

CONTENTS

PREFACE **xiii**

1

INTRODUCTION **1**

- 1.1 Historical Development of Structural Concrete 1
- 1.2 Basic Hypothesis of Reinforced Concrete 2
- 1.3 Analysis versus Design of Sections 3

2

CONCRETE-PRODUCING MATERIALS **7**

- 2.1 Introduction 7
- 2.2 Portland Cement 8
- 2.3 Water and Air 11
- 2.4 Aggregates 12
- 2.5 Admixtures 15
- Selected References 19

3

CONCRETE **20**

- 3.1 Introduction 20
- 3.2 Proportioning Theory 22
- 3.3 High-Strength High-Performance Concrete Mixtures Design 29
- 3.4 PCA Method of Mixture Design 40
- 3.5 Estimating Compressive Strength of a Trial Mixture Using the Specified Compressive Strength 40
- 3.6 Mixture Designs for Nuclear-shielding Concrete 45
- 3.7 Quality Tests on Concrete 45
- 3.8 Placing and Curing of Concrete 46
- 3.9 Properties of Hardened Concrete 47
- 3.10 High-strength Concrete 58
- Selected References 66
- Problems for Solution 67

4

REINFORCED CONCRETE **68**

- 4.1 Introduction 68
- 4.2 Types and Properties of Steel Reinforcement 69
- 4.3 Bar Spacing and Concrete Cover for Steel Reinforcement 70
- 4.4 Concrete Structural Systems 73
- 4.5 Reliability and Structural Safety of Concrete Components 74
- 4.6 ACI Load Factors and Safety Margins 79
- 4.7 Design Strength versus Nominal Strength: Strength Reduction Factor ϕ 80
- 4.8 Quality Control and Quality Assurance 81

5**FLEXURE IN BEAMS 89**

- 5.1 Introduction 89
- 5.2 The Equivalent Rectangular Block 93
- 5.3 Balanced Reinforcement Ratio ρ_b 97
- 5.4 Analysis of Singly Reinforced Rectangular Beams for Flexure 99
- 5.5 Trial-and-Adjustment Procedures for the Design of Singly Reinforced Beams 104
- 5.6 One-Way Slabs 108
- 5.7 Doubly Reinforced Sections 110
- 5.8 Nonrectangular Sections 120
- 5.9 Analysis of T and L Beams 121
- 5.10 Trial-and-Adjustment Procedure for the Design of Flanged Sections 128
- 5.11 Strain Limits Approach 135
- 5.12 Concrete Joist Construction 153
- 5.13 SI Expressions and Example for Flexural Design of Beams 155
- Selected References 159
- Problems for Solution 160

6**SHEAR AND DIAGONAL TENSION IN BEAMS 165**

- 6.1 Introduction 165
- 6.2 Behavior of Homogeneous Beams 167
- 6.3 Behavior of Reinforced Concrete Beams as Nonhomogeneous Sections 168
- 6.4 Reinforced Concrete Beams without Diagonal Tension Reinforcement 170
- 6.5 Diagonal Tension Analysis of Slender and Intermediate Beams 173
- 6.6 Web Steel Planar Truss Analogy 175
- 6.7 Web Reinforcement Design Procedure for Shear 179
- 6.8 Examples of the Design of Web Steel for Shear 180
- 6.9 Deep Beams 185
- 6.10 Brackets or Corbels 197
- 6.11 SI Design Expressions and Example for Shear Design 206
- Selected References 209
- Problems for Solution 210

7**TORSION 213**

- 7.1 Introduction 213
- 7.2 Pure Torsion in Plain Concrete Elements 216
- 7.3 Torsion in Reinforced Concrete Elements 223
- 7.4 Shear-Torsion-Bending Interaction 228
- 7.5 Design of Reinforced Concrete Beams Subjected to Combined Torsion, Bending, and Shear 229
- 7.6 SI Metric Torsion Expressions and Example for Torsion Design 255
- Selected References 259
- Problems for Solution 261

8**SERVICEABILITY OF BEAMS AND ONE-WAY SLABS 264**

- 8.1 Introduction 264
- 8.2 Significance of Deflection Observation 265
- 8.3 Deflection Behavior of Beams 265
- 8.4 Long-term Deflection 272

- 8.5 Permissible Deflections in Beams and One-way Slabs 274
- 8.6 Computation of Deflections 275
- 8.7 Deflection of Continuous Beams 280
- 8.8 Operational Deflection Calculation Procedure and Flow Chart 290
- 8.9 Deflection Control in One-way Slabs 291
- 8.10 Flexural Cracking in Beams and One-way Slabs 295
- 8.11 Tolerable Crack Widths 301
- 8.12 ACI 318 Code Provisions for Control of Flexural Cracking 301
- 8.13 SI Conversion Expressions and Example of Deflection Evaluation 303
- Selected References 306
- Problems for Solution 306

9

COMBINED COMPRESSION AND BENDING: COLUMNS 309

- 9.1 Introduction 309
- 9.2 Types of Columns 310
- 9.3 Strength of Short Centrally Loaded Columns 313
- 9.4 Strength of Eccentrically Loaded Columns: Axial Load and Bending 316
- 9.5 Modes of Material Failure in Columns 319
- 9.6 Whitney's Approximate Solution in Lieu of Exact Solutions 330
- 9.7 Column Strength Reduction Factor ϕ 335
- 9.8 Load-Moment Strength Interaction Diagrams (P - M Diagrams) for Columns Controlled by Material Failure 338
- 9.9 Practical Design Considerations 343
- 9.10 Operational Procedure for the Design of Nonslender Columns 347
- 9.11 Numerical Examples for Analysis and Design of Nonslender Columns 348
- 9.12 Limit State at Buckling Failure (Slender or Long Columns) 353
- 9.13 Moment Magnification: First-order Analysis 357
- 9.14 Second-order Frame Analysis and the P - Δ Effect 361
- 9.15 Operational Procedure and Flow Chart for the Design of Slender Columns 362
- 9.16 Compression Members in Biaxial Bending: Load Contour Method; Reciprocal Load Method; Modified Load Contour Method 367
- 9.17 SI Expression and Example for the Design of Compression Members 384
- Selected References 386
- Problems for Solution 387

10

BOND DEVELOPMENT OF REINFORCING BARS 390

- 10.1 introduction 390
- 10.2 Bond Stress Development 391
- 10.3 Basic Development Length 395
- 10.4 Development of Flexural Reinforcement in Continuous Beams 406
- 10.5 Splicing of Reinforcement 412
- 10.6 Examples of Embedment Length and Splice Design for Beam Reinforcement 414
- 10.7 Typical Detailing of Reinforcement and Bar Scheduling 418
- Selected References 428
- Problems for Solution 428

11

DESIGN OF TWO-WAY SLABS AND PLATES 430

- 11.1 Introduction: Review of Methods 430
- 11.2 Flexural Behavior of Two-way Slabs and Plates 433
- 11.3 The Direct Design Method 434

- 11.4 Distributed Factored Moments and Slab Reinforcement by the Direct Design Method 438
- 11.5 Design and Analysis Procedure: Direct Design method 448
- 11.6 Equivalent Frame Method for Floor Slab Design 470
- 11.7 SI Two-way Slab Design Expressions and Example 481
- 11.8 Direct Method of Deflection Evaluation 490
- 11.9 Cracking Behavior and Crack Control in Two-way-action Slabs and Plates 496
- 11.10 Yield-line Theory for Two-way Action Plates 503
- Selected References 517
- Problems for Solution 518

12

FOOTINGS 520

- 12.1 Introduction 520
- 12.2 Types of Foundations 522
- 12.3 Shear and Flexural Behavior of Footings 523
- 12.4 Soil Bearing Pressure at Base of Footings 526
- 12.5 Design Considerations in Flexure 531
- 12.6 Design Considerations in Shear 532
- 12.7 Operational Procedure for the Design of Footings 534
- 12.8 Examples of Footing Design 537
- 12.9 Structural Design of Other Types of Foundations 550
- Selected References 550
- Problems for Solution 551

13

CONTINUOUS REINFORCED CONCRETE STRUCTURES 552

- 13.1 Introduction 552
- 13.2 Longhand Displacement Methods 554
- 13.3 Force Method of Analysis 554
- 13.4 Displacement Method of Analysis 560
- 13.5 Finite-element Methods and Computer Usage 567
- 13.6 Approximate Analysis of Continuous Beams and Frames 568
- 13.7 Limit Design (Analysis) of Indeterminate Beams and Frames 594
- Selected References 604
- Problems for Solution 605

14

INTRODUCTION TO PRESTRESSED CONCRETE 607

- 14.1 Basic Concepts of Prestressing 607
- 14.2 Partial Loss of Prestress 613
- 14.3 Flexural Design of Prestressed Concrete Elements 619
- 14.4 Ultimate-strength Flexural Design of Prestressed Beams 634
- 14.5 Flow Chart for Strength Flexural Analysis of Prestressed Beams 639
- 14.6 Example 14.5: Ultimate-strength Design of Prestressed Simply Supported Beam by Strain Compatibility 639
- 14.7 Web Reinforcement Design Procedure for Shear 644
- Selected References 648
- Problems for Solution 648

15

SEISMIC DESIGN OF CONCRETE STRUCTURES 652

- 15.1 Introduction: Mechanism of Earthquakes 652
- 15.2 Spectral Response Method 657

15.3	Equivalent Lateral Force Method	664
15.4	Simplified Analysis Procedure for Seismic Design of Buildings	670
15.5	Other Aspects in Seismic Design	671
15.6	Flexural Design of Beams and Columns	671
15.7	Seismic Detailing Requirements for Beams and Columns	675
15.8	Horizontal Shear in Beam-Column Connections (Joints)	679
15.9	Design of Shear Walls	681
15.10	Design Procedure for Earthquake-Resistant Construction	684
15.11	Example 15.1: Seismic Base Shear and Lateral Forces and Moments by the International Building Code (IBC) Approach	693
15.12	Example 15.2: Design of Confining Reinforcement for Beam-Column Connection	696
15.13	Example 15.3: Transverse Reinforcement in a Beam Potential Hinge Region	700
15.14	Example 15.4: Probable Shear Strength of Monolithic Beam-Column Joint	701
15.15	Example 15.5: Seismic Shear Wall Design and Detailing	703
	Selected References	709
	Problems for Solution	710

APPENDIX A COMPUTER PROGRAMS IN Q-BASIC 711

A.1	Computer Program EGNAWY1 for Rectangular Beams in Flexure, Shear, and Torsion	712
A.2	Computer Programs EGNAWY2, EGNAWY3, and EGNAWY4 for Compression Members	716
A.3	Computer Programs EGNAWY5 and EGNAWY6 for Flexural Analysis and Design of Flanged Sections	730
A.4	Computer Program EGNAWY7 for Corbels	733
A.5	Computer Program EGNAWY8 for Deep Beams	736

APPENDIX B TABLES AND NOMOGRAMS 739

INDEX 769