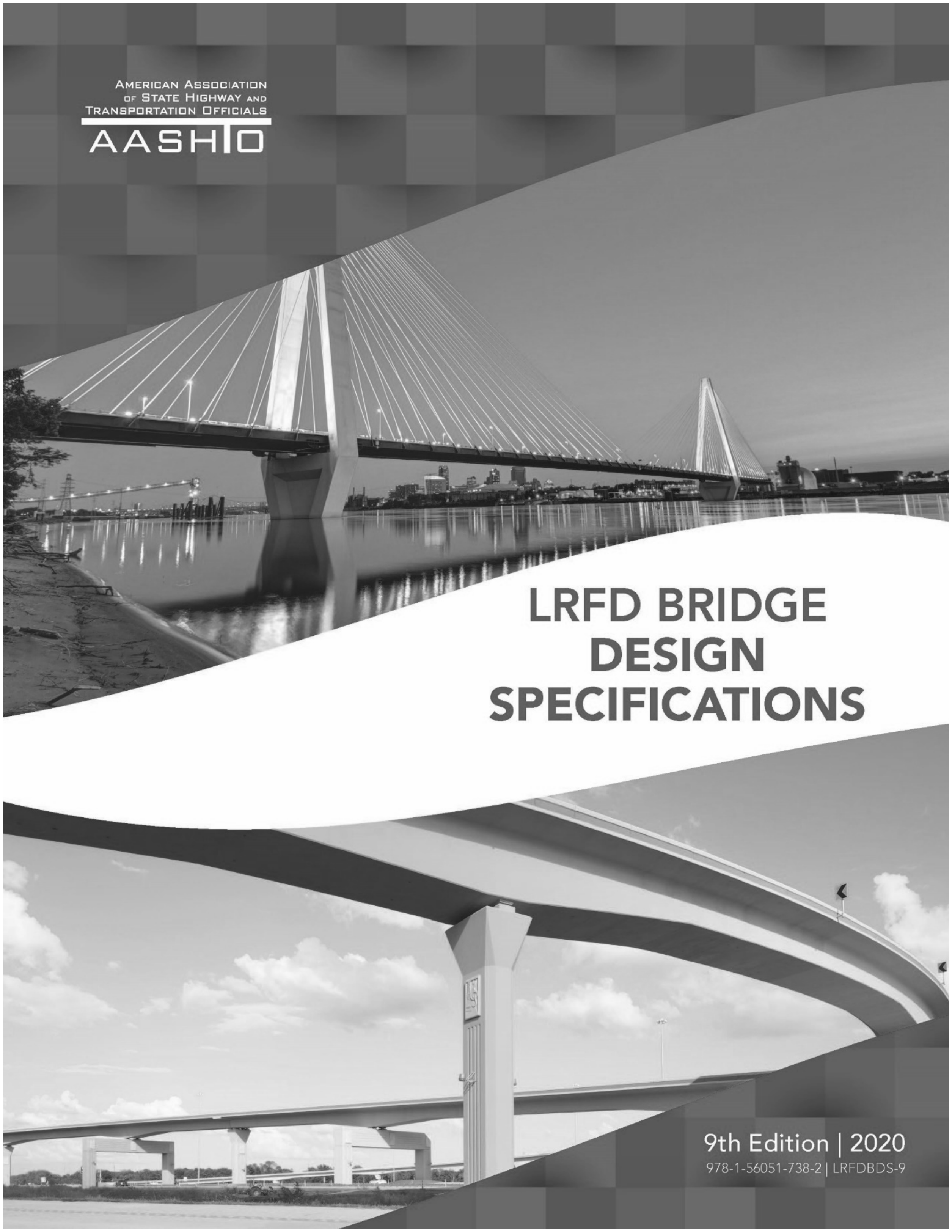
AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

AASHTO

LRFD BRIDGE DESIGN SPECIFICATIONS

9th Edition | 2020

978-1-56051-738-2 | LRFDBDS-9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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.

ISBN: 978-1-56051-738-2 Pub Code: LRFDBDS-9

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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:

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.

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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.

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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.

C2.1

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

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.

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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.

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.

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.

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SECTION 4

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.

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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.

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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

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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)

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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.

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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.

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.

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.

SECTION 10

FOUNDATIONS

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.

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.

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.

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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.

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SECTION 12

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.

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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.

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.

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.

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SECTION 14

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.

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SECTION 15

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)