

Contents

Editor's remarks.....	iii
Preface	iv
9 THROUGH-LIFE CARE AND MANAGEMENT OF CONCRETE STRUCTURES - ASSESSMENT, PROTECTION, REPAIR AND STRENGTHENING	1
9.1 Introduction.....	1
9.1.1 Background.....	1
9.1.2 Concrete - A family of materials	2
9.1.3 Service life design and through-life management aspects	2
9.1.4 Reactive and proactive approaches to structure management.....	5
9.1.5 Management systems for populations of structures	9
9.1.6 Assessment of existing buildings and structures.....	10
9.1.7 The condition of infrastructure – The challenge for assessment, management and repair ...	15
9.2 Brief overview of the development and history of concrete construction.....	18
9.2.1 Introduction.....	18
9.2.2 Early forms of concrete and concrete construction.....	19
9.2.3 19 th century development of reinforced concrete.....	21
9.2.4 Early 20 th century development of reinforced concrete	22
9.2.5 Overview of historical developments in concrete construction and design guidance.....	26
9.2.6 Evolution in the properties of concrete	31
9.2.7 Change in the strength of steel reinforcement	35
9.2.8 Early prestressing systems	36
9.2.9 Overview of historical design requirements and approaches to concrete structure design...	37
9.3 Guidance, standards and sources of information for the assessment of existing concrete structures	38
9.3.1 Introduction.....	38
9.3.2 CEB Bulletin 243.....	39
9.3.3 CONTECVET project.....	41
9.3.4 ISO 13822: Bases for design of structures- Assessment of existing structures	65
9.3.5 JCSS report: Probabilistic assessment of existing structures.....	67
9.3.6 fib Bulletin 17	70
9.3.7 LIFECON project	71
9.3.8 REHABCON project	75
9.3.9 NORECON project	80
9.3.10 Management of highway structures	82
9.3.11 CONREPNET project.....	90

9.3.12	CBDG guidance on the assessment of concrete bridges.....	99
9.3.13	Sustainable Bridges project.....	101
9.3.14	<i>fib</i> Bulletin 44	107
9.3.15	Management of deteriorating concrete structures.....	109
9.3.16	Institution of Structural Engineers: Appraisal of existing structures - 3 rd Edition.....	111
9.3.17	<i>fib</i> Model Code 2010	114
9.3.18	Swiss codes for the conservation of existing structures.....	115
9.3.19	BRE handbook on the assessment of large panel system dwelling blocks for accidental loading	119
9.3.20	<i>fib</i> Bulletin 59: Condition control and assessment of reinforced concrete structures exposed to corrosive environments (carbonation / chlorides).....	122
9.4	Through-life management of existing structures	133
9.4.1	Introduction.....	133
9.4.2	Performance requirements and owner obligations	136
9.4.3	Reliability and functionality requirements.....	137
9.4.4	Responsibilities and liabilities	138
9.4.5	Societal and sustainability perspectives.....	142
9.4.6	Value judgements, decision criteria and probabilistic concepts	147
9.4.7	Asset management systems.....	150
9.4.8	Conservation strategies	154
9.4.9	Hazard and risk issues.....	156
9.4.10	Reasons for assessment (owner's brief or other requirements)	164
9.4.11	Conservation of historical structures - attitudes and influences.....	165
9.5	Previous experience - In-service performance of concrete structures and remedial interventions	165
9.5.1	Introduction.....	165
9.5.2	Durability of concrete structures in Denmark (Idorn)	166
9.5.3	Lessons to be learnt from European failures (Hauser).....	166
9.5.4	Errors associated with USA concrete structures (Fraczek / ACI)	167
9.5.5	In-service performance of 200 UK concrete bridges (Wallbank)	167
9.5.6	Quality of UK concrete construction (Clark et al)	168
9.5.7	In-service performance inadequacies and the premature deterioration of concrete structures (Jones et al)	168
9.5.8	Performance of 40 UK concrete bridges (Tajalli and Rigden)	169
9.5.9	Durability of post-tensioning tendons (<i>fib</i> Bulletin 15)	170
9.5.10	Stress corrosion cracking and associated failures in prestressed concrete construction in Germany (<i>fib</i> Task Group 9.5).....	176
9.5.11	Effectiveness of concrete repairs (Baldwin and King)	180
9.5.12	Strategic improvements to the concrete repair industry in the USA (Emmons)	180

9.5.13	Remedial interventions on concrete structures (CONREPNET)	182
9.5.14	Chloride penetration into high strength and high performance concretes (Helland et al) ..	184
9.5.15	Overview of recommendations for improving the durability and through-life performance	185
9.5.16	SCOSS and CROSS	186
9.6	Conservation management - Overview of philosophy and process steps.....	188
9.6.1	Introduction.....	188
9.6.2	Proactive conservation measures (Strategy A)	189
9.6.3	Reactive conservation measures (Strategy B).....	190
9.6.4	Situations where conservation measures are not feasible (Strategy C).....	191
9.6.5	Conservation management processes.....	191
9.6.6	Condition survey and monitoring activities	194
9.6.7	Condition assessment.....	195
9.6.8	Condition evaluation and decision-making.....	196
9.6.9	Interventions - Preventive, maintenance, remedial and strengthening works.....	197
9.6.10	Selection of interventions	197
9.6.11	Recording of life cycle information, reporting of assessment outcomes and recommendations	197
9.7	Deterioration and damage mechanisms.....	198
9.7.1	Introduction.....	198
9.7.2	Deterioration mechanisms	199
9.7.3	Classification of environmental aggressivity	202
9.7.4	Corrosion induced deterioration of structural concrete.....	205
9.7.5	Accidental damage mechanisms – fire, impact, etc	217
9.7.6	Extreme events.....	220
9.7.7	Progressive collapse, disproportionate structural damage and related issues	223
9.7.8	Influence of deterioration upon through-life performance.....	237
9.8	Gathering of information, condition survey, inspection, monitoring and associated activities	240
9.8.1	Introduction.....	240
9.8.2	Review of available technical information	240
9.8.3	Gathering data for condition control purposes.....	242
9.8.4	Condition survey, testing and inspection activities.....	243
9.8.5	Locations for survey, testing and other information gathering activities.....	247
9.8.6	Other survey / inspection tasks and activities	248
9.8.7	Structural monitoring	249
9.9	Condition survey - Testing and investigations	256
9.9.1	Introduction.....	256

9.9.2	General observations upon testing	257
9.9.3	Simple on-site testing.....	262
9.9.4	Non-destructive testing techniques	265
9.9.5	Laboratory testing of material samples.....	273
9.9.6	Static load testing.....	274
9.9.7	Dynamic response measurements and testing.....	277
9.9.8	Advantages and limitations of selected testing and inspection techniques.....	277
9.9.9	Criteria for the interpretation of the results of some non-destructive tests	284
9.10	Structural condition assessment	286
9.10.1	Introduction.....	286
9.10.2	General approach	286
9.10.3	Overview of structural condition assessment activities	287
9.10.4	Structural condition assessment process steps	290
9.10.5	Safety concepts in general	295
9.10.6	Material influences.....	296
9.10.7	Re-calculation	296
9.10.8	Modelling of deteriorated concrete and corroded reinforcement.....	299
9.10.9	Hidden strengths	301
9.10.10	Reliability updating and estimating residual service life	305
9.11	Condition evaluation and decision-making	306
9.11.1	Introduction.....	306
9.11.2	Verification against performance criteria for safety and other parameters	306
9.11.3	Formats for verification of safety and other parameters	308
9.11.4	Target reliability levels	308
9.11.5	Partial safety factors for use in the assessment of existing structures.....	312
9.11.6	Relevance of guidance in earlier codes of practice.....	315
9.11.7	Safety concepts in codes of practice for design	317
9.11.8	Evaluation and selection of a structure management or intervention option	323
9.11.9	Assessment and treatment of historical and heritage concrete structures and associated architectural concrete surfaces.....	324
9.12	Interventions and through-life management activities and measures	332
9.12.1	General – Types of intervention	332
9.12.2	Maintenance interventions	333
9.12.3	Preventive interventions.....	334
9.12.4	Remedial interventions	334
9.12.5	Rebuild, reconstruction and replacement.....	335
9.12.6	Strengthening or upgrading interventions.....	335

9.12.7	Other through-life management activities and measures	336
9.12.8	Execution of interventions	337
9.12.9	Recording.....	338
9.13	Standards for the protection, repair and strengthening of concrete structures.....	338
9.13.1	Introduction.....	338
9.13.2	European Standards	338
9.13.3	Japanese Standards.....	341
9.13.4	Australian Standards.....	344
9.13.5	USA Standards.....	346
9.13.6	ISO Standards	348
9.14	The protection, repair and strengthening of concrete structures using the EN 1504 standards.....	350
9.14.1	Introduction.....	350
9.14.2	Durability investigation and assessment procedure	350
9.14.3	Selection of an intervention method for concrete protection, repair or strengthening.....	352
9.14.4	EN 1504 series: Overview of principles and methods related to protection and repair of concrete structures	356
9.14.5	Supplementary information and guidance	359
9.15	Structural assessment and repair after a fire.....	360
9.15.1	Introduction.....	360
9.15.2	Effects of heating and subsequent cooling.....	360
9.15.3	Investigation and structural assessment procedure	361
9.15.4	Assessment of damage	362
9.15.5	Procedures for structural repair after a fire	363
9.16	Recording and reporting	363
9.16.1	Recording.....	363
9.16.2	Types and purpose of report	364
9.16.3	General requirements for a report	365
9.16.4	Report structure and content	365
9.16.5	Process of preparing a report	367
9.17	Application example	368
9.17.1	Introduction.....	368
9.17.2	Steps for making an assessment and a subsequent intervention on a structure.....	370
9.17.3	Illustration of process - Intervention works upon a bridge	370
9.18	Proactive durability management - Example from practice of the protection and repair of a concrete structure	377

9.19	Case study – Reliability assessment of a bridge subject to chloride induced corrosion and associated structural deterioration	380
9.19.1	Synopsis	380
9.19.2	Introduction.....	381
9.19.3	The Neumarkt Bridge	381
9.19.4	Inspection.....	382
9.19.5	Performance assessment activities	384
9.19.6	Bridge management – Some possible scenarios	402
9.19.7	Concluding comments	406
9.20	Future look	408
9.20.1	Overview.....	408
9.20.2	Potential implications of climate change	411
9.20.3	Work of <i>fib</i> Special Activity Group 7 (SAG7): <i>Assessment and interventions upon existing structures</i>	411
9.20.4	Future reduction in CO ₂ emissions and the work of <i>fib</i> Special Activity Group 8 (SAG8): <i>Sustainability</i>	413
9.21	Acknowledgements	416
9.22	References and bibliography	417
9.22.1	References and bibliography.....	417
9.22.2	Useful conference proceedings and other texts.....	444
Abbreviations and short form names of projects		446
Glossary: Definitions and terminology.....		449