


AMERICAN ASSOCIATION
OF STATE HIGHWAY AND
TRANSPORTATION OFFICIALS

AASHTO



LRFD BRIDGE DESIGN SPECIFICATIONS



9th Edition | 2020


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Cover photos: **Top:** Stan Musial Veterans Memorial Bridge at sunset, with the St. Louis, MO city skyline in the distance. Photo provided by Missouri Department of Transportation. **Bottom:** Segment K, Shreveport, LA. Segment K is a portion of the 36-mile I-49 Corridor which is a four-lane Interstate highway with a 4 ft inside shoulder and a 10 ft outside shoulder from the Arkansas state line to the Port of NOLA. Photo provided by PCL Civil Constructors, Inc.

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FOREWORD

The first broadly recognized national standard for the design and construction of bridges in the United States was published in 1931 by the American Association of State Highway Officials (AASHO), the predecessor to AASHTO. With the advent of the automobile and the establishment of highway departments in all of the American states dating back to just before the turn of the century, the design, construction, and maintenance of most U.S. bridges was the responsibility of these departments and, more specifically, the chief bridge engineer within each department. It was natural, therefore, that these engineers, acting collectively as the AASHTO Highway Subcommittee on Bridges and Structures (now the Committee on Bridges and Structures), would become the author and guardian of this first bridge standard.

This first publication was entitled *Standard Specifications for Highway Bridges and Incidental Structures*. It quickly became the *de facto* national standard and, as such, was adopted and used by not only the state highway departments but also other bridge-owning authorities and agencies in the United States and abroad. Rather early on, the last three words of the original title were dropped and it has been reissued in consecutive editions at approximately four-year intervals ever since as *Standard Specifications for Highway Bridges*, with the final 17th edition appearing in 2002.

The body of knowledge related to the design of highway bridges has grown enormously since 1931 and continues to do so. Theory and practice have evolved greatly, reflecting advances through research in understanding the properties of materials, in improved materials, in more rational and accurate analysis of structural behavior, in the advent of computers and rapidly advancing computer technology, in the study of external events representing particular hazards to bridges such as seismic events and stream scour, and in many other areas. The pace of advances in these areas has, if anything, stepped up in recent years.

In 1986, the Subcommittee submitted a request to the AASHTO Standing Committee on Research to undertake an assessment of U.S. bridge design specifications, to review foreign design specifications and codes, to consider design philosophies alternative to those underlying the Standard Specifications, and to render recommendations based on these investigations. This work was accomplished under the National Cooperative Highway Research Program (NCHRP), an applied research program directed by the AASHTO Standing Committee on Research and administered on behalf of AASHTO by the Transportation Research Board (TRB). The work was completed in 1987, and, as might be expected with a standard incrementally adjusted over the years, the Standard Specifications were judged to include discernible gaps, inconsistencies, and even some conflicts. Beyond this, the specification did not reflect or incorporate the most recently developing design philosophy, load-and-resistance factor design (LRFD), a philosophy which has been gaining ground in other areas of structural engineering and in other parts of the world such as Canada and Europe.

From its inception until the early 1970s, the sole design philosophy embedded within the Standard Specifications was one known as working stress design (WSD). WSD establishes allowable stresses as a fraction or percentage of a given material's load-carrying capacity, and requires that calculated design stresses not exceed those allowable stresses. Beginning in the early 1970s, WSD began to be adjusted to reflect the variable predictability of certain load types, such as vehicular loads and wind forces, through adjusting design factors, a design philosophy referred to as load factor design (LFD).

A further philosophical extension results from considering the variability in the properties of structural elements, in similar fashion to load variabilities. While considered to a limited extent in LFD, the design philosophy of load-and-resistance factor design (LRFD) takes variability in the behavior of structural elements into account in an explicit manner. LRFD relies on extensive use of statistical methods, but sets forth the results in a manner readily usable by bridge designers and analysts.

Starting with the Eighth Edition of the *AASHTO LRFD Bridge Design Specifications*, interim changes to the Specifications were discontinued, and new editions are published on a three-year cycle. Changes are balloted and approved by at least two-thirds of the members of the Committee on Bridges and Structures. AASHTO members include the 50 State Highway or Transportation Departments, the District of Columbia, and Puerto Rico. Each member has one vote. The U.S. Department of Transportation is a non-voting member.

Orders for Specifications may be placed by visiting the AASHTO Store, store.transportation.org; calling the AASHTO Publication Sales Office toll free (within the U.S. and Canada), 1-800-231-3475; or mailing to P.O. Box 933538, Atlanta, GA 31193-3538. A free copy of the current publication catalog can be downloaded from the AASHTO Store.

For additional publications prepared and published by the Committee on Bridges and Structures and by other AASHTO Committees, please look online in the AASHTO Store (store.transportation.org) under “Bridges and Structures.”

Suggestions for the improvement of the *AASHTO LRFD Bridge Design Specifications* are welcomed, just as they were for the *Standard Specifications for Highway Bridges* before them, at www.transportation.org.

The following have served as chair of the Committee on Bridges and Structures since its inception in 1921: E. F. Kelley, who pioneered the work of the Committee; Albin L. Gemeny; R. B. McMinn; Raymond Archiband; G. S. Paxson; E. M. Johnson; Ward Goodman; Charles Matlock; Joseph S. Jones; Sidney Poleynard; Jack Freidenrich; Henry W. Derthick; Robert C. Cassano; Clellon Loveall; James E. Siebels; David Pope; Tom Lulay; Malcolm T. Kerley; Gregg Fredrick; and Carmen Swanwick. The Committee expresses its sincere appreciation of the work of these individuals and of those active members of the past, whose names, because of retirement, are no longer on the roll.

The Committee would also like to thank John M. Kulicki, Ph.D., and his associates at Modjeski and Masters for their valuable assistance in the preparation of the *AASHTO LRFD Bridge Design Specifications*.

PREFACE AND ABBREVIATED TABLE OF CONTENTS

The *AASHTO LRFD Bridge Design Specifications*, Ninth Edition contains the following 15 sections and an index:

1. Introduction
 2. General Design and Location Features
 3. Loads and Load Factors
 4. Structural Analysis and Evaluation
 5. Concrete Structures
 6. Steel Structures
 7. Aluminum Structures
 8. Wood Structures
 9. Decks and Deck Systems
 10. Foundations
 11. Abutments, Piers, and Walls
 12. Buried Structures and Tunnel Liners
 13. Railings
 14. Joints and Bearings
 15. Design of Sound Barriers
- Index

Detailed Tables of Contents precede each section. The last article of each section is a list of references displayed alphabetically by author.

Figures, tables, and equations are denoted by their home article number and an extension, for example 1.2.3.4.5-1 wherever they are cited. In early editions, when they were referenced in their home article or its commentary, these objects were identified only by the extension. For example, in Article 1.2.3.4.5, Eq. 1.2.3.4.5-2 would simply have been called “Eq. 2.” The same convention applies to figures and tables. Starting with this edition, these objects are identified by their whole nomenclature throughout the text, even within their home articles. This change was to increase the speed and accuracy of electronic production (i.e., CDs and downloadable files) with regard to linking citations to objects.

Please note that the AASHTO materials standards (starting with M or T) cited throughout the LRFD Bridge Design Specifications can be found in *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, adopted by the AASHTO Highway Subcommittee on Materials. The individual standards are also available as downloads on the AASHTO Store, <https://store.transportation.org>. Unless otherwise indicated, these citations refer to the current edition. ASTM materials specifications are also cited and have been updated to reflect ASTM’s revised coding system, i.e., spaces removed between the letter and number.

SECTION 1: INTRODUCTION

TABLE OF CONTENTS

1.1—SCOPE OF THE SPECIFICATIONS..... 1-1
1.2—DEFINITIONS..... 1-2
1.3—DESIGN PHILOSOPHY 1-3
 1.3.1—General..... 1-3
 1.3.2—Limit States 1-3
 1.3.2.1—General 1-3
 1.3.2.2—Service Limit State..... 1-4
 1.3.2.3—Fatigue and Fracture Limit State..... 1-4
 1.3.2.4—Strength Limit State 1-4
 1.3.2.5—Extreme Event Limit States 1-5
 1.3.3—Ductility 1-5
 1.3.4—Redundancy 1-6
 1.3.5—Operational Importance 1-7
1.4—REFERENCES 1-7

SECTION 1

INTRODUCTION

Commentary is opposite the text it annotates.

1.1—SCOPE OF THE SPECIFICATIONS

The provisions of these Specifications are intended for the design, evaluation, and rehabilitation of both fixed and movable highway bridges. Mechanical, electrical, and special vehicular and pedestrian safety aspects of movable bridges, however, are not covered. Provisions are not included for bridges used solely for railway, rail-transit, or public utilities. For bridges not fully covered herein, the provisions of these Specifications may be applied, and augmented with additional design criteria where required.

These Specifications are not intended to supplant proper training or the exercise of judgment by the Designer, and state only the minimum requirements necessary to provide for public safety. The Owner or the Designer may require the sophistication of design or the quality of materials and construction to be higher than the minimum requirements.

The concepts of safety through redundancy and ductility and of protection against scour and collision are emphasized.

The design provisions of these Specifications employ the Load and Resistance Factor Design (LRFD) methodology. The factors have been developed from the theory of reliability based on current statistical knowledge of loads and structural performance.

Methods of analysis other than those included in previous Specifications and the modeling techniques inherent in them are included, and their use is encouraged.

Seismic design shall be in accordance with either the provisions in these Specifications or those given in the *AASHTO Guide Specifications for LRFD Seismic Bridge Design*.

The commentary is not intended to provide a complete historical background concerning the development of these or previous Specifications, nor is it intended to provide a detailed summary of the studies and research data reviewed in formulating the provisions of the Specifications. However, references to some of the research data are provided for those who wish to study the background material in depth.

The commentary directs attention to other documents that provide suggestions for carrying out the requirements and intent of these Specifications. However, those documents and this commentary are not intended to be a part of these Specifications.

Construction specifications consistent with these design specifications are the *AASHTO LRFD Bridge Construction Specifications*. Unless otherwise specified, the Materials Specifications referenced herein are the *AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing*.

C1.1

The term “notional” is often used in these Specifications to indicate an idealization of a physical phenomenon, as in “notional load” or “notional resistance.” Use of this term strengthens the separation of an engineer's “notion” or perception of the physical world in the context of design from the physical reality itself.

The term “shall” denotes a requirement for compliance with these Specifications.

The term “should” indicates a strong preference for a given criterion.

The term “may” indicates a criterion that is usable, but other local and suitably documented, verified, and approved criteria may also be used in a manner consistent with the LRFD approach to bridge design.

SECTION 2: GENERAL DESIGN AND LOCATION FEATURES

TABLE OF CONTENTS

2.1—SCOPE 2-1

2.2—DEFINITIONS 2-1

2.3—LOCATION FEATURES 2-3

 2.3.1—Route Location 2-3

 2.3.1.1—General 2-3

 2.3.1.2—Waterway and Floodplain Crossings 2-3

 2.3.2—Bridge Site Arrangement 2-4

 2.3.2.1—General 2-4

 2.3.2.2—Traffic Safety 2-4

 2.3.2.2.1—Protection of Structures 2-4

 2.3.2.2.2—Protection of Users 2-4

 2.3.2.2.3—Geometric Standards 2-5

 2.3.2.2.4—Road Surfaces 2-5

 2.3.2.2.5—Vessel Collisions 2-5

 2.3.3—Clearances 2-5

 2.3.3.1—Navigational 2-5

 2.3.3.2—Highway Vertical 2-5

 2.3.3.3—Highway Horizontal 2-6

 2.3.3.4—Railroad Overpass 2-6

 2.3.4—Environment 2-7

2.4—FOUNDATION INVESTIGATION 2-7

 2.4.1—General 2-7

 2.4.2—Topographic Studies 2-7

2.5—DESIGN OBJECTIVES 2-7

 2.5.1—Safety 2-7

 2.5.1.1—Structural Survival 2-7

 2.5.1.2—Limited Serviceability 2-7

 2.5.1.3—Immediate Use 2-7

 2.5.2—Serviceability 2-8

 2.5.2.1—Durability 2-8

 2.5.2.1.1—Materials 2-8

 2.5.2.1.2—Self-Protecting Measures 2-8

 2.5.2.2—Inspectability 2-9

 2.5.2.3—Maintainability 2-9

 2.5.2.4—Rideability 2-9

 2.5.2.5—Utilities 2-9

 2.5.2.6—Deformations 2-10

 2.5.2.6.1—General 2-10

 2.5.2.6.2—Criteria for Deflection 2-11

 2.5.2.6.3—Optional Criteria for Span-to-Depth Ratios 2-13

 2.5.2.7—Consideration of Future Widening 2-14

 2.5.2.7.1—Exterior Beams on Girder System Bridges 2-14

 2.5.2.7.2—Substructure 2-14

 2.5.3—Constructability 2-14

 2.5.4—Economy 2-15

 2.5.4.1—General 2-15

 2.5.4.2—Alternative Plans 2-15

 2.5.5—Bridge Aesthetics 2-15

2.6—HYDROLOGY AND HYDRAULICS 2-17

 2.6.1—General 2-17

 2.6.2—Site Data 2-18

 2.6.3—Hydrologic Analysis 2-18

 2.6.4—Hydraulic Analysis 2-19

 2.6.4.1—General 2-19

2.6.4.2—Stream Stability	2-19
2.6.4.3—Bridge Waterway	2-20
2.6.4.4—Bridge Foundations	2-20
2.6.4.4.1—General.....	2-20
2.6.4.4.2—Bridge Scour	2-21
2.6.4.5—Roadway Approaches to Bridge.....	2-22
2.6.5—Culvert Location, Length, and Waterway Area.....	2-23
2.6.6—Roadway Drainage	2-23
2.6.6.1—General.....	2-23
2.6.6.2—Design Storm.....	2-23
2.6.6.3—Type, Size, and Number of Drains	2-23
2.6.6.4—Discharge from Deck Drains	2-24
2.6.6.5—Drainage of Structures.....	2-24
2.7—BRIDGE SECURITY.....	2-24
2.7.1—General.....	2-24
2.7.2—Design Demand.....	2-25
2.8—REFERENCES.....	2-25

SECTION 2

GENERAL DESIGN AND LOCATION FEATURES

Commentary is opposite the text it annotates.

2.1—SCOPE

Minimum requirements are provided for clearances, environmental protection, aesthetics, geological studies, economy, rideability, durability, constructability, inspectability, and maintainability. Minimum requirements for traffic safety are referenced.

Minimum requirements for drainage facilities and self-protecting measures against water, ice, and water-borne salts are included.

In recognition that many bridge failures have been caused by scour, hydrology and hydraulics are covered in detail.

2.2—DEFINITIONS

Aggradation—A general and progressive buildup or raising of the longitudinal profile of the channel bed as a result of sediment deposition.

Check Flood for Bridge Scour—The flood resulting from storm, storm surge, tide, or some combination thereof having a flow rate in excess of the design flood for scour, but in no case a flood with a recurrence interval exceeding the typically used 500 years. The check flood for bridge scour is used in the investigation and assessment of a bridge foundation to determine whether the foundation can withstand that flow and its associated scour and remain stable with no reserve. See also superflood.

Clear Zone—An unobstructed, relatively flat area beyond the edge of the traveled way for the recovery of errant vehicles. The traveled way does not include shoulders or auxiliary lanes.

Clearance—An unobstructed horizontal or vertical space.

Degradation—A general and progressive lowering of the longitudinal profile of the channel bed as a result of long-term erosion.

Design Discharge—Maximum flow of water a bridge is expected to accommodate without exceeding the adopted design constraints.

Design Flood for Bridge Scour—The flood flow equal to or less than the 100-year flood that creates the deepest scour at bridge foundations. The highway or bridge may be inundated at the stage of the design flood for bridge scour. The worst-case scour condition may occur for the overtopping flood as a result of the potential for pressure flow.

Design Flood for Waterway Opening—The peak discharge, volume, stage, or wave crest elevation and its associated probability of exceedence that are selected for the design of a highway or bridge over a watercourse or floodplain. By definition, the highway or bridge will not be inundated at the stage of the design flood for the waterway opening.

Detention Basin—A storm water management facility that impounds runoff and temporarily discharges it through a hydraulic outlet structure to a downstream conveyance system.

Drip Groove—Linear depression in the bottom of components to cause water flowing on the surface to drop.

Five-Hundred-Year Flood—The flood due to storm, tide, or both having a 0.2 percent chance of being equaled or exceeded in any given year.

General or Contraction Scour—Scour in a channel or on a floodplain that is not localized at a pier or other obstruction to flow. In a channel, general/contraction scour usually affects all or most of the channel width and is typically caused by a contraction of the flow.

Hydraulics—The science concerned with the behavior and flow of liquids, especially in pipes and channels.

C2.1

This Section is intended to provide the Designer with sufficient information to determine the configuration and overall dimensions of a bridge.

SECTION 3: LOADS AND LOAD FACTORS

TABLE OF CONTENTS

3.1—SCOPE	3-1
3.2—DEFINITIONS.....	3-1
3.3—NOTATION.....	3-3
3.3.1—General.....	3-3
3.3.2—Load and Load Designation	3-8
3.4—LOAD FACTORS AND COMBINATIONS	3-9
3.4.1—Load Factors and Load Combinations	3-9
3.4.2—Load Factors for Construction Loads.....	3-19
3.4.2.1—Evaluation at the Strength Limit State	3-19
3.4.2.2—Evaluation of Deflection at the Service Limit State.....	3-20
3.4.3—Load Factors for Jacking and Post-Tensioning Forces	3-20
3.4.3.1—Jacking Forces	3-20
3.4.3.2—Force for Post-Tensioning Anchorage Zones.....	3-20
3.4.4—Load Factors for Orthotropic Decks	3-20
3.5—PERMANENT LOADS	3-21
3.5.1—Dead Loads: <i>DC</i> , <i>DW</i> , and <i>EV</i>	3-21
3.5.2—Earth Loads: <i>EH</i> , <i>ES</i> , and <i>DD</i>	3-22
3.6—LIVE LOADS	3-22
3.6.1—Gravity Loads: <i>LL</i> and <i>PL</i>	3-22
3.6.1.1—Vehicular Live Load	3-22
3.6.1.1.1—Number of Design Lanes	3-22
3.6.1.1.2—Multiple Presence of Live Load.....	3-22
3.6.1.2—Design Vehicular Live Load	3-23
3.6.1.2.1—General	3-23
3.6.1.2.2—Design Truck	3-24
3.6.1.2.3—Design Tandem.....	3-25
3.6.1.2.4—Design Lane Load.....	3-25
3.6.1.2.5—Tire Contact Area	3-25
3.6.1.2.6—Distribution of Wheel Load through Earth Fills	3-26
3.6.1.2.6a—General	3-26
3.6.1.2.6b—Traffic Parallel to the Culvert Span.....	3-27
3.6.1.2.6c—Traffic Perpendicular to the Culvert Span	3-28
3.6.1.3—Application of Design Vehicular Live Loads	3-29
3.6.1.3.1—General	3-29
3.6.1.3.2—Loading for Optional Live Load Deflection Evaluation	3-29
3.6.1.3.3—Design Loads for Decks, Deck Systems, and the Top Slabs of Box Culverts	3-30
3.6.1.3.4—Deck Overhang Load.....	3-31
3.6.1.4—Fatigue Load	3-31
3.6.1.4.1—Magnitude and Configuration.....	3-31
3.6.1.4.2—Frequency	3-31
3.6.1.4.3—Load Distribution for Fatigue	3-32
3.6.1.4.3a—Refined Methods.....	3-32
3.6.1.4.3b—Approximate Methods.....	3-32
3.6.1.5—Rail Transit Load	3-33
3.6.1.6—Pedestrian Loads.....	3-33
3.6.1.7—Loads on Railings	3-33
3.6.2—Dynamic Load Allowance: <i>IM</i>	3-33
3.6.2.1—General	3-33
3.6.2.2—Buried Components	3-34
3.6.2.3—Wood Components	3-35
3.6.3—Centrifugal Forces: <i>CE</i>	3-35
3.6.4—Braking Force: <i>BR</i>	3-35
3.6.5—Vehicular Collision Force: <i>CT</i>	3-38

3.6.5.1—Protection of Structures.....	3-38
3.6.5.2—Vehicle Collision with Barriers.....	3-45
3.7—WATER LOADS: <i>WA</i>	3-45
3.7.1—Static Pressure.....	3-45
3.7.2—Buoyancy.....	3-45
3.7.3—Stream Pressure.....	3-45
3.7.3.1—Longitudinal.....	3-45
3.7.3.2—Lateral.....	3-46
3.7.4—Wave Load.....	3-47
3.7.5—Change in Foundations Due to Limit State for Scour.....	3-47
3.8—WIND LOAD: <i>WL</i> AND <i>WS</i>	3-48
3.8.1—Horizontal Wind Load.....	3-48
3.8.1.1—Exposure Conditions.....	3-48
3.8.1.1.1—General.....	3-48
3.8.1.1.2—Wind Speed.....	3-48
3.8.1.1.3—Wind Direction for Determining Wind Exposure Category.....	3-52
3.8.1.1.4—Ground Surface Roughness Categories.....	3-52
3.8.1.1.5—Wind Exposure Categories.....	3-53
3.8.1.2—Wind Load on Structures: <i>WS</i>	3-53
3.8.1.2.1—General.....	3-53
3.8.1.2.2—Loads on the Superstructure.....	3-56
3.8.1.2.3—Loads on the Substructure.....	3-57
3.8.1.2.3a—Loads from the Superstructure.....	3-57
3.8.1.2.3b—Loads Applied Directly to the Substructure.....	3-57
3.8.1.2.4—Wind Loads on Sound Barriers.....	3-58
3.8.1.3—Wind Load on Live Load: <i>WL</i>	3-59
3.8.2—Vertical Wind Load.....	3-59
3.8.3—Wind-Induced Bridge Motions.....	3-60
3.8.3.1—General.....	3-60
3.8.3.2—Wind-Induced Motions.....	3-60
3.8.3.3—Control of Dynamic Responses.....	3-61
3.8.4—Site-Specific and Structure-Specific Studies.....	3-61
3.9—ICE LOADS: <i>IC</i>	3-62
3.9.1—General.....	3-62
3.9.2—Dynamic Ice Forces on Piers.....	3-63
3.9.2.1—Effective Ice Strength.....	3-63
3.9.2.2—Crushing and Flexing.....	3-64
3.9.2.3—Small Streams.....	3-65
3.9.2.4—Combination of Longitudinal and Transverse Forces.....	3-66
3.9.2.4.1—Piers Parallel to Flow.....	3-66
3.9.2.4.2—Piers Skewed to Flow.....	3-67
3.9.2.5—Slender and Flexible Piers.....	3-67
3.9.3—Static Ice Loads on Piers.....	3-67
3.9.4—Hanging Dams and Ice Jams.....	3-67
3.9.5—Vertical Forces Due to Ice Adhesion.....	3-67
3.9.6—Ice Accretion and Snow Loads on Superstructures.....	3-69
3.10—EARTHQUAKE EFFECTS: <i>EQ</i>	3-70
3.10.1—General.....	3-70
3.10.2—Seismic Hazard.....	3-71
3.10.2.1—General Procedure.....	3-71
3.10.2.2—Site-Specific Procedure.....	3-100
3.10.3—Site Effects.....	3-101
3.10.3.1—Site Class Definitions.....	3-101
3.10.3.2—Site Factors.....	3-105
3.10.4—Seismic Hazard Characterization.....	3-106
3.10.4.1—Design Response Spectrum.....	3-106

3.10.4.2—Elastic Seismic Response Coefficient.....	3-107
3.10.5—Operational Classification.....	3-107
3.10.6—Seismic Performance Zones.....	3-108
3.10.7—Response Modification Factors.....	3-108
3.10.7.1—General.....	3-108
3.10.7.2—Application.....	3-109
3.10.8—Combination of Seismic Force Effects.....	3-109
3.10.9—Calculation of Design Forces.....	3-110
3.10.9.1—General.....	3-110
3.10.9.2—Seismic Zone 1.....	3-110
3.10.9.3—Seismic Zone 2.....	3-112
3.10.9.4—Seismic Zones 3 and 4.....	3-112
3.10.9.4.1—General.....	3-112
3.10.9.4.2—Modified Design Forces.....	3-113
3.10.9.4.3—Inelastic Hinging Forces.....	3-113
3.10.9.4.3a—General.....	3-113
3.10.9.4.3b—Single Columns and Piers.....	3-113
3.10.9.4.3c—Piers with Two or More Columns.....	3-114
3.10.9.4.3d—Column and Pile Bent Design Forces.....	3-115
3.10.9.4.3e—Pier Design Forces.....	3-115
3.10.9.4.3f—Foundation Design Forces.....	3-115
3.10.9.5—Longitudinal Restrainers.....	3-116
3.10.9.6—Hold-Down Devices.....	3-116
3.10.10—Requirements for Temporary Bridges and Stage Construction.....	3-117
3.11—EARTH PRESSURE: <i>EH</i> , <i>ES</i> , <i>LS</i> , AND <i>DD</i>	3-117
3.11.1—General.....	3-117
3.11.2—Compaction.....	3-118
3.11.3—Presence of Water.....	3-118
3.11.4—Effect of Earthquake.....	3-119
3.11.5—Earth Pressure: <i>EH</i>	3-119
3.11.5.1—Lateral Earth Pressure.....	3-119
3.11.5.2—At-Rest Lateral Earth Pressure Coefficient, k_o	3-120
3.11.5.3—Active Lateral Earth Pressure Coefficient, k_a	3-121
3.11.5.4—Passive Lateral Earth Pressure Coefficient, k_p	3-124
3.11.5.5—Equivalent-fluid Method of Estimating Rankine Lateral Earth Pressures.....	3-127
3.11.5.6—Lateral Earth Pressures for Nongravity Cantilevered Walls.....	3-129
3.11.5.7—Apparent Earth Pressure (<i>AEP</i>) for Anchored Walls.....	3-134
3.11.5.7.1—Cohesionless Soils.....	3-134
3.11.5.7.2—Cohesive Soils.....	3-135
3.11.5.7.2a—Stiff to Hard.....	3-136
3.11.5.7.2b—Soft to Medium Stiff.....	3-136
3.11.5.8—Lateral Earth Pressures for Mechanically Stabilized Earth Walls.....	3-137
3.11.5.8.1—General.....	3-137
3.11.5.8.2—Internal Stability.....	3-138
3.11.5.9—Lateral Earth Pressures for Prefabricated Modular Walls.....	3-139
3.11.5.10—Lateral Earth Pressures for Sound Barriers Supported on Discrete and Continuous Vertical Embedded Elements.....	3-140
3.11.6—Surcharge Loads: <i>ES</i> and <i>LS</i>	3-143
3.11.6.1—Uniform Surcharge Loads (<i>ES</i>).....	3-144
3.11.6.2—Point, Line, and Strip Loads (<i>ES</i>): Walls Restrained from Movement.....	3-144
3.11.6.3—Strip Loads (<i>ES</i>): Flexible Walls.....	3-148
3.11.6.4—Live Load Surcharge (<i>LS</i>).....	3-151
3.11.6.5—Reduction of Surcharge.....	3-152
3.11.7—Reduction Due to Earth Pressure.....	3-152
3.11.8—Downdrag.....	3-152
3.12—FORCE EFFECTS DUE TO SUPERIMPOSED DEFORMATIONS: <i>TU</i> , <i>TG</i> , <i>SH</i> , <i>CR</i> , <i>SE</i> , <i>PS</i>	3-154

3.12.1—General	3-154
3.12.2—Uniform Temperature	3-155
3.12.2.1—Temperature Range for Procedure A	3-155
3.12.2.2—Temperature Range for Procedure B	3-155
3.12.2.3—Design Thermal Movements	3-157
3.12.3—Temperature Gradient	3-158
3.12.4—Differential Shrinkage	3-159
3.12.5—Creep	3-159
3.12.6—Settlement	3-160
3.12.7—Secondary Forces from Post-Tensioning, <i>PS</i>	3-160
3.13—FRICTION FORCES: <i>FR</i>	3-160
3.14—VESSEL COLLISION: <i>CV</i>	3-160
3.14.1—General	3-160
3.14.2—Owner’s Responsibility	3-162
3.14.3—Operational Classification	3-162
3.14.4—Design Vessel	3-162
3.14.5—Annual Frequency of Collapse	3-163
3.14.5.1—Vessel Frequency Distribution	3-164
3.14.5.2—Probability of Aberrancy	3-165
3.14.5.2.1—General	3-165
3.14.5.2.2—Statistical Method	3-165
3.14.5.2.3—Approximate Method	3-165
3.14.5.3—Geometric Probability	3-168
3.14.5.4—Probability of Collapse	3-169
3.14.5.5 Protection Factor	3-169
3.14.6—Design Collision Velocity	3-171
3.14.7—Vessel Collision Energy	3-171
3.14.8—Ship Collision Force on Pier	3-172
3.14.9—Ship Bow Damage Length	3-174
3.14.10—Ship Collision Force on Superstructure	3-174
3.14.10.1—Collision with Bow	3-174
3.14.10.2—Collision with Deck House	3-174
3.14.10.3—Collision with Mast	3-175
3.14.11—Barge Collision Force on Pier	3-175
3.14.12—Barge Bow Damage Length	3-176
3.14.13—Damage at the Extreme Limit State	3-176
3.14.14—Application of Impact Force	3-177
3.14.14.1—Substructure Design	3-177
3.14.14.2—Superstructure Design	3-178
3.14.15—Protection of Substructures	3-178
3.14.16—Security Considerations	3-179
3.15—BLAST LOADING: <i>BL</i>	3-180
3.15.1—Introduction	3-180
3.16—REFERENCES	3-180
APPENDIX A3—SEISMIC DESIGN FLOWCHARTS	3-189
APPENDIX B3—OVERSTRENGTH RESISTANCE	3-191

SECTION 3

LOADS AND LOAD FACTORS

Commentary is opposite the text it annotates.

3.1—SCOPE

This Section specifies minimum requirements for loads and forces, the limits of their application, load factors, and load combinations used for the design of new bridges. The load provisions may also be applied to the structural evaluation of existing bridges.

Where multiple performance levels are provided, the selection of the design performance level is the responsibility of the Owner.

A minimum load factor is specified for force effects that may develop during construction. Additional requirements for construction of segmental concrete bridges are specified in Article 5.12.5.

3.2—DEFINITIONS

Active Earth Pressure—Lateral pressure resulting from the retention of the earth by a structure or component that is tending to move away from the soil mass.

Active Earth Wedge—Wedge of earth with a tendency to become mobile if not retained by a structure or component.

Aeroelastic Vibration—Periodic, elastic response of a structure to wind.

Apparent Earth Pressure—Lateral pressure distribution for anchored walls constructed from the top down.

Axle Unit—Single axle or tandem axle.

Berm—An earthwork used to redirect or slow down impinging vehicles or vessels and to stabilize fill, embankment, or soft ground and cut slopes.

Centrifugal Force—A lateral force resulting from a change in the direction of a vehicle's movement.

Damper—A device that transfers and reduces forces between superstructure elements, superstructure and substructure elements, or both, while permitting thermal movements. The device provides damping by dissipating energy under seismic, braking, or other dynamic loads.

Deep Draft Waterways—A navigable waterway used by merchant ships with loaded drafts of 14–60+ ft.

Design Lane—A notional traffic lane positioned transversely on the roadway.

Design Thermal Movement Range—The structure movement range resulting from the difference between the maximum design temperature and minimum design temperature as defined in Article 3.12.

Design Water Depth—Depth of water at mean high water.

Distortion—Change in structural geometry.

Dolphin—Protective object that may have its own fender system and that is usually circular in plan and structurally independent from the bridge.

Dynamic Load Allowance—An increase in the applied static force effects to account for the dynamic interaction between the bridge and moving vehicles.

C3.1

This Section includes, in addition to traditional loads, the force effects due to collisions, earthquakes, and settlement and distortion of the structure.

Vehicle and vessel collisions, earthquakes, and aeroelastic instability develop force effects that are dependent upon structural response. Therefore, such force effects cannot be determined without analysis and/or testing.

With the exception of segmental concrete bridges, construction loads are not provided, but the Designer should obtain pertinent information from prospective contractors.

SECTION 4: STRUCTURAL ANALYSIS AND EVALUATION

TABLE OF CONTENTS

4.1—SCOPE 4-1

4.2—DEFINITIONS 4-2

4.3—NOTATION 4-7

4.4—ACCEPTABLE METHODS OF STRUCTURAL ANALYSIS 4-10

4.5—MATHEMATICAL MODELING 4-11

 4.5.1—General 4-11

 4.5.2—Structural Material Behavior 4-11

 4.5.2.1—Elastic Versus Inelastic Behavior 4-11

 4.5.2.2—Elastic Behavior 4-11

 4.5.2.3—Inelastic Behavior 4-12

 4.5.3—Geometry 4-12

 4.5.3.1—Small Deflection Theory 4-12

 4.5.3.2—Large Deflection Theory 4-13

 4.5.3.2.1—General 4-13

 4.5.3.2.2—Approximate Methods 4-14

 4.5.3.2.2a—General 4-14

 4.5.3.2.2b—Moment Magnification—Beam Columns 4-14

 4.5.3.2.2c—Moment Magnification—Arches 4-16

 4.5.3.2.3—Refined Methods 4-16

 4.5.4—Modeling Boundary Conditions 4-16

 4.5.5—Equivalent Members 4-17

4.6—STATIC ANALYSIS 4-17

 4.6.1—Influence of Plan Geometry 4-17

 4.6.1.1—Plan Aspect Ratio 4-17

 4.6.1.2—Structures Curved in Plan 4-17

 4.6.1.2.1—General 4-17

 4.6.1.2.2—Single-Girder Torsionally Stiff Superstructures 4-18

 4.6.1.2.3—Concrete Box Girder Bridges 4-18

 4.6.1.2.4—Steel Multiple-Beam Superstructures 4-20

 4.6.1.2.4a—General 4-20

 4.6.1.2.4b—I-Girders 4-20

 4.6.1.2.4c—Closed Box and Tub Girders 4-22

 4.6.2—Approximate Methods of Analysis 4-22

 4.6.2.1—Decks 4-22

 4.6.2.1.1—General 4-22

 4.6.2.1.2—Applicability 4-23

 4.6.2.1.3—Width of Equivalent Interior Strips 4-23

 4.6.2.1.4—Width of Equivalent Strips at Edges of Slabs 4-25

 4.6.2.1.4a—General 4-25

 4.6.2.1.4b—Longitudinal Edges 4-25

 4.6.2.1.4c—Transverse Edges 4-25

 4.6.2.1.5—Distribution of Wheel Loads 4-26

 4.6.2.1.6—Calculation of Force Effects 4-26

 4.6.2.1.7—Cross-Sectional Frame Action 4-27

 4.6.2.1.8—Live Load Force Effects for Fully and Partially Filled Grids and for Unfilled Grid Decks Composite with Reinforced Concrete Slabs 4-27

 4.6.2.1.9—Inelastic Analysis 4-29

 4.6.2.2—Beam-Slab Bridges 4-29

 4.6.2.2.1—Application 4-29

 4.6.2.2.2—Distribution Factor Method for Moment and Shear 4-35

 4.6.2.2.2a—Interior Beams with Wood Decks 4-35

 4.6.2.2.2b—Interior Beams with Concrete Decks 4-36

 4.6.2.2.2c—Interior Beams with Corrugated Steel Decks 4-38

 4.6.2.2.2d—Exterior Beams 4-39

 4.6.2.2.2e—Skewed Bridges 4-40

4.6.2.2.2f—Flexural Moments and Shear in Transverse Floorbeams.....	4-41
4.6.2.2.3—Distribution Factor Method for Shear.....	4-42
4.6.2.2.3a—Interior Beams.....	4-42
4.6.2.2.3b—Exterior Beams.....	4-44
4.6.2.2.3c—Skewed Bridges.....	4-46
4.6.2.2.4—Curved Steel Bridges.....	4-47
4.6.2.2.5—Special Loads with Other Traffic.....	4-47
4.6.2.3—Equivalent Strip Widths for Slab-Type Bridges.....	4-48
4.6.2.4—Truss and Arch Bridges.....	4-49
4.6.2.5—Effective Length Factor, K	4-49
4.6.2.6—Effective Flange Width.....	4-54
4.6.2.6.1—General.....	4-54
4.6.2.6.2—Segmental Concrete Box Beams and Single-Cell, Cast-in-Place Box Beams.....	4-55
4.6.2.6.3—Cast-in-Place Multicell Superstructures.....	4-59
4.6.2.6.4—Orthotropic Steel Decks.....	4-59
4.6.2.6.5—Transverse Floorbeams and Integral Bent Caps.....	4-60
4.6.2.7—Lateral Wind Load Distribution in Girder System Bridges.....	4-60
4.6.2.7.1—I-Sections.....	4-60
4.6.2.7.2—Box Sections.....	4-62
4.6.2.7.3—Construction.....	4-62
4.6.2.8—Seismic Lateral Load Distribution.....	4-62
4.6.2.8.1—Applicability.....	4-62
4.6.2.8.2—Design Criteria.....	4-62
4.6.2.8.3—Load Distribution.....	4-63
4.6.2.9—Analysis of Segmental Concrete Bridges.....	4-63
4.6.2.9.1—General.....	4-63
4.6.2.9.2—Strut-and-Tie Models.....	4-64
4.6.2.9.3—Effective Flange Width.....	4-64
4.6.2.9.4—Transverse Analysis.....	4-64
4.6.2.9.5—Longitudinal Analysis.....	4-64
4.6.2.9.5a—General.....	4-64
4.6.2.9.5b—Erection Analysis.....	4-65
4.6.2.9.5c—Analysis of the Final Structural System.....	4-65
4.6.2.10—Equivalent Strip Widths for Box Culverts.....	4-65
4.6.2.10.1—General.....	4-65
4.6.2.10.2—Case 1: Traffic Travels Parallel to Span.....	4-65
4.6.2.10.3—Case 2: Traffic Travels Perpendicular to Span.....	4-66
4.6.2.10.4—Precast Box Culverts.....	4-66
4.6.3—Refined Methods of Analysis.....	4-67
4.6.3.1—General.....	4-67
4.6.3.2—Decks.....	4-67
4.6.3.2.1—General.....	4-67
4.6.3.2.2—Isotropic Plate Model.....	4-68
4.6.3.2.3—Orthotropic Plate Model.....	4-68
4.6.3.2.4—Refined Orthotropic Deck Model.....	4-68
4.6.3.3—Beam-Slab Bridges.....	4-69
4.6.3.3.1—General.....	4-69
4.6.3.3.2—Grid and Plate and Eccentric Beam Analyses of Curved and/or Skewed Steel I-Girder Bridges.....	4-70
4.6.3.3.3—Curved Steel Bridges.....	4-70
4.6.3.3.4—Cross-Frames and Diaphragms.....	4-71
4.6.3.4—Cellular and Box Bridges.....	4-72
4.6.3.5—Truss Bridges.....	4-72
4.6.3.6—Arch Bridges.....	4-73
4.6.3.7—Cable-Stayed Bridges.....	4-73
4.6.3.8—Suspension Bridges.....	4-74
4.6.4—Redistribution of Negative Moments in Continuous Beam Bridges.....	4-74

4.6.4.1—General.....	4-74
4.6.4.2—Refined Method	4-75
4.6.4.3—Approximate Procedure	4-75
4.6.5—Stability.....	4-75
4.6.6—Analysis for Temperature Gradient.....	4-75
4.7—DYNAMIC ANALYSIS.....	4-77
4.7.1—Basic Requirements of Structural Dynamics	4-77
4.7.1.1—General.....	4-77
4.7.1.2—Distribution of Masses	4-77
4.7.1.3—Stiffness	4-78
4.7.1.4—Damping	4-78
4.7.1.5—Natural Frequencies	4-78
4.7.2—Elastic Dynamic Responses	4-78
4.7.2.1—Vehicle-Induced Vibration	4-78
4.7.2.2—Wind-Induced Vibration.....	4-79
4.7.2.2.1—Wind Velocities	4-79
4.7.2.2.2—Dynamic Effects	4-79
4.7.2.2.3—Design Considerations.....	4-79
4.7.3—Inelastic Dynamic Responses	4-79
4.7.3.1—General.....	4-79
4.7.3.2—Plastic Hinges and Yield Lines	4-80
4.7.4—Analysis for Earthquake Loads.....	4-80
4.7.4.1—General.....	4-80
4.7.4.2—Single-Span Bridges	4-80
4.7.4.3—Multispan Bridges.....	4-80
4.7.4.3.1—Selection of Method.....	4-80
4.7.4.3.2—Single-Mode Methods of Analysis	4-81
4.7.4.3.2a—General	4-81
4.7.4.3.2b—Single-Mode Spectral Method.....	4-81
4.7.4.3.2c—Uniform Load Method.....	4-83
4.7.4.3.3—Multimode Spectral Method.....	4-84
4.7.4.3.4—Time-History Method	4-85
4.7.4.3.4a—General	4-85
4.7.4.3.4b—Acceleration Time Histories.....	4-85
4.7.4.4—Minimum Support Length Requirements	4-87
4.7.4.5— P - Δ Requirements	4-88
4.7.5—Analysis for Collision Loads	4-89
4.7.6—Analysis of Blast Effects.....	4-89
4.8—ANALYSIS BY PHYSICAL MODELS	4-90
4.8.1—Scale Model Testing	4-90
4.8.2—Bridge Testing	4-90
4.9—REFERENCES	4-90
APPENDIX A4—DECK SLAB DESIGN TABLE.....	4-97

STRUCTURAL ANALYSIS AND EVALUATION

Commentary is opposite the text it annotates.

4.1—SCOPE

This section describes methods of analysis suitable for the design and evaluation of bridges, and is limited to the modeling of structures and the determination of force effects.

Other methods of analysis that are based on documented material characteristics and that satisfy equilibrium and compatibility may also be used.

In general, bridge structures are to be analyzed elastically. However, this section permits the inelastic analysis or redistribution of force effects in some continuous beam superstructures. It specifies inelastic analysis for compressive members behaving inelastically and as an alternative for extreme event limit states.

C4.1

This section identifies and promotes the application of methods of structural analysis that are suitable for bridges. The selected method of analysis may vary from the approximate to the very sophisticated, depending on the size, complexity, and priority of the structure. The primary objective in the use of more sophisticated methods of analysis is to obtain a better understanding of structural behavior. Such improved understanding may often, but not always, lead to the potential for saving material.

The methods of analysis outlined herein, which are suitable for the determination of deformations and force effects in bridge structures, have been successfully demonstrated, and most have been used for years. Although many methods will require a computer for practical implementation, simpler methods that are amenable to hand calculation and/or the use of existing computer programs based on line-structure analysis are also provided. Comparison with hand calculations should always be encouraged and basic equilibrium checks should be standard practice.

With rapidly improving computing technology, the more refined and complex methods of analysis are expected to become commonplace. Hence, this section addresses the assumptions and limitations of such methods. It is important that the user understand the method employed and its associated limitations.

In general, the suggested methods of analysis are based on linear material models. This does not mean that cross-sectional resistance is limited to the linear range. This presents an obvious inconsistency in that the analysis is based on material linearity and the resistance model may be based on inelastic behavior for the strength limit states. This same inconsistency existed, however, in the load factor design method of the *AASHTO Standard Specifications for Highway Bridges*, and is present in design codes of other nations using a factored design approach.

The loads and load factors, defined in Section 3, and the resistance factors specified throughout these Specifications were developed using probabilistic principles combined with analyses based on linear material models. Hence, analysis methods based on material nonlinearities to obtain force effects that are more realistic at the strength limit states and subsequent economics that may be derived are permitted only where explicitly outlined herein.

Some nonlinear behavioral effects are addressed in both the analysis and resistance sections. For example, long column behavior may be modeled via geometric nonlinear methods and may also be modeled using approximate formulae in Sections 5, 6, 7, and 8. Either method may be used, but the more refined formulations are recommended.

SECTION 5: CONCRETE STRUCTURES

TABLE OF CONTENTS

5.1—SCOPE 5-1

5.2—DEFINITIONS..... 5-1

5.3—NOTATION..... 5-6

5.4—MATERIAL PROPERTIES 5-15

 5.4.1—General..... 5-15

 5.4.2—Normal Weight and Lightweight Concrete 5-15

 5.4.2.1—Compressive Strength..... 5-15

 5.4.2.2—Coefficient of Thermal Expansion..... 5-17

 5.4.2.3—Creep and Shrinkage..... 5-17

 5.4.2.3.1—General 5-17

 5.4.2.3.2—Creep 5-17

 5.4.2.3.3—Shrinkage..... 5-19

 5.4.2.4—Modulus of Elasticity..... 5-20

 5.4.2.5—Poisson’s Ratio 5-20

 5.4.2.6—Modulus of Rupture..... 5-20

 5.4.2.7—Tensile Strength..... 5-21

 5.4.2.8—Concrete Density Modification Factor..... 5-21

 5.4.3—Reinforcing Steel 5-22

 5.4.3.1—General 5-22

 5.4.3.2—Modulus of Elasticity..... 5-22

 5.4.3.3—Special Applications 5-22

 5.4.4—Prestressing Steel 5-22

 5.4.4.1—General 5-22

 5.4.4.2—Modulus of Elasticity..... 5-23

 5.4.5—Post-Tensioning Anchorages and Couplers 5-23

 5.4.6—Post-Tensioning Ducts 5-23

 5.4.6.1—General 5-23

 5.4.6.2—Size of Ducts..... 5-24

 5.4.6.3—Ducts at Deviation Saddles..... 5-24

5.5—LIMIT STATES AND DESIGN METHODOLOGIES..... 5-24

 5.5.1—General..... 5-24

 5.5.1.1—Limit-State Applicability 5-24

 5.5.1.2—Design Methodologies 5-24

 5.5.1.2.1—General 5-24

 5.5.1.2.2—B-Regions 5-25

 5.5.1.2.3—D-Regions..... 5-25

 5.5.2—Service Limit State..... 5-26

 5.5.3—Fatigue Limit State..... 5-26

 5.5.3.1—General 5-26

 5.5.3.2—Reinforcing Bars and Welded Wire Reinforcement 5-27

 5.5.3.3—Prestressing Steel..... 5-28

 5.5.3.4—Welded or Mechanical Splices of Reinforcement..... 5-28

 5.5.4—Strength Limit State 5-29

 5.5.4.1—General 5-29

 5.5.4.2—Resistance Factors 5-29

 5.5.4.3—Stability..... 5-32

 5.5.5—Extreme Event Limit State..... 5-32

 5.5.5.1—General 5-32

 5.5.5.2—Special Requirements for Seismic Zones 2, 3, and 4..... 5-32

5.6—DESIGN FOR FLEXURAL AND AXIAL FORCE EFFECTS—B REGIONS 5-32

 5.6.1—Assumptions for Service and Fatigue Limit States 5-33

 5.6.2—Assumptions for Strength and Extreme Event Limit States..... 5-33

 5.6.2.1—General 5-33

 5.6.2.2—Rectangular Stress Distribution 5-36

 5.6.3—Flexural Members 5-37

5.6.3.1—Stress in Prestressing Steel at Nominal Flexural Resistance	5-37
5.6.3.1.1—Components with Bonded Tendons	5-37
5.6.3.1.2—Components with Unbonded Tendons	5-38
5.6.3.1.3—Components with Both Bonded and Unbonded Tendons	5-39
5.6.3.1.3a—Detailed Analysis	5-39
5.6.3.1.3b—Simplified Analysis	5-39
5.6.3.2—Flexural Resistance	5-40
5.6.3.2.1—Factored Flexural Resistance	5-40
5.6.3.2.2—Flanged Sections	5-40
5.6.3.2.3—Rectangular Sections	5-41
5.6.3.2.4—Other Cross Sections	5-41
5.6.3.2.5—Strain Compatibility Approach	5-41
5.6.3.2.6—Composite Girder Sections	5-41
5.6.3.3—Minimum Reinforcement	5-42
5.6.3.4—Moment Redistribution	5-43
5.6.3.5—Deformations	5-43
5.6.3.5.1—General	5-43
5.6.3.5.2—Deflection and Camber	5-44
5.6.3.5.3—Axial Deformation	5-45
5.6.4—Compression Members	5-45
5.6.4.1—General	5-45
5.6.4.2—Limits for Reinforcement	5-46
5.6.4.3—Approximate Evaluation of Slenderness Effects	5-47
5.6.4.4—Factored Axial Resistance	5-48
5.6.4.5—Biaxial Flexure	5-49
5.6.4.6—Spirals, Hoops, and Ties	5-50
5.6.4.7—Hollow Rectangular Compression Members	5-51
5.6.4.7.1—Wall Slenderness Ratio	5-51
5.6.4.7.2—Limitations on the Use of the Rectangular Stress Block Method	5-52
5.6.4.7.2a—General	5-52
5.6.4.7.2b—Refined Method for Adjusting Maximum Usable Strain Limit	5-52
5.6.4.7.2c—Approximate Method for Adjusting Factored Resistance	5-52
5.6.5—Bearing	5-53
5.6.6—Tension Members	5-55
5.6.6.1—Resistance to Tension	5-55
5.6.6.2—Resistance to Combined Tension and Flexure	5-55
5.6.7—Control of Cracking by Distribution of Reinforcement	5-55
5.7—DESIGN FOR SHEAR AND TORSION—B-REGIONS	5-58
5.7.1—Design Procedures	5-58
5.7.1.1—Flexural Regions	5-58
5.7.1.2—Regions near Discontinuities	5-58
5.7.1.3—Interface Regions	5-58
5.7.1.4—Slabs and Footings	5-58
5.7.1.5—Webs of Curved Post-Tensioned Box Girder Bridges	5-58
5.7.2—General Requirements	5-59
5.7.2.1—General	5-59
5.7.2.2—Transfer and Development Lengths	5-61
5.7.2.3—Regions Requiring Transverse Reinforcement	5-61
5.7.2.4—Types of Transverse Reinforcement	5-62
5.7.2.5—Minimum Transverse Reinforcement	5-62
5.7.2.6—Maximum Spacing of Transverse Reinforcement	5-63
5.7.2.7—Design and Detailing Requirements	5-64
5.7.2.8—Shear Stress on Concrete	5-64
5.7.3—Sectional Design Model	5-66
5.7.3.1—General	5-66
5.7.3.2—Sections near Supports	5-66
5.7.3.3—Nominal Shear Resistance	5-67

5.7.3.4—Procedures for Determining Shear Resistance Parameters β and θ	5-69
5.7.3.4.1—Simplified Procedure for Nonprestressed Sections.....	5-70
5.7.3.4.2—General Procedure	5-70
5.7.3.5—Longitudinal Reinforcement	5-75
5.7.3.6—Sections Subjected to Combined Shear and Torsion	5-77
5.7.3.6.1—Transverse Reinforcement.....	5-77
5.7.3.6.2—Torsional Resistance.....	5-77
5.7.3.6.3—Longitudinal Reinforcement.....	5-78
5.7.4—Interface Shear Transfer—Shear Friction	5-79
5.7.4.1—General	5-79
5.7.4.2—Minimum Area of Interface Shear Reinforcement.....	5-79
5.7.4.3—Interface Shear Resistance.....	5-80
5.7.4.4—Cohesion and Friction Factors	5-81
5.7.4.5—Computation of the Factored Interface Shear Force for Girder/Slab Bridges.....	5-83
5.7.4.6—Interface Shear in Box Girder Bridges.....	5-85
5.8—DESIGN OF D-REGIONS	5-85
5.8.1—General.....	5-85
5.8.2—Strut-and-Tie Method (STM).....	5-85
5.8.2.1—General	5-85
5.8.2.2—Structural Modeling	5-87
5.8.2.3—Factored Resistance	5-93
5.8.2.4—Proportioning of Ties.....	5-93
5.8.2.4.1—Strength of Tie.....	5-93
5.8.2.4.2—Anchorage of Tie.....	5-93
5.8.2.5—Proportioning of Node Regions	5-94
5.8.2.5.1—Strength of a Node Face	5-94
5.8.2.5.2—Effective Cross-Sectional Area of the Node Face	5-94
5.8.2.5.3—Limiting Compressive Stress at the Node Face	5-95
5.8.2.5.3a—General	5-95
5.8.2.5.3b—Back Face of a CCT Node.....	5-96
5.8.2.6—Crack Control Reinforcement.....	5-97
5.8.2.7—Application to the Design of the General Zones of Post-Tensioning Anchorages.....	5-98
5.8.2.7.1—General	5-98
5.8.2.7.2—Nodes.....	5-100
5.8.2.7.3—Struts.....	5-100
5.8.2.7.4—Ties	5-101
5.8.2.8—Application to the Design of Pier Diaphragms	5-101
5.8.2.9—Application to the Design of Brackets and Corbels.....	5-102
5.8.3—Elastic Stress Analysis	5-103
5.8.3.1—General	5-103
5.8.3.2—General Zones of Post-Tensioning Anchorages.....	5-103
5.8.4—Approximate Stress Analysis and Design.....	5-103
5.8.4.1—Deep Components.....	5-103
5.8.4.2—Brackets and Corbels	5-104
5.8.4.2.1—General	5-104
5.8.4.2.2—Alternative to Strut-and-Tie Model	5-105
5.8.4.3—Beam Ledges	5-106
5.8.4.3.1—General	5-106
5.8.4.3.2—Design for Shear	5-107
5.8.4.3.3—Design for Flexure and Horizontal Force	5-108
5.8.4.3.4—Design for Punching Shear	5-108
5.8.4.3.5—Design of Hanger Reinforcement	5-110
5.8.4.3.6—Design for Bearing.....	5-112
5.8.4.4—Local Zones	5-112
5.8.4.4.1—Dimensions of Local Zone	5-112
5.8.4.4.2—Bearing Resistance	5-113
5.8.4.4.3—Special Anchorage Devices	5-114

5.8.4.5—General Zone of Post-Tensioning Anchorages	5-115
5.8.4.5.1—Limitations of Application	5-115
5.8.4.5.2—Compressive Stresses	5-117
5.8.4.5.3—Bursting Forces	5-118
5.8.4.5.4—Edge Tension Forces	5-119
5.8.4.5.5—Multiple Slab Anchorages	5-119
5.9—PRESTRESSING	5-120
5.9.1—General Design Considerations	5-120
5.9.1.1—General	5-120
5.9.1.2—Design Concrete Strengths	5-121
5.9.1.3—Section Properties	5-121
5.9.1.4—Crack Control	5-121
5.9.1.5—Buckling	5-121
5.9.1.6—Tendons with Angle Points or Curves	5-121
5.9.2—Stress Limitations	5-122
5.9.2.1—Stresses Due to Imposed Deformation	5-122
5.9.2.2—Stress Limitations for Prestressing Steel	5-122
5.9.2.3—Stress Limits for Concrete	5-123
5.9.2.3.1—For Temporary Stresses before Losses	5-123
5.9.2.3.1a—Compressive Stresses	5-123
5.9.2.3.1b—Tensile Stresses	5-123
5.9.2.3.2—For Stresses at Service Limit State after Losses	5-125
5.9.2.3.2a—Compressive Stresses	5-125
5.9.2.3.2b—Tensile Stresses	5-126
5.9.2.3.3—Principal Tensile Stresses in Webs	5-127
5.9.3—Prestress Losses	5-129
5.9.3.1—Total Prestress Loss	5-129
5.9.3.2—Instantaneous Losses	5-130
5.9.3.2.1—Anchorage Set	5-130
5.9.3.2.2—Friction	5-130
5.9.3.2.2a—Pretensioned Members	5-130
5.9.3.2.2b—Post-Tensioned Members	5-130
5.9.3.2.3—Elastic Shortening	5-132
5.9.3.2.3a—Pretensioned Members	5-132
5.9.3.2.3b—Post-Tensioned Members	5-133
5.9.3.2.3c—Combined Pretensioning and Post-Tensioning	5-134
5.9.3.3—Approximate Estimate of Time-Dependent Losses	5-135
5.9.3.4—Refined Estimates of Time-Dependent Losses	5-136
5.9.3.4.1—General	5-136
5.9.3.4.2—Losses: Time of Transfer to Time of Deck Placement	5-137
5.9.3.4.2a—Shrinkage of Girder Concrete	5-137
5.9.3.4.2b—Creep of Girder Concrete	5-138
5.9.3.4.2c—Relaxation of Prestressing Strands	5-138
5.9.3.4.3—Losses: Time of Deck Placement to Final Time	5-139
5.9.3.4.3a—Shrinkage of Girder Concrete	5-139
5.9.3.4.3b—Creep of Girder Concrete	5-139
5.9.3.4.3c—Relaxation of Prestressing Strands	5-140
5.9.3.4.3d—Shrinkage of Deck Concrete	5-140
5.9.3.4.4—Precast Pretensioned Girders without Composite Topping	5-141
5.9.3.4.5—Post-Tensioned Nonsegmental Girders	5-141
5.9.3.5—Losses in Multi-Stage Prestressing	5-141
5.9.3.6—Losses for Deflection Calculations	5-141
5.9.4—Details for Pretensioning	5-142
5.9.4.1—Minimum Spacing of Pretensioning Strand	5-142
5.9.4.2—Maximum Spacing of Pretensioning Strand in Slabs	5-142
5.9.4.3—Development of Pretensioning Strand	5-143
5.9.4.3.1—General	5-143

5.9.4.3.2—Bonded Strand	5-143
5.9.4.3.3—Debonded Strands.....	5-144
5.9.4.4—Pretensioned Anchorage Zones	5-146
5.9.4.4.1—Splitting Resistance	5-146
5.9.4.4.2—Confinement Reinforcement.....	5-147
5.9.4.5—Temporary Strands.....	5-147
5.9.5—Details for Post-Tensioning	5-148
5.9.5.1—Minimum Spacing of Post-Tensioning Tendons and Ducts	5-148
5.9.5.1.1—Post-Tensioning Ducts—Girders Straight in Plane	5-148
5.9.5.1.2—Post-Tensioning Ducts—Girders Curved in Plan	5-149
5.9.5.2—Maximum Spacing of Post-Tensioning Ducts in Slabs.....	5-149
5.9.5.3—Couplers in Post-Tensioning Tendons	5-149
5.9.5.4—Tendon Confinement	5-149
5.9.5.4.1—General	5-149
5.9.5.4.2—Wobble Effect in Slabs.....	5-150
5.9.5.4.3—Effects of Curved Tendons	5-150
5.9.5.4.4—Design for In-Plane Force Effects	5-151
5.9.5.4.4a—In-Plane Force Effects	5-151
5.9.5.4.4b—Shear Resistance to Pullout	5-152
5.9.5.4.4c—Cracking of Cover Concrete	5-154
5.9.5.4.4d—Regional Bending	5-154
5.9.5.4.5—Out-of-Plane Force Effects.....	5-155
5.9.5.5—External Tendon Supports	5-156
5.9.5.6—Post-Tensioned Anchorage Zones	5-156
5.9.5.6.1—General	5-156
5.9.5.6.2—General Zone	5-158
5.9.5.6.3—Local Zone.....	5-158
5.9.5.6.4—Responsibilities.....	5-159
5.9.5.6.5—Design of the General Zone.....	5-159
5.9.5.6.5a—Design Methods.....	5-159
5.9.5.6.5b—Design Principles.....	5-160
5.9.5.6.6—Special Anchorage Devices	5-164
5.9.5.6.7—Intermediate Anchorages	5-164
5.9.5.6.7a—General	5-164
5.9.5.6.7b—Crack Control behind Intermediate Anchors.....	5-164
5.9.5.6.7c—Blister and Rib Reinforcement	5-166
5.9.5.6.8—Diaphragms.....	5-166
5.9.5.6.9—Deviation Saddles	5-167
5.10—REINFORCEMENT	5-167
5.10.1—Concrete Cover	5-167
5.10.2—Hooks and Bends	5-169
5.10.2.1—Standard Hooks.....	5-169
5.10.2.2—Seismic Hooks	5-170
5.10.2.3—Minimum Bend Diameters.....	5-170
5.10.3—Spacing of Reinforcement.....	5-171
5.10.3.1 Minimum Spacing of Reinforcing Bars	5-171
5.10.3.1.1—Cast-in-Place Concrete	5-171
5.10.3.1.2—Precast Concrete	5-171
5.10.3.1.3—Multilayers.....	5-171
5.10.3.1.4—Splices.....	5-171
5.10.3.1.5—Bundled Bars	5-171
5.10.3.2—Maximum Spacing of Reinforcing Bars	5-172
5.10.4—Transverse Reinforcement for Compression Members.....	5-172
5.10.4.1—General.....	5-172
5.10.4.2—Spirals	5-172
5.10.4.3—Ties	5-173
5.10.5—Transverse Reinforcement for Flexural Members	5-174

5.10.6—Shrinkage and Temperature Reinforcement.....	5-174
5.10.7—Reinforcement for Hollow Rectangular Compression Members	5-175
5.10.7.1—General.....	5-175
5.10.7.2—Spacing of Reinforcement.....	5-175
5.10.7.3—Ties.....	5-175
5.10.7.4—Splices	5-176
5.10.7.5—Hoops	5-176
5.10.8—Development and Splices of Reinforcement	5-176
5.10.8.1—General	5-176
5.10.8.1.1—Basic Requirements	5-176
5.10.8.1.2—Flexural Reinforcement	5-177
5.10.8.1.2a—General.....	5-177
5.10.8.1.2b—Positive Moment Reinforcement	5-178
5.10.8.1.2c—Negative Moment Reinforcement.....	5-179
5.10.8.1.2d—Moment Resisting Joints.....	5-179
5.10.8.2—Development of Reinforcement	5-179
5.10.8.2.1—Deformed Bars and Deformed Wire in Tension	5-180
5.10.8.2.1a—Tension Development Length.....	5-180
5.10.8.2.1b—Modification Factors which Increase ℓ_d	5-181
5.10.8.2.1c—Modification Factors which Decrease ℓ_d	5-181
5.10.8.2.2—Deformed Bars in Compression.....	5-183
5.10.8.2.2a—Compressive Development Length.....	5-183
5.10.8.2.2b—Modification Factors.....	5-183
5.10.8.2.3—Bundled Bars.....	5-183
5.10.8.2.4—Standard Hooks in Tension.....	5-184
5.10.8.2.4a—Basic Hook Development Length.....	5-184
5.10.8.2.4b—Modification Factors.....	5-185
5.10.8.2.4c—Hooked-Bar Tie Requirements	5-185
5.10.8.2.5—Welded Wire Reinforcement	5-186
5.10.8.2.6—Shear Reinforcement.....	5-187
5.10.8.2.6a—General.....	5-187
5.10.8.2.6b—Anchorage of Deformed Reinforcement.....	5-188
5.10.8.2.6c—Anchorage of Wire Fabric Reinforcement.....	5-188
5.10.8.2.6d—Closed Stirrups.....	5-189
5.10.8.3—Development by Mechanical Anchorages.....	5-189
5.10.8.4—Splices of Bar Reinforcement	5-189
5.10.8.4.1—Detailing	5-190
5.10.8.4.2—General Requirements.....	5-190
5.10.8.4.2a—Lap Splices.....	5-190
5.10.8.4.2b—Mechanical Connections.....	5-191
5.10.8.4.2c—Welded Splices.....	5-191
5.10.8.4.3—Splices of Reinforcement in Tension	5-191
5.10.8.4.3a—Lap Splices in Tension.....	5-191
5.10.8.4.3b—Mechanical Connections or Welded Splices in Tension.....	5-192
5.10.8.4.4—Splices in Tie Members	5-192
5.10.8.4.5—Splices of Bars in Compression	5-192
5.10.8.4.5a—Lap Splices in Compression.....	5-192
5.10.8.4.5b—Mechanical Connections or Welded Splices in Compression.....	5-193
5.10.8.4.5c—End-Bearing Splices.....	5-193
5.10.8.5—Splices of Welded Wire Reinforcement.....	5-194
5.10.8.5.1—Splices of Deformed Welded Wire Reinforcement in Tension.....	5-194
5.10.8.5.2—Splices of Plain Welded Wire Reinforcement in Tension.....	5-194
5.11—SEISMIC DESIGN AND DETAILS	5-195
5.11.1—General.....	5-195
5.11.2—Seismic Zone 1	5-195
5.11.3—Seismic Zone 2.....	5-196
5.11.3.1—General.....	5-196

5.11.3.2—Concrete Piles	5-196
5.11.3.2.1—General	5-196
5.11.3.2.2—Cast-in-Place Piles	5-197
5.11.3.2.3—Precast Reinforced Piles	5-197
5.11.3.2.4—Precast Prestressed Piles	5-197
5.11.4—Seismic Zones 3 and 4	5-197
5.11.4.1—Column Requirements	5-197
5.11.4.1.1—Longitudinal Reinforcement	5-198
5.11.4.1.2—Flexural Resistance	5-198
5.11.4.1.3—Column Shear and Transverse Reinforcement	5-198
5.11.4.1.4—Transverse Reinforcement for Confinement at Plastic Hinges	5-199
5.11.4.1.5—Spacing of Transverse Reinforcement for Confinement	5-201
5.11.4.1.6—Splices	5-202
5.11.4.2—Requirements for Wall-Type Piers	5-203
5.11.4.3—Column Connections	5-203
5.11.4.4—Construction Joints in Piers and Columns	5-204
5.11.4.5—Concrete Piles	5-204
5.11.4.5.1—General	5-204
5.11.4.5.2—Confinement Length	5-204
5.11.4.5.3—Volumetric Ratio for Confinement	5-205
5.11.4.5.4—Cast-in-Place Piles	5-205
5.11.4.5.5—Precast Piles	5-205
5.12—PROVISIONS FOR STRUCTURE COMPONENTS AND TYPES	5-205
5.12.1—Deck Slabs	5-205
5.12.2—Slab Superstructures	5-205
5.12.2.1—Cast-in-Place Solid Slab Superstructures	5-205
5.12.2.2—Cast-in-Place Voids Slab Superstructures	5-206
5.12.2.2.1—Cross Section Dimensions	5-206
5.12.2.2.2—Minimum Number of Bearings	5-207
5.12.2.2.3—Solid End Sections	5-207
5.12.2.2.4—General Design Requirements	5-207
5.12.2.2.5—Compressive Zones in Negative Moment Area	5-207
5.12.2.2.6—Drainage of Voids	5-208
5.12.2.3—Precast Deck Bridges	5-208
5.12.2.3.1—General	5-208
5.12.2.3.2—Shear Transfer Joints	5-208
5.12.2.3.3—Shear-Flexure Transfer Joints	5-208
5.12.2.3.3a—General	5-208
5.12.2.3.3b—Design	5-209
5.12.2.3.3c—Post-Tensioning	5-209
5.12.2.3.3d—Longitudinal Construction Joints	5-209
5.12.2.3.3e—Cast-in-Place Closure Joints	5-209
5.12.2.3.3f—Structural Overlay	5-209
5.12.3—Beams and Girders	5-210
5.12.3.1—General	5-210
5.12.3.2—Precast Beams	5-210
5.12.3.2.1—Preservice Conditions	5-210
5.12.3.2.2—Extreme Dimensions	5-210
5.12.3.2.3—Lifting Devices	5-211
5.12.3.2.4—Detail Design	5-211
5.12.3.2.5—Concrete Strength	5-211
5.12.3.3—Bridges Composed of Simple Span Precast Girders Made Continuous	5-211
5.12.3.3.1—General	5-211
5.12.3.3.2—Restraint Moments	5-212
5.12.3.3.3—Material Properties	5-212
5.12.3.3.4—Age of Girder When Continuity Is Established	5-213
5.12.3.3.5—Degree of Continuity at Various Limit States	5-214

5.12.3.3.6—Service Limit State.....	5-215
5.12.3.3.7—Strength Limit State	5-215
5.12.3.3.8—Negative Moment Connections.....	5-216
5.12.3.3.9—Positive Moment Connections	5-216
5.12.3.3.9a—General.....	5-216
5.12.3.3.9b—Positive Moment Connection Using Nonprestressed Reinforcement	5-217
5.12.3.3.9c—Positive Moment Connection Using Prestressing Strand.....	5-217
5.12.3.3.9d—Details of Positive Moment Connection	5-218
5.12.3.3.10—Continuity Diaphragms	5-218
5.12.3.4—Spliced Precast Girders	5-219
5.12.3.4.1—General.....	5-219
5.12.3.4.2—Joints Between Spliced Girders	5-220
5.12.3.4.2a—General.....	5-220
5.12.3.4.2b—Details of Closure Joints	5-221
5.12.3.4.2c—Details of Match-Cast Joints	5-221
5.12.3.4.2d—Joint Design	5-221
5.12.3.4.3—Girder Segment Design.....	5-222
5.12.3.4.4—Post-Tensioning	5-222
5.12.3.5—Cast-in-Place Box Girders and T-Beams	5-223
5.12.3.5.1—Flange and Web Thickness	5-223
5.12.3.5.1a—Top Flange	5-223
5.12.3.5.1b—Bottom Flange	5-223
5.12.3.5.1c—Web.....	5-223
5.12.3.5.2—Reinforcement.....	5-223
5.12.3.5.2a—Deck Slab Reinforcement Cast-in-Place in T-Beams and Box Girders	5-223
5.12.3.5.2b—Bottom Slab Reinforcement in Cast-in-Place Box Girders.....	5-224
5.12.4—Diaphragms	5-224
5.12.5—Segmental Concrete Bridges	5-224
5.12.5.1—General	5-224
5.12.5.2—Analysis of Segmental Bridges	5-225
5.12.5.2.1—General.....	5-225
5.12.5.2.2—Construction Analysis.....	5-225
5.12.5.2.3—Analysis of the Final Structural System.....	5-225
5.12.5.3—Design	5-226
5.12.5.3.1—Loads.....	5-226
5.12.5.3.2—Construction Loads	5-226
5.12.5.3.3—Construction Load Combinations at the Service Limit State	5-227
5.12.5.3.4—Construction Load Combinations at Strength Limit States	5-230
5.12.5.3.4a—Superstructure Load Effects and Structural Stability	5-230
5.12.5.3.4b—Substructures.....	5-230
5.12.5.3.5—Thermal Effects During Construction.....	5-230
5.12.5.3.6—Creep and Shrinkage	5-230
5.12.5.3.7—Prestress Losses	5-231
5.12.5.3.8—Alternative Shear Design Procedure	5-232
5.12.5.3.8a—General.....	5-232
5.12.5.3.8b—Loading	5-232
5.12.5.3.8c—Nominal Shear Resistance	5-232
5.12.5.3.8d—Torsional Reinforcement	5-234
5.12.5.3.8e—Reinforcement Details.....	5-235
5.12.5.3.9—Provisional Post-Tensioning Ducts and Anchorages	5-235
5.12.5.3.9a—General.....	5-235
5.12.5.3.9b—Bridges with Internal Ducts	5-236
5.12.5.3.9c—Provision for Future Dead Load or Deflection Adjustment	5-236
5.12.5.3.10—Plan Presentation.....	5-236
5.12.5.3.11—Box Girder Cross section Dimensions and Details	5-237
5.12.5.3.11a—Minimum Flange Thickness.....	5-237
5.12.5.3.11b—Minimum Web Thickness.....	5-237

5.12.5.3.11c—Length of Top Flange Cantilever	5-238
5.12.5.3.11d—Overall Cross Section Dimensions	5-238
5.12.5.3.12—Seismic Design	5-239
5.12.5.4—Types of Segmental Bridges	5-239
5.12.5.4.1—General	5-239
5.12.5.4.2—Details for Precast Construction	5-240
5.12.5.4.3—Details for Cast-in-Place Construction	5-241
5.12.5.4.4—Cantilever Construction	5-241
5.12.5.4.5—Span-by-Span Construction	5-242
5.12.5.4.6—Incrementally Launched Construction	5-242
5.12.5.4.6a—General	5-242
5.12.5.4.6b—Force Effects Due to Construction Tolerances	5-242
5.12.5.4.6c—Design Details	5-243
5.12.5.4.6d—Design of Construction Equipment	5-244
5.12.5.5—Use of Alternative Construction Methods	5-245
5.12.5.6—Segmentally Constructed Bridge Substructures	5-247
5.12.5.6.1—General	5-247
5.12.5.6.2—Construction Load Combinations	5-247
5.12.5.6.3—Longitudinal Reinforcement of Hollow, Rectangular Precast Segmental Piers	5-247
5.12.6—Arches	5-247
5.12.6.1—General	5-247
5.12.6.2—Arch Ribs	5-247
5.12.7—Culverts	5-248
5.12.7.1—General	5-248
5.12.7.2—Design for Flexure	5-248
5.12.7.3—Design for Shear in Slabs of Box Culverts	5-248
5.12.8—Footings	5-249
5.12.8.1—General	5-249
5.12.8.2—Loads and Reactions	5-249
5.12.8.3—Resistance Factors	5-250
5.12.8.4—Moment in Footings	5-250
5.12.8.5—Distribution of Moment Reinforcement	5-250
5.12.8.6—Shear in Slabs and Footings	5-251
5.12.8.6.1—Critical Sections for Shear	5-251
5.12.8.6.2—One-Way Action	5-251
5.12.8.6.3—Two-Way Action	5-251
5.12.8.7—Development of Reinforcement	5-252
5.12.8.8—Transfer of Force at Base of Column	5-252
5.12.9—Concrete Piles	5-253
5.12.9.1—General	5-253
5.12.9.2—Splices	5-254
5.12.9.3—Precast Reinforced Piles	5-254
5.12.9.3.1—Pile Dimensions	5-254
5.12.9.3.2—Reinforcement	5-254
5.12.9.4—Precast Prestressed Piles	5-254
5.12.9.4.1—Pile Dimensions	5-254
5.12.9.4.2—Concrete Quality	5-255
5.12.9.4.3—Reinforcement	5-255
5.12.9.5—Cast-in-Place Piles	5-255
5.12.9.5.1—Pile Dimensions	5-256
5.12.9.5.2—Reinforcement	5-256
5.13—ANCHORS	5-256
5.13.1—General	5-256
5.13.2—General Strength Requirements	5-258
5.13.2.1—Failure Modes to be Considered	5-258
5.13.2.2—Resistance Factors	5-258
5.13.2.3—Determination of Anchor Resistance	5-259

5.13.3—Seismic Design Requirements	5-259
5.13.4—Installation.....	5-260
5.14—DURABILITY	5-260
5.14.1—Design Concepts	5-260
5.14.2—Major Chemical and Mechanical Factors Affecting Durability	5-261
5.14.2.1—General	5-261
5.14.2.2—Corrosion Resistance.....	5-263
5.14.2.3—Freeze–Thaw Resistance	5-263
5.14.2.4—External Sulfate Attack	5-264
5.14.2.5—Delayed Ettringite Formation.....	5-264
5.14.2.6—Alkali–Silica Reactive Aggregates	5-264
5.14.2.7—Alkali–Carbonate Reactive Aggregates	5-264
5.14.3—Concrete Cover	5-265
5.14.4—Corrosion-Resistant Reinforcement	5-265
5.14.5—Deck Protection Systems.....	5-265
5.14.6—Protection for Prestressing Tendons.....	5-265
5.15—REFERENCES.....	5-266
APPENDIX A5—BASIC STEPS FOR CONCRETE BRIDGES	5-279
A5.1—GENERAL	5-279
A5.2—GENERAL CONSIDERATIONS.....	5-279
A5.3—BEAM AND GIRDER SUPERSTRUCTURE DESIGN.....	5-279
A5.4—SLAB BRIDGES.....	5-280
A5.5—SUBSTRUCTURE DESIGN	5-281
APPENDIX B5—GENERAL PROCEDURE FOR SHEAR DESIGN WITH TABLES.....	5-283
B5.1—BACKGROUND	5-283
B5.2—SECTIONAL DESIGN MODEL—GENERAL PROCEDURE	5-283
APPENDIX C5—UPPER LIMITS FOR ARTICLES AFFECTED BY CONCRETE COMPRESSIVE STRENGTH.....	5-291
APPENDIX D5—ARTICLES MODIFIED TO ALLOW THE USE OF REINFORCEMENT WITH A SPECIFIED MINIMUM YIELD STRENGTH UP TO 100 KSI.....	5-293
APPENDIX E5—CROSSWALK BETWEEN 7 TH AND 8 TH EDITIONS	5-297

SECTION 5

CONCRETE STRUCTURES

Commentary is opposite the text it annotates.

5.1—SCOPE

The provisions in this Section apply to the design of bridge and ancillary structures constructed of normal weight or lightweight concrete and reinforced with steel bars, welded wire reinforcement, and/or prestressing strands, bars, or wires. The provisions are based on design concrete compressive strengths varying from 2.4 ksi to 10.0 ksi for normal weight and lightweight concrete, except where higher strengths not exceeding 15.0 ksi are allowed for normal weight concrete. The exceptions are noted in the specific articles and tabulated in Appendix C5.

The provisions of this Section characterize regions of concrete structures by their behavior as B- (beam or Bernoulli) Regions or D- (disturbed or discontinuity) Regions, as defined in Article 5.2. The characterization of regions into B-Regions and D-Regions is discussed in Article 5.5.1.

The provisions of this Section combine and unify the requirements for reinforced and prestressed concrete.

A brief outline for the design of some routine concrete components is contained in Appendix A5.

C5.1

This section was substantially reorganized and updated in the 8th Edition. As a transitional aid in locating information retained from the 7th Edition, a cross-walk between article numbers in the 7th and 8th Editions was included in Appendix E5 and remains in the 9th Edition as a historical reference.

These specifications use kips and ksi units. Some other specifications, such as ACI 318, use pound and psi units. For most variables the conversion is obvious, but for those which have the form $N\sqrt{f'_c}$, the conversion is

$\frac{N\sqrt{f'_c}}{\sqrt{1,000}}$. For commonly used values of N , the relation

between psi and ksi is given below:

N , psi	N , ksi
1	0.0316
2	0.0632
3	0.0948
4	0.126
6	0.190
7.5	0.237
12	0.379

5.2—DEFINITIONS

Adhesive Anchor—A post-installed anchor, inserted into hardened concrete with an anchor hole diameter not greater than 1.5 times the anchor diameter, that transfers loads to the concrete by characteristic bond of the anchor system as defined in ACI 318-14.

Anchor—Steel element either cast into concrete or post-installed into a hardened concrete member and used to transmit applied loads to the concrete. Cast-in-place anchors include headed bolts, hooked bolts (J- or L-bolt), and headed studs. Post-installed anchors include expansion anchors, undercut anchors, and adhesive anchors. Steel elements for adhesive anchors include threaded rods, deformed reinforcing bars, or internally threaded steel sleeves with external deformations.

Anchor Pullout Strength—The strength corresponding to the anchoring device or a major component of the device sliding out from the concrete without breaking out a substantial portion of the surrounding concrete.

Anchorage—In post-tensioning, a mechanical device used to anchor the tendon to the concrete; in pretensioning, a device used to anchor the tendon until the concrete has reached a predetermined strength, and the prestressing force has been transferred to the concrete; for reinforcing bars, a length of reinforcement, or a mechanical anchor or hook, or combination thereof at the end of a bar needed to transfer the force carried by the bar into the concrete.

Anchorage Blister—A build-out area in the web, flange, or flange–web junction for the incorporation of tendon anchorage fittings.

Anchorage Zone—The portion of the structure in which the prestressing force is transferred from the anchorage device onto the local zone of the concrete, and then distributed more widely into the general zone of the structure.

At Jacking—At the time of tensioning the prestressing tendons.

SECTION 6: STEEL STRUCTURES

TABLE OF CONTENTS

6.1—SCOPE.....	6-1
6.2—DEFINITIONS.....	6-2
6.3—NOTATION.....	6-12
6.4—MATERIALS.....	6-30
6.4.1—Structural Steels.....	6-30
6.4.2—Pins, Rollers, and Rockers.....	6-32
6.4.3—Bolts, Nuts, and Washers.....	6-32
6.4.3.1—High-Strength Structural Fasteners.....	6-32
6.4.3.1.1—High-Strength Bolts.....	6-32
6.4.3.1.2—Nuts Used with ASTM F3125 Bolts.....	6-32
6.4.3.1.3—Washers Used with ASTM F3125 Bolts.....	6-32
6.4.3.1.4—Direct Tension Indicators.....	6-33
6.4.3.2—Low-Strength Steel Bolts.....	6-33
6.4.3.3—Fasteners for Structural Anchorage.....	6-33
6.4.3.3.1—Anchor Rods.....	6-33
6.4.3.3.2—Nuts Used with Anchor Rods.....	6-33
6.4.4—Stud Shear Connectors.....	6-33
6.4.5—Weld Metal.....	6-34
6.4.6—Cast Metal.....	6-34
6.4.6.1—Cast Steel and Ductile Iron.....	6-34
6.4.6.2—Malleable Castings.....	6-34
6.4.6.3—Cast Iron.....	6-34
6.4.7—Stainless Steel.....	6-34
6.4.8—Cables.....	6-35
6.4.8.1—Bright Wire.....	6-35
6.4.8.2—Galvanized Wire.....	6-35
6.4.8.3—Epoxy-Coated Wire.....	6-35
6.4.8.4—Bridge Strand.....	6-35
6.4.9—Dissimilar Metals.....	6-35
6.5—LIMIT STATES.....	6-35
6.5.1—General.....	6-35
6.5.2—Service Limit State.....	6-35
6.5.3—Fatigue and Fracture Limit State.....	6-36
6.5.4—Strength Limit State.....	6-36
6.5.4.1—General.....	6-36
6.5.4.2—Resistance Factors.....	6-36
6.5.5—Extreme Event Limit State.....	6-37
6.6—FATIGUE AND FRACTURE CONSIDERATIONS.....	6-38
6.6.1—Fatigue.....	6-38
6.6.1.1—General.....	6-38
6.6.1.2—Load-Induced Fatigue.....	6-38
6.6.1.2.1—Application.....	6-38
6.6.1.2.2—Design Criteria.....	6-39
6.6.1.2.3—Detail Categories.....	6-40
6.6.1.2.4—Detailing to Reduce Constraint.....	6-53
6.6.1.2.5—Fatigue Resistance.....	6-56
6.6.1.3—Distortion-Induced Fatigue.....	6-60
6.6.1.3.1—Transverse Connection Plates.....	6-60
6.6.1.3.2—Lateral Connection Plates.....	6-61
6.6.1.3.3—Orthotropic Decks.....	6-61
6.6.2—Fracture.....	6-61
6.6.2.1—Member or Component Designations and Charpy V-Notch Testing Requirements.....	6-61
6.6.2.2—Fracture-Critical Members.....	6-64
6.7—GENERAL DIMENSION AND DETAIL REQUIREMENTS.....	6-65

6.7.1—Effective Length of Span	6-65
6.7.2—Dead Load Camber and Detailing of Structural Components	6-65
6.7.3—Minimum Thickness of Steel	6-71
6.7.4—Diaphragms and Cross-Frames	6-71
6.7.4.1—General	6-71
6.7.4.2—I-Section Members	6-72
6.7.4.3—Composite Box-Section Members	6-76
6.7.4.4—Noncomposite Box-Section Members	6-77
6.7.4.4.1—General	6-77
6.7.4.4.2—Square and Rectangular HSS Members	6-77
6.7.4.4.3—Welded and Nonwelded Built-Up Noncomposite Box-Section Members	6-78
6.7.4.5—Trusses and Arches	6-79
6.7.5—Lateral Bracing	6-79
6.7.5.1—General	6-79
6.7.5.2—I-Section Members	6-80
6.7.5.3—Tub Section Members	6-80
6.7.5.4—Trusses	6-83
6.7.6—Pins	6-83
6.7.6.1—Location	6-83
6.7.6.2—Resistance	6-83
6.7.6.2.1—Combined Flexure and Shear	6-83
6.7.6.2.2—Bearing	6-84
6.7.6.3—Minimum Size Pin for Eyebars	6-84
6.7.6.4—Pins and Pin Nuts	6-84
6.7.7—Heat-Curved Rolled Beams and Welded Plate Girders	6-85
6.7.7.1—Scope	6-85
6.7.7.2—Geometric Limitations	6-85
6.7.8—Bent Plates	6-85
6.8—TENSION MEMBERS	6-86
6.8.1—General	6-86
6.8.2—Tensile Resistance	6-86
6.8.2.1—General	6-86
6.8.2.2—Reduction Factor, U	6-87
6.8.2.3—Combined Axial Tension, Flexure, and Flexural and/or Torsional Shear	6-90
6.8.2.3.1—General	6-90
6.8.2.3.2—Interaction with Torsional and/or Flexural Shear	6-92
6.8.2.3.3—Tension Rupture under Axial Tension or Compression Combined with Flexure	6-93
6.8.3—Net Area	6-95
6.8.4—Limiting Slenderness Ratio for Tension Members	6-95
6.8.5—Builtup Members	6-96
6.8.5.1—General	6-96
6.8.5.2—Perforated Plates	6-96
6.8.6—Eyebars	6-96
6.8.6.1—Factored Resistance	6-96
6.8.6.2—Proportions	6-96
6.8.6.3—Packing	6-97
6.8.7—Pin-Connected Plates	6-97
6.8.7.1—General	6-97
6.8.7.2—Pin Plates	6-97
6.8.7.3—Proportions	6-98
6.8.7.4—Packing	6-98
6.9—COMPRESSION MEMBERS	6-98
6.9.1—General	6-98
6.9.2—Compressive Resistance	6-99
6.9.2.1—Axial Compression	6-99
6.9.2.2—Combined Axial Compression, Flexure, and Flexural and/or Torsional Shear	6-99
6.9.2.2.1—General	6-99
6.9.2.2.2—Interaction with Torsional and/or Flexural Shear	6-102

6.9.3—Limiting Slenderness Ratio for Compression Members	6-108
6.9.4—Noncomposite Members	6-109
6.9.4.1—Nominal Compressive Resistance	6-109
6.9.4.1.1—General	6-109
6.9.4.1.2—Elastic Flexural Buckling Resistance	6-113
6.9.4.1.3—Elastic Torsional Buckling and Flexural–Torsional Buckling Resistance.....	6-113
6.9.4.2—Effects of Local Buckling on the Nominal Compressive Resistance.....	6-115
6.9.4.2.1—Classification of Cross-Section Elements.....	6-115
6.9.4.2.2—Slender Longitudinally Unstiffened Cross-Section Elements.....	6-117
6.9.4.2.2a—General	6-117
6.9.4.2.2b—Effective Width of Slender Elements	6-119
6.9.4.2.2c—Effective Area of Circular Tubes and Round HSS	6-121
6.9.4.3—Built-Up Members	6-121
6.9.4.3.1—General	6-121
6.9.4.3.2—Perforated Plates	6-122
6.9.4.4—Single-Angle Members	6-123
6.9.4.5—Plate Buckling under Service and Construction Loads.....	6-126
6.9.5—Composite Members	6-128
6.9.5.1—Nominal Compressive Resistance	6-128
6.9.5.2—Limitations.....	6-130
6.9.5.2.1—General	6-130
6.9.5.2.2—Concrete-Filled Tubes	6-130
6.9.5.2.3—Concrete-Encased Shapes	6-130
6.9.6—Composite Concrete-Filled Steel Tubes (CFSTs).....	6-130
6.9.6.1—General	6-130
6.9.6.2—Limitations.....	6-131
6.9.6.3—Combined Axial Compression and Flexure.....	6-132
6.9.6.3.1—General	6-132
6.9.6.3.2—Axial Compressive Resistance	6-133
6.9.6.3.3—Nominal Flexural Composite Resistance.....	6-134
6.9.6.3.4—Nominal Stability-Based Interaction Curve.....	6-134
6.10—I-SECTION FLEXURAL MEMBERS.....	6-135
6.10.1—General.....	6-135
6.10.1.1—Composite Sections	6-137
6.10.1.1.1—Stresses	6-137
6.10.1.1.1a—Sequence of Loading	6-137
6.10.1.1.1b—Stresses for Sections in Positive Flexure.....	6-137
6.10.1.1.1c—Stresses for Sections in Negative Flexure.....	6-138
6.10.1.1.1d—Concrete Deck Stresses	6-138
6.10.1.1.1e—Effective Width of Concrete Deck.....	6-139
6.10.1.2—Noncomposite Sections	6-139
6.10.1.3—Hybrid Sections	6-139
6.10.1.4—Variable Web Depth Members	6-139
6.10.1.5—Stiffness	6-141
6.10.1.6—Flange Stresses and Member Bending Moments.....	6-142
6.10.1.7—Minimum Negative Flexure Concrete Deck Reinforcement.....	6-144
6.10.1.8—Tension Flanges with Holes.....	6-146
6.10.1.9—Web Bend-Buckling Resistance	6-147
6.10.1.9.1—Webs without Longitudinal Stiffeners.....	6-147
6.10.1.9.2—Webs with Longitudinal Stiffeners.....	6-148
6.10.1.10—Flange-Strength Reduction Factors.....	6-150
6.10.1.10.1—Hybrid Factor, R_h	6-150
6.10.1.10.2—Web Load-Shedding Factor, R_b	6-151
6.10.2—Cross-Section Proportion Limits.....	6-157
6.10.2.1—Web Proportions	6-157
6.10.2.1.1—Webs without Longitudinal Stiffeners.....	6-157
6.10.2.1.2—Webs with Longitudinal Stiffeners.....	6-158
6.10.2.2—Flange Proportions.....	6-158

6.10.3—Constructibility.....	6-160
6.10.3.1—General.....	6-160
6.10.3.2—Flexure.....	6-160
6.10.3.2.1—Discretely Braced Flanges in Compression.....	6-160
6.10.3.2.2—Discretely Braced Flanges in Tension.....	6-162
6.10.3.2.3—Continuously Braced Flanges in Tension or Compression.....	6-162
6.10.3.2.4—Concrete Deck.....	6-163
6.10.3.3—Shear.....	6-163
6.10.3.4—Deck Placement.....	6-163
6.10.3.4.1—General.....	6-163
6.10.3.4.2—Global Displacement Amplification in Narrow I-Girder Bridge Units.....	6-165
6.10.3.5—Dead Load Deflections.....	6-167
6.10.4—Service Limit State.....	6-167
6.10.4.1—Elastic Deformations.....	6-167
6.10.4.2—Permanent Deformations.....	6-168
6.10.4.2.1—General.....	6-168
6.10.4.2.2—Flexure.....	6-168
6.10.5—Fatigue and Fracture Limit State.....	6-171
6.10.5.1—Fatigue.....	6-171
6.10.5.2—Fracture.....	6-171
6.10.5.3—Special Fatigue Requirement for Webs.....	6-171
6.10.6—Strength Limit State.....	6-172
6.10.6.1—General.....	6-172
6.10.6.2—Flexure.....	6-174
6.10.6.2.1—General.....	6-174
6.10.6.2.2—Composite Sections in Positive Flexure.....	6-174
6.10.6.2.3—Composite Sections in Negative Flexure and Noncomposite Sections.....	6-175
6.10.6.3—Shear.....	6-178
6.10.6.4—Shear Connectors.....	6-178
6.10.7—Flexural Resistance—Composite Sections in Positive Flexure.....	6-178
6.10.7.1—Compact Sections.....	6-178
6.10.7.1.1—General.....	6-178
6.10.7.1.2—Nominal Flexural Resistance.....	6-178
6.10.7.2—Noncompact Sections.....	6-181
6.10.7.2.1—General.....	6-181
6.10.7.2.2—Nominal Flexural Resistance.....	6-181
6.10.7.3—Ductility Requirement.....	6-182
6.10.8—Flexural Resistance—Composite Sections in Negative Flexure and Noncomposite Sections.....	6-182
6.10.8.1—General.....	6-182
6.10.8.1.1—Discretely Braced Flanges in Compression.....	6-182
6.10.8.1.2—Discretely Braced Flanges in Tension.....	6-183
6.10.8.1.3—Continuously Braced Flanges in Tension or Compression.....	6-183
6.10.8.2—Compression–Flange Flexural Resistance.....	6-183
6.10.8.2.1—General.....	6-183
6.10.8.2.2—Local Buckling Resistance.....	6-185
6.10.8.2.3—Lateral–Torsional buckling Resistance.....	6-186
6.10.8.3—Flexural Resistance Based on Tension Flange Yielding.....	6-193
6.10.9—Shear Resistance.....	6-193
6.10.9.1—General.....	6-193
6.10.9.2—Nominal Resistance of Unstiffened Webs.....	6-194
6.10.9.3—Nominal Resistance of Stiffened Webs.....	6-194
6.10.9.3.1—General.....	6-194
6.10.9.3.2—Interior Panels.....	6-195
6.10.9.3.3—End Panels.....	6-196
6.10.10—Shear Connectors.....	6-197
6.10.10.1—General.....	6-197
6.10.10.1.1—Types.....	6-197
6.10.10.1.2—Pitch.....	6-197

6.10.10.1.3—Transverse Spacing	6-199
6.10.10.1.4—Cover and Penetration	6-199
6.10.10.2—Fatigue Resistance	6-199
6.10.10.3—Special Requirements for Points of Permanent Load Contraflexure	6-200
6.10.10.4—Strength Limit State	6-201
6.10.10.4.1—General	6-201
6.10.10.4.2—Nominal Shear Force	6-202
6.10.10.4.3—Nominal Shear Resistance	6-203
6.10.11—Web Stiffeners	6-204
6.10.11.1—Web Transverse Stiffeners	6-204
6.10.11.1.1—General	6-204
6.10.11.1.2—Projecting Width	6-204
6.10.11.1.3—Moment of Inertia	6-205
6.10.11.2—Bearing Stiffeners	6-208
6.10.11.2.1—General	6-208
6.10.11.2.2—Minimum Thickness	6-208
6.10.11.2.3—Bearing Resistance	6-209
6.10.11.2.4—Axial Resistance of Bearing Stiffeners	6-209
6.10.11.2.4a—General	6-209
6.10.11.2.4b—Effective Section	6-209
6.10.11.3—Web Longitudinal Stiffeners	6-210
6.10.11.3.1—General	6-210
6.10.11.3.2—Projecting Width	6-212
6.10.11.3.3—Moment of Inertia and Radius of Gyration	6-213
6.10.12—Cover Plates	6-214
6.10.12.1—General	6-214
6.10.12.2—End Requirements	6-214
6.10.12.2.1—General	6-214
6.10.12.2.2—Welded Ends	6-215
6.10.12.2.3—Bolted Ends	6-215
6.11—COMPOSITE BOX-SECTION FLEXURAL MEMBERS	6-215
6.11.1—General	6-215
6.11.1.1—Stress Determinations	6-217
6.11.1.2—Bearings	6-220
6.11.1.3—Flange-to-Web Connections	6-221
6.11.1.4—Access and Drainage	6-221
6.11.2—Cross-Section Proportion Limits	6-222
6.11.2.1—Web Proportions	6-222
6.11.2.1.1—General	6-222
6.11.2.1.2—Webs without Longitudinal Stiffeners	6-222
6.11.2.1.3—Webs with Longitudinal Stiffeners	6-222
6.11.2.2—Flange Proportions	6-222
6.11.2.3—Special Restrictions on Use of Live Load Distribution Factor for Multiple Box Sections	6-222
6.11.3—Constructibility	6-223
6.11.3.1—General	6-223
6.11.3.2—Flexure	6-224
6.11.3.3—Shear	6-226
6.11.4—Service Limit State	6-226
6.11.5—Fatigue and Fracture Limit State	6-227
6.11.6—Strength Limit State	6-229
6.11.6.1—General	6-229
6.11.6.2—Flexure	6-229
6.11.6.2.1—General	6-229
6.11.6.2.2—Sections in Positive Flexure	6-229
6.11.6.2.3—Sections in Negative Flexure	6-230
6.11.6.3—Shear	6-230
6.11.6.4—Shear Connectors	6-231
6.11.7—Flexural Resistance—Sections in Positive Flexure	6-231

6.11.7.1—Compact Sections.....	6-231
6.11.7.1.1—General.....	6-231
6.11.7.1.2—Nominal Flexural Resistance	6-231
6.11.7.2—Noncompact Sections.....	6-231
6.11.7.2.1—General.....	6-231
6.11.7.2.2—Nominal Flexural Resistance	6-232
6.11.8—Flexural Resistance—Sections in Negative Flexure	6-233
6.11.8.1—General.....	6-233
6.11.8.1.1—Box Flanges in Compression	6-233
6.11.8.1.2—Continuously Braced Flanges in Tension	6-234
6.11.8.2—Flexural Resistance of Box Flanges in Compression.....	6-235
6.11.8.2.1—General.....	6-235
6.11.8.2.2—Unstiffened Flanges	6-235
6.11.8.2.3—Longitudinally Stiffened Flanges.....	6-237
6.11.8.3—Flexural Resistance Based on Tension Flange Yielding	6-238
6.11.9—Shear Resistance	6-238
6.11.10—Shear Connectors	6-239
6.11.11—Stiffeners	6-240
6.11.11.1—Web Stiffeners	6-240
6.11.11.2—Longitudinal Compression—Flange Stiffeners.....	6-240
6.12—MISCELLANEOUS FLEXURAL MEMBERS	6-243
6.12.1—General.....	6-243
6.12.1.1—Scope.....	6-243
6.12.1.2—Strength Limit State	6-244
6.12.1.2.1—Flexure	6-244
6.12.1.2.2—Combined Flexure, Axial Load, and Flexural and/or Torsional Shear	6-245
6.12.1.2.3—Flexural Shear and/or Torsion.....	6-245
6.12.1.2.3a—General.....	6-245
6.12.1.2.3b—Circular Tubes and Round HSS.....	6-247
6.12.1.2.4—Special Provisions for HSS Members.....	6-248
6.12.2—Nominal Flexural Resistance	6-248
6.12.2.1—General.....	6-248
6.12.2.2—Noncomposite Members	6-248
6.12.2.2.1—I- and H-Shaped Members	6-248
6.12.2.2.2—Rectangular Box-Section Members	6-249
6.12.2.2.2a—General.....	6-249
6.12.2.2.2b—Cross-Section Proportion Limits.....	6-251
6.12.2.2.2c—Classification of Sections with a Longitudinally Unstiffened Compression flange	6-253
6.12.2.2.2d—Classification of Sections with a Longitudinally Stiffened Compression Flange...6-261	6-261
6.12.2.2.2e—General Yielding, Compression—Flange Local Buckling and Lateral—Torsional Buckling	6-263
6.12.2.2.2f—Service and Fatigue Limit States and Constructibility	6-265
6.12.2.2.2g—Flange Effective Width or Area Accounting for Shear Lag Effects	6-266
6.12.2.2.3—Circular Tubes and Round HSS	6-268
6.12.2.2.4—Tees and Double Angles	6-269
6.12.2.2.4a—General.....	6-269
6.12.2.2.4b—Yielding	6-269
6.12.2.2.4c—Lateral—Torsional Buckling	6-269
6.12.2.2.4d—Flange Local Buckling.....	6-271
6.12.2.2.4e—Local Buckling of Tee Stems and Double Angle Web Legs.....	6-272
6.12.2.2.5—Channels	6-274
6.12.2.2.6—Single Angles.....	6-276
6.12.2.2.7—Rectangular Bars and Solid Rounds.....	6-277
6.12.2.3—Composite Members	6-278
6.12.2.3.1—Concrete-Encased Shapes	6-278
6.12.2.3.2—Concrete-Filled Tubes.....	6-279
6.12.2.3.3—Composite Concrete-Filled Steel Tubes (CFSTs).....	6-279

6.12.3—Nominal Shear Resistance of Composite Members	6-283
6.12.3.1—Concrete-Encased Shapes	6-283
6.12.3.2—Concrete-Filled Tubes	6-283
6.12.3.2.1—Rectangular Tubes	6-283
6.12.3.2.2—Composite Concrete-Filled Steel Tubes	6-283
6.13—CONNECTIONS AND SPLICES	6-284
6.13.1—General	6-284
6.13.2—Bolted Connections	6-285
6.13.2.1—General	6-285
6.13.2.1.1—Slip-Critical Connections	6-285
6.13.2.1.2—Bearing-Type Connections	6-286
6.13.2.2—Factored Resistance	6-286
6.13.2.3—Bolts, Nuts, and Washers	6-287
6.13.2.3.1—Bolts and Nuts	6-287
6.13.2.3.2—Washers	6-287
6.13.2.4—Holes	6-288
6.13.2.4.1—Type	6-288
6.13.2.4.1a—General	6-288
6.13.2.4.1b—Oversize Holes	6-288
6.13.2.4.1c—Short-Slotted Holes	6-288
6.13.2.4.1d—Long-Slotted Holes	6-288
6.13.2.4.2—Size	6-288
6.13.2.5—Size of Bolts	6-288
6.13.2.6—Spacing of Bolts	6-289
6.13.2.6.1—Minimum Spacing and Clear Distance	6-289
6.13.2.6.2—Maximum Spacing for Sealing Bolts	6-289
6.13.2.6.3—Maximum Pitch for Stitch Bolts	6-289
6.13.2.6.4—Maximum Pitch for Stitch Bolts at the End of Compression Members	6-290
6.13.2.6.5—End Distance	6-290
6.13.2.6.6—Edge Distances	6-290
6.13.2.7—Shear Resistance	6-290
6.13.2.8—Slip Resistance	6-291
6.13.2.9—Bearing Resistance at Bolt Holes	6-295
6.13.2.10—Tensile Resistance	6-296
6.13.2.10.1—General	6-296
6.13.2.10.2—Nominal Tensile Resistance	6-296
6.13.2.10.3—Fatigue Resistance	6-296
6.13.2.10.4—Prying Action	6-296
6.13.2.11—Combined Tension and Shear	6-297
6.13.2.12—Shear Resistance of Anchor Rods	6-298
6.13.3—Welded Connections	6-298
6.13.3.1—General	6-298
6.13.3.2—Factored Resistance	6-298
6.13.3.2.1—General	6-298
6.13.3.2.2—Complete Penetration Groove-Welded Connections	6-299
6.13.3.2.2a—Tension and Compression	6-299
6.13.3.2.2b—Shear	6-299
6.13.3.2.3—Partial Penetration Groove-Welded Connections	6-299
6.13.3.2.3a—Tension or Compression	6-299
6.13.3.2.3b—Shear	6-299
6.13.3.2.4—Fillet-Welded Connections	6-300
6.13.3.3—Effective Area	6-300
6.13.3.4—Size of Fillet Welds	6-300
6.13.3.5—Minimum Effective Length of Fillet Welds	6-301
6.13.3.6—Fillet Weld End Returns	6-301
6.13.3.7—Fillet Welds for Sealing	6-301
6.13.4—Block Shear Rupture Resistance	6-302
6.13.5—Connection Elements	6-303

6.13.5.1—General.....	6-303
6.13.5.2—Tension.....	6-303
6.13.5.3—Shear	6-303
6.13.6—Splices	6-304
6.13.6.1—Bolted Splices	6-304
6.13.6.1.1—Tension Members	6-304
6.13.6.1.2—Compression Members	6-304
6.13.6.1.3—Flexural Members	6-304
6.13.6.1.3a—General.....	6-304
6.13.6.1.3b—Flange Splices.....	6-305
6.13.6.1.3c—Web Splices	6-308
6.13.6.1.4—Fillers	6-311
6.13.6.2—Welded Splices.....	6-312
6.13.7—Rigid Frame Connections.....	6-313
6.13.7.1—General.....	6-313
6.13.7.2—Webs	6-313
6.14—PROVISIONS FOR STRUCTURE TYPES	6-314
6.14.1—Through-Girder Spans.....	6-314
6.14.2—Trusses	6-314
6.14.2.1—General.....	6-314
6.14.2.2—Truss Members.....	6-315
6.14.2.3—Secondary Stresses.....	6-315
6.14.2.4—Diaphragms	6-315
6.14.2.5—Camber.....	6-315
6.14.2.6—Working Lines and Gravity Axes	6-316
6.14.2.7—Portal and Sway Bracing.....	6-316
6.14.2.7.1—General.....	6-316
6.14.2.7.2—Through-Truss Spans	6-316
6.14.2.7.3—Deck Truss Spans.....	6-316
6.14.2.8—Gusset Plates	6-316
6.14.2.8.1—General.....	6-316
6.14.2.8.2—Multilayered Gusset and Splice Plates.....	6-317
6.14.2.8.3—Shear Resistance	6-317
6.14.2.8.4—Compressive Resistance.....	6-319
6.14.2.8.5—Tensile Resistance.....	6-320
6.14.2.8.6—Chord Splices.....	6-321
6.14.2.8.7—Edge Slenderness	6-323
6.14.2.9—Half Through-Trusses	6-323
6.14.2.10—Factored Resistance.....	6-323
6.14.3—Orthotropic Deck Superstructures	6-323
6.14.3.1—General.....	6-323
6.14.3.2—Decks in Global Compression.....	6-324
6.14.3.2.1—General.....	6-324
6.14.3.2.2—Local Buckling.....	6-324
6.14.3.2.3—Panel Buckling.....	6-324
6.14.3.3—Effective Width of Deck	6-325
6.14.3.4—Superposition of Global and Local Effects	6-325
6.14.4—Solid Web Arches	6-325
6.14.4.1—General.....	6-325
6.14.4.2—Web Slenderness	6-327
6.14.4.3—Moment Amplification.....	6-327
6.14.4.4—Nominal Compressive Resistance.....	6-327
6.14.4.5—Nominal Flexural Resistance	6-327
6.14.4.6—Combined Axial Compression or Tension with Flexure and Torsion.....	6-328
6.15—PILES	6-328
6.15.1—General.....	6-328
6.15.2—Structural Resistance.....	6-328
6.15.3—Compressive Resistance.....	6-330

6.15.3.1—Axial Compression	6-330
6.15.3.2—Combined Axial Compression and Flexure	6-330
6.15.3.3—Buckling.....	6-330
6.15.4—Maximum Permissible Driving Stresses	6-330
6.16—PROVISIONS FOR SEISMIC DESIGN	6-330
6.16.1—General.....	6-330
6.16.2—Materials	6-332
6.16.3—Design Requirements for Seismic Zone 1.....	6-332
6.16.4—Design Requirements for Seismic Zones 2, 3, or 4.....	6-332
6.16.4.1—General.....	6-332
6.16.4.2—Deck.....	6-333
6.16.4.3—Shear Connectors	6-335
6.16.4.4—Elastic Superstructures.....	6-337
6.17—REFERENCES	6-337
APPENDIX A6—FLEXURAL RESISTANCE OF COMPOSITE I-SECTIONS IN NEGATIVE FLEXURE AND NONCOMPOSITE I-SECTIONS WITH COMPACT OR NONCOMPACT WEBS IN STRAIGHT BRIDGES	6-353
A6.1—GENERAL	6-353
A6.1.1—Sections with Discretely Braced Compression Flanges	6-354
A6.1.2—Sections with Discretely Braced Tension Flanges	6-355
A6.1.3—Sections with Continuously Braced Compression Flanges	6-356
A6.1.4—Sections with Continuously Braced Tension Flanges	6-356
A6.2—WEB PLASTIFICATION FACTORS	6-356
A6.2.1—Compact Web Sections	6-356
A6.2.2—Noncompact Web Sections	6-358
A6.3—FLEXURAL RESISTANCE BASED ON THE COMPRESSION FLANGE	6-359
A6.3.1—General.....	6-359
A6.3.2—Local Buckling Resistance.....	6-360
A6.3.3—Lateral-Torsional buckling Resistance	6-361
A6.4—FLEXURAL RESISTANCE BASED ON TENSION FLANGE YIELDING	6-365
APPENDIX B6—MOMENT REDISTRIBUTION FROM INTERIOR-PIER I-SECTIONS IN STRAIGHT CONTINUOUS-SPAN BRIDGES	6-367
B6.1—GENERAL	6-367
B6.2—SCOPE	6-367
B6.2.1—Web Proportions.....	6-368
B6.2.2—Compression Flange Proportions	6-368
B6.2.3—Section Transitions.....	6-369
B6.2.4—Compression Flange Bracing	6-369
B6.2.5—Shear	6-369
B6.2.6—Bearing Stiffeners.....	6-370
B6.3—SERVICE LIMIT STATE.....	6-370
B6.3.1—General	6-370
B6.3.2—Flexure	6-370
B6.3.2.1—Adjacent to Interior-Pier Sections	6-370
B6.3.2.2—At All Other Locations	6-370
B6.3.3—Redistribution Moments	6-371
B6.3.3.1—At Interior-Pier Sections	6-371
B6.3.3.2—At All Other Locations	6-371
B6.4—STRENGTH LIMIT STATE	6-372
B6.4.1—Flexural Resistance	6-372
B6.4.1.1—Adjacent to Interior-Pier Sections	6-372
B6.4.1.2—At All Other Locations	6-372
B6.4.2—Redistribution Moments	6-372
B6.4.2.1—At Interior-Pier Sections	6-372
B6.4.2.2—At All Other Sections	6-373
B6.5—EFFECTIVE PLASTIC MOMENT	6-373
B6.5.1—Interior-Pier Sections with Enhanced Moment-Rotation Characteristics	6-373
B6.5.2—All Other Interior-Pier Sections	6-374

B6.6—REFINED METHOD	6-374
B6.6.1—General	6-374
B6.6.2—Nominal Moment-Rotation Curves	6-376
APPENDIX C6—BASIC STEPS FOR STEEL BRIDGE SUPERSTRUCTURES	6-379
C6.1—GENERAL	6-379
C6.2—GENERAL CONSIDERATIONS	6-379
C6.3—SUPERSTRUCTURE DESIGN	6-379
C6.4—FLOWCHARTS FOR FLEXURAL DESIGN OF I-SECTION MEMBERS	6-382
C6.4.1—Flowchart for LRFD Article 6.10.3	6-382
C6.4.2—Flowchart for LRFD Article 6.10.4	6-383
C6.4.3—Flowchart for LRFD Article 6.10.5	6-384
C6.4.4—Flowchart for LRFD Article 6.10.6	6-385
C6.4.5—Flowchart for LRFD Article 6.10.7	6-386
C6.4.6—Flowchart for LRFD Article 6.10.8	6-387
C6.4.7—Flowchart for Appendix A6.....	6-389
C6.4.8—Flowchart for Article D6.4.1	6-391
C6.4.9—Flowchart for Article D6.4.2	6-392
C6.4.10—Moment Gradient Modifier, C_b (Sample Cases).....	6-393
C6.5—FLOWCHARTS FOR LRFD ARTICLES 6.9.4 AND 6.12.2.2.2	6-395
C6.5.1—Flowchart for LRFD Article 6.9.4	6-395
C6.5.2—Flowchart for LRFD Article 6.12.2.2.2.....	6-397
APPENDIX D6—FUNDAMENTAL CALCULATIONS FOR FLEXURAL MEMBERS.....	6-400
D6.1—PLASTIC MOMENT	6-401
D6.2—YIELD MOMENT	6-405
D6.2.1—Noncomposite Sections	6-405
D6.2.2—Composite Sections in Positive Flexure	6-405
D6.2.3—Composite Sections in Negative Flexure	6-406
D6.2.4—Sections with Cover Plates.....	6-406
D6.3—DEPTH OF THE WEB IN COMPRESSION	6-406
D6.3.1—In the Elastic Range (D_c).....	6-406
D6.3.2—At Plastic Moment (D_{cp}).....	6-407
D6.4—LATERAL-TORSIONAL BUCKLING EQUATIONS FOR $C_B > 1.0$, WITH EMPHASIS ON UNBRACED LENGTH REQUIREMENTS FOR DEVELOPMENT OF THE MAXIMUM FLEXURAL RESISTANCE	6-408
D6.4.1—By the Provisions of Article 6.10.8.2.3	6-408
D6.4.2—By the Provisions of Article A6.3.3	6-409
D6.5—CONCENTRATED LOADS APPLIED TO WEBS WITHOUT BEARING STIFFENERS	6-410
D6.5.1—General	6-410
D6.5.2—Web Local Yielding	6-410
D6.5.3—Web Crippling.....	6-411
APPENDIX E6—NOMINAL COMPRESSIVE RESISTANCE OF NONCOMPOSITE MEMBERS CONTAINING LONGITUDINALLY STIFFENED PLATES.....	6-413
E6.1—NOMINAL COMPRESSIVE RESISTANCE	6-413
E6.1.1—General	6-413
E6.1.2—Classification of Longitudinally Stiffened Plate Panels.....	6-415
E6.1.3—Nominal Compressive Resistance and Effective Area of Plates with Equally-Spaced Equal-Size Longitudinal Stiffeners	6-415
E6.1.4—Longitudinal Stiffeners	6-419
E6.1.5—Transverse Stiffeners	6-421
E6.1.5.1—General	6-421
E6.1.5.2—Moment of Inertia.....	6-424

SECTION 6

STEEL STRUCTURES

Commentary is opposite the text it annotates.

6.1—SCOPE

This Section addresses the design of steel components, splices, and connections for straight or horizontally-curved beam and girder structures, frames, trusses and arches, cable-stayed and suspension systems, and metal deck systems, as applicable.

When applied to curved steel girders, these provisions shall be taken to apply to the design and construction of highway superstructures with horizontally-curved steel I-shaped or single-cell box-shaped longitudinal girders with radii greater than 100 ft. Exceptions to this limit shall be based on a thorough evaluation of the application of the bridge under consideration consistent with structural fundamentals.

An outline of the steps for the design of steel girder bridges is presented in Appendix C6.

C6.1

The LRFD provisions have no span limit. There has been a history of construction problems associated with curved bridges with spans greater than about 350 ft. Large girder self-weight may cause critical stresses and deflections during erection when the steel work is incomplete. Large lateral deflections and girder rotations associated with longer spans tend to make it difficult to fit up cross-frames. Large curved steel bridges have been built successfully; however, these bridges deserve special considerations such as the possible need for more than one temporary support in large spans.

Most of the provisions for proportioning main elements are grouped by structural action:

- Tension and combined axial tension, flexure, and flexural and/or torsional shear (Article 6.8)
- Compression and combined axial compression, flexure, and flexural and/or torsional shear (Article 6.9)
- Flexure, flexural shear, and torsion:
 - I-sections (Article 6.10)
 - Composite box sections (Article 6.11)
 - Noncomposite box sections and other miscellaneous sections (Article 6.12)

Provisions for connections and splices are contained in Article 6.13.

Article 6.14 contains provisions specific to particular assemblages or structural types, e.g., through-girder spans, trusses, orthotropic deck systems, and arches.

For certain types of steel structures, benefits may be gained by applying advanced analysis methods for the design of the structure and/or its components. Using these methods, the member and structure stability are assessed using a second-order analysis directly considering initial geometric imperfections and residual stress effects. These methods provide greater rigor for consideration of innovative structural systems and member geometries. In addition, they provide capabilities for recognizing reserve capacities not addressed by the Section 6 provisions. Using these procedures, the members may be checked for their local “cross-section level” resistance given refined estimates of the internal strength demands as influenced by the member and overall system stability effects. These types of capabilities typically would be applied by focusing on a limited set of potentially critical factored design load combinations. Hendy and Murphy (2007) discuss the application of these types of methods in the context of steel bridge design according to the Eurocodes. Advanced analysis methods are an area of continued evolution as computer hardware and software continue to grow in their power and capabilities. Generally, advanced

SECTION 7: ALUMINUM STRUCTURES

TABLE OF CONTENTS

7.1—SCOPE	7-1
7.2—DEFINITIONS.....	7-1
7.3—NOTATION.....	7-1
7.4—MATERIALS.....	7-5
7.4.1—Aluminum Alloys	7-5
7.4.2—Pins, Rollers, and Rockers	7-6
7.4.3—Bolts, Nuts, and Washers	7-7
7.4.3.1—Bolts.....	7-7
7.4.3.2—Nuts Used with ASTM F3125 Bolts.....	7-7
7.4.3.3—Washers Used with ASTM F3125 Bolts.....	7-7
7.4.3.4—Direct Tension Indicators.....	7-7
7.4.4—Shear Connectors	7-7
7.4.5—Weld Metal	7-7
7.5—LIMIT STATES.....	7-8
7.5.1—General.....	7-8
7.5.2—Service Limit State.....	7-8
7.5.3—Fatigue Limit State.....	7-8
7.5.4—Strength Limit State	7-8
7.5.4.1—General.....	7-8
7.5.4.2—Resistance Factors	7-8
7.5.4.3—Buckling Constants.....	7-9
7.5.4.4—Nominal Resistance of Elements in Uniform Compression.....	7-10
7.5.4.4.1—General	7-10
7.5.4.4.2—Flat Elements Supported on One Edge	7-11
7.5.4.4.3—Flat Elements Supported on Both Edges	7-11
7.5.4.4.4—Flat Elements Supported on One Edge and with a Stiffener on the Other Edge.....	7-12
7.5.4.4.5—Flat Elements Supported on Both Edges and with an Intermediate Stiffener.....	7-13
7.5.4.4.6—Round Hollow Elements and Curved Elements Supported on Both Edges	7-14
7.5.4.4.7—Alternative Method for Flat Elements	7-15
7.5.4.5—Nominal Resistance of Elements in Flexural Compression	7-15
7.5.4.5.1—General	7-15
7.5.4.5.2—Flat Elements Supported on Both Edges	7-16
7.5.4.5.3—Flat Elements Supported on Tension Edge, Compression Edge Free.....	7-17
7.5.4.5.4—Flat Elements Supported on Both Edges and with a Longitudinal Stiffener	7-17
7.5.4.5.5—Pipes and Round Tubes	7-18
7.5.4.5.6—Alternative Method for Flat Elements	7-18
7.5.4.6—Nominal Resistance of Elements in Shear	7-19
7.5.4.6.1—General	7-19
7.5.4.6.2—Flat Elements Supported on Both Edges	7-19
7.5.4.6.3—Flat Elements Supported on One Edge	7-21
7.5.4.6.4—Pipes and Round or Oval Tubes	7-22
7.5.4.7—Elastic Buckling Stress of Elements	7-23
7.5.5—Extreme Event Limit State.....	7-23
7.6—FATIGUE	7-24
7.6.1—General.....	7-24
7.6.2—Load-Induced Fatigue	7-24
7.6.2.1—Application	7-24
7.6.2.2—Design Criteria.....	7-24
7.6.2.3—Detail Categories	7-24
7.6.2.4—Detailing to Reduce Constraint.....	7-30
7.6.2.5—Fatigue Resistance	7-30
7.6.3—Distortion-Induced Fatigue	7-31
7.6.3.1—Transverse Connection Plates.....	7-31
7.6.3.2—Lateral Connection Plates	7-31
7.7—GENERAL DIMENSION AND DETAIL REQUIREMENTS.....	7-31

7.7.1—Effective Length of Span	7-31
7.7.2—Dead Load Camber	7-31
7.7.3—Minimum Thickness.....	7-31
7.7.4—Diaphragms and Cross-Frames	7-32
7.7.5—Lateral Bracing.....	7-32
7.8—TENSION MEMBERS	7-32
7.8.1—General.....	7-32
7.8.2—Tensile Resistance.....	7-32
7.8.2.1—General.....	7-32
7.8.2.2—Effective Net Area	7-33
7.8.2.3—Combined Tension and Flexure	7-33
7.8.3—Net Area.....	7-34
7.8.4—Limiting Slenderness Ratio	7-34
7.8.5—Built-Up Members	7-35
7.9—COMPRESSION MEMBERS	7-35
7.9.1—General.....	7-35
7.9.2—Axial Compression Resistance.....	7-35
7.9.2.1—Member Buckling	7-35
7.9.2.1.1—General.....	7-35
7.9.2.1.2—Flexural Buckling	7-36
7.9.2.1.3—Torsional and Flexural-Torsional Buckling	7-37
7.9.2.2—Local Buckling.....	7-38
7.9.2.2.1—General.....	7-38
7.9.2.2.2—Weighted Average Local Buckling Resistance.....	7-38
7.9.2.2.3—Alternative Local Buckling Resistance.....	7-38
7.9.2.3—Interaction between Member Buckling and Local Buckling.....	7-38
7.9.3—Limiting Slenderness Ratio	7-39
7.9.4—Combined Axial Compression and Flexure	7-39
7.10—FLEXURAL MEMBERS	7-40
7.10.1—General.....	7-40
7.10.2—Yielding and Rupture	7-40
7.10.3—Local Buckling	7-41
7.10.3.1—Weighted Average Method	7-41
7.10.3.2—Direct Strength Method.....	7-42
7.10.3.3—Limiting Element Method.....	7-42
7.10.4—Lateral-Torsional Buckling.....	7-42
7.10.4.1—Bending Coefficient, C_b	7-43
7.10.4.1.1—Doubly Symmetric Shapes.....	7-43
7.10.4.1.2—Singly Symmetric Shapes	7-44
7.10.4.2—Slenderness for Lateral-Torsional Buckling.....	7-44
7.10.4.2.1—Shapes Symmetric about the Bending Axis	7-44
7.10.4.2.2—Singly Symmetric Open Shapes Asymmetric about the Bending Axis	7-45
7.10.4.2.3—Closed Shapes	7-45
7.10.4.2.4—Rectangular Bars.....	7-45
7.10.4.2.5—Any Shape.....	7-45
7.10.4.3—Interaction between Local Buckling and Lateral-Torsional Buckling.....	7-46
7.11—MEMBERS IN SHEAR	7-47
7.11.1—General.....	7-47
7.11.2—Stiffeners	7-47
7.11.2.1—Crippling of Flat Webs.....	7-47
7.11.2.2—Bearing Stiffeners	7-48
7.11.2.3—Combined Crippling and Bending of Flat Webs	7-48
7.12—CONNECTIONS AND SPLICES.....	7-49
7.12.1—General.....	7-49
7.12.2—Bolted Connections	7-49
7.12.2.1—General.....	7-49
7.12.2.2—Factored Resistance.....	7-49

7.12.2.3—Washers	7-50
7.12.2.4—Holes.....	7-50
7.12.2.5—Size of Bolts.....	7-50
7.12.2.6—Spacing of Bolts.....	7-51
7.12.2.6.1—Minimum Spacing and Clear Distance	7-51
7.12.2.6.2—Minimum Edge Distance	7-51
7.12.2.7—Shear Resistance	7-51
7.12.2.8—Slip Resistance.....	7-51
7.12.2.9—Bearing Resistance at Holes and Slots.....	7-51
7.12.2.10—Tensile Resistance	7-52
7.12.2.11—Combined Tension and Shear	7-52
7.12.2.12—Shear Resistance of Anchor Bolts.....	7-52
7.12.3—Welded Connections	7-52
7.12.3.1—General.....	7-52
7.12.3.2—Factored Resistance	7-52
7.12.3.2.1—General	7-52
7.12.3.2.2—Complete Penetration Groove-Welded Connections	7-53
7.12.3.2.2a—Tension and Compression.....	7-53
7.12.3.2.2b—Shear.....	7-53
7.12.3.2.3—Partial Penetration Groove-Welded Connections	7-53
7.12.3.2.3a—Tension and Compression.....	7-54
7.12.3.2.3b—Shear.....	7-54
7.12.3.2.4—Fillet-Welded Connections	7-55
7.12.3.3—Effective Area.....	7-55
7.12.3.4—Size of Fillet Welds	7-55
7.12.3.5—Fillet Weld End Returns	7-56
7.12.4—Block Shear Rupture Resistance	7-56
7.12.5—Connection Elements	7-57
7.12.5.1—General.....	7-57
7.12.5.2—Tension	7-57
7.12.5.3—Shear	7-57
7.12.6—Splices.....	7-57
7.12.7—Pins	7-58
7.12.7.1—Factored Resistance	7-58
7.12.7.2—Minimum Edge Distance	7-58
7.12.7.3—Holes.....	7-59
7.12.7.4—Shear Resistance	7-59
7.12.7.5—Flexural Resistance.....	7-59
7.12.7.6—Bearing Resistance.....	7-60
7.12.7.7—Combined Shear and Flexure.....	7-60
7.13—PROVISIONS FOR STRUCTURE TYPES	7-60
7.13.1—Deck Superstructures	7-60
7.13.1.1—General.....	7-60
7.13.1.2—Equivalent Strips.....	7-61
7.14—REFERENCES	7-61

SECTION 7

ALUMINUM STRUCTURES

Commentary is opposite the text it annotates.

7.1—SCOPE

This Section covers the design of aluminum components and connections for beam and girder structures, and metal deck systems. Horizontally curved girders and non-redundant structures are not addressed.

C7.1

In highway bridges, aluminum is usually used in conjunction with other materials such as steel or concrete. This Section addresses the design of the aluminum components; the Designer should use other Sections for the design of components of other materials.

Many of the provisions in this Section are based on the *Specification for Aluminum Structures*, published by the Aluminum Association as Part I of the 2015 *Aluminum Design Manual* (AA, 2015).

7.2—DEFINITIONS

The provisions of Article 6.2 apply to terms used in this Section that are not defined below.

Beam—A structural member whose primary function is to transmit loads to the support primarily through flexure and shear.

Clear Distance of Bolts—The distance between the edges of adjacent bolt holes.

Closed Shape—A hollow shape that resists lateral-torsional buckling primarily by torsional resistance rather than warping resistance.

Column—A structural member that has the primary function of resisting a compressive axial force.

Element—A part of a shape's cross-section that is rectangular in cross-section or of constant curvature and thickness. Elements are connected to other elements only along their longitudinal edges. An I-beam, for example, consists of five elements, which include a web element and two elements in each flange.

Longitudinal Weld—A weld whose axis is parallel to the member's length axis.

Plate—A flat, rolled product whose thickness equals or exceeds 0.250 in.

Transverse Weld—A weld whose axis is perpendicular to the member's length axis.

Weld-Affected Zone—Material within 1.0 in. of the centerline of a weld.

7.3—NOTATION

$(ADTT)_{SL}$	=	single lane ADTT as specified in Article 3.6.1.4.2 (7.6.2.5)
A_e	=	effective net area of the member (in. ²) (7.8.2.1)
A_f	=	area of the member farther than $2c/3$ from the neutral axis, where c is the distance from the neutral axis to the extreme compression fiber (in. ²) (7.10.4)
A_g	=	gross cross-sectional area (in. ²) (7.5.4.4.1)
A_{gc}	=	gross area of the element in compression (in. ²) (7.5.4.5.1)
A_{gt}	=	gross area in tension (in. ²) (7.12.4)
A_{gv}	=	gross area in shear (in. ²); gross area of the connection element subject to shear (in. ²) (7.12.4) (7.12.5.3)
A_i	=	area of element i (in. ²) (7.9.2.2.2)
A_L	=	cross-sectional area of the longitudinal stiffener (in. ²) (7.5.4.5.4)
A_n	=	net area of the web (in. ²); net area of the pipe or tube (in. ²); net area of the member at the connection (in. ²) (7.5.4.6.2) (7.5.4.6.4) (7.8.2.2)
A_{nt}	=	net area in tension (in. ²) (7.12.4)
A_{nv}	=	net area in shear (in. ²); net area of the connection element subject to shear (in. ²) (7.12.4) (7.12.5.3)
A_s	=	area of the stiffener (in. ²) (7.5.4.4.5)
A_v	=	shear area (in. ²) (7.5.4.6.1)
A_w	=	area of the web (in. ²) (7.5.4.6.2)

SECTION 8: WOOD STRUCTURES

TABLE OF CONTENTS

8.1—SCOPE 8-1

8.2—DEFINITIONS 8-1

8.3—NOTATION 8-4

8.4—MATERIALS 8-6

 8.4.1—Wood Products 8-6

 8.4.1.1—Sawn Lumber 8-6

 8.4.1.1.1—General 8-6

 8.4.1.1.2—Dimensions 8-6

 8.4.1.1.3—Moisture Content 8-7

 8.4.1.1.4—Reference Design Values 8-7

 8.4.1.2—Structural Glued Laminated Timber (Glulam) 8-12

 8.4.1.2.1—General 8-12

 8.4.1.2.2—Dimensions 8-13

 8.4.1.2.3—Reference Design Values 8-14

 8.4.1.3—Tension-Reinforced Glulams 8-18

 8.4.1.3.1—General 8-18

 8.4.1.3.2—Dimensions 8-18

 8.4.1.3.3—Fatigue 8-19

 8.4.1.3.4—Reference Design Values for Tension-Reinforced Glulams 8-19

 8.4.1.3.5—Volume Effect 8-20

 8.4.1.3.6—Preservative Treatment 8-21

 8.4.1.4—Piles 8-21

 8.4.2—Metal Fasteners and Hardware 8-21

 8.4.2.1—General 8-21

 8.4.2.2—Minimum Requirements 8-21

 8.4.2.2.1—Fasteners 8-21

 8.4.2.2.2—Prestressing Bars 8-22

 8.4.2.2.3—Split Ring Connectors 8-22

 8.4.2.2.4—Shear Plate Connectors 8-22

 8.4.2.2.5—Nails and Spikes 8-22

 8.4.2.2.6—Drift Pins and Bolts 8-22

 8.4.2.2.7—Spike Grids 8-22

 8.4.2.2.8—Toothed Metal Plate Connectors 8-22

 8.4.2.3—Corrosion Protection 8-23

 8.4.2.3.1—Metallic Coating 8-23

 8.4.2.3.2—Alternative Coating 8-23

 8.4.3—Preservative Treatment 8-23

 8.4.3.1—Requirement for Treatment 8-23

 8.4.3.2—Treatment Chemicals 8-23

 8.4.3.3—Inspection and Marking 8-24

 8.4.3.4—Fire Retardant Treatment 8-24

 8.4.4—Adjustment Factors for Reference Design Values 8-24

 8.4.4.1—General 8-24

 8.4.4.2—Format Conversion Factor, C_{KF} 8-25

 8.4.4.3—Wet Service Factor, C_M 8-26

 8.4.4.4—Size Factor, C_F , for Sawn Lumber 8-26

 8.4.4.5—Volume Factor, C_V , (Glulam) 8-27

 8.4.4.6—Flat-Use Factor, C_{fu} 8-28

 8.4.4.7—Incising Factor, C_i 8-29

 8.4.4.8—Deck Factor, C_d 8-29

 8.4.4.9—Time Effect Factor, C_λ 8-30

8.5—LIMIT STATES 8-30

 8.5.1—Service Limit State 8-30

 8.5.2—Strength Limit State 8-30

 8.5.2.1—General 8-30

8.5.2.2—Resistance Factors.....	8-31
8.5.2.3—Stability.....	8-31
8.5.3—Extreme Event Limit State	8-31
8.6—COMPONENTS IN FLEXURE.....	8-31
8.6.1—General.....	8-31
8.6.2—Rectangular Section.....	8-31
8.6.3—Circular Section.....	8-33
8.7—COMPONENTS UNDER SHEAR	8-33
8.8—COMPONENTS IN COMPRESSION.....	8-33
8.8.1—General.....	8-33
8.8.2—Compression Parallel to Grain	8-33
8.8.3—Compression Perpendicular to Grain	8-34
8.9—COMPONENTS IN TENSION PARALLEL TO GRAIN.....	8-35
8.10—COMPONENTS IN COMBINED FLEXURE AND AXIAL LOADING	8-35
8.10.1—Components in Combined Flexure and Tension.....	8-35
8.10.2—Components in Combined Flexure and Compression Parallel to Grain	8-36
8.11—BRACING REQUIREMENTS	8-36
8.11.1—General.....	8-36
8.11.2—Sawn Wood Beams	8-36
8.11.3—Glued Laminated Timber Girders	8-37
8.11.4—Bracing of Trusses.....	8-37
8.12—CAMBER REQUIREMENTS	8-37
8.12.1—Glued Laminated Timber Girders	8-37
8.12.2—Trusses	8-37
8.12.3—Stress Laminated Timber Deck Bridge	8-37
8.13—CONNECTION DESIGN	8-37
8.14—REFERENCES.....	8-37

SECTION 8

WOOD STRUCTURES

Commentary is opposite the text it annotates.

8.1—SCOPE

This Section specifies design requirements for structural components made of sawn lumber products, stressed wood, glued laminated timber, wood piles, and mechanical connections.

8.2—DEFINITIONS

Adjusted Design Value—Reference design value multiplied by applicable adjustment factors.

Beams and Stringers (B&S)—Beams and stringers are rectangular pieces that are 5.0 or more in. thick (nominal), with a depth more than 2.0 in. (nominal) greater than the thickness. B&S are graded primarily for use as beams, with loads applied to the narrow face.

Bent—Type of pier consisting of two or more columns or column-like components connected at their top ends by a cap, strut, or other component holding them in their correct positions.

Bonded Reinforcement—Reinforcing material that is continuously attached to a glulam beam through adhesive bonding.

Bumper Lamination—Sacrificial wood lamination continuously bonded to the outer face of reinforcement to protect the reinforcement from damage or fire, or for visual appearance. The bumper lam is an option, not a requirement.

Cap—Sawn lumber or glulam component placed horizontally on an abutment or pier to distribute the live load and dead load of the superstructure. Also, a metal, wood, or mastic cover to protect exposed wood end grain from wetting.

Combination Symbol—Product designation used by the structural glued laminated timber industry; see AITC 117.

Conventional Lamstock—Solid sawn wood laminations with a net thickness of 2.0 in. or less, graded either visually or through mechanical means, finger-jointed and face-bonded to form a glulam per ASTM D7199.

Crib—Structure consisting of a foundation grillage and a framework providing compartments that are filled with gravel, stones, or other material satisfactory for supporting the structure to be placed thereon.

Decking—Subcategory of dimension lumber, graded primarily for use with the wide face placed flatwise.

Delamination—Adhesive failure causing the separation of laminations.

Development Length—Length of the bond line along the axis of the beam required to develop the design tensile strength of the reinforcement.

Diaphragm—Blocking between two main longitudinal beams consisting of solid lumber, glued laminated timber, or steel cross bracing.

Dimension Lumber—Lumber with a nominal thickness of from 2.0 up to but not including 5.0 in. and having a nominal width of 2.0 in. or more.

Dowel—Relatively short length of round metal bar used to interconnect or attach two wood components in a manner to minimize movement and displacement.

Dressed Lumber—Lumber that has been surfaced by a planing machine on one or more sides or edges.

Dry—Condition of having a relatively low moisture content, i.e., not more than 19 percent for sawn lumber and 16 percent for glued laminated timber.

SECTION 9: DECKS AND DECK SYSTEMS

TABLE OF CONTENTS

9.1—SCOPE.....9-1

9.2—DEFINITIONS.....9-1

9.3—NOTATION.....9-4

9.4—GENERAL DESIGN REQUIREMENTS.....9-4

 9.4.1—Interface Action9-4

 9.4.2—Deck Drainage9-4

 9.4.3—Concrete Appurtenances9-5

 9.4.4—Edge Supports9-5

 9.4.5—Stay-in-Place Formwork for Overhangs.....9-5

9.5—LIMIT STATES.....9-5

 9.5.1—General.....9-5

 9.5.2—Service Limit States9-5

 9.5.3—Fatigue and Fracture Limit State.....9-6

 9.5.4—Strength Limit States.....9-6

 9.5.5—Extreme Event Limit States.....9-6

9.6—ANALYSIS.....9-6

 9.6.1—Methods of Analysis9-6

 9.6.2—Loading.....9-6

9.7—CONCRETE DECK SLABS9-7

 9.7.1—General.....9-7

 9.7.1.1—Minimum Depth and Cover9-7

 9.7.1.2—Composite Action9-7

 9.7.1.3—Skewed Decks.....9-7

 9.7.1.4—Edge Support9-8

 9.7.1.5—Design of Cantilever Slabs.....9-8

 9.7.2—Empirical Design9-8

 9.7.2.1—General9-8

 9.7.2.2—Application9-9

 9.7.2.3—Effective Length9-9

 9.7.2.4—Design Conditions.....9-10

 9.7.2.5—Reinforcement Requirements.....9-11

 9.7.2.6—Deck with Stay-in-Place Formwork9-12

 9.7.3—Traditional Design9-12

 9.7.3.1—General9-12

 9.7.3.2—Distribution Reinforcement.....9-12

 9.7.4—Stay-in-Place Formwork9-13

 9.7.4.1—General9-13

 9.7.4.2—Steel Formwork.....9-13

 9.7.4.3—Concrete Formwork9-13

 9.7.4.3.1—Depth9-13

 9.7.4.3.2—Reinforcement9-13

 9.7.4.3.3—Creep and Shrinkage Control.....9-14

 9.7.4.3.4—Bedding of Panels.....9-14

 9.7.5—Precast Deck Slabs on Girders.....9-14

 9.7.5.1—General9-14

 9.7.5.2—Transversely Joined Precast Decks.....9-15

 9.7.5.3—Longitudinally Post-Tensioned Precast Decks.....9-15

 9.7.6—Deck Slabs in Segmental Construction9-15

 9.7.6.1—General9-15

 9.7.6.2—Joints in Decks9-15

9.8—METAL DECKS.....9-16

 9.8.1—General.....9-16

 9.8.2—Metal Grid Decks.....9-16

 9.8.2.1—General9-16

 9.8.2.2—Open Grid Floors.....9-17

9.8.2.3—Filled and Partially Filled Grid Decks.....	9-17
9.8.2.3.1—General.....	9-17
9.8.2.3.2—Design Requirements.....	9-18
9.8.2.3.3—Fatigue and Fracture Limit State.....	9-18
9.8.2.4—Unfilled Grid Decks Composite with Reinforced Concrete Slabs.....	9-19
9.8.2.4.1—General.....	9-19
9.8.2.4.2—Design.....	9-19
9.8.2.4.3—Fatigue Limit State.....	9-20
9.8.3—Orthotropic Steel Decks.....	9-20
9.8.3.1—General.....	9-20
9.8.3.2—Wheel Load Distribution.....	9-20
9.8.3.3—Wearing Surface.....	9-20
9.8.3.4—Analysis of Orthotropic Decks.....	9-21
9.8.3.4.1—General.....	9-21
9.8.3.4.2—Level 1 Design.....	9-23
9.8.3.4.3—Level 2 Design.....	9-24
9.8.3.4.3a—General.....	9-24
9.8.3.4.3b—Decks with Open Ribs.....	9-24
9.8.3.4.3c—Decks with Closed Ribs.....	9-24
9.8.3.4.4—Level 3 Design.....	9-24
9.8.3.5—Design.....	9-25
9.8.3.5.1—Superposition of Local and Global Effects.....	9-25
9.8.3.5.2—Limit States.....	9-26
9.8.3.5.2a—General.....	9-26
9.8.3.5.2b—Service Limit State.....	9-26
9.8.3.5.2c—Strength Limit State.....	9-26
9.8.3.5.2d—Fatigue Limit State.....	9-26
9.8.3.6—Detailing Requirements.....	9-27
9.8.3.6.1—Minimum Plate Thickness.....	9-27
9.8.3.6.2—Closed Ribs.....	9-27
9.8.3.6.3—Welding to Orthotropic Decks.....	9-27
9.8.3.6.4—Deck and Rib Details.....	9-27
9.8.4—Orthotropic Aluminum Decks.....	9-28
9.8.4.1—General.....	9-28
9.8.4.2—Approximate Analysis.....	9-28
9.8.4.3—Limit States.....	9-29
9.8.5—Corrugated Metal Decks.....	9-29
9.8.5.1—General.....	9-29
9.8.5.2—Distribution of Wheel Loads.....	9-29
9.8.5.3—Composite Action.....	9-29
9.9—WOOD DECKS AND DECK SYSTEMS.....	9-30
9.9.1—Scope.....	9-30
9.9.2—General.....	9-30
9.9.3—Design Requirements.....	9-30
9.9.3.1—Load Distribution.....	9-30
9.9.3.2—Shear Design.....	9-30
9.9.3.3—Deformation.....	9-31
9.9.3.4—Thermal Expansion.....	9-31
9.9.3.5—Wearing Surfaces.....	9-31
9.9.3.6—Skewed Decks.....	9-31
9.9.4—Glued Laminated Decks.....	9-31
9.9.4.1—General.....	9-31
9.9.4.2—Deck Tie-Downs.....	9-32
9.9.4.3—Interconnected Decks.....	9-32
9.9.4.3.1—Panels Parallel to Traffic.....	9-32
9.9.4.3.2—Panels Perpendicular to Traffic.....	9-32
9.9.4.4—Noninterconnected Decks.....	9-32

9.9.5—Stress-Laminated Decks..... 9-32

 9.9.5.1—General 9-32

 9.9.5.2—Nailing 9-33

 9.9.5.3—Staggered Butt Joints 9-33

 9.9.5.4—Holes in Laminations 9-34

 9.9.5.5—Deck Tie-Downs 9-34

 9.9.5.6—Stressing..... 9-34

 9.9.5.6.1—Prestressing System 9-34

 9.9.5.6.2—Prestressing Materials..... 9-36

 9.9.5.6.3—Design Requirements 9-37

 9.9.5.6.4—Corrosion Protection..... 9-38

 9.9.5.6.5—Railings..... 9-38

9.9.6—Spike-Laminated Decks 9-38

 9.9.6.1—General 9-38

 9.9.6.2—Deck Tie-Downs 9-39

 9.9.6.3—Panel Decks 9-39

9.9.7—Plank Decks 9-40

 9.9.7.1—General 9-40

 9.9.7.2—Deck Tie-Downs 9-40

9.9.8—Wearing Surfaces for Wood Decks..... 9-40

 9.9.8.1—General 9-40

 9.9.8.2—Plant Mix Asphalt 9-40

 9.9.8.3—Chip Seal..... 9-41

9.10—REFERENCES 9-41

SECTION 9

DECKS AND DECK SYSTEMS

Commentary is opposite the text it annotates.

9.1—SCOPE

This Section contains provisions for the analysis and design of bridge decks and deck systems of concrete, metal, wood, or combinations thereof subjected to gravity loads.

For monolithic concrete bridge decks satisfying specific conditions, an empirical design, requiring no analysis, is permitted.

Continuity in the deck and its supporting components is encouraged.

Composite action between the deck and its supporting components is required where technically feasible.

9.2—DEFINITIONS

Appurtenances—Curbs, parapets, railings, barriers, dividers, and sign and lighting posts attached to the deck.

Arching Action—A structural phenomenon in which wheel loads are transmitted primarily by compressive struts formed in the slab.

Band—A strip of laminated wood deck within which the pattern of butt joints is not repeated.

Bolster—A spacer between a metal deck and a beam.

Bulkhead—A steel element attached to the side of stress-laminated timber decks to distribute the prestressing force and reduce the tendency to crush the wood.

Cellular Deck—A concrete deck with void-ratio in excess of 40 percent.

Clear Span—The face-to-face distance between supporting components.

Closed Rib—A rib in an orthotropic deck consisting of a plate forming a trough, welded to the deck plate along both sides of the rib.

Closure Joint—A cast-in-place concrete fill between precast components to provide continuity.

Compatibility—The equality of deformation at the interface of elements, components, or both joined together.

Component—A structural element or combination of elements requiring individual design consideration.

Composite Action—A condition in which two or more elements or components are made to act together by preventing relative movement at their interface.

Continuity—In decks, both structural continuity and the ability to prevent water penetration without the assistance of nonstructural elements.

Core Depth—The distance between the top of top reinforcement and the bottom of bottom reinforcement in a concrete slab.

Deck—A component, with or without wearing surface, that supports wheel loads directly and is supported by other components.

Deck Joint—A complete or partial interruption of the deck to accommodate relative movement between portions of a structure.

C9.1

Implicit in this Section is a design philosophy that prefers jointless, continuous bridge decks and deck systems to improve the weather- and corrosion-resisting effects of the whole bridge, reduce inspection efforts and maintenance costs, and increase structural effectiveness and redundancy.

SECTION 10

FOUNDATIONS

10.1—SCOPE 10-1

10.2—DEFINITIONS..... 10-1

10.3—NOTATION..... 10-3

10.4—SOIL AND ROCK PROPERTIES..... 10-8

 10.4.1—Informational Needs 10-8

 10.4.2—Subsurface Exploration..... 10-8

 10.4.3—Laboratory Tests 10-11

 10.4.3.1—Soil Tests 10-11

 10.4.3.2—Rock Tests 10-11

 10.4.4—In-Situ Tests..... 10-11

 10.4.5—Geophysical Tests..... 10-12

 10.4.6—Selection of Design Properties..... 10-13

 10.4.6.1—General..... 10-13

 10.4.6.2—Soil Strength 10-15

 10.4.6.2.1—General 10-15

 10.4.6.2.2—Undrained Strength of Cohesive Soils..... 10-15

 10.4.6.2.3—Drained Strength of Cohesive Soils..... 10-16

 10.4.6.2.4—Drained Strength of Granular Soils 10-16

 10.4.6.3—Soil Deformation 10-18

 10.4.6.4—Rock Mass Strength..... 10-21

 10.4.6.5—Rock Mass Deformation..... 10-26

 10.4.6.6—Erodibility of Rock 10-29

10.5—LIMIT STATES AND RESISTANCE FACTORS 10-29

 10.5.1—General..... 10-29

 10.5.2—Service Limit States 10-29

 10.5.2.1—General..... 10-29

 10.5.2.2—Tolerable Movements and Movement Criteria 10-30

 10.5.2.2.1—General 10-30

 10.5.2.2.2—Assessment of Differential Movement and Its Effects 10-31

 10.5.2.3—Abutment Transitions 10-32

 10.5.3—Strength Limit States 10-32

 10.5.3.1—General..... 10-32

 10.5.3.2—Spread Footings 10-32

 10.5.3.3—Driven Piles 10-33

 10.5.3.4—Drilled Shafts 10-33

 10.5.3.5—Micropiles..... 10-33

 10.5.4—Extreme Events Limit States..... 10-33

 10.5.4.1—Extreme Events Design..... 10-33

 10.5.4.2—Liquefaction Design Requirements..... 10-34

 10.5.5—Resistance Factors..... 10-40

 10.5.5.1—Service Limit States..... 10-40

 10.5.5.2—Strength Limit States 10-40

 10.5.5.2.1—General 10-40

 10.5.5.2.2—Spread Footings 10-42

 10.5.5.2.3—Driven Piles 10-42

 10.5.5.2.4—Drilled Shafts..... 10-48

 10.5.5.2.5—Micropiles..... 10-50

 10.5.5.3—Extreme Limit States 10-51

 10.5.5.3.1—General 10-51

 10.5.5.3.2—Scour..... 10-51

 10.5.5.3.3—Other Extreme Limit States 10-52

10.6—SPREAD FOOTINGS 10-52

 10.6.1—General Considerations..... 10-52

 10.6.1.1—General..... 10-52

10.6.1.2—Bearing Depth	10-52
10.6.1.3—Effective Footing Dimensions.....	10-53
10.6.1.4—Bearing Stress Distributions.....	10-53
10.6.1.5—Anchorage of Inclined Footings.....	10-54
10.6.1.6—Groundwater	10-54
10.6.1.7—Uplift.....	10-54
10.6.1.8—Nearby Structures.....	10-54
10.6.2—Service Limit State Design.....	10-54
10.6.2.1—General.....	10-54
10.6.2.2—Tolerable Movements	10-54
10.6.2.3—Loads.....	10-55
10.6.2.4—Settlement Analyses.....	10-55
10.6.2.4.1—General.....	10-55
10.6.2.4.2—Settlement of Footings on Cohesionless Soils	10-56
10.6.2.4.2a—General.....	10-56
10.6.2.4.2b—Hough Method	10-58
10.6.2.4.2c—Schmertmann Method.....	10-59
10.6.2.4.3—Settlement of Footings on Cohesive Soils	10-62
10.6.2.4.4—Settlement of Footings on Rock.....	10-66
10.6.2.5—Bearing Resistance at the Service Limit State.....	10-67
10.6.2.5.1—Presumptive Values for Bearing Resistance	10-67
10.6.2.5.2—Semiempirical Procedures for Bearing Resistance	10-68
10.6.3—Strength Limit State Design.....	10-69
10.6.3.1—Bearing Resistance of Soil	10-69
10.6.3.1.1—General.....	10-69
10.6.3.1.2—Theoretical Estimation	10-70
10.6.3.1.2a—Basic Formulation.....	10-70
10.6.3.1.2b—Considerations for Punching Shear.....	10-73
10.6.3.1.2c—Considerations for Footings on Slopes.....	10-74
10.6.3.1.2d—Considerations for Two-Layer Soil Systems—Critical Depth.....	10-79
10.6.3.1.2e—Two-Layered Soil System in Undrained Loading.....	10-79
10.6.3.1.2f—Two-Layered Soil System in Drained Loading	10-81
10.6.3.1.3—Semiempirical Procedures	10-81
10.6.3.1.4—Plate Load Tests.....	10-82
10.6.3.2—Bearing Resistance of Rock	10-83
10.6.3.2.1—General.....	10-83
10.6.3.2.2—Semiempirical Procedures	10-83
10.6.3.2.3—Analytic Method	10-83
10.6.3.2.4—Load Test.....	10-83
10.6.3.3—Eccentric Load Limitations	10-83
10.6.3.4—Failure by Sliding.....	10-84
10.6.3.5—Overall Stability.....	10-85
10.6.4—Extreme Event Limit State Design.....	10-86
10.6.4.1—General.....	10-86
10.6.4.2—Eccentric Load Limitations	10-86
10.6.5—Structural Design.....	10-86
10.7—DRIVEN PILES	10-86
10.7.1—General.....	10-86
10.7.1.1—Application.....	10-86
10.7.1.2—Minimum Pile Spacing, Clearance, and Embedment into Cap	10-87
10.7.1.3—Piles through Embankment Fill.....	10-87
10.7.1.4—Batter Piles	10-87
10.7.1.5—Pile Design Requirements	10-88
10.7.1.6—Determination of Pile Loads	10-88
10.7.1.6.1—General.....	10-88
10.7.1.6.2—Downdrag.....	10-88
10.7.1.6.3—Uplift Due to Expansive Soils.....	10-89
10.7.1.6.4—Nearby Structures	10-89

10.7.2—Service Limit State Design	10-89
10.7.2.1—General.....	10-89
10.7.2.2—Tolerable Movements	10-90
10.7.2.3—Settlement	10-90
10.7.2.3.1—Equivalent Footing Analogy.....	10-90
10.7.2.3.2—Pile Groups in Cohesive Soil.....	10-92
10.7.2.4—Horizontal Pile Foundation Movement.....	10-93
10.7.2.5—Settlement Due to Downdrag.....	10-95
10.7.2.6—Lateral Squeeze.....	10-95
10.7.3—Strength Limit State Design.....	10-95
10.7.3.1—General.....	10-95
10.7.3.2—Point Bearing Piles on Rock	10-96
10.7.3.2.1—General	10-96
10.7.3.2.2—Piles Driven to Soft Rock	10-96
10.7.3.2.3—Piles Driven to Hard Rock.....	10-96
10.7.3.3—Pile Length Estimates for Contract Documents.....	10-97
10.7.3.4—Nominal Axial Resistance Change after Pile Driving.....	10-99
10.7.3.4.1—General	10-99
10.7.3.4.2—Relaxation.....	10-99
10.7.3.4.3—Setup.....	10-99
10.7.3.5—Groundwater Effects and Buoyancy	10-100
10.7.3.6—Scour.....	10-100
10.7.3.7—Downdrag	10-101
10.7.3.8—Determination of Nominal Bearing Resistance for Piles	10-102
10.7.3.8.1—General	10-102
10.7.3.8.2—Static Load Test.....	10-103
10.7.3.8.3—Dynamic Testing.....	10-104
10.7.3.8.4—Wave Equation Analysis	10-105
10.7.3.8.5—Dynamic Formula.....	10-105
10.7.3.8.6—Static Analysis	10-106
10.7.3.8.6a—General.....	10-106
10.7.3.8.6b— α -Method.....	10-107
10.7.3.8.6c— β -Method	10-108
10.7.3.8.6d— λ -Method.....	10-109
10.7.3.8.6e—Tip Resistance in Cohesive Soils.....	10-110
10.7.3.8.6f—Nordlund/Thurman Method in Cohesionless Soils	10-110
10.7.3.8.6g—Using SPT or CPT in Cohesionless Soils.....	10-115
10.7.3.9—Resistance of Pile Groups in Compression.....	10-118
10.7.3.10—Uplift Resistance of Single Piles.....	10-119
10.7.3.11—Uplift Resistance of Pile Groups.....	10-120
10.7.3.12—Nominal Lateral Resistance of Pile Foundations	10-122
10.7.3.13—Pile Structural Resistance	10-123
10.7.3.13.1—Steel Piles	10-123
10.7.3.13.2—Concrete Piles.....	10-123
10.7.3.13.3—Timber Piles.....	10-123
10.7.3.13.4—Buckling and Lateral Stability	10-123
10.7.4—Extreme Event Limit State.....	10-124
10.7.5—Corrosion and Deterioration	10-125
10.7.6—Determination of Minimum Pile Penetration.....	10-126
10.7.7—Determination of R_{ndr} Used to Establish Contract Driving Criteria for Nominal Bearing Resistance.....	10-126
10.7.8—Drivability Analysis.....	10-127
10.7.9—Probe Piles	10-128
10.8—DRILLED SHAFTS.....	10-128
10.8.1—General.....	10-128
10.8.1.1—Scope	10-128
10.8.1.2—Shaft Spacing, Clearance, and Embedment into Cap.....	10-129
10.8.1.3—Shaft Diameter and Enlarged Bases.....	10-129

10.8.1.4—Battered Shafts	10-130
10.8.1.5—Drilled Shaft Resistance	10-130
10.8.1.6—Determination of Shaft Loads	10-131
10.8.1.6.1—General	10-131
10.8.1.6.2—Downdrag	10-131
10.8.1.6.3—Uplift	10-132
10.8.2—Service Limit State Design	10-132
10.8.2.1—Tolerable Movements	10-132
10.8.2.2—Settlement	10-132
10.8.2.2.1—General	10-132
10.8.2.2.2—Settlement of Single-Drilled Shaft	10-132
10.8.2.2.3—Intermediate Geo Materials (IGMs)	10-135
10.8.2.2.4—Group Settlement	10-135
10.8.2.3—Horizontal Movement of Shafts and Shaft Groups	10-135
10.8.2.4—Settlement Due to Downdrag	10-136
10.8.2.5—Lateral Squeeze	10-136
10.8.3—Strength Limit State Design	10-136
10.8.3.1—General	10-136
10.8.3.2—Groundwater Table and Buoyancy	10-136
10.8.3.3—Scour	10-136
10.8.3.4—Downdrag	10-136
10.8.3.5—Nominal Axial Compression Resistance of Single Drilled Shafts	10-137
10.8.3.5.1—Estimation of Drilled Shaft Resistance in Cohesive Soils	10-138
10.8.3.5.1a—General	10-138
10.8.3.5.1b—Side Resistance	10-138
10.8.3.5.1c—Tip Resistance	10-140
10.8.3.5.2—Estimation of Drilled Shaft Resistance in Cohesionless Soils	10-140
10.8.3.5.2a—General	10-140
10.8.3.5.2b—Side Resistance	10-141
10.8.3.5.2c—Tip Resistance	10-142
10.8.3.5.3—Shafts in Strong Soil Overlying Weaker Compressible Soil	10-142
10.8.3.5.4—Estimation of Drilled Shaft Resistance in Rock	10-143
10.8.3.5.4a—General	10-143
10.8.3.5.4b—Side Resistance	10-144
10.8.3.5.4c—Tip Resistance	10-145
10.8.3.5.4d—Combined Side and Tip Resistance	10-145
10.8.3.5.5—Estimation of Drilled Shaft Resistance in Intermediate Geo Materials (IGMs)	10-146
10.8.3.5.6—Shaft Load Test	10-147
10.8.3.6—Shaft Group Resistance	10-147
10.8.3.6.1—General	10-147
10.8.3.6.2—Cohesive Soil	10-148
10.8.3.6.3—Cohesionless Soil	10-148
10.8.3.6.4—Shaft Groups in Strong Soil Overlying Weak Soil	10-149
10.8.3.7—Uplift Resistance	10-149
10.8.3.7.1—General	10-149
10.8.3.7.2—Uplift Resistance of Single Drilled Shaft	10-149
10.8.3.7.3—Group Uplift Resistance	10-150
10.8.3.7.4—Uplift Load Test	10-150
10.8.3.8—Nominal Horizontal Resistance of Shaft and Shaft Groups	10-150
10.8.3.9—Shaft Structural Resistance	10-150
10.8.3.9.1—General	10-150
10.8.3.9.2—Buckling and Lateral Stability	10-150
10.8.3.9.3—Reinforcement	10-150
10.8.3.9.4—Transverse Reinforcement	10-151
10.8.3.9.5—Concrete	10-151
10.8.3.9.6—Reinforcement into Superstructure	10-151
10.8.3.9.7—Enlarged Bases	10-151
10.8.4—Extreme Event Limit State	10-151

10.9—MICROPILES	10-152
10.9.1—General	10-152
10.9.1.1—Scope	10-152
10.9.1.2—Minimum Micropile Spacing, Clearance, and Embedment into Cap	10-153
10.9.1.3—Micropiles through Embankment Fill	10-153
10.9.1.4—Battered Micropiles	10-153
10.9.1.5—Micropile Design Requirements	10-153
10.9.1.6—Determination of Micropile Loads.....	10-153
10.9.1.6.1—Downdrag	10-153
10.9.1.6.2—Uplift Due to Expansive Soils	10-153
10.9.1.6.3—Nearby Structures	10-154
10.9.2—Service Limit State Design	10-154
10.9.2.1—General.....	10-154
10.9.2.2—Tolerable Movements	10-154
10.9.2.3—Settlement	10-154
10.9.2.3.1—Micropile Groups in Cohesive Soil	10-154
10.9.2.3.2—Micropile Groups in Cohesionless Soil	10-154
10.9.2.4—Horizontal Micropile Foundation Movement	10-154
10.9.2.5—Settlement Due to Downdrag.....	10-154
10.9.2.6—Lateral Squeeze.....	10-154
10.9.3—Strength Limit State Design.....	10-154
10.9.3.1—General.....	10-154
10.9.3.2—Ground Water Table and Bouyancy	10-155
10.9.3.3—Scour.....	10-155
10.9.3.4—Downdrag	10-155
10.9.3.5—Nominal Axial Compression Resistance of a Single Micropile.....	10-155
10.9.3.5.1—General	10-155
10.9.3.5.2—Estimation of Grout-to-Ground Bond Resistance.....	10-156
10.9.3.5.3—Estimation of Micropile Tip Resistance in Rock.....	10-157
10.9.3.5.4—Micropile Load Test	10-158
10.9.3.6—Resistance of Micropile Groups in Compression	10-158
10.9.3.7—Nominal Uplift Resistance of a Single Micropile.....	10-158
10.9.3.8—Nominal Uplift Resistance of Micropile Groups	10-158
10.9.3.9—Nominal Horizontal Resistance of Micropiles and Micropile Groups.....	10-159
10.9.3.10—Structural Resistance	10-159
10.9.3.10.1—General	10-159
10.9.3.10.2—Axial Compressive Resistance	10-159
10.9.3.10.2a—Cased Length	10-160
10.9.3.10.2b—Uncased Length	10-160
10.9.3.10.3—Axial Tension Resistance	10-161
10.9.3.10.3a—Cased Length	10-161
10.9.3.10.3b—Uncased Length	10-162
10.9.3.10.4—Plunge Length Transfer Load	10-162
10.9.3.10.5—Grout-to-Steel Bond	10-163
10.9.3.10.6—Buckling and Lateral Stability	10-163
10.9.3.10.7—Reinforcement into Superstructure	10-163
10.9.4—Extreme Event Limit State.....	10-163
10.9.5—Corrosion and Deterioration	10-163
10.10—REFERENCES	10-163
APPENDIX A10—SEISMIC ANALYSIS AND DESIGN OF FOUNDATIONS	10-172
A10.1—INVESTIGATION.....	10-172
A10.2—FOUNDATION DESIGN.....	10-172
A10.3—SPECIAL PILE REQUIREMENTS	10-176

SECTION 10
FOUNDATIONS

10.1—SCOPE

Provisions of this Section shall apply for the design of spread footings, driven piles, drilled shaft, and micropile foundations.

The probabilistic LRFD basis of these Specifications, which produces an interrelated combination of load, load factor resistance, resistance factor, and statistical reliability, shall be considered when selecting procedures for calculating resistance other than that specified herein. Other methods, especially when locally recognized and considered suitable for regional conditions, may be used if resistance factors are developed in a manner that is consistent with the development of the resistance factors for the method(s) provided in these Specifications, and are approved by the Owner.

10.2—DEFINITIONS

Battered Pile—A pile or micropile installed at an angle inclined to the vertical to provide higher resistance to lateral loads.

Bearing Pile—A pile or micropile whose purpose is to carry axial load through friction or point bearing.

Bent—A type of pier comprised of multiple columns or piles supporting a single cap and in some cases connected with bracing.

Bent Cap—A flexural substructure element supported by columns or piles that receives loads from the superstructure.

Bond Length—The length of a micropile that is bonded to the ground and which is conceptually used to transfer the applied axial loads to the surrounding soil or rock. Also known as the load transfer length.

Casing—Steel pipe introduced during the drilling process to temporarily stabilize the drill hole. Depending on the details of micropile construction and composition, this casing may be fully extracted during or after grouting, or may remain partially or completely in place as part of the final micropile pile configuration.

Centralizer—A device to centrally locate the core steel within a borehole.

Column Bent—A type of bent that uses two or more columns to support a cap. Columns may be drilled shafts or other independent units supported by individual footings or a combined footing; and may employ bracing or struts for lateral support above ground level.

Combination Point Bearing and Friction Pile—Pile that derives its capacity from contributions of both point bearing developed at the pile tip and resistance mobilized along the embedded shaft.

Combined Footing—A footing that supports more than one column.

Core Steel—Reinforcing bars or pipes used to strengthen or stiffen a micropile, excluding any left-in casing.

CPT—Cone Penetration Test.

CU—Consolidated Undrained.

Deep Foundation—A foundation that derives its support by transferring loads to soil or rock at some depth below the structure by end bearing, adhesion or friction, or both.

DMT—Flat Plate Dilatometer Test.

C10.1

The development of the resistance factors provided in this Section are summarized in Allen (2005), with additional details provided in Appendix A of Barker et al. (1991), in Paikowsky et al. (2004), in Allen (2005), and in D'Appolonia (2006).

The specification of methods of analysis and calculation of resistance for foundations herein is not intended to imply that field verification and/or reaction to conditions actually encountered in the field are no longer needed. These traditional features of foundation design and construction are still practical considerations when designing in accordance with these Specifications.

TABLE OF CONTENTS

11.1—SCOPE	11-1
11.2—DEFINITIONS	11-1
11.3—NOTATION	11-2
11.3.1—General	11-2
11.4—SOIL PROPERTIES AND MATERIALS	11-7
11.4.1—General	11-7
11.4.2—Determination of Soil Properties	11-7
11.5—LIMIT STATES AND RESISTANCE FACTORS	11-7
11.5.1—General	11-7
11.5.2—Service Limit States	11-8
11.5.3—Strength Limit State	11-9
11.5.4—Extreme Event Limit State	11-9
11.5.4.1—General Requirements	11-9
11.5.4.2—Extreme Event I, No Analysis	11-9
11.5.5—Resistance Requirement	11-11
11.5.6—Load Combinations and Load Factors	11-11
11.5.7—Resistance Factors—Service and Strength	11-15
11.5.8—Resistance Factors—Extreme Event Limit State	11-18
11.6—ABUTMENTS AND CONVENTIONAL RETAINING WALLS	11-19
11.6.1—General Considerations	11-19
11.6.1.1—General	11-19
11.6.1.2—Loading	11-19
11.6.1.3—Integral Abutments	11-20
11.6.1.4—Wingwalls	11-20
11.6.1.5—Reinforcement	11-20
11.6.1.5.1—Conventional Walls and Abutments	11-20
11.6.1.5.2—Wingwalls	11-20
11.6.1.6—Expansion and Contraction Joints	11-21
11.6.2—Movement at the Service Limit State	11-21
11.6.2.1—Abutments	11-21
11.6.2.2—Conventional Retaining Walls	11-21
11.6.3—Bearing Resistance and Stability at the Strength Limit State	11-21
11.6.3.1—General	11-21
11.6.3.2—Bearing Resistance	11-21
11.6.3.3—Eccentricity Limits	11-24
11.6.3.4—Subsurface Erosion	11-24
11.6.3.5—Passive Resistance	11-24
11.6.3.6—Sliding	11-24
11.6.3.7—Overall Stability	11-24
11.6.4—Safety against Structural Failure	11-25
11.6.5—Seismic Design for Abutments and Conventional Retaining Walls	11-25
11.6.5.1—General	11-25
11.6.5.2—Calculation of Seismic Acceleration Coefficients for Wall Design	11-27
11.6.5.2.1—Characterization of Acceleration at Wall Base	11-27
11.6.5.2.2—Estimation of Acceleration Acting on Wall Mass	11-28
11.6.5.3—Calculation of Seismic Active Earth Pressures	11-29
11.6.5.4—Calculation of Seismic Earth Pressure for Nonyielding Abutments and Walls	11-32
11.6.5.5—Calculation of Seismic Passive Earth Pressure	11-32
11.6.5.6—Wall Details for Improved Seismic Performance	11-34
11.6.6—Drainage	11-35
11.7—PIERS	11-35
11.7.1—Load Effects in Piers	11-35
11.7.2—Pier Protection	11-35
11.7.2.1—Collision	11-35
11.7.2.2—Collision Walls	11-35
11.7.2.3—Scour	11-36

11.7.2.4—Facing.....	11-36
11.8—NONGRAVITY CANTILEVERED WALLS	11-36
11.8.1—General.....	11-36
11.8.2—Loading	11-36
11.8.3—Movement at the Service Limit State.....	11-36
11.8.3.1—Movement	11-36
11.8.4—Safety against Soil Failure at the Strength Limit State.....	11-36
11.8.4.1—Overall Stability	11-36
11.8.5—Safety against Structural Failure	11-38
11.8.5.1—Vertical Wall Elements	11-38
11.8.5.2—Facing.....	11-38
11.8.6—Seismic Design of Nongravity Cantilever Walls.....	11-39
11.8.6.1—General.....	11-39
11.8.6.2—Seismic Active Lateral Earth Pressure.....	11-40
11.8.6.3—Seismic Passive Lateral Earth Pressure.....	11-41
11.8.6.4—Wall Displacement Analyses to Determine Earth Pressures.....	11-42
11.8.7—Corrosion Protection	11-44
11.8.8—Drainage.....	11-44
11.9—ANCHORED WALLS.....	11-44
11.9.1—General.....	11-44
11.9.2—Loading	11-45
11.9.3—Movement at the Service Limit State.....	11-45
11.9.3.1—Movement	11-45
11.9.4—Safety against Soil Failure.....	11-46
11.9.4.1—Bearing Resistance.....	11-46
11.9.4.2—Anchor Pullout Capacity	11-47
11.9.4.3—Passive Resistance	11-50
11.9.4.4—Overall Stability	11-50
11.9.5—Safety Against Structural Failure	11-50
11.9.5.1—Anchors	11-50
11.9.5.2—Vertical Wall Elements	11-52
11.9.5.3—Facing.....	11-52
11.9.6—Seismic Design.....	11-53
11.9.7—Corrosion Protection	11-54
11.9.8—Construction and Installation	11-54
11.9.8.1—Anchor Stressing and Testing	11-54
11.9.9—Drainage.....	11-55
11.10—MECHANICALLY STABILIZED EARTH WALLS	11-55
11.10.1—General.....	11-55
11.10.2—Structure Dimensions.....	11-57
11.10.2.1—Minimum Length of Soil Reinforcement	11-58
11.10.2.2—Minimum Front Face Embedment	11-59
11.10.2.3—Facing.....	11-60
11.10.2.3.1—Stiff or Rigid Concrete, Steel, and Timber Facings	11-60
11.10.2.3.2—Flexible Wall Facings	11-61
11.10.2.3.3—Corrosion Issues for MSE Facing	11-61
11.10.3—Loading	11-61
11.10.4—Movement at the Service Limit State.....	11-61
11.10.4.1—Settlement	11-61
11.10.4.2—Lateral Displacement	11-62
11.10.4.3—Soil Failure (Internal Stability)	11-63
11.10.5—Safety against Soil Failure (External Stability).....	11-64
11.10.5.1—General.....	11-64
11.10.5.2—Loading	11-64
11.10.5.3—Sliding.....	11-65
11.10.5.4—Bearing Resistance.....	11-66
11.10.5.5—Overturning.....	11-66
11.10.5.6—Overall and Compound Stability.....	11-66
11.10.6—Safety against Structural Failure (Internal Stability).....	11-68

11.10.6.1—General.....	11-68
11.10.6.2—Loading (Internal Stability)	11-68
11.10.6.2.1—Maximum Reinforcement Loads	11-69
11.10.6.2.1a—Special Loading Conditions.....	11-70
11.10.6.2.1b—Reinforcement Spacing for Calculation of T_{max}	11-72
11.10.6.2.1c—Calculation of Lateral Earth Pressure Coefficients for Determination of T_{max}	11-73
11.10.6.2.1d—Coherent Gravity Method.....	11-74
11.10.6.2.1e—Stiffness Method.....	11-76
11.10.6.2.2—Reinforcement Loads at Connection to Wall Face	11-79
11.10.6.3—Reinforcement Pullout.....	11-79
11.10.6.3.1—Boundary between Active and Resistant Zones.....	11-79
11.10.6.3.2—Reinforcement Pullout Design.....	11-81
11.10.6.4—Reinforcement Strength	11-84
11.10.6.4.1—General	11-84
11.10.6.4.2—Design Life Considerations	11-88
11.10.6.4.2a—Steel Reinforcements	11-88
11.10.6.4.2b—Geosynthetic Reinforcements.....	11-90
11.10.6.4.3—Design Tensile Resistance	11-93
11.10.6.4.3a—Steel Reinforcements	11-93
11.10.6.4.3b—Geosynthetic Reinforcements.....	11-94
11.10.6.4.4—Reinforcement/Facing Connection Design Strength.....	11-94
11.10.6.4.4a—Steel Reinforcements	11-94
11.10.6.4.4b—Geosynthetic Reinforcements.....	11-95
11.10.7—Seismic Design of MSE Walls.....	11-97
11.10.7.1—External Stability	11-97
11.10.7.2—Internal Stability	11-99
11.10.7.3—Facing Reinforcement Connections.....	11-103
11.10.7.4—Wall Details for Improved Seismic Performance	11-104
11.10.8—Drainage.....	11-106
11.10.9—Subsurface Erosion	11-106
11.10.10—Special Loading Conditions.....	11-106
11.10.10.1—Concentrated Dead Loads.....	11-106
11.10.10.2—Traffic Loads and Barriers.....	11-109
11.10.10.3—Hydrostatic Pressures.....	11-110
11.10.10.4—Obstructions in the Reinforced Soil Zone.....	11-111
11.10.11—MSE Abutments.....	11-112
11.11—PREFABRICATED MODULAR WALLS	11-113
11.11.1—General.....	11-113
11.11.2—Loading	11-114
11.11.3—Movement at the Service Limit State.....	11-114
11.11.4—Safety against Soil Failure	11-115
11.11.4.1—General.....	11-115
11.11.4.2—Sliding.....	11-115
11.11.4.3—Bearing Resistance.....	11-115
11.11.4.4—Overturning.....	11-115
11.11.4.5—Subsurface Erosion	11-116
11.11.4.6—Overall Stability.....	11-116
11.11.4.7—Passive Resistance and Sliding	11-116
11.11.5—Safety against Structural Failure	11-116
11.11.5.1—Module Members.....	11-116
11.11.6—Seismic Design for Prefabricated Modular Walls.....	11-117
11.11.7—Abutments.....	11-117
11.11.8—Drainage.....	11-118
11.12—SOIL NAIL WALLS	11-118
11.12.1—General Considerations.....	11-118
11.12.2—Loading	11-120
11.12.3—Movement at the Service Limit State.....	11-122
11.12.4—Safety against Soil Failure (External and Overall Stability—Strength Limit State).....	11-122
11.12.4.1—Sliding.....	11-122

11.12.4.2—Overall Stability	11-122
11.12.5—Safety against Soil Failure (Internal and Compound Stability—Strength Limit State).....	11-123
11.12.5.1—Soil Shear Strength.....	11-123
11.12.5.2—Soil Nail Pullout.....	11-123
11.12.6—Safety against Structural Failure (Internal and Compound Stability—Strength Limit State)	11-125
11.12.6.1—Soil Nail in Tension	11-125
11.12.6.2—Soil Nail Wall Facing—Strength Limit State.....	11-126
11.12.6.2.1—General.....	11-126
11.12.6.2.2—Facing Flexure	11-127
11.12.6.2.3—Facing Punching Shear Resistance	11-130
11.12.6.2.4—Headed Stud in Tension	11-132
11.12.7—Seismic Design of Soil Nail Walls	11-133
11.12.7.1—External and Global Stability	11-133
11.12.7.2—Internal Stability.....	11-134
11.12.8—Corrosion Protection	11-134
11.12.9—Soil Nail Testing	11-136
11.12.10—Drainage	11-136
11.13—REFERENCES.....	11-137
APPENDIX A11—SEISMIC DESIGN OF RETAINING STRUCTURES	11-143
A11.1—GENERAL	11-143
A11.2—PERFORMANCE OF WALLS IN PAST EARTHQUAKES.....	11-143
A11.3—CALCULATION OF SEISMIC ACTIVE PRESSURE.....	11-144
A11.3.1—Mononobe–Okabe Method.....	11-144
A11.3.2—Modification of Mononobe–Okabe Method to Consider Cohesion	11-146
A11.3.3—Generalized Limit Equilibrium (GLE) Method.....	11-149
A11.4—SEISMIC PASSIVE PRESSURE	11-149
A11.5—ESTIMATING WALL SEISMIC ACCELERATION CONSIDERING WAVE SCATTERING AND WALL DISPLACEMENT	11-154
A11.5.1—Kavazanjian et al., (1997).....	11-155
A11.5.2—NCHRP Report 611—Anderson et al. (2008).....	11-155
A11.5.3—Bray et al. (2010), and Bray and Travasarou (2009)	11-158
A11.6—APPENDIX REFERENCES	11-158
APPENDIX B11—DETERMINATION OF T_{MAX} FOR MSE WALLS USING THE SIMPLIFIED METHOD... 11-161	
B11.1—GENERAL	11-161
B11.2—DETERMINATION OF T_{MAX}	11-161
B11.3—APPENDIX REFERENCE.....	11-163

WALLS, ABUTMENTS, AND PIERS

11.1—SCOPE

This Section provides requirements for design of abutments and walls. Conventional retaining walls, nongravity cantilevered walls, anchored walls, mechanically stabilized earth (MSE) walls, prefabricated modular walls, and soil nail walls are considered.

11.2—DEFINITIONS

Abutment—A structure that supports the end of a bridge span, and provides lateral support for fill material on which the roadway rests immediately adjacent to the bridge. In practice, different types of abutments may be used. These include:

- *Stub Abutment*—Stub abutments are located at or near the top of approach fills, with a backwall depth sufficient to accommodate the structure depth and bearings which sit on the bearing seat.
- *Partial-Depth Abutment*—Partial-depth abutments are located approximately at middepth of the front slope of the approach embankment. The higher backwall and wingwalls may retain fill material, or the embankment slope may continue behind the backwall. In the latter case, a structural approach slab or end span design must bridge the space over the fill slope, and curtain walls are provided to close off the open area. Inspection access should be provided for this situation.
- *Full-Depth Abutment*—Full-depth abutments are located at the approximate front toe of the approach embankment, restricting the opening under the structure.
- *Integral Abutment*—Integral abutments are rigidly attached to the superstructure and are supported on a spread footing or a deep foundation capable of permitting necessary horizontal movements.

Anchored Wall—An earth retaining system typically composed of the same elements as nongravity cantilevered walls, and that derive additional lateral resistance from one or more tiers of anchors.

Geogrid—A geosynthetic formed by a regular network of integrally connected elements with apertures greater than 0.25 in. to allow interlocking with surrounding soil, rock, earth, and other surrounding materials to function primarily as reinforcement.

Geostrip—Polymeric material in the form of a strip (also sometimes called a polymer strap) of width not more than 8.0 in., used in contact with soil or other materials in geotechnical and civil engineering applications, or both.

Geotextile—A permeable geosynthetic comprised solely of textiles.

Mechanically Stabilized Earth Wall—A soil-retaining system, employing either strip- or grid-type, metallic, or polymeric tensile reinforcements in the soil mass, and a facing element that is either vertical or nearly vertical.

Nongravity Cantilever Wall—A soil-retaining system that derives lateral resistance through embedment of vertical wall elements and supports retained soil with facing elements. Vertical wall elements may consist of discrete elements, e.g., piles, drilled shafts, or auger-cast piles spanned by a structural facing, e.g., lagging, panels, or shotcrete. Alternatively, the vertical wall elements and facing may be continuous, e.g., sheet piles, diaphragm wall panels, tangent-piles, or tangent drilled shafts.

Pier—Part of a bridge structure that provides intermediate support to the superstructure. Different types of piers may be used. These include:

- *Solid Wall Piers*—Solid wall piers are designed as columns for forces and moments acting about the weak axis and as piers for those acting about the strong axis. They may be pinned, fixed, or free at the top, and are conventionally fixed at the base. Short, stubby types are often pinned at the base to eliminate the high moments which would develop due to fixity. Earlier, more massive designs were considered gravity types.

SECTION 12: BURIED STRUCTURES AND TUNNEL LINERS

TABLE OF CONTENTS

12.1—SCOPE	12-1
12.2—DEFINITIONS.....	12-1
12.3—NOTATION.....	12-2
12.3.1—Abbreviations.....	12-6
12.4—SOIL AND MATERIAL PROPERTIES	12-6
12.4.1—Determination of Soil Properties.....	12-6
12.4.1.1—General.....	12-6
12.4.1.2—Foundation Soils	12-7
12.4.1.3—Envelope Backfill Soils	12-7
12.4.2—Materials	12-8
12.4.2.1—Aluminum Pipe and Structural Plate Structures	12-8
12.4.2.2—Concrete.....	12-8
12.4.2.3—Precast Concrete Pipe	12-8
12.4.2.4—Precast Concrete Structures	12-8
12.4.2.5—Steel Pipe and Structural Plate Structures	12-8
12.4.2.6—Deep Corrugated Structures.....	12-8
12.4.2.7—Steel Reinforcement.....	12-8
12.4.2.8—Thermoplastic Pipe	12-9
12.4.2.9—Fiberglass Pipe.....	12-9
12.4.2.10—Steel-Reinforced Thermoplastic Culverts.....	12-9
12.5—LIMIT STATES AND RESISTANCE FACTORS	12-9
12.5.1—General.....	12-9
12.5.2—Service Limit State.....	12-10
12.5.3—Strength Limit State	12-10
12.5.4—Load Modifiers and Load Factors.....	12-11
12.5.5—Resistance Factors.....	12-11
12.5.6—Flexibility Limits and Construction Stiffness	12-13
12.5.6.1—Corrugated Metal Pipe and Structural Plate Structures.....	12-13
12.5.6.2—Spiral Rib Metal Pipe and Pipe Arches.....	12-13
12.5.6.3—Thermoplastic and Fiberglass Pipe	12-14
12.5.6.4—Steel Tunnel Liner Plate	12-14
12.6—GENERAL DESIGN FEATURES	12-14
12.6.1—Loading	12-14
12.6.2—Service Limit State.....	12-15
12.6.2.1—Tolerable Movement.....	12-15
12.6.2.2—Settlement	12-15
12.6.2.2.1—General	12-15
12.6.2.2.2—Longitudinal Differential Settlement	12-15
12.6.2.2.3—Differential Settlement between Structure and Backfill	12-15
12.6.2.2.4—Footing Settlement.....	12-15
12.6.2.2.5—Unbalanced Loading.....	12-16
12.6.2.3—Uplift.....	12-19
12.6.3—Safety Against Soil Failure	12-19
12.6.3.1—Bearing Resistance and Stability	12-19
12.6.3.2—Corner Backfill for Metal Pipe Arches	12-20
12.6.4—Hydraulic Design	12-20
12.6.5—Scour.....	12-20
12.6.6—Soil Envelope.....	12-20
12.6.6.1—Trench Installations	12-20
12.6.6.2—Embankment Installations.....	12-21
12.6.6.3—Minimum Cover.....	12-21
12.6.7—Minimum Spacing between Multiple Lines of Pipe.....	12-22
12.6.8—End Treatment.....	12-23
12.6.8.1—General.....	12-23
12.6.8.2—Flexible Culverts Constructed on Skew.....	12-23

12.6.9—Corrosive and Abrasive Conditions	12-24
12.7—METAL PIPE, PIPE ARCH, ARCH STRUCTURES, AND STEEL-REINFORCED THERMOPLASTIC CULVERTS	12-24
12.7.1—General	12-24
12.7.2—Safety Against Structural Failure	12-24
12.7.2.1—Section Properties	12-25
12.7.2.2—Thrust	12-25
12.7.2.3—Wall Resistance	12-26
12.7.2.4—Resistance to Buckling	12-26
12.7.2.5—Seam Resistance	12-27
12.7.2.6—Handling and Installation Requirements	12-27
12.7.2.7—Profile Evaluation for Steel-Reinforced Thermoplastic Culverts	12-27
12.7.3—Smooth Lined Pipe	12-27
12.7.4—Stiffening Elements for Structural Plate Structures	12-28
12.7.5—Construction and Installation	12-28
12.8—LONG-SPAN STRUCTURAL PLATE STRUCTURES	12-28
12.8.1—General	12-28
12.8.2—Service Limit State	12-29
12.8.3—Safety Against Structural Failure	12-29
12.8.3.1—Section Properties	12-30
12.8.3.1.1—Cross-Section	12-30
12.8.3.1.2—Shape Control	12-31
12.8.3.1.3—Mechanical and Chemical Requirements	12-31
12.8.3.2—Thrust	12-31
12.8.3.3—Wall Area	12-31
12.8.3.4—Seam Strength	12-31
12.8.3.5—Acceptable Special Features	12-31
12.8.3.5.1—Continuous Longitudinal Stiffeners	12-31
12.8.3.5.2—Reinforcing Ribs	12-31
12.8.4—Safety Against Structural Failure—Foundation Design	12-31
12.8.4.1—Settlement Limits	12-31
12.8.4.2—Footing Reactions in Arch Structures	12-32
12.8.4.3—Footing Design	12-33
12.8.5—Safety Against Structural Failure—Soil Envelope Design	12-33
12.8.5.1—General	12-33
12.8.5.2—Construction Requirements	12-34
12.8.5.3—Service Requirements	12-34
12.8.6—Safety Against Structural Failure—End Treatment Design	12-35
12.8.6.1—General	12-35
12.8.6.2—Standard Shell End Types	12-35
12.8.6.3—Balanced Support	12-37
12.8.6.4—Hydraulic Protection	12-37
12.8.6.4.1—General	12-37
12.8.6.4.2—Backfill Protection	12-38
12.8.6.4.3—Cut-Off (Toe) Walls	12-38
12.8.6.4.4—Hydraulic Uplift	12-38
12.8.6.4.5—Scour	12-38
12.8.7—Concrete Relieving Slabs	12-38
12.8.8—Construction and Installation	12-39
12.8.9—Deep Corrugated Structural Plate Structures	12-39
12.8.9.1—General	12-39
12.8.9.2—Width of Structural Backfill	12-39
12.8.9.2.1—Deep Corrugated Structures with Ratio of Crown Radius to Haunch Radius ≤ 5	12-39
12.8.9.2.2—Deep Corrugated Structures with Ratio of Crown Radius to Haunch Radius > 5	12-39
12.8.9.3—Safety Against Structural Failure	12-40
12.8.9.3.1—Structural Plate Requirements	12-40
12.8.9.3.2—Structural Analysis	12-40

12.8.9.4—Minimum Depth of Fill.....	12-40
12.8.9.5—Combined Thrust and Moment	12-41
12.8.9.6—Global Buckling.....	12-42
12.8.9.7—Connections	12-42
12.9—STRUCTURAL PLATE BOX STRUCTURES	12-42
12.9.1—General.....	12-42
12.9.2—Loading.....	12-43
12.9.3—Service Limit State.....	12-43
12.9.4—Safety Against Structural Failure.....	12-43
12.9.4.1—General.....	12-43
12.9.4.2—Moments Due to Factored Loads.....	12-44
12.9.4.3—Plastic Moment Resistance	12-46
12.9.4.4—Crown Soil Cover Factor, C_H	12-47
12.9.4.5—Footing Reactions	12-47
12.9.4.6—Concrete Relieving Slabs.....	12-48
12.9.5—Construction and Installation	12-49
12.10—REINFORCED CONCRETE PIPE	12-49
12.10.1—General.....	12-49
12.10.2 Loading.....	12-50
12.10.2.1 Standard Installations.....	12-50
12.10.2.2 Pipe Fluid Weight.....	12-54
12.10.2.3—Live Loads	12-54
12.10.3—Service Limit State.....	12-54
12.10.4—Safety Against Structural Failure.....	12-55
12.10.4.1—General.....	12-55
12.10.4.2—Direct Design Method.....	12-55
12.10.4.2.1—Loads and Pressure Distribution.....	12-55
12.10.4.2.2—Analysis for Force Effects with the Pipe Ring.....	12-57
12.10.4.2.3—Process and Material Factors	12-57
12.10.4.2.4—Flexural Resistance at the Strength Limit State	12-57
12.10.4.2.4a—Circumferential Reinforcement	12-57
12.10.4.2.4b—Minimum Reinforcement	12-58
12.10.4.2.4c—Maximum Flexural Reinforcement without Stirrups	12-58
12.10.4.2.4d—Reinforcement for Crack Width Control	12-59
12.10.4.2.4e—Minimum Concrete Cover	12-61
12.10.4.2.5—Shear Resistance without Stirrups	12-61
12.10.4.2.6—Shear Resistance with Radial Stirrups	12-62
12.10.4.2.7—Stirrup Reinforcement Anchorage.....	12-63
12.10.4.2.7a—Radial Tension Stirrup Anchorage	12-63
12.10.4.2.7b—Shear Stirrup Anchorage	12-63
12.10.4.2.7c—Stirrup Embedment.....	12-63
12.10.4.3—Indirect Design Method	12-64
12.10.4.3.1—Bearing Resistance	12-64
12.10.4.3.2—Bedding Factor	12-64
12.10.4.3.2a—Earth Load Bedding Factor for Circular Pipe	12-64
12.10.4.3.2b—Earth Load Bedding Factor for Arch and Elliptical Pipe.....	12-65
12.10.4.3.2c—Live Load Bedding Factors.....	12-66
12.10.4.4—Development of Quadrant Mat Reinforcement.....	12-66
12.10.4.4.1—Minimum Cage Reinforcement	12-66
12.10.4.4.2—Development Length of Welded Wire Fabric.....	12-67
12.10.4.4.3—Development of Quadrant Mat Reinforcement Consisting of Welded Plain Wire Fabric.....	12-67
12.10.4.4.4—Development of Quadrant Mat Reinforcement Consisting of Deformed Bars, Deformed Wire, or Deformed Wire Fabric	12-67
12.10.5—Construction and Installation	12-68
12.11—REINFORCED CONCRETE CAST-IN-PLACE AND PRECAST BOX CULVERTS AND REINFORCED CAST-IN-PLACE ARCHES	12-68
12.11.1—General.....	12-68

12.11.2—Loads and Live Load Distribution	12-68
12.11.2.1—General.....	12-68
12.11.2.2—Modification of Earth Loads for Soil–Structure Interaction	12-69
12.11.2.2.1—Embankment and Trench Conditions.....	12-69
12.11.2.2.2—Other Installations.....	12-71
12.11.2.3—Distribution of Concentrated Loads to Bottom Slab of Box Culvert	12-71
12.11.2.4—Distribution of Concentrated Loads in Skewed Box Culverts	12-72
12.11.3—Strength Limit State	12-72
12.11.4—Service Limit State	12-72
12.11.5—Safety Against Structural Failure	12-73
12.11.5.1—General.....	12-73
12.11.5.2—Design Moment for Box Culverts	12-73
12.11.5.3—Minimum Reinforcement.....	12-73
12.11.5.3.1—Cast-in-Place Structures.....	12-73
12.11.5.3.2—Precast Box Structures	12-73
12.11.5.4—Minimum Cover for Precast Box Structures	12-73
12.11.6—Construction and Installation	12-74
12.12—THERMOPLASTIC PIPES	12-74
12.12.1—General	12-74
12.12.2—Service Limit States	12-74
12.12.2.1—General.....	12-74
12.12.2.2—Deflection Requirement	12-74
12.12.3—Safety Against Structural Failure	12-75
12.12.3.1—General.....	12-75
12.12.3.2—Section Properties	12-75
12.12.3.3—Chemical and Mechanical Requirements	12-76
12.12.3.4—Thrust	12-77
12.12.3.5—Factored and Service Loads	12-78
12.12.3.6—Handling and Installation Requirements	12-82
12.12.3.7—Soil Prism.....	12-82
12.12.3.8—Hydrostatic Pressure	12-83
12.12.3.9—Live Load.....	12-84
12.12.3.10—Wall Resistance.....	12-84
12.12.3.10.1—Resistance to Axial Thrust	12-84
12.12.3.10.1a—General.....	12-84
12.12.3.10.1b—Local Buckling Effective Area	12-84
12.12.3.10.1c—Compression Strain.....	12-85
12.12.3.10.1d—Thrust Strain Limits	12-86
12.12.3.10.1e—General Buckling Strain Limits	12-86
12.12.3.10.2—Bending and Thrust Strain Limits.....	12-87
12.12.3.10.2a—General.....	12-87
12.12.3.10.2b—Combined Strain	12-87
12.12.4—Construction and Installation	12-89
12.13—STEEL TUNNEL LINER PLATE.....	12-89
12.13.1—General.....	12-89
12.13.2—Loading	12-89
12.13.2.1—Earth Loads.....	12-90
12.13.2.2—Live Loads	12-91
12.13.2.3—Grouting Pressure.....	12-91
12.13.3—Safety Against Structural Failure	12-91
12.13.3.1—Section Properties	12-91
12.13.3.2—Wall Area	12-91
12.13.3.3—Buckling.....	12-91
12.13.3.4—Seam Strength	12-91
12.13.3.5—Construction Stiffness	12-91
12.14—PRECAST REINFORCED CONCRETE THREE-SIDED STRUCTURES	12-93
12.14.1—General.....	12-93

12.14.2—Materials	12-93
12.14.2.1—Concrete	12-93
12.14.2.2—Reinforcement.....	12-93
12.14.3—Concrete Cover for Reinforcement	12-93
12.14.4—Geometric Properties	12-93
12.14.5—Design	12-93
12.14.5.1—General.....	12-93
12.14.5.2—Distribution of Concentrated Load Effects in Top Slab and Sides	12-94
12.14.5.3—Distribution of Concentrated Loads in Skewed Culverts.....	12-94
12.14.5.4—Shear Transfer in Transverse Joints between Culvert Sections	12-94
12.14.5.5—Span Length.....	12-94
12.14.5.6—Resistance Factors	12-95
12.14.5.7—Crack Control.....	12-95
12.14.5.8—Minimum Reinforcement.....	12-95
12.14.5.9—Deflection Control at the Service Limit State	12-95
12.14.5.10—Footing Design.....	12-95
12.14.5.11—Structural Backfill.....	12-95
12.14.5.12—Scour Protection and Waterway Considerations.....	12-95
12.15—FIBERGLASS PIPE	12-95
12.15.1—General.....	12-95
12.15.2—Section Properties	12-96
12.15.3—Mechanical Requirements.....	12-96
12.15.3.1—Circumferential Flexural Modulus.....	12-96
12.15.3.2—Long-Term Ring-Bending Strain	12-96
12.15.4—Total Allowable Deflection.....	12-96
12.15.5—Service Limit States	12-97
12.15.5.1—General.....	12-97
12.15.5.2—Deflection Requirement.....	12-97
12.15.6—Safety Against Structural Failure	12-97
12.15.6.1—General.....	12-97
12.15.6.2—Flexure.....	12-98
12.15.6.3—Global Buckling.....	12-98
12.15.6.4—Flexibility Limit.....	12-99
12.15.7—Construction and Installation	12-99
12.16—REFERENCES	12-99
APPENDIX A12—PLATE, PIPE, AND PIPE ARCH PROPERTIES	12-103

BURIED STRUCTURES AND TUNNEL LINERS

12.1—SCOPE

This Section provides requirements for the selection of structural properties and dimensions of buried structures, e.g., culverts, and steel plate used to support tunnel excavations in soil.

Buried structure systems considered herein are metal pipe, structural plate pipe, long-span structural plate, deep corrugated plate, structural plate box, reinforced concrete pipe, reinforced concrete cast-in-place and precast arch, box and elliptical structures, thermoplastic pipe, and fiberglass pipe.

The type of liner plate considered is cold-formed steel panels.

C12.1

For buried structures, refer to Article 2.6.6 and the *AASHTO Drainage Manual* (2014) for hydraulic design considerations and for design methods related to location, length, and waterway openings.

Thermoplastic and fiberglass pipe are flexible plastic pipes that have similarities in installation and design; however, not all thermoplastic pipe design and installation specifications are applicable to fiberglass pipe. Fiberglass pipe is a smooth-walled thermoset resin pipe that relies on composite glass fiber within its wall for strength; thermoplastic pipe can have either solid or profile walls of homogenous material. The design specifications for fiberglass pipe are contained in Article 12.15 with reference to applicable sections from the thermoplastic pipe design specifications. Construction specifications for fiberglass pipe are included in the *AASHTO LRFD Bridge Construction Specifications*, Section 30, “Thermoplastic Pipe,” with the provisions for thermoplastic pipe applicable to fiberglass pipe installations except as noted.

12.2—DEFINITIONS

Abrasion—Loss of section or coating of a culvert by the mechanical action of water conveying suspended bed load of sand, gravel, and cobble-size particles at high velocities with appreciable turbulence.

Buried Structure—A generic term for a structure built by embankment or trench methods.

Corrosion—Loss of section or coating of a buried structure by chemical and/or electrochemical processes.

Culvert—A curved or rectangular buried conduit for conveyance of water, vehicles, utilities, or pedestrians.

Culvert Material Service Life—The time duration for a material that can satisfy the structural loading, hydraulic loading, and joint performance for the culvert service life duration.

Culvert Service Life—The time duration during which a culvert is expected to provide the desired function with a specified level of maintenance established at the design or retrofit stage.

Deep Corrugated Plate—Structural Plate in AASHTO M 167M/M 167 with a corrugation depth greater than 5.0 in.

FEM—Finite Element Method.

Narrow Trench Width—The outside span of rigid pipe, plus 1.0 ft.

Projection Ratio—Ratio of the vertical distance between the outside top of the pipe and the ground or bedding surface to the outside vertical height of the pipe, applicable to reinforced concrete pipe only.

Side Radius—For deep corrugated plate structures, the side radius is the radius of the plate in the section adjacent to crown (top) section of the structure. In box-shaped structures, this is often called the haunch radius.

Soil Envelope—Zone of controlled soil backfill around culvert structure required to ensure anticipated performance based on soil–structure interaction considerations.

Soil–Structure Interaction System—A buried structure whose structural behavior is influenced by interaction with the soil envelope.

SECTION 13: RAILINGS

TABLE OF CONTENTS

13.1—SCOPE 13-1

13.2—DEFINITIONS..... 13-1

13.3—NOTATION..... 13-3

13.4—GENERAL..... 13-4

13.5—MATERIALS..... 13-5

13.6—LIMIT STATES AND RESISTANCE FACTORS 13-5

 13.6.1—Strength Limit State 13-5

 13.6.2—Extreme Event Limit State 13-5

13.7—TRAFFIC RAILINGS..... 13-5

 13.7.1—Railing System 13-5

 13.7.1.1—General 13-5

 13.7.1.2—Approach Railings 13-6

 13.7.1.3—End Treatment 13-6

 13.7.2—Test Level Selection Criteria..... 13-7

 13.7.3—Railing Design 13-8

 13.7.3.1—General 13-8

 13.7.3.1.1—Application of Previously Tested Systems 13-8

 13.7.3.1.2—New Systems 13-9

 13.7.3.2—Height of Traffic Parapet or Railing 13-9

13.8—PEDESTRIAN RAILINGS..... 13-9

 13.8.1—Geometry 13-9

 13.8.2—Design Loads 13-10

13.9—BICYCLE RAILINGS 13-11

 13.9.1—General..... 13-11

 13.9.2—Geometry 13-11

 13.9.3—Design Live Loads 13-11

13.10—COMBINATION RAILINGS..... 13-12

 13.10.1—General..... 13-12

 13.10.2—Geometry 13-12

 13.10.3—Design Live Loads 13-12

13.11—CURBS AND SIDEWALKS..... 13-12

 13.11.1—General..... 13-12

 13.11.2—Sidewalks 13-13

 13.11.3—End Treatment of Separation Railing..... 13-13

13.12—REFERENCES 13-13

APPENDIX A13..... 13-15

A13.1—GEOMETRY AND ANCHORAGES 13-15

 A13.1.1—Separation of Rail Elements 13-15

 A13.1.2—Anchorages..... 13-17

A13.2—TRAFFIC RAILING DESIGN FORCES..... 13-17

A13.3—DESIGN PROCEDURE FOR RAILING TEST SPECIMENS 13-19

 A13.3.1—Concrete Railings..... 13-19

 A13.3.2—Post-and-Beam Railings..... 13-21

 A13.3.3—Concrete Parapet and Metal Rail..... 13-22

 A13.3.4—Wood Barriers..... 13-24

A13.4—DECK OVERHANG DESIGN 13-25

 A13.4.1—Design Cases 13-25

 A13.4.2—Decks Supporting Concrete Parapet Railings..... 13-25

 A13.4.3—Decks Supporting Post-and-Beam Railings 13-26

 A13.4.3.1—Overhang Design..... 13-26

 A13.4.3.2—Resistance to Punching Shear 13-27

SECTION 13

RAILINGS

13.1—SCOPE

This Section applies to railings for new bridges and for rehabilitated bridges to the extent that railing replacement is determined to be appropriate.

This Section provides six bridge railing test levels and their associated crash test requirements. Guidance for determining the level to meet the warrants for the more common types of bridge sites and guidance for structural and geometric design of railings are provided.

A process for the design of crash test specimens to determine their crashworthiness is described in Appendix A13. This methodology is based on an application of the yield line theory. For use beyond the design of test specimens with expected failure modes similar to those shown in Figures CA13.3.1-1 and CA13.3.1-2, a rigorous yield line solution or a finite element solution should be developed. The procedures of Appendix A13 are not applicable to traffic railings mounted on rigid structures, such as retaining walls or spread footings, when the cracking pattern is expected to extend to the supporting components.

13.2—DEFINITIONS

Agency—A responsible business or service authorized to act on behalf of others, e.g., a governmental department, consulting engineering firm, or owner of the facility or feature.

Barrier Curb—A platform or block used to separate a raised sidewalk for pedestrians, bicycles, or both above the roadway level; see Figure 13.7.1.1-1.

Bicycle Railing—A railing or fencing system, as illustrated in Figure 13.9.3-1, that provides a physical guide for bicyclists crossing bridges to minimize the likelihood of a bicyclist falling over the system.

Bridge Approach Railing—A roadside guardrail system preceding the structure and attached to the bridge rail system that is intended to prevent a vehicle from impacting the end of the bridge railing or parapet.

Combination Railing—A bicycle or pedestrian railing system, as illustrated in Figures 13.8.2-1 and 13.9.3-1, added to a crashworthy bridge vehicular railing or barrier system.

Concrete Barrier—A railing system of reinforced concrete having a traffic face that usually but not always adopts some form of a safety shape.

Concrete Parapet—A railing system of reinforced concrete, usually considered an adequately reinforced concrete wall.

Crash Testing of Bridge Railings—Conducting a series of full-scale impact tests of a bridge railing in accordance with the recommended guidelines in NCHRP Report 350 or AASHTO's *Manual for Assessing Safety Hardware* in order to evaluate the railing's strength and safety performance.

Crashworthy—A system that has been successfully crash-tested to a currently acceptable crash test matrix and test level or one that can be geometrically and structurally evaluated as equal to a crash-tested system.

C13.1

All bridge traffic barrier systems will be referred to as railings herein.

The bridge railing performance need not be identical over the whole highway network. New railing designs should match site needs leading to a multiple test level concept, as described in NCHRP Report 350 or AASHTO's *Manual for Assessing Safety Hardware* (MASH).

All highway safety hardware accepted prior to the adoption of MASH, using criteria contained in NCHRP Report 350, may remain in place and may continue to be manufactured and installed. Highway safety hardware accepted using NCHRP Report 350 criteria is not required to be retested using MASH criteria. New highway safety hardware not previously evaluated must utilize MASH for testing and evaluation.

With the finite resources available to bridge owners, it is not reasonable to expect all existing rails to be updated any more than to expect every existing building to be immediately updated with the passing of a new building code. Many existing bridge rails have proven functional and need only be replaced when removed for bridge widenings.

SECTION 14: JOINTS AND BEARINGS

TABLE OF CONTENTS

14.1—SCOPE	14-1
14.2—DEFINITIONS.....	14-1
14.3—NOTATION.....	14-3
14.4—MOVEMENTS AND LOADS.....	14-6
14.4.1—General.....	14-6
14.4.2—Design Requirements	14-10
14.4.2.1—Elastomeric Pads and Steel Reinforced Elastomeric Bearings.....	14-11
14.4.2.2—High Load Multitrotational (HLMR) Bearings.....	14-12
14.4.2.2.1—Pot Bearings and Curved Sliding Surface Bearings.....	14-12
14.4.2.2.2—Disc Bearings.....	14-12
14.5—BRIDGE JOINTS	14-12
14.5.1—Requirements	14-12
14.5.1.1—General	14-12
14.5.1.2—Structural Design	14-13
14.5.1.3—Geometry	14-14
14.5.1.4—Materials.....	14-14
14.5.1.5—Maintenance.....	14-14
14.5.2—Selection	14-15
14.5.2.1—Number of Joints.....	14-15
14.5.2.2—Location of Joints	14-15
14.5.3—Design Requirements	14-16
14.5.3.1—Movements during Construction.....	14-16
14.5.3.2—Design Movements	14-16
14.5.3.3—Protection.....	14-17
14.5.3.4—Bridging Plates	14-17
14.5.3.5—Armor.....	14-18
14.5.3.6—Anchors.....	14-18
14.5.3.7—Bolts.....	14-18
14.5.4—Fabrication	14-18
14.5.5—Installation	14-19
14.5.5.1—Adjustment.....	14-19
14.5.5.2—Temporary Supports	14-19
14.5.5.3—Field Splices	14-19
14.5.6—Considerations for Specific Joint Types	14-20
14.5.6.1—Open Joints	14-20
14.5.6.2—Closed Joints.....	14-20
14.5.6.3—Waterproofed Joints.....	14-20
14.5.6.4—Joint Seals	14-21
14.5.6.5—Poured Seals	14-21
14.5.6.6—Compression and Cellular Seals	14-21
14.5.6.7—Sheet and Strip Seals	14-22
14.5.6.8—Plank Seals.....	14-22
14.5.6.9—Modular Bridge Joint Systems (MBSJ).....	14-22
14.5.6.9.1—General	14-22
14.5.6.9.2—Performance Requirements.....	14-24
14.5.6.9.3—Testing and Calculation Requirements	14-25
14.5.6.9.4—Loads and Load Factors.....	14-25
14.5.6.9.5—Distribution of Wheel Loads	14-27
14.5.6.9.6—Strength Limit State Design Requirements.....	14-28
14.5.6.9.7—Fatigue Limit State Design Requirements	14-29
14.5.6.9.7a—General	14-29
14.5.6.9.7b—Design Stress Range	14-31
14.6—REQUIREMENTS FOR BEARINGS	14-36
14.6.1—General.....	14-36

14.6.2—Characteristics	14-37
14.6.3—Force Effects Resulting from Restraint of Movement at the Bearing.....	14-38
14.6.3.1—Horizontal Force and Movement.....	14-38
14.6.3.2—Moment.....	14-39
14.6.4—Fabrication, Installation, Testing, and Shipping.....	14-41
14.6.5—Seismic and Other Extreme Event Provisions for Bearings	14-41
14.6.5.1—General.....	14-41
14.6.5.2—Applicability	14-41
14.6.5.3—Design Criteria	14-41
14.7—SPECIAL DESIGN PROVISIONS FOR BEARINGS	14-43
14.7.1—Metal Rocker and Roller Bearings	14-43
14.7.1.1—General.....	14-43
14.7.1.2—Materials	14-44
14.7.1.3—Geometric Requirements.....	14-44
14.7.1.4—Contact Stresses	14-44
14.7.2—PTFE Sliding Surfaces	14-45
14.7.2.1—PTFE Surface.....	14-45
14.7.2.2—Mating Surface.....	14-46
14.7.2.3—Minimum Thickness.....	14-46
14.7.2.3.1—PTFE.....	14-46
14.7.2.3.2—Stainless Steel Mating Surfaces	14-47
14.7.2.4—Contact Pressure.....	14-47
14.7.2.5—Coefficient of Friction.....	14-48
14.7.2.6—Attachment.....	14-49
14.7.2.6.1—PTFE.....	14-49
14.7.2.6.2—Mating Surface.....	14-49
14.7.3—Bearings with Curved Sliding Surfaces.....	14-50
14.7.3.1—General.....	14-50
14.7.3.2—Bearing Resistance.....	14-50
14.7.3.3—Resistance to Lateral Load.....	14-51
14.7.4—Pot Bearings	14-52
14.7.4.1—General.....	14-52
14.7.4.2—Materials	14-52
14.7.4.3—Geometric Requirements.....	14-52
14.7.4.4—Elastomeric Disc	14-54
14.7.4.5—Sealing Rings	14-54
14.7.4.5.1—General.....	14-54
14.7.4.5.2—Rings with Rectangular Cross-Sections	14-55
14.7.4.5.3—Rings with Circular Cross-Sections	14-55
14.7.4.6—Pot.....	14-55
14.7.4.7—Piston	14-56
14.7.5—Steel-Reinforced Elastomeric Bearings—Method B.....	14-57
14.7.5.1—General.....	14-57
14.7.5.2—Material Properties.....	14-58
14.7.5.3—Design Requirements	14-60
14.7.5.3.1—Scope	14-60
14.7.5.3.2—Shear Deformations	14-60
14.7.5.3.3—Combined Compression, Rotation, and Shear.....	14-61
14.7.5.3.4—Stability of Elastomeric Bearings.....	14-64
14.7.5.3.5—Reinforcement.....	14-65
14.7.5.3.6—Compressive Deflection.....	14-66
14.7.5.3.7—Seismic and Other Extreme Event Provisions.....	14-67
14.7.5.4—Anchorage for Bearings without Bonded External Plates	14-67
14.7.6—Elastomeric Pads and Steel-Reinforced Elastomeric Bearings—Method A.....	14-68
14.7.6.1—General.....	14-68
14.7.6.2—Material Properties.....	14-70

14.7.6.3—Design Requirements	14-71
14.7.6.3.1—Scope	14-71
14.7.6.3.2—Compressive Stress	14-71
14.7.6.3.3—Compressive Deflection.....	14-72
14.7.6.3.4—Shear.....	14-74
14.7.6.3.5—Rotation	14-74
14.7.6.3.5a—General	14-74
14.7.6.3.5b—Rotation of CDP	14-75
14.7.6.3.6—Stability.....	14-76
14.7.6.3.7—Reinforcement	14-76
14.7.6.3.8—Seismic and Other Extreme Event Provisions	14-76
14.7.7—Bronze or Copper Alloy Sliding Surfaces.....	14-77
14.7.7.1—Materials	14-77
14.7.7.2—Coefficient of Friction	14-78
14.7.7.3—Limit on Load	14-78
14.7.7.4—Clearances and Mating Surfaces.....	14-78
14.7.8—Disc Bearings.....	14-78
14.7.8.1—General	14-78
14.7.8.2—Materials	14-79
14.7.8.3—Elastomeric Disc.....	14-79
14.7.8.4—Shear Resisting Mechanism	14-80
14.7.8.5—Steel Plates.....	14-80
14.7.9—Guides and Restraints	14-80
14.7.9.1—General	14-80
14.7.9.2—Design Loads	14-81
14.7.9.3—Materials.....	14-81
14.7.9.4—Geometric Requirements	14-81
14.7.9.5—Design Basis	14-81
14.7.9.5.1—Load Location.....	14-81
14.7.9.5.2—Contact Stress	14-82
14.7.9.6—Attachment of Low-Friction Material.....	14-82
14.7.10—Other Bearing Systems.....	14-82
14.8—LOAD PLATES AND ANCHORAGE FOR BEARINGS	14-83
14.8.1—Plates for Load Distribution.....	14-83
14.8.2—Tapered Plates.....	14-84
14.8.3—Anchorage and Anchor Bolts	14-84
14.8.3.1—General	14-84
14.8.3.2—Seismic and Other Extreme Event Design and Detailing Requirements	14-85
14.9—CORROSION PROTECTION.....	14-85
14.10—REFERENCES	14-86

JOINTS AND BEARINGS

14.1—SCOPE

This Section contains requirements for the design and selection of structural bearings and deck joints.

Units used in this Section shall be taken as kip, in., rad., °F, and Shore Hardness, unless otherwise noted.

14.2—DEFINITIONS

Bearing—A structural device that transmits loads while facilitating translation and/or rotation.

Bearing Joint—A deck joint provided at bearings and other deck supports to facilitate horizontal translation and rotation of abutting structural elements. It may or may not provide for differential vertical translation of these elements.

Bronze Bearing—A bearing in which displacements or rotations take place by the sliding of a bronze surface against a mating surface.

Cotton-Duck-Reinforced Pad (CDP)—A pad made from closely spaced layers of elastomer and cotton-duck, bonded together during vulcanization.

Closed Joint—A deck joint designed to prevent the passage of debris through the joint and to safeguard pedestrian and cycle traffic.

Compression Seal—A preformed elastomeric device that is precompressed in the gap of a joint with expected total range of movement less than 2.0 in.

Construction Joint—A temporary joint used to permit sequential construction.

Cycle-Control Joint—A transverse approach slab joint designed to permit longitudinal cycling of integral bridges and attached approach slabs.

Damper—A device that transfers and reduces forces between superstructure elements and/or superstructure and substructure elements, while permitting thermal movements. The device provides damping by dissipating energy under seismic, braking, or other dynamic loads.

Deck Joint—A structural discontinuity between two elements, at least one of which is a deck element. It is designed to permit relative translation and/or rotation of abutting structural elements.

Disc Bearing—A bearing that accommodates rotation by deformation of a single elastomeric disc molded from a urethane compound. It may be movable, guided, unguided, or fixed. Movement is accommodated by sliding of polished stainless steel on PFTE.

Double Cylindrical Bearing—A bearing made from two cylindrical bearings placed on top of each other with their axes at right angles to facilitate rotation about any horizontal axis.

Fiberglass-Reinforced Pad (FGP)—A pad made from discrete layers of elastomer and woven fiberglass bonded together during vulcanization.

Fixed Bearing—A bearing that prevents differential longitudinal translation of abutting structural elements. It may or may not provide for differential lateral translation or rotation.

Integral Bridge—A bridge without deck joints.

Joint—A structural discontinuity between two elements. The structural members used to frame or form the discontinuity.

TABLE OF CONTENTS

15.1—SCOPE 15-1

15.2—DEFINITIONS..... 15-1

15.3—NOTATION..... 15-1

15.4—GENERAL FEATURES..... 15-2

 15.4.1—Functional Requirements 15-2

 15.4.1.1—General..... 15-2

 15.4.1.2—Lateral Clearance 15-2

 15.4.2—Drainage..... 15-2

 15.4.3—Emergency Responders and Maintenance Access 15-2

 15.4.4—Differential Settlement of Foundations..... 15-3

15.5—LIMIT STATES AND RESISTANCE FACTORS 15-3

 15.5.1—General..... 15-3

 15.5.2—Service Limit State..... 15-3

 15.5.3—Strength Limit State 15-3

 15.5.4—Extreme Event Limit State..... 15-4

15.6—EXPANSION DEVICES 15-4

 15.6.1—General..... 15-4

 15.6.2—Structure-Mounted Sound Barriers 15-4

 15.6.3—Ground-Mounted Sound Barriers..... 15-4

15.7—SOUND BARRIERS INSTALLED ON EXISTING BRIDGES 15-5

15.8—LOADS 15-5

 15.8.1—General..... 15-5

 15.8.2—Wind Load 15-5

 15.8.3—Earth Load 15-5

 15.8.4—Vehicular Collision Forces 15-6

15.9—FOUNDATION DESIGN..... 15-8

 15.9.1—General..... 15-8

 15.9.2—Determination of Soil and Rock Properties 15-9

 15.9.3—Limit States 15-9

 15.9.4—Resistance Requirements 15-9

 15.9.5—Resistance Factors..... 15-9

 15.9.6—Loading 15-10

 15.9.7—Movement at the Service Limit State..... 15-10

 15.9.8—Safety against Geotechnical Failure at the Strength Limit State..... 15-10

 15.9.9—Seismic Design 15-10

 15.9.10—Corrosion Protection 15-10

 15.9.11—Drainage..... 15-10

15.10—REFERENCES 15-10

DESIGN OF SOUND BARRIERS

15.1—SCOPE

This Section applies to the structural design of sound barriers which are either ground-mounted or structure-mounted and the design of the foundations of ground-mounted sound barriers.

C15.1

This Section specifies the design forces and the design requirements unique to sound barriers constructed along highways. This Section does not cover sound barriers constructed adjacent to railroad tracks or the acoustical requirements for sound barriers.

These provisions are largely based on the requirements of the *Guide Specifications for Structural Design of Sound Barriers* (1989).

15.2—DEFINITIONS

Clear Zone—The total roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles.

Crashworthy—A traffic railing system that has been successfully crash-tested to a currently acceptable crash test matrix and test level or one that can be geometrically and structurally evaluated as equal to a crash-tested system.

Ground-Mounted Sound Barriers—Sound barriers supported on shallow or deep foundations.

Post-and-Panel Construction—Type of sound barrier construction consisting of vertical posts supported on a structure or on the foundations and panels spanning horizontally between adjacent posts.

Right-of-Way—The land on which a roadway and its associated facilities and appurtenances are located. The highway right-of-way is owned and maintained by the agency having jurisdiction over that specific roadway.

Right-of-Way Line—The boundary of the right-of-way.

Sound Barrier—A wall constructed along a highway to lower the highway noise level in the area behind the wall.

Sound Barrier Setback—The distance between the point on the traffic face of the sound barrier wall that is closest to traffic and the closest point on the traffic face of the traffic railing the sound barrier is mounted on or located behind as defined in Article 15.8.4.

Structure-Mounted Sound Barriers—Sound barriers supported on bridges, crashworthy traffic railings, or retaining walls.

Traffic Railing—Synonymous with vehicular railing; used as a bridge- or structure-mounted railing rather than as a guardrail or median barrier, as in other publications.

Vehicular Railing—Synonymous with traffic railing; used as a bridge- or structure-mounted railing rather than as a guardrail or median barrier, as in other publications.

15.3—NOTATION

- S = setback distance of sound barrier (15.8.4)
 ϕ = soil angle of internal friction (degrees) (C15.4.2)
 γ_p = load factor for permanent loads (15.9.9)