Contents

| Pref Abo | | e Autho | or | xix xxiii | |
|-------------|--------------|---------|--|--------------|--|
| 1 | Introduction | | | | |
| | 1.1 | The Si | ignificance of Thermal Stress in Mass Concrete | 1 1 | |
| | 1.2 | | eatures of Thermal Stresses in Concrete Structures | 3 | |
| | 1.3 | | ariation of Temperature and Thermal Stress of Mass | · | |
| | | | ete with Time | 4 | |
| | | 1.3.1 | The Variation of Temperature of Mass Concrete with Time | 4 | |
| | | 1.3.2 | The Variation of the Thermal Stress in Mass Concrete | 5 | |
| | 1.4 | Kinds | of Thermal Stress | 6 | |
| | 1.5 | Analy | sis of Thermal Stress of a Massive Concrete Structure | 6 | |
| | 1.6 | | nal Stress—The Cause of Crack | 7 | |
| | 1.7 | Techn | ical Measures for Control of Thermal Stress and Prevention | | |
| | | of Cra | | 8 | |
| | 1.8 | The E | xperience of the Temperature Control and Crack Prevention | | |
| | | of Ma | ss Concrete in the Last 30 Years | 10 | |
| 2 | | | of Heat in Mass Concrete, Boundary Conditions, | | |
| | and | | ds of Solution | 11 | |
| | 2.1 | | ential Equation of Heat Conduction, Initial and Boundary | | |
| | | Condi | | 11 | |
| | | 2.1.1 | Differential Equation of Heat Conduction | 11 | |
| | | 2.1.2 | | 12 | |
| | | 2.1.3 | = 0 min min y = 0 min vi o m | 13 | |
| | | 2.1.4 | The Approximate Treatment of the Third Kind of | | |
| | | | Boundary Condition | 14 | |
| | 2.2 | | e Conductance and Computation of Superficial Thermal | | |
| | | Insula | | 16 | |
| | | 2.2.1 | | 16 | |
| | | 2.2.2 | 1 | | |
| | | | Insulation | 17 | |
| | 2.3 | | emperature | 19 | |
| | | | Annual Variation of Air Temperature | 19 | |
| | 2 4 | | Cold Wave | 19 | |
| | 2.4 | | erature Increments due to Sunshine | 20 | |
| | | 2.4.1 | Sun Radiation on Horizontal Surface | 20 | |

| | | 2.4.2 | Temperature Increment of the Dam Surface due to | 22 |
|---|-------|--------|---|------------|
| | | 2 4 3 | Sunshine Influence of Sunshine on the Temperature of Horizontal | 22 |
| | | 2.4.3 | Lift Surface | 22 |
| | 2.5 | Fetime | ation of Water Temperature in Reservoir | 25 |
| | 2.6 | | rical Computation of Water Temperature in Reservoir | 28 |
| | 2.7 | | all Properties of Concrete | 29 |
| | 2.8 | | of Hydration of Cement and the Adiabatic Temperature | 2) |
| | 2.0 | | of Concrete | 31 |
| | | | Heat of Hydration of Cement | 31 |
| | | 2.8.2 | · | 32 |
| | 2.9 | | erature on the Surface of Dam | 35 |
| | 2.10 | | Autogenous Deformation of Concrete | 36 |
| | 2.10 | | -Mature Age of Concrete | 36 |
| | 2,11 | 2.11.1 | | 30 |
| | | ∠,11.1 | Concrete | 37 |
| | | 2.11.2 | | 31 |
| | | 2.11.2 | Concrete | 38 |
| | | 2.11.3 | | 40 |
| | | | Example of the Influence of Semi-Mature Age | 40 |
| | | | Measures for Adjusting the Semi-Mature Ages of Concrete | 41 |
| | | 2.11.6 | | 42 |
| | 2.12 | | rmation of Concrete Caused by Change of Humidity | 42 |
| | 2.12 | | ficients of Thermal Expansion of Concrete | 43 |
| | 2.13 | | tion of Temperature Field by Finite Difference Method | 44 |
| | 2,17 | Solu | tion of Temperature Field by Finite Difference Method | 77 |
| 3 | | _ | re Field in the Operation Period of a Massive Concrete | |
| | | icture | | 49 |
| | 3.1 | | of Influence of the Variation of Exterior Temperature | |
| | | | Operation Period | 49 |
| | | | Depth of Influence of Variation of Water Temperature | 49 |
| | | | Depth of Influence of Variation of Air Temperature | 50 |
| | 3.2 | | tion of Concrete Temperature from the Beginning of | |
| | | | ruction to the Period of Operation | 53 |
| | 3.3 | Stead | y Temperature Field of Concrete Dams | 54 |
| 4 | Plac | ing Te | mperature and Temperature Rise of Concrete Lift due | |
| • | | | on Heat of Cement | 57 |
| | 4.1 | | In the second of the second o | 57 |
| | 4.2 | | Forming Temperature of Concrete T_1 | 58 |
| | 4.3 | | ag Temperature of Concrete T_p | 60 |
| | 4.4 | | retical Solution of Temperature Rise of Concrete Lift due | 00 |
| | ¬•,¬₹ | | dration Heat of Cement | 62 |
| | | 4.4.1 | Temperature Rise due to Hydration Heat in Concrete | 0 2 |
| | | 1. 1.1 | Lift with First Kind of Boundary Condition | 62 |
| | | | VIII - ILUVILUV L- VIII-VIII VVIII-VIII | |

| | | 4.4.2 Temperature Rise due to Hydration Heat in Concrete | |
|---|------|--|-----|
| | | Lift with Third Kind of Boundary Condition | 64 |
| | | 4.4.3 Temperature Rise due to Hydration Heat with | |
| | | Adiabatic Temperature Rise Expressed by Compound | |
| | | Exponentials | 66 |
| | 4.5 | Theoretical Solution of Temperature Field of Concrete Lift due | |
| | | to Simultaneous Action of Natural Cooling and Pipe Cooling | 67 |
| | 4.6 | Temperature Field in Concrete Lift Computed by Finite | |
| | | Difference Method | 69 |
| | | 4.6.1 Temperature Field in Concrete Lift due to Hydration Heat | |
| | | Computed by Finite Difference Method | 69 |
| | | 4.6.2 Temperature Field due to Hydration Heat in Concrete Lift | |
| | | with Cooling Pipe Computed by Finite Difference Method | 70 |
| | 4.7 | Practical Method for Computing Temperature Field in Construction | |
| | | Period of Concrete Dams | 72 |
| | | 4.7.1 Practical Method for Computing Temperature Field in | |
| | | Concrete Lift without Pipe Cooling | 74 |
| | | 4.7.2 Influence of the Placing Temperature T_p of the | |
| | | New Concrete | 75 |
| | | 4.7.3 Practical Method for Computing Temperature in Concrete | |
| | | Lift without Pipe Cooling | 77 |
| | | 4.7.4 Practical Method for Computing Temperature Field in | |
| | | Concrete Lift with Pipe Cooling | 77 |
| | | 4.7.5 Practical Treatment of Boundary Condition on the Top | |
| | | Surface | 80 |
| 5 | Nati | ural Cooling of Mass Concrete | 83 |
| | 5.1 | Cooling of Semi-Infinite Solid, Third Kind of Boundary | ••• |
| | | Condition | 83 |
| | 5.2 | Cooling of a Slab with First Kind of Boundary Condition | 85 |
| | 5.3 | Cooling of a Slab with Third Kind of Boundary Condition | 89 |
| | 5.4 | Temperature in a Concrete Slab with Harmonic Surface | |
| | | | 91 |
| | | 5.4.1 Concrete Slab with Zero Initial Temperature and | |
| | | | 91 |
| | | 5.4.2 Concrete Slab, Initial Temperature T_0 , Harmonic | |
| | | Surface Temperature | 94 |
| | 5.5 | Temperature in a Slab with Arbitrary External Temperature | 98 |
| | 5.6 | Cooling of Mass Concrete in Two and Three Directions, Theorem | |
| | | of Product | l01 |
| 6 | Stre | ess-Strain Relation and Analysis of Viscoelastic Stress of Mass | |
| | | | 105 |
| | 6.1 | | 105 |
| | | | 105 |

| | | 6.1.2 Strain of Concrete due to Variable Stress | 107 |
|---|-----|--|------|
| | | 6.1.3 Modulus of Elasticity and Creep of Concrete | 107 |
| | | 6.1.4 Lateral Strain and Poisson's Ratio of Concrete | 110 |
| | 6.2 | Stress Relaxation of Concrete | 111 |
| | | 6.2.1 Stress Relaxation of Concrete Subjected to Constant Strain | 111 |
| | | 6.2.2 Method for Computing the Relaxation Coefficient | |
| | | from Creep of Concrete | 112 |
| | | 6.2.3 Formulas for Relaxation Coefficient | 114 |
| | 6.3 | Modulus of Elasticity, Unit Creep, and Relaxation Coefficient | |
| | | of Concrete for Preliminary Analysis | 115 |
| | 6.4 | Two Theorems About the Influence of Creep on the Stresses | |
| | | and Deformations of Concrete Structures | 115 |
| | 6.5 | Classification of Massive Concrete Structures and Method of | |
| | | Analysis | 117 |
| | 6.6 | Method of Equivalent Modulus for Analyzing Stresses in | |
| | | Matured Concrete due to Harmonic Variation of Temperature | 117 |
| 7 | The | rmal Stresses in Fixed Slab or Free Slab | 121 |
| | 7.1 | Thermal Stresses in Fixed Slab | 121 |
| | | 7.1.1 Computation of the Temperature Field | 121 |
| | | 7.1.2 The Elastic Thermal Stress | 121 |
| | | 7.1.3 The Viscoelastic Thermal Stresses | 123 |
| | | 7.1.4 The Thermal Stresses in Fixed Slab Due to Hydration | |
| | | Heat of Cement | 123 |
| | 7.2 | Method for Computing Thermal Stresses in a Free Slab | 126 |
| | | 7.2.1 Elastic Thermal Stress in a Free Slab When the | |
| | | Modulus of Elasticity is Constant | 126 |
| | | 7.2.2 Viscoelastic Thermal Stress in a Free Slab Considering the | |
| | | Influence of Age | 128 |
| | 7.3 | Thermal Stresses in Free Concrete Slab due to Hydration Heat of | |
| | | Cement | 129 |
| | 7.4 | Thermal Stresses in Free Slabs with Periodically Varying Surface | |
| | | Temperature | 129 |
| | | 7.4.1 The Temperature Field | 129 |
| | | 7.4.2 The Viscoelastic Thermal Stresses | 134 |
| | 7.5 | Thermal Stress in Free Slab with Third Kind of Boundary | |
| | | Condition and Periodically Varying Air Temperature | 134 |
| | 7.6 | & • | 138 |
| | | 7.6.1 Stresses Due to Removing Forms of Infinite Slab | 138 |
| | | 7.6.2 Stresses Due to Removing Forms of Semi-infinite Solid | 139 |
| | | 7.6.3 Computing Thermal Stress Due to Removing | 4.44 |
| | | Forms by Finite Element Method | 141 |
| 8 | | ermal Stresses in Concrete Beams on Elastic Foundation | 143 |
| | 8.1 | Self-Thermal Stress in a Beam | 143 |

| | 8.2 | Restraint Thermal Stress of Beam on Foundation of | |
|----|------|---|-----|
| | 0.2 | Semi-infinite Plane | 145 |
| | | 8.2.1 Nonhomogeneous Beam on Elastic Foundation | 145 |
| | | 8.2.2 Homogeneous Beam on Elastic Foundation | 152 |
| | 8.3 | Restraint Stresses of Beam on Old Concrete Block | 156 |
| | 8.4 | Approximate Analysis of Thermal Stresses in Thin Beam | |
| | | on Half-Plane Foundation | 159 |
| | 8.5 | Thermal Stress on the Lateral Surface of Beam on Elastic | |
| | | Foundation | 159 |
| | 8.6 | Thermal Stresses in Beam on Winkler Foundation | 161 |
| | | 8.6.1 Restraint Stress of Beam in Pure Tension | 161 |
| | | 8.6.2 Restraint Stress of Beam in Pure Bending | 162 |
| | | 8.6.3 Restraint Stresses of Beam in Bending and Tension | 163 |
| | | 8.6.4 Coefficients of Resistance of Foundation | 165 |
| | | 8.6.5 Approximate Method for Beam on Winkler | |
| | | Foundation | 167 |
| | | 8.6.6 Analysis of Effect of Restraint of Soil Foundation | 167 |
| | 8.7 | Thermal Stresses in Beams on Elastic Foundation When | |
| | | Modulus of Elasticity of Concrete Varying with Time | 169 |
| 9 | Fini | te Element Method for Computing Temperature Field | 171 |
| | 9.1 | Variational Principle for the Problem of Heat Conduction | 171 |
| | | 9.1.1 Euler's Equation | 171 |
| | | 9.1.2 Variational Principle of Problem of Heat Conduction | 172 |
| | 9.2 | Discretization of Continuous Body | 174 |
| | 9.3 | Fundamental Equations for Solving Unsteady Temperature | |
| | | Field by FEM | 174 |
| | 9.4 | Two-Dimensional Unsteady Temperature Field, Triangular | |
| | | Elements | 178 |
| | 9.5 | Isoparametric Elements | 180 |
| | | 9.5.1 Two-Dimensional Isoparametric Elements | 180 |
| | | 9.5.2 Three-Dimensional Isoparametric Elements | 182 |
| | 9.6 | Computing Examples of Unsteady Temperature Field | 183 |
| 10 | | ite Element Method for Computing the Viscoelastic Thermal | |
| | | esses of Massive Concrete Structures | 185 |
| | 10.1 | FEM for Computing Elastic Thermal Stresses | 185 |
| | | 10.1.1 Displacements of an Element | 185 |
| | | 10.1.2 Strains of an Element | 187 |
| | | 10.1.3 Stresses of an Element | 188 |
| | | 10.1.4 Nodal Forces and Stiffness Matrix of an Element | 189 |
| | | 10.1.5 Nodal Loads | 190 |
| | | 10.1.6 Equilibrium Equation of Nodes and the Global | |
| | | Stiffness Matrix | 191 |
| | | 10.1.7 Collection of FEM Formulas | 191 |

| | 10.2 | Implicit Method for Solving Viscoelastic Stress—Strain | |
|----|------|--|------------|
| | | Equation of Mass Concrete | 192 |
| | | 10.2.1 Computing Increment of Strain | 192 |
| | | 10.2.2 Relationship Between Stress Increment and Strain | |
| | | - | 196 |
| | | 10.2.3 Relationship Between Stress Increment and Strain | |
| | | | 197 |
| | 10.3 | 1 | 199 |
| | | • | 202 |
| | | 1 | 203 |
| 11 | Stre | sses due to Change of Air Temperature and Superficial Thermal | |
| | Insu | lation | 205 |
| | 11.1 | Superficial Thermal Stress due to Linear Variation of Air | |
| | | - | 205 |
| | 11.2 | Superficial Thermal Insulation, Harmonic Variation of Air | |
| | | - | 208 |
| | | 11.2.1 Superficial Thermal Insulation, Daily Variation of Air | |
| | | · · · · · · · · · · · · · · · · · · · | 208 |
| | | 11.2.2 Superficial Thermal Insulation for Cold Wave, | |
| | | One-Dimensional Heat Flow | 211 |
| | | 11.2.3 Superficial Thermal Insulation, Temperature | |
| | | Drop in Winter, One-Dimensional Heat Flow | 214 |
| | 113 | Superficial Thermal Insulation, Harmonic Variation of | |
| | 11.5 | Air Temperature, Two-Dimensional Heat Flow | 216 |
| | | 11.3.1 Two-Dimensional Heat Flow, Thermal Insulation for Daily | 410 |
| | | Variation of Air Temperature | 216 |
| | | 11.3.2 Two-Dimensional Heat Flow, Thermal Insulation for Cold | 410 |
| | | Wave | 217 |
| | | | 21/ |
| | | 11.3.3 Two-Dimensional Heat Flow, the Superficial | 220 |
| | 11 / | Thermal Insulation During Winter | 220 |
| | 11.4 | Thermal Stresses in Concrete Block During Winter and | 220 |
| | | Supercritical Thermal Insulation | 220 220 |
| | | 11.4.1 Superficial Thermal Stresses During Winter | 223 |
| | | 11.4.2 Computation of Superficial Thermal Insulation | |
| | | 11.4.3 Determining the Thickness of Superficial Thermal Insulation | |
| | | Plate | 225 |
| | 11.5 | Comprehensive Analysis of Effect of Superficial Thermal | 226 |
| | | Insulation for Variation of Air Temperature | 226 |
| | 11.6 | The Necessity of Long Time Thermal Insulation for Important | |
| | | Concrete Surface | 227 |
| | 11.7 | Materials for Superficial Thermal Insulation | 230 |
| | | 11.7.1 Foamed Polystyrene Plate | 230 |
| | | 11.7.2 Foamed Polythene Wadded Quilt | 230 |
| | | 11.7.3 Polyurethane Foamed Coating | 231 |
| | | 11.7.4 Compound Permanent Insulation Plate | 231 |

| | | 11.7.5 Permanent Thermal Insulation and Anti-Seepage Plate | 231 |
|----|------|---|-----|
| | | 11.7.6 Straw Bag | 232 |
| | | 11.7.7 Sand Layer | 232 |
| | | 11.7.8 Requirements of Thermal Insulation for Different | |
| | | Concrete Surfaces | 233 |
| 12 | | rmal Stresses in Massive Concrete Blocks | 235 |
| | 12.1 | Thermal Stresses of Concrete Block on Elastic Foundation | |
| | | due to Uniform Cooling | 235 |
| | | 12.1.1 Thermal Stresses of Block on Horizontal Foundation | 235 |
| | | 12.1.2 Danger of Cracking of Thin Block with Long Time of Cooling | 238 |
| | | 12.1.3 Concrete Block on Inclined Foundation | 238 |
| | 12.2 | Influence Lines of Thermal Stress in Concrete Block | 239 |
| | | Influence of Height of Cooling Region on Thermal Stresses | 243 |
| | | 12.3.1 Influence of Height of Cooling Region on Elastic Thermal | |
| | | Stresses 12.2.2. Inflyance of Height of Capling Region on the Wigner lastic | 243 |
| | | 12.3.2 Influence of Height of Cooling Region on the Viscoelastic Thermal Stresses | 245 |
| | 12.4 | Influence of Height of Cooling Region on Opening of Contraction | |
| | | Joints | 246 |
| | 12.5 | Two Kinds of Temperature Difference Between Upper and | |
| | | Lower Parts of Block | 247 |
| | 12.6 | Two Principles for Temperature Control and the Allowable | |
| | | Temperature Differences of Mass Concrete on Rock | |
| | | Foundation | 249 |
| | | 12.6.1 Stresses due to Stepwise Temperature Difference | 249 |
| | | 12.6.2 Positive Stepwise Temperature Difference and the | |
| | | First Principle About the Control of Temperature | |
| | | Difference of Concrete on Rock Foundation | 252 |
| | | 12.6.3 Negative Stepwise Temperature Difference and the | |
| | | Second Principle About the Control of Temperature | |
| | | Difference of Concrete on Rock Foundation | 255 |
| | | 12.6.4 Stresses due to Multi-Stepwise Temperature Difference | 255 |
| | | 12.6.5 Viscoelastic Thermal Stresses Simulating Process of | |
| | | Construction of Multilayer Concrete Block on Rock | |
| | | Foundation | 256 |
| | 12.7 | Approximate Formula for Thermal Stress in Concrete Block | |
| | | on Rock Foundation in Construction Period | 259 |
| | 12.8 | Influence of Length of Concrete Block on the Thermal Stress | 260 |
| | | 12.8.1 Influence of Length of Concrete Block on the Thermal | |
| | | Stress due to Temperature Difference Between the Upper | |
| | | and Lower Parts | 260 |
| | | 12.8.2 Influence of Joint Spacing on the Thermal Stress | |
| | | due to Annual Variation of Temperature | 262 |
| | 12.9 | Danger of Cracking due to Over-precooling of Concrete | 263 |

| | 12.10 Thermal Stresses in Concrete Blocks Standing Side by Side | 265 |
|----|---|-----|
| | 12.11 Equivalent Temperature Rise due to Self-Weight of Concrete | 265 |
| 13 | Thermal Stresses in Concrete Gravity Dams | 267 |
| | 13.1 Thermal Stresses in Gravity Dams due to Restraint of Foundation | 267 |
| | 13.2 Influence of Longitudinal Joints on Thermal Stress in | |
| | Gravity Dam | 270 |
| | 13.3 The Temperatures and Stresses in a Gravity Dam Without | |
| | Longitudinal Joint | 271 |
| | 13.4 Gravity Dam with Longitudinal Crack | 271 |
| | 13.5 Deep Crack on the Upstream Face of Gravity Dam | 272 |
| | 13.6 Opening of Longitudinal Joint of Gravity Dam in the Period | |
| | of Operation | 273 |
| | , | 274 |
| | 13.7.1 Peculiarity of Thermal Stresses of Gravity Dam in | |
| | e | 274 |
| | 1 | 275 |
| | 13.7.3 Measures for Preventing Cracking of Gravity Dam in | |
| | 201111 2111 2111 | 278 |
| | | 279 |
| | 13.9 Technical Measures to Reduce the Thermal Stress due to | |
| | Heightening of Gravity Dam | 284 |
| 14 | | 287 |
| | | 287 |
| | | 287 |
| | • | 288 |
| | | 289 |
| | 1 6 | 289 |
| | 77.2 | 290 |
| | | 291 |
| | 1 6 | 292 |
| | 14.3.1 Computation of Surface Temperature of Dam for Variable | |
| | | 292 |
| | 14.3.2 Temperature Loading on Arch Dam for Variable Water | ••• |
| | Level | 294 |
| | 14.4 Temperature Loadings on Arch Dams in Cold Region with | 207 |
| | Superficial Thermal Insulation Layer | 297 |
| | 14.4.1 T_{m1} and T_{d1} for the Annual Mean Temperature Field $T_1(x)$ | 297 |
| | 14.4.2 Exact Solution of T_{m2} and T_{d2} for the Yearly Varying | 200 |
| | Temperature Field $T_2(x,T)$ | 300 |
| | 14.4.3 Approximate Solution of $T_{\rm m2}$ and $T_{\rm d2}$ for the Yearly | 204 |
| | Varying Temperature Field $T_2(x,\tau)$ | 304 |
| | 14.5 Measures for Reducing Temperature Loadings of Arch Dam | 305 |
| | 14.5.1 Optimizing Grouting Temperature | 306 |

| | 14.5.2 Superficial Thermal Insulation | 306 |
|-----|---|-----|
| | 14.6 Temperature Control of RCC Arch Dams | 306 |
| | 14.6.1 RCC Arch Dams without Transverse Joint | 306 |
| | 14.6.2 RCC Arch Dam with Transverse Joints | 307 |
| | 14.7 Observed Thermal Stresses and Deformations of Arch Dams | 308 |
| | | |
| 15 | Thermal Stresses in Docks, Locks, and Sluices | 313 |
| | 15.1 Self-Thermal Stresses in Walls of Docks and Piers of Sluices | 313 |
| | 15.2 Restraint Stress in the Wall of Dock | 314 |
| | 15.2.1 General Theory for the Restraint Stress in the Wall | |
| | of Dock | 314 |
| | 15.2.2 Computation for Wide Bottom Plate | 317 |
| | 15.2.3 Computation for Bottom Plate with Moderate Width | 320 |
| | 15.3 Restraint Stress in the Piers of Sluices | 321 |
| | 15.4 Restraint Stress in the Wall of Dock or the Pier of Sluice on | |
| | Narrow Bottom Plate | 323 |
| | 15.5 Simplified Computing Method | 325 |
| | 15.5.1 <i>T</i> Beam | 325 |
| | 15.5.2 Simplified Computation of Thermal Stresses in Dock | 327 |
| | 15.5.3 Simplified Method for Thermal Stresses in Sluices | 328 |
| | 15.5.4 Simplified Method for $E(y, \tau)$ Varying with Age τ | 329 |
| | 15.6 Thermal Stresses in a Sluice by FEM | 329 |
| | 15.6.1 Thermal Stress due to Hydration Heat of Cement in | |
| | Construction Period | 329 |
| 16 | Simulation Analysis, Dynamic Temperature Control, Numerical Monitoring, and Model Test of Thermal Stresses in Massive Concrete Structures | 333 |
| | 16.1 Full Course Simulation Analysis of Concrete Dams | 333 |
| | 16.2 Dynamic Temperature Control and Decision Support System | |
| | of Concrete Dam | 334 |
| | 16.3 Numerical Monitoring of Concrete Dams | 335 |
| | 16.3.1 The Drawbacks of Instrumental Monitoring | 336 |
| | 16.3.2 Numerical Monitoring | 336 |
| | 16.3.3 The Important Functions of Numerical Monitoring16.4 Model Test of Temperature and Stress Fields of Massive | 336 |
| | Concrete Structures | 337 |
| 17 | Dina Casling of Mass Courses | 241 |
| 1 / | Pipe Cooling of Mass Concrete 17.1 Introduction | 341 |
| | | 341 |
| | 17.2 Plane Temperature Field of Pipe Cooling in Late Stage 17.2.1 Plane Temperature Field of Concrete Cooled by | 342 |
| | Nonmetal Pipe in Late Stage | 342 |
| | 17.2.2 Plane Temperature Field of Concrete Cooled by | |
| | Metal Pipe in Late Stage | 346 |
| | 17.3 Spatial Temperature Field of Pipe Cooling in Late Stage | 348 |
| | | |

| | 17.3.1 | Method of Solution of the Spatial Problem of Pipe | |
|------|---------|--|-----|
| | | Cooling | 348 |
| | 17.3.2 | Spatial Cooling of Concrete by Metal Pipe in | |
| | | Late Stage | 352 |
| | 17.3.3 | Spatial Cooling of Concrete by Nonmetal Pipe in | |
| | | Late Stage | 356 |
| 17.4 | Tempe | rature Field of Pipe Cooling in Early Stage | 358 |
| | 17.4.1 | Plane Problem of Pipe Cooling of Early Stage | 358 |
| | | Spatial Problem of Pipe Cooling of Late Stage | 360 |
| 17.5 | Practic | al Formulas for Pipe Cooling of Mass Concrete | 362 |
| | 17.5.1 | Mean Temperature of Concrete Cylinder with | |
| | | Length L | 362 |
| | 17.5.2 | Mean Temperature of the Cross Section of Concrete | |
| | | Cylinder | 364 |
| | 17.5.3 | Time of Cooling | 365 |
| | 17.5.4 | Formula for Water Temperature | 366 |
| 17.6 | | alent Equation of Heat Conduction Considering Effect of | |
| | Pipe C | | 367 |
| | 17.6.1 | Temperature Variation of Concrete with Insulated | |
| | | Surface and Cooling Pipe | 367 |
| | 17.6.2 | Equivalent Equation of Heat Conduction Considering | |
| | | the Effect of Pipe Cooling | 370 |
| 17.7 | Theore | etical Solution of the Elastocreeping Stresses Due to | |
| | | Cooling and Self-Restraint | 371 |
| | | The Elastic Thermal Stress Due to Self-Restraint | 371 |
| | 17.7.2 | The Elastocreeping Thermal Stress Due to | |
| | | Self-Restraint | 373 |
| | 17.7.3 | A Practical Formula for the Elastocreeping Thermal | |
| | | Stress Due to Self-Restraint | 374 |
| | 17.7.4 | Reducing Thermal Stress by Multistage Cooling with | |
| | | Small Temperature Differences—Theoretical Solution | 374 |
| | 17.7.5 | The Elastocreeping Self-Stress Due to Pipe Cooling and | |
| | | Hydration Heat of Cement | 375 |
| 17.8 | Nume | rical Analysis of Elastocreeping Self-Thermal Stress of Pipe | |
| | Coolir | ng | 376 |
| | 17.8.1 | Computing Model | 376 |
| | 17.8.2 | Elastocreeping Stresses in 60 Days Early Pipe Cooling | 377 |
| | 17.8.3 | Elastocreeping Stresses in 20 Days Early Pipe Cooling | 377 |
| | 17.8.4 | Elastocreeping Stresses in Late Pipe Cooling | 377 |
| | 17.8.5 | New Method of Cooling—Multistep Early and Slow | |
| | | Cooling with Small Temperature Differences—Numerical | |
| | | Analysis | 379 |
| 17.9 | The F | EM for Computing Temperatures and Stresses in Pipe | |
| | Coole | d Concrete | 380 |
| | 17.9.1 | Pipe Cooling Temperature Field Solved Directly by FEM | 380 |

| Stresses in Mass Concrete Block with Cooling Pipe 17.9.3 Comparison Between the Direct Method and the Equivalent Method for Pipe Cooling 17.10 Three Principles for Pipe Cooling 17.11 Research on the Pattern of Early Pipe Cooling 17.12 Research on the Pattern of the Medium and the Late Cooling 17.12.1 The Influence of Temperature Gradient on the Thermal Stress 17.12.2 The Influence of Pipe Spacing on the Thermal Stress 17.12.3 The Influence of the Number of Stages of Pipe Cooling 17.13 Strengthen Cooling by Close Polythene Pipe 17.13.1 Effect of Cooling by Close Pipe 17.13.2 Influence of Cooling by Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference To Two Two 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Water Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.3 Spraying Fog over Top of the Concrete Block 18.5.4 Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference 19.2.4 Dam Type Difference | | 17.9.2 Equivalent FEM for Computing the Temperatures and | |
|---|----|--|-----|
| 17.9.3 Comparison Between the Direct Method and the Equivalent Method for Pipe Cooling 17.10 Three Principles for Pipe Cooling 17.11 Research on the Pattern of Early Pipe Cooling 17.12 Research on the Pattern of the Medium and the Late Cooling 17.12 Research on the Pattern of the Medium and the Late Cooling 17.12.1 The Influence of Temperature Gradient on the Thermal Stress 17.12.2 The Influence of Pipe Spacing on the Thermal Stress 17.12.3 The Influence of the Number of Stages of Pipe Cooling 17.13 Strengthen Cooling by Close Polythene Pipe 17.13.1 Effect of Cooling by Close Pipe 17.13.2 Influence of Cooling of Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference To Two Two Temperature Difference To Two Two Temperature Difference To Two Two Two Two Two Two Two Two Two | | | 382 |
| Equivalent Method for Pipe Cooling 17.10 Three Principles for Pipe Cooling 17.11 Research on the Pattern of Early Pipe Cooling 17.12 Research on the Pattern of the Medium and the Late Cooling 17.12.1 The Influence of Temperature Gradient on the Thermal Stress 17.12.2 The Influence of Pipe Spacing on the Thermal Stress 17.12.3 The Influence of the Number of Stages of Pipe Cooling 17.13 Strengthen Cooling by Close Polythene Pipe 17.13.1 Effect of Cooling by Close Pipe 17.13.2 Influence of Cooling of Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference To Two Two Two Two Two Tremal Stress 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.3 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.3 Spraying Fog over Top of the Concrete Block 18.5.1 Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Time Difference 19.2.3 Regional Difference | | | |
| 17.11 Research on the Pattern of Early Pipe Cooling 17.12 Research on the Pattern of the Medium and the Late Cooling 17.12.1 The Influence of Temperature Gradient on the Thermal Stress 17.12.2 The Influence of Pipe Spacing on the Thermal Stress 17.12.3 The Influence of the Number of Stages of Pipe Cooling 17.13 Strengthen Cooling by Close Polythene Pipe 17.13.1 Effect of Cooling by Close Pipe 17.13.2 Influence of Cooling of Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference To Tw 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.3 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.3 Preculiarities of MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference 19.2.3 Regional Difference | | Equivalent Method for Pipe Cooling | 384 |
| 17.12 Research on the Pattern of the Medium and the Late Cooling 17.12.1 The Influence of Temperature Gradient on the Thermal Stress 17.12.2 The Influence of Pipe Spacing on the Thermal Stress 17.12.3 The Influence of the Number of Stages of Pipe Cooling 17.13 Strengthen Cooling by Close Polythene Pipe 17.13.1 Effect of Cooling by Close Pipe 17.13.2 Influence of Cooling of Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference To Tw 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.3 Precooling of Aggregate by Secondary Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.3 Preculiarities of MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 17.10 Three Principles for Pipe Cooling | 384 |
| 17.12.1 The Influence of Temperature Gradient on the Thermal Stress 17.12.2 The Influence of Pipe Spacing on the Thermal Stress 17.12.3 The Influence of the Number of Stages of Pipe Cooling 17.13 Strengthen Cooling by Close Polythene Pipe 17.13.1 Effect of Cooling by Close Pipe 17.13.2 Influence of Cooling of Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference To Tw 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate by Water Cooling 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.3 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.3 Preculiarities of MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 17.11 Research on the Pattern of Early Pipe Cooling | 386 |
| Stress 17.12.2 The Influence of Pipe Spacing on the Thermal Stress 17.12.3 The Influence of the Number of Stages of Pipe Cooling 17.13 Strengthen Cooling by Close Polythene Pipe 17.13.1 Effect of Cooling by Close Pipe with Small Spacing on the Thermal Stress 17.13.2 Influence of Cooling of Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference To Tw 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate by Water Cooling 18.4.1 Precooling of Aggregate by Air Cooling 18.4.2 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.3 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.3 Praying Fog Over Top of the Concrete Block 18.5.4 Precooling of Dam by MgO Concrete 19.2 Six Peculiarities of MgO Concrete 19.2 Time Difference 19.2.3 Regional Difference | | 17.12 Research on the Pattern of the Medium and the Late Cooling | 387 |
| 17.12.3 The Influence of the Number of Stages of Pipe Cooling 17.13 Strengthen Cooling by Close Polythene Pipe 17.13.1 Effect of Cooling by Close Pipe 17.13.2 Influence of Cooling of Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference To Tw 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.3 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.2 Six Peculiarities of MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | | 387 |
| 17.12.3 The Influence of the Number of Stages of Pipe Cooling 17.13 Strengthen Cooling by Close Polythene Pipe 17.13.1 Effect of Cooling by Close Pipe 17.13.2 Influence of Cooling of Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference To Tw 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.3 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.2 Six Peculiarities of MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 17.12.2 The Influence of Pipe Spacing on the Thermal Stress | 389 |
| 17.13 Strengthen Cooling by Close Polythene Pipe 17.13.1 Effect of Cooling by Close Pipe 17.13.2 Influence of Cooling of Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference To - Tw 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.3 Precooling of Aggregate by Secondary Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.3 Cooling by Flowing Water over Top of the Concrete Block 18.5.4 Precooling of Aggregate Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 17.12.3 The Influence of the Number of Stages of Pipe Cooling | 389 |
| 17.13.1 Effect of Cooling by Close Pipe 17.13.2 Influence of Cooling of Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference To Tw 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Air Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog Ocerete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference | | | 389 |
| 17.13.2 Influence of Cooling of Pipe with Small Spacing on the Thermal Stress 17.13.3 The Principle for Control of Pipe Spacing and Temperature Difference $T_0 - T_w$ 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Air Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | | 389 |
| Temperature Difference $T_0 - T_w$ 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate by Water Cooling 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.3 Precooling of Aggregate by Secondary Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.3 Spraying Fog Ochrete 19.4 MgO Concrete 19.5 Six Peculiarities of MgO Concrete 19.6 Difference Between Indoor and Outdoor Expansive Deformation 19.6 Time Difference 19.7 Time Difference | | 17.13.2 Influence of Cooling of Pipe with Small Spacing on the | 391 |
| Temperature Difference $T_0 - T_w$ 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate by Water Cooling 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.3 Precooling of Aggregate by Secondary Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.3 Spraying Fog Ochrete 19.4 MgO Concrete 19.5 Six Peculiarities of MgO Concrete 19.6 Difference Between Indoor and Outdoor Expansive Deformation 19.6 Time Difference 19.7 Time Difference | | 17.13.3 The Principle for Control of Pipe Spacing and | |
| 17.14 Advantages and Disadvantages of Pipe Cooling 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Air Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | Temperature Difference $T_0 - T_w$ | 394 |
| 17.15 Superficial Thermal Insulation of Mass Concrete During Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Air Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | | 395 |
| Pipe Cooling in Hot Seasons 18 Precooling and Surface Cooling of Mass Concrete 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Air Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | | |
| 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Air Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19.5 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | | 398 |
| 18.1 Introduction 18.2 Getting Aggregates from Underground Gallery 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Air Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19.5 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | 18 | Precooling and Surface Cooling of Mass Concrete | 401 |
| 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Air Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | | 401 |
| 18.3 Mixing with Cooled Water and Ice 18.4 Precooling of Aggregate 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Air Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 18.2 Getting Aggregates from Underground Gallery | 402 |
| 18.4.1 Precooling of Aggregate by Water Cooling 18.4.2 Precooling of Aggregate by Air Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 18.3 Mixing with Cooled Water and Ice | 403 |
| 18.4.2 Precooling of Aggregate by Air Cooling 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 18.4 Precooling of Aggregate | 404 |
| 18.4.3 Precooling of Aggregate by Mixed Type of Water Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 18.4.1 Precooling of Aggregate by Water Cooling | 404 |
| Spraying and Air Cooling 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 18.4.2 Precooling of Aggregate by Air Cooling | 405 |
| 18.4.4 Precooling of Aggregate by Secondary Air Cooling 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 18.4.3 Precooling of Aggregate by Mixed Type of Water | |
| 18.5 Cooling by Spraying Fog or Flowing Water over Top of the Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | | 405 |
| Concrete Block 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 18.4.4 Precooling of Aggregate by Secondary Air Cooling | 406 |
| 18.5.1 Spraying Fog over Top of the Concrete Block 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | 18.5 Cooling by Spraying Fog or Flowing Water over Top of the | |
| 18.5.2 Cooling by Flowing Water over Top of the Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | Concrete Block | 406 |
| Concrete Block 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | | 406 |
| 19 Construction of Dam by MgO Concrete 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | | |
| 19.1 MgO Concrete 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | Concrete Block | 408 |
| 19.2 Six Peculiarities of MgO Concrete Dams 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | 19 | | 409 |
| 19.2.1 Difference Between Indoor and Outdoor Expansive Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | | 409 |
| Deformation 19.2.2 Time Difference 19.2.3 Regional Difference | | | 410 |
| 19.2.2 Time Difference19.2.3 Regional Difference | | | |
| 19.2.3 Regional Difference | | | 410 |
| | | | 412 |
| 19.2.4 Dam Type Difference | | | 413 |
| | | 19.2.4 Dam Type Difference | 414 |

| | | 19.2.5 Two Kinds of Temperature Difference | 414 |
|----|------|--|-----|
| | | 19.2.6 Dilatation Source Difference | 414 |
| | 19.3 | The Calculation Model of the Expansive Deformation | |
| | | of MgO Concrete | 415 |
| | | 19.3.1 The Calculation Model of the Expansive Deformation | |
| | | for Test Indoors | 415 |
| | | 19.3.2 The Calculation of the Expansive Deformation of MgO | |
| | | Concrete of Dam Body Outdoors | 415 |
| | | 19.3.3 The Incremental Calculation of the Autogenous Volume | |
| | | Deformation | 416 |
| | 19.4 | The Application of MgO Concrete in Gravity Dams | 416 |
| | | 19.4.1 Conventional Concrete Gravity Dams | 416 |
| | 19.5 | The Application of MgO Concrete in Arch Dams | 419 |
| | | 19.5.1 Arch Dams with Contraction Joints | 419 |
| | | 19.5.2 Arch Dams without Contraction Joints, Time | |
| | | Difference | 420 |
| | | 19.5.3 Example of Application of MgO Concrete, Sanjianghe | |
| | | MgO Concrete Arch Dam | 423 |
| 20 | Con | struction of Mass Concrete in Winter | 425 |
| | 20.1 | Problems and Design Principles of Construction of Mass | |
| | | Concrete in Winter | 425 |
| | | 20.1.1 Problems of Construction of Mass Concrete in Winter | 425 |
| | | 20.1.2 Design Principles of Construction of Mass Concrete in | |
| | | Winter | 426 |
| | 20.2 | Technical Measures of Construction of Mass Concrete | |
| | | in Winter | 426 |
| | 20.3 | Calculation of Thermal Insulation of Mass Concrete | |
| | | Construction in Winter | 428 |
| 21 | Ten | perature Control of Concrete Dam in Cold Region | 431 |
| | 21.1 | Climate Features of the Cold Region | 431 |
| | 21.2 | Difficulties of Temperature Control of Concrete Dam in Cold | |
| | | Region | 432 |
| | 21.3 | Temperature Control of Concrete Dam in Cold Region | 433 |
| 22 | Allo | wable Temperature Difference, Cooling Capacity, Inspection | |
| | and | Treatment of Cracks, and Administration of Temperature | |
| | Con | trol | 439 |
| | 22.1 | Computational Formula for Concrete Crack Resistance | 439 |
| | | Laboratory Test of Crack Resistance of Concrete | 441 |
| | 22.3 | The Difference of Tensile Properties Between Prototype | |
| | | Concrete and Laboratory Testing Sample | 441 |
| | | 22.3.1 Coefficient b_1 for Size and Screening Effect | 441 |
| | | 22.3.2 Time Effect Coefficient b_2 | 442 |

| 2 | 2.4 Reason | nable Value for the Safety Factor of Crack Resistance | 443 |
|---|--|---|------------|
| | 22.4.1 | Theoretical Safety Factor of Crack Resistance | 443 |
| | 22.4.2 | Practical Safety Factor of Concrete Crack Resistance | 443 |
| | 22.4.3 | Safety Factors for Crack Resistance in Preliminary Design | 445 |
| 2 | 2.5 Calcul | ation of Allowable Temperature Difference and Ability | |
| | | perficial Thermal Insulation of Mass Concrete | 447 |
| | 22.5.1 | General Formula for Allowable Temperature Difference | |
| | | and Superficial Thermal Insulation | 447 |
| | 22.5.2 | Approximate Calculation of Allowable Temperature | |
| | | Difference and Insulation Ability | 447 |
| 2 | 22.6 The Allowable Temperature Difference Adopted by Practical | | |
| | Concrete Dam Design Specifications | | |
| | | Regulations of Allowable Temperature Difference in | |
| | | Chinese Concrete Dam Design Specifications | 450 |
| | 22.6.2 | The Requirement of Temperature Control in "Design | |
| | | Guideline of Roller Compacted Concrete Dam" of China | 451 |
| | 22.6.3 | Temperature Control Regulation of Concrete Dam by | |
| | | U.S. Bureau of Reclamation and U.S. Army Corps of | |
| | | Engineering | 452 |
| | 22.6.4 | Temperature Control Requirements of Concrete Dam of | |
| | | Russia | 453 |
| 2 | 2.7 Practic | cal Examples for Temperature Control of Concrete Dams | 453 |
| | | Laxiwa Arch Dam | 453 |
| | 22.7.2 | Toktogulskaya Gravity Dam | 455 |
| | | Dworshak Gravity Dam | 459 |
| 2 | | ng Capacity | 460 |
| | 22.8.1 | Calculation for the Total Cooling Capacity | 460 |
| | | Cooling Load for Different Cases | 463 |
| 2 | 2.9 Inspec | tion and Classification of Concrete Cracks | 463 |
| | 22.9.1 | Inspection of Concrete Cracks | 463 |
| | 22.9.2 | Classification of Cracks in Mass Concrete | 464 |
| 2 | 2.10 Treat | ment of Concrete Cracks | 464 |
| | 22.10. | 1 Harm of Cracks | 464 |
| | | 2 Environmental Condition of Cracks | 465 |
| | 22.10. | 3 Principle of Crack Treatment | 465 |
| | 22.10. | 4 Method of Crack Treatment | 466 |
| | | | |
| ŀ | Key Princi _l | ples for Temperature Control of Mass Concrete | 469 |
| | | ion of the Form of Structure | 469 |
| | _ | ization of Concrete Material | 470 |
| | | ation of Crack Resistance of Concrete | 470 |
| 2 | | ol of Temperature Difference of Mass Concrete | 471 |
| | 23.4.1 | Temperature Difference Above Dam Foundation and | |
| | | Temperature Difference Between Upper and Lower | |
| | | Parts of Dam Block | 471 |

| 23.4.2 Surface—Interior Temperature Difference | 47 | |
|--|-----|--|
| 23.4.3 Maximum Temperature of Concrete | 47: | |
| 23.5 Analysis of Thermal Stress of Mass Concrete | 47 | |
| 23.5.1 Estimation of Thermal Stress | 47 | |
| 23.5.2 Primary Calculation of the Temperature Stress | 47. | |
| 23.5.3 Detailed Calculation of Thermal Stress | 47. | |
| 23.5.4 Whole Process Simulation Calculation | 47 | |
| 23.6 Dividing the Dam into Blocks | 47 | |
| 23.7 Temperature Control of Gravity Dam | 47 | |
| 23.8 Temperature Control of Arch Dam | 47 | |
| 23.9 Control of Placing Temperature of Mass Concrete | 47 | |
| 23.10 Pipe Cooling of Mass Concrete | 47 | |
| 23.11 Surface Thermal Insulation | 47 | |
| 23.12 Winter Construction | 47 | |
| 23.13 Conclusion | 47 | |
| Appendix: Unit Conversion References | | |
| | | |