TABLE OF CONTENTS

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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.

1.2—DEFINITIONS

Bridge—Any structure having an opening not less than 20.0 ft that forms part of a highway or that is located over or under a highway.

Collapse—A major change in the geometry of the bridge rendering it unfit for use.

Component—Either a discrete element of the bridge or a combination of elements requiring individual design consideration.

Design—Proportioning and detailing the components and connections of a bridge.

Design Life—Period of time on which the statistical derivation of transient loads is based, which is 75 years for these Specifications.

Ductility—Property of a component or connection that allows inelastic response.

Engineer—Person responsible for the design of the bridge and/or review of design-related field submittals such as erection plans.

Evaluation—Determination of load-carrying capacity of an existing bridge.

Extreme Event Limit States—Limit states relating to events such as earthquakes, ice load, and vehicle and vessel collision, with return periods in excess of the design life of the bridge.

Factored Load—The nominal loads multiplied by the appropriate load factors specified for the load combination under consideration.

Factored Resistance—The nominal resistance multiplied by a resistance factor.

Fixed Bridge—A bridge with a fixed vehicular or navigational clearance.

Force Effect—A deformation, stress, or stress resultant (i.e., axial force, shear force, or torsional or flexural moment) caused by applied loads, imposed deformations, or volumetric changes.

Limit State—A condition beyond which the bridge or component ceases to satisfy the provisions for which it was designed.

Load and Resistance Factor Design (LRFD)—A reliability-based design methodology in which force effects caused by factored loads are not permitted to exceed the factored resistance of the components.

Load Factor—A statistically-based multiplier applied to force effects accounting primarily for the variability of loads, the lack of accuracy in analysis, and the probability of simultaneous occurrence of different loads, but also related to the statistics of the resistance through the calibration process.

Load Modifier—A factor accounting for ductility, redundancy, and the operational classification of the bridge.

Model—An idealization of a structure for the purpose of analysis.

Movable Bridge—A bridge with a variable vehicular or navigational clearance.

Multiple-Load-Path Structure—A structure capable of supporting the specified loads following loss of a main load-carrying component or connection.

Nominal Resistance—Resistance of a component or connection to force effects, as indicated by the dimensions specified in the contract documents and by permissible stresses, deformations, or specified strength of materials.

Owner—Person or agency having jurisdiction over the bridge.

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Regular Service—Condition excluding the presence of special permit vehicles, wind exceeding 55 mph, and extreme events, including scour.

Rehabilitation—A process in which the resistance of the bridge is either restored or increased.

Resistance Factor—A statistically-based multiplier applied to nominal resistance accounting primarily for variability of material properties, structural dimensions and workmanship, and uncertainty in the prediction of resistance, but also related to the statistics of the loads through the calibration process.

Service Life—The period of time that the bridge is expected to be in operation.

Service Limit States—Limit states relating to stress, deformation, and cracking under regular operating conditions.

Strength Limit States—Limit states relating to strength and stability during the design life.

1.3—DESIGN PHILOSOPHY

1.3.1—General

Bridges shall be designed for specified limit states to achieve the objectives of constructibility, safety, and serviceability, with due regard to issues of inspectability, economy, and aesthetics, as specified in Article 2.5.

Regardless of the type of analysis used, Eq. 1.3.2.1-1 shall be satisfied for all specified force effects and combinations thereof.

C1.3.1

The limit states specified herein are intended to provide for a buildable, serviceable bridge, capable of safely carrying design loads for a specified lifetime.

The resistance of components and connections is determined, in many cases, on the basis of inelastic behavior, although the force effects are determined by using elastic analysis. This inconsistency is common to most current bridge specifications as a result of incomplete knowledge of inelastic structural action.

1.3.2—Limit States

1.3.2.1—General

Each component and connection shall satisfy Eq. 1.3.2.1-1 for each limit state, unless otherwise specified. For service and extreme event limit states, resistance factors shall be taken as 1.0, except for bolts, for which the provisions of Article 6.5.5 shall apply, and for concrete columns in Seismic Zones 2, 3, and 4, for which the provisions of Articles 5.11.3 and 5.11.4.1.2 shall apply. All limit states shall be considered of equal importance.

$$\sum \eta_i \gamma_i Q_i \leq \phi R_n = R_r \qquad (1.3.2.1\text{-}1)$$

in which:

For loads for which a maximum value of γ_i is appropriate:

$$\eta_i = \eta_D \eta_R \eta_I \geq 0.95 \qquad (1.3.2.1\text{-}2)$$

For loads for which a minimum value of γ_i is appropriate:

$$\eta_i = \frac{1}{\eta_D \eta_R \eta_I} \leq 1.0 \qquad (1.3.2.1\text{-}3)$$

C1.3.2.1

Eq. 1.3.2.1-1 is the basis of LRFD methodology.

Assigning resistance factor $\phi = 1.0$ to all nonstrength limit states is a default, and may be overridden by provisions in other Sections.

Ductility, redundancy, and operational classification are considered in the load modifier η. Whereas the first two directly relate to physical strength, the last concerns the consequences of the bridge being out of service. The grouping of these aspects on the load side of Eq. 1.3.2.1-1 is, therefore, arbitrary. However, it constitutes a first effort at codification. In the absence of more precise information, each effect, except that for fatigue and fracture, is estimated as ±5 percent, accumulated geometrically. This is a clearly subjective approach, and a rearrangement of Eq. 1.3.2.1-1 may be attained with time. Such a rearrangement might account for improved quantification of ductility, redundancy, and operational classification, and their interactions with system reliability in such an equation.

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where:

γ_i = load factor: a statistically based multiplier applied to force effects

ϕ = resistance factor: a statistically based multiplier applied to nominal resistance, as specified in Sections 5, 6, 7, 8, 10, 11, and 12

η_i = load modifier: a factor relating to ductility, redundancy, and operational classification

η_D = a factor relating to ductility, as specified in Article 1.3.3

η_R = a factor relating to redundancy, as specified in Article 1.3.4

η_I = a factor relating to operational classification, as specified in Article 1.3.5

Q_i = force effect

R_n = nominal resistance

R_r = factored resistance: ϕR_n

The influence of η on the girder reliability index, β, can be estimated by observing its effect on the minimum values of β calculated in a database of girder-type bridges. Cellular structures and foundations were not a part of the database; only individual member reliability was considered. For discussion purposes, the girder bridge data used in the calibration of these Specifications was modified by multiplying the total factored loads by $\eta = 0.95$, 1.0, 1.05, and 1.10. The resulting minimum values of β for 95 combinations of span, spacing, and type of construction were determined to be approximately 3.0, 3.5, 3.8, and 4.0, respectively. In other words, using $\eta > 1.0$ relates to a β higher than 3.5.

A further approximate representation of the effect of η values can be obtained by considering the percent of random normal data less than or equal to the mean value plus $\lambda\ \sigma$, where λ is a multiplier, and σ is the standard deviation of the data. If λ is taken as 3.0, 3.5, 3.8, and 4.0, the percent of values less than or equal to the mean value plus $\lambda\ \sigma$ would be about 99.865 percent, 99.977 percent, 99.993 percent, and 99.997 percent, respectively.

The Strength I Limit State in the *AASHTO LRFD Design Specifications* has been calibrated for a target reliability index of 3.5 with a corresponding probability of exceedance of 2.0E-04 during the 75-year design life of the bridge. This 75-year reliability is equivalent to an annual probability of exceedance of 2.7E-06 with a corresponding annual target reliability index of 4.6. Similar calibration efforts for the Service Limit States are underway. Return periods for extreme events are often based on annual probability of exceedance, and caution must be used when comparing reliability indices of various limit states.

1.3.2.2—Service Limit State

The service limit state shall be taken as restrictions on stress, deformation, and crack width under regular service conditions.

C1.3.2.2

The service limit state provides certain experience-related provisions that cannot always be derived solely from strength or statistical considerations.

1.3.2.3—Fatigue and Fracture Limit State

The fatigue limit state shall be taken as restrictions on stress range as a result of a single design truck occurring at the number of expected stress range cycles.

The fracture limit state shall be taken as a set of material toughness requirements of the *AASHTO Materials Specifications.*

C1.3.2.3

The fatigue limit state is intended to limit crack growth under repetitive loads to prevent fracture during the design life of the bridge.

1.3.2.4—Strength Limit State

Strength limit state shall be taken to ensure that strength and stability, both local and global, are provided to resist the specified statistically significant load combinations that a bridge is expected to experience in its design life.

C1.3.2.4

The strength limit state considers stability or yielding of each structural element. If the resistance of any element, including splices and connections, is exceeded, it is assumed that the bridge resistance has been exceeded. In fact, there is significant elastic reserve capacity in almost all multigider bridges beyond such a load level. The live load cannot be positioned to maximize the force effects on all parts of the cross-section simultaneously. Thus, the flexural resistance of the bridge cross-section typically exceeds the resistance required for the total live load that can be applied in the number of lanes available. Extensive distress and structural damage may occur under strength limit state, but overall structural integrity is expected to be maintained.

1.3.2.5—Extreme Event Limit States

The extreme event limit state shall be taken to ensure the structural survival of a bridge during a major earthquake or flood, or when collided with by a vessel, vehicle, or ice floe, possibly under scoured conditions.

C1.3.2.5

Extreme event limit states are considered to be unique occurrences that may have severe operational impact and whose return period may be significantly greater than the design life of the bridge.

The Owner may choose to require that the extreme event limit state provide restricted or immediate serviceability in special cases of operational importance of the bridge or transportation corridor.

1.3.3—Ductility

The structural system of a bridge shall be proportioned and detailed to ensure the development of significant and visible inelastic deformations at the strength and extreme event limit states before failure.

Energy-dissipating devices may be substituted for conventional ductile earthquake resisting systems and the associated methodology addressed in these Specifications or in the *AASHTO Guide Specifications for LRFD Seismic Bridge Design*.

For the strength limit state:

$\eta_D \geq$ 1.05 for nonductile components and connections

$=$ 1.00 for conventional designs and details complying with these Specifications

$\geq$ 0.95 for components and connections for which additional ductility-enhancing measures have been specified beyond those required by these Specifications

For all other limit states:

$\eta_D =$ 1.00

C1.3.3

The response of structural components or connections beyond the elastic limit can be characterized by either brittle or ductile behavior. Brittle behavior is undesirable because it implies the sudden loss of load-carrying capacity immediately when the elastic limit is exceeded. Ductile behavior is characterized by significant inelastic deformations before any loss of load-carrying capacity occurs. Ductile behavior provides warning of structural failure by large inelastic deformations. Under repeated seismic loading, large reversed cycles of inelastic deformation dissipate energy and have a beneficial effect on structural survival.

If, by means of confinement or other measures, a structural component or connection made of brittle materials can sustain inelastic deformations without significant loss of load-carrying capacity, this component can be considered ductile. Such ductile performance shall be verified by testing.

In order to achieve adequate inelastic behavior, the system should have a sufficient number of ductile members and either:

- joints and connections that are also ductile and can provide energy dissipation without loss of capacity; or
- joints and connections that have sufficient excess strength so as to assure that the inelastic response occurs at the locations designed to provide ductile, energy absorbing response.

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Statically ductile but dynamically nonductile response characteristics should be avoided. Examples of this behavior are shear and bond failures in concrete members and loss of composite action in flexural components.

Past experience indicates that typical components designed in accordance with these provisions generally exhibit adequate ductility. Connection and joints require special attention to detailing and the provision of load paths.

The Owner may specify a minimum ductility factor as an assurance that ductile failure modes will be obtained. The factor may be defined as:

$$\mu = \frac{\Delta_u}{\Delta_y} \quad \text{(C1.3.3-1)}$$

where:

Δ_u = deformation at ultimate

Δ_y = deformation at the elastic limit

The ductility capacity of structural components or connections may either be established by full- or large-scale testing or with analytical models based on documented material behavior. The ductility capacity for a structural system may be determined by integrating local deformations over the entire structural system.

The special requirements for energy dissipating devices are imposed because of the rigorous demands placed on these components.

1.3.4—Redundancy

Multiple-load-path and continuous structures should be used unless there are compelling reasons not to use them.

For the strength limit state:

η_R ≥ 1.05 for nonredundant members

= 1.00 for conventional levels of redundancy, foundation elements where ϕ already accounts for redundancy as specified in Article 10.5

≥ 0.95 for exceptional levels of redundancy beyond girder continuity and a torsionally-closed cross-section

C1.3.4

For each load combination and limit state under consideration, member redundancy classification (redundant or nonredundant) should be based upon the member contribution to the bridge safety. Several redundancy measures have been proposed (Frangopol and Nakib, 1991).

Single-cell boxes and single-column bents may be considered nonredundant at the Owner's discretion. For prestressed concrete boxes, the number of tendons in each web should be taken into consideration. For steel cross-sections and fracture-critical considerations, see Section 6.

The Manual for Bridge Evaluation (2018) defines bridge redundancy as "the capability of a bridge structural system to carry loads after damage to or the failure of one or more of its members." System factors are provided for post-tensioned segmental concrete box girder bridges in Section 6A.5.11.6 of the Manual.

System reliability encompasses redundancy by considering the system of interconnected components and members. Rupture or yielding of an individual component may or may not mean collapse or failure of the whole structure or system (Nowak, 2000). Reliability indexes for entire systems are a subject of ongoing research and are anticipated to encompass ductility, redundancy, and member correlation.

For all other limit states:

η_R = 1.00

1.3.5—Operational Importance

The Owner may declare a bridge or any structural component and connection thereof to be of operational priority.

For the strength limit state:

η_I ≥ 1.05 for critical or essential bridges

= 1.00 for typical bridges

≥ 0.95 for relatively less important bridges.

For all other limit states:

η_I = 1.00

C1.3.5

Such classification should be done by personnel responsible for the affected transportation network and knowledgeable of its operational needs. The definition of operational priority may differ from Owner to Owner and network to network. Guidelines for classifying critical or essential bridges are as follows:

- Bridges that are required to be open to all traffic once inspected after the design event and be usable by emergency vehicles and for security, defense, economic, or secondary life safety purposes immediately after the design event.
- Bridges that should, as a minimum, be open to emergency vehicles and for security, defense, or economic purposes after the design event, and open to all traffic within days after that event.

Owner-classified bridges may use a value for $\eta < 1.0$ based on ADTT, span length, available detour length, or other rationale to use less stringent criteria.

1.4—REFERENCES

AASHTO. *AASHTO LRFD Bridge Construction Specifications*, Fourth Edition with 2020 Interims, LRFDCONS-4. American Association of State Highway and Transportation Officials, Washington, DC, 2019.

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