Contents

Preface iii
Contributors iv
Notations xx
Acronyms xxxvi

1 Scope 1
1.1 Aim of the Model Code 1
1.2 Format 1
1.3 Levels of approximation 2
1.4 Structure of the Model Code 2

2 Terminology 3
2.1 Definitions 3
2.2 References 24

3 Basic principles 25
3.1 General 25
3.1.1 Levels of performance 25
3.1.2 Levels-of-Approximation approach 26
3.2 Performance-based design and assessment 28
3.2.1 General approach 28
3.2.2 Basis for verification 28
3.3 Performance requirements for serviceability, structural safety, service life and reliability 30
3.3.1 Performance criteria for serviceability and structural safety 31
3.3.1.1 Serviceability limit states 32
3.3.1.2 Ultimate limit states 34
3.3.1.3 Robustness 36
3.3.2 Service life 37
3.3.2.1 Specified service life and residual service life 37
3.3.2.2 Verification of service life 38
3.3.3 Reliability 39
3.3.3.1 Target reliability level 39
3.3.3.2 Component reliability and system reliability 44
3.4 Performance requirements for sustainability 45
3.4.1 General 45
3.4.2 Performance requirements for environmental impacts 46
3.4.3 Performance requirements for impacts on society 48
3.5 Life Cycle Management 49
3.5.1 General 49
3.5.2 Quality Management 50
3.5.2.1 General 50
3.5.2.2 Project Quality Plan 51
3.5.2.3 Life Cycle File 53
3.5.3 Quality Management in Design 54
3.5.3.1 Objectives 54
3.5.3.2 Design File 55

3.5.3.3 Briefing Phase 56
3.5.3.4 Scouting Phase 57
3.5.3.5 Basis of Design Phase 58
3.5.3.6 Project Specification Phase 61
3.5.3.7 Final design phase 64
3.5.3.8 Detailed design phase 65
3.5.4 Quality Management in Construction 66
3.5.4.1 Objectives 66
3.5.4.2 “As-Built Documentation”: Birth Certificate Document 67
3.5.5 Quality Management in Conservation 67
3.5.5.1 Objectives 67
3.5.5.2 Service-Life File 68
3.5.6 Quality Management in Dismantlement 69
3.5.6.1 Objectives 69
3.5.6.2 Dismantlement Document 69

4 Principles of structural design 70
4.1 Design situations 70
4.2 Design strategies 71
4.3 Design methods 72
4.3.1 Limit state design principles 72
4.3.2 Safety formats 72
4.4 Probabilistic safety format 74
4.4.1 General 74
4.4.2 Basic rules for probabilistic approach 75
4.5 Partial factor format 76
4.5.1 General 76
4.5.1.1 Basic variables 76
4.5.1.2 Design condition 77
4.5.1.3 Design values of basic variables 78
4.5.1.4 Representative values of basic variables 81
4.5.2 Basic rules for partial factor approach 92
4.5.2.1 General 92
4.5.2.2 Ultimate limit states 93
4.5.2.3 Fatigue verification 102
4.5.2.4 Verification of structures subjected to impact and explosion 104
4.5.2.5 Serviceability limit states 104
4.6 Global resistance format 106
4.6.1 General 106
4.6.2 Basic rules for global resistance approach 107
4.6.2.1 Representative variables 107
4.6.2.2 Design condition 108
4.7 Deemed-to-satisfy approach 109
4.7.1 General 109
4.7.2 Durability related exposure categories 110
4.8 Design by avoidance 112

5 **Materials** **113**
5.1 Concrete 113
5.1.1 General and range of applicability 113
5.1.2 Classification by strength 114
5.1.3 Classification by density 115
5.1.4 Compressive strength 116
5.1.5 Tensile strength and fracture properties 118
5.1.5.1 Tensile strength 118
5.1.5.2 Fracture energy 120
5.1.6 Strength under multiaxial states of stress 121
5.1.7 Modulus of elasticity and Poisson's ratio 124
5.1.7.1 Range of application 124
5.1.7.2 Modulus of elasticity 124
5.1.7.3 Poisson's ratio 127
5.1.8 Stress-strain relations for short-term loading 127
5.1.8.1 Compression 127
5.1.8.2 Tension 129
5.1.8.3 Multiaxial states of stress 130
5.1.8.4 Shear friction behaviour in cracks 134
5.1.9 Time effects 135
5.1.9.1 Development of strength with time 135
5.1.9.2 Strength under sustained loads 137
5.1.9.3 Development of modulus of elasticity with time 138
5.1.9.4 Creep and shrinkage 139
5.1.10 Temperature effects 148
5.1.10.1 Range of application 148
5.1.10.2 Maturity 149
5.1.10.3 Thermal expansion 149
5.1.10.4 Compressive strength 150
5.1.10.5 Tensile strength and fracture properties 150
5.1.10.6 Modulus of elasticity 152
5.1.10.7 Creep and shrinkage 152
5.1.10.8 Effect of high temperatures 155
5.1.10.9 Low temperature (cryogenic temperature) 156
5.1.11 Properties related to non-static loading 156
5.1.11.1 Fatigue 156
5.1.11.2 Stress and strain rate effects – impact 160
5.1.12 Transport of liquids and gases in hardened concrete 162
5.1.12.1 Permeation 163
5.1.12.2 Diffusion 165
5.1.12.3 Capillary suction 170
5.1.13 Properties related to durability 171
5.1.13.1 General 171
5.1.13.2 Carbonation progress 171
5.1.13.3 Ingress of chlorides 172
5.1.13.4 Freeze-thaw and freeze-thaw de-icing agent degradation 173
5.1.13.5 Alkali-aggregate reaction 174
5.1.13.6 Degradation by acids 175
5.1.13.7 Leaching progress 176

5.2 Reinforcing steel 177
5.2.1 General 177
5.2.2 Quality control 178
5.2.3 Designation 178
5.2.4 Geometrical properties 178
5.2.4.1 Size 178
5.2.4.2 Surface characteristics 179
5.2.5 Mechanical properties 180
5.2.5.1 Tensile properties 180
5.2.5.2 Steel grades 181
5.2.5.3 Stress-strain diagram 181
5.2.5.4 Ductility 182
5.2.5.5 Shear of welded joints in welded fabric 183
5.2.5.6 Fatigue behaviour 184
5.2.5.7 Behaviour under extreme thermal conditions 184
5.2.5.8 Effect of strain rate 184
5.2.6 Technological properties 184
5.2.6.1 Bendability 184
5.2.6.2 Weldability 185
5.2.6.3 Coefficient of thermal expansion 185
5.2.6.4 Provisions for quality control 185
5.2.7 Special types of steels 185
5.2.8 Assumptions used for design 186
5.3 Prestressing steel 188
5.3.1 General 188
5.3.2 Quality control 189
5.3.3 Designation 189
5.3.4 Geometrical properties 190
5.3.5 Mechanical properties 191
5.3.5.1 Tensile properties 191
5.3.5.2 Stress-strain diagram 191
5.3.5.3 Fatigue behaviour 192
5.3.5.4 Behaviour under extreme thermal conditions 193
5.3.5.5 Effect of strain rate 195
5.3.5.6 Bond characteristics 195
5.3.6 Technological properties 195
5.3.6.1 Isothermal stress relaxation 195
5.3.6.2 Deflected tensile behaviour (only for strands with nominal diameter ≥ 12.5 mm) 197
5.3.6.3 Stress corrosion resistance 197
5.3.6.4 Coefficient of thermal expansion 197
5.3.6.5 Residual stresses 197
5.3.7 Special types of prestressing steel 198
5.3.7.1 Metallic coating 198
5.3.7.2 Organic coating 198
5.3.7.3 Exterior sheathing with a filling product 198
5.3.8 Assumptions used for design 200

5.4 Prestressing systems 201
5.4.1 General 201
5.4.2 Post-tensioning system components and materials 202
5.4.2.1 Anchorages and coupling devices 202
5.4.2.2 Ducts 204
5.4.2.3 Filling materials 206
5.4.2.4 Quality control 207
5.4.3 Protection of tendons 207
5.4.3.1 Temporary corrosion protection 207
5.4.3.2 Permanent corrosion protection 207
5.4.3.3 Permanent corrosion protection of prestressing steel 208
5.4.3.4 Permanent protection of FRP materials 208
5.4.3.5 Fire protection 209
5.4.4 Stresses at tensioning, time of tensioning 209
5.4.4.1 Time of tensioning 209
5.4.4.2 Tendons made from prestressing steel 209
5.4.4.3 Tendons made from FRP materials 210
5.4.5 Initial prestress 210
5.4.5.1 General 210
5.4.5.2 Losses occurring in pretensioning beds 210
5.4.5.3 Immediate losses occurring during stressing 210
5.4.6 Value of prestressing force during design life (time $t > 0$) 216
5.4.6.1 Calculation of time-dependent losses made of prestressing steel 216
5.4.6.2 Calculation of time-dependent losses made of FRP 222
5.4.7 Design values of forces in prestressing 222
5.4.7.1 General 222
5.4.7.2 Design values for SLS and fatigue verifications 222
5.4.7.3 Design values for ULS verifications 223
5.4.8 Design values of tendon elongations 223
5.4.9 Detailing rules for prestressing tendons 223
5.4.9.1 Pretensioning tendons 223
5.4.9.2 Post-tensioning tendons 224
5.5 Non-metallic reinforcement 225
5.5.1 General 225
5.5.2 Quality control 227
5.5.3 Designation 227
5.5.4 Geometrical properties 227
5.5.4.1 Configuration 227
5.5.4.2 Size 227
5.5.4.3 Surface characteristics 228
5.5.5 Mechanical properties 228
5.5.5.1 Tensile strength and ultimate strain 228
5.5.5.2 Type 228
5.5.5.3 Stress-strain diagram and modulus of elasticity 228
5.5.5.4 Compressive and shear strength 229
5.5.5.5 Fatigue behaviour 229
5.5.5.6 Creep behaviour 230
5.5.5.7 Relaxation 230

5.5.5.8 Behaviour under elevated temperature and under extreme thermal conditions 231
5.5.6 Technological properties 231
5.5.6.1 Bond characteristics 231
5.5.6.2 Bendability 231
5.5.6.3 Coefficient of thermal expansion 231
5.5.6.4 Durability 232
5.6 Fibres/Fibre Reinforced Concrete 234
5.6.1 Introduction 234
5.6.2 Material properties 235
5.6.2.1 Behaviour in compression 235
5.6.2.2 Behaviour in tension 236
5.6.3 Classification 238
5.6.4 Constitutive laws 239
5.6.5 Stress-strain relationship 243
5.6.6 Partial safety factors 246
5.6.7 Orientation factor 246
6 Interface characteristics 247
6.1 Bond of embedded steel reinforcement 247
6.1.1 Local bond-slip relationship 247
6.1.1.1 Local bond stress-slip model, ribbed bars 247
6.1.1.2 Influence of transverse cracking 251
6.1.1.3 Influence of yielding, transverse stress and longitudinal cracking and cyclic loading 251
6.1.1.4 Influence of creep and fatigue loading 255
6.1.1.5 Unloading branch 256
6.1.1.6 Plain (non-ribbed) surface bars 256
6.1.2 Influence on serviceability 257
6.1.3 Anchorage and lapped joints of reinforcement 257
6.1.3.1 Minimum detailing requirements 258
6.1.3.2 Basic bond strength 259
6.1.3.3 Design bond strength 261
6.1.3.4 Design anchorage length 263
6.1.3.5 Contribution of hooks and bends 264
6.1.3.6 Headed reinforcement 265
6.1.3.7 Laps of bars in tension 266
6.1.3.8 Laps of bars in compression 267
6.1.3.9 Anchorage of bundled bars 268
6.1.3.10 Lapped joints of bundled bars 268
6.1.4 Anchorage and lapped joints of welded fabric 269
6.1.4.1 Design anchorage length of welded fabric 269
6.1.4.2 Design lap length of welded fabric in tension 269
6.1.4.3 Design lap length of welded fabric in compression 270
6.1.5 Special circumstances 271
6.1.5.1 Slipform construction 271
6.1.5.2 Bentonite walling 271
6.1.5.3 Post-installed reinforcement 271
6.1.5.4 ECE (electrochemical extraction of chlorides) 271

6.1.6 Conditions of service 272
6.1.6.1 Cryogenic conditions 272
6.1.6.2 Elevated temperatures 272
6.1.7 Degradation 272
6.1.7.1 Corrosion 272
6.1.7.2 ASR 274
6.1.7.3 Frost 274
6.1.7.4 Fire 275
6.1.8 Anchorage of pretensioned prestressing tendons 275
6.1.8.1 General 275
6.1.8.2 Design bond strength 276
6.1.8.3 Basic anchorage length 276
6.1.8.4 Transmission length 277
6.1.8.5 Design anchorage length 278
6.1.8.6 Development length 278
6.2 Bond of non-metallic reinforcement 279
6.2.1 Local bond stress-slip model 279
6.2.1.1 Local bond stress-slip model for FRP rebars 280
6.2.1.2 Local bond stress-slip model for externally bonded FRP 280
6.2.2 Bond and anchorage of internal FRP reinforcement 281
6.2.3 Bond and anchorage of externally bonded FRP reinforcement 282
6.2.3.1 Bond-critical failure modes 283
6.2.3.2 Maximum bonded length 283
6.2.3.3 Ultimate strength for end debonding – anchorage capacity 284
6.2.3.4 Ultimate strength for end debonding – concrete rip-off 285
6.2.3.5 Ultimate strength for intermediate debonding 286
6.2.3.6 Interfacial stresses for the serviceability limit state 286
6.2.4 Mechanical anchorages for externally bonded FRP reinforcement 286
6.3 Concrete to concrete 287
6.3.1 Definitions and scope 287
6.3.2 Interface roughness characteristics 287
6.3.3 Mechanisms of shear transfer 289
6.3.4 Modelling and design 293
6.3.5 Detailing 297
6.4 Concrete to steel 299
6.4.1 Classification of interaction mechanisms 299
6.4.2 Bond of metal sheeting and profiles 299
6.4.2.1 Metal sheeting 300
6.4.2.2 Steel profiles 300
6.4.2.3 Interface strength 301
6.4.2.4 Shear stress-slip relationships 302
6.4.2.5 Influence of the type of loading 302
6.4.2.6 Determination of properties by testing 303
6.4.3 Mechanical interlock 303
6.4.3.1 Classification of devices 304
6.4.3.2 Strength evaluation 304
6.4.3.3 Force-shear slip constitutive relationships 308
6.4.3.4 Influence of the type of loading 310
6.4.3.5 Determination of properties by testing 310