TABLE OF CONTENTS

1. INTRODUCTION

1.1 Definition of an Ordinary Standard Bridge 1-1

1.2 Types of Components Addressed in the SDC 1-2

1.3 Bridge Systems 1-2

1.4 Local and Global Behavior 1-3

2. DEMANDS ON STRUCTURE COMPONENTS

2.1 Ground Motion Representation 2-1

2.1.1 Spectral Acceleration 2-1

2.1.2 Horizontal Ground Motion 2-1

2.1.3 Vertical Ground Motion 2-2

2.1.4 Vertical/Horizontal Load Combination 2-2

2.1.5 Damping 2-2

2.2 Displacement Demand 2-3

2.2.1 Estimated Displacement 2-3

2.2.2 Global Structure Displacement and Local Member Displacement 2-4

2.2.3 Displacement Ductility Demand 2-4

2.2.4 Target Displacement Ductility Demand 2-4

2.3 Force Demand 2-8

2.3.1 Moment Demand 2-8

2.3.2 Shear Demand 2-8

2.3.2.1 Column Shear Demand 2-8

2.3.2.2 Pier Wall Shear Demand 2-8

2.3.3 Shear Demand for Capacity Protected Members 2-8

3. CAPACITIES OF STRUCTURE COMPONENTS

3.1 Displacement Capacity of Ductile Concrete Members 3-1

3.1.1 Ductile Member Definition 3-1

3.1.2 Distinction Between Local Member Capacity & Global Structure System Capacity 3-1

3.1.3 Local Member Displacement Capacity 3-1

3.1.4 Local Member Displacement Ductility Capacity 3-3

3.1.4.1 Minimum Local Displacement Ductility Capacity 3-3

3.2 Material Properties for Concrete Components 3-5

3.2.1 Expected Material Properties 3-5

3.2.2 Nonlinear Reinforcing Steel Models for Ductile Reinforced Concrete Members 3-5

3.2.3 Reinforcing Steel A706/A706M (Grade 60/Grade 400) 3-5

3.2.4 Nonlinear Prestressing Steel Model 3-6

3.2.5 Nonlinear Concrete Models for Ductile Reinforced Concrete Members 3-8

3.2.6 Normal Weight Portland Cement Concrete Properties 3-8

3.2.7 Other Material Properties 3-9

3.3 Plastic Moment Capacity for Ductile Concrete Members 3-9

3.3.1 Moment Curvature (M-ϕ) Analysis 3-9

3.4 Requirements for Capacity Protected Components 3-10

3.5 Minimum Lateral Strength 3-10

3.6 Seismic Shear Design for Ductile Concrete Members 3-11

3.6.1 Nominal Shear Capacity 3-11

3.6.2 Concrete Shear Capacity 3-11

3.6.3 Shear Reinforcement Capacity 3-12

3.6.4 *Deleted* 3-12

3.6.5 Maximum and Minimum Shear Reinforcement Requirements for Columns 3-13

3.6.5.1 Maximum Shear Reinforcement 3-13

3.6.5.2 Minimum Shear Reinforcement 3-13

3.6.5.3 Minimum Vertical Reinforcement in Interlocking Portion 3-13

3.6.6 Shear Capacity of Pier Walls 3-13

3.6.6.1 Shear Capacity in the Weak Direction 3-13

3.6.6.2 Shear Capacity in the Strong Direction 3-13

3.6.7 Shear Capacity of Capacity Protected Members 3-14

3.7 Maximum and Minimum Longitudinal Reinforcement 3-14

3.7.1 Maximum Longitudinal Reinforcement 3-14

3.7.2 Minimum Longitudinal Reinforcement 3-14
3.7.3 Maximum Reinforcement Ratio 3-14
3.8 Lateral Reinforcement of Ductile Members 3-14
3.8.1 Lateral Reinforcement Inside the Analytical Plastic Hinge Length 3-14
3.8.2 Lateral Column Reinforcement Inside the Plastic Hinge Region 3-15
3.8.3 Lateral Column Reinforcement Outside the Plastic Hinge Region 3-15
3.8.4 Lateral Reinforcement of Pier Walls 3-15
3.8.5 Lateral Reinforcement Requirements for Columns Supported on Type II Pile Shafts 3-15
3.8.6 Lateral Confinement for Type II Pile Shafts 3-15

4. DEMAND VS. CAPACITY

4.1 Performance Criteria 4-1
4.1.1 Global Displacement Criteria 4-1
4.1.2 Demand Ductility Criteria 4-1
4.1.3 Capacity Ductility Criteria 4-1
4.2 P-Δ Effects 4-3
4.3 Component Overstrength Factors 4-3
4.3.1 Column Overstrength Factor 4-3
4.3.2 Superstructure/Bent Cap Demand & Capacity 4-4
4.3.2.1 Longitudinal Superstructure Capacity 4-5
4.3.2.2 Bent Cap Capacity 4-5
4.3.3 Foundation Capacity 4-6

5. ANALYSIS

5.1 Analysis Requirements 5-1
5.1.1 Analysis Objective 5-1
5.2 Analytical Methods 5-1
5.2.1 Equivalent Static Analysis (ESA) 5-1
5.2.2 Elastic Dynamic Analysis (EDA) 5-1
5.2.3 Inelastic Static Analysis (ISA) 5-2
5.3 Structural System “Global” Analysis 5-2

5.4 Stand-Alone "Local" Analysis 5-3
5.4.1 Transverse Stand-Alone Analysis 5-3
5.4.2 Longitudinal Stand-Alone Analysis 5-4
5.5 Simplified Analysis 5-4
5.6 Effective Section Properties 5-5
5.6.1 Effective Section Properties for Seismic Analysis 5-5
5.6.1.1 I_{eff} for Ductile Members 5-5
5.6.1.2 I_{eff} for Box Girder Superstructures 5-5
5.6.1.3 I_{eff} for Other Superstructure Types 5-5
5.6.2 Effective Torsional Moment of Inertia 5-7
5.7 Effective Member Properties for Non-Seismic Loading 5-7

6. SEISMICITY AND FOUNDATION PERFORMANCE

6.1 Site Assessment 6-1
6.1.1 Seismicity and Foundation Data 6-1
6.1.2 ARS Curves 6-1
6.1.2.1 Standard ARS Curves 6-1
6.1.2.2 Site Specific ARS Curves 6-2
6.2 Foundation Design 6-2
6.2.1 Foundation Performance 6-2
6.2.2 Soil Classification 6-2
6.2.2(A) Competent Soil 6-3
6.2.2(B) Poor Soil 6-3
6.2.2(C) Marginal Soil 6-3
6.2.3 Foundation Design Criteria 6-4
6.2.3.1 Foundation Strength 6-4
6.2.3.2 Foundation Flexibility 6-4

7. DESIGN

7.1 Frame Design 7-1

7.1.1 Balanced Stiffness 7-1

7.1.2 Balanced Frame Geometry 7-2

7.1.3 Adjusting Dynamic Characteristics 7-2

7.1.4 End Span Considerations 7-2

7.2 Superstructure 7-4

7.2.1 Girders 7-4

7.2.1.1 Effective Superstructure Width 7-4

7.2.2 Vertical Acceleration 7-4

7.2.3 Pre-cast Girders 7-6

7.2.4 Slab Bridges 7-6

7.2.5 Hinges 7-6

7.2.5.1 Longitudinal Hinge Performance 7-6

7.2.5.2 Transverse Hinge Performance 7-6

7.2.5.3 Frames Meeting the Requirements of Section 7.1.2 7-6

7.2.5.4 Hinge Seat Width for Frames Meeting the Requirements of Section 7.1.2 7-7

7.2.5.5 Frames Not Meeting the Requirements of Section 7.1.2 7-8

7.2.6 Hinge Restrainers 7-8

7.2.7 Pipe Seat Extenders 7-9

7.2.8 Equalizing Bolts 7-9

7.3 Bent Caps 7-9

7.3.1 Integral Bent Caps 7-9

7.3.1.1 Effective Bent Cap Width 7-9

7.3.2 Non-Integral Bent Caps 7-10

7.3.2.1 Minimum Bent Cap Seat Width 7-10

7.3.3 *Deleted* 7-10

7.3.4 Bent Cap Depth 7-10

7.4 Superstructure Joint Design 7-10

7.4.1 Joint Performance 7-10

7.4.2 Joint Proportioning 7-10

7.4.2.1 Minimum Bent Cap Width 7-11

7.4.3 Joint Description 7-11

7.4.4 T Joint Shear Design 7-11

7.4.4.1 Principal Stress Definition 7-11
7.4.4.2 Minimum Joint Shear Reinforcement 7-12
7.4.4.3 Joint Shear Reinforcement 7-13
7.4.5 Knee Joints 7-14
7.5 Bearings 7-18
7.5.1 Elastomeric Bearings 7-18
7.5.2 Sliding Bearings 7-18
7.6 Columns & Pier Walls 7-18
7.6.1 Column Dimensions 7-18
7.6.2 Analytical Plastic Hinge Length 7-18
7.6.3 Plastic Hinge Region 7-19
7.6.4 Multi-Column Bents 7-19
7.6.5 Column Flares 7-19
7.6.5.1 Horizontally Isolated Column Flares 7-19
7.6.5.2 Lightly Reinforced Column Flares 7-20
7.6.5.3 Flare Reinforcement 7-20
7.6.6 Pier Walls 7-20
7.6.7 Column Key Design 7-20
7.7 Foundations 7-21
7.7.1 Footing Design 7-21
7.7.1.1 Pile Foundations in Competent Soil 7-21
7.7.1.2 Pile Foundations in Marginal Soil 7-23
7.7.1.2.1 Lateral Design 7-23
7.7.1.2.2 Lateral Capacity of Fixed Head Piles 7-24
7.7.1.2.3 Passive Earth Resistance for Pile Caps in Marginal Soil 7-24
7.7.1.3 Rigid Footing Response 7-24
7.7.1.4 Footing Joint Shear 7-24
7.7.1.5 Effective Footing Width for Flexure 7-25
7.7.1.6 Effects of Large Capacity Piles on Footing Design 7-25
7.7.2 Pier Wall Pile Foundations 7-26
7.7.2.1 Pier Wall Spread Footing Foundations 7-26
7.7.3 Pile Shafts 7-26
7.7.3.1 Shear Demand on Type I Pile Shafts 7-26
7.7.3.2 Flexure Demand/Capacity Requirements for Type II Pile Shafts 7-27

7.7.3.3 Pile Shaft Diameter 7-27
7.7.3.4 Minimum Pile Shaft Length 7-27
7.7.3.5 Enlarged Pile Shafts 7-27
7.7.4 Pile Extensions 7-27
7.8 Abutments 7-28
7.8.1 Longitudinal Abutment Response 7-28
7.8.2 Transverse Abutment Response 7-30
7.8.3 Abutment Seat Width 7-31
7.8.4 Abutment Shear Key Design 7-31

8. SEISMIC DETAILING

8.1 Splices in Reinforcing Steel 8-1
8.1.1 No Splice Regions in Ductile Components 8-1
8.1.2 Reinforcement Spliced in Ductile Components & Components Expected to Accept Damage … 8-1
8.1.3 Reinforcement Spliced in Capacity Protected Members 8-1
8.1.4 Hoop and Spiral Reinforcement Splices 8-1
8.2 Development of Longitudinal Column Reinforcement 8-1
8.2.1 Minimum Development Length of Reinforcing Steel for Seismic Loads 8-2
8.2.2 Anchorage of Bundled Bars in Ductile Components 8-2
8.2.3 Flexural Bond Requirements for Columns 8-2
8.2.3.1 Maximum Bar Diameter 8-2
8.2.4 Development Length for Column Reinforcement Extended Into Enlarged Type II Shafts 8-3
8.2.5 Maximum Spacing for Lateral Reinforcement 8-3

APPENDICES

Appendix A Notations & Acronyms A1-A6
Appendix B ARS Curves B1-B14
Appendix C Bibliography C1

FIGURES

Figure 2.1 Local-Global Axis Definition 2-2
Figure 2.2 The Effects of Foundation Flexibility on Force-Deflection Curve of a Single Column Bent 2-5
Figure 2.3 The Effects of Bent Cap and Foundation Flexibility on Force-Deflection Curve of a Bent Frame 2-6
Figure 2.4 Pile Shaft Definitions 2-7
Figure 3.1 Local Displacement Capacity – Cantilever Column w/Fixed Base 3-2
Figure 3.2 Local Displacement Capacity – Framed Column, Assumed as Fixed-Fixed 3-3
Figure 3.3 Local Ductility Assessment 3-4
Figure 3.4 Steel Stress Strain Model 3-6
Figure 3.5 Prestressing Strand Stress Strain Model 3-7
Figure 3.6 Concrete Stress Strain Model 3-9
Figure 3.7 Moment Curvature Curve 3-10
Figure 3.8 Concrete Shear Factors 3-12
Figure 4.1 Global Force Deflection Relationship 4-2
Figure 4.2 P-D Effects on Bridge Columns 4-3
Figure 4.3 Superstructure Demand Generated by Column Overstrength Moment 4-5
Figure 4.4 Capacity Provided by Superstructure Internal Resultant Force Couple 4-5
Figure 5.1 EDA Modeling Techniques 5-3
Figure 5.2 Stand-Alone Analysis 5-4
Figure 5.3 Effective Stiffness of Cracked Reinforced Concrete Sections 5-6
Figure 7.1 Balanced Stiffness 7-3
Figure 7.2 Effective Superstructure Width 7-5
Figure 7.3 Equivalent Static Vertical Loads & Moments 7-5
Figure 7.4 Seat Width Requirements 7-7
Figure 7.5 Effective Bent Cap Width 7-9
Figure 7.6 Joint Shear Stresses in T Joints 7-12
Figure 7.7 Location of Vertical Joint Reinforcement 7-14
Figure 7.8 Joint Shear Reinforcement Details 7-15
Figure 7.9 Location of Horizontal Joint Shear Steel 7-16
Figure 7.10 Additional Joint Shear Steel for Skewed Bridges 7-17
Figure 7.11 Footing Force Equilibrium 7-21
Figure 7.12 Simplified Pile Model for Foundations in Competent Soil 7-23
Figure 7.13 Effective Joint Width for Footing Joint Stress Calculation 7-26
Figure 7.14A/ B/ C Effective Abutment Stiffness/ Area/ Width for Skewed Bridges 7-28/29
Figure 7.15 Abutment Seat Width Requirements 7-31