

# Contents

<b>1</b>	<b>Reinforced Concrete Technology . . . . .</b>	<b>1</b>
1.1	Introduction . . . . .	1
1.2	The ACI Code . . . . .	2
1.3	Concrete Ingredients . . . . .	3
1.3.1	Portland Cement . . . . .	4
1.3.2	Fine and Coarse Aggregates . . . . .	5
1.3.3	Water and Air . . . . .	6
1.3.4	Admixtures . . . . .	9
1.4	Curing . . . . .	11
1.5	Testing Concrete . . . . .	11
1.5.1	Slump Test . . . . .	12
1.5.2	Cylinder Test . . . . .	14
1.5.3	Core-Cylinder Test and In Situ Tests . . . . .	16
1.6	Mechanical Behavior of Concrete . . . . .	16
1.6.1	Concrete in Compression . . . . .	16
1.6.2	Concrete in Tension . . . . .	20
1.7	Volume Changes in Concrete . . . . .	23
1.7.1	Temperature Change . . . . .	23
1.7.2	Concrete Shrinkage . . . . .	25
1.7.3	Creep of Concrete . . . . .	27
1.8	Reinforcing Steel . . . . .	28
1.8.1	Behavior of Steel Under Stress . . . . .	29
	Problems . . . . .	34
	Self-Experiments . . . . .	34
<b>2</b>	<b>Rectangular Beams and One-Way Slabs . . . . .</b>	<b>37</b>
2.1	Introduction . . . . .	37
2.2	Advantages of Reinforced Concrete . . . . .	37
2.3	Disadvantages of Reinforced Concrete . . . . .	38
2.4	On the Nature of the Design Process . . . . .	38

2.5	Live Load Reduction Factors . . . . .	41
2.6	Continuity in Reinforced Concrete Construction . . . . .	43
2.7	Propagation of Internal Forces . . . . .	46
2.8	On the “Fickleness” of Live Loads . . . . .	49
2.9	The ACI Code Moment and Shear Coefficients . . . . .	52
2.10	The Concept of Strength Design . . . . .	53
2.11	Design (Ultimate) Strength . . . . .	55
2.12	Assumptions for the Flexural Design of Reinforced Concrete Beams . . . . .	58
2.13	Different Failure Modes . . . . .	65
2.14	The Equivalent Stress Block . . . . .	67
2.15	The Steel Ratio ( $\rho$ ) . . . . .	70
2.16	The Balanced Steel Ratio . . . . .	71
2.17	Elaboration on the Net Tensile Strain in Steel ( $\epsilon_t$ ) . . . . .	72
2.18	The Location of the Neutral Axis and Limit Positions . . . . .	75
2.19	Relationship Between $\phi$ and $d_t/c$ . . . . .	77
2.20	Limitations on the Steel Percentage ( $\rho$ ) for Flexural Members . . . . .	77
2.21	Minimum Steel Ratio ( $\rho_{\min}$ ) for Reinforced Concrete Beams . . . . .	79
2.22	Analysis of Rectangular Reinforced Concrete Sections . . . . .	80
2.22.1	$M_R$ Calculation: Method I . . . . .	80
2.22.2	$M_R$ Calculation: Method II . . . . .	86
2.23	Selection of Appropriate Dimensions for Reinforced Concrete Beams and One-Way Slabs . . . . .	92
2.23.1	Selection of Depth . . . . .	92
2.23.2	Selection of Width . . . . .	94
2.24	Crack Control in Reinforced Concrete Beams and One-Way Slabs . . . . .	95
2.25	Design of Beams . . . . .	98
2.26	Slabs . . . . .	111
2.27	Behavior of Reinforced Concrete Slabs Under Loads . . . . .	113
2.28	Reinforcement in One-Way Slabs . . . . .	115
2.28.1	Main Reinforcement . . . . .	115
2.28.2	Shrinkage and Temperature (S & T) Reinforcement . . . . .	116
2.28.3	Minimum Reinforcements for One-Way Slabs . . . . .	117
2.29	Areas of Reinforcing Bars in Slabs . . . . .	120
2.30	Analysis of Reinforced Concrete One-Way Slabs . . . . .	120
2.31	Design of Reinforced Concrete One-Way Slabs . . . . .	130
	Problems . . . . .	137
	Self-Experiments . . . . .	146
<b>3</b>	<b>Special Topics in Flexure . . . . .</b>	<b>151</b>
3.1	T-beams . . . . .	151
3.1.1	Introduction . . . . .	151
3.1.2	Effective Flange Width ( $b_{\text{eff}}$ ) . . . . .	153

3.1.3	Minimum Steel for T-beams . . . . .	155
3.1.4	Analysis of T-beams . . . . .	155
3.1.5	Design of T-beams . . . . .	165
3.2	Doubly-Reinforced Beams . . . . .	176
3.2.1	Introduction . . . . .	176
3.2.2	Analysis of Doubly-Reinforced Concrete Beams . . . . .	176
3.2.3	Design of Doubly-Reinforced Concrete Beams . . . . .	190
3.2.4	Lateral Support for Compression Steel . . . . .	199
3.3	Deflection of Reinforced Concrete Beams . . . . .	200
3.3.1	Introduction . . . . .	200
3.3.2	The Effective Moment of Inertia ( $I_e$ ) . . . . .	202
3.3.3	Cracked Section Moment of Inertia ( $I_{cr}$ ) . . . . .	205
3.3.4	Applications . . . . .	212
3.3.5	Comments on the Effective Moment of Inertia ( $I_e$ ) . . . . .	214
3.3.6	Long-Term Deflections . . . . .	214
3.4	Reinforcement Development and Splices . . . . .	216
3.4.1	Bond Stresses . . . . .	216
3.4.2	Development Length for Bars in Tension . . . . .	218
3.4.3	Tension Bars Terminated in Hooks . . . . .	220
3.4.4	Development Length for Bars in Compression . . . . .	223
3.4.5	Splices of Reinforcement . . . . .	224
	Problems . . . . .	225
	Self-Experiments . . . . .	230
<b>4</b>	<b>Shear in Reinforced Concrete Beams . . . . .</b>	<b>235</b>
4.1	Introduction . . . . .	235
4.2	Shear in Beams . . . . .	235
4.3	The Design of Shear Reinforcement . . . . .	242
4.3.1	Zone 1 ( $V_u \leq \phi V_c/2$ ) . . . . .	246
4.3.2	Zone 2 ( $\phi V_c/2 < V_u \leq \phi V_c$ ) . . . . .	246
4.3.3	Zone 3 ( $\phi V_c < V_u$ ) . . . . .	246
4.4	Additional Requirements for the Design of Shear Reinforcing . . . . .	249
4.5	Stirrup Design Procedure . . . . .	251
4.6	Additional Formulas to Calculate the Shear Strength of a Beam Section . . . . .	262
4.6.1	Beams Subject to Flexure and Shear Only . . . . .	262
4.6.2	Members Subject to Axial Compression . . . . .	262
4.6.3	Members Subject to Significant Axial Tension . . . . .	262
4.7	Corbels and Brackets . . . . .	264
	Problems . . . . .	271
	Self-Experiments . . . . .	274
<b>5</b>	<b>Columns . . . . .</b>	<b>277</b>
5.1	Introduction . . . . .	277
5.2	Types of Columns . . . . .	277

5.2.1	Based on Reinforcement . . . . .	277
5.2.2	Based on Shape . . . . .	280
5.2.3	Based on Loading . . . . .	282
5.2.4	Based on Structural System . . . . .	284
5.2.5	Based on Length . . . . .	285
5.3	Behavior of Short Columns with Small Eccentricity Under Load . . . . .	285
5.4	General ACI Code Requirements for Columns . . . . .	288
5.5	Some Considerations on the Design of Reinforced Concrete Columns . . . . .	294
5.5.1	Column Size . . . . .	294
5.5.2	High-Strength Material Use . . . . .	294
5.6	Analysis of Short Columns with Small Eccentricity . . . . .	294
5.7	Design of Short Columns with Small Eccentricity . . . . .	302
5.7.1	$A_g = \text{Known}, A_{st} = \text{Unknown}$ . . . . .	302
5.7.2	$A_g$ and $A_{st} = \text{Unknown}$ . . . . .	308
5.8	Behavior of Short Columns Under Eccentric Loads . . . . .	316
5.9	ACI Column Interaction Diagrams . . . . .	330
5.10	Design Axial Load Strength ( $\phi P_n$ ), and Moment Capacity ( $\phi M_n$ ) . . . . .	334
5.11	Analysis of Short Columns with Large Eccentricity Using Interaction Diagrams . . . . .	336
5.11.1	Analysis of Columns with Compression-Controlled Behavior . . . . .	337
5.11.2	Analysis of Non-compression-Controlled Columns . . . . .	339
5.12	Design of Short Columns with Large Eccentricity . . . . .	347
5.12.1	Design of Columns with Compression-Controlled Behavior . . . . .	347
5.12.2	Design of Non-compression-Controlled Columns . . . . .	350
5.13	Slender Columns . . . . .	358
5.13.1	Column Buckling and Slenderness Ratio . . . . .	358
5.13.2	P- $\Delta$ Effects . . . . .	362
	Problems . . . . .	364
	Self-Experiments . . . . .	369
<b>6</b>	<b>Floor Systems . . . . .</b>	<b>371</b>
6.1	Introduction . . . . .	371
6.2	Flat Slabs and Plates . . . . .	372
6.3	Shears in Flat Slabs and Plates . . . . .	375
6.4	Flexure in Flat Slabs and Plates . . . . .	380
6.5	Flat Slabs and the Use of Drop Panels . . . . .	390
6.6	Waffle Slab Structures . . . . .	392
6.7	One-Way Joists . . . . .	395
6.8	Beams and One-Way Slabs . . . . .	398

6.9	Two-Way Slabs on Beams . . . . .	399
6.10	Two-Way Joists with Slab Band Beams . . . . .	400
	Problems . . . . .	401
	Self-Experiments . . . . .	402
<b>7</b>	<b>Foundations and Earth Supporting Walls . . . . .</b>	<b>403</b>
7.1	Introduction . . . . .	403
7.2	Types of Soil . . . . .	403
7.3	Soil Classification . . . . .	404
7.4	Test Borings and the Standard Penetration Test (SPT) . . . . .	404
7.5	Soil Failure Under Footings . . . . .	406
7.6	Pressure Distribution Under Footing and Soil Settlement . . . . .	408
7.7	Allowable Bearing Soil Pressure . . . . .	410
7.8	Types of Foundations . . . . .	411
	7.8.1 Shallow Foundations . . . . .	411
	7.8.2 Deep Foundations . . . . .	414
	7.8.3 Considerations for the Placement of Foundations . . . . .	418
7.9	Distribution of Soil Pressure Under Footings . . . . .	420
7.10	Design of Wall Footings . . . . .	421
	7.10.1 Plain Concrete Wall Footings . . . . .	421
	7.10.2 Reinforced Concrete Wall Footings . . . . .	428
7.11	Reinforced Concrete Square Spread Footing Design . . . . .	436
7.12	Rectangular Reinforced Concrete Footing . . . . .	460
7.13	Earth Supporting Walls . . . . .	474
	7.13.1 Lateral Earth Pressure . . . . .	474
	7.13.2 Basement Walls . . . . .	479
	7.13.3 Retaining Walls . . . . .	493
	Problems . . . . .	510
	Self-Experiments . . . . .	514
<b>8</b>	<b>Formwork for Monolithic Concrete Construction . . . . .</b>	<b>517</b>
8.1	Introduction . . . . .	517
8.2	Planning for Formwork . . . . .	518
8.3	Loads on Formwork . . . . .	519
	8.3.1 Gravity Loads . . . . .	519
	8.3.2 Lateral Pressure on Formwork . . . . .	520
	8.3.3 Lateral Loads on the Shoring and Forming Assembly . . . . .	522
8.4	Materials for Formwork . . . . .	523
	8.4.1 Form Panels . . . . .	523
	8.4.2 Lumber . . . . .	526
	8.4.3 Formwork Accessories . . . . .	529
	8.4.4 Release Agents . . . . .	532
8.5	Design of Formwork Elements . . . . .	533
	8.5.1 Typical Design Formulas . . . . .	533
8.6	Wall Formwork Design . . . . .	537

8.7	Column Formwork Design . . . . .	546
8.8	Floor Slab Formwork Design . . . . .	550
8.9	Beam Formwork Design . . . . .	557
	Problems . . . . .	563
	Self-Experiments . . . . .	564
<b>9</b>	<b>Overview of Prestressed Concrete . . . . .</b>	<b>567</b>
9.1	Introduction . . . . .	567
9.2	Advantages of Prestressed Concrete Structures . . . . .	571
9.3	Types of Prestressing . . . . .	572
9.3.1	Pretensioning . . . . .	572
9.3.2	Posttensioning . . . . .	575
9.4	Prestressed Concrete Materials . . . . .	576
9.4.1	Concrete . . . . .	576
9.4.2	Prestressing Steel . . . . .	577
9.5	Loss of Prestressing . . . . .	577
9.5.1	Elastic Shortening of Concrete . . . . .	578
9.5.2	Shrinkage of Concrete . . . . .	578
9.5.3	Creep of Concrete . . . . .	579
9.5.4	Relaxation of the Prestressing Steel . . . . .	579
9.5.5	Friction Losses in Curved Tendons . . . . .	579
9.5.6	Total Losses . . . . .	581
9.6	Ultimate Strength . . . . .	581
9.7	The Concept of Load Balancing . . . . .	582
	Problems . . . . .	587
	Self-Experiments . . . . .	588
<b>10</b>	<b>Metric System in Reinforced Concrete Design and Construction . . . . .</b>	<b>591</b>
10.1	Introduction . . . . .	591
10.2	Brief History of Metric System Adoption in the United States . . . . .	591
10.3	Conversion to SI Units . . . . .	592
	Problems . . . . .	603
	<b>Appendix A: Tables and Diagrams . . . . .</b>	<b>607</b>
	<b>Appendix B: Concrete Structure and Construction Images . . . . .</b>	<b>643</b>
	<b>Appendix C: Standard ACI Notations . . . . .</b>	<b>657</b>
	<b>Index . . . . .</b>	<b>663</b>



<http://www.springer.com/978-3-319-24113-5>

Concrete Structures

Setareh, M.; Darvas, R.

2017, XVIII, 680 p. 428 illus., Hardcover

ISBN: 978-3-319-24113-5