
**Notations**  XXIII  
**Acronyms**  XXXI  

**Preface**  1  
1 **Scope**  2  
1.1 Aim of the fib Model Code 2010  3  
1.2 Format  3  
1.3 Levels of approximation  3  
1.4 Structure of the fib Model Code 2010  4  

2 **Terminology**  6  
2.1 Definitions  7  
2.2 References  19  

3 **Basic principles**  20  
3.1 General  21  
3.2 Performance-based design and assessment  23  
3.3 Performance requirements for serviceability, structural safety, service life and reliability  25  
3.3.1 Levels of performance  21  
3.3.2 Levels-of-approximation approach  21  
3.4 Performance requirements for sustainability  33  
3.4.1 General  33  
3.4.2 Performance requirements for environmental impact  34  
3.4.3 Performance requirements for impact on society  34  
3.5 Life cycle management  35  
3.5.1 General  35  
3.5.2 Quality management  35  
3.5.2.1 General  35  
3.5.2.2 Project quality plan  36  
3.5.2.3 Life cycle file  37  
3.5.3 Quality management in design  38  
3.5.3.1 Objectives  38  
3.5.3.2 Design file  39  
3.5.3.3 Briefing phase  39  
3.5.3.4 Scouting phase  40  
3.5.3.5 Basis of design phase  40  
3.5.3.6 Project specification phase  42  

COPYRIGHTED MATERIAL
### 4 Principles of structural design 48

#### 4.1 Design situations 49

**Limit state design principles** 50

**Safety formats** 50

#### 4.2 Design strategies 49

**Basic rules for probabilistic approach** 52

#### 4.3 Design methods 50

**General** 52

**Design condition** 53

**Design values of basic variables** 53

**Representative values of basic variables** 55

**Basic rules for partial factor approach** 60

**General** 60

**Ultimate limit states** 61

**Fatigue verification** 66

**Verification of structures subjected to impact and explosion** 67

**Serviceability limit states** 67

#### 4.4 Probabilistic safety format 51

**General** 51

**Basic rules for probabilistic approach** 52

#### 4.5 Partial factor format 52

**General** 52

**Basic variables** 52

**Design condition** 53

**Design values of basic variables** 53

**Representative values of basic variables** 55

**Basic rules for partial factor approach** 60

**General** 60

**Ultimate limit states** 61

**Fatigue verification** 66

**Verification of structures subjected to impact and explosion** 67

**Serviceability limit states** 67

#### 4.6 Global resistance format 69

**General** 69

**Basic rules for global resistance approach** 69

**Representative variables** 69

**Design condition** 70

**General** 71

**Design by avoidance** 73

#### 4.7 Deemed-to-satisfy approach 71

**General** 71

**Durability related exposure categories** 71

#### 4.8 Design by avoidance 73

**General and range of applicability** 75

**Classification by strength** 75

**Classification by density** 76

**Compressive strength** 76

**Tensile strength and fracture properties** 77

**Tensile strength** 77

**Fracture energy** 78

**Strength under multiaxial states of stress** 79

**Modulus of elasticity and Poisson’s ratio** 81

**Range of application** 81

**Modulus of elasticity** 81

**Poisson’s ratio** 82

**Stress–strain relations for short term loading** 82

**Compression** 82

**Tension** 83

**Multiaxial states of stress** 84

### 5 Materials 74

#### 5.1 Concrete 75

**General and range of applicability** 75

**Classification by strength** 75

**Classification by density** 76

**Compressive strength** 76

**Tensile strength and fracture properties** 77

**Tensile strength** 77

**Fracture energy** 78

**Strength under multiaxial states of stress** 79

**Modulus of elasticity and Poisson’s ratio** 81

**Range of application** 81

**Modulus of elasticity** 81

**Poisson’s ratio** 82

**Stress–strain relations for short term loading** 82

**Compression** 82

**Tension** 83

**Multiaxial states of stress** 84
5.2 Reinforcing steel  110

5.2.1 General  110
5.2.2 Quality control  110
5.2.3 Designation  110
5.2.4 Geometrical properties  111
5.2.4.1 Size  111
5.2.4.2 Surface characteristics  111
5.2.5 Mechanical properties  111
5.2.5.1 Tensile properties  111
5.2.5.2 Steel grades  112
5.2.5.3 Stress–strain diagram  112
5.2.5.4 Ductility  113
5.2.5.5 Shear of welded joints in welded fabric  113
5.2.5.6 Fatigue behaviour  113
5.2.5.7 Behaviour under extreme thermal conditions  114
5.2.5.8 Effect of strain rate  114
5.2.6 Technological properties  114
5.2.6.1 Bendability  114
5.2.6.2 Weldability  114
5.2.6.3 Coefficient of thermal expansion  114
5.2.6.4 Provisions for quality control  114
5.2.7 Special types of steels  115
5.2.8 Assumptions used for design  115

5.3 Prestressing steel  117

5.3.1 General  117
5.3.2 Quality control  117
5.3.3 Designation  117
5.3.4 Geometrical properties  118
5.3.5 Mechanical properties  118
5.3.5.1 Tensile properties  118
### Table of Contents

5.3.5.2 Stress–strain diagram 118
5.3.5.3 Fatigue behaviour 119
5.3.5.4 Behaviour under extreme thermal conditions 119
5.3.5.5 Effect of strain rate 120
5.3.5.6 Bond characteristics 121
5.3.6 Technological properties 121
5.3.6.1 Isothermal stress relaxation 121
5.3.6.2 Deflected tensile behaviour (only for strands with nominal diameter ≥ 12.5 mm) 122
5.3.6.3 Stress corrosion resistance 122
5.3.6.4 Coefficient of thermal expansion 122
5.3.6.5 Residual stresses 122
5.3.7 Special types of prestressing steel 122
5.3.7.1 Metallic coating 122
5.3.7.2 Organic coating 123
5.3.7.3 Exterior sheathing with a filling product 123
5.3.8 Assumptions used for design 123

5.4 Prestressing systems 125
5.4.1 General 125
5.4.2 Post-tensioning system components and materials 125
5.4.2.1 Anchorages and coupling devices 125
5.4.2.2 Ducts 126
5.4.2.3 Filling materials 127
5.4.2.4 Quality control 128
5.4.3 Protection of tendons 128
5.4.3.1 Temporary corrosion protection 128
5.4.3.2 Permanent corrosion protection 128
5.4.3.3 Permanent corrosion protection of prestressing steel 128
5.4.3.4 Permanent protection of FRP materials 129
5.4.3.5 Fire protection 129
5.4.4 Stresses at tensioning, time of tensioning 129
5.4.4.1 Time of tensioning 129
5.4.4.2 Tendons made from prestressing steel 129
5.4.4.3 Tendons made from FRP materials 130
5.4.5 Initial prestress 130
5.4.5.1 General 130
5.4.5.2 Losses occurring in pretensioning beds 130
5.4.5.3 Immediate losses occurring during stressing 130
5.4.6 Value of prestressing force during design life (time \( t \geq 0 \)) 133
5.4.6.1 Calculation of time-dependent losses made of prestressing steel 133
5.4.6.2 Calculation of time-dependent losses made of FRP 137
5.4.7 Design values of forces in prestressing 137
5.4.7.1 General 137
5.4.7.2 Design values for SLS and fatigue verifications 137
5.4.7.3 Design values for ULS verifications 137
5.4.8 Design values of tendon elongations 137
5.4.9 Detailing rules for prestressing tendons 138
5.4.9.1 Pretensioning tendons 138
5.4.9.2 Post-tensioning tendons 138

5.5 Non-metallic reinforcement 139
5.5.1 General 139
5.5.2 Quality control 139
5.5.3 Designation 139
5.5.4 Geometrical properties 140
5.5.4.1 Configuration 140
5.5.4.2 Size 140
5.5.4.3 Surface characteristics 140
5.5.5 Mechanical properties 140
5.5.5.1 Tensile strength and ultimate strain 140
5.5.5.2 Type 141
### 5.5.5.3 Stress–strain diagram and modulus of elasticity 141
### 5.5.5.4 Compressive and shear strength 141
### 5.5.5.5 Fatigue behaviour 141
### 5.5.5.6 Creep behaviour 142
### 5.5.5.7 Relaxation 142
### 5.5.5.8 Behaviour under elevated temperature and under extreme thermal conditions 142
### 5.5.6 Technological properties 142
#### 5.5.6.1 Bond characteristics 142
#### 5.5.6.2 Bendability 142
#### 5.5.6.3 Coefficient of thermal expansion 142
#### 5.5.6.4 Durability 143
#### 5.5.7 Assumptions used for design 143

### 5.6 Fibres/fibre reinforced concrete 144
#### 5.6.1 Introduction 144
#### 5.6.2 Material properties 144
##### 5.6.2.1 Behaviour in compression 144
##### 5.6.2.2 Behaviour in tension 145
#### 5.6.3 Classification 146
#### 5.6.4 Constitutive laws 146
#### 5.6.5 Stress–strain relationship 148
#### 5.6.6 Partial safety factors 150
#### 5.6.7 Orientation factor 150

### 6 Interface characteristics 152
#### 6.1 Bond of embedded steel reinforcement 153
##### 6.1.1 Local bond–slip relationship 153
##### 6.1.1.1 Local bond stress–slip model, ribbed bars 153
##### 6.1.1.2 Influence of transverse cracking 155
##### 6.1.1.3 Influence of yielding, transverse stress and longitudinal cracking and cyclic loading 155
##### 6.1.1.4 Influence of creep and fatigue loading 157
##### 6.1.1.5 Unloading branch 158
##### 6.1.1.6 Plain (non-ribbed) surface bars 158
##### 6.1.2 Influence on serviceability 159
##### 6.1.3 Anchorage and lapped joints of reinforcement 159
##### 6.1.3.1 Minimum detailing requirements 159
##### 6.1.3.2 Basic bond strength 160
##### 6.1.3.3 Design bond strength 161
##### 6.1.3.4 Design anchorage length 162
##### 6.1.3.5 Contribution of hooks and bends 163
##### 6.1.3.6 Headed reinforcement 163
##### 6.1.3.7 Laps of bars in tension 164
##### 6.1.3.8 Laps of bars in compression 164
##### 6.1.3.9 Anchorage of bundled bars 165
##### 6.1.3.10 Lapped joints of bundled bars 165
##### 6.1.4 Anchorage and lapped joints of welded fabric 165
##### 6.1.4.1 Design anchorage length of welded fabric 165
##### 6.1.4.2 Design lap length of welded fabric in tension 165
##### 6.1.4.3 Design lap length of welded fabric in compression 166
##### 6.1.5 Special circumstances 166
##### 6.1.5.1 Slipform construction 166
##### 6.1.5.2 Bentonite walling 166
##### 6.1.5.3 Post-installed reinforcement 166
##### 6.1.5.4 Electrochemical extraction of chlorides (ECE) 167
##### 6.1.6 Conditions of service 167
##### 6.1.6.1 Cryogenic conditions 167
##### 6.1.6.2 Elevated temperatures 167
##### 6.1.7 Degradation 167
##### 6.1.7.1 Corrosion 167
##### 6.1.7.2 Alkali silica reaction (ASR) 168
##### 6.1.7.3 Frost 168
Table of Contents

6.1.7.4 Fire 168
6.1.8 Anchorage of pretensioned prestressing tendons 169
6.1.8.1 General 169
6.1.8.2 Design bond strength 169
6.1.8.3 Basic anchorage length 169
6.1.8.4 Transmission length 170
6.1.8.5 Design anchorage length 170
6.1.8.6 Development length 170

6.2 Bond of non-metallic reinforcement 171
6.2.1 Local bond stress–slip model 171
6.2.1.1 Local bond stress–slip model for FRP rebars 171
6.2.1.2 Local bond stress–slip model for externally bonded FRP 171
6.2.2 Bond and anchorage of internal FRP reinforcement 172
6.2.3 Bond and anchorage of externally bonded FRP reinforcement 172
6.2.3.1 Bond-critical failure modes 172
6.2.3.2 Maximum bond length 173
6.2.3.3 Ultimate strength for end debonding – anchorage capacity 174
6.2.3.4 Ultimate strength for end debonding – concrete rip-off 175
6.2.3.5 Ultimate strength for intermediate debonding 175
6.2.3.6 Interfacial stresses for the serviceability limit state 175
6.2.4 Mechanical anchorage for externally bonded FRP reinforcement 175

6.3 Concrete to concrete 176
6.3.1 Definitions and scope 176
6.3.2 Interface roughness characteristics 176
6.3.3 Mechanisms of shear transfer 177
6.3.4 Modelling and design 179
6.3.5 Detailing 181

6.4 Concrete to steel 183
6.4.1 Classification of interaction mechanisms 183
6.4.2 Bond of metal sheeting and profiles 183
6.4.2.1 Metal sheeting 183
6.4.2.2 Steel profiles 183
6.4.2.3 Interface strength 184
6.4.2.4 Shear stress–slip relationships 184
6.4.2.5 Influence of the type of loading 184
6.4.2.6 Determination of properties by testing 185
6.4.3 Mechanical interlock 185
6.4.3.1 Classification of devices 185
6.4.3.2 Strength evaluation 186
6.4.3.3 Force-shear slip constitutive relationships 187
6.4.3.4 Influence of the type of loading 189
6.4.3.5 Determination of properties by testing 189

7 Design 190
7.1 Conceptual design 191
7.1.1 General 191
7.1.2 Methodology 191
7.1.2.1 Input 192
7.1.2.2 Activities 192
7.1.2.3 The role of expertise, insight and tools 193
7.1.3 Structural concept and basis for design 193

7.2 Structural analysis and dimensioning 194
7.2.1 General 194
7.2.2 Structural modelling 194
7.2.2.1 General 194
7.2.2.2 Geometric imperfections 195
7.2.2.3 Structural geometry 195
7.2.2.4 Calculation methods 196
7.2.3 Dimensioning values 199
7.2.3.1 Concrete 199
7.2.3.2 Reinforcing steel 204
7.2.3.3 Prestressing steel 205
7.2.4 Analysis of structural effects of time-dependent behaviour of concrete 205
7.2.4.1 General 205
7.2.4.2 Levels of refinement of the analysis 206
7.2.4.3 Probabilistic and deterministic approach 207
7.2.4.4 Prediction models for concrete and significance of the analysis 207
7.2.4.5 Time-dependent analysis based on ageing linear viscoelasticity 208
7.2.4.6 Constitutive laws in ageing linear viscoelasticity 208
7.2.4.7 Simplified approaches for time-dependent analysis 208
7.2.4.8 Effective homogeneous concrete structures with rigid or stress-independent yielding of restraints 208
7.2.4.9 Effective homogeneous concrete structures with additional steel structural elements 211
7.2.4.10 Approximate algebraic formulation for the constitutive relation: age-adjusted effective modulus (AAEM) method 212
7.2.4.11 General method 213

7.3 Verification of structural safety (ULS) for predominantly static loading 215

7.3.1 General 215
7.3.2 Bending with and without axial force 215
7.3.2.1 Beams, columns and slabs 215
7.3.2.2 Shells 215
7.3.3 Shear 217
7.3.3.1 General 217
7.3.3.2 Members without shear reinforcement 219
7.3.3.3 Members with shear reinforcement 220
7.3.3.4 Hollow core slabs 222
7.3.3.5 Shear between web and flanges of T-sections 223
7.3.3.6 Shear at the interface between concrete cast at different times 224
7.3.4 Torsion 226
7.3.5 Punching 227
7.3.5.1 General 227
7.3.5.2 Design shear force, shear-resisting effective depth and control perimeter 227
7.3.5.3 Punching shear strength 230
7.3.5.4 Calculation of rotations around the supported area 231
7.3.5.5 Punching shear resistance outside the zones with shear reinforcement or shearheads 233
7.3.5.6 Integrity reinforcement 234
7.3.6 Design with stress fields and strut-and-tie models 234
7.3.6.1 General 234
7.3.6.2 Struts 235
7.3.6.3 Ties 235
7.3.6.4 Nodes 236
7.3.7 Compression members 236
7.3.7.1 Stability of compressed members in general 236
7.3.7.2 Biaxial eccentricities and out-of-plane buckling 238
7.3.8 Lateral instability of beams 239
7.3.9 3D solids 240
7.3.9.1 Stress limit requirements 240
7.3.9.2 Ductility requirements 240
7.4 Verification of structural safety (ULS) for non-static loading 242

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4.1 Fatigue design</td>
<td>242</td>
</tr>
<tr>
<td>7.4.1.1 Scope</td>
<td>242</td>
</tr>
<tr>
<td>7.4.1.2 Analysis of stresses in reinforced and prestressed members under fatigue loading</td>
<td>242</td>
</tr>
<tr>
<td>7.4.1.3 Level II approximation: the simplified procedure</td>
<td>243</td>
</tr>
<tr>
<td>7.4.1.4 Level III approximation: verification by means of a single load level</td>
<td>243</td>
</tr>
<tr>
<td>7.4.1.5 Level IV approximation: verification by means of a spectrum of load levels</td>
<td>245</td>
</tr>
<tr>
<td>7.4.1.6 Shear design</td>
<td>246</td>
</tr>
<tr>
<td>7.4.1.7 Increased deflections under fatigue loading in the SLS</td>
<td>246</td>
</tr>
<tr>
<td>7.4.2 Impact and explosion</td>
<td>246</td>
</tr>
<tr>
<td>7.4.2.1 General remarks</td>
<td>246</td>
</tr>
<tr>
<td>7.4.2.2 Determination of design loads</td>
<td>247</td>
</tr>
<tr>
<td>7.4.2.3 Dimensioning for overall stresses</td>
<td>248</td>
</tr>
<tr>
<td>7.4.2.4 Structural detailing and other measures</td>
<td>250</td>
</tr>
<tr>
<td>7.4.3 Seismic design</td>
<td>251</td>
</tr>
<tr>
<td>7.4.3.1 Format of the verifications</td>
<td>251</td>
</tr>
<tr>
<td>7.4.3.2 Determination of seismic action effects through analysis</td>
<td>251</td>
</tr>
<tr>
<td>7.4.3.3 ULS verifications of inelastic flexural deformations</td>
<td>260</td>
</tr>
<tr>
<td>7.4.3.4 Cyclic plastic chord rotation capacity</td>
<td>260</td>
</tr>
<tr>
<td>7.4.3.5 Cyclic shear resistance at the ULS in members with shear reinforcement</td>
<td>263</td>
</tr>
<tr>
<td>7.4.3.6 ULS verification of joints between horizontal and vertical elements</td>
<td>263</td>
</tr>
<tr>
<td>7.4.3.7 SLS verifications of flexural deformations</td>
<td>263</td>
</tr>
</tbody>
</table>

7.5 Verification of structural safety (ULS) for extreme thermal conditions 264

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5.1 Fire design</td>
<td>264</td>
</tr>
<tr>
<td>7.5.1.1 Introduction</td>
<td>264</td>
</tr>
<tr>
<td>7.5.1.2 Fire design principles</td>
<td>265</td>
</tr>
<tr>
<td>7.5.1.3 Calculation method</td>
<td>269</td>
</tr>
<tr>
<td>7.5.1.4 Structural elements</td>
<td>273</td>
</tr>
<tr>
<td>7.5.1.5 Compartmentation</td>
<td>275</td>
</tr>
<tr>
<td>7.5.2 Cryogenic design</td>
<td>276</td>
</tr>
<tr>
<td>7.5.2.1 General</td>
<td>276</td>
</tr>
<tr>
<td>7.5.2.2 Design loads to be considered in the design of structures for refrigerated liquefied gases</td>
<td>276</td>
</tr>
<tr>
<td>7.5.2.3 Failure mechanisms to be regarded in the design of structures for storing refrigerated liquefied gases</td>
<td>276</td>
</tr>
<tr>
<td>7.5.2.4 Concrete material properties under cryogenic conditions</td>
<td>277</td>
</tr>
</tbody>
</table>

7.6 Verification of serviceability (SLS) of RC and PC structures 279

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.6.1 Requirements</td>
<td>279</td>
</tr>
<tr>
<td>7.6.2 Design criteria</td>
<td>279</td>
</tr>
<tr>
<td>7.6.3 Stress limitation</td>
<td>279</td>
</tr>
<tr>
<td>7.6.3.1 Tensile stresses in the concrete</td>
<td>280</td>
</tr>
<tr>
<td>7.6.3.2 Limit state of decompression</td>
<td>280</td>
</tr>
<tr>
<td>7.6.3.3 Compressive stresses in the concrete</td>
<td>280</td>
</tr>
<tr>
<td>7.6.3.4 Steel stresses</td>
<td>280</td>
</tr>
<tr>
<td>7.6.4 Limit state of cracking</td>
<td>281</td>
</tr>
<tr>
<td>7.6.4.1 Requirements</td>
<td>281</td>
</tr>
<tr>
<td>7.6.4.2 Design criteria versus cracking</td>
<td>282</td>
</tr>
<tr>
<td>7.6.4.3 Limitation of crack width</td>
<td>282</td>
</tr>
<tr>
<td>7.6.4.4 Calculation of crack width in reinforced concrete members</td>
<td>283</td>
</tr>
</tbody>
</table>
7.7 Verification of safety and serviceability of FRC structures 296

7.7.1 Classification 296
7.7.2 Design principles 296
7.7.3 Verification of safety (ULS) 298
7.7.3.1 Bending and/or axial compression in linear members 298
7.7.3.2 Shear in beams 298
7.7.3.3 Torsion in beams 300
7.7.3.4 Walls 300
7.7.3.5 Slabs 301
7.7.4 Verification of serviceability (SLS) 302
7.7.4.1 Stress limitation 302
7.7.4.2 Crack width in members with conventional reinforcement 302
7.7.4.3 Minimum reinforcement for crack control 302

7.8 Verification of limit states associated with durability 304

7.8.1 General 304
7.8.2 Carbonation induced corrosion – uncracked concrete 305
7.8.2.1 Probabilistic safety format 305
7.8.2.2 Partial safety factor format 307
7.8.2.3 Deemed-to-satisfy design 308
7.8.2.4 Avoidance-of-deterioration design 308
7.8.3 Chloride induced corrosion – uncracked concrete 308
7.8.3.1 Probabilistic safety format 308
7.8.3.2 Partial safety factor format 310
7.8.3.3 Deemed-to-satisfy design 310
7.8.3.4 Avoidance-of-deterioration design 310
7.8.4 Influence of cracks upon reinforcement corrosion 310
7.8.5 Risk of depassivation with respect to prestressed steel 310
7.8.6 Freeze-thaw attack 311
7.8.6.1 Probabilistic safety format 311
7.8.6.2 Partial safety factor format 311
7.8.6.3 Deemed-to-satisfy approach 312
7.8.6.4 Avoidance-of-deterioration method 312
7.8.7 Chemical attack 312
7.8.7.1 Acid attack 312
7.8.7.2 Sulphate attack 313
7.8.8 Alkali–aggregate reactions 314
7.8.8.1 Probabilistic safety format 314
7.8.8.2 Partial safety factor format 314
7.8.8.3 Deemed-to-satisfy approach 314
7.8.8.4 Avoidance-of-deterioration approach 314
7.8.9 Delayed ettringite formation 314
7.8.9.1 Probabilistic safety format 315
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.8.9.2 Partial safety factor format</td>
<td>315</td>
</tr>
<tr>
<td>7.8.9.3 Deemed-to-satisfy approach</td>
<td>315</td>
</tr>
<tr>
<td>7.8.9.4 Avoidance-of-deterioration approach</td>
<td>315</td>
</tr>
<tr>
<td>7.9 Verification of robustness</td>
<td>316</td>
</tr>
<tr>
<td>7.9.1 General</td>
<td>316</td>
</tr>
<tr>
<td>7.9.2 Specific methods to improve robustness by structural measures</td>
<td>317</td>
</tr>
<tr>
<td>7.9.2.1 Robustness by creating an alternative loading path</td>
<td>317</td>
</tr>
<tr>
<td>7.9.2.2 Capacity design</td>
<td>317</td>
</tr>
<tr>
<td>7.10 Verification of sustainability</td>
<td>318</td>
</tr>
<tr>
<td>7.10.1 Impact on environment</td>
<td>318</td>
</tr>
<tr>
<td>7.10.1.1 General</td>
<td>318</td>
</tr>
<tr>
<td>7.10.1.2 Verification</td>
<td>319</td>
</tr>
<tr>
<td>7.10.2 Impact on society</td>
<td>320</td>
</tr>
<tr>
<td>7.10.2.1 General</td>
<td>320</td>
</tr>
<tr>
<td>7.10.2.2 Verification</td>
<td>320</td>
</tr>
<tr>
<td>7.11 Verifications assisted by numerical simulations</td>
<td>322</td>
</tr>
<tr>
<td>7.11.1 Purpose</td>
<td>322</td>
</tr>
<tr>
<td>7.11.2 Methods of numerical simulation</td>
<td>322</td>
</tr>
<tr>
<td>7.11.2.1 Numerical model</td>
<td>322</td>
</tr>
<tr>
<td>7.11.2.2 Finite element method</td>
<td>322</td>
</tr>
<tr>
<td>7.11.2.3 Material models</td>
<td>323</td>
</tr>
<tr>
<td>7.11.2.4 Validation of numerical models</td>
<td>323</td>
</tr>
<tr>
<td>7.11.3 Safety formats for non-linear analysis</td>
<td>324</td>
</tr>
<tr>
<td>7.11.3.1 General</td>
<td>324</td>
</tr>
<tr>
<td>7.11.3.2 Probabilistic method</td>
<td>324</td>
</tr>
<tr>
<td>7.11.3.3 Global resistance methods</td>
<td>325</td>
</tr>
<tr>
<td>7.11.3.4 Partial factor method</td>
<td>326</td>
</tr>
<tr>
<td>7.11.4 Resistance parameter identification</td>
<td>327</td>
</tr>
<tr>
<td>7.12 Verification assisted by testing</td>
<td>328</td>
</tr>
<tr>
<td>7.12.1 Scope</td>
<td>328</td>
</tr>
<tr>
<td>7.12.2 Definition</td>
<td>328</td>
</tr>
<tr>
<td>7.12.3 Aims of verification assisted by testing</td>
<td>329</td>
</tr>
<tr>
<td>7.12.4 Requirements</td>
<td>329</td>
</tr>
<tr>
<td>7.12.5 Planning</td>
<td>329</td>
</tr>
<tr>
<td>7.12.5.1 Calculation model-limit states</td>
<td>329</td>
</tr>
<tr>
<td>7.12.5.2 Information on basic variables</td>
<td>330</td>
</tr>
<tr>
<td>7.12.5.3 Number of specimens</td>
<td>330</td>
</tr>
<tr>
<td>7.12.5.4 Scale effects</td>
<td>330</td>
</tr>
<tr>
<td>7.12.5.5 Actions</td>
<td>331</td>
</tr>
<tr>
<td>7.12.5.6 Origin of specimens</td>
<td>331</td>
</tr>
<tr>
<td>7.12.6 Testing conditions and measurements</td>
<td>331</td>
</tr>
<tr>
<td>7.12.6.1 Basic and nominal variables</td>
<td>331</td>
</tr>
<tr>
<td>7.12.6.2 Actions</td>
<td>331</td>
</tr>
<tr>
<td>7.12.6.3 Deformation – structural behaviour</td>
<td>331</td>
</tr>
<tr>
<td>7.12.7 Laboratory report</td>
<td>331</td>
</tr>
<tr>
<td>7.12.8 Statistical analysis of test results</td>
<td>332</td>
</tr>
<tr>
<td>7.12.8.1 Estimation of the unknown coefficients D</td>
<td>332</td>
</tr>
<tr>
<td>7.12.8.2 Characteristic value</td>
<td>332</td>
</tr>
<tr>
<td>7.12.9 Verification procedure</td>
<td>332</td>
</tr>
<tr>
<td>7.12.9.1 Design values</td>
<td>332</td>
</tr>
<tr>
<td>7.12.9.2 Verification</td>
<td>333</td>
</tr>
<tr>
<td>7.13 Detailing</td>
<td>334</td>
</tr>
<tr>
<td>7.13.1 Basic principles</td>
<td>334</td>
</tr>
<tr>
<td>7.13.2 Positioning of reinforcement</td>
<td>334</td>
</tr>
<tr>
<td>7.13.2.1 General</td>
<td>334</td>
</tr>
<tr>
<td>7.13.2.2 Cover of reinforcement</td>
<td>334</td>
</tr>
<tr>
<td>7.13.2.3 Minimum bar spacing</td>
<td>335</td>
</tr>
<tr>
<td>7.13.2.4 Forms and bends</td>
<td>335</td>
</tr>
<tr>
<td>7.13.2.5 Anchorage</td>
<td>336</td>
</tr>
<tr>
<td>7.13.2.6 Lapped joints</td>
<td>338</td>
</tr>
</tbody>
</table>
# Table of Contents

7.13.2.7 Deviations and curvatures 339  
7.13.3 Prestressed structures 340  
7.13.3.1 Anchorage of prestressing wires and strands 340  
7.13.4 Bearings and joints 340  
7.13.5 Structural members 341  
7.13.5.1 Unreinforced structural members 341  
7.13.5.2 Beams and T-beams 341  
7.13.5.3 Slabs 342  
7.13.5.4 Compression members 343  
7.13.6 Special aspects of precast concrete elements and composite structural members 345  
7.13.6.1 General 345  
7.13.6.2 Bearings 345  
7.13.6.3 Mortar joints 347  
7.13.6.4 Loop connections 347  
7.13.6.5 Transverse stresses in the anchorage zone of prestressed tendons 348  

7.14 Verification of anchorages in concrete 350  

# 8 Construction 352  
8.1 General 353  
8.2 Execution management 353  

8.2.1 Assumptions 353  
8.2.2 Documentation 353  
8.2.3 Quality management 353  

8.3 Reinforcing steel works 354  

8.3.1 Transportation and storage 354  
8.3.2 Identification 354  
8.3.3 Cutting and bending 355  
8.3.4 Welding 356  
8.3.5 Joints 357  
8.3.6 Assembly and placing of the reinforcement 357  
8.3.7 Construction documents – reinforcement 357  

8.4 Prestressing works 357  

8.4.1 General 357  
8.4.2 Packaging, transportation, storage and handling of materials and components 358  
8.4.3 Prestressing works for post-tensioning tendons 358  
8.4.3.1 Installation of tendons 358  
8.4.3.2 Tensioning operations 359  
8.4.3.3 Grouting of prestressing ducts 360  
8.4.4 Prestressing works for pretensioning tendons 361  
8.4.4.1 Installation of tendons 361  
8.4.4.2 Tensioning operations 361  
8.4.4.3 Sealing 362  
8.4.5 Replacement of tendons 362  
8.4.6 Construction documents – prestressing 363  

8.5 Falsework and formwork 363  

8.6 Concreting 363  

8.6.1 Specification of concrete 363  
8.6.2 Placing and compaction 364  
8.6.3 Curing 364  
8.6.4 Execution with precast concrete elements 364  
8.6.5 Geometrical tolerances 364  

# 9 Conservation 366  
9.1 General 367  
9.2 Conservation strategies and tactics 367  

9.2.1 General 367  
9.2.2 Strategy using proactive conservation measures 368  
9.2.2.1 Condition based conservation 368
## Table of Contents

9.2.2.2 Time dependent conservation 369  
9.2.3 Strategy using reactive conservation measures 369  
9.2.4 Situations where conservation measures are not feasible 369

9.3 Conservation management 370  
9.3.1 Through-life conservation process 370  
9.3.2 Conservation plan 373

9.4 Condition survey 373  
9.4.1 Condition survey and monitoring activities 373  
9.4.3 Tools and techniques for surveys and monitoring 374  
9.4.4 Gathering data for condition control purposes 375  
9.4.5 General flow of condition survey process 377

9.5 Condition assessment 378  
9.5.1 Identification of deterioration mechanisms and prediction of damage 378  
9.5.2 Identification of deterioration mechanism 378  
9.5.3 Factors influencing deterioration 379  
9.5.4 Determination of deterioration level and rate 379

9.6 Condition evaluation and decision-making 379  
9.6.1 General 379  
9.6.2 Threshold levels for deterioration of material and/or structural performance 380  
9.6.3 Judgement criteria 380  
9.6.4 Selection of interventions 380

9.7 Interventions 381  
9.7.1 Maintenance interventions 382  
9.7.2 Preventative interventions 382  
9.7.3 Remedial interventions 382  
9.7.4 Rebuild, reconstruction and replacement 382  
9.7.5 Strengthening or upgrading interventions 383  
9.7.6 Other activities and measures 383  
9.7.7 Execution of interventions 384

9.8 Recording 385

10 Dismantlement 386  
10.1 General 387

10.2 Preparing dismantlement 388  
10.2.1 General 388  
10.2.2 Consequence class of the structure 388  
10.2.3 Structural analysis for dismantlement 388  
10.2.4 Investigation of potential contamination 388  
10.2.5 Waste disposal concept 388  
10.2.6 Preparation report 389

10.3 Health and safety provisions 389

Index 390