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AASHTO

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8th Edition
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AASHTO

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Cover photos: **Upper Left:** Photo taken in Portland, Oregon, at the 2013 AASHTO Bridge Subcommittee meeting during the dinner cruise on the Willamette River, at sunset. This is the Tilicum Crossing used for pedestrian traffic and transit. Photo © Tony Allen 2013. **Upper Right:** Award-winning West 7th Street Bridge, Ft. Worth, Texas. Photo © TxDOT. **Bottom Right:** The new two-mile Route 52 Causeway between Somers Pont and Ocean City, NJ; completed in 2012, it is one of the largest bridges constructed by NJDOT in South Jersey. Photo provided by Stokes Creative Group, 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, 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.

With this edition, the eighth, of the AASHTO LRFD Bridge Design Specifications, Interim Specifications will no longer be issued. Instead, changes balloted and approved by at least two-thirds of the members of the Subcommittee will be published in the next full edition of the Specifications, to be published on a three-year cycle. 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 our web site, bookstore.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 our website or requested from the Publications Sales Office.

Attention is also directed to the following publications prepared and published by the Subcommittee on Bridges and Structures:

AASHTO Guide for Commonly Recognized (CoRe) Structural Elements. 1998.

AASHTO Guide Manual for Bridge Element Inspection. 2011.

AASHTO Guide Specifications for Horizontally Curved Steel Girder Highway Bridges with Design Examples for I-Girder and Box-Girder Bridges. 2003. Archived.

AASHTO Guide Specifications—Thermal Effects in Concrete Bridge Superstructures. 1989. Archived but download available.

AASHTO LRFD Bridge Construction Specifications. 2010.

AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings. 2009.

AASHTO LRFD Movable Highway Bridge Design Specifications. 2007.

Bridge Data Exchange (BDX) Technical Data Guide. 1995. Archived.

Bridge Security Guidelines, 2011.

Bridge Welding Code: AASHTO/AWS D1.5M/D1.5:2010, an American National Standard. 2015.

Construction Handbook for Bridge Temporary Works. 2017.

Guide Design Specifications for Bridge Temporary Works. 2017.

Guide for Painting Steel Structures. 1997. Archived.

Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges. 2003. Archived but download available.

Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges. 2009. Archived, download available.

Guide Specifications for Alternate Load Factor Design Procedures for Steel Beam Bridges Using Braced Compact Sections. 1991. Archived.

Guide Specifications for Aluminum Highway Bridges. 1991. Archived.

Guide Specifications for Bridge Railings. 1989. Archived.

Guide Specifications for Design and Construction of Segmental Concrete Bridges. 1999.

Guide Specifications for Fatigue Evaluation of Existing Steel Bridges. 1990. Archived but download available.

Guide Specifications for Highway Bridge Fabrication with HPS 70W (HPS 485W) Steel. 2003. Archived but download available.

Guide Specifications for Seismic Isolation Design. 2014.

Guide Specifications for Strength Design of Truss Bridges (Load Factor Design). 1986. Archived but download available.

Guide Specifications for Strength Evaluation of Existing Steel and Concrete Bridges. 1989. Archived but download available.

Guide Specifications for Structural Design of Sound Barriers. 1989. Archived but download available.

Guide Specifications for the Design of Stress-Laminated Wood Decks. 1991. Archived but download available.

Guidelines for Bridge Management Systems. 1993. Archived but download available.

LRFD Guide Specifications for Design of Pedestrian Bridges. 2009.

The Manual for Bridge Evaluation. 2011.

Movable Bridge Inspection, Evaluation, and Maintenance Manual. 2017.

Standard Specifications for Movable Highway Bridges. 1988. Archived but download available.

Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals. 2009.

Technical Manual for Design and Construction of Road Tunnels—Civil Elements. 2010.

Additional bridges and structures publications prepared and published by other AASHTO committees and task forces are as follows:

AASHTO Maintenance Manual: The Maintenance and Management of Roadways and Bridges. 2007.

Guide Specifications for Cathodic Protection of Concrete Bridge Decks. 1994. Archived but download available.

Guide Specifications for Concrete Overlay of Pavements and Bridge Decks. 1990. Archived but download available.

Guide Specifications for Polymer Concrete Bridge Deck Overlays. 1995.

Guide Specifications for Shotcrete Repair of Highway Bridges. 1998. Archived but download available.

Inspector's Guide for Shotcrete Repair of Bridges. 1999. Archived but download available.

Manual for Corrosion Protection of Concrete Components in Bridges. 1992. Archived but download available.

The following bridges and structures titles are the result of the AASHTO–NSBA Steel Bridge Collaboration and are available for free download from the AASHTO web site, bookstore.transportation.org:

Design Drawing Presentation Guidelines, G 1.2. 2003.

Guidelines for Design Constructability, G 12.1. 2016.

Guidelines for Design Details, G 1.4. 2006.

Guidelines for Resolution of Steel Bridge Fabrications Errors, G 2.2. 2016.

Guidelines for Steel Girder Bridge Analysis, G 13.1. 2011.

Guide Specification for Application of Coating Systems with Zinc-Rich Primers to Steel Bridges, S 8.1. 2006.

Recommendations for the Qualification of Structural Bolting Inspectors, G 4.2. 2006.

Sample Owners Quality Assurance Manual, G 4.4. 2006.

Shop Detail Drawing Presentation Guidelines, G 1.3. 2003.

Shop Detail Drawing Review/Approval Guidelines, G1.1. 2000.

Steel Bridge Bearing Design and Detailing Guidelines, 1st Edition, G 9.1. 2004.

Steel Bridge Erection Guide Specification, S 10.1. 2014.

Steel Bridge Fabrication Guide Specification, S 2.1. 2016.

Steel Bridge Fabrication QC/QA Guide Specification, S 4.1. 2002.

The following have served as chairmen of the Subcommittee on Bridges and Structures since its inception in 1921: Messrs. E. F. Kelley, who pioneered the work of the Subcommittee; 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; and Malcolm T. Kerley. The Subcommittee expresses its sincere appreciation of the work of these men and of those active members of the past, whose names, because of retirement, are no longer on the roll.

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

Suggestions for the improvement of the LRFD Specifications are welcomed, just as they were for the Standard Specifications before them. They should be sent to the Chairman, Subcommittee on Bridges and Structures, AASHTO, 444 North Capitol Street, N.W., Suite 249, Washington, DC 20001. Inquiries as to intent or application of the specifications should be sent to the same address.

PREFACE AND ABBREVIATED TABLE OF CONTENTS

The *AASHTO LRFD Bridge Design Specifications*, Eighth 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 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 Bookstore, https://bookstore.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, e.g., spaces removed between the letter and number.

CHANGED AND DELETED ARTICLES, 2017

SUMMARY OF AFFECTED SECTIONS

The revisions included in the *AASHTO LRFD Bridge Design Specifications*, Eighth Edition affect the following sections:

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. Walls, Abutments, and Piers
12. Buried Structures and Tunnel Liners
14. Joints and Bearings

SECTION 1 REVISIONS

Changed Articles

The following Articles in Section 1 contain changes or additions to the specifications, the commentary, or both:

1.3.2.5

Deleted Articles

No Articles were deleted from Section 1.

SECTION 2 REVISIONS

Changed Articles

The following Articles in Section 2 contain changes or additions to the specifications, the commentary, or both:

2.5.1
2.5.1.1
2.5.1.2
2.5.1.3
2.5.2.6.2

Deleted Articles

No Articles were deleted from Section 2.

SECTION 3 REVISIONS

Changed Articles

The following Articles in Section 3 contain changes or additions to the specifications, the commentary, or both:

3.3.1
3.4.1
3.6.1.2.6a
3.8.1.2.1
3.11.5.3
3.11.5.6
3.11.5.8.1
3.11.6.2
3.16

Deleted Articles

No Articles were deleted from Section 3.

SECTION 4 REVISIONS

Changed Articles

The following Articles in Section 4 contain changes or additions to the specifications, the commentary, or both:

4.6.1.2.4b
4.6.1.2.4c
4.6.2.10.4
4.9

Deleted Articles

No Articles were deleted from Section 4.

SECTION 5 REVISIONS

Changed Articles

Section 5 has been reorganized and replaced in its entirety.

SECTION 6 REVISIONS

Changed Articles

The following Articles in Section 6 contain changes or additions to the specifications, the commentary, or both:

6.2
6.3
6.4.1
6.4.3.1
6.4.3.1.1
6.4.3.1.2
6.4.3.1.3
6.4.3.1.4
6.4.3.2
6.4.3.3
6.4.3.3.1
6.4.3.3.2
6.4.4
6.5.4.1
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6.6.1.2.3
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6.6.1.3.2
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6.14.2.8.3
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6.14.3.2.3
6.16.1
6.16.4.1
6.16.4.2
6.17
A6.3.2
D6.2.3

Deleted Articles

6.4.3.4
6.4.3.5

SECTION 7 REVISIONS

Changed Articles

The following Articles in Section 7 contain changes or additions to the specifications, the commentary, or both:

7.1
7.2
7.4.1
7.4.3.1
7.4.3.2
7.4.3.3
7.4.3.4
7.4.5
7.5.4.2
7.5.4.3
7.5.4.4.1
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7.5.4.4.6
7.5.4.4.7
7.5.4.5.1
7.5.4.5.2
7.5.4.5.3
7.5.4.5.4
7.5.4.5.5
7.5.4.5.6
7.5.4.6
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7.12.2.1
7.12.2.6.1
7.12.2.6.2
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7.12.2.9
7.12.3.2.1
7.12.3.3
7.12.4
7.12.7
7.12.7.1
7.12.7.2
7.12.7.3
7.12.7.4
7.12.7.5
7.12.7.6
7.12.7.7
7.14

*Article has been replaced in its entirety.

Deleted Articles

7.4.3.5
7.7.6
7.7.6.1
7.7.6.2
7.7.6.2.1
7.7.6.3

SECTION 8 REVISIONS

Changed Articles

The following Articles in Section 8 contain changes or additions to the specifications, the commentary, or both:

8.4.1.1.4
8.4.1.4

Deleted Articles

No Articles were deleted from Section 8.

SECTION 9 REVISIONS

Changed Articles

The following Articles in Section 9 contain changes or additions to the specifications, the commentary, or both:

9.8.3.6.2
9.10

Deleted Articles

No Articles were deleted from Section 9.

SECTION 10 REVISIONS

Changed Articles

The following Articles in Section 10 contain changes or additions to the specifications, the commentary, or both:

10.3
10.6.3.1.2c
10.6.3.4
10.10

Deleted Articles

No Articles were deleted from Section 10.

SECTION 11 REVISIONS

Changed Articles

The following Articles in Section 11 contain changes or additions to the specifications, the commentary, or both:

11.10.5.2
11.10.7.1
11.8.4.1
11.5.4.2
11.6.5.6
11.10.7.4
11.11.6

Deleted Articles

No Articles were deleted from Section 11.

SECTION 12 REVISIONS

Changed Articles

The following Articles in Section 12 contain changes or additions to the specifications, the commentary, or both:

12.4.2.7
12.10.1
12.10.4.2.2
12.10.4.2.4
12.10.4.2.4a
12.10.4.2.4b
12.10.4.2.4c
12.11.2.1
12.11.3
12.11.4
12.14.5.6
12.16

Deleted Articles

No Articles were deleted from Section 12.

SECTION 14 REVISIONS

Changed Articles

The following Articles in Section 14 contain changes or additions to the specifications, the commentary, or both:

14.5.6.9.7a
14.5.6.9.7b

Deleted Articles

No Articles were deleted from Section 14.

AASHTO Publications Staff
September 2017

TABLE OF CONTENTS

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SECTION 1

INTRODUCTION

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, as 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 criterion 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: 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, 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.

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.

$$\sum \eta_i \gamma_i Q_i \le \phi R_n = R_r \tag{1.3.2.1-1}$$

in which:

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

$$\eta_i = \eta_D \eta_R \eta_I \ge 0.95 \tag{1.3.2.1-2}$$

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

$$\eta_i = \frac{1}{\eta_D \eta_R \eta_I} \le 1.0 \tag{1.3.2.1-3}$$

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, a clearly subjective approach. 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 interaction with system reliability in such an equation.

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

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.

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.*

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.

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.

C1.3.2.2

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

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.

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, in multigirder cross-sections there is significant elastic reserve capacity in almost all such bridges beyond such a load level. The live load cannot be positioned to

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 a vessel, vehicle, or ice floe, possibly under scoured conditions.

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 Seismic Design of Bridges*.

For the strength limit state:

$\eta_D \geq$ 1.05 for nondeductile 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

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.

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.

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.

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:

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

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 (2008) 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 Appendix E of the Guide 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

This Article shall apply to the strength and extreme event limit states only.

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 are 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

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