



AASHTO LRFD *Movable* Highway Bridge Design Specifications

2nd Edition
2007



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INSTRUCTIONS AND INFORMATION

General

AASHTO has issued proposed interim revisions to *AASHTO LRFD Movable Bridge Design Specifications*, Second Edition (2007). This packet contains the revised pages. They are not designed to replace the corresponding pages in the book but rather to be kept with the book for fast reference.

Affected Articles

Underlined text indicates revisions that were approved in 2010 by the AASHTO Highways Subcommittee on Bridges and Structures. ~~Strikethrough text~~ indicates any deletions that were likewise approved by the Subcommittee. A list of affected articles is included below.

All interim pages are printed on blue paper to make the changes stand out when inserted in the second edition binder. They also have a page header displaying the section number affected and the interim publication year. Please note that these pages may also contain nontechnical (e.g. editorial) changes made by AASHTO publications staff; any changes of this type will not be marked in any way so as not to distract the reader from the technical changes.

Although not applicable to this especially short interim, please note that in response to user concerns, page breaks are now being added within sections between noncontiguous articles. This change makes it an option to insert the changes closer to the affected articles.

Table i—2010 Changed Article

SECTION 8: ELECTRICAL DESIGN

8.6.1.5

SECTION 8: ELECTRICAL DESIGN

8.6.1.5—Variable Frequency Speed Control

Revise the following Article as follows:

~~In general, Volts-hertz type~~ variable frequency drives ~~should~~ shall not be used for movable bridge drives.

C8.6.1.5

Replace the existing commentary with the following:

Volts-hertz type variable frequency speed control has seen limited success for speed control of movable bridges. While these drives are compatible with squirrel cage induction motors, inverter duty motors should be considered for their ability to withstand the higher harmonic voltages that may be produced.

Volts-hertz type variable frequency drives have historically lacked the ability for precise control of torque at low speed. Control of torque under overhauling loads and stall conditions, such as seating, has sometimes been unsuccessful.

The exclusion of variable frequency drives in this Article is for volts-hertz type only. Flux vector variable frequency drives are acceptable as outlined in Article 8.6.1.6.

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Table i—2011 Changed Article

SECTION 1: GENERAL PROVISIONS

C.1.3.3

SECTION 1: GENERAL PROVISIONS

Add the following commentary to Article 1.3.3:

C1.3.3

The operating system is applicable to mechanical machinery design.

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Table i—2012 Changed Articles

SECTION 6: MECHANICAL DESIGN

6.6.3.2 6.8.1.5.1

SECTION 6: MECHANICAL DESIGN

6.6.3.2—Endurance Limit

Equation 6.6.3.2-3 should be modified as follows:

- For $D > 0.3$ in., $C_D = \frac{(D+7.6)}{3.342D} (3.342D)^{-0.113}$

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6.8.1.5.1—Locking Devices

Add the following commentary to Article 6.8.1.5.1:

C6.8.1.5.1

The following interim guidance may be applied to the structural design of lock bars that are of uniform cross section and free of stress raisers:

- Design for Strength I or II, or both; Service II; and Fatigue I or II limit states per the requirements of the *AASHTO LRFD Bridge Design Specifications*;
- Utilize twice the normal vehicular dynamic load allowance (IM) as per the requirements of the *AASHTO LRFD Bridge Design Specifications* Article 3.6.2 for nondeck joint components and consider the full stress range (stress reversal) caused by passage of the design truck from one side of the center lock to the other for fatigue design;
- The receiver components or guideways for the lock bars shall be designed based on these Specifications. Additional research is anticipated in the future for the span lock bar and receiver components, investigating revisions to the factors of safety and load factors.

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Affected Articles

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Please note: starting with this ballot year, the subcommittee has asked that their interims be dated the calendar year *after* the ballot year for consistency, even though some smaller interims, like this one, may be released in the same calendar year.

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Table i—2012 Changed Articles

SECTION 6: MECHANICAL DESIGN

6.6.3.2	6.7.5.2.2	6.7.7.2.4	6.8.3.3.6
6.7.4.2	6.7.5.2.3	6.7.10.1	6.8.3.4.2
6.7.5.1	6.7.5.2.4	6.8.3.3.4	

SECTION 6: MECHANICAL DESIGN

6.6.3.2—Endurance Limit

Equation 6.6.3.2-4 should be modified as follows:

$$C_S = a (\sigma_{ut})^b$$

$$C_S = a \left(\frac{\sigma_{ut}}{1000} \right)^b$$

6.7.4.2—Shaft Length and Deformation

Modify the second bullet as follows:

- Where less twist is desirable, as in shafts driving end-lifting devices.....~~(0.006)~~ (0.00667)

6.7.5—Design of Open Spur Gearing**6.7.5.1—General**

Revise paragraphs 5 and 6 as follows:

For full depth spur gear teeth, the addendum shall be the inverse of the diametral pitch (equal to the tooth module), the dedendum shall be 1.250 divided by the diametral pitch (~~1.157 times the module~~), and the circular pitch shall be π divided by the diametral pitch (~~π times the tooth module~~).

The face width of a spur gear should be not less than $8/P_d$, nor more than $14P_d$ ~~14/ P_d (not less than 8, nor more than 14, times the tooth module)~~.

Revise the second bullet list as follows:

- for pinions other than motor pinions, transmitting power for moving the span.....~~3.14 in.~~ 3.14 in.^{-1}
- for motor pinions.....~~4.19 in.~~ 4.19 in.^{-1}
- for main rack teeth.....~~2.09 in.~~ 2.09 in.^{-1}

6.7.5.2.2—Design for the Fatigue Limit State

Modify the second to last bullet as follows:

- 1.00 for 99 percent reliability
- 1.25 for 99.9 percent reliability

6.7.5.2.3—Surface Durability and Wear—Design Equations

In paragraph 2, make the following change:

The factored surface durability resistance, $F_{tez} (N)$ ~~$W_{tac} (lb)$~~ , of the spur gear teeth based on pitting resistance...

6.7.5.2.4—Yield Failure at Intermittent Overload

Modify where list item as follows:

K_f = stress correction factor = 1 (dim)

6.7.7.2.4—Sizing of Large Rolling Element Bearings

Modify the second where list as follows:

X_o = a static ~~axial~~ radial load factor (dim)

Y_o = a static ~~radial~~ axial load factor (dim)

6.7.10—Keys and Keyways**6.7.10.1—General**

In Table C6.7.10.1-1, modify rows 12 and 13 as follows:

$4 \frac{1}{2}$	$5 \frac{1}{2}$	~~$1 \frac{1}{2} \times 1 \frac{1}{2}$~~ $1 \frac{1}{4} \times 1 \frac{1}{4}$
$5 \frac{1}{2}$	$6 \frac{1}{2}$	~~$32 \times 1 \frac{1}{2}$~~ $1 \frac{1}{2} \times 1 \frac{1}{2}$

6.8.3.3.4—Wire Rope Stresses

In the commentary, move the paragraph that follows across from “ P_o ” in the where list:

When determining P_o for counterweight ropes, only inertial loads are effective.

6.8.3.3.6—Wire Rope Tensile Strengths

In the commentary, modify the last paragraph as follows:

E_R (psi)	Percent of Ultimate Load
10.8×10^6 (~~74,500~~)	0–20
12×10^6 (~~83,000~~)	21–65

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6.8.3.4.2—Counterweight Sheaves

In the last paragraph, modify the last sentence as follows:

The distance center-to-center of grooves shall be at least ~~6.5 mm~~ 0.25 in. more than the diameter of the rope.

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2014 Changed Articles

SECTION 6: MECHANICAL DESIGN

6.6.1

6.6.4.2

C6.6.4.2

SECTION 6: MECHANICAL DESIGN

Revise second paragraph as follows:

6.6.1

In lieu of a more precise determination, the following approximate effective length may be used:

- Pinned-Pinned Ends Member $L_{eff} = L_{act}$.
- Pinned-Fixed Ends Member $L_{eff} = 0.80 L_{act}$.
- Fixed-Fixed Ends Member $L_{eff} = 0.65 L_{act}$.
- Fixed-Free Ends Member $L_{eff} = 2.1 L_{act}$.

where:

L_{act} = actual length, end to end between supports
of the compression member

Fixed bearing resistance shall be determined based upon the minimum static design factor of safety, n_{s2} , specified herein and applied to the minimum specified yield strength of the component material.

- Forged, drawn, rolled, wrought steel $n_s = 2.5$
- Cast steel $n_s = 3.0$

Revise the last paragraphs of this section and commentary as follows:

6.6.4.2 Spur Gear Bending Resistance at the Fatigue Limit State, S_{at}

Resistance shall be based upon the allowable bending stress S_{at} (psi) used in the equations specified in Article 6.7.5.2.2.

When through hardened steel gear teeth having a Brinell hardness between 180 and 400 are subjected to one-way bending during any revolution and use AGMA Grade 1 material, then S_{at} may be taken as:

$$S_{at} = 77.3H_B + 12,800 \quad (6.6.4.2-1)$$

where:

H_B = Brinell hardness for the teeth (dim)

For gears subjected to two-way bending during a ~~rotation~~ load cycle, such as idler gears, use 70 percent of this value for S_{at} given above.

C6.6.4.2

See AGMA 2001-C95 or latest revision for the definition of Grade 1 steel.

This could be extrapolated to an HB value as low as 150.

AGMA defines an idler gear as any gear whose teeth see a stress reversal (two-way reverse bending) every ~~revolution~~ load cycle. Operating drums on span drive vertical lift bridges may have idler gears, so that each hoisting drum rotates in the desired direction. Also, a rack on a bascule span has teeth that see reverse bending every opening and closing cycle.



2015 Interim
Revisions to

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Movable
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2006–2007

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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. To accommodate this growth in bridge engineering knowledge, the Subcommittee on Bridges and Structures has been granted authority under AASHTO's governing documents to approve and issue Bridge Interims each year, not only with respect to the Standard Specifications but also to incrementally modify and enhance the twenty-odd additional documents on bridges and structures engineering that are under its guidance and sponsorship.

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). Both WSD and LFD are reflected in the current edition of the Standard Specifications.

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 the advent of these specifications, bridge engineers had a choice of two standards to guide their designs, the long-standing AASHTO *Standard Specifications for Highway Bridges*, and the alternative, newly adopted *AASHTO LRFD Bridge Design Specifications*, and its companions, *AASHTO LRFD Bridge Construction Specifications* and *AASHTO LRFD Movable Highway Bridge Design Specifications*. Subsequently, the Federal Highway Administration (FHWA) and the states have established a goal that LRFD standards be incorporated in all new bridge designs after 2007.

Interim Specifications are usually published in the middle of the calendar year, and a revised edition of this book is generally published every four years. The Interim Specifications have the same status as AASHTO standards, but are tentative revisions approved by at least two-thirds of the Subcommittee. These revisions are voted on by the AASHTO member departments prior to the publication of each new edition of this book and, if approved by at least two-thirds of the

members, they are included in the new edition as standards of the Association. AASHTO members are 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 nonvoting member.

Annual Interim Specifications are generally used by the States after their adoption by the Subcommittee. Orders for these annual Interim 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 96716, Washington, DC 20906-6716. 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 Specifications for Horizontally Curved Steel Girder Highway Bridges with Design Examples for I-Girder and Box-Girder Bridges. 2003.

AASHTO Guide Specifications—Thermal Effects in Concrete Bridge Superstructures. 1989.

AASHTO LRFD Bridge Construction. 2004.

AASHTO LRFD Bridge Design Specifications. 2004.

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

Bridge Welding Code: AASHTO/AWS-D1.5M/D1.5: 2002, an American National Standard. 2002.

Construction Handbook for Bridge Temporary Works. 1995.

Guide Design Specifications for Bridge Temporary Works. 1995.

Guide for Painting Steel Structures. 1997.

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

Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges. 1991.

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

Guide Specifications for Aluminum Highway Bridges. 1991.

Guide Specifications for Bridge Railings. 1989.

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

Guide Specifications for Design of Pedestrian Bridges. 1997.

Guide Specifications for Fatigue Evaluation of Existing Steel Bridges. 1990.

Guide Specifications for Highway Bridge Fabrication with HPS070W Steel. 2000.

Guide Specifications for Seismic Isolation Design. 1999.

Guide Specifications for Strength Design of Truss Bridges (Load Factor Design). 1986.

Guide Specifications for Strength Evaluation of Existing Steel and Concrete Bridges. 1989.

Guide Specifications for Structural Design of Sound Barriers. 1989.

Guide Specifications for the Design of Stress-Laminated Wood Decks. 1991.

Guidelines for Bridge Management Systems. 1993.

Manual for Condition Evaluation of Bridges. 2000.

Movable Bridge Inspection, Evaluation and Maintenance Manual. 1998.

Standard Specifications for Movable Highway Bridges. 1988.

Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals. 2001.

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

Guide Specifications for Cathodic Protection of Concrete Bridge Decks. 1994.

Guide Specifications for Polymer Concrete Bridge Deck Overlays. 1995.

Guide Specifications for Shotcrete Repair of Highway Bridges. 1998.

Inspector's Guide for Shotcrete Repair of Bridges. 1999.

Manual for Corrosion Protection of Concrete Components in Bridges. 1992.

Two Parts: Guide Specifications for Concrete Overlay Pavements and Bridge Decks. 1990.

AASHTO Maintenance Manual: The Maintenance and Management of Roadways and Bridges. 1999.

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. 2003.

Guidelines for Design Constructability. 2003.

Guide Specification for Coating Systems with Inorganic Zinc-Rich Primer. 2003.

Shop Detail Drawing Presentation Guidelines. 2003.

Shop Detail Drawing Review/Approval Guidelines. 2003.

Steel Bridge Bearing Design and Detailing Guidelines. 2004.

Steel Bridge Fabrication Guide Specification. 2003.

Steel Bridge Fabrication QC/QA Guide Specification. 2003.

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.



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PREFACE AND ABBREVIATED TABLE OF CONTENTS

The *AASHTO LRFD Movable Highway Bridge Design Specifications*, 2nd Edition contains the following 8 sections and an appendix:

1. General Provisions
 2. Structural Design
 3. Seismic Design
 4. Vessel Collision Considerations
 5. Mechanical Design Loads and Power Requirements
 6. Mechanical Design
 7. Hydraulic Design
 8. Electrical Design
- Appendix

Detailed Tables of Contents precede each section. References follow each section, listed 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, but when they are referenced in their home article or its commentary, they are identified only by the extension. For example, in Article 1.2.3.4.5, Eq. 1.2.3.4.5-2 would simply be called “Eq. 2.” When this equation is referenced anywhere else other than its home article, it is identified by its whole nomenclature; in other words, “Eq. 1.2.3.4.5-2.” The same convention applies to figures and tables.

Please note that the AASHTO materials standards (starting with M, R, 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 Materials standards are also available in downloadable form on the AASHTO Web site in the Bookstore. Unless otherwise indicated, these citations refer to the current 26th edition.

Please note that the 2nd Edition of the *AASHTO LRFD Movable Highway Bridge Design Specifications* has been completely converted to customary U.S. units.

CHANGED AND DELETED ARTICLES, 2007

SUMMARY OF AFFECTED SECTIONS

Due mainly to the conversion from SI to customary U.S. units, the revisions to the *AASHTO LRFD Movable Highway Bridge Design Specifications*, 2nd Edition affect all sections.

SECTION 1 REVISIONS

Changed Articles

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

1.3.2.1	1.4.4.7	1.5.2	1.6	References
1.4.4.6.1	1.5.1	1.5.3	1.6.2	

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:

2.1.1	2.4.1.3.3	2.5.1.1.3	2.5.1.2.6	References
2.3	2.4.1.5	2.5.1.2.4		

Deleted Articles

No Articles were deleted from Section 2.

SECTION 3 REVISIONS

Changed Articles

The following Article in Section 3 contains changes or additions:

References

Deleted Articles

No Articles were deleted from Section 3.

SECTION 4 REVISIONS

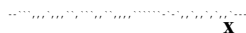
Changed Articles

The following Article in Section 4 contains changes or additions:

References

Deleted Articles

No Articles were deleted from Section 4.



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SECTION 5 REVISIONS

Changed Articles

The following Articles in Section 5 contain changes or additions to the specifications, the commentary, or both:

5.3	5.4.3	5.5.2	5.7.2.1	5.8.3
5.4.1	5.4.4	5.6.2	5.8.2	References
5.4.2	5.5.1	5.6.4		

Deleted Articles

No Articles were deleted from Section 5.

SECTION 6 REVISIONS

Changed Articles

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

6.2	6.7.2.2	6.7.7.1.1	6.7.13.5	6.8.3.3.1
6.3.1	6.7.2.3	6.7.7.1.2	6.7.15	6.8.3.3.4
6.4.2	6.7.3.2	6.7.7.1.3	6.7.16.3	6.8.3.3.6
6.4.3	6.7.3.3.1	6.7.7.1.4a	6.7.16.5	6.8.3.3.7
6.6.1	6.7.3.3.2	6.7.7.1.4b	6.8.1.2.2	6.8.3.4.1
6.6.2.3	6.7.4.1	6.7.7.2.1	6.8.1.3.1	6.8.3.5.3
6.6.2.4	6.7.4.2	6.7.7.2.2	6.8.1.4	6.8.3.7.2
6.6.2.5	6.7.4.3	6.7.7.2.3	6.8.1.5.2	6.8.3.8
6.6.2.6	6.7.5.1	6.7.7.2.4	6.8.2.2	6.9.1
6.6.3.2	6.7.5.2.1	6.7.8	6.8.2.4	6.10.3.1
6.6.4.2	6.7.5.2.2	6.7.10.1	6.8.2.8	6.10.4.1
6.6.4.3	6.7.5.2.3	6.7.11	6.8.2.9	References
6.6.4.4	6.7.5.2.4	6.7.13.1	6.8.3.1.3	

Deleted Articles

No Articles were deleted from Section 6.

SECTION 7 REVISIONS

Changed Articles

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

7.1.3	7.5.2.2	7.5.9.1	7.6.2	7.6.9.2
7.1.4	7.5.5.1	7.5.10	7.6.4	7.9.1.1
7.3	7.5.5.2	7.5.12.1	7.6.8	7.9.1.2
7.5.1	7.5.6.3	7.5.12.2	7.6.9.1	References
7.5.2.1	7.5.7	7.5.12.3		

Deleted Articles

No Articles were deleted from Section 7.

SECTION 8 REVISIONS

Changed Articles

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

8.4.5.1	8.8	8.9.7.1	8.9.7.5	8.10.1.5
8.4.6.3	8.9.1	8.9.7.2	8.10.1	8.11
8.5.2.2.1	8.9.6	8.9.7.3	8.10.1.1	8.12.3
8.6.5	8.9.7	8.9.7.4	8.10.1.2	References

Deleted Articles

No Articles were deleted from Section 8.

APPENDIX A

Changed Articles

SI versions of equations, tables, and figures are provided in this new Appendix. The specifications, the commentary, or both in the following Articles are affected:

2.5.1.1.3	6.6.3.2	6.7.4.3	6.7.7.1.4a	6.8.3.3.1
5.4.1	6.6.4.2	6.7.5.2.1	6.7.7.1.4b	6.8.3.3.4
5.8.2	6.6.4.3	6.7.5.2.2	6.7.7.2.2	6.8.3.3.6
6.6.1	6.6.4.4	6.7.5.2.3	6.7.8	8.9.1
6.6.2.5	6.7.3.2	6.7.5.2.4	6.7.10.1	8.9.7.3
6.6.2.6	6.7.4.2	6.7.7.1.2	6.7.15	8.9.7.4

AASHTO Publications Staff
March 2007

ADDENDUM TO PREFACE: CHANGED AND DELETED ARTICLES, 2008

SUMMARY OF AFFECTED SECTIONS

The 2008 interim revisions to the *AASHTO LRFD Movable Bridge Design Specifications*, 2nd Edition affect the following sections:

- 6. Mechanical Design
- 7. Hydraulic Design
- 8. Electrical Design

SECTION 6 REVISIONS

Changed Articles

The following Article in Section 6 contains changes or additions to the specifications, commentary, or both:

6.4.2

Deleted Articles

No Articles were deleted from Section 6.

SECTION 7 REVISIONS

Changed Articles

The following Article in Section 7 contains changes or additions to the specifications, commentary, or both:

7.8.4.2.2

Deleted Articles

No Articles were deleted from Section 7.

SECTION 8 REVISIONS

Changed Articles

The following Article in Section 8 contains changes or additions to the specifications, commentary, or both:

8.5.2.3

Deleted Articles

No Articles were deleted from Section 8.

AASHTO Publications Staff
September 2007

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GENERAL PROVISIONS

1.1 GENERAL CRITERIA

These Specifications cover the design of movable highway bridges.

The requirements for fixed span bridges, as given in the latest edition of the *AASHTO LRFD Bridge Design Specifications*, shall apply to movable bridges, except as otherwise provided herein. The concepts of structural safety through redundancy and ductility and of protection against scour and collision are emphasized in those specifications.

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

The parts of the Specification dealing with workmanship and erection are intended to be guidelines for the designer, to include as required in the specifications written for the specific project.

The structural, mechanical, hydraulic, and electrical design will be furnished by the Owner, unless it is expressly stated in the invitation for bids that such designs, or specified portions of them, are to be furnished by the Contractor.

The operating time shall be stated in the contract documents and all gates, warning devices, and operating equipment and control systems shall be designed to meet or exceed the criterion for time of opening.

The contracts shall state:

- the time of opening,
- assumed time of vessel passage, and
- the time of operation for both the main and auxiliary power.

The contract documents shall make clear the division of responsibility between the Owner and the Contractor for designing, furnishing, and erecting or installing all components of the structure, and shall fully specify or describe all of such components which are the responsibility of, or affect the work of, the Contractor.

C1.1

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 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.

In the context of this Article exceeding the design criteria means performing the intended function in less time than stated.

The Contractor shall furnish and erect the structure ready for operation and to receive traffic, except for such components as are specified to be furnished or installed by the Owner.

1.2 ABBREVIATIONS, DEFINITIONS, AND COMPONENT CLASSIFICATIONS

Bascule—Bridge type which rotates in the vertical plane and one end is counterbalanced by the other on the principle of a seesaw or by weights. Rotation is about a horizontal axis which may or may not be fixed.

Swing—Bridge type which a portion of the span rotates about a vertical axis.

Vertical Lift—Bridge type which movable span is moved up/down while remaining horizontal.

The following abbreviations are used herein:

AASHTO—American Association of State Highway and Transportation Officials

ABMA—American Bearing Manufacturers Association

AGMA—American Gear Manufacturers Association

AISI—American Iron and Steel Institute

ANSI—American National Standards Institute

AREMA—American Railway Engineering and Maintenance-of-Way Association

ASM—American Society for Materials

ASME—American Society of Mechanical Engineers

ASTM—American Society for Testing and Materials

AWS—American Welding Society

CAD—Computer Aided Design (Drafting)

EEIPS—Double Extra Improved Plow Steel

EIPS—Extra Improved Plow Steel

EP—Extreme Pressure

FEA—Finite Element Analysis

IEEE—Institute of Electrical and Electronics Engineers, Inc.

IPCEA—Insulated Power Cable Engineers Association

IPS—Improved Plow Steel

ISO—International Organization for Standardization

IWRC—Independent Wire Rope Core

MUTCD—Manual on Uniform Traffic Control Devices for Streets and Highways

NCHRP—National Cooperative Highway Research Program

NEC—National Electrical Code

NEMA—National Electrical Manufacturers Association

NESC—National Electrical Safety Code

NFPA—National Fluid Power Association; National Fire Protection Association

NLGI—National Lubricating Grease Institute

PTFE—Polytetrafluoroethylene

SAE—Society of Automotive Engineers

SI—System International for Units

UL—Underwriter's Laboratories

WRTB—Wire Rope Technical Board

The parts of the bridge will be classified as follows and may be paid for as indicated below:

Communication Facilities—Radio, telephone and any other communication facilities, including wiring therefore.

Concrete—Concrete or mortar used in counterweights, including concrete balance blocks, and concrete in pockets of column bases and similar places. No deductions shall be made for enclosed reinforcing steel, scrap metal, or steel punchings.

Counterweight Sheaves—Cast or welded sheaves together with their shafts, bearings and their connecting bolts.

Electrical Equipment—High-voltage equipment and transformers as specified, the control panels and control console with their attachments, and electrical parts beyond (whether on or off the moving span), such as motors, tachometers and encoders, generators, gear motors, controllers, programmable logic controllers and computers, resistors, electric brakes, solenoids, circuit breakers, fuses, relays, contactors, switches, electric indicators, synchronizing and leveling equipment, limit switches, meters, trolley wheels and contact shoes, service and indicating lights, navigation lights and signals, traffic gates and barriers, traffic signs, electric heaters, conductors, wiring, submarine and other cables, boxes, ducts, and conduits and their fittings, as specified for the operation of the moving span and accessories, and the lighting and climate control of the houses.

Elevators—The complete elevator system, including cars, gates, motors, and other operating machinery; guide rails and shoes, counterweights, buffers, hoisting cables, governors or other speed control devices, and wiring.

Engines, Tanks, Pumps—Internal combustion engines with tanks, compressors, starters, pumps, indicators, whistles, air compressor tanks, and interrelated piping to and including clutch shaft, but not clutch for delivery of power, and piping not including valve for delivery of air and not to include such engines used as prime movers for standby electric power.

Houses for Machinery and Operators—All parts of such houses, except steel framing and plating if any; also all furniture, heating/ventilating/air conditioning, cranes and hoists, fire extinguishers, supplies, and similar items, as specified in the invitation to bid.

Hydraulic Equipment—All hydraulic equipment, including hydraulic fluid and portable filtration units used during reservoir filling, necessary to provide the operating system specified.

Machinery

Air buffers	Indicators
Axles	Levers
Bars	Racks
Bearings	Rollers
Bells	Roller guides
Brakes (unless part of electrical equipment)	Roller treads
Bridge locks	Screws
Cables and wires for push-pull devices	Shafts
Capstans	Sheaves (except counterweight sheaves)
Center-pivot stands	Shims
Centering devices	Shock absorbers
Clutches	Speed reducers
Clutch operators	Spools
Couplings	Toggles
Cranks	Wedges
Deflector castings and plates	Wedge bases
Disks	Wheels
Eccentrics	Whistles
Gear covers and guards	Winding drums
Gears	Worm gearings
Hooks	Wrenches

Pins about whose axes the connecting members rotate.

Equalizing devices and other fastenings for wire ropes (except sockets).

Bolts attaching machinery parts to each other and to their supports.

Similar parts which require machine shopwork and which are not included in any other class. Pumps, tanks, cylinders, piping valves of hydraulic systems.

Machinery parts attached to structural parts shall be separately weighed before attachment thereto. Lubricants and hydraulic fluids will not be included in the weight measured for payment.

Metal in Counterweights—Cast iron or other metal used as counterweights; also scrap metal or steel punchings used to increase the unit weight of counterweight concrete.

Reinforcing Steel—All reinforcing bars and mesh for concrete.

Removals—Any and all parts of an existing structure required to be removed.

Roadway and Sidewalk Floor—Roadway deck and footwalks at roadway level complete in place.

Structural Carbon Steel and Special Structural Steel—In addition to the moving span, any parts of rolled, forged, or cast steel which can be fabricated by the common shop methods such as punching, reaming, drilling, boring, shearing, planing, bending, welding, etc., usual for stationary structures, except structural steel parts that function as machinery parts, which shall be classified under the appropriate machinery items.

Rim girders in swing bridges, segmental girders in rolling bascule bridges and the girders on which they roll, parts supporting the machinery, machinery housing, except gear cases, counterweight frames, counterweight trusses, counterweight boxes, operating struts, rope attachment brackets or hangers, towers, steel framing and plates in houses for machinery and operators, handrails, stairways, and ladders shall be classified as structural steel.

Members composed wholly of carbon steel shall be classified as structural carbon steel.

Members composed wholly of high-strength steel, or other special structural steel shall be classified as such. Members or parts containing two or more classes of structural steel shall be classified and paid for according to the computed ratios of weights of the several classes of steel contained therein.

Timber—Any lumber not allocated to another class by the foregoing definitions, together with nails, bolts, and other fastenings. Measurement of lumber shall be based on nominal sizes for the lengths in place.

Time of Opening—The total elapsed time from the signal to stop traffic to the signal to release the stopped traffic.

Time of Operation—Normal length of time for opening the bridge, after all span locks are released and any lifts or wedges are withdrawn.

Time of Vessel Passage—The time specified by the Owner for the bridge to remain in the open position to allow for vessels passing through the channel.

Tread Plates and Castings—Tread plates or castings for segmental girders and track girders for rolling-lift bridges, together with their shims and connecting bolts.

Trunnions and Bearings—Trunnions for moving leaves and counterweights of bascule bridges together with their bearings, supporting pedestals, and their bolts.

Wire Ropes and Sockets—Wire ropes and their sockets, shims and attachments, together with the socket pins.

1.3 DESIGN PHILOSOPHY

1.3.1 General

Bridges shall be designed for specified limit states to achieve the objectives of constructability, safety, and serviceability, with due regard to issues of inspectability, economy, and aesthetics, as specified in Article 2.5 of the *AASHTO LRFD Bridge Design Specifications*.

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 design of bridge machinery in the United States is based on allowable working stress design, therefore, this Specification follows the accepted industry design practice in this regard. As of this writing (2006), reliability-based design at the strength limit state is not possible given the dearth of necessary data.

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 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 of the *AASHTO LRFD Bridge Design Specifications* shall apply. All limit states shall be considered of equal importance.

$$\sum \eta_i Y_i Q_i \leq \Phi R_n = R_r \quad (1.3.2.1-1)$$

in which:

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

$$\eta_i = \eta_D \eta_R \eta_I \geq 0.95 \quad (1.3.2.1-2)$$

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

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

where:

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

Φ = resistance factor

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

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 1.3.3

η_I = a factor relating to operational importance as specified in Article 1.3.3

Q_i = force effect

R_n = nominal resistance

R_r = factored resistance: ΦR_n

Application of Eq. 1 to structural design shall be as specified in Section 3 of the *AASHTO LRFD Bridge Design Specifications* and Section 2 herein. Application of Eq. 1 to machinery design may take different forms for the various limit states under consideration, such as:

C1.3.2.1

Eq. 1 is the basis of LRFD methodology. Ductility, redundancy, and operational importance are significant aspects affecting the margin of structural safety of bridges. 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 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. With time, improved quantification of ductility, redundancy, and operational importance, and their interaction and system synergy, may be attained, possibly leading to a rearrangement of Eq. 1, in which these effects may appear on either side of the equation or on both sides.

In the case of structural design, some of the limit states may be based on non-linear response of cross-sections. In the case of operating machinery, where even small amounts of misalignment from inelastic behavior may result in an inability of gears, especially high speed gears, to mesh properly, or may result in high local stresses in gears, shafts, and operating rods, such inelastic behavior must be avoided, even at the overload and extreme event limit states. This being the case, the resistance, R_n , will be based on the allowable stresses typical in machinery design, which have a relatively high factor of safety, and a resistance factor, Φ , which may be on the order of 2.25 to 3.6, depending on the individual provisions. Nonetheless, even when the resistance factor appears to be relatively high, the intent of the Specification is that the operating machinery remain below the yield point even under relatively extraordinary events. This approach is significantly different than the approach taken in the structural design which allows significant damage to occur, including permanent deformations, as a result of the loads anticipated under the strength and extreme event limit states. Certain provisions of these Specifications will require the designer to reassess the amount of structural damage which will be tolerated under these limit states so as to control the alignment of the movable bridge.

- For the service limit state, the load factors, Y_i , will be taken as 1.0 unless specified otherwise and the resistance factor, Φ , will usually be taken equal to 1.0. Resistance should be based on allowable stresses, i.e., a measure of resistance divided by a factor of safety.

In the overload limit state, applicable only to operating equipment, the load factors, Y_i , may be taken as 1.0 or greater, and the resistance factor, Φ , will typically be greater than 1.0. Nominal resistance will be taken as specified for the service limit state.

- In the extreme event limit state, the load factors are taken as 1.0 or greater and resistance factors will be taken greater than 1.0 and typically greater than as specified for the overload limit state. Nominal resistance should be taken as specified for the service limit state.

1.3.2.2 Service Limit State

For both the structural system and the operating equipment, the service limit state shall be taken as restrictions on stress, deformation, and crack width under regular service conditions, as appropriate, and as specified in Sections 6, and 7, and in the *AASHTO LRFD Bridge Design Specifications* for mechanical design, hydraulic design, and structural design, respectively.

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, and
- in the case of the operating equipment, the anticipated effects of bridge operation, possibly including the first and last live load cycle.
- structural loads resulting from bridge opening, possibly including the first and last live load cycle.

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.

The structural fracture limit state shall be taken as a set of material toughness requirements of the *AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing*.

1.3.2.4 Overload Limit State

The overload limit state, applicable only to the operating equipment and associated structural supports, shall be taken to provide some relief from the requirements of the stress limitation specified for the service limit state for loadings which are generally:

- more frequent than the higher loads considered under the extreme event limit state,
- much less frequent than the loads considered under the fatigue limit state, and
- higher than the routine loads considered under the service limit state.

1.3.2.5 Strength Limit State

The strength limit state shall apply only to structural components and 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.

C1.3.2.5

Extensive distress and structural damage may occur under strength limit state, but overall structural integrity is expected to be maintained. This limit state does not apply to operating equipment because extensive distress could lead to inoperability for extended periods of time. The statistical data to calibrate this limit state to allow inelastic behavior in the case of the operating response is not yet available, and the extent of tolerable inelastic behavior which can be tolerated in machinery, if any, has not yet been established.

1.3.2.6 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 by a vessel, vehicle, or ice flow, possibly under scoured conditions, and
- variable operability requirements for the bridge under seismic events specified in Section 3.

C1.3.2.6

Extreme event limit states are considered to be unique occurrences whose return period may be significantly greater than the design life of the bridge.

1.3.3 Factors for Ductility, Redundancy, and Operation

For the structural system, the load multipliers, η_i , η_d , and η_r shall be taken as specified in Articles 1.3.3, 1.3.4, and 1.3.5 of the *AASHTO LRFD Bridge Design Specifications*:

- Consideration should be given to selection of an importance factor, η_i , of 1.05 due to the operational importance of movable bridges and the potential for disruption to highway and marine traffic.

- Consideration should be given to the selection of a redundancy factor, η_r , equal to 1.05 for movable bridges which are non-redundant, as is the usual case.
- Consideration of a ductility factor, η_d , equal to 1.0 where detailings conform to the requirements of the *AASHTO LRFD Bridge Design Specifications*, and these Specifications.

In the case of the operating system, η_s , η_d , and η_r , should normally be taken as 1.0.

1.4 DESIGN OF BRIDGE SYSTEMS

1.4.1 Structural Design

The requirements for fixed span bridges, as given in the latest edition of the *AASHTO LRFD Bridge Design Specifications*, shall apply to movable bridges except as otherwise provided in Section 2.

The structural design will be furnished by the Owner, unless it is expressly stated in the invitation for bids that such designs, or specified portions of them, are to be furnished by the Contractor.

1.4.2 Machinery Design

The mechanical and hydraulic machinery design will be furnished by the Owner, unless it is expressly stated in the invitation for bids that such designs, or specified portions of them, are to be furnished by the Contractor.

Machinery design shall comply with the provisions of Sections 5, 6, and 7.

1.4.3 Electrical Design

The electrical design will be furnished by the Owner, unless it is expressly stated in the invitation for bids that such designs, or specified portions of them, are to be furnished by the Contractor. The provisions of Section 8 of these Specifications shall apply to electrical design.

Where feasible, movable bridges should be operated by electric power. Electric power operated bridges shall be equipped with an auxiliary source of power when specified. This auxiliary power source may be a second electric service originating from a separate utility substation, an internal combustion engine, an engine-generator set, manual power, or other prime mover, as specified by the Engineer.

Any engine shall be equipped with suitable mufflers to control noise.



When electric motors are used, emergency motors and their associated motor control equipment shall be provided when specified by the Engineer, separate and independent of those used in conjunction with normal operation.

When emergency operation of the movable span is by a prime mover other than an electric motor, standby electric power may be limited to that necessary for the operation of navigation and other warning signals.

1.4.4 Safety Design

1.4.4.1 General

Warning signs, hazard identification beacons, traffic signals, signal bells and gongs, gates and barriers, and other safety devices shall be provided for the protection of pedestrian and vehicular traffic. These shall be designed to be operative prior to the opening of the movable span and until the span has again been completely closed. The devices shall conform to the requirements for "Traffic Control at Movable Bridges," in the "Manual on Uniform Traffic Control Devices for Streets and Highways" (MUTCD).

1.4.4.2 Clearances

Vertical and horizontal clearances of movable bridges, in the closed and open positions, shall be subject to the approval of regulatory authorities having jurisdiction over waterway navigation.

1.4.4.3 Protection From Waterway Traffic

The superstructure and substructure of movable bridges adjacent to a navigable channel shall be protected against damage from waterway traffic by suitable fenders, dolphins, or other protective devices. The provisions of Section 4 shall apply.

1.4.4.4 Traffic Gates and Barriers

Two types of gates should be provided on each approach roadway to a movable span bridge: a warning gate and a physical barrier, i.e., resistance gate. They should extend across the full width of undivided roadways. If a median barrier is provided, warning gates should extend across all roadways, while barriers may extend across only the roadways approaching the draw. Markings shall be provided on the gates and shall be in accordance with the MUTCD. Red signal lights shall be mounted on the gates and interconnected to operate with the traffic signals, and any time the gates are less than fully opened. The contract documents shall specify that the gates be furnished by the Contractor as complete units with operating motors and limit switches. Energy absorbing systems may be utilized for barrier gates.

C1.4.4.4



Documents

Document Sharing Hub

Gates shall be specified to operate reliably at the maximum wind velocities for which the movable bridge is considered operational. In ice-prone regions, gates shall be specified to operate reliably with the maximum ice build-up on gate arms, without adjustment to the counterweight.

Provision for manual operation in case of power failure shall be required on all gates. Interlocking with the span mechanisms should be provided to prevent bridge openings before gate closure. The gates should operate independently using separate switches on the control console. Group raise switches may be specified, in addition to the individual controls, to allow raising all gates simultaneously. The switches, contactors, relays, etc., shall be furnished as part of the bridge control panel.

Consideration should be given to location of traffic gates off approach spans exposed to vessel collision to ensure the safety of motorists waiting for the bridge to close.

Momentary switches without seal-in contacts should be provided to permit the gate closure to stop upon release of the operating switch. Opening should be continuous upon and after momentary closure of the switch controls.

1.4.4.5 Pedestrian Gates

Where a pedestrian walkway is provided, either a separate gate shall be provided to block access to the span walkway, or the traffic gates may be designed to also serve this purpose.

1.4.4.6 Warning Lights, Alarms, and Traffic Signals

1.4.4.6.1 Traffic Signals and Bells

Traffic signals shall be provided on all movable span bridges, other than manually-operated bridges, and shall be in accordance with the requirements in the MUTCD. Warning bells or gongs should be provided to supplement the traffic signals. For the manually-operated spans, standard stop signs supplemented by red flags or lights may be used.

Bells and gongs should be operated in conjunction with the gate closing and should be interconnected with the gate mechanism. An interlock shall be provided to break the bell and gong circuit when the last device prior to opening the span has been operated. This will usually occur when the span locks or end wedges are withdrawn.

Problems have been experienced with wind-induced deflections of gate arms preventing unlatching of the resistance gate arm ends. Problems have also been experienced with gates with long arms failing to operate with the unbalance due to ice accumulation.

In 1972, a freighter hit the approach spans of the Sidney Lanier Bridge in Georgia causing fatalities in the cars that were waiting on the approach spans for the lift span to close.

C1.4.4.6.1

Signals installed at movable bridges are a specific application of the broader discipline of traffic control signals. The Federal Manual on Uniform Traffic Control Devices recognizes both the standard three color signal, and the multiple red signals in vertical array for movable bridges. However, the standard three color signals are preferred from a traffic safety standpoint, since the non-standard signals are more likely to generate motorist confusion from lack of the intermediate yellow light warning of the imminent red stop signal. Use of the non-standard signals should be restricted to roadways with posted speeds of 25 mph or less and low average daily traffic.

1.4.4.6.2 Audible Navigation Signals, Navigation Lights, Aviation Lights

Navigation lights, aviation obstruction lights, beacons and other signals or markings required by regulatory authorities shall be furnished and provided with a suitable means of access to such lights and signals.

All navigation and other light units on the movable span and on fenders shall be capable of withstanding shocks and rough treatment, and shall be completely weatherproof.

Audible navigation signals, such as air whistles, air horns, sirens, or other devices, shall be provided, as specified. Audible navigation signals shall conform to the requirements of all legally constituted bodies, agencies, or authorities having jurisdiction over the waterway, and shall be installed to their satisfaction and approval.

1.4.4.7 Stairways and Walkways

Stairways, platforms, and walks with railings and toe plates shall be provided to give safe access to the operator's house, machinery, trunnions, counterweights, lights, bridge seats, and all points requiring lubrication or other servicing. Unless specified otherwise, all access appurtenances shall be of metal construction. Ladders may be installed only where stairways are not feasible, and shall be provided with safety cages where required by codes. In vertical lift bridges, ladders, stairs, or walks shall be installed to give access to the moving span in any position from either tower. Hand railings shall be made of galvanized corrosion-resistant steel, or other rust-resistant metal pipe not less than 1.75 in. outside diameter, or of structural shapes. Stairways and ladders shall be made of steel or aluminum.

1.4.4.8 Rotating and Moving Machinery

The contract documents shall require all moving machinery parts to be painted Federal Safety orange. This shall include shafts, couplings, sides of open gears, brake wheels, crank arms, and other moving parts as applicable. The working surfaces of these parts shall not be painted.

1.5 BALANCE AND COUNTERWEIGHTS

1.5.1 General

The Contractor shall be made responsible for the balance of the movable spans throughout the entire contract period, unless otherwise specified, and shall make such adjustments as are necessary to balance the span as specified. As near practical, the counterweights shall be sufficient to balance the movable span and its attachments in any position, except that there shall be small positive dead load reactions, specified by the designer, at the supports when the bridge is seated. Auxiliary counterweights or balance chains shall be provided for vertical lift bridges with vertical movements exceeding 80 ft.

Provision shall be made for unbalanced conditions in the design of the machinery and the power equipment.

A swing span having unequal lengths or unbalanced dead loads shall be balanced by counterweighting.

C1.5.1

Theories on the best balance condition vary among Owners. The designer should verify the Owner's preference. In the absence of a stated preference, the following guidelines may be considered:

- If a bascule bridge has a roadway break behind the trunnion, i.e., toward the counterweight, the span imbalance should be greater than live loading cases that would tend to cause uplift, but shall not be less than the general cases below.
- For all bascule bridges, the movable leaves should be balanced such that the center of gravity with the span fully seated is located towards the channel at an angle no greater than 20 degrees above or below a horizontal line passing through the trunnion.
- For single leaf bascules, the equivalent downward reaction at the toe should be 1,000 lb. per bascule girder with the leaf fully seated.
- For double leaf bascules, the equivalent downward reaction at the toe should be 1,500 lb. per bascule girder with the leaf fully seated.
- Bascule bridges operated hydraulically, especially with cylinders, should be balanced such that they are span heavy in all positions. The amount of imbalance must be carefully considered by the designer. The imbalance may range from the values specified herein to a non-counterweighted design. There have been several single leaf bascule spans constructed without counterweights.
- Vertical lift bridges should have a downward reaction of no less than 1,000 lb. per corner with the span fully seated. This value should increase with the size and mass of the vertical lift up to a maximum of 2,700 lb. per corner.

