

Table of Contents

Preface	xi
Gilles PIJAUDIER-CABOT and Frédéric DUFOUR	
Chapter 1. Bottom-Up: From Atoms to Concrete Structures	1
Franz-Josef ULM and Roland J-M PELLENQ	
1.1. Introduction	1
1.2. A realistic molecular model for calcium-silicate-hydrates	2
1.2.1. Background	3
1.2.2. Molecular properties of C-S-H	5
1.2.3. From molecular properties to C-S-H microtexture	7
1.3. Probing C-S-H microtexture by nanoindentation	9
1.3.1. Does particle shape matter?	9
1.3.2. Implementation for back analysis of packing density distributions	11
1.3.3. Functionalized properties: nanogranular origin of concrete creep	12
1.4. Conclusions	15
1.5. Bibliography	16

Chapter 2. Poromechanics of Saturated Isotropic Nanoporous Materials	19
Romain VERMOREL, Gilles PIJAUDIER-CABOT, Christelle MIQUEU and Bruno MENDIBOURE	
2.1. Introduction	20
2.2. Results from molecular simulations	22
2.3. Poromechanical model.	24
2.3.1. Nomenclature and definitions	24
2.3.2. Effective pore pressure	26
2.3.3. Thermodynamical equilibrium condition	28
2.3.4. Constitutive equation of the effective pore pressure	31
2.3.5. Effect on the volumetric strain	33
2.3.6. Effect on the permeability	34
2.4. Adsorption-induced swelling and permeability change in nanoporous materials	37
2.4.1. Comparison with data by Day <i>et al.</i>	39
2.4.2. Comparison with data by Ottiger <i>et al.</i>	41
2.4.3. Variation of effective permeability	41
2.5. Discussion – interaction energy and entropy	42
2.6. Conclusions	46
2.7. Acknowledgments	47
2.8. Bibliography	48
 Chapter 3. Stress-based Non-local Damage Model	 51
Cédric GIRY and Frédéric DUFOUR	
3.1. Introduction	52
3.2. Non-local damage models	57
3.2.1. Continuum damage theory	57
3.2.2. Original integral non-local approach	60
3.2.3. Non-local integral method based on stress state	62
3.2.4. Numerical implementation	65
3.3. Initiation of failure	67
3.4. Bar under traction	70
3.4.1. Global behavior	71
3.4.2. Mechanical quantities in the FPZ	72

3.4.3. Crack opening estimation	75
3.5. Description of the cracking evolution in a 3PBT of a concrete notched beam	79
3.5.1. Global behavior	80
3.5.2. Cracking analysis	81
3.6. Conclusions	82
3.7. Acknowledgments	84
3.8. Bibliography	84

Chapter 4. Discretization of Higher Order Gradient Damage Models Using Isogeometric Finite Elements	89
Clemens V. VERHOESEL, Michael A. SCOTT, Michael J. BORDEN, Thomas J.R. HUGHES and René DE BORST	

4.1. Introduction	89
4.2. Isotropic damage formulation	91
4.2.1. Constitutive modeling	92
4.2.2. Implicit gradient damage formulation	95
4.3. Isogeometric finite elements	97
4.3.1. Univariate B-splines and NURBS	97
4.3.2. Multivariate B-splines and NURBS	100
4.3.3. Isogeometric finite-element discretization	101
4.4. Numerical simulations	103
4.4.1. One-dimensional rod loaded in tension	103
4.4.2. Three-point bending beam	107
4.5. Conclusions	115
4.6. Acknowledgments	116
4.7. Bibliography	116

Chapter 5. Macro and Mesoscale Models to Predict Concrete Failure and Size Effects.	121
David GRÉGOIRE, Peter GRASSL, Laura B. ROJAS-SOLANO and Gilles PIJAUDIER-CABOT	

5.1. Introduction	122
5.2. Experimental procedure	125

5.2.1. Material, specimens and test rig descriptions	125
5.2.2. Experimental results	128
5.2.3. Size effect analysis	131
5.3. Numerical simulations	134
5.3.1. Macroscale modeling	135
5.3.2. Mesoscale modeling approach	140
5.3.3. Analysis of three-point bending tests	143
5.4. Conclusions	152
5.5. Acknowledgments	153
5.6. Bibliography	153

**Chapter 6. Statistical Aspects of Quasi-Brittle
Size Effect and Lifetime, with Consequences
for Safety and Durability of Large Structures . . .** 161
Zdeněk P. BAŽANT, Jia-Liang LE and Qiang YU

6.1. Introduction	161
6.2. Type-I size effect derived from atomistic fracture mechanics	164
6.2.1. Strength distribution of one RVE.	164
6.2.2. Size effect on mean structural strength	168
6.3. Size effect on structural lifetime.	170
6.4. Consequences of ignoring Type-2 size effect	172
6.5. Conclusion	177
6.6. Acknowledgments	177
6.7. Bibliography.	178

**Chapter 7. Tertiary Creep: A Coupling Between
Creep and Damage – Application to the Case of
Radioactive Waste Disposal** 183
J.M. TORRENTI, T. DE LARRARD and F. BENBOUDJEMA

7.1. Introduction to tertiary creep	184
7.2. Modeling of tertiary creep using a damage model coupled to creep.	185
7.2.1. Creep model	186
7.2.2. Damage model.	188
7.2.3. Coupling between damage and creep	188

7.3. Comparison with experimental results	189
7.4. Application to the case of nuclear waste disposal	190
7.4.1. Leaching of concrete	191
7.4.2. Coupled mechanical and chemical damage	192
7.4.3. Chemical damage	193
7.4.4. Example of application: creep coupled to leaching	194
7.4.5. Probabilistic effects	194
7.5. Conclusions	197
7.6. Bibliography	198

**Chapter 8. Study of Damages and Risks Related
to Complex Industrial Facilities 203**
Bruno GÉRARD, Bruno CAPRA, Gaël THILLARD and
Christophe BAILLIS

8.1. Context	203
8.2. Introduction to risk management	204
8.3. Case study: computation process.	206
8.3.1. Identifying the owner's issues	208
8.3.2. Simplifying the system	208
8.3.3. Choosing the best models	210
8.3.4. Defining the most realistic load boundaries.	210
8.4. Application	212
8.4.1. Deformed structure after impact	213
8.4.2. Damage variables of concrete.	214
8.4.3. Analysis of results	217
8.5. Conclusion	219
8.6. Acknowledgment.	220
8.7. Bibliography	220

**Chapter 9. Measuring Earthquake Damages
to a High Strength Concrete Structure 221**
Patrick PAULTRE, Benedikt WEBER, Sébastien MOUSSEAU
and Jean PROULX

9.1. Introduction	221
9.2. Overview of the selected testing methods	222
9.3. Two-storey HPC building	223

9.4. Inducing damage – pseudo-dynamic	
testing procedures	227
9.4.1. Input ground motion	228
9.4.2. Earthquake responses	230
9.5. Evaluating damage – forced vibration	
testing procedures	236
9.5.1. Frequency responses	238
9.6. Damage detection – analytical evaluation . . .	239
9.6.1. Modal analysis	240
9.6.2. Finite-element model	240
9.6.3. Model updating	242
9.6.4. Regularization	244
9.6.5. Results	246
9.7. Summary and conclusions	248
9.8. Bibliography	249
List of Authors	251
Index	253