
Contents

| | |
|---------------------------------------------------------------------------------------------------------------|-----------|
| <i>Preface</i> | ix |
| <i>Illustration credits</i> | xi |
| <i>Acknowledgements</i> | xiii |
| | |
| 1 Introduction | 1 |
| <i>References</i> | 4 |
| | |
| 2 Corrosion of steel in concrete | 7 |
| 2.1 <i>The corrosion process</i> | 8 |
| 2.2 <i>Black rust</i> | 10 |
| 2.3 <i>Pits, stray current and bacterial corrosion</i> | 10 |
| 2.4 <i>Electrochemistry, cells and half cells</i> | 14 |
| 2.5 <i>Conclusions</i> | 15 |
| <i>References</i> | 16 |
| | |
| 3 Causes and mechanisms of corrosion in concrete | 17 |
| 3.1 <i>Carbonation</i> | 17 |
| 3.2 <i>Chloride attack</i> | 21 |
| 3.3 <i>Corrosion damage</i> | 26 |
| 3.4 <i>Cracks, crack orientation and corrosion</i> | 29 |
| 3.5 <i>The synergistic relationship between chloride and carbonation attack, chloride binding and release</i> | 30 |
| <i>References</i> | 30 |
| | |
| 4 Condition evaluation | 31 |
| 4.1 <i>Desk study</i> | 33 |
| 4.2 <i>Preliminary survey</i> | 33 |

| | | |
|------|-------------------------------------------------------------------------|-----|
| 4.3 | <i>The detailed survey</i> | 33 |
| 4.4 | <i>Available techniques</i> | 35 |
| 4.5 | <i>Visual inspection</i> | 36 |
| 4.6 | <i>Delamination</i> | 37 |
| 4.7 | <i>Cover</i> | 42 |
| 4.8 | <i>Reference electrode (half cell) potential measurements</i> | 44 |
| 4.9 | <i>Carbonation depth measurement</i> | 55 |
| 4.10 | <i>Chloride determination</i> | 57 |
| 4.11 | <i>Resistivity measurement</i> | 63 |
| 4.12 | <i>Corrosion rate measurement</i> | 68 |
| 4.13 | <i>Permeability and absorption tests</i> | 81 |
| 4.14 | <i>Concrete characteristics: cement content, petrography, W/C ratio</i> | 83 |
| 4.15 | <i>Ground penetrating radar</i> | 84 |
| 4.16 | <i>Ultrasonic pulse velocity</i> | 86 |
| 4.17 | <i>Impact-echo</i> | 89 |
| 4.18 | <i>Radiography</i> | 90 |
| 4.19 | <i>Survey and assessment methodology</i> | 93 |
| 4.20 | <i>Special conditions – prestressing and coated rebars</i> | 94 |
| | <i>References</i> | 96 |
| 5 | Corrosion monitoring | 103 |
| 5.1 | <i>Regular surveys to monitor corrosion</i> | 104 |
| 5.2 | <i>Permanent corrosion monitoring systems</i> | 104 |
| 5.3 | <i>Remote monitoring systems and data management</i> | 112 |
| | <i>References</i> | 112 |
| 6 | Physical and chemical repair and rehabilitation techniques | 115 |
| 6.1 | <i>Concrete removal and surface preparation</i> | 116 |
| 6.2 | <i>Patches</i> | 122 |
| 6.3 | <i>Coatings, sealers, membranes and barriers</i> | 125 |
| 6.4 | <i>Encasement and overlays</i> | 131 |
| 6.5 | <i>Sprayed concrete</i> | 132 |
| 6.6 | <i>Corrosion inhibitors</i> | 133 |
| 6.7 | <i>Standards and guidance on physical and chemical repair</i> | 138 |
| | <i>References</i> | 140 |

| | | |
|----------|--------------------------------------------------------------------------------------------------------------------|------------|
| 7 | Electrochemical repair techniques | 143 |
| 7.1 | <i>Basic principles of electrochemical techniques</i> | 143 |
| 7.2 | <i>Cathodic protection principles</i> | 144 |
| 7.3 | <i>Galvanic anode systems</i> | 149 |
| 7.4 | <i>The components of an impressed current cathodic protection system</i> | 156 |
| 7.5 | <i>Cathodic protection system design</i> | 177 |
| 7.6 | <i>Control criteria</i> | 182 |
| 7.7 | <i>Standards and guidance documents for cathodic protection of steel in concrete</i> | 185 |
| 7.8 | <i>System installation</i> | 188 |
| 7.9 | <i>Cathodic protection of prestressed concrete</i> | 193 |
| 7.10 | <i>Cathodic protection of epoxy coated reinforcing steel</i> | 194 |
| 7.11 | <i>Cathodic protection of structures with ASR</i> | 195 |
| 7.12 | <i>Electrochemical chloride extraction</i> | 195 |
| 7.13 | <i>Realkalization</i> | 204 |
| 7.14 | <i>Standards and guidance for electrochemical chloride extraction and realkalization</i> | 206 |
| 7.15 | <i>Electro-osmosis</i> | 207 |
| 7.16 | <i>Comparison of techniques</i> | 208 |
| | <i>References</i> | 210 |
| 8 | Rehabilitation methodology | 215 |
| 8.1 | <i>Technical differences between repair options</i> | 216 |
| 8.2 | <i>Repair costs</i> | 216 |
| 8.3 | <i>Carbonation options</i> | 220 |
| 8.4 | <i>Chloride options</i> | 224 |
| 8.5 | <i>Standards and guidance for selection of repairs</i> | 229 |
| 8.6 | <i>Training</i> | 232 |
| | <i>References</i> | 234 |
| 9 | Modelling and calculating corrosion, deterioration and life cycle costing of reinforced concrete structures | 237 |
| 9.1 | <i>Activation time T_0 carbonation-induced corrosion</i> | 237 |
| 9.2 | <i>Chloride ingress rates (initiation)</i> | 240 |
| 9.3 | <i>Rate of depassivation (activation)</i> | 243 |
| 9.4 | <i>Activation time T_1</i> | 243 |
| 9.5 | <i>The Clear/Stratfull empirical calculation</i> | 246 |
| 9.6 | <i>Corrosion without spalling and high corrosion rates</i> | 246 |

| | | |
|-------|------------------------------------------------------------------------------------------|-----|
| 9.7 | <i>Cracking and spalling rates, condition indexes and end of functional service life</i> | 247 |
| 9.8 | <i>Summary of methodology to determine service life</i> | 248 |
| 9.9 | <i>Diffusion models proposed in literature</i> | 249 |
| | <i>References</i> | 251 |
| 10 | Design for durability | 255 |
| 10.1 | <i>Cover, concrete and design</i> | 255 |
| 10.2 | <i>Fusion bonded epoxy coated rebars</i> | 258 |
| 10.3 | <i>Galvanized rebar</i> | 264 |
| 10.4 | <i>Penetrating sealers</i> | 265 |
| 10.5 | <i>Other corrosion resistant reinforcement</i> | 265 |
| 10.6 | <i>Waterproofing membranes</i> | 265 |
| 10.7 | <i>Stainless steel reinforcement</i> | 267 |
| 10.8 | <i>Corrosion inhibitors</i> | 268 |
| 10.9 | <i>Installing cathodic protection in new structures</i> | 269 |
| 10.10 | <i>Durable buildings</i> | 270 |
| 10.11 | <i>Conclusions</i> | 272 |
| | <i>References</i> | 272 |
| 11 | Sustainability and future developments | 275 |
| | <i>References</i> | 278 |
| | <i>Appendix: Sources of information on corrosion of steel in concrete</i> | 279 |
| | <i>Glossary and index</i> | 283 |