Contents

PREFACE

1 ANCIENT MASONRY **1**

1.1 Introduction 1

1.2 History of Masonry Materials 1
1.2.1 Stone 2
1.2.2 Clay Units 2
1.2.3 Calcium Silicate Units 4
1.2.4 Concrete Masonry Units 4
1.2.5 Mortars 5

1.3 Early Building Elements 6
1.3.1 Building Up 6
1.3.2 Spanning Across 11
1.3.3 Enclosing Space 17

1.4 Development of Building Structure 20
1.4.1 Posts and Lintels 21
1.4.2 Vaults and Domes 21
1.4.3 Gothic 22
1.4.4 Single-Story Loadbearing Buildings 25
1.4.5 Multistory Loadbearing Buildings 25

1.5 Performance of Existing Structures 27

1.6 Restoration and Retrofit of Heritage Structures 29

1.7 Closure 31

1.8 References 31

1.9 Problems 32

2 CONTEMPORARY MASONRY 33

2.1 Introduction 33

2.2 Masonry Elements 33
2.2.1 Walls 34
2.2.2 Columns and Pilasters 39
2.2.3 Beams and Lintels 41

2.3 Masonry Building Systems 42
2.3.1 Single-Story Loadbearing Buildings 42
2.3.2 Multistory Loadbearing Buildings 43
2.3.3 Hybrid Buildings 45

2.4 Types of Masonry Construction 45
2.4.1 Unreinforced Masonry 45
2.4.2 Reinforced Masonry 48
2.4.3 Prestressed Masonry 51

2.5 Research, Codes and Standards 52

2.6 Sources of Information 54

2.7 Closure 55

2.8 References 55

2.9 Problems 56

3 BUILDING DESIGN 57

3.1 Introduction 57

3.2 Structural Elements 58
3.2.1 Design Criteria 58
3.2.2 Structural Design Loads 60

3.3 Environmental Requirements 76
3.3.1 Temperature Control 76
3.3.2 Sound Control 77
3.3.3 Moisture Control 77
3.3.4 Fire Control 78

3.4 Aesthetics 78

3.5 Integration of Requirements 81

3.6 Planning the Building 82
3.6.1 Building Form 82
3.6.2 Elevation 83
3.6.3 Plan 86
3.6.4 Wall Configuration and Layout 88
3.6.5 Building Irregularities 92
3.6.6 Floors and Roofs 93
3.6.7 Connections 96
3.6.8 Movement Joints and Joints Between Adjoining Elements 98
3.6.9 Foundations 99

3.7 Economic Aspects 100

3.8 Closure 101

3.9 References 102

3.10 Problems 102

4 MASONRY MATERIALS 105

4.1 Introduction 105

4.2 Common Properties of Masonry Units *106*
4.2.1 Description and Geometry of Masonry Units 106
4.2.2 Properties of Masonry Units 108

4.3 Clay Masonry Units 113
4.3.1 Manufacture 113
4.3.2 Grades 116
4.3.3 Sizes and Shapes 117
4.3.4 Compressive Strength 118
4.3.5 Tensile Strength 119

4.3.6 Absorption Properties 120
4.3.7 Freeze-Thaw Durability 121
4.3.8 Thermal Movement 122
4.3.9 Moisture Expansion 122
4.3.10 Creep 123
4.3.11 Freezing Expansion 123
4.3.12 Selection of Brick Units 123

4.4 Concrete Masonry Units 124
4.4.1 Manufacture 124
4.4.2 Grades, Types and Density 125
4.4.3 Sizes and Shapes 126
4.4.4 Compressive Strength 128
4.4.5 Tensile Strength 129
4.4.6 Absorption 130
4.4.7 Durability 131
4.4.8 Thermal Movement 131
4.4.9 Shrinkage 131
4.4.10 Creep 131

4.5 Calcium Silicate Units 132
4.5.1 Manufacture 132
4.5.2 Grades and Durability 132
4.5.3 Sizes and Shapes 132
4.5.4 Compressive and Tensile Strengths 133
4.5.5 Absorption 133
4.5.6 Thermal Movement, Shrinkage and Creep 133

4.6 Building Stone 133
4.6.1 Groups 134
4.6.2 Sizes, Shapes and Finishes 134
4.6.3 Physical Requirements 134
4.6.4 Durability 136
4.6.5 Thermal Movement 137

4.7 Glass Masonry Units 137

4.8 Special Nonconventional Masonry Units 138
4.8.1 Interlocking Mortarless Units 138
4.8.2 AAC Masonry Units 139

4.9 Mortar 140
4.9.1 Functions of Mortar 140
4.9.2 Mortar Types 140

4.9.3 Properties of Plastic Mortar 142
4.9.4 Properties of Hardened Mortar 143
4.9.5 Mortar Aggregates 147
4.9.6 Admixtures and Colors 147

4.10 Grout 148
4.10.1 Workability Requirements 148
4.10.2 Types 148
4.10.3 Admixtures 150
4.10.4 Compressive Strength 151

4.11 Reinforcement 151
4.11.1 Reinforcing Bars 151
4.11.2 Joint Reinforcement 152
4.11.3 Connectors 153
4.11.4 Prestressing Steels 153
4.11.5 Corrosion Protection 153

4.12 Associated Materials 154
4.12.1 Movement Joint Filler Materials 154
4.12.2 Dampproofing 154
4.12.3 Parging 154
4.12.4 Flashing and Weep Holes 155
4.12.5 Air Barriers and Vapor Barriers 156
4.12.6 Coatings 156
4.12.7 Insulation 157

4.13 Closure 158

4.14 References 158

4.15 Problems 163

5 MASONRY ASSEMBLAGES 165

5.1 Introduction 165

5.2 Axial Compression 166
5.2.1 Introduction 166
5.2.2 Standard Prism Tests 166
5.2.3 General Failure Mechanism 168
5.2.4 Factors Affecting Prism Strength 171
5.2.5 Stress-Strain Relationships 179

5.2.6 Relationship Between Wall Strength and Prism Strength 184
5.2.7 Compressive Strength for Loading Parallel to Bed Joint 184

5.3 Combined Axial Compression and Flexure 185
5.3.1 Introduction 185
5.3.2 Prism Tests 185
5.3.3 General Failure Mechanisms 186
5.3.4 Factors Affecting the Influence of Strain Gradient 186
5.3.5 Compression Stress-Strain Relationship 188

5.4 Flexural Tensile Strength for Out-of-Plane Bending 191
5.4.1 Introduction 191
5.4.2 Test Methods 191
5.4.3 Failure Mechanisms 193
5.4.4 Factors Affecting the Tensile Bond Between Masonry Units and Mortar 195
5.4.5 Factors Affecting the Flexural Tensile Strength of Grout-Filled Hollow Masonry 198
5.4.6 Orthogonal Strength Ratio 200
5.4.7 Biaxial Strength 203

5.5 Shear Strength Along Mortar Bed Joints 203
5.5.1 Introduction 203
5.5.2 Test Methods 204
5.5.3 Failure Modes 204
5.5.4 Relationships Between Shear Strength Along Bed Joints and Normal Compressive Stress 204
5.5.5 Interaction of Shear and Tension Along Bed Joints 206
5.5.6 Factors Affecting the Shear Strength Along Mortar Bed Joints 207
5.5.7 Shear Strengths of Collar Joints and Head Joints 208

5.6 In-Plane Tensile Strength 209
5.6.1 Introduction 209
5.6.2 Test Methods 209
5.6.3 Failure Modes 211
5.6.4 Factors Affecting In-Plane Tensile Strength 211

5.7 Combined Loading and Biaxial Strength 214
5.7.1 Introduction 214
5.7.2 Test Methods 214
5.7.3 Failure Modes 215
5.7.4 Factors Affecting Failure Loads Under Biaxial Compression-Tension Stresses 215

5.8 Examples 217
5.8.1 Example 5.1: Bearing Plate for Prism Test 217
5.8.2 Example 5.2: Selection of Masonry Unit and Mortar 218
5.8.3 Example 5.3: Axial Deformation Under Load 218
5.8.4 Example 5.4: Effect of Grouting in Increasing Joint Shear Strength of Concrete Masonry under In-Plane Loads 219
5.8.5 Example 5.5: Modulus of Rupture of Partially Grouted Concrete Masonry 219
5.8.6 Example 5.6: Effect of Grouting on Increasing Moment Carrying Capacity of Concrete Masonry Under Out-of-Plane Loads 219
5.8.7 Example 5.7: Orthogonal Tensile Strength Ratio of Brick Masonry 220
5.8.8 Example 5.8: Orthogonal Tensile Strength Ratio of Brick Masonry 221

5.9 Closure 222

5.10 References 222

5.11 Problems 229

6 REINFORCED BEAMS AND LINTELS 231

6.1 Introduction 231

6.2 Flexural Behavior and Design 233
6.2.1 Fundamental Assumptions 233
6.2.2 Behavior of Beams with Tension Reinforcement 233
6.2.3 Elastic Analysis of Beams with Tension Reinforcement 235
6.2.4 Strength Analysis of Beams with Tension Reinforcement 237
6.2.5 Design Considerations 240
6.2.6 Example 6.1: Beam Flexural Analysis 242
6.2.7 Example 6.2: Flexural Design 242

6.3 Shear Behavior and Design 244
6.3.1 Shear Cracking (Diagonal Tension Cracking) Behavior 244
6.3.2 Development of Design Methods 245
6.3.3 Example 6.3: Shear Design 250

6.4 Development, Anchorage and Splicing of Reinforcement 251
6.4.1 General Requirements 251
6.4.2 Development Length for Reinforcement 252
6.4.3 Example 6.4: Bond and Development Length 255

6.5 Serviceability Requirements 256
6.5.1 General 256
6.5.2 Deflection 256
6.5.3 Example 6.5: Deflection Calculation 256

6.6 Load Distribution on Lintel Beams 258
6.6.1 Behavior 258
6.6.2 Example 6.6: Lintel Beam Loading Example 259
6.6.3 Software for Lintel Design 259

6.7 Closure 260

6.8 References 260

6.9 Problems 262

7 FLEXURAL WALL 265

7.1 Introduction 265

7.2 Load-Resisting Mechanisms 266

7.3 Flexural Behavior of Unreinforced Walls 269
7.3.1 Background 269
7.3.2 Vertical Flexure (Single-Wythe) 269
7.3.3 Effect of Superimposed Axial Load 271
7.3.4 Horizontal Flexure (Single-Wythe) 271
7.3.5 Two-Way Flexure (Single-Wythe) 274
7.3.6 Multiple-Wythe Walls 276

7.4 Analysis and Design of Unreinforced Walls 276
7.4.1 Introduction 276
7.4.2 Design from Basic Principles 276
7.4.3 Yield Line and Failure Line Design Methods 277
7.4.4 Application of Failure Line Design for Flexural Wall Panels 278
7.4.5 Example 7.1: Two-Way Bending 281
7.4.6 Diaphragm Walls 283
7.4.7 Glass Block Panels 284
7.4.8 Masonry Partition Walls 284

7.5 Arching 285
7.5.1 Mechanics of Rigid Arching 286

7.5.2 Mechanism of Gapped Arching 288
7.5.3 Influence of Axial Shortening on Arching Mechanism 289
7.5.4 Influence of Movement of Supports on Arching Mechanisms 289
7.5.5 Design 289
7.5.6 Example 7.2: Arching Action of URM Wall 290

7.6 Reinforced Flexural Walls 293
7.6.1 Background 293
7.6.2 Vertical One-Way Flexural Behavior 294
7.6.3 Horizontal One-Way Flexural Behavior 296
7.6.4 Two-Way Flexural Behavior 298

7.7 Analysis and Design of Reinforced Flexural Walls 299
7.7.1 Vertical Flexural Design 299
7.7.2 Horizontal Flexural Design 300
7.7.3 Two-Way Flexural Design 300
7.7.4 Walls with Openings 301
7.7.5 Reinforced Cavity and Veneer Walls 301
7.7.6 Limits on Spacing and Amount of Reinforcement 301
7.7.7 Partially (Nominally) Reinforced Walls 301
7.7.8 Shear Design 302
7.7.9 Anchorage of Reinforcement 302

7.8 Reinforced Flexural Wall Design Examples 303
7.8.1 Example 7.3: Vertically Spanning Reinforced Concrete Block Wall 303
7.8.2 Example 7.4: Two-Way Bending of Reinforced Concrete Block Wall 306

7.9 Prestressed Masonry Walls 307
7.9.1 Introduction 307
7.9.2 Behavior of Prestressed Walls under Lateral Loads 309
7.9.3 Design Methods 310
7.9.4 Permissible Stress in Prestressing Tendons 311
7.9.5 Strength Requirements 311
7.9.6 Slenderness Effects 312
7.9.7 Shear Design 313
7.9.8 Deflection under Service Loads 313
7.9.9 Example 7.7: Design of Nonloadbearing Walls to Resist Wind Pressure 313

7.10 Closure 316

7.11 References 317

7.12 Problems 321

8 LOADBEARING WALLS UNDER AXIAL LOAD AND OUT-OF-PLANE BENDING 323

8.1 Introduction 323

8.2 Overview of Status and Trends in Design Provisions 324
8.2.1 Current Status of Design Provisions 324
8.2.2 Types of Wall Construction 325

8.3 Analysis and Design under Combined Axial Load and Bending 326
8.3.1 Stress-Strain Relationships for Masonry and Steel 326
8.3.2 Design of Unreinforced Masonry 327
8.3.3 Section Analysis of Solid Unreinforced Masonry 327
8.3.4 Section Analysis of Reinforced Masonry 330

8.4 Effects of Slenderness 330
8.4.1 Introduction 330
8.4.2 TMS 402 Code Provisions for Slenderness 331
8.4.3 Discussion 337

8.5 Concentrated Loads 337
8.5.1 Introduction 337
8.5.2 State of Stress Under Concentrated Loads 337
8.5.3 Strength Enhancement Factor 337
8.5.4 Design Provisions 338
8.5.5 Limiting Compressive Stress for Bearing 339

8.6 Design Examples 339
8.6.1 Example 8.1: Strength Analysis of Unreinforced Wall Under Concentric Axial Compression 339
8.6.2 Example 8.2: Design of Concrete Block Wall Under Eccentric Axial and Wind Loads 341
8.6.3 Example 8.3: Analysis of Bearing Capacity Under Concentrated Load 345

8.7 Closure 346

8.8 References 347

8.9 Problems 348

9 COLUMNS AND PILASTERS **349**

9.1 Introduction 349

9.2 Column Behavior 351
9.2.1 Introduction 351
9.2.2 Failure Modes and Compressive Strength 351
9.2.3 Slenderness Effect 353

9.3 Column Design 353
9.3.1 Design Considerations 353
9.3.2 Design of Columns Under Axial Load and Uniaxial Bending 354
9.3.3 Design of Columns under Biaxial Bending 356
9.3.4 Seismic Design Considerations 358

9.4 Column Design Examples 359
9.4.1 Example 9.1: Design of Column Under Concentric Axial Compression 359
9.4.2 Example 9.2: Eccentrically Loaded Column 361
9.4.3 Example 9.3: Design of a Column Under Biaxial Bending 362

9.5 Pilaster Design 364
9.5.1 Introduction 364
9.5.2 Load Sharing Between Walls and Pilasters 365
9.5.3 Example 9.4: Pilaster Design Using TMS 402 Strength Design Method 366

9.6 Closure 370

9.7 References 370

9.8 Problems 371

10 SHEAR WALLS **373**

10.1 Introduction 373

10.2 Influence of Types and Layout of Shear Walls 374

10.3 Behavior and Failure Modes 375
10.3.1 Unreinforced Shear Walls 376
10.3.2 Multistory Unreinforced Shear Walls 377

10.3.3 Fully Grouted Reinforced Masonry Shear Walls 380
10.3.4 Fully Grouted Reinforced Masonry Shear Walls With Openings 385
10.3.5 Multistory Fully Grouted Reinforced Masonry Shear Walls 387
10.3.6 Partially Grouted Reinforced Masonry Shear Walls 389
10.3.7 Partially Grouted Reinforced Masonry One-Story Buildings 390

10.4 Distribution of Loads to Shear Walls 392
10.4.1 Gravity Loads 392
10.4.2 Lateral Forces 392
10.4.3 Factors Affecting the Distribution of Lateral Loads 395

10.5 Effect of Openings on Wall Rigidity and Force Distribution 397
10.5.1 Horizontal and Vertical Combinations of Shear Wall Segments 397
10.5.2 Rigidity of Walls with Openings in Low-Rise Buildings 398
10.5.3 Example 10.1: Lateral Load Distribution to Walls in a Low-Rise Building 400
10.5.4 Multistory Shear Walls 403
10.5.5 Example 10.2: Forces on Piers in Multistory Walls with Openings 404
10.5.6 Limit Analysis of Reinforced Masonry Shear Walls 405

10.6 Design of Shear Walls 407
10.6.1 Unreinforced Shear Walls 408
10.6.2 Reinforced Shear Walls 410
10.6.3 Special Seismic Design Considerations 414
10.6.4 Moment-Resisting Wall Frames 420
10.6.5 Limit Design of Special Reinforced Masonry Shear Walls 422
10.6.6 Wall Connections 423

10.7 Design Examples 424
10.7.1 Example 10.3: Unreinforced Shear Wall 424
10.7.2 Example 10.4: Reinforced Shear Wall 428
10.7.3 Example 10.5: Pier in a Perforated Wall 430
10.7.4 Example 10.6: Seismic Design of a Perforated Two-Story Reinforced Masonry Shear Wall 433
10.7.5 Example 10.7: Example of Ductility Calculations of a Multistory Shear Wall 436
10.7.6 Example 10.8:Shear Strength of Partially Grouted Shear Walls 439

10.8 Closure 440

10.9 References 440

10.10 Problems 443

11 INFILL WALLS AND PARTITIONS 447

11.1 Introduction 447

11.2 Infill Walls 448
11.2.1 Behavior of Participating Infill Not Anchored to Frames for Composite Action 449
11.2.2 Analysis of Infilled Frames 452
11.2.3 Strength of Infill Walls 458
11.2.4 Infill Walls With Openings 460
11.2.5 Infill Walls With Movement Joints at the Top 460
11.2.6 Transverse Strength of Participating Infill Walls 462
11.2.7 Seismic Design Considerations 463
11.2.8 Example 11.1: Elastic Analysis of the Initial Elastic Stiffness of an Infilled Frame 464
11.2.9 Example 11.2: Cracked Stiffness of An Infilled Frame 466
11.2.10 Example 11.3: Design of Infill Wall 467

11.3 Walls Supported on Beams 468
11.3.1 Introduction 468
11.3.2 Interaction Mechanism and Failure Modes 468
11.3.3 Analysis 469
11.3.4 Limitations of Analysis 471
11.3.5 Example 11.4: Masonry Wall Supported on a Beam 472

11.4 Closure 473

11.5 References 474

11.6 Problems 476

12 MASONRY VENEER AND CAVITY WALLS 479

12.1 Introduction 479
12.1.1 Background 479
12.1.2 Components of Masonry Veneer and Cavity Walls 480
12.1.3 Critical Features in Design and Construction 482

12.2 Masonry Rain Screen Walls 485
12.2.1 Introduction 485
12.2.2 Design of Masonry Veneer Rain Screens 485
12.2.3 Additional Precautions to Avoid Rain Penetration 492

12.2.4 Detailing Requirements for Rain Screen Performance 494

12.3 Shelf Angle Supports 496
12.3.1 Design of Anchors for Shelf Angles 496
12.3.2 Example 12.1: Calculation of Anchor Connection 497
12.3.3 Design of Shelf Angles 498
12.3.4 Flashing Materials 499
12.3.5 Construction Details for Shelf Angles 501

12.4 Structural Design Considerations 502
12.4.1 Structural Requirements for Masonry Veneer Walls 502
12.4.2 Structural Requirements for Masonry Cavity Walls 505
12.4.3 Requirements for Ties and Anchors 508
12.4.4 Special Design Considerations for High Seismic Intensity Areas 508

12.5 Design for Movement Joints 509
12.5.1 Horizontal Movement Joints 509
12.5.2 Vertical Movement Joints 510

12.6 Residential Construction of Brick Veneer 511

12.7 Adhered Veneer 511

12.8 Closure 511

12.9 References 512

12.10 Problems 515

13 CONNECTORS 517

13.1 Introduction 517

13.2 Wall Ties 518
13.2.1 Basic Functions 518
13.2.2 Performance Requirements 520
13.2.3 Types of Ties 521
13.2.4 Strength 522
13.2.5 Stiffness 524
13.2.6 Adjustability 525
13.2.7 Design Considerations for Cavity Wall Ties 526
13.2.8 Analysis of Load Distribution 528
13.2.9 Example 13.1: Tie Forces in Cavity Walls 529

13.2.10 Construction Considerations 529
13.2.11 Tie Materials and Corrosion Resistance 531

13.3 Anchors 534
13.3.1 Veneer Anchors 534
13.3.2 Non-Veneer Anchors 536
13.3.3 Design and Construction Considerations 536

13.4 Fasteners 538
13.4.1 Basic Functions 538
13.4.2 Types of Fasteners 538
13.4.3 Strength of Anchor Bolts 538
13.4.4 Design of Fasteners 539
13.4.5 Example 13.2: Anchor Bolt Design 542

13.5 Closure 543

13.6 References 543

13.7 Problems 545

14 FIRE RESISTANCE AND DESIGN FOR ENVIRONMENTAL LOADS 547

14.1 Introduction 547

14.2 Applications of Building Science to Masonry Construction 548

14.3 Fire Resistance 549
14.3.1 Introduction 549
14.3.2 Design Practice 550
14.3.3 Fire-Resistance Rating 550
14.3.4 Methods for Increasing Fire Resistance 555
14.3.5 Other Aspects of Fire Protection 556
14.3.6 Example 14.1: Design for Fire Resistance of a Nonloadbearing Partition 558
14.3.7 Example 14.2: Calculation of Fire Resistance of a Multi-wythe Wall 559

14.4 Thermal Performance 559
14.4.1 Introduction 559
14.4.2 Introduction to Heat Transfer at Building Surfaces 559
14.4.3 Heat Transfer and Thermal Resistance 561

14.4.4 Example 14.3: Thermal Resistance and Temperatures in a Cavity Wall 562
14.4.5 Other Factors Affecting Thermal Resistance of Masonry Walls 564
14.4.6 Thermal Inertia 566
14.4.7 Other Considerations 567

14.5 Condensation Considerations 569
14.5.1 Introduction 569
14.5.2 Water Vapor Condensation 570
14.5.3 Example 14.3 (continued): Potential for Water Vapor Flow 571
14.5.4 Diffusion of Water Vapor and Potential for Condensation 572
14.5.5 Condensation from Airborne Moisture 575
14.5.6 Example 14.3 (continued): Calculation of Condensation Due to Exfiltration of Air 576
14.5.7 Interaction Between Air and Vapor Barriers 576

14.6 Rain Penetration 577
14.6.1 Background 577
14.6.2 Factors Affecting Rain Penetration 577
14.6.3 Design Provisions to Minimize the Potential for Rain Penetration 578
14.6.4 Measurement of Water Permeance 580

14.7 Sound Control 580
14.7.1 Introduction 580
14.7.2 Sound Transmission 581
14.7.3 Sound Transmission Loss 583
14.7.4 Sound Absorption 586
14.7.5 Noise Barrier Walls 587
14.7.6 Other Design and Construction Considerations 588

14.8 Closure 589

14.9 References 590

14.10 Problems 592

15 CONSTRUCTION CONSIDERATIONS AND DETAILS 595

15.1 Introduction 595

15.2 Workmanship and Construction Practices 596
15.2.1 Effect of Workmanship on Strength 597

15.2.2 Effect of Workmanship on Water Permeance 598
15.2.3 Preparations in Advance of Laying Masonry 598
15.2.4 Preparation of Mortar Mixes 601
15.2.5 Use of Mortar 602
15.2.6 Laying of Units 605
15.2.7 Reinforcing and Grouting 607
15.2.8 Tolerances 615

15.3 Influence of Weather on Construction Requirements 615
15.3.1 Cold Weather Construction 615
15.3.2 Hot Weather Construction 617
15.3.3 Wet Weather Construction 618
15.3.4 Construction in Windy Weather 619

15.4 Protection of Masonry During Construction 619
15.4.1 Covering and Curing 619
15.4.2 Avoiding Unintended Loads 619
15.4.3 Wind Bracing 620

15.5 Flashing and Dampproof Courses 623
15.5.1 Description 623
15.5.2 Installation of Flashings and Dampproof Courses 624
15.5.3 Effect on Wall Strength 625

15.6 Movement Joints 625
15.6.1 Functions and Types of Movement Joints 625
15.6.2 Spacing, Location and Size Requirements 626
15.6.3 Joint Sealants 629
15.6.4 Construction Details 629

15.7 Connection Details 629

15.8 More Competitive Masonry Construction 632
15.8.1 Robotics in Masonry Construction 632
15.8.2 Increasing Productivity of Masons 633
15.8.3 Dry-Stack Interlocking Mortarless Masonry 633

15.9 Inspection and Quality Control 634
15.9.1 Introduction 634
15.9.2 Quality Assurance and Quality Control 635
15.9.3 Inspection 635

15.10 Closure 637

15.11 References 637

15.12 Problems 639

16 DESIGN OF LOADBEARING SINGLE-STORY MASONRY BUILDINGS 641

16.1 General Introduction 641

16.2 Behavior, Form and Layout 642
16.2.1 Wall Layout Requirements for Stability 642
16.2.2 Wall Layout to Resist Lateral Loads 644
16.2.3 Example 16.1: Lateral Load Distribution for a Rigid Diaphragm Roof System 645
16.2.4 Example 16.2: Lateral Load Distribution for a Nonrigid Roof System 647
16.2.5 Effect of Shear Wall Deflection on Out-of-Plane Wall Behavior 647
16.2.6 Example 16.3: Effect of Top Deflection on Out-of-Plane Bending in Walls 648

16.3 Design Loads 649
16.3.1 Gravity Loads 649
16.3.2 Wind Loading 649
16.3.3 Seismic Loading 650

16.4 Design of Components 650
16.4.1 Design of Walls for Axial Load and Bending 650
16.4.2 Design of Walls for In-Plane Shear and Bending 651
16.4.3 Design Requirements for Roof Diaphragms 652
16.4.4 Example 16.4: Extra Stiffening of the Roof 652
16.4.5 Design of Walls for Hold-Down of Roof Systems 654
16.4.6 Example 16.5: Hold-Down of a Roof 654

16.5 Example Design of Single-Story Building 656
16.5.1 Introduction 656
16.5.2 Description of the Building 656
16.5.3 Design Loads 659
16.5.4 Design of a Typical Wall for Axial Load and Out-of-Plane Bending 661
16.5.5 Design of Other Walls and Walls with Openings for Axial Load and Out of-Plane Bending 667
16.5.6 Design of Walls for Uplift Forces 671
16.5.7 Design of Walls for In-Plane Shear and Bending 671
16.5.8 Required Stiffness of Roof Diaphragm 674

16.5.9 Bearing 674
16.5.10 Other Considerations 675

16.6 Closure 676

16.7 References 676

16.8 Problems 676

17 DESIGN OF MULTI-STORY LOADBEARING MASONRY BUILDINGS 679

17.1 Introduction 679

17.2 Basic Design Concepts 681
17.2.1 Introduction 681
17.2.2 Vertical Load Transfer 681
17.2.3 Lateral Load Transfer 683

17.3 Distribution of Shear and Moment Due to Lateral Load 684
17.3.1 Relative Wall Rigidity for Structural Analysis 684
17.3.2 Choice of Method for Determination of Relative Wall Rigidity 686
17.3.3 Other Factors Affecting the Distribution of Lateral Loads 687

17.4 Torsional Effects 689
17.4.1 Basic Concept 689
17.4.2 Calculation of Torsional Moments 690

17.5 Design Example of Multistory Building 692
17.5.1 Description of the Building 692
17.5.2 Loads 693
17.5.3 Calculation of Lateral Forces 696
17.5.4 Distribution of Lateral Loads to Shear Walls 699
17.5.5 Calculation of Shear Forces and Moments at the Base of the Shear Walls 701
17.5.6 Material Properties 709
17.5.7 Drift Calculations 709
17.5.8 Wall Design 711
17.5.9 Out-of-Plane Loading 711
17.5.10 In-Plane Loading (Shear Walls) 712

17.6 Closure 721

17.7 References 721

17.8 Problems 722

Appendix A : Sources of Information **725**

Appendix B: Design Information Material Properties **731**

Index **737**