

# Creep of plain and structural concrete

---

**A. M. Neville**

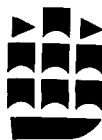
Principal and Vice-Chancellor, University of Dundee, Scotland

**W. H. Dilger**

Professor of Civil Engineering, University of Calgary, Canada

**J. J. Brooks**

Lecturer in Civil Engineering, University of Leeds, England



**Construction Press**  
London and New York

Institut f. Massivbau  
der Techn. Hochschule D...

Inv.-Nr. 6875

# Contents

---

Preface v

Acknowledgements x

Notation xi

## Chapter 1 Introduction 1

Historical note 1  
Concrete as a non-elastic structural material 4  
Structure of concrete and of hydrated cement paste 5  
References 6

## Chapter 2 Classification of deformations 8

Definition of terms used 8  
Creep 8  
Creep recovery 10  
Instantaneous strain 10  
Relaxation 11  
Concrete as a composite material 11  
Types of deformation 13  
References 16

## Chapter 3 Influence of cement and admixtures on creep 17

Composition and type of Portland cement 17  
High-alumina cement 23  
Fineness of cement 25  
Resin, polymer and polymer-impregnated concretes 26  
Air entrainment 28  
Plasticizing and superplasticizing admixtures 29  
Plasticizers 29  
Superplasticizers 33  
Accelerators 35  
General 35  
References 36

## Chapter 4 Influence of aggregate on creep 38

Influence of type of aggregate 38  
Observations on influence of aggregate content 40  
Creep as a function of the content and modulus of elasticity of the aggregate 40  
Composite models for creep 42  
Influence of other properties of aggregate 44  
Reinforced cement composites 47  
Concluding remarks 49  
References 49

## Chapter 5 Influence on creep of strength, stress, water/cement ratio, age and size 51

Stress/strength ratio 51  
Water/cement ratio 56  
Age at application of load 57  
Shape, size and isotropy of specimen 61  
Revibration of concrete 64  
References 67

## Chapter 6 Influence of humidity on creep 69

Relative humidity of storage: moist-cured concrete 69  
Drying creep and shrinkage 72  
Relative humidity of storage: dry-cured concrete 74  
Wetting creep 77  
Effect of wind 77  
Carbonation 78  
Alternating humidity 78  
Influence of other environments 81  
References 84

## Chapter 7 Influence of temperature and curing on creep 87

Influence of temperature on elasticity 87  
Influence of temperature on basic creep 87  
Influence of temperature on total creep 94  
Creep at freezing temperatures 98  
Influence of stress and strength at various temperatures 98  
Prediction of basic and total creep at elevated temperature 99  
Creep under varying temperature 100  
Influence of steam curing and autoclaving 106  
Influence of irradiation 108  
References 109

## Chapter 8 Creep under different states of stress 111

Creep in tension 111  
Creep in torsion 118  
Creep in bond 119  
Lateral creep and creep Poisson's ratio in uniaxial compression 120  
Creep and creep Poisson's ratio under multiaxial stress 122  
Creep under alternating loading 128  
Creep under very high stresses 135  
Influence of gradient of strain 136  
References 136

## **Chapter 9 Creep recovery 139**

- Principle of superposition 139
- Factors in creep recovery 144
  - Type of cement, strength, stress and admixtures 145
  - Aggregate 146
  - Humidity 150
  - Age 151
  - Temperature 151
- Creep recovery under different states of stress 152
- Recoverable and irrecoverable creep 152
- References 155

## **Chapter 10 Mechanisms and theories of creep 158**

- Mechanisms 158
  - Mechanical deformation theory 158
  - Plastic theories 158
  - Viscous and visco-elastic flow theories 159
  - Elastic after-effect theories 160
  - Solid solution theory 160
  - Seepage theory 161
- Contribution of microcracking to creep 163
- Possible mechanism of action of admixtures 165
- Creep hypotheses 166
  - Kesler's hypothesis 167
  - Ruetz's hypothesis 169
  - Cilosani's hypothesis 169
  - Activation energy approach 169
  - Feldman and Sereda's hypothesis 173
  - Ishai's hypothesis 174
  - Powers' hypothesis 176
  - Bazant's analysis 177
- Concluding remarks 178
- References 179

## **Chapter 11 Prediction of long-term deformations from experimental data 182**

- Creep-time expressions 182
  - Power expression 182
  - Logarithmic expression 182
  - Exponential expression 183
  - Hyperbolic expression 183
- Shrinkage-time expressions 183
- Elastic strain-time expressions 183
  - Effect of rate of loading 183
  - Age dependence 184
- Accuracy of prediction 185
- References 189

## **Chapter 12 General prediction of creep and shrinkage from strength, mix composition and physical conditions 191**

- Methods of prediction 191
- 1. Comité Européen du Béton (CEB-FIP), 1970 191
  - Creep 191
  - Shrinkage 194
- 2. Comité Européen odel II, 1978 194
  - Creep 194
  - Shrinkage 197

- 3. American Concrete Institute (ACI), 1978 199
  - Creep 199
  - Shrinkage 199
- 4. Bazant and Panula's model II, 1978 200
  - Shrinkage 200
  - Basic creep 201
  - Total creep 201
- 5. Concrete Society (CS), 1978 201
- 6. Proposed modification 202
  - Creep 202
  - Shrinkage 203
- Comparison of prediction methods 203
- Final comments 205
- References 206

## **Chapter 13 Prediction of stress and strain under varying history, and relaxation of stress 207**

- Methods of calculation 207
  - Effective modulus method (EM method) 207
  - Rate of creep method (RC method) 208
  - Rate of flow method (RF method) 210
  - Improved Dischinger method (ID method) 211
  - Method of superposition 212
  - Trost-Bazant method (TB method) 214
- References 214

## **Chapter 14 Rheological models and damping 216**

- Elements of rheological models 216
- Basic models 216
- Models for concrete 219
- Usefulness of rheological models 228
- Damping 229
- Damping and creep of concrete 230
- References 232

## **Chapter 15 Apparatus for measurement of creep 233**

- Compression apparatus 233
- Apparatus for different states of stress 237
- Measurement of creep 240
- Control of ambient conditions 242
- ASTM method of test for creep 243
- References 245

## **Chapter 16 Methods of creep analysis of structural members 246**

- Effective modulus method (EM method) 247
- Rate of creep method (RC method) 248
- Rate of flow method (RF method) 249
- Improved Dischinger method (ID method) 251
- Principle of superposition of virgin creep curves 252
  - Solution using a step-by-step method 253
- Trost-Bazant method (TB method) 255
- Mathematical formulation of the CEB-FIP, 1978 creep function 259
- Final comments 262
- References 262

## **Chapter 17 Creep analysis of uncracked reinforced and prestressed concrete members 264**

- Cross-section with two layers of steel subjected to a sustained load 264
- Stresses and strains due to shrinkage 266
- Total time-dependent effects due to creep and shrinkage 267
  - Symmetrical reinforcement 268
  - One layer of steel 270
- Axial strain 270
- Curvature 271
- Deflection 274
- Step-by-step analysis of creep and shrinkage problems 275
- Prestressed concrete 275
- Relaxation of steel 276
- General case of a beam with two layers of tendons 277
- Loss of prestress with one layer of steel 278
- Multi-stage prestressing 281
- Deformation of prestressed concrete members with one layer of steel 282
- Time-dependent analysis using creep-transformed section properties 283
- Deformations 285
- References 286

## **Chapter 18 Creep design of composite members 287**

- Composite steel-concrete member 287
  - Negligible flexural rigidity of the deck 289
  - Deformations 289
- Effects of shrinkage and creep in a composite precast-cast-in-situ structure 289
  - Case 1: Flexural rigidities of deck slab and of reinforcement neglected 291
  - Case 2: Reinforcement neglected 293
  - Case 3: Reinforcement and rigidity of deck neglected 294
- Example and comparison with experiments 294
- Creep-transformed section method 297
- Application to steel-concrete composite girders 302
- References 302

## **Chapter 19 Time-dependent forces in continuous concrete structures 304**

- Two-span continuous beam with same concrete properties throughout 305
- Two-span continuous beam with different creep properties in the two spans 305
- Two-span continuous beam built in two stages 305
- Two-span beam made continuous by a cast-in-situ joint 306
- Structure with boundary conditions changed at two different ages 307

- Continuous structure with different creep properties 308
- Continuous structure built in stages 309
  - Structure built in three stages 309
  - Structure built in more than three stages 314
- Effects of shrinkage in statically indeterminate structures 316
- Effect of reinforcement on redistribution of forces 317
- Continuous composite structures 318
- Time-dependent forces induced by settlement of supports of a continuous beam 318
  - Instantaneous differential settlement in a two-span beam 319
  - Instantaneous differential settlement in a  $n$ -times statically indeterminate system 319
- Differential settlement occurring at the same rate as creep 320
- Differential settlement following any time-consolidation curve 321
- Differential settlement progressing at a standard rate of consolidation 322
- References 327

## **Chapter 20 Time-dependent deformations of reinforced concrete structures 328**

- Flexural deflection of beams and one-way slabs 328
  - Initial deflection of cracked beam 328
  - Long-term deflection 330
  - Deflection due to creep 330
  - Deflection due to shrinkage 333
  - Comparison of calculated values with test result of Washa and Fluck 334
- Beam subjected to variable load or to differential settlement 335
- Deflection of a two-way slab 337
  - Initial deflection 338
  - Time-dependent deflection 338
- Deflection due to shear 340
  - Initial deflection 342
  - Empirical modification 342
  - Long-term shear deflection 342
- Deformation due to torsion 343
- Post-cracking stiffness in pure torsion 344
  - Empirical modifications of the expression for post-cracking stiffness 345
- Effect of creep and shrinkage on torsional stiffness 346
- Combined torsion, bending and shear 347
- Long columns 347
- Concluding remark 349
- References 349

## **Name Index 352**

## **Subject Index 357**