

## A Policy on Geometric Design of Highways and Streets

### Table of Contents

|                | <b>Page</b> |
|----------------|-------------|
| Foreword ..... | xliii       |

#### **Chapter Titles**

|  |     |
|--|-----|
| Chapter 1 Highway Functions .....                  | 1   |
| Chapter 2 Design Controls and Criteria .....       | 15  |
| Chapter 3 Elements of Design.....                  | 109 |
| Chapter 4 Cross Section Elements .....             | 305 |
| Chapter 5 Local Roads and Streets.....             | 379 |
| Chapter 6 Collector Roads and Streets.....         | 419 |
| Chapter 7 Rural and Urban Arterials.....           | 443 |
| Chapter 8 Freeways .....                           | 503 |
| Chapter 9 Intersections.....                       | 555 |
| Chapter 10 Grade Separations and Interchanges..... | 743 |

#### **Chapter 1 Highway Functions**

|   |    |
|---|----|
| Systems and Classifications .....                   | 1  |
| The Concept of Functional Classification .....      | 1  |
| Hierarchies of Movements and Components .....       | 1  |
| Functional Relationships.....                       | 4  |
| Access Needs and Controls.....                      | 6  |
| Functional System Characteristics .....             | 7  |
| Definitions of Urban and Rural Areas .....          | 7  |
| Functional Categories .....                         | 8  |
| Functional Systems for Rural Areas .....            | 8  |
| Rural Principal Arterial System .....               | 8  |
| Rural Minor Arterial System.....                    | 9  |
| Rural Collector System .....                        | 9  |
| Rural Local Road System.....                        | 9  |
| Extent of Rural Systems .....                       | 10 |
| Functional Highway Systems in Urbanized Areas.....  | 10 |
| Urban Principal Arterial System .....               | 10 |
| Urban Minor Arterial Street System.....             | 11 |
| Urban Collector Street System .....                 | 12 |
| Urban Local Street System.....                      | 12 |
| Length of Roadway and Travel on Urban Systems ..... | 12 |
| Functional Classification as a Design Type .....    | 13 |
| References .....                                    | 14 |

## Chapter 2

### Design Controls and Criteria

|   |    |
|---|----|
| Introduction .....                            | 15 |
| Design Vehicles .....                         | 15 |
| General Characteristics .....                 | 15 |
| Minimum Turning Paths of Design Vehicles..... | 18 |
| Vehicle Performance.....                      | 43 |
| Vehicular Pollution .....                     | 43 |
| Driver Performance .....                      | 46 |
| Introduction.....                             | 46 |
| Older Drivers .....                           | 47 |
| The Driving Task .....                        | 47 |
| The Guidance Task .....                       | 48 |
| Lane Placement and Road Following.....        | 48 |
| Car Following.....                            | 48 |
| Passing Maneuvers .....                       | 49 |
| Other Guidance Activities .....               | 49 |
| The Information System.....                   | 49 |
| Traffic Control Devices .....                 | 49 |
| The Roadway and Its Environment .....         | 49 |
| Information Handling.....                     | 50 |
| Reaction Time .....                           | 50 |
| Primacy.....                                  | 53 |
| Expectancy .....                              | 53 |
| Driver Error.....                             | 53 |
| Errors Due to Driver Deficiencies .....       | 54 |
| Errors Due to Situation Demands .....         | 56 |
| Speed and Design.....                         | 56 |
| Design Assessment .....                       | 57 |
| Traffic Characteristics .....                 | 58 |
| General Considerations .....                  | 58 |
| Volume.....                                   | 58 |
| Average Daily Traffic.....                    | 58 |
| Peak-Hour Traffic .....                       | 59 |
| Directional Distribution .....                | 62 |
| Composition of Traffic.....                   | 63 |
| Projection of Future Traffic Demands .....    | 65 |
| Speed.....                                    | 66 |
| Operating Speed .....                         | 66 |
| Running Speed.....                            | 67 |
| Design Speed .....                            | 67 |
| Traffic Flow Relationships.....               | 72 |
| Highway Capacity .....                        | 74 |
| General Characteristics .....                 | 74 |
| Application.....                              | 74 |

|   |            |
|---|------------|
| <b>Capacity as a Design Control.....</b>  | <b>75</b>  |
| Design Service Flow Rate Versus Design Volume .....                             | 75         |
| Measures of Congestion.....   | 75         |
| Relation between Congestion and Traffic Flow Rate.....                          | 76         |
| Acceptable Degrees of Congestion .....  | 77         |
| Principles for Acceptable Degrees of Congestion.....                            | 78         |
| Reconciliation of Principles for Acceptable Degrees of Congestion .....         | 80         |
| <b>Factors Other than Traffic Volume That Affect Operating Conditions .....</b> | <b>81</b>  |
| Highway Factors .....   | 81         |
| Alignment.....  | 82         |
| Weaving Sections.....   | 82         |
| Ramp Terminals.....   | 82         |
| Traffic Factors.....  | 83         |
| Peak Hour Factor.....   | 83         |
| <b>Levels of Service .....</b>  | <b>84</b>  |
| <b>Design Service Flow Rates .....</b>  | <b>85</b>  |
| Weaving Sections.....   | 85         |
| Multilane Highways without Access Control.....                                  | 86         |
| Arterial Streets and Urban Highways.....  | 86         |
| Intersections .....   | 88         |
| Pedestrians and Bicycles .....  | 88         |
| <b>Access Control and Access Management.....</b>                                | <b>88</b>  |
| General Conditions .....  | 88         |
| Basic Principles of Access Management .....                                     | 90         |
| Access Classifications.....   | 90         |
| Methods of Controlling Access .....   | 91         |
| Benefits of Controlling Access .....  | 91         |
| <b>The Pedestrian.....</b>  | <b>96</b>  |
| General Considerations.....   | 96         |
| General Characteristics .....   | 96         |
| Walking Speeds .....  | 97         |
| Walkway Capacities .....  | 98         |
| Sidewalks .....   | 98         |
| Intersections .....   | 99         |
| Reducing Pedestrian-Vehicular Conflicts .....                                   | 99         |
| Characteristics of Persons with Disabilities.....                               | 99         |
| Mobility Impairments.....   | 100        |
| Visual Impairments .....  | 100        |
| Developmental Impairments .....   | 100        |
| <b>Bicycle Facilities .....</b>   | <b>100</b> |
| <b>Safety.....</b>  | <b>101</b> |
| <b>Environment.....</b>   | <b>106</b> |
| <b>Economic Analysis.....</b>   | <b>106</b> |
| <b>References.....</b>  | <b>106</b> |

## Chapter 3

### ELEMENTS OF DESIGN

|   |     |
|---|-----|
| Introduction .....  | 109 |
| Sight Distance.....   | 109 |
| General Considerations .....  | 109 |
| Stopping Sight Distance.....  | 110 |
| Brake Reaction Time .....   | 110 |
| Braking Distance .....  | 111 |
| Design Values.....  | 113 |
| Effect of Grade on Stopping .....   | 113 |
| Variation for Trucks .....  | 114 |
| Decision Sight Distance .....   | 115 |
| Passing Sight Distance for Two-Lane Highways.....                             | 118 |
| Criteria for Design.....  | 118 |
| Design Values.....  | 122 |
| Effect of Grade on Passing Sight Distance .....                               | 125 |
| Frequency and Length of Passing Sections .....                                | 125 |
| Sight Distance for Multilane Highways.....                                    | 126 |
| Criteria for Measuring Sight Distance .....                                   | 127 |
| Height of Driver's Eye .....  | 127 |
| Height of Object .....  | 127 |
| Sight Obstructions .....  | 128 |
| Measuring and Recording Sight Distance on Plans.....                          | 128 |
| Horizontal Alignment.....   | 131 |
| Theoretical Considerations.....   | 131 |
| General Considerations .....  | 132 |
| Superelevation .....  | 132 |
| Side Friction Factor .....  | 133 |
| Distribution of $e$ and $f$ over a Range of Curves .....                      | 140 |
| Design Considerations .....   | 143 |
| Normal Cross Slope.....   | 143 |
| Sharpest Curve without Superelevation.....                                    | 144 |
| Maximum Superelevation Rates for Streets and Highways.....                    | 144 |
| Maximum Superelevation for Turning Roadways.....                              | 145 |
| Minimum Radius.....   | 146 |
| Effects of Grades .....   | 148 |
| Design for Low-Speed Urban Streets.....                                       | 148 |
| Side Friction Factors.....  | 148 |
| Superelevation .....  | 149 |
| Sharpest Curve without Superelevation.....                                    | 149 |
| Design for Rural Highways, Urban Freeways, and High-Speed Urban Streets ..... | 153 |
| Side Friction Factors.....  | 153 |
| Superelevation .....  | 153 |
| Procedure for Development of Method 5 Superelevation Distribution .....       | 153 |
| Turning Roadways .....  | 163 |

|   |     |
|---|-----|
| Design Speed.....   | 164 |
| Use of Compound Curves .....  | 164 |
| Design Superelevation Tables.....                                   | 165 |
| Sharpest Curve without Superelevation .....                         | 166 |
| Transition Design Controls.....                                     | 175 |
| General Considerations .....  | 175 |
| Tangent-to-Curve Transition.....                                    | 176 |
| Spiral Curve Transitions.....                                       | 184 |
| Length of Spiral.....   | 185 |
| Compound Curve Transition.....                                      | 192 |
| Methods of Attaining Superelevation.....                            | 192 |
| Design of Smooth Profiles for Traveled Way Edges.....               | 196 |
| Axis of Rotation with a Median .....                                | 197 |
| Minimum Transition Grades .....                                     | 198 |
| Transitions and Compound Curves for Turning Roadways .....          | 199 |
| Length of Spiral for Turning Roadways.....                          | 200 |
| Compound Circular Curves.....                                       | 201 |
| Offtracking.....  | 202 |
| Derivation of Design Values for Widening on Horizontal Curves.....  | 202 |
| Traveled Way Widening on Horizontal Curves.....                     | 208 |
| Design Values for Traveled Way Widening.....                        | 210 |
| Application of Widening on Curves.....                              | 214 |
| Widths for Turning Roadways at Intersections.....                   | 216 |
| Design Values .....   | 219 |
| Widths Outside Traveled Way .....                                   | 222 |
| Sight Distance on Horizontal Curves.....                            | 224 |
| Stopping Sight Distance.....  | 224 |
| Passing Sight Distance .....  | 228 |
| General Controls for Horizontal Alignment .....                     | 229 |
| Vertical Alignment.....   | 231 |
| Terrain .....   | 231 |
| Grades.....   | 231 |
| Vehicle Operating Characteristics on Grades.....                    | 232 |
| Control Grades for Design .....                                     | 233 |
| Critical Lengths of Grade for Design .....                          | 236 |
| Climbing Lanes.....   | 241 |
| Climbing Lanes for Two-Lane Highways.....                           | 241 |
| Climbing Lanes on Freeways and Multilane Highways.....              | 247 |
| Methods for Increasing Passing Opportunities on Two-Lane Roads..... | 250 |
| Passing Lanes.....  | 250 |
| Turnouts .....  | 253 |
| Shoulder Driving .....  | 254 |
| Shoulder Use Sections.....  | 255 |
| Emergency Escape Ramps.....   | 255 |
| General .....   | 255 |
| Need and Location for Emergency Escape Ramps .....                  | 257 |

|   |     |
|---|-----|
| Types of Emergency Escape Ramps.....                        | 258 |
| Design Considerations.....                                  | 260 |
| Brake Check Areas .....                                     | 265 |
| Maintenance .....   | 265 |
| Vertical Curves .....                                       | 265 |
| General Considerations.....                                 | 265 |
| Crest Vertical Curves.....                                  | 267 |
| Sag Vertical Curves.....                                    | 273 |
| Sight Distance at Undercrossings .....                      | 277 |
| General Controls for Vertical Alignment .....               | 279 |
| Combinations of Horizontal and Vertical Alignment.....      | 280 |
| General Considerations .....                                | 280 |
| General Design Controls .....                               | 281 |
| Alignment Coordination in Design .....                      | 282 |
| Other Elements Affecting Geometric Design.....              | 283 |
| Drainage.....   | 286 |
| Erosion Control and Landscape Development.....              | 288 |
| Rest Areas, Information Centers, and Scenic Overlooks ..... | 289 |
| Lighting.....   | 290 |
| Utilities.....  | 292 |
| General .....   | 292 |
| Urban.....  | 293 |
| Rural.....  | 293 |
| Traffic Control Devices.....                                | 294 |
| Signing and Marking .....                                   | 294 |
| Traffic Signals.....  | 295 |
| Noise Barriers .....  | 296 |
| Fencing.....  | 296 |
| Maintenance of Traffic through Construction Areas.....      | 297 |
| References .....  | 299 |

## Chapter 4 Cross Section Elements

|                               |     |
|-------------------------------|-----|
| General .....                 | 305 |
| Pavement .....                | 305 |
| Surface Type .....            | 305 |
| Cross Slope .....             | 305 |
| Skid Resistance .....         | 310 |
| Lane Widths.....              | 311 |
| Shoulders.....                | 312 |
| General Characteristics ..... | 312 |
| Width of Shoulders .....      | 314 |
| Shoulder Cross Sections.....  | 315 |
| Shoulder Stability.....       | 317 |
| Shoulder Contrast.....        | 318 |
| Turnouts .....                | 318 |

|  |     |
|--|-----|
| Horizontal Clearance to Obstructions ..... | 318 |
| Curbs .....                                | 319 |
| General Considerations .....               | 319 |
| Curb Configurations .....                  | 320 |
| Curb Placement .....                       | 322 |
| Drainage Channels and Sideslopes .....     | 323 |
| General Considerations .....               | 323 |
| Drainage Channels .....                    | 323 |
| Sideslopes .....                           | 326 |
| Illustrative Outer Cross Sections .....    | 329 |
| Normal Crown Sections .....                | 329 |
| Superelevated Sections .....               | 330 |
| Traffic Barriers .....                     | 331 |
| General Considerations .....               | 331 |
| Longitudinal Barriers .....                | 333 |
| Roadside Barriers .....                    | 333 |
| Median Barriers .....                      | 334 |
| Bridge Railings .....                      | 335 |
| Crash Cushions .....                       | 336 |
| Medians .....                              | 337 |
| Frontage Roads .....                       | 339 |
| Outer Separations .....                    | 342 |
| Noise Control .....                        | 344 |
| General Considerations .....               | 344 |
| General Design Procedures .....            | 345 |
| Noise Reduction Designs .....              | 346 |
| Roadside Control .....                     | 348 |
| General Considerations .....               | 348 |
| Driveways .....                            | 348 |
| Mailboxes .....                            | 349 |
| Tunnels .....                              | 351 |
| General Considerations .....               | 351 |
| Types of Tunnels .....                     | 352 |
| General Design Considerations .....        | 352 |
| Tunnel Sections .....                      | 353 |
| Examples of Tunnels .....                  | 355 |
| Pedestrian Facilities .....                | 357 |
| Sidewalks .....                            | 357 |
| Grade-Separated Pedestrian Crossings ..... | 359 |
| Sidewalk Curb Ramps .....                  | 361 |
| Bicycle Facilities .....                   | 367 |
| Bus Turnouts .....                         | 367 |
| Freeways .....                             | 368 |
| Arterials .....                            | 368 |
| Park-and-Ride Facilities .....             | 370 |
| Location .....                             | 370 |

|                         |     |
|-------------------------|-----|
| Design.....             | 371 |
| On-Street Parking ..... | 373 |
| References .....        | 376 |

## **Chapter 5 Local Roads and Streets**

|  |     |
|--|-----|
| Introduction.....                                  | 379 |
| Local Rural Roads .....                            | 380 |
| General Design Considerations.....                 | 380 |
| Design Traffic Volume.....                         | 380 |
| Design Speed.....                                  | 380 |
| Sight Distance.....                                | 380 |
| Grades.....  | 382 |
| Alignment.....                                     | 382 |
| Cross Slope.....                                   | 383 |
| Superelevation.....                                | 383 |
| Number of Lanes .....                              | 383 |
| Width of Traveled Way, Shoulder, and Roadway ..... | 383 |
| Structures.....                                    | 385 |
| Bridges to Remain in Place .....                   | 385 |
| Vertical Clearance .....                           | 385 |
| Right-of-Way Width.....                            | 387 |
| Foreslopes.....                                    | 387 |
| Horizontal Clearance to Obstructions.....          | 387 |
| Curbs .....  | 388 |
| Intersection Design.....                           | 388 |
| Railroad-Highway Grade Crossings .....             | 388 |
| Traffic Control Devices .....                      | 389 |
| Bicycle Facilities .....                           | 389 |
| Erosion Control .....                              | 389 |
| Local Urban Streets .....                          | 389 |
| General Design Considerations.....                 | 389 |
| Design Traffic Volume.....                         | 390 |
| Design Speed.....                                  | 390 |
| Sight Distance.....                                | 391 |
| Grades.....  | 391 |
| Alignment.....                                     | 391 |
| Cross Slope.....                                   | 392 |
| Superelevation.....                                | 392 |
| Number of Lanes .....                              | 392 |
| Width of Traveled Way .....                        | 393 |
| Parking Lanes .....                                | 393 |
| Median.....  | 393 |
| Curbs .....  | 394 |
| Drainage .....                                     | 394 |
| Cul-de-Sacs and Turnarounds .....                  | 394 |

|   |            |
|---|------------|
| Alleys .....  | 396        |
| Sidewalks .....                                     | 396        |
| Sidewalk Curb Ramps.....                            | 398        |
| Driveways .....                                     | 398        |
| Roadway Widths for Bridges .....                    | 399        |
| Horizontal Clearance to Obstructions .....          | 399        |
| Vertical Clearance.....                             | 399        |
| Border Area.....                                    | 399        |
| Right-of-Way Width .....                            | 400        |
| Provision for Utilities.....                        | 400        |
| Intersection Design.....                            | 400        |
| Railroad-Highway Grade Crossings.....               | 401        |
| Street and Roadway Lighting .....                   | 402        |
| Traffic Control Devices.....                        | 403        |
| Erosion Control .....                               | 403        |
| Landscaping .....                                   | 403        |
| Bicycle Facilities .....                            | 404        |
| <b>Special-Purpose Roads.....</b>                   | <b>404</b> |
| <b>Introduction.....</b>                            | <b>404</b> |
| <b>Recreational Roads.....</b>                      | <b>404</b> |
| General Considerations .....                        | 404        |
| Design Speed.....                                   | 405        |
| Design Vehicle .....                                | 406        |
| Sight Distance .....                                | 406        |
| Passing Sight Distance .....                        | 406        |
| Grades .....  | 407        |
| Vertical Alignment.....                             | 409        |
| Horizontal Alignment.....                           | 409        |
| Number of Lanes.....                                | 411        |
| Widths of Traveled Way, Shoulder, and Roadway ..... | 411        |
| Cross Slope.....                                    | 411        |
| Clear Recovery Area.....                            | 413        |
| Roadside Slopes .....                               | 413        |
| Roadside Barriers .....                             | 413        |
| Signing and Marking .....                           | 414        |
| Structures.....                                     | 414        |
| <b>Resource Recovery Roads .....</b>                | <b>414</b> |
| <b>Very Low-Volume Local Roads (ADT ≤ 400).....</b> | <b>416</b> |
| <b>References.....</b>                              | <b>416</b> |

## **Chapter 6** **Collector Roads and Streets**

|   |            |
|---|------------|
| <b>Introduction.....</b>                  | <b>419</b> |
| <b>Rural Collectors.....</b>              | <b>420</b> |
| <b>General Design Considerations.....</b> | <b>420</b> |
| <b>Design Traffic Volumes.....</b>        | <b>420</b> |

|   |     |
|---|-----|
| Design Speed.....                         | 420 |
| Sight Distance.....                       | 421 |
| Grades.....                               | 421 |
| Alignment.....                            | 421 |
| Cross Slope.....                          | 421 |
| Superelevation.....                       | 424 |
| Number of Lanes .....                     | 424 |
| Width of Roadway.....                     | 424 |
| Foreslopes.....                           | 424 |
| Structures.....                           | 426 |
| Bridges to Remain in Place .....          | 426 |
| Vertical Clearance .....                  | 427 |
| Horizontal Clearance to Obstructions..... | 427 |
| Right-of-Way Width.....                   | 428 |
| Intersection Design.....                  | 428 |
| Railroad-Highway Grade Crossings.....     | 428 |
| Traffic Control Devices .....             | 429 |
| Erosion Control .....                     | 429 |
| Urban Collectors.....                     | 429 |
| General Design Considerations.....        | 429 |
| Design Traffic Volumes .....              | 430 |
| Design Speed.....                         | 430 |
| Sight Distance.....                       | 431 |
| Grades.....                               | 431 |
| Alignment.....                            | 431 |
| Cross Slope.....                          | 431 |
| Superelevation.....                       | 431 |
| Number of Lanes .....                     | 433 |
| Width of Roadway.....                     | 433 |
| Parking Lanes .....                       | 433 |
| Medians .....                             | 434 |
| Curbs .....                               | 435 |
| Drainage .....                            | 435 |
| Sidewalks.....                            | 436 |
| Driveways.....                            | 436 |
| Roadway Widths for Bridges.....           | 436 |
| Vertical Clearance .....                  | 436 |
| Horizontal Clearance to Obstructions..... | 437 |
| Right-of-Way Width.....                   | 437 |
| Provision for Utilities .....             | 437 |
| Border Area.....                          | 438 |
| Intersection Design.....                  | 438 |
| Railroad-Highway Grade Crossings.....     | 439 |
| Street and Roadway Lighting .....         | 439 |
| Traffic Control Devices .....             | 439 |
| Erosion Control .....                     | 440 |

|                   |     |
|-------------------|-----|
| Landscaping ..... | 440 |
| References.....   | 440 |

**Chapter 7**  
**Rural and Urban Arterials**

|  |     |
|--|-----|
| Introduction .....                                       | 443 |
| Rural Arterials .....                                    | 443 |
| General Characteristics .....                            | 443 |
| General Design Considerations.....                       | 444 |
| Design Speed.....  | 444 |
| Design Traffic Volume.....                               | 444 |
| Levels of Service.....                                   | 444 |
| Sight Distance .....                                     | 445 |
| Alignment.....   | 445 |
| Grades .....   | 446 |
| Number of Lanes.....                                     | 446 |
| Superelevation.....                                      | 446 |
| Cross Slope.....   | 446 |
| Vertical Clearances .....                                | 447 |
| Structures.....  | 447 |
| Traffic Control Devices.....                             | 447 |
| Erosion Control .....                                    | 447 |
| Widths .....   | 448 |
| Horizontal Clearance to Obstructions .....               | 448 |
| Cross Section and Right-of-Way.....                      | 449 |
| Provision for Passing.....                               | 449 |
| Ultimate Development of Four-Lane Divided Arterials..... | 450 |
| Multilane Undivided Arterials .....                      | 453 |
| Divided Arterials .....                                  | 454 |
| General Features.....                                    | 454 |
| Lane Widths .....  | 455 |
| Cross Slope.....   | 455 |
| Shoulders.....   | 455 |
| Median Barrier Clearance .....                           | 456 |
| Medians.....   | 456 |
| Alignment and Profile .....                              | 457 |
| Climbing Lanes on Multilane Arterials.....               | 458 |
| Superelevated Cross Sections.....                        | 459 |
| Cross Section and Right-of-Way Widths .....              | 462 |
| Sections with Widely Separated Roadways .....            | 465 |
| Intersections .....                                      | 466 |
| Access Management.....                                   | 467 |
| Bikeways and Pedestrian Facilities .....                 | 467 |
| Bus Turnouts .....                                       | 468 |
| Railroad-Highway Crossings .....                         | 468 |
| Rest Areas .....   | 468 |

|  |            |
|--|------------|
| <b>Urban Arterials .....</b>   | <b>469</b> |
| <b>General Characteristics .....</b>                                   | <b>469</b> |
| <b>General Design Considerations.....</b>                              | <b>470</b> |
| <b>Design Speed.....</b>   | <b>470</b> |
| <b>Design Traffic Volume.....</b>                                      | <b>470</b> |
| <b>Levels of Service .....</b>   | <b>470</b> |
| <b>Sight Distance.....</b>   | <b>471</b> |
| <b>Alignment.....</b>  | <b>471</b> |
| <b>Grades.....</b>   | <b>471</b> |
| <b>Superelevation.....</b>   | <b>471</b> |
| <b>Cross Slope.....</b>  | <b>472</b> |
| <b>Vertical Clearances.....</b>  | <b>472</b> |
| <b>Lane Widths.....</b>  | <b>472</b> |
| <b>Curbs and Shoulders.....</b>  | <b>473</b> |
| <b>Number of Lanes .....</b>   | <b>473</b> |
| <b>Width of Roadway.....</b>   | <b>474</b> |
| <b>Medians .....</b>   | <b>474</b> |
| <b>Drainage .....</b>  | <b>478</b> |
| <b>Parking Lanes .....</b>   | <b>478</b> |
| <b>Borders and Sidewalks .....</b>                                     | <b>479</b> |
| <b>Railroad-Highway Crossings.....</b>                                 | <b>480</b> |
| <b>Roadway Width for Bridges.....</b>                                  | <b>481</b> |
| <b>Bridges to Remain in Place .....</b>                                | <b>481</b> |
| <b>Horizontal Clearance to Obstructions.....</b>                       | <b>481</b> |
| <b>Right-of-Way Width.....</b>   | <b>482</b> |
| <b>Traffic Barriers .....</b>  | <b>482</b> |
| <b>Access Management .....</b>   | <b>482</b> |
| <b>General Features .....</b>  | <b>482</b> |
| <b>Access Control by Statute.....</b>                                  | <b>483</b> |
| <b>Access Control by Zoning .....</b>                                  | <b>483</b> |
| <b>Access Control Through Driveway Regulations .....</b>               | <b>483</b> |
| <b>Access Control through Geometric Design .....</b>                   | <b>484</b> |
| <b>Pedestrian Facilities .....</b>                                     | <b>484</b> |
| <b>Provision for Utilities.....</b>                                    | <b>486</b> |
| <b>Intersection Design .....</b>                                       | <b>486</b> |
| <b>Operational Control and Regulations.....</b>                        | <b>486</b> |
| <b>Traffic Control Devices .....</b>                                   | <b>486</b> |
| <b>Regulatory Measures .....</b>                                       | <b>488</b> |
| <b>Operational and Control Measures for Right-Turn Maneuvers .....</b> | <b>488</b> |
| <b>Operational and Control Measures for Left-Turn Maneuvers .....</b>  | <b>488</b> |
| <b>Regulation of Curb Parking .....</b>                                | <b>491</b> |
| <b>Directional Lane Usage .....</b>                                    | <b>491</b> |
| <b>Frontage Roads and Outer Separations .....</b>                      | <b>494</b> |
| <b>Grade Separations and Interchanges .....</b>                        | <b>494</b> |
| <b>Erosion Control.....</b>  | <b>496</b> |
| <b>Lighting.....</b>   | <b>496</b> |

|                                 |     |
|---------------------------------|-----|
| Bikeways .....                  | 496 |
| Public Transit Facilities ..... | 496 |
| Location of Bus Stops .....     | 497 |
| Bus Turnouts .....              | 500 |
| Reserved Bus Lanes .....        | 500 |
| Traffic Control Measures .....  | 501 |
| References.....                 | 502 |

## **Chapter 8 Freeways**

|  |     |
|--|-----|
| Introduction.....                                    | 503 |
| General Design Considerations .....                  | 503 |
| Design Speed .....                                   | 503 |
| Design Traffic Volumes.....                          | 504 |
| Levels of Service .....                              | 504 |
| Pavement and Shoulders.....                          | 504 |
| Curbs.....   | 505 |
| Superelevation .....                                 | 505 |
| Grades...  | 505 |
| Structures.....                                      | 506 |
| Vertical Clearance.....                              | 506 |
| Horizontal Clearance to Obstructions.....            | 507 |
| Ramps and Terminals .....                            | 508 |
| Outer Separations, Borders, and Frontage Roads ..... | 508 |
| Rural Freeways.....                                  | 508 |
| Alignment and Profile.....                           | 509 |
| Medians .....  | 509 |
| Sideslopes .....                                     | 512 |
| Frontage Roads .....                                 | 512 |
| Urban Freeways.....                                  | 513 |
| General Design Characteristics .....                 | 513 |
| Medians .....  | 513 |
| Depressed Freeways .....                             | 513 |
| General Characteristics .....                        | 513 |
| Slopes and Walls .....                               | 514 |
| Typical Cross Section.....                           | 515 |
| Restricted Cross Section.....                        | 517 |
| Walled Cross Section .....                           | 517 |
| Examples of Depressed Freeways.....                  | 518 |
| Elevated Freeways .....                              | 520 |
| General Characteristics .....                        | 520 |
| Medians.....   | 521 |
| Ramps and Terminals.....                             | 521 |
| Frontage Roads.....                                  | 522 |
| Clearance to Building Line.....                      | 522 |
| Typical Cross Section.....                           | 522 |

|   |     |
|---|-----|
| Viaduct Freeways without Ramps .....                                | 523 |
| Two-Way Viaduct Freeways with Ramps .....                           | 524 |
| Freeways on Earth Embankment.....                                   | 525 |
| Examples of Elevated Freeways.....                                  | 526 |
| Ground-Level Freeways.....  | 527 |
| General Characteristics.....  | 527 |
| Typical Cross Section.....  | 528 |
| Restricted Cross Section.....                                       | 529 |
| Example of a Ground-Level Freeway.....                              | 530 |
| Combination-Type Freeways.....                                      | 530 |
| General Characteristics.....  | 530 |
| Profile Control.....  | 531 |
| Cross-Section Control.....  | 533 |
| Examples of Combination-Type Freeways.....                          | 533 |
| Special Freeway Designs .....                                       | 537 |
| Reverse-Flow Roadways .....   | 537 |
| Dual-Divided Freeways .....   | 540 |
| Freeways with Collector-Distributor Roads .....                     | 543 |
| Accommodation of Transit and High-Occupancy Vehicle Facilities..... | 543 |
| General Considerations.....   | 543 |
| Buses .....   | 545 |
| Rail Transit .....  | 550 |
| References .....  | 554 |

## **Chapter 9 Intersections**

|   |     |
|---|-----|
| Introduction .....                                | 555 |
| General Design Considerations and Objectives..... | 555 |
| Types and Examples of Intersections .....         | 558 |
| General Considerations .....                      | 558 |
| Three-Leg Intersections .....                     | 559 |
| Basic Types of Intersections.....                 | 559 |
| Channelized Three-Leg Intersections .....         | 564 |
| Four-Leg Intersections .....                      | 565 |
| Basic Types .....                                 | 565 |
| Channelized Four-Leg Intersections.....           | 566 |
| Multileg Intersections .....                      | 571 |
| Modem Roundabouts .....                           | 574 |
| Capacity Analysis .....                           | 579 |
| Alignment and Profile .....                       | 579 |
| General Considerations .....                      | 579 |
| Alignment .....                                   | 580 |
| Profile.....                                      | 582 |
| Types of Turning Roadways.....                    | 583 |
| General .....                                     | 583 |
| Minimum Edge-of-Traveled-Way Designs.....         | 583 |

|  |     |
|--|-----|
| Design for Specific Conditions (Right-Angle Turns) .....         | 592 |
| Passenger Vehicles.....  | 593 |
| Single-Unit Trucks and City Transit Buses.....                   | 609 |
| Semitrailer Combination Trucks .....                             | 610 |
| Oblique-Angle Turns.....   | 610 |
| Effect of Curb Radii on Turning Paths.....                       | 611 |
| Effect of Curb Radii on Pedestrians .....                        | 614 |
| Corner Radii Into Local Urban Streets.....                       | 621 |
| Islands .....  | 621 |
| General Characteristics .....                                    | 621 |
| Channelizing Islands.....  | 623 |
| Divisional Islands .....   | 625 |
| Refuge Islands .....   | 626 |
| Island Size and Designation.....                                 | 627 |
| Island Delineation and Approach Treatment .....                  | 628 |
| Turning Roadways with Corner Islands .....                       | 634 |
| Right-Angle Turns with Corner Islands.....                       | 634 |
| Oblique-Angle Turns with Corner Islands.....                     | 637 |
| Free-Flow Turning Roadways at Intersections.....                 | 639 |
| Superelevation for Turning Roadways at Intersections.....        | 639 |
| General Design Guidelines .....                                  | 639 |
| Superelevation Runoff .....                                      | 642 |
| Development of Superelevation at Turning Roadway Terminals ..... | 642 |
| General Procedure .....  | 643 |
| Turn-Lane Cross-Slope Rollover .....                             | 648 |
| Superelevation Transition and Gradeline Control.....             | 648 |
| Traffic Control Devices.....                                     | 649 |
| Intersection Sight Distance.....                                 | 650 |
| General Considerations.....                                      | 650 |
| Sight Triangles.....   | 651 |
| Approach Sight Triangles.....                                    | 651 |
| Departure Sight Triangles .....                                  | 653 |
| Identification of Sight Obstructions within Sight Triangles..... | 653 |
| Intersection Control .....                                       | 654 |
| Case A—Intersections with No Control.....                        | 654 |
| Case B—Intersections with Stop Control on the Minor Road .....   | 657 |
| Case B1—Left Turn from the Minor Road .....                      | 657 |
| Case B2—Right Turn from the Minor Road.....                      | 663 |
| Case B3—Crossing Maneuver from the Minor Road .....              | 663 |
| Case C—Intersections with Yield Control on the Minor Road .....  | 666 |
| Case C1—Crossing Maneuver from the Minor Road .....              | 666 |
| Case C2—Left- and Right-Turn Maneuvers .....                     | 671 |
| Case D—Intersections with Traffic Signal Control.....            | 671 |
| Case E—Intersections with All-Way Stop Control.....              | 674 |
| Case F—Left Turns from the Major Road .....                      | 674 |
| Effect of Skew .....   | 677 |

|  |            |
|--|------------|
| <b>Stopping Sight Distance at Intersections for Turning Roadways .....</b> | <b>678</b> |
| General Considerations .....   | 678        |
| Vertical Control.....  | 678        |
| Horizontal Control .....   | 678        |
| <b>Design to Discourage Wrong-Way Entry .....</b>                          | <b>679</b> |
| <b>General Intersection Types.....</b>                                     | <b>682</b> |
| General Design Considerations.....   | 682        |
| Channelization.....  | 686        |
| Speed-Change Lanes at Intersections .....                                  | 688        |
| Median Openings.....   | 689        |
| General Design Considerations.....   | 689        |
| Control Radii for Minimum Turning Paths.....                               | 690        |
| Shape of Median End.....   | 697        |
| Minimum Length of Median Opening .....                                     | 697        |
| Median Openings Based on Control Radii for Design Vehicles .....           | 698        |
| Passenger Vehicles .....   | 698        |
| Single-Unit Trucks or Buses.....   | 699        |
| Semitrailer Combinations.....  | 700        |
| Effect of Skew.....  | 700        |
| Above-Minimum Designs for Direct Left Turns .....                          | 702        |
| <b>Indirect Left Turns and U-turns.....</b>                                | <b>705</b> |
| General Design Considerations.....   | 705        |
| Indirect Left Turn or Indirect U-Turn—Using Local Streets .....            | 707        |
| Indirect Left Turn or Indirect U-Turn—Wide Medians .....                   | 708        |
| Location and Design of U-Turn Median Openings.....                         | 709        |
| Flush or Traversable Medians .....   | 712        |
| <b>Auxiliary Lanes .....</b>   | <b>713</b> |
| General Design Considerations.....   | 713        |
| Deceleration Length.....   | 714        |
| Storage Length.....  | 714        |
| Taper .....  | 715        |
| Median Left-Turn Lanes .....   | 716        |
| Median End Treatment.....  | 722        |
| Offset Left-Turn Lanes .....   | 723        |
| Simultaneous Left Turns .....  | 723        |
| Intersection Design Elements with Frontage Roads .....                     | 725        |
| Bicycles at Intersections .....  | 728        |
| Wheelchair Ramps at Intersections.....                                     | 728        |
| Lighting at Intersections .....  | 729        |
| Driveways.....   | 729        |
| Railroad-Highway Grade Crossings .....                                     | 731        |
| Horizontal Alignment .....   | 731        |
| Vertical Alignment.....  | 731        |
| General .....  | 732        |
| References .....   | 739        |

## Chapter 10

### Grade Separations and Interchanges

|   |     |
|---|-----|
| Introduction and General Types of Interchanges.....                   | 743 |
| Warrants for Interchanges and Grade Separations .....                 | 745 |
| Adaptability of Highway Grade Separations and Interchanges.....       | 747 |
| Traffic and Operation.....  | 747 |
| Site Conditions.....  | 748 |
| Type of Highway and Intersecting Facility.....                        | 748 |
| Access Separations and Control on the Crossroad at Interchanges ..... | 749 |
| Safety .....  | 751 |
| Stage Development.....  | 751 |
| Economic Factors .....  | 751 |
| Initial Costs .....   | 751 |
| Maintenance Costs .....   | 751 |
| Vehicular Operating Costs .....                                       | 752 |
| Grade Separation Structures.....                                      | 752 |
| Introduction.....   | 752 |
| Types of Separation Structures .....                                  | 752 |
| Overpass versus Underpass Roadways .....                              | 758 |
| General Design Considerations.....                                    | 758 |
| Structure Widths.....   | 760 |
| Underpass Roadways.....   | 761 |
| Lateral Clearances.....   | 761 |
| Vertical Clearance .....  | 763 |
| Overpass Roadways.....  | 764 |
| Bridge Railings.....  | 764 |
| Lateral Clearances .....  | 766 |
| Medians .....   | 766 |
| Longitudinal Distance to Attain Grade Separation.....                 | 767 |
| Grade Separations without Ramps.....                                  | 769 |
| Interchanges .....  | 770 |
| General Considerations.....   | 770 |
| Three-Leg Designs.....  | 771 |
| Four-Leg Designs .....  | 776 |
| Ramps in One Quadrant .....   | 776 |
| Diamond Interchanges.....   | 778 |
| Single-Point Urban Interchanges.....                                  | 783 |
| Cloverleafs .....   | 788 |
| Directional and Semidirectional Interchanges.....                     | 794 |
| Other Interchange Configurations.....                                 | 799 |
| Offset Interchanges .....   | 799 |
| Combination Interchanges.....   | 799 |
| General Design Considerations.....                                    | 802 |
| Determination of Interchange Configuration .....                      | 802 |
| Approaches to the Structure .....                                     | 805 |

|   |            |
|---|------------|
| <b>Interchange Spacing .....</b>                            | <b>807</b> |
| Uniformity of Interchange Patterns .....                    | 807        |
| Route Continuity .....                                      | 807        |
| Overlapping Routes.....                                     | 809        |
| Signing and Marking .....                                   | 809        |
| Basic Number of Lanes .....                                 | 810        |
| Coordination of Lane Balance and Basic Number of Lanes..... | 811        |
| Auxiliary Lanes .....                                       | 814        |
| Lane Reductions .....                                       | 818        |
| Weaving Sections .....                                      | 819        |
| Collector-Distributor Roads .....                           | 819        |
| Two-Exit versus Single-Exit Interchange Design.....         | 820        |
| Wrong-Way Entrances .....                                   | 821        |
| <b>Ramps .....</b>  | <b>823</b> |
| Types and Examples.....                                     | 823        |
| General Ramp Design Considerations.....                     | 825        |
| Ramp Traveled-Way Widths .....                              | 838        |
| Ramp Terminals .....  | 840        |
| Single-Lane Free-Flow Terminals, Entrances .....            | 845        |
| Single-Lane Free-Flow Terminals, Exits.....                 | 849        |
| <b>Other Interchange Design Features .....</b>              | <b>863</b> |
| Testing for Ease of Operation.....                          | 863        |
| Pedestrians.....  | 864        |
| Ramp Metering.....  | 865        |
| Grading and Landscape Development.....                      | 865        |
| Models.....   | 867        |
| <b>References .....</b>                                     | <b>867</b> |

## LIST OF EXHIBITS

| <b>Exhibit<br/>Number</b> | <b>Exhibit Caption</b>  | <b>Page</b> |
|---------------------------|---|-------------|
| 1-1                       | Hierarchy of Movement .....   | 2           |
| 1-2                       | Channelization of Trips .....   | 4           |
| 1-3                       | Schematic Illustration of a Functionally Classified Rural Highway Network .....                   | 5           |
| 1-4                       | Schematic Illustration of a Portion of a Suburban Street Network .....                            | 6           |
| 1-5                       | Relationship of Functionally Classified Systems in Serving Traffic Mobility and Land Access ..... | 7           |
| 1-6                       | Typical Distribution of Rural Functional Systems .....  | 10          |
| 1-7                       | Typical Distribution of Urban Functional Systems .....  | 12          |
| 2-1                       | Design Vehicle Dimensions .....   | 16–17       |
| 2-2                       | Minimum Turning Radii of Design Vehicles .....  | 19–20       |
| 2-3                       | Minimum Turning Path for Passenger Car (P) Design Vehicle .....                                   | 21          |
| 2-4                       | Minimum Turning Path for Single-Unit (SU) Truck Design Vehicle .....                              | 22          |
| 2-5                       | Minimum Turning Path for Intercity Bus (BUS-12 [BUS-40]) Design Vehicle .....                     | 23          |
| 2-6                       | Minimum Turning Path for Intercity Bus (BUS-14 [BUS-45]) Design Vehicle .....                     | 24          |
| 2-7                       | Minimum Turning Path for City Transit Bus (CITY-BUS) Design Vehicle .....                         | 25          |
| 2-8                       | Minimum Turning Path for Conventional School Bus (S-BUS-11 [S-BUS-36]) Design Vehicle .....       | 26          |
| 2-9                       | Minimum Turning Path for Large School Bus (S-BUS-12 [S-BUS-40]) Design Vehicle .....              | 27          |
| 2-10                      | Minimum Turning Path for Articulated Bus (A-BUS) Design Vehicle .....                             | 28          |
| 2-11                      | Turning Characteristics of a Typical Tractor-Semitrailer Combination Truck .....                  | 29          |
| 2-12                      | Lengths of Commonly Used Truck Tractors .....   | 30          |
| 2-13                      | Minimum Turning Path for Intermediate Semitrailer (WB-12 [WB-40]) Design Vehicle .....            | 31          |
| 2-14                      | Minimum Turning Path for Intermediate Semitrailer (WB-15 [WB-50]) Design Vehicle .....            | 32          |
| 2-15                      | Minimum Turning Path for Interstate Semitrailer (WB-19 [WB-62]) Design Vehicle .....              | 33          |
| 2-16                      | Minimum Turning Path for Interstate Semitrailer (WB-20 [WB-65 and WB-67]) Design Vehicle .....    | 34          |
| 2-17                      | Minimum Turning Path for Double-Trailer Combination (WB-20D [WB-67D]) Design Vehicle .....        | 35          |
| 2-18                      | Minimum Turning Path for Triple-Trailer Combination (WB-30T [WB-100T]) Design Vehicle .....       | 36          |
| 2-19                      | Minimum Turning Path for Turnpike-Double Combination (WB-33D [WB-109D]) Design Vehicle .....      | 37          |
| 2-20                      | Minimum Turning Path for Motor Home (MH) Design Vehicle .....                                     | 38          |
| 2-21                      | Minimum Turning Path for Passenger Car and Camper Trailer (P/T) Design Vehicle .....              | 39          |
| 2-22                      | Minimum Turning Path for Passenger Car and Boat Trailer (P/B) Design Vehicle .....                | 40          |
| 2-23                      | Minimum Turning Path for Motor Home and Boat Trailer (MH/B) Design Vehicle .....                  | 41          |
| 2-24                      | Acceleration of Passenger Cars, Level Conditions .....  | 44          |

| Exhibit<br>Number | Exhibit Caption  | Page    |
|-------------------|--|---------|
| 2-25              | Deceleration Distances for Passenger Vehicles Approaching Intersections.....                         | 45      |
| 2-26              | Median Driver Reaction Time to Expected and Unexpected Information .....                             | 51      |
| 2-27              | 85th-Percentile Driver Reaction Time to Expected and Unexpected Information .....                    | 52      |
| 2-28              | Relation between Peak-Hour and Average Daily Traffic Volumes<br>on Rural Arterials .....             | 60      |
| 2-29              | Corresponding Design Speeds in Metric and US Customary Units .....                                   | 70      |
| 2-30              | Generalized Speed-Volume-Density Relationships.....  | 73      |
| 2-31              | General Definitions of Levels of Service .....   | 84      |
| 2-32              | Guidelines for Selection of Design Levels of Service.....  | 85      |
| 2-33              | Weaving Sections .....   | 87      |
| 2-34              | Simple and Multiple Weaving Sections .....   | 87      |
| 2-35              | Estimated Crash Rates by Type of Median—Urban and Suburban Areas .....                               | 93      |
| 2-36              | Estimated Crash Rates by Type of Median—Rural Areas .....  | 94      |
| 2-37              | Estimated Crash Rates by Unsignalized and Signalized Access Density—Urban<br>and Suburban Areas..... | 95      |
| 3-1               | Stopping Sight Distance .....  | 112     |
| 3-2               | Stopping Sight Distance on Grades .....  | 115     |
| 3-3               | Decision Sight Distance .....  | 116     |
| 3-4               | Elements of Passing Sight Distance for Two-Lane Highways .....                                       | 119     |
| 3-5               | Elements of Safe Passing Sight Distance for Design of Two-Lane Highways.....                         | 120     |
| 3-6               | Total Passing Sight Distance and Its Components—Two-Lane Highways.....                               | 123     |
| 3-7               | Passing Sight Distance for Design of Two-Lane Highways.....  | 124     |
| 3-8               | Scaling and Recording Sight Distances on Plans .....   | 129     |
| 3-9               | Geometry for Ball-Bank Indicator.....  | 134     |
| 3-10              | Side Friction Factors for High-Speed Streets and Highways .....                                      | 137     |
| 3-11              | Side Friction Factors for Low-Speed Streets and Highways.....  | 138     |
| 3-12              | Side Friction Factors Assumed for Design.....  | 139     |
| 3-13              | Methods of Distributing Superelevation and Side Friction .....                                       | 141     |
| 3-14              | Average Running Speeds .....   | 143     |
| 3-15              | Minimum Radius Using Limiting Values of $e$ and $f$ .....  | 147     |
| 3-16              | Minimum Radii and Superelevation for Low-Speed Urban Streets .....                                   | 150–151 |
| 3-17              | Superelevation, Radius, and Design Speed for Low-Speed Urban Street Design.....                      | 152     |
| 3-18              | Method 5 Procedure for Development of the Finalized $e$ Distribution.....                            | 154     |
| 3-19              | Design Superelevation Rates for Maximum Superelevation Rate of 4 Percent.....                        | 155     |
| 3-20              | Design Superelevation Rates for Maximum Superelevation Rate of 6 Percent.....                        | 156     |
| 3-21              | Design Superelevation Rates for Maximum Superelevation Rate of 8 Percent.....                        | 157     |
| 3-22              | Design Superelevation Rates for Maximum Superelevation Rate of 10 Percent.....                       | 158     |
| 3-23              | Design Superelevation Rates for Maximum Superelevation Rate of 12 Percent.....                       | 159     |
| 3-24              | Lengths of Circular Arcs for Different Compound Curve Radii .....                                    | 165     |
| 3-25              | Minimum Radii for Design Superelevation Rates, Design Speeds,<br>and $e_{max} = 4\%$ .....           | 167     |
| 3-26              | Minimum Radii for Design Superelevation Rates, Design Speeds,<br>and $e_{max} = 6\%$ .....           | 168     |

| Exhibit<br>Number | Exhibit Caption   | Page    |
|-------------------|---|---------|
| 3-27              | Minimum Radii for Design Superelevation Rates, Design Speeds, and $e_{max} = 8\%$ .....   | 169–170 |
| 3-28              | Minimum Radii for Design Superelevation Rates, Design Speeds, and $e_{max} = 10\%$ .....  | 171–172 |
| 3-29              | Minimum Radii for Design Superelevation Rates, Design Speeds, and $e_{max} = 12\%$ .....  | 173–174 |
| 3-30              | Maximum Relative Gradients .....  | 177     |
| 3-31              | Adjustment Factor for Number of Lanes Rotated .....   | 178     |
| 3-32              | Superelevation Runoff $L_r$ (m) (ft) for Horizontal Curves.....   | 180–181 |
| 3-33              | Runoff Locations that Minimize the Vehicle's Lateral Motion .....   | 183     |
| 3-34              | Limiting Superelevation Rates .....   | 184     |
| 3-35              | Transition Spirals .....  | 186     |
| 3-36              | Maximum Radius for Use of a Spiral Curve Transition.....  | 187     |
| 3-37              | Desirable Length of Spiral Curve Transition .....   | 189     |
| 3-38              | Superelevation Rates Associated with Large Relative Gradients.....  | 190     |
| 3-39              | Tangent Runout Length for Spiral Curve Transition Design .....  | 192     |
| 3-40              | Diagrammatic Profiles Showing Methods of Attaining Superelevation for a Curve to the Right.....   | 194–195 |
| 3-41              | Minimum Lengths of Spiral for Intersection Curves.....  | 200     |
| 3-42              | Length of Circular Arc for a Compound Intersection Curve When Followed by a Curve of One-Half Radius or Preceded by a Curve of Double Radius..... | 202     |
| 3-43              | Track Width for Widening of Traveled Way on Curves.....   | 204     |
| 3-44              | Front Overhang for Widening of Traveled Way on Curves.....  | 206     |
| 3-45              | Extra Width Allowance for Difficulty of Driving on Traveled Way on Curves .....   | 207     |
| 3-46              | Widening Components on Open Highway Curves (Two-Lane Highways, One-Way or Two-Way) .....  | 209     |
| 3-47              | Calculated and Design Values for Traveled Way Widening on Open Highway Curves (Two-Lane Highways, One-Way or Two-Way) .....                       | 211–212 |
| 3-48              | Adjustments for Traveled Way Widening Values on Open Highway Curves (Two-Lane Highways, One-Way or Two-Way) .....                                 | 213     |
| 3-49              | Derivation of Turning Roadway Widths on Curves at Intersections .....   | 215     |
| 3-50              | Derived Pavement Widths for Turning Roadways for Different Design Vehicles .....  | 217–218 |
| 3-51              | Design Widths of Pavements for Turning Roadways .....   | 220     |
| 3-52              | Range of Usable Shoulder Widths or Equivalent Lateral Clearances Outside of Turning Roadways, Not on Structure .....                              | 224     |
| 3-53              | Design Controls for Stopping Sight Distance on Horizontal Curves .....  | 225–226 |
| 3-54              | Diagram Illustrating Components for Determining Horizontal Sight Distance .....   | 227     |
| 3-55              | Speed-Distance Curves for a Typical Heavy Truck of 120 kg/kW [200 lb/hp] for Deceleration on Upgrades .....                                       | 228     |
| 3-56              | Speed-Distance Curves for Acceleration of a Typical Heavy Truck of 120 kg/kW [200 lb/hp] on Upgrades and Downgrades .....                         | 235     |
| 3-57              | Speed-Distance Curves for a Typical Recreational Vehicle on the Selected Upgrades .....   | 237     |
| 3-58              | Crash Involvement Rate of Trucks for Which Running Speeds Are Reduced below Average Running Speed of All Traffic.....                             | 238     |

| Exhibit<br>Number | Exhibit Caption   | Page    |
|-------------------|---|---------|
| 3-59              | Critical Lengths of Grade for Design, Assumed Typical Heavy Truck of 120 kg/kW [200 lb/hp], Entering Speed = 110 km/h [70 mph]..... | 242     |
| 3-60              | Critical Lengths of Grade Using an Approach Speed of 90 km/h [55 mph] for Typical Recreational Vehicle .....                        | 243     |
| 3-61              | Climbing Lanes on Two-Lane Highways.....  | 244     |
| 3-62              | Climbing Lane on Freeways and Multilane Highways.....   | 250     |
| 3-63              | Passing Lanes Section on Two-Lane Roads.....  | 252     |
| 3-64              | Recommended Lengths of Turnouts Including Taper.....  | 254     |
| 3-65              | Forces Acting on a Vehicle in Motion.....   | 256     |
| 3-66              | Rolling Resistance of Roadway Surfacing Materials .....   | 257     |
| 3-67              | Basic Types of Emergency Escape Ramps.....  | 260     |
| 3-68              | Typical Emergency Escape Ramp.....  | 264     |
| 3-69              | Types of Vertical Curves.....   | 266     |
| 3-70              | Parameters Considered in Determining the Length of a Crest Vertical Curve to Provide Sight Distance .....                           | 268     |
| 3-71              | Design Controls for Crest Vertical Curves—Open Road Conditions.....   | 271     |
| 3-72              | Design Controls for Stopping Sight Distance and for Crest and Sag Vertical Curves ...   | 272     |
| 3-73              | Design Controls for Crest Vertical Curves Based on Passing Sight Distance.....  | 272     |
| 3-74              | Design Controls for Sag Vertical Curves—Open Road Conditions.....   | 275     |
| 3-75              | Design Controls for Sag Vertical Curves .....   | 277     |
| 3-76              | Sight Distance at Undercrossings .....  | 278     |
| 3-77              | Alignment and Profile Relationships in Roadway Design .....   | 284–286 |
| 4-1               | Typical Cross Section, Normal Crown.....  | 306     |
| 4-2               | Typical Cross Section, Superelevated .....  | 307     |
| 4-3               | Roadway Sections for Divided Highway (Basic Cross Slope Arrangements) .....   | 308     |
| 4-4               | Normal Traveled-Way Cross Slope.....  | 310     |
| 4-5               | Graded and Usable Shoulders .....   | 313     |
| 4-6               | Typical Highway Curbs.....  | 321     |
| 4-7               | Designation of Roadside Regions.....  | 326     |
| 4-8               | Typical Frontage Road Arrangements.....   | 340     |
| 4-9               | Frontage Roads, Irregular Pattern.....  | 341     |
| 4-10              | One-Way Frontage Roads, Entrance and Exit Ramps .....   | 342     |
| 4-11              | Two-Way Frontage Roads, Entrance and Exit Ramps .....   | 342     |
| 4-12              | Frontage Road in Business Area with Narrow Outer Separation .....   | 343     |
| 4-13              | Typical Outer Separations .....   | 344     |
| 4-14              | Noise-Abatement Criteria for Various Land Uses.....   | 346     |
| 4-15              | Effects of Depressing the Highway .....   | 347     |
| 4-16              | Effects of Elevating the Highway.....   | 348     |
| 4-17              | Typical Two-Lane Tunnel Sections .....  | 354     |
| 4-18              | Diagrammatic Tunnel Sections .....  | 356     |
| 4-19              | Entrance to a Freeway Tunnel .....  | 356     |
| 4-20              | Interior of a Three-Lane One-Way Tunnel.....  | 357     |
| 4-21              | Typical Pedestrian Overpasses on Major Highways .....   | 362     |

| Exhibit<br>Number | Exhibit Caption  | Page |
|-------------------|--|------|
| 4-22              | Mid-Block Sidewalk Curb Ramp Details.....  | 364  |
| 4-23              | Sidewalk Curb Ramp at Middle of Radius—Discouraged Where Pedestrian and/or Vehicular Volumes Are Moderate to High..... | 365  |
| 4-24              | Sidewalk Curb Ramp at End of Curb Radius.....  | 365  |
| 4-25              | Sidewalk Curb Ramp at Mid-Block.....   | 366  |
| 4-26              | Median and Island Openings.....  | 366  |
| 4-27              | Bus Turnouts.....  | 369  |
| 4-28              | Midblock Bus Turnout.....  | 370  |
| 4-29              | Sawtooth Bus Loading Area .....  | 372  |
| 4-30              | Typical Park-and-Ride Facility .....   | 374  |
| 4-31              | Parking Lane Transition at Intersection .....  | 375  |
| 5-1               | Minimum Design Speeds for Local Rural Roads.....   | 381  |
| 5-2               | Design Controls for Stopping Sight Distance and for Crest and Sag Vertical Curves.....                                 | 381  |
| 5-3               | Design Controls for Crest Vertical Curves Based on Passing Sight Distance.....   | 382  |
| 5-4               | Maximum Grades for Local Rural Roads .....   | 382  |
| 5-5               | Minimum Width of Traveled Way and Shoulders .....  | 384  |
| 5-6               | Minimum Clear Roadway Widths and Design Loadings for New and Reconstructed Bridges.....                                | 386  |
| 5-7               | Minimum Structural Capacities and Minimum Roadway Widths for Bridges to Remain in Place .....                          | 386  |
| 5-8               | Types of Cul-de-Sac and Dead-End Streets .....   | 395  |
| 5-9               | Alley Turnarounds .....  | 397  |
| 5-10              | Actual Curb Radius and Effective Radius for Right-Turn Movements at Intersections .....                                | 401  |
| 5-11              | Minimum Illumination Levels .....  | 402  |
| 5-12              | Potential Road Network .....   | 405  |
| 5-13              | Design Controls for Stopping Sight Distance and for Crest and Sag Vertical Curves—Recreational Roads .....             | 407  |
| 5-14              | Design Controls for Passing Sight Distance for Crest Vertical Curves—Recreational Roads .....                          | 408  |
| 5-15              | Maximum Grades for Recreational Roads .....  | 409  |
| 5-16              | Minimum-Radius Horizontal Curve for Gravel Surface .....   | 410  |
| 5-17              | Turnout Design .....   | 412  |
| 5-18              | Widths of Traveled Way and Shoulders—Recreational Roads.....   | 412  |
| 5-19              | Design Speeds for Resource Recovery and Local Service Roads.....   | 415  |
| 6-1               | Minimum Design Speeds for Rural Collectors .....   | 422  |
| 6-2               | Design Controls for Stopping Sight Distance and for Crest and Sag Vertical Curves.....                                 | 422  |
| 6-3               | Design Controls for Crest Vertical Curves Based on Passing Sight Distance.....   | 423  |
| 6-4               | Maximum Grades for Rural Collectors .....  | 423  |
| 6-5               | Minimum Width of Traveled Way and Shoulders .....  | 425  |
| 6-6               | Minimum Roadway Widths and Design Loadings for New and Reconstructed Bridges.....                                      | 426  |

| Exhibit<br>Number | Exhibit Caption   | Page |
|-------------------|---|------|
| 6-7               | Structural Capacities and Minimum Roadway Widths for Bridges to Remain in Place.....              | 427  |
| 6-8               | Maximum Grades for Urban Collectors .....   | 432  |
| 7-1               | Minimum Sight Distances for Arterials.....  | 445  |
| 7-2               | Maximum Grades for Rural Arterials.....   | 426  |
| 7-3               | Minimum Width of Traveled Way and Usable Shoulder for Rural Arterials.....                        | 448  |
| 7-4               | Climbing Lane on Two-Lane Rural Arterial.....   | 450  |
| 7-5               | Two-Lane Arterial Cross Section with Ultimate Development to a Four-Lane Arterial.....            | 453  |
| 7-6               | Methods of Attaining Superelevation on Divided Arterials .....                                    | 461  |
| 7-7               | Typical Medians on Divided Arterials .....  | 462  |
| 7-8               | Cross Sectional Arrangements on Divided Arterials.....  | 464  |
| 7-9               | Cross Sectional Arrangements on Divided Arterials.....  | 465  |
| 7-10              | Maximum Grades for Urban Arterials.....   | 472  |
| 7-11              | Continuous Two-Way Left-Turn Lane .....   | 476  |
| 7-12              | Parking Turnouts in Downtown District.....  | 479  |
| 7-13              | Arterial Street in Residential Area.....  | 480  |
| 7-14              | Divided Arterial Street with Parking Lanes.....   | 481  |
| 7-15              | Urban Arterial with Dual Left-Turn Lanes.....   | 490  |
| 7-16              | Divided Arterial Street with Two-Way Frontage Road.....   | 495  |
| 7-17              | Bus Stops at Special Locations Adjacent to Certain Arterials.....                                 | 499  |
| 7-18              | Exclusive Bus Lane .....  | 501  |
| 8-1               | Maximum Grades for Rural and Urban Freeways.....  | 506  |
| 8-2               | Typical Ground-Level Rural Freeway.....   | 510  |
| 8-3               | Typical Rural Medians .....   | 511  |
| 8-4               | Typical Cross Section for Depressed Freeways .....  | 516  |
| 8-5               | Restricted Cross Sections for Depressed Freeways.....   | 516  |
| 8-6               | Cross Sections with Retaining Walls on Depressed Freeways without Ramps.....                      | 518  |
| 8-7               | Depressed Freeway.....  | 519  |
| 8-8               | Depressed Freeway.....  | 520  |
| 8-9               | Typical Cross Sections for Elevated Freeways on Structures without Ramps .....                    | 524  |
| 8-10              | Typical and Restricted Cross Sections for Elevated Freeways on Structure with Frontage Roads..... | 525  |
| 8-11              | Typical and Restricted Cross Sections for Elevated Freeways on Embankment.....                    | 526  |
| 8-12              | Viaduct Freeway.....  | 527  |
| 8-13              | Two-Level Viaduct Freeway .....   | 528  |
| 8-14              | Typical Cross Sections for Ground-Level Freeways.....   | 529  |
| 8-15              | Restricted Cross Sections for Ground-Level Freeways.....  | 530  |
| 8-16              | Profile Control—Rolling Terrain Combination-Type Freeway .....                                    | 531  |
| 8-17              | Profile Control—Flat Terrain Combination-Type Freeway .....                                       | 532  |
| 8-18              | Cross-Section Control—Combination-Type Freeway.....   | 534  |
| 8-19              | Combination-Type Freeway.....   | 535  |
| 8-20              | Four-Level Cantilevered Freeway.....  | 536  |

| <b>Exhibit<br/>Number</b> | <b>Exhibit Caption</b>  | <b>Page</b> |
|---------------------------|---|-------------|
| 8-21                      | Typical Cross Sections for Reverse-Flow Operation .....                           | 537         |
| 8-22                      | Typical Reverse Roadway Terminals.....  | 539         |
| 8-23                      | Reverse-Flow Freeway.....   | 540         |
| 8-24                      | Typical Dual-Divided Freeway .....  | 542         |
| 8-25                      | Dual-Divided Freeway with a 4-3-3-4 Roadway Arrangement .....                     | 542         |
| 8-26                      | Bus Roadway Located between a Freeway and a Parallel Frontage Road.....           | 544         |
| 8-27                      | Bus Stops at Freeway Level .....  | 547         |
| 8-28                      | Bus Stops at Freeway-Level Diamond Interchange .....                              | 548         |
| 8-29                      | Freeway-Level Bus Stop at Cloverleaf Interchange.....                             | 548         |
| 8-30                      | Bus Stops at Street Level on Diamond Interchange .....                            | 549         |
| 8-31                      | Joint Freeway-Transit Right-of-Way .....  | 551         |
| 8-32                      | Typical Sections with Rail Transit in Freeway Median .....                        | 552         |
| 8-33                      | Example of Transit Station Layout .....   | 553         |
| 8-34                      | Depressed Freeway with Rail Rapid Transit in the Median .....                     | 554         |
| 9-1                       | Physical and Functional Intersection Area .....                                   | 557         |
| 9-2                       | Elements of the Functional Area of an Intersection .....                          | 557         |
| 9-3                       | Channelized High-Type "T" Intersections .....                                     | 559         |
| 9-4                       | Three-Leg Rural Intersection, Channelized "T" .....                               | 559         |
| 9-5                       | "T" Intersections .....   | 560         |
| 9-6                       | Channelized "T" Intersections .....   | 561         |
| 9-7                       | "T" Intersections .....   | 562         |
| 9-8                       | Channelized "T" Intersections .....   | 563         |
| 9-9                       | Unchannelized Four-Leg Intersections, Plain and Flared .....                      | 566         |
| 9-10                      | Channelized Four-Leg Intersections .....  | 567         |
| 9-11                      | Channelized Four-Leg Intersections .....  | 569         |
| 9-12                      | Four-Leg Intersections (Channelized High-Type) .....                              | 570         |
| 9-13                      | Four-Leg Intersections (Channelized High-Type) .....                              | 572         |
| 9-14                      | Realigning Multi-Leg Intersections .....  | 573         |
| 9-15                      | Geometric Elements of a Single-Lane Modern Roundabout.....                        | 575         |
| 9-16                      | Typical Modern Roundabout .....   | 576         |
| 9-17                      | Roundabout with Entry Flaring in Two Quadrants .....                              | 578         |
| 9-18                      | Realignment Variations at Intersections.....                                      | 580         |
| 9-19                      | Edge-of-Traveled-Way Designs for Turns at Intersections.....                      | 584–587     |
| 9-20                      | Edge of Traveled Way for Turns at Intersections .....                             | 588–591     |
| 9-21                      | Minimum Traveled Way (Passenger Vehicles).....                                    | 594–595     |
| 9-22                      | Minimum Traveled Way Designs (Single-Unit Trucks and City Transit Buses).....     | 596–597     |
| 9-23                      | Minimum Edge-of-Traveled-Way Designs (WB-12 [WB-40]<br>Design Vehicle Path).....  | 598–599     |
| 9-24                      | Minimum Edge-of-Traveled-Way Designs (WB-15 [WB-50])<br>Design Vehicle Path)..... | 600         |
| 9-25                      | Minimum Edge-of-Traveled-Way Designs (WB-15 [WB-50])<br>Design Vehicle Path)..... | 601–602     |

| Exhibit<br>Number | Exhibit Caption  | Page    |
|-------------------|--|---------|
| 9-26              | Minimum Edge-of-Traveled-Way Designs (WB-19 [WB-62])<br>Design Vehicle Path).....                        | 603–604 |
| 9-27              | Minimum Edge-of-Traveled-Way Designs (WB-30T [WB-100T])<br>Design Vehicle Path).....                     | 605–606 |
| 9-28              | Minimum Edge-of-Traveled-Way Designs (WB-33D [WB-109D])<br>Design Vehicle Path).....                     | 607–608 |
| 9-29              | Effect of Curbed Radii on Right Turning Paths of Various<br>Design Vehicles.....                         | 612     |
| 9-30              | Effect of Curbed Radii on Right Turning Paths of Various<br>Design Vehicles.....                         | 613     |
| 9-31              | Cross Street Width Occupied by Turning Vehicle for Various Angles<br>of Intersection and Curb Radii..... | 615–616 |
| 9-32              | Effect of Curbed Radii and Parking on Right-Turning Paths.....   | 617–618 |
| 9-33              | Variations in Length of Crosswalk with Different Curb Radii<br>and Width of Borders .....                | 620     |
| 9-34              | Corner Setbacks with Different Curb Radii and Width of Borders .....                                     | 620     |
| 9-35              | General Types and Shapes of Islands and Medians.....   | 624     |
| 9-36              | Alignment for Addition of Divisional Islands at Intersections.....                                       | 626     |
| 9-37              | Details of Corner Island Designs for Turning Roadways (Urban Location) .....                             | 630     |
| 9-38              | Details of Corner Island Designs for Turning Roadways (Rural Cross<br>Section on Approach).....          | 631     |
| 9-39              | Nose Ramping at Approach End of Median or Corner Island.....   | 632     |
| 9-40              | Details of Divisional Island Design.....   | 633     |
| 9-41              | Minimum Turning Roadway Designs with Corner Islands at Urban Locations.....                              | 635–636 |
| 9-42              | Typical Designs for Turning Roadways.....  | 638     |
| 9-43              | Use of Simple and Compound Curves at Free-Flow Turning Roadways.....                                     | 640–641 |
| 9-44              | Effective Maximum Relative Gradients .....   | 643     |
| 9-45              | Development of Superelevation at Turning Roadway Terminals.....  | 644     |
| 9-46              | Development of Superelevation at Turning Roadway Terminals.....  | 645     |
| 9-47              | Development of Superelevation at Turning Roadway Terminals.....  | 646     |
| 9-48              | Development of Superelevation at Turning Roadway Terminals.....  | 647     |
| 9-49              | Maximum Algebraic Difference in Cross Slope at Turning<br>Roadway Terminals.....                         | 648     |
| 9-50              | Intersection Sight Triangles.....  | 652     |
| 9-51              | Length of Sight Triangle Leg—Case A—No Traffic Control .....   | 655     |
| 9-52              | Length of Sight Triangle Leg—Case A—No Traffic Control .....   | 656     |
| 9-53              | Adjustment Factors for Sight Distance Based on Approach Grade .....                                      | 658     |
| 9-54              | Time Gap for Case B1—Left Turn from Stop.....  | 660     |
| 9-55              | Design Intersection Sight Distance—Case B1—Left Turn from Stop .....                                     | 661     |
| 9-56              | Intersection Sight Distance—Case B1—Left Turn from Stop .....  | 662     |
| 9-57              | Time Gap for Case B2—Right Turn from Stop and<br>Case B3—Crossing Maneuver .....                         | 664     |
| 9-58              | Design Intersection Sight Distance—Case B2—Right Turn from Stop<br>and Case B3—Crossing Maneuver .....   | 664     |

| Exhibit<br>Number | Exhibit Caption   | Page    |
|-------------------|---|---------|
| 9-59              | Intersection Sight Distance—Case B2—Right Turn from Stop and Case B3—Crossing Maneuver .....                        | 665     |
| 9-60              | Case C1—Crossing Maneuvers from Yield-Controlled Approaches—Length of Minor Road Leg and Travel Times.....          | 668     |
| 9-61              | Length of Sight Triangle Leg along Major Road—Case C1—Crossing Maneuver at Yield Controlled Intersections.....      | 669     |
| 9-62              | Length of Sight Triangle Leg along Major Road for Passenger Cars—Case C1—Crossing Maneuver.....                     | 670     |
| 9-63              | Time Gap for Case C2—Left or Right Turn .....   | 672     |
| 9-64              | Design Intersection Sight Distance—Case C2—Left or Right Turn at Yield Controlled Intersections.....                | 672     |
| 9-65              | Intersection Sight Distance—Case C2—Yield Controlled Left or Right Turn .....                                       | 673     |
| 9-66              | Time Gap for Case F—Left Turns from the Major Road.....   | 674     |
| 9-67              | Intersection Sight Distance—Case F—Left Turn from Major Road.....   | 675     |
| 9-68              | Intersection Sight Distance—Case F—Left Turn from Major Road.....   | 676     |
| 9-69              | Sight Triangles at Skewed Intersections .....   | 677     |
| 9-70              | Stopping Sight Distance for Turning Roadways.....   | 678     |
| 9-71              | Two-Lane Crossroad Designs to Discourage Wrong-Way Entry .....  | 680     |
| 9-72              | Divided Crossroad Designs to Discourage Wrong-Way Entry .....   | 681     |
| 9-73              | General Types of Intersections.....   | 683     |
| 9-74              | General Types of Intersections.....   | 684     |
| 9-75              | Guide for Left-Turn Lanes on Two-Lane Highways .....  | 685     |
| 9-76              | Control Radii at Intersections for 90-Degree Left Turns .....   | 691–692 |
| 9-77              | Minimum Design of Median Openings (P Design Vehicle, Control Radius of 12 m [40 ft]).....                           | 693     |
| 9-78              | Minimum Design of Median Openings (P Design Vehicle, Control Radius of 12 m [40 ft]).....                           | 694     |
| 9-79              | Minimum Design of Median Openings (SU Design Vehicle, Control Radius of 15 m [50 ft]).....                          | 694     |
| 9-80              | Minimum Design of Median Openings (WB-12 [WB-40] Design Vehicle, Control Radius of 23 m [75 ft]).....               | 695     |
| 9-81              | Minimum Design of Median Openings (SU Design Vehicle, Control Radius of 15 m [50 ft]).....                          | 695     |
| 9-82              | Minimum Design of Median Openings (WB-12 [WB-40] Design Vehicle, Control Radius of 23 m [75 ft]).....               | 696     |
| 9-83              | Minimum Design of Median Openings (WB-12 [WB-40] Design Vehicle, Control Radius of 30 m [100 ft]).....              | 696     |
| 9-84              | Minimum Design of Median Openings (Effect of Skew) .....  | 700     |
| 9-85              | Design Controls for Minimum Median Openings.....  | 701     |
| 9-86              | Effect of Skew on Minimum Design for Median Openings (Typical Values Based on Control Radius of 15 m [50 ft]) ..... | 703     |
| 9-87              | Above-Minimum Design of Median Openings (Typical Bullet-Nose Ends).....   | 704     |
| 9-88              | Jughandle-Type Ramp with Crossroad .....  | 706     |
| 9-89              | At-Grade Loop (Surface Loop) with Crossroad.....  | 706     |

| Exhibit<br>Number | Exhibit Caption   | Page    |
|-------------------|---|---------|
| 9-90              | Special Indirect Left-Turn Designs for Traffic Leaving Highway with Narrow Median .....   | 707     |
| 9-91              | Indirect Left Turn through a Crossover.....   | 709     |
| 9-92              | Minimum Designs for U-Turns .....   | 711     |
| 9-93              | Special Indirect U-Turn with Narrow Medians .....   | 712     |
| 9-94              | Flush or Traversable Median Lane Markings.....  | 713     |
| 9-95              | Taper Design for Auxiliary Lanes .....  | 717–718 |
| 9-96              | 4.2- to 5.4-m [14- to 18-ft] Median Width Left-Turn Design .....  | 719–720 |
| 9-97              | Median Left-Turn Design for Median Width in Excess of 5.4 m [18 ft].....  | 721     |
| 9-98              | Parallel and Tapered Offset Left-Turn Lane .....  | 724     |
| 9-99              | Four-Leg Intersection Providing Simultaneous Left Turns .....   | 725     |
| 9-100             | Intersections with Frontage Roads .....   | 727     |
| 9-101             | Cumulative Frequency Distribution of Impact Lengths .....   | 730     |
| 9-102             | Railroad-Highway Grade Crossing .....   | 732     |
| 9-103             | Case A: Moving Vehicle to Safely Cross or Stop at Railroad Crossing.....  | 735     |
| 9-104             | Required Design Sight Distance for Combination of Highway and Train Vehicle Speeds; 20-m [65-ft] Truck Crossing a Single Set of Tracks at 90 Degrees..... | 737     |
| 9-105             | Case B: Departure of Vehicle from Stopped Position to Cross Single Railroad Track.....  | 738     |
| 10-1              | Interchange Configurations .....  | 744     |
| 10-2              | Factors Influencing Length of Access Control along an Interchange Crossroad.....  | 750     |
| 10-3              | Typical Grade Separation Structures with Closed Abutments .....   | 756     |
| 10-4              | Typical Grade Separation Structure with Open-End Span .....   | 757     |
| 10-5              | Multilevel Grade Separation Structures.....   | 758     |
| 10-6              | Lateral Clearances for Major Roadway Underpasses.....   | 762     |
| 10-7              | Typical Overpass Structures.....  | 765     |
| 10-8              | Flat Terrain, Distance Required to Effect Grade Separation.....   | 768–769 |
| 10-9              | Three-Leg Interchanges with Single Structures .....   | 772     |
| 10-10             | Three-Leg Interchanges with Multiple Structures.....  | 773     |
| 10-11             | Three-Leg Interchange (T-Type or Trumpet).....  | 774     |
| 10-12             | Three-Leg Interchange Semidirectional Design.....   | 774     |
| 10-13             | Directional Three-Leg Interchange of a River Crossing.....  | 775     |
| 10-14             | Trumpet Freeway-to-Freeway Interchange .....  | 776     |
| 10-15             | Four-Leg Interchanges, Ramps in One Quadrant .....  | 777     |
| 10-16             | Diamond Interchanges, Conventional Arrangements.....  | 779     |
| 10-17             | Diamond Interchange Arrangements to Reduce Traffic Conflicts .....  | 779     |
| 10-18             | Diamond Interchanges with Additional Structures.....  | 780     |
| 10-19             | Freeway with a Three-Level Diamond Interchange .....  | 781     |
| 10-20             | Existing Four-Leg Interchange with Diamond Stage Construction.....  | 782     |
| 10-21             | X-Pattern Ramp Arrangement .....  | 782     |
| 10-22             | Underpass Single Point Urban Interchange.....   | 784     |
| 10-23             | An SPUI Underpass in Restricted Right-of-Way .....  | 784     |

| Exhibit<br>Number | Exhibit Caption   | Page |
|-------------------|---|------|
| 10-24             | Overpass Layout with a Frontage Road and a Separate U-Turn Movement .....                           | 786  |
| 10-25             | Underpass SPUI and Overpass SPUI .....  | 787  |
| 10-26             | Four-Leg Interchange, Full Cloverleaf with Collector-Distributor Roads .....                        | 789  |
| 10-27             | Cloverleaf Interchange with Collector-Distributor Roads.....  | 790  |
| 10-28             | Schematic of Partial Cloverleaf Ramp Arrangements, Exit and Entrance Turns .....                    | 791  |
| 10-29             | Four-Leg Interchange (Partial or Two-Quadrant Cloverleaf with Ramps before Main Structure) .....    | 792  |
| 10-30             | Four-Leg Interchange (Partial or Two-Quadrant Cloverleaf with Ramps beyond Main Structure).....     | 793  |
| 10-31             | Semidirect Interchanges with Weaving.....   | 795  |
| 10-32             | Semidirect Interchanges with No Weaving.....  | 795  |
| 10-33             | Semidirectional and Directional Interchanges—Multilevel Structures .....                            | 796  |
| 10-34             | Directional Interchange, Two Semidirect Connections.....  | 797  |
| 10-35             | Four-Level Directional Interchange .....  | 797  |
| 10-36             | Four-Level Directional Interchange .....  | 798  |
| 10-37             | Semidirectional Interchange with Loops.....   | 798  |
| 10-38             | Offset Interchange via Ramp Highway .....   | 799  |
| 10-39             | Four-Leg Interchange, Diamond with a Semidirect Connection.....                                     | 800  |
| 10-40             | Four-Leg Interchange, Cloverleaf with a Semidirect Connection.....                                  | 801  |
| 10-41             | Complex Interchange Arrangement .....   | 801  |
| 10-42             | Freeway with a Three-Level Cloverleaf Interchange .....   | 802  |
| 10-43             | Adaptability of Interchanges on Freeways as Related to Types of Intersecting Facilities .....       | 804  |
| 10-44             | Widening for Divisional Island at Interchanges.....   | 806  |
| 10-45             | Arrangement of Exits Between Successive Interchanges.....   | 808  |
| 10-46             | Interchange Forms to Maintain Route Continuity .....  | 808  |
| 10-47             | Collector-Distributor Road on Major-Minor Roadway Overlap .....                                     | 810  |
| 10-48             | Schematic of Basic Number of Lanes .....  | 811  |
| 10-49             | Typical Examples of Lane Balance.....   | 812  |
| 10-50             | Coordination of Lane Balance and Basic Number of Lanes .....  | 813  |
| 10-51             | Alternative Methods of Dropping Auxiliary Lanes.....  | 815  |
| 10-52             | Coordination of Lane Balance and Basic Number of Lanes through Application of Auxiliary Lanes ..... | 816  |
| 10-53             | Auxiliary Lane Dropped at Two-Lane Exit.....  | 817  |
| 10-54             | Interchange Forms with One and Two Exits.....   | 822  |
| 10-55             | General Types of Ramps.....   | 824  |
| 10-56             | Guide Values for Ramp Design Speed as Related to Highway Design Speed.....                          | 826  |
| 10-57             | Ramp Shapes.....  | 827  |
| 10-58             | Development of Superelevation at Free-Flow Ramp Terminals .....                                     | 831  |
| 10-59             | Typical Gore Area Characteristics .....   | 833  |
| 10-60             | Typical Gore Details .....  | 834  |
| 10-61             | Minimum Length of Taper Beyond an Offset Nose.....  | 835  |
| 10-62             | Traveled-Way Narrowing on Entrance Ramps .....  | 835  |

| <b>Exhibit<br/>Number</b> | <b>Exhibit Caption</b>  | <b>Page</b> |
|---------------------------|---|-------------|
| 10-63                     | Gore Area, Single-Lane Exit .....   | 836         |
| 10-64                     | Gore Area, Major Fork .....   | 836         |
| 10-65                     | Gore Area, Two-Lane Exit.....   | 837         |
| 10-66                     | Entrance Terminal .....   | 837         |
| 10-67                     | Design Widths for Turning Roadways .....  | 839         |
| 10-68                     | Recommended Minimum Ramp Terminal Spacing .....   | 844         |
| 10-69                     | Typical Single-Lane Entrance Ramps .....  | 845         |
| 10-70                     | Minimum Acceleration Lengths for Entrance Terminals with Flat<br>Grades of Two Percent or Less..... | 847         |
| 10-71                     | Speed Change Lane Adjustment Factors as a Function of Grade.....                                    | 848         |
| 10-72                     | Exit Ramps—Single Lane .....  | 850         |
| 10-73                     | Minimum Deceleration Lengths for Exit Terminals with Flat Grades<br>of Two Percent or Less.....     | 851         |
| 10-74                     | Layout of Taper-Type Terminals on Curves .....  | 853–854     |
| 10-75                     | Parallel-Type Ramp Terminals on Curves .....  | 855         |
| 10-76                     | Typical Two-Lane Entrance Ramps .....   | 858         |
| 10-77                     | Two-Lane Exit Terminals.....  | 859         |
| 10-78                     | Major Forks .....   | 861         |
| 10-79                     | Branch Connections .....  | 862         |
| 10-80                     | Diagram of Freeway Operational Problem and Solution.....  | 864         |