Part I  Planning and implementing non-destructive testing of reinforced concrete structures  1

1  Planning a non-destructive test programme for reinforced concrete structures  3
C. MAIERHOFER, BAM Federal Institute for Materials Research and Testing, Germany

1.1  Introduction  3
1.2  Strategies for the application of non-destructive testing (NDT) methods  4
1.3  Overview of non-destructive testing (NDT) methods  6
1.4  Qualification/validation of methods  8
1.5  Sources of further information and advice  10
1.6  References  12

2  Non-destructive testing methods for building diagnosis – state of the art and future trends  14
C. FLOHRER, HOCHTIEF Construction AG, Germany

2.1  Introduction  14
2.2  Tasks for building diagnosis  14
2.3  Efficient testing methods  15
2.4  Examples of the application of the testing methods  18
2.5  Future trends  28
2.6  References  29
3 Development of automated non-destructive evaluation (NDE) systems for reinforced concrete structures and other applications

G. Dobmann and J. H. Kurz, Fraunhofer-IZFP, Germany; A. Taffe, BAM Federal Institute for Materials Research and Testing, Germany; D. Streicher, Joint Lab of Fraunhofer & BAM, Germany

3.1 Introduction

3.2 The innovation cycles

3.3 Data acquisition, control and evaluation in automated multisensor systems

3.4 Case studies of successful innovations to automated systems in non-destructive testing (NDT) engineering

3.5 Non-destructive testing for structural engineering

3.6 Multiple-sensor data acquisition by the OSSCAR (On-Site SCAnneR) scanner

3.7 Conclusions

3.8 Acknowledgements

3.9 References

4 Structural health monitoring systems for reinforced concrete structures

W. R. Habel, BAM Federal Institute for Materials Research and Testing, Germany

4.1 Introduction

4.2 Demands on monitoring systems: monitoring capabilities

4.3 Innovative monitoring methods

4.4 Selected examples of effective and innovative monitoring technologies

4.5 Reliability of structural health monitoring (SHM) systems and standardization

4.6 Future trends

4.7 References

5 Combining the results of various non-destructive evaluation techniques for reinforced concrete: data fusion

C. Maierhofer, C. Kohl and J. Wöstmann, BAM Federal Institute for Materials Research and Testing, Germany

5.1 Introduction

5.2 Combination of non-destructive testing (NDT) and minor destructive testing (MDT) methods

5.3 Data fusion
Part II Individual non-destructive testing techniques

6 Wireless monitoring of reinforced concrete structures
M. Krüger, University of Stuttgart, Germany

6.1 Introduction
6.2 Basic principles of wireless monitoring
6.3 Definition of the monitoring task
6.4 Monitoring system design and assembly
6.5 Wireless monitoring systems in operation
6.6 Application of intelligent wireless monitoring
6.7 Conclusions and future trends
6.8 References

7 Non-destructive testing of concrete with electromagnetic and acoustic-elastic waves: data analysis
K.-J. Sandmeier, Sandmeier Scientific Software, Germany

7.1 Introduction
7.2 Similarities and differences between seismic, ultrasonic and electromagnetic wave propagation and their implications on data processing
7.3 Standard data processing
7.4 Sophisticated data processing
7.5 Conclusions and future trends
7.6 References

8 Non-destructive testing of concrete with electromagnetic, acoustic and elastic waves: modelling and imaging
K. J. Langenberg, K. Mayer and R. Marklein, University of Kassel, Germany

8.1 Introduction
8.2 Electromagnetic, acoustic and elastic waves
8.3 Numerical wave field modelling for acoustic, electromagnetic and elastic waves 151
8.4 Wave field inversion and imaging: acoustic waves 154
8.5 Wave field inversion: electromagnetic and elastic waves 158
8.6 Conclusions 159
8.7 References 161

9 Laser-induced breakdown spectroscopy (LIBS) for evaluation of reinforced concrete structures 163
G. Wilsch, BAM Federal Institute for Materials Research and Testing; A. Molkenthin, Specht, Kalleja + Partner GmbH, Germany
9.1 Introduction 163
9.2 Laser-induced breakdown spectroscopy (LIBS): fundamentals and measurement 164
9.3 Characterization of cement, mortar and concrete 167
9.4 Detection of specific elements: specific testing problems 173
9.5 Mobile set-up: on-site applications 180
9.6 Limitations and reliability 183
9.7 References 184

10 Acoustic emission (AE) evaluation of reinforced concrete structures 185
C. U. Grosse, Technical University of Munich, Germany
10.1 Introduction 185
10.2 Basics: parametric and signal-based acoustic emission (AE) analysis 187
10.3 Sensors and instruments 191
10.4 Source localization 193
10.5 Source mechanisms and moment tensor analysis 197
10.6 Applications 199
10.7 Limitations and accuracy 206
10.8 References 210

11 Magnetic flux leakage (MFL) for the non-destructive evaluation of pre-stressed concrete structures 215
G. Sawade, University of Stuttgart, Germany; H.-J. Krause, Forschungszentrum Jülich, Germany
11.1 Magnetic method for inspection of reinforced concrete structures 215
11.2 Description of equipment required 233
11.3 Examples of applications of the magnetic method on site 235
11.4 Perspective: recent developments of the magnetic method for inspection of reinforced concrete 239
11.5 Recommendations for the application of the magnetic flux leakage (MFL) method 240
11.6 References 241

12 Electrical resistivity for the evaluation of reinforced concrete structures 243
J.-F. Lataste, University of Bordeaux 1, France

12.1 Introduction 243
12.2 Physical principles and theory 244
12.3 Use of electrical resistivity 255
12.4 Other developments 264
12.5 Impedance spectroscopy 268
12.6 References 270

13 Capacimetry for the evaluation of reinforced concrete structures 276
X. Dérobért, LCPC, France

13.1 Physical principle and theory 276
13.2 Equipment 279
13.3 Calibration 280
13.4 Data acquisition and interpretation 280
13.5 Applications 281
13.6 Limitations and reliability 282
13.7 References 283

14 Techniques for measuring the corrosion rate (polarization resistance) and the corrosion potential of reinforced concrete structures 284
C. Andrade and I. Martínez, Instituto de Ciencias de la Construcción Eduardo Torroja (CSIC), Spain

14.1 Introduction 284
14.2 Principles 285
14.3 Measurement methods 293
14.4 How to interpret the measurements 303
14.5 Practical application 306
14.6 Monitoring systems 310
14.7 Future trends: new techniques 311
14.8 Conclusions 312
14.9 References 313
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Ground penetrating radar for the evaluation of reinforced concrete structures</td>
<td>317</td>
</tr>
<tr>
<td>J. HUGENSCHEIT, EMPA, Switzerland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.1</td>
<td>Introduction to ground penetrating radar (GPR)</td>
<td>317</td>
</tr>
<tr>
<td>15.2</td>
<td>Physical principles and theory</td>
<td>318</td>
</tr>
<tr>
<td>15.3</td>
<td>Display formats for ground penetrating radar (GPR) data</td>
<td>322</td>
</tr>
<tr>
<td>15.4</td>
<td>Data processing and interpretation</td>
<td>323</td>
</tr>
<tr>
<td>15.5</td>
<td>Equipment</td>
<td>325</td>
</tr>
<tr>
<td>15.6</td>
<td>Limitations and reliability of ground penetrating radar (GPR)</td>
<td>326</td>
</tr>
<tr>
<td>15.7</td>
<td>Current and future trends</td>
<td>327</td>
</tr>
<tr>
<td>15.8</td>
<td>Symbols and constants</td>
<td>331</td>
</tr>
<tr>
<td>15.9</td>
<td>References</td>
<td>332</td>
</tr>
<tr>
<td>16</td>
<td>Radar tomography for evaluation of reinforced concrete structures</td>
<td>334</td>
</tr>
<tr>
<td>L. ZANZI, Politecnico di Milano, Italy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.1</td>
<td>Introduction</td>
<td>334</td>
</tr>
<tr>
<td>16.2</td>
<td>Physical principles</td>
<td>335</td>
</tr>
<tr>
<td>16.3</td>
<td>Fundamental equations</td>
<td>337</td>
</tr>
<tr>
<td>16.4</td>
<td>Resolution</td>
<td>338</td>
</tr>
<tr>
<td>16.5</td>
<td>Equipment</td>
<td>339</td>
</tr>
<tr>
<td>16.6</td>
<td>Acquisition procedures</td>
<td>341</td>
</tr>
<tr>
<td>16.7</td>
<td>Data pre-processing</td>
<td>344</td>
</tr>
<tr>
<td>16.8</td>
<td>Data inversion</td>
<td>346</td>
</tr>
<tr>
<td>16.9</td>
<td>Artefacts</td>
<td>349</td>
</tr>
<tr>
<td>16.10</td>
<td>Interpretation of results</td>
<td>350</td>
</tr>
<tr>
<td>16.11</td>
<td>Examples</td>
<td>354</td>
</tr>
<tr>
<td>16.12</td>
<td>Hints on advanced algorithms</td>
<td>363</td>
</tr>
<tr>
<td>16.13</td>
<td>Conclusions</td>
<td>365</td>
</tr>
<tr>
<td>16.14</td>
<td>References</td>
<td>365</td>
</tr>
<tr>
<td>17</td>
<td>Active thermography for evaluation of reinforced concrete structures</td>
<td>370</td>
</tr>
<tr>
<td>C. MAIERHOFER, M. RÖLLIG and J. SCHLICHTING, BAM Federal Institute for Materials Research and Testing, Germany</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17.1</td>
<td>Introduction</td>
<td>370</td>
</tr>
<tr>
<td>17.2</td>
<td>Physical principle and theoretical background</td>
<td>372</td>
</tr>
<tr>
<td>17.3</td>
<td>State of the art</td>
<td>375</td>
</tr>
<tr>
<td>17.4</td>
<td>Experimental equipment and calibration</td>
<td>376</td>
</tr>
<tr>
<td>17.5</td>
<td>Data processing</td>
<td>380</td>
</tr>
<tr>
<td>17.6</td>
<td>Areas of applications</td>
<td>386</td>
</tr>
</tbody>
</table>
21.3 Data interpretation 469
21.4 Numerical simulations 474
21.5 Signal processing, data presentation and imaging 475
21.6 Equipment 480
21.7 Impact-echo method applications 481
21.8 Future trends 484
21.9 References 485

22 Ultrasonic techniques for evaluation of reinforced concrete structures 490
M. Schickert, Institute of Materials Research and Testing (MFPA Weimar), Germany; M. Krause, BAM Federal Institute for Materials Research and Testing, Germany

22.1 Introduction 490
22.2 Ultrasonic wave propagation in concrete 491
22.3 Applications and requirements of ultrasonic non-destructive testing 499
22.4 Transmission methods 500
22.5 Imaging of concrete elements 503
22.6 Future trends 521
22.7 Sources of further information and advice 525
22.8 References 526

Part III Case studies 531

23 Inspection of concrete retaining walls using ground penetrating radar (GPR): a case study 533
J. Hugenschmidt, EMPA, Switzerland

23.1 Problem description 533
23.2 Data acquisition 534
23.3 Data processing 536
23.4 Results 538
23.5 Conclusions 542
23.6 Reference 542

24 Acoustic emission and impact-echo techniques for evaluation of reinforced concrete structures: a case study 543
M. Ohtsu, Kumamoto University, Japan

24.1 Introduction 543
24.2 Applications of acoustic emission (AE) and impact-echo (IE) for concrete structures
24.3 Case studies
24.4 Conclusions and future trends for on-site application
24.5 References

25 Using ground-penetrating radar (GPR) to assess an eight-span post-tensioned viaduct: a case study
X. DÉROBERT, LCPC, France; B. BERENGER, LRPC Angers, France

25.1 Introduction
25.2 Localization of post-tensioned ducts
25.3 Gammagraphic imaging
25.4 Windowing
25.5 Evaluation of the structure and reinforcement proposal
25.6 Localization of post-tensioned ducts and coring
25.7 Discussion of the applied methodology
25.8 Acknowledgements
25.9 References

Index