

Contents

1	Lifetime-Oriented Design Concepts	1
1.1	Lifetime-Related Structural Damage Evolution	1
1.2	Time-Dependent Reliability of Ageing Structures	3
1.3	Idea of Working-Life Related Building Classes.....	4
1.4	Economic and Further Aspects of Service-Life Control.....	5
1.5	Fundamentals of Lifetime-Oriented Design	7
2	Damage-Oriented Actions and Environmental Impact	9
2.1	Wind Actions	9
2.1.1	Wind Buffeting with Relation to Fatigue	10
2.1.1.1	Gust Response Factor	11
2.1.1.2	Number of Gust Effects.....	14
2.1.2	Influence of Wind Direction on Cycles of Gust Responses	18
2.1.2.1	Wind Data in the Sectors of the Wind Rosette.....	19
2.1.2.2	Structural Safety Considering the Occurrence Probability of the Wind Loading	22
2.1.2.3	Advanced Directional Factors	23
2.1.3	Vortex Excitation Including Lock-In	25
2.1.3.1	Relevant Wind Load Models	27
2.1.3.2	Wind Load Model for the Fatigue Analysis of Bridge Hangers.....	29
2.1.4	Micro and Macro Time Domain	33
2.1.4.1	Renewal Processes and Pulse Processes	34
2.2	Thermal Actions	35
2.2.1	General Comments	35
2.2.2	Thermal Impacts on Structures	35

2.2.3	Test Stand	39
2.2.4	Modelling of Short Term Thermal Impacts and Experimental Results	40
2.2.5	Application: Thermal Actions on a Cooling Tower Shell	43
2.3	Transport and Mobility	46
2.3.1	Traffic Loads on Road Bridges	46
2.3.1.1	General	46
2.3.1.2	Basic European Traffic Data	47
2.3.1.3	Basic Assumptions of the Load Models for Ultimate and Serviceability Limit States in Eurocode	52
2.3.1.4	Principles for the Development of Fatigue Load Models	62
2.3.1.5	Actual Traffic Trends and Required Future Investigations	73
2.3.2	Aerodynamic Loads along High-Speed Railway Lines	79
2.3.2.1	Phenomena	80
2.3.2.2	Dynamic Load Parameters	82
2.3.2.3	Load Pattern for Static and Dynamic Design Calculations	87
2.3.2.4	Dynamic Response	90
2.4	Load-Independent Environmental Impact	92
2.4.1	Interactions of External Factors Influencing Durability	93
2.4.2	Frost Attack (with and without Deicing Agents).....	95
2.4.2.1	The "Frost Environment": External Factors and Frost Attack	96
2.4.2.2	Damage Due to Frost Attack	103
2.4.3	External Chemical Attack	106
2.4.3.1	Sulfate Attack	107
2.4.3.2	Calcium Leaching	107
2.5	Geotechnical Aspects	109
2.5.1	Settlement Due to Cyclic Loading	109
2.5.2	Multidimensional Amplitude for Soils under Cyclic Loading	114
3	Deterioration of Materials and Structures	123
3.1	Phenomena of Material Degradation on Various Scales	124
3.1.1	Load Induced Degradation	124
3.1.1.1	Quasi Static Loading in Cementitious Materials	124

3.1.1.1.1	Fracture Mechanism of Concrete Subjected to Uniaxial Compression Loading	124
3.1.1.1.2	Fracture Mechanism of Concrete Subjected to Uniaxial Tension Loadings	125
3.1.1.1.3	Concrete under Multiaxial Loadings	126
3.1.1.2	Cyclic Loading	129
3.1.1.2.1	Ductile Mode of Degradation in Metals	129
3.1.1.2.2	Quasi-Brittle Damage	131
3.1.1.2.2.1	Cementitious Materials.....	131
3.1.1.2.2.2	Metallic Materials....	137
3.1.2	Non-mechanical Loading	140
3.1.2.1	Thermal Loading	140
3.1.2.1.1	Degradation of Concrete Due to Thermal Incompatibility of Its Components	140
3.1.2.1.2	Stresses Due to Thermal Loading	141
3.1.2.1.3	Temperature and Stress Development in Concrete at the Early Age Due to Heat of Hydration	142
3.1.2.2	Thermo-Hygral Loading	143
3.1.2.2.1	Hygral Behaviour of Hardened Cement Paste	143
3.1.2.2.2	Influence of Cracks on the Moisture Transport	147
3.1.2.2.3	Freeze Thaw	148
3.1.2.3	Chemical Loading	150
3.1.2.3.1	Microstructure of Cementitious Materials	150
3.1.2.3.2	Dissolution.....	152
3.1.2.3.3	Expansion	157
3.1.2.3.3.1	Sulphate Attack on Concrete and Mortar.....	157
3.1.2.3.3.2	Alkali-Aggregate Reaction in Concrete	158
3.1.3	Accumulation in Soils Due to Cyclic Loading: A Deterioration Phenomenon?	160

3.2	Experiments	163
3.2.1	Laboratory Testing of Structural Materials	163
3.2.1.1	Micro-macrocrack Detection in Metals	163
3.2.1.1.1	Electric Resistance Measurements	163
3.2.1.1.1.1	Introduction	163
3.2.1.1.1.2	Measurement of the Electrical Resistance	165
3.2.1.1.1.3	Calculation of the Electrical Resistance ..	166
3.2.1.1.1.4	Experiments	166
3.2.1.1.1.5	Experimental Results	167
3.2.1.1.2	Acoustic Emission	169
3.2.1.1.2.1	Location of Acoustic Emission Sources	171
3.2.1.1.2.2	Linear Location of Acoustic Emission Sources	171
3.2.1.1.2.3	Location of Sources in Two Dimensions ...	171
3.2.1.1.2.4	Kaiser Effect	172
3.2.1.1.2.5	Experimental Procedures	172
3.2.1.1.2.6	Experimental Results	174
3.2.1.2	Degradation of Concrete Subjected to Cyclic Compressive Loading	180
3.2.1.2.1	Test Series and Experimental Strategy	180
3.2.1.2.2	Degradation Determined by Decrease of Stiffness	182
3.2.1.2.3	Degradation Determined by Changes in Stress-Strain Relation	183
3.2.1.2.4	Adequate Description of Degradation by Fatigue Strain	185
3.2.1.2.5	Behaviour of High Strength Concrete and Air-Entrained Concrete	187
3.2.1.2.6	Influence of Various Coarse Aggregates and Different Grading Curves	189

	3.2.1.2.7	Cracking in the Microstructure Due to Cyclic Loading.....	190
	3.2.1.2.8	Influence of Single Rest Periods...	191
	3.2.1.2.9	Sequence Effect Determined by Two-Stage Tests.....	193
	3.2.1.3	Degradation of Concrete Subjected to Freeze Thaw	194
3.2.2		High-Cycle Laboratory Tests on Soils	198
3.2.3		Structural Testing of Composite Structures of Steel and Concrete	207
	3.2.3.1	General.....	207
	3.2.3.2	Basic Tests for the Fatigue Resistance of Shear Connectors	212
	3.2.3.2.1	Test Program	212
	3.2.3.2.2	Test Specimens	215
	3.2.3.2.3	Test Setup and Loading Procedure	216
	3.2.3.2.4	Material Properties	217
	3.2.3.2.5	Results of the Push-Out Tests	219
	3.2.3.2.5.1	General	219
	3.2.3.2.5.2	Results of the Constant Amplitude Tests	219
	3.2.3.2.6	Results of the Tests with Multiple Blocks of Loading.....	222
	3.2.3.2.7	Results of the Tests Regarding the Mode Control and the Effect of Low Temperature	223
	3.2.3.2.8	Results of the Tests Regarding Crack Initiation and Crack Propagation.....	225
	3.2.3.3	Fatigue Tests of Full-Scale Composite Beams.....	225
	3.2.3.3.1	General.....	225
	3.2.3.3.2	Test Program	226
	3.2.3.4	Test Specimen.....	227
	3.2.3.5	Test Setup	227
	3.2.3.6	Material Properties	231
	3.2.3.7	Main Results of the Beam Tests	232
3.3		Modelling	236
	3.3.1	Load Induced Damage	237
	3.3.1.1	Damage in Cementitious Materials Subjected to Quasi Static Loading	237
	3.3.1.1.1	Continuum-Based Models.....	237

	3.3.1.1.1.1	Damage Mechanics- Based Models	238
	3.3.1.1.1.2	Elastoplastic Models	244
	3.3.1.1.1.3	Coupled Elastoplastic- Damage Models	244
	3.3.1.1.1.4	Multisurface Elastoplastic- Damage Model for Concrete	246
	3.3.1.1.2	Embedded Crack Models	252
3.3.1.2		Cyclic Loading	255
	3.3.1.2.1	Mechanism-Oriented Simulation of Low Cycle Fatigue of Metallic Structures	255
	3.3.1.2.1.1	Macroscopic Elasto-Plastic Damage Model for Cyclic Loading	256
	3.3.1.2.1.2	Model Validation	259
	3.3.1.2.2	Quasi-Brittle Damage in Materials	261
	3.3.1.2.2.1	Cementitious Materials	261
	3.3.1.2.2.2	Metallic Materials	270
3.3.2		Non-mechanical Loading and Interactions	285
	3.3.2.1	Thermo-Hygro-Mechanical Modelling of Cementitious Materials - Shrinkage and Creep	285
	3.3.2.1.1	Introductory Remarks	285
	3.3.2.1.2	State Equations	286
	3.3.2.1.3	Identification of Coupling Coefficients	288
	3.3.2.1.4	Effective Stresses	289
	3.3.2.1.5	Multisurface Damage-Plasticity Model for Partially Saturated Concrete	290
	3.3.2.1.6	Long-Term Creep	291
	3.3.2.1.7	Moisture and Heat Transport	292
	3.3.2.1.7.1	Freeze Thaw	293
	3.3.2.2	Chemo-Mechanical Modelling of Cementitious Materials	294
	3.3.2.2.1	Models for Ion Transport and Dissolution Processes	295

	3.3.2.2.1.1	Introductory Remarks	295
	3.3.2.2.1.2	Initial Boundary Value Problem	296
	3.3.2.2.1.3	Constitutive Laws	297
	3.3.2.2.1.4	Migration of Calcium Ions in Water and Electrolyte Solutions	298
	3.3.2.2.1.5	Evolution Laws	300
	3.3.2.2.2	Models for Expansive Processes	302
	3.3.2.2.2.1	Introductory Remarks	302
	3.3.2.2.2.2	Balance Equations	305
	3.3.2.2.2.3	Constitutive Laws	307
	3.3.2.2.2.4	Model Calibration	311
3.3.3	A High-Cycle Model for Soils		313
3.3.4	Models for the Fatigue Resistance of Composite Structures		316
	3.3.4.1	General	316
	3.3.4.2	Modelling of the Local Behaviour of Shear Connectors in the Case of Cyclic Loading	317
	3.3.4.2.1	Static Strength of Headed Shear Studs without Any Pre-damage	317
	3.3.4.2.2	Failure Modes of Headed Shear Studs Subjected to High-Cycle Loading	322
	3.3.4.2.3	Correlation between the Reduced Static Strength and the Geometrical Property of the Fatigue Fracture Area	327
	3.3.4.2.4	Lifetime - Number of Cycles to Failure Based on Force Controlled Fatigue Tests	329
	3.3.4.2.5	Reduced Static Strength over Lifetime	330
	3.3.4.2.6	Load-Slip Behaviour	332
	3.3.4.2.7	Crack Initiation and Crack Development	334
	3.3.4.2.8	Improved Damage Accumulation Model	337
	3.3.4.2.9	Ductility and Crack Formation	341

3.3.4.2.10	Finite Element Calculations of the (Reduced) Static Strength of Headed Shear Studs in Push-Out Specimens	341
3.3.4.2.11	Effect of the Control Mode - Effect of Low Temperatures	344
3.3.4.3	Modelling of the Global Behaviour of Composite Beams Subjected to Cyclic Loading	345
3.3.4.3.1	Material Model for the Concrete Behaviour	345
3.3.4.3.2	Effect of High-Cycle Loading on Load Bearing Capacity of Composite Beams.....	346
3.3.4.3.3	Cyclic Behaviour of Composite Beams - Development of Slip	349
3.3.4.3.4	Effect of Cyclic Loading on Beams with Tension Flanges	350
3.4	Numerical Examples	351
3.4.1	Durability Analysis of a Concrete Tunnel Shell	351
3.4.2	Durability Analysis of a Cementitious Beam Exposed to Calcium Leaching and External Loading	354
3.4.3	Durability Analysis of a Sealed Panel with a Leakage	356
3.4.4	Numerical Simulation of a Concrete Beam Affected by Alkali-Silica Reaction	359
3.4.5	Lifetime Assessment of a Spherical Metallic Container	362
4	Methodological Implementation	365
4.1	Fundamentals	365
4.1.1	Classification of Deterioration Problems	366
4.1.2	Numerical Methods.....	368
4.1.3	Uncertainty.....	369
4.1.4	Design	370
4.2	Numerical Methods	372
4.2.1	Generalization of Single- and Multi-field Models	372
4.2.1.1	Integral Format of Balance Equations	373
4.2.1.2	Strong Form of Individual Balance Equations.....	374
4.2.2	Strategy of Numerical Solution	376
4.2.3	Weak Formulation	377
4.2.3.1	Weak Form of Coupled Balance Equations ..	377

4.2.3.2	Linearized Weak Form of Coupled Balance Equations.....	378
4.2.4	Spatial Discretization Methods.....	379
4.2.4.1	Introduction	379
4.2.4.2	Generalized Finite Element Discretization of Multifield Problems.....	380
4.2.4.2.1	Approximations	380
4.2.4.2.2	Non-Linear Semidiscrete Balance	383
4.2.4.2.3	Linearized Semidiscrete Balance ..	385
4.2.4.2.4	Generation of Element and Structural Quantities.....	386
4.2.4.3	p -Finite Element Method	387
4.2.4.3.1	Onedimensional Higher-Order Shape Function Concepts	389
4.2.4.3.1.1	Shape Functions of the Legendre-Type ...	389
4.2.4.3.1.2	Comparison of Both Shape Function Concepts.....	390
4.2.4.3.2	$3D$ - p -Finite Element Method Based on Hierarchical Legendre Polynomials.....	392
4.2.4.3.2.1	Generation of $3D$ - p -Shape Functions	392
4.2.4.3.2.2	Spatially Anisotropic Approximation Orders.....	394
4.2.4.3.2.3	Field-wise Choice of the Approximation Order.....	397
4.2.4.3.2.4	Geometry Approximation.....	402
4.2.5	Solution of Stationary Problems.....	403
4.2.5.1	Numerical Solution Technique	403
4.2.5.2	Iteration Methods	403
4.2.5.3	Arc-Length Controlled Analysis	407
4.2.6	Temporal Discretization Methods.....	408
4.2.6.1	Introduction	409
4.2.6.1.1	Motivation.....	410
4.2.6.1.2	Newmark- α Time Integration Schemes	411

4.2.6.1.3	Galerkin Time Integration Schemes	411
4.2.6.2	Newmark- α Time Integration Schemes	412
4.2.6.2.1	Non-linear Semidiscrete Initial Value Problem	412
4.2.6.2.2	Numerical Concept of Newmark- α Time Integration Schemes	413
4.2.6.2.3	Time Discretization	414
4.2.6.2.4	Approximation of State Variables	414
4.2.6.2.5	Algorithmic Semidiscrete Balance Equation	415
4.2.6.2.6	Effective Balance Equation	415
4.2.6.2.7	Newmark- α Algorithm	416
4.2.6.3	Discontinuous and Continuous Galerkin Time Integration Schemes	416
4.2.6.3.1	Time Discretization	418
4.2.6.3.2	Continuity Condition	418
4.2.6.3.3	Temporal Weak Form	419
4.2.6.3.4	Linearization	419
4.2.6.3.5	Temporal Galerkin Approximation	419
4.2.6.3.6	Discontinuous Bubnov-Galerkin Schemes $dG(p)$	421
4.2.6.3.7	Continuous Petrov-Galerkin Schemes $cG(p)$	422
4.2.6.3.8	Newton-Raphson Iteration	422
4.2.6.3.9	Algorithmic Set-Up of Galerkin Schemes	422
4.2.7	Generalized Computational Durability Mechanics	424
4.2.8	Adaptivity in Space and Time	425
4.2.8.1	Error-Controlled Spatial Adaptivity	425
4.2.8.1.1	Variational Functional	427
4.2.8.1.2	Interpolation	428
4.2.8.1.3	Stress Computation	428
4.2.8.1.4	Discretized Weak Form	429
4.2.8.1.5	Summary	430
4.2.8.1.6	Hanging Node Concept	431
4.2.8.1.7	Error Criteria	431
4.2.8.1.7.1	Warping-Based Error Criterion	431
4.2.8.1.7.2	Residual-Based Error Criterion	432
4.2.8.1.8	Program Flow	433

	4.2.8.1.9 Transfer of History Variables	434
	4.2.8.1.10 Examples	434
	4.2.8.1.10.1 Uniaxial Bending (Beam of Uniform Thickness)	434
	4.2.8.1.10.2 Uniaxial Bending (Beam of Variable Thickness)	437
	4.2.8.1.10.3 Biaxial Bending (Thick Plate of Uniform Thickness)	439
	4.2.8.2 Error-Controlled Temporal Adaptivity	443
	4.2.8.2.1 Local a Posteriori h - and p -Method Error Estimates	443
	4.2.8.2.2 Local a Posteriori h - and p -Method Error Indicators	444
	4.2.8.2.3 Local Zienkiewicz a Posteriori Error Indicators	444
	4.2.8.2.4 Adaptive Time Stepping Procedure	446
	4.2.8.2.5 Algorithmic Set-Up	447
4.2.9	Discontinuous Finite Elements	448
	4.2.9.1 Overview and Motivation	448
	4.2.9.2 Concepts	449
	4.2.9.2.1 Extended Finite Element Method (XFEM)	449
	4.2.9.2.1.1 Partition of Unity	449
	4.2.9.2.1.2 XFEM Displacement Field	452
	4.2.9.2.1.3 Integrating Discontinuous Functions	458
	4.2.9.2.1.4 p -Version of the XFEM	469
	4.2.9.2.1.5 3D XFEM	473
	4.2.9.2.1.6 XFEM for Cohesive Cracks	476
	4.2.9.2.2 Strong Discontinuity Approach and Enhanced Assumed Strain	479
	4.2.9.2.2.1 Kinematics: Modeling Embedded Strong Discontinuities	479

	4.2.9.2.2.2	Numerical Implementation	482
	4.2.9.2.2.3	Numerical Example: 3-Point Bending Problem	486
	4.2.9.3	Crackgrowth Criteria	488
	4.2.9.3.1	Hoop Stresses	489
	4.2.9.3.2	Mode-I-Crack Extension	490
	4.2.9.3.3	Minimum Energy	492
	4.2.9.4	Examples	493
	4.2.9.4.1	Double Notched Slab	493
	4.2.9.4.2	Anchor Pull-Out	494
4.2.10		Substructuring and Model Reduction of Partially Damaged Structures	498
	4.2.10.1	Motivation and Overview	499
	4.2.10.2	Concept	501
	4.2.10.3	Derivation of a Substructure Technique for Nonlinear Dynamics	502
	4.2.10.3.1	Craig-Bampton Method	502
	4.2.10.3.2	Model Reduction of Linear Dynamic Structures	503
	4.2.10.3.2.1	Modal Reduction	503
	4.2.10.3.2.2	Proper Orthogonal Decomposition	504
	4.2.10.3.2.3	Padé-Via-Lanczos Algorithm	504
	4.2.10.3.2.4	Load-Dependent Ritz Vectors	506
	4.2.10.3.3	Substructuring in the Framework of Nonlinear Dynamics	506
	4.2.10.3.3.1	Discretisation and Linearisation	506
	4.2.10.3.3.2	Primal Assembly	509
	4.2.10.3.3.3	Solution of the Decomposed Structure	511
	4.2.10.4	Example	512
4.2.11		Strategy for Polycyclic Loading of Soil	517
4.3		System Identification	519
	4.3.1	Covariance Analysis	520
	4.3.2	Subspace Methods	520
	4.3.2.1	State Space Model	520
	4.3.2.2	Subspace Identification	522
	4.3.2.3	Modal Analysis	527

4.4	Reliability Analysis	528
4.4.1	General Problem Definition	529
4.4.2	Time-Invariant Problems	531
4.4.2.1	Approximation Methods	531
4.4.2.2	Simulation Methods.....	533
4.4.2.2.1	Importance Sampling.....	534
4.4.2.2.2	Latin Hypercube Sampling	535
4.4.2.2.3	Subset Methods	536
4.4.2.3	Response Surface Methods	537
4.4.2.4	Evaluation of Uncertainties and Choice of Random Variables	539
4.4.3	Time-Variant Problems	540
4.4.3.1	Time-Integrated Approach	540
4.4.3.2	Time Discretization Approach	540
4.4.3.3	Outcrossing Methods.....	541
4.4.4	Parallelization of Reliability Analyses	542
4.4.4.1	Reliability Analysis of Fatigue Processes ...	543
4.4.4.2	Parallelization Example	544
4.5	Optimization and Design	545
4.5.1	Classification of Optimization Problems	546
4.5.2	Design as an Optimization Problem.....	547
4.5.3	Numerical Optimization Methods	551
4.5.3.1	Derivative-Based Methods	552
4.5.3.2	Derivative-Free Strategies	555
4.5.4	Parallelization of Optimization Strategies.....	559
4.5.4.1	Parallelization with Gradient-Based Algorithms.....	560
4.5.4.2	Parallelization Using Evolution Strategies...	560
4.5.4.3	Distributed and Parallel Software Architecture	561
4.6	Application of Lifetime-Oriented Analysis and Design	561
4.6.1	Testing of Beam-Like Structures.....	562
4.6.1.1	Experimental Setup	563
4.6.1.2	Identification of Modal Data	563
4.6.1.3	Updating of the Finite Element Model.....	566
4.6.2	Lifetime Analysis for Dynamically Loaded Structures at BMW AG	572
4.6.2.1	Works for the New 3-Series Convertible....	572
4.6.2.2	The Shaker Test	574
4.6.2.3	Approach 1: Time History Calculation and Amplitude Counting	574
4.6.2.3.1	Structural Analysis Using Time Integration	575
4.6.2.3.2	Cycle Counting Using the Rainflow Method	575

	4.6.2.3.3	Damage Calculation.....	576
	4.6.2.4	Approach 2: Power Spectral Density Functions and Calculation of Spectral Moments	577
	4.6.2.4.1	Structural Analysis Using Power Spectral Density (PSD) Functions	577
	4.6.2.4.2	Analytical Counting Method	578
	4.6.2.4.3	Damage Accumulation for the Analytical Case.....	579
	4.6.2.5	Comparison of the Results	580
	4.6.2.6	Summary and Outlook	582
4.6.3		Lifetime-Oriented Analysis of Concrete Structures Subjected to Environmental Attack.....	583
	4.6.3.1	Hygro-Mechanical Analysis of a Concrete Shell Structure	583
	4.6.3.1.1	Conclusive Remarks on the Hygro-Mechanical Analysis	590
	4.6.3.2	Calcium Leaching of Cementitious Materials	591
	4.6.3.2.1	Calcium Leaching of a Cementitious Bar	592
	4.6.3.2.1.1	Analysis of the Numerical Results....	592
	4.6.3.2.1.2	Adaptive Newmark Solution	594
	4.6.3.2.1.3	Robustness of Galerkin Solutions....	594
	4.6.3.2.1.4	Error Estimates for Newmark Solutions...	594
	4.6.3.2.1.5	Error Estimates for Galerkin Solutions....	598
	4.6.3.2.1.6	Order of Accuracy of Galerkin Schemes ..	600
	4.6.3.2.2	Calcium Leaching of a Cementitious Beam	601
	4.6.3.2.2.1	Analysis of the Numerical Results....	602
	4.6.3.2.2.2	Robustness of Continuous Galerkin Solutions....	603
4.6.4		Arched Steel Bridge Under Wind Loading	607
	4.6.4.1	Definition of Structural Problem	607
	4.6.4.2	Probabilistic Lifetime Assessment	610
	4.6.4.2.1	Micro Time Scale	610

4.6.4.2.2	Macro Time Scale	611
4.6.4.3	Results of Structural Optimization	613
4.6.4.4	Parallelization of Analyses	614
4.6.4.5	Final Conclusion	615
4.6.5	Arched Reinforced Concrete Bridge	616
4.6.5.1	Numerical Simulation	617
4.6.5.1.1	Experimental Investigation on Mechanical Concrete Properties ..	618
4.6.5.1.1.1	Non-destructive Tests	618
4.6.5.1.1.2	Destructive Tests.....	619
4.6.5.1.1.3	Microscopic Analysis	621
4.6.5.1.1.4	Cyclic Tests	621
4.6.5.1.2	Finite Element Model	624
4.6.5.1.3	Material Model	625
4.6.5.1.4	Damage Mechanisms	625
4.6.5.1.4.1	Corrosion of the Reinforcement Steel Bars	625
4.6.5.1.4.2	Fatigue of the Prestressing Tendons	626
4.6.5.1.5	Modelling of Uncertainties	627
4.6.5.1.5.1	Long-Term Development of Concrete Strength.....	628
4.6.5.1.5.2	Determination of Material Properties...	630
4.6.5.1.5.3	Modelling of Spatial Scatter by Random Fields	631
4.6.5.1.6	Lifetime Simulation	632
4.6.5.1.7	Conclusions	634
4.6.5.2	Experimental Verification	634
4.6.5.2.1	State Space Model for Mechanical Structures	635
4.6.5.2.2	White Box Model - Physical Interpretable Parameters	636
4.6.5.2.3	Identification of Measured Mechanical Structures	637
4.6.5.2.3.1	Black Box Model - Deterministic System Identification	637

	4.6.5.2.3.2	Differences between Theory and Experiment	638
	4.6.5.2.4	Experiments	641
	4.6.5.2.4.1	Cantilever Bending Beam	641
	4.6.5.2.4.2	Tied-Arch Bridge near Hünxe - Germany	642
	4.6.5.2.5	Conclusion	645
	4.6.6	Examples for the Prediction of Settlement Due to Polycyclic Loading	646
5	Future Life Time Oriented Design Concepts		653
	5.1	Exemplary Realization of Lifetime Control Using Concepts as Presented Here	653
	5.1.1	Reinforced Concrete Column under Fatigue Load	653
	5.1.2	Connection Plates of an Arched Steel Bridge	655
	5.1.3	Conclusion	658
	5.2	Lifetime-Control Provisions in Current Standardization	658
	5.3	Incorporation into Structural Engineering Standards	659
	References		661
	Subject Index		711