

Contents

1	Introduction	1
1.1	Creep Phenomena in Structural Engineering	3
1.1.1	Stochastic Modeling of Creep (Deterioration)	10
1.1.2	Random Variable Model	10
1.1.3	Second-Order Process Model	11
1.1.4	Cumulative Damage/Shock Model	12
1.2	High Temperature Engineering Creep: Deterministic Approach	14
1.2.1	Incremental Quasi-elastic Stress–Strain Relations (Piecewise Collocation Method)	29
1.2.2	Strip Method (Volterra Integral Equations)	31
1.3	High Temperature Engineering Creep: Probabilistic Approach	32
1.3.1	Case Studies	33
1.3.2	An Integrated Design Approach	35
1.3.3	Definition of Acceptable Probability of Failure (Target Probability)	36
1.3.4	Structural Reliability Assessment	37
1.3.5	Limit State Design	38
1.3.6	Partial Safety Factor ψ and Reliability Index β	41
	References	53
2	Integral Volterra Equations	55
2.1	Overview	55
2.1.1	Structure of Kernel	56
2.1.2	Singular and Weakly Singular Equations	57
2.1.3	Eigenvalue Problem	57
2.1.4	Nonlinear Fredholm Equation of the Second Kind	58
2.1.5	Integral Equations Volterra	59
2.2	Reduction of ODEs to the Volterra Integral Equation (IE)	65

2.3	Sequential Approximation Method (<i>Method of Successive Approximation</i>)	68
2.4	Linear Volterra IE of the Second Kind	71
2.4.1	Basic Steps of the Method of Moments (MoM) Galerkin Method	71
2.4.2	Linear Integral Equations (IEs) with Degenerate Kernels	73
2.5	Special Types of Integral Equations	75
2.5.1	Strip Method (Integral Equations)	75
2.5.2	Power Series Solution for Integral Equations	76
2.5.3	Hammerstein Integral Equation	77
2.6	Examples	77
	References.	100
3	Phenomenological Time Invariant Creep Models	101
3.1	Introduction	102
3.1.1	Stress Relaxation, Constant Strain	104
3.1.2	Limit State Design.	105
3.1.3	Linear and Nonlinear Viscoelasticity	105
3.2	Linear Viscoelastic Material: Constitutive Equations	106
3.2.1	Definitions	107
3.2.2	Closed-Cycle Condition.	110
3.2.3	Relationship Between Relaxation Modulus and Compliance.	111
3.2.4	Principle of Fading Memory	111
3.2.5	The Maxwell Model [18]	112
3.2.6	The Kelvin–Voigt Model.	123
3.2.7	The Standard Linear Model.	126
3.3	Various Cases of Loading Conditions.	130
3.3.1	Constant Load	130
3.3.2	Unloading	131
3.3.3	Load Increases with Time Uniformly	132
3.3.4	Load Decreases with Time Uniformly.	133
3.3.5	Permanent Deformations in Time	133
3.3.6	Linearly Increasing (Decreasing) Deformations in Time	134
3.4	Substitution Method	136
3.4.1	Linear Strain Increase	137
3.4.2	Linear Strain Decrease.	139
3.5	Harmonic Variation of the Stress and Strain.	143
3.6	Arbitrary Law of Variation of Stress and Strain	145
3.7	Impulse Stress Function	147

3.8	Linearly Hereditary Creep.	147
3.8.1	Infinite Number of Series-Connected Standard Linear Models	148
3.8.2	Infinite Number of Parallel-Connected Standard Linear Models	150
3.9	Retardation and Relaxation Spectrum	150
3.10	Long-Term Modulus of Elasticity	152
3.11	The Resolvent of Linear Equation Hereditary Deformation	153
3.12	Examples	155
	References.	158
4	Phenomenological Time Variant Nonlinear Creep Models.	161
4.1	Introduction	162
4.2	Volterra Equation and Creep Constitutive Law.	164
4.2.1	Volterra Equations.	166
4.2.2	Creep Compliance Function and Material Property Parameters	166
4.3	Thermal Analysis	168
4.3.1	Principle of Superposition	172
4.3.2	Rate-Type Creep Law and Rheological Model	174
4.4	Nonlinearity Due to Temperature Variation	181
4.4.1	Relationship Between Modulus of Elasticity and Temperature	182
4.4.2	Approximate Solutions of Linear Volterra Integral Equation	185
4.4.3	Method of Moments	185
4.4.4	Galerkin Method (Linear Volterra Equation).	187
4.5	Replacement of the Integral Equation with Finite System of Linear Algebraic Equations	193
4.5.1	Derivation of Two-Point Gauss Quadrature Rule	194
4.6	Successive Approximation (Sequential Approximation Method)	197
4.7	Nonlinear Integral Type Creep Constitutive Law	206
4.7.1	Strip Method and Stress Function Linearization	208
4.7.2	Galerkin Method (Nonlinear Creep Law)	212
4.7.3	Method of Moments	216
4.8	Comparison of the Numerical Solution Obtained by Different Approximate Methods.	227
4.9	Stress–Strain Unload.	231
4.9.1	Ordinary Differential Equation (ODE) of Creep Constitutive Law	241
	References.	246

5	Transient Engineering Creep of Materials Under Various Fire Conditions	249
5.1	Introduction	252
5.1.1	Overview	252
5.1.2	Temperature–Time Function	253
5.2	Creep Constitutive Equation. Very Fast Fire (VFF)	263
5.2.1	Creep Constitutive Equation. Equivalent ODE Method	265
5.2.2	The Functional Dependencies of Creep Stresses and Strains from Material Properties Parameters (MPP)	271
5.2.3	Functional Dependencies of Creep Stresses and Strains from the Stress Exponent “ n ”	289
5.3	Creep Stress–Strain Diagram. Fast Fire	305
5.3.1	Temperature–Time Function	305
5.3.2	Analytical Expression of the Inverse Function θ^{-1} and Its First Derivative	306
5.3.3	Creep Constitutive Equation. Equivalent ODE Method	309
5.3.4	The Functional Dependencies of Creep Stresses and Strains from Material Properties Parameters (MPP)	313
5.3.5	Functional Dependencies of Creep Stresses and Strains from the Stress Exponent “ n ”	324
5.3.6	Temperature–Time Function. Medium Fire	330
5.3.7	Analytical Expression of the Inverse Function θ^{-1} and Its First Derivative	332
5.3.8	Creep Constitutive Equation. Equivalent ODE Method	335
5.3.9	The Functional Dependencies of Creep Stresses and Strains from Material Properties Parameters (MPP)	340
5.3.10	Functional Dependencies of Creep Stresses and Strains from the Stress Exponent “ n ”	350
5.4	Stress–Strain Diagram. Slow Fire	356
5.4.1	Temperature–Time Function	356
5.4.2	Analytical Expression of the Inverse Function θ^{-1} and Its First Derivative	358
5.4.3	Creep Constitutive Equation. Equivalent ODE Method	361

5.4.4	The Functional Dependencies of Creep Stresses and Strains from Material Properties Parameters (MPP)	365
5.4.5	Functional Dependencies of Creep Stresses and Strains from the Stress Exponent “ n ”	375
	References.	382
6	Anisotropic Structural Plates—Anisotropic Materials and Composite Structures.	385
6.1	Introduction	388
6.2	Stress, Strain, and Deformations in Solids. Constitutive Relations.	390
6.3	Principal Stresses and Stress Invariants.	393
6.4	Maximum and Minimum Shear Stresses.	395
6.5	Stress Deviator Tensor	395
6.5.1	Invariants of the Stress Deviator Tensor	396
6.6	Failure Theories	396
6.7	General Equations of Anisotropic Creep.	398
6.7.1	Anisotropic Creep (2D Model) with Temperature-Dependent Material Properties	400
6.8	High-Temperature Effect on Modulus of Elasticity Deterioration.	409
6.9	Stress–Temperature–Strain Diagram for Different MPP in Case of Fire	423
6.10	Nonlinear Creep Deformations	437
6.11	Conclusions	456
	References.	456
7	Probabilistic Modeling of Creep and Stress–Strain Diagram.	459
7.1	Introduction	462
7.1.1	Deterministic Approach to Structural Fire Resistance Engineering	462
7.1.2	Ultimate Limit State	463
7.1.3	Methods Used	463
7.2	Introduction to Probability Theory	464
7.2.1	Random Variables: Definition of a Probability	464
7.3	Why Probabilistic Approach Is Needed?.	469
7.4	Very Fast Fire: Statistical Data.	472
7.5	The First-Order Reliability Method (FORM)	479
7.5.1	Most Probable Point Methods	481
7.5.2	Limit State Approximation	483
7.5.3	Partial Safety Factor ψ and Reliability Index β	489
7.6	Confidence Interval—Minimum Dimensionless Allowable Stress	495
7.7	Structural Failures in Time	500

7.8	Ergodicity: Very Fast Fire	503
7.9	The First-Occurrence Time Problem and the Probability Density $P(a_0, \theta)$	512
	References.	515
8	Probability-Based Engineering Creep and Design Fire Exposure . . .	517
8.1	Probability-Based Stress–Strain Diagram. Fast Fire	519
8.1.1	Introduction.	519
8.1.2	Phenomenological Laws and Coefficients	520
8.1.3	High-Temperature Creep and Structural Fire Resistance	522
8.1.4	Temperature–Time Function	524
8.1.5	Fast Fire: Statistical Data.	527
8.1.6	The First-Order Reliability Method (FORM).	532
8.1.7	Confidence Interval—Fast Fire	533
8.1.8	Creep Stress–Strain Diagrams (Ergodic Process).	534
8.1.9	The First-Occurrence Time Problem and the Probability Density $P(a_0, \theta)$	538
8.2	Probability-Based Stress–Strain Diagram. Medium Fire	540
8.2.1	Temperature–Time Function. Medium Fire	540
8.2.2	Analytical Expression of the Inverse Function θ^{-1} and Its First Derivative	541
8.2.3	Medium Fire: Statistical Data	543
8.2.4	The First-Order Reliability Method (FORM).	550
8.2.5	Confidence Interval—Fast Fire	551
8.2.6	Creep Stress–Strain Diagrams (Ergodic Process).	552
8.2.7	The First-Occurrence Time Problem and the Probability Density $P(a_0, \theta)$	557
8.3	Probability-Based Stress–Strain Diagram. Slow Fire.	558
8.3.1	Temperature–Time Function. Slow Fire.	558
8.3.2	Analytical Expression of the Inverse Function θ^{-1} and Its First Derivative	560
8.3.3	Fast Fire: Statistical Data.	561
8.3.4	The First-Order Reliability Method (FORM).	569
8.3.5	Confidence Interval—Fast Fire	570
8.3.6	Creep Stress–Strain Diagrams (Ergodic Process).	571
8.3.7	The First-Occurrence Time Problem and the Probability Density $P(a_0, \theta)$	575
	References.	577
9	Fire Severity and Structural Creep Analysis/Design.	579
9.1	Introduction	581
9.1.1	Basic Assumptions and Code Recommendations.	583
9.1.2	Non-linearity Due to Cracking or Strain-Softening	583

9.1.3	Non-linearity at Unloading and Adaptation	583
9.1.4	Composite and Inhomogeneous Cross-Sections of Beams	584
9.2	Axial Compression. Linear Creep Deformations	585
9.2.1	The Standard Linear Model	585
9.2.2	Axial Compression. Linear Creep Constitutive Equation	590
9.3	Combined Flexure and Axial Load Resistance with High Temperature Creep Effect	601
9.4	Design for Stochastic Behavior of Structures	614
9.4.1	Introduction	614
9.4.2	Stochastic Behavior of Structures	616
9.4.3	The First-Occurrence Time Problem and the Probability Density $P(a_0, \theta)$	618
9.5	Beams on Elastic Foundation	618
9.6	Beams on Elastic Foundation Subjected to High Temperature Load	626
9.7	Design for Stochastic Behavior of Beams on Elastic Foundation	629
9.7.1	Probability-Based Data	629
9.7.2	The First-Occurrence Time Problem and the Probability Density $P(a_0, \theta)$	636
9.8	Composite Materials and Structures	636
9.8.1	Introduction	636
9.8.2	Nonlinear Creep of Core Material	639
	References	649
	Index	651

Probability Based High Temperature Engineering
Creep and Structural Fire Resistance

Razdolsky, L.

2017, XVII, 656 p. 308 illus., 257 illus. in color.,

Hardcover

ISBN: 978-3-319-41907-7