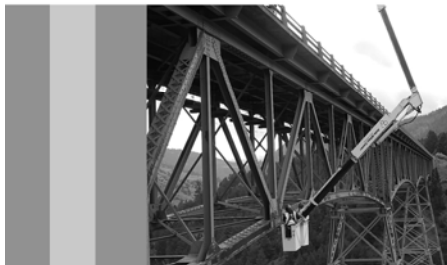


# THE MANUAL FOR BRIDGE EVALUATION



AMERICAN ASSOCIATION  
OF STATE HIGHWAY AND  
TRANSPORTATION OFFICIALS  
**AASHTO**

3rd Edition • 2018



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Cover photos: **Top Left:** Photo of a demonstration of Olson Instruments Bridge Deck Scanner system on a bridge taken by Larry Olson, Olson Engineering, Inc. **Second Left:** Photo of a through truss bridge taken by Thomas Drda, FHWA. **Third Left:** Photo courtesy of Idaho Department of Transportation. **Bottom Left:** Photo of an inspection of a deck truss bridge using an under bridge inspection truck. Taken by John Thiel, FHWA. **Right:** Leonard P. Zakim Bunker Hill Bridge in Boston, MA. Courtesy of Shay Burrows, FHWA.

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## FOREWORD

*The Manual for Bridge Evaluation* (MBE) was first adopted by the AASHTO Highways Subcommittee on Bridges and Structures in 2005. The MBE combined the *Manual for Condition Evaluation of Bridges* with the *Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges* to provide owners with a single document for evaluating and load rating bridges.

*The Manual for Bridge Evaluation*, Third Edition incorporates the Interim Revisions issued to the Second Edition, as well as many other improvements. In order to better address the evolving requirements and technology related to bridge management systems, Section 3: Bridge Management Systems has been completely revised and updated.

AASHTO Highways Subcommittee on Bridges and Structures

## PREFACE

*The Manual for Bridge Evaluation* (MBE) offers assistance to Bridge Owners at all phases of bridge inspection and evaluation. An abbreviated table of contents follows this preface. Detailed tables of contents precede Sections 1 through 8.

Appendix A includes nine illustrative examples (A1 through A9), previously in the *Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges*, and two more (A10 and A11) that were added in the Interim Revisions for the Second Edition of this title. All examples are rated using the LRFR method. In addition, Examples A1 and A2 are also rated using the ASR and LFR methods, A4 is also rated using the ASR method, and A11 is also rated using the LFR method. To clarify which rating method is being illustrated, examples using multiple methods are generally divided into Parts A through C and their articles are numbered accordingly as follows:

- Part A, LRFR;
- Part B, ASR and LFR; and
- Part C, example summary.

For ease of reference, the table of contents for Appendix A includes a summary table of the bridge types, rated members, rating live loads, limit states for evaluation, and rating methods, with the starting page number for each example and, in the case of Examples A1, A2, A4, and A11, for each rating method. The typical detailed table of contents follows this summary table.

Appendix A includes numerous citations of other AASHTO bridge publications. To save space, the following shorthand has been adopted:

- “AASHTO Standard Specifications” refers to the current edition of the *AASHTO Standard Specifications for Highway Bridges*, 17th Edition, HB-17,
- “LRFD Design” refers to the current edition of the *AASHTO LRFD Bridge Design Specifications*, Eighth Edition, LRFD-8, and
- “MBE” refers to this publication, *The Manual for Bridge Evaluation*, Third Edition, MBE-3.

AASHTO Publications Staff

## ABBREVIATED TABLE OF CONTENTS

SECTION 1: INTRODUCTION.....	1-i
SECTION 2: BRIDGE FILES AND DOCUMENTATION.....	2-i
SECTION 3: BRIDGE MANAGEMENT SYSTEMS .....	3-i
SECTION 4: INSPECTION .....	4-i
SECTION 5: MATERIAL TESTING.....	5-i
SECTION 6: LOAD RATING.....	6-i
SECTION 7: FATIGUE EVALUATION OF STEEL BRIDGES.....	7-i
SECTION 8: NONDESTRUCTIVE LOAD TESTING .....	8-i
APPENDIX A: ILLUSTRATIVE EXAMPLES.....	A-i

**SECTION 1: INTRODUCTION**

**TABLE OF CONTENTS**

1.1—PURPOSE..... 1-2

1.2—SCOPE..... 1-2

1.3—APPLICABILITY..... 1-2

1.4—QUALITY..... 1-2

    1.4.1—Provisions to Support the NBIS Requirements..... 1-3

    1.4.2—QC/QA Procedures..... 1-3

1.5—DEFINITIONS AND TERMINOLOGY..... 1-4

1.6—REFERENCES..... 1-6

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# INTRODUCTION

## 1.1—PURPOSE

The purpose of *The Manual for Bridge Evaluation* (MBE) is to serve as a resource for use in developing specific policy and procedures for the inspection and evaluation of existing in-service highway bridges. The MBE also includes the nationally recognized guidance for the load rating of highway bridges.

The National Bridge Inspection Standards (NBIS), as found in the Code of Federal Regulations (23 CFR 650 Subpart C), define the regulations for the inspection and evaluation of the nation's bridges.

The MBE is incorporated by reference in the CFR (23 CFR 650 Subpart C) to be used along with other reference documents such as the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Bridge Element Inspection*, the Federal Highway Administration's (FHWA) *Bridge Inspector's Reference Manual* (BIRM), and the latest National Bridge Inventory (NBI) coding guidance document for the inspection and evaluation of the nation's bridges.

The NBIS have evolved and been improved over the years since their creation in the early 1970s.

The MBE has also evolved and been revised and improved to reflect best practices as determined by research, state departments of transportation (DOTs), and others. In the future as improved practices and research are developed, the MBE will reflect those improvements.

Throughout this Manual there are subsections titled in part "Provisions to Support the NBIS Requirements." These subsections were developed to provide specific guidance and best practices that are considered to be required under the regulations.

## 1.2—SCOPE

The Manual has been divided into eight Sections, with each Section representing a distinct phase of an overall bridge inspection and evaluation program.

- Section 1—Purpose, scope, applicability, inspection and evaluation quality measures, and definition of general interest terms.
- Section 2—Provisions for proper documentation to be included in a bridge file. The bridge file associated with each bridge provides the foundation against which changes in physical condition can be compared.

- Section 3—Overview of bridge management systems and their key elements.
- Section 4—Types and frequency of field inspections, as well as specific inspection techniques and procedures.
- Section 5—Various inspection and evaluation testing methods. Conditions at a bridge site or the absence of information from original construction may warrant more elaborate material tests to determine properties for evaluation.
- Section 6—Nationally recognized specification for the load rating of bridges. Includes the Load and Resistance Factor method, the Load Factor method, and the Allowable Stress method.
- Section 7—Provisions for the evaluation of existing bridges for fatigue.
- Section 8—Field-performed load test procedures. Field load testing is a means of supplementing analytical procedures in determining the live-load capacity of a bridge and for improving the confidence in the assumptions.

The successful application of this Manual is directly related to the DOT organizational structure. Such a structure should be both effective and responsive so that the unique characteristics and special problems of individual bridges are considered in developing an appropriate inspection plan and load capacity determination.

### 1.3—APPLICABILITY

The provisions of this Manual apply to all highway structures that qualify as bridges in accordance with the AASHTO definition of a bridge (see Article 1.5). These provisions may be applied to smaller structures which do not qualify as bridges at the discretion of the DOT.

The NBIS establish minimum requirements for inspection programs and minimum qualifications for bridge inspection personnel. The NBIS apply to all highway bridges that are more than 20 ft in length and located on public roads.

Where conflicts or inconsistencies exist between this Manual and the federal requirements specified in the NBIS, the FHWA coding guidance, or BIRM, the federal requirements shall govern.

### 1.4—QUALITY

To maintain the accuracy and consistency of inspections and load ratings, bridge inspection programs need to have appropriate quality control (QC) and quality assurance (QA) measures in place. QC procedures are intended to maintain the quality of the bridge inspections, bridge data, scour evaluations, and load ratings, and are usually performed continuously

within the bridge inspection teams or units performing these functions. QC procedures can vary depending on the structural and scour conditions of a bridge with increased level of review commensurate with increased deterioration of bridge conditions. QA procedures are used to verify the adequacy of the quality control procedures to meet or exceed the standards established by the program manager. QA procedures are usually performed independently of the bridge inspection and load rating teams on a sample of their work.

#### **1.4.1—Provisions to Support the NBIS Requirements**

A quality control and quality assurance (QC/QA) program is to include periodic field review of inspection teams, periodic bridge inspection refresher training for program managers and team leaders, QC/QA measures for inventory data, and independent review of inspection reports and computations. The program manager is responsible for developing a QC/QA program that generally conforms to the provisions of Article 1.4. Specific details are to be determined by the program manager.

#### **1.4.2—QC/QA Procedures**

Typical quality procedures may include the use of checklists to ensure uniformity and completeness, the review of reports and computations by a person other than the originating individual, and the periodic field review of inspection teams and their work. The documented quality control plan may include:

- Defined QC roles and responsibilities;
- Qualifications for the program manager, bridge inspection personnel, and load rating personnel, including:
  - Education,
  - Certification or registration,
  - Training, and
  - Years and type of experience;
- Procedures for review and validation of inspection reports and data;
- Procedures for documenting important bridge inspection information;
- Procedures for review validation of load rating and scour calculations and data; and
- Procedures for identification and resolution of data issues including errors, omissions, compatibility between items, changes, or any combination thereof.

QA measures include the overall review of the inspection and rating program to ascertain that the

results meet or exceed the standards established by the program manager. The documented QA plan may include:

- Defined quality assurance roles and responsibilities;
- Frequency parameters for review of districts or units and bridges; and
- Procedures and sampling parameters for selecting bridges to conduct independent review and check of results, including:
  - Condition rating of elements or change in condition rating,
  - Load rating and scour evaluations,
  - Posting status,
  - Deficiency status,
  - Critical findings and the status of any follow-up action, and
  - Location of bridge.

QA measures provide a validation that QC practices are resulting in accurate and thorough inspections, complete bridge files, accurate and complete load ratings and scour evaluations, and qualified inspectors and load raters. Results from QA reviews are used by the program manager to maintain the quality of the program and make improvements where needed.

## 1.5—DEFINITIONS AND TERMINOLOGY

*AASHTO*—American Association of State Highway and Transportation Officials.

*As-Built Plans*—Plans that show the state of the bridge at the end of construction; usually prepared by the Contractor or the resident Engineer.

*ASR*—Allowable Stress Rating.

*Bias*—The ratio of mean to nominal value of a random variable.

*Bridge*—A structure including supports erected over a depression or an obstruction such as water, highway, or railway; having a track or passageway for carrying traffic or other moving loads; and having an opening measured along the center of the roadway of more than 20 ft between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes. It may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening.

*Bridge Management System (BMS)*—A system designed to optimize the use of available resources for the inspection, maintenance, rehabilitation, and replacement of bridges.

*Calibration*—A process of adjusting the parameters in a new standard to achieve approximately the same reliability as exists in a current standard or specification or to achieve a target reliability index.

*Coefficient of Variation*—The ratio of the standard deviation to the mean of a random variable.

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

*Complex Bridges*—Movable, suspension, cable stayed, and other bridges with unusual characteristics.

*Condition Rating*—The result of the assessment of the functional capability and the physical condition of bridge components by considering the extent of deterioration and other defects.

*Evaluation*—An assessment of the performance of an existing bridge.

*Exclusion Vehicle*—Grandfather provisions in the federal statutes which allow states to retain higher limits than the federal weight limits if such limits were in effect when the applicable federal statutes were enacted. Exclusion vehicles are vehicles routinely permitted on highways of various states under grandfather exclusions to weight laws.

*Failure*—A condition where a limit state is reached or exceeded. This may or may not involve collapse or other catastrophic occurrences.

*FHWA*—Federal Highway Administration, U.S. Department of Transportation.

*Inventory Rating*—Load ratings based on the inventory level allow comparisons with the capacity for new structures and, therefore, results in a live load, which can safely utilize an existing structure for an indefinite period of time.

*Inventory Level Rating (LRF)*—Generally corresponds to the rating at the design level of reliability for new bridges in the *AASHTO LRFD Bridge Design Specifications*, but reflects the existing bridge and material conditions with regard to deterioration and loss of section.

*LFR*—Load Factor Rating.

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

*Load Effect*—The response (axial force, shear force, bending moment, torque) in a member or an element due to the loading.

*Load Factor*—A load multiplier accounting for the variability of loads, the lack of accuracy in analysis, and the probability of simultaneous occurrence of different loads.

*Load Rating*—The determination of the live-load carrying capacity of an existing bridge.

*LRFD*—Load and Resistance Factor Design.

*LRFD Exclusion Limits*—Weight and length limits of trucks operating under grandfather exclusions to federal weight laws.

*LRFR*—Load and Resistance Factor Rating.

*Margin of Safety*—Defined as  $R/S$ , where  $S$  is the maximum loading and  $R$  is the corresponding resistance ( $R$  and  $S$  are assumed to be independent random variables).

*MUTCD*—*Manual on Uniform Traffic Control Devices*.

*National Bridge Inventory (NBI)*—The aggregation of structure inventory and appraisal data collected to fulfill the requirements of the National Bridge Inspection Standards.

*National Bridge Inspection Standards (NBIS)*—Federal regulations establishing requirements for inspection procedures, frequency of inspections, a bridge inspection organization, qualifications of personnel, inspection reports, and preparation and maintenance of bridge inventory records. The NBIS apply to all structures defined as highway bridges located on or over all public roads.

*NICET*—National Institute for Certification in Engineering Technologies.

*Nominal Resistance*—Resistance of a component or connection to load effects, based on its geometry, permissible stresses, or specified strength of materials.

*Operating Rating (ASR, LFR)*—Load ratings based on the operating rating level generally describe the maximum permissible live load to which the structure may be subjected. Allowing unlimited numbers of vehicles to use the bridge at operating level may shorten the life of the bridge.

*Operating Level Rating (LRF<sub>R</sub>)*—Maximum load level to which a structure may be subjected. Generally corresponds to the rating at the operating level of reliability in past load rating practice.

*Owner*—Agency having jurisdiction over the bridge.

*Posting*—Signing a bridge for load restriction.

*Quality Assurance*—The use of sampling and other measures to assure the adequacy of quality control procedures in order to verify or measure the quality level of the entire bridge inspection and load rating program.

*Quality Control*—Procedures that are intended to maintain the quality of a bridge inspection and load rating at or above a specified level.

*RF*—Rating Factor.

*Reliability Index*—A computed quantity defining the relative safety of a structural element or structure expressed as the number of standard deviations that the mean of the margin of safety falls on the safe side.

*Resistance Factor*—A resistance multiplier accounting for the variability of material properties, structural dimensions and workmanship, and the uncertainty in the prediction of resistance.

*Safe Load Capacity*—A live load that can safely utilize a bridge repeatedly over the duration of a specified inspection cycle.

*Scour Critical Bridge*—A bridge whose foundation (or foundations) has been determined to be unstable for the predicted scour conditions.

*Service Limit State*—Limit state relating to stress, deformation, and cracking.

*Serviceability*—A term that denotes restrictions on stress, deformation, and crack opening under regular service conditions.

*Serviceability Limit States*—Collective term for service and fatigue limit states.

*Specialized Hauling Vehicle (SHV)*—Short wheelbase multi-axle trucks used in the construction, waste management, bulk cargo and commodities hauling industries.

*Strength Limit State*—Safety limit state relating to strength and stability.

*Structure Inventory and Appraisal Sheet (SI&A)*—A summary sheet of bridge data required by NBIS.

*Target Reliability*—A desired level of reliability (safety) in a proposed evaluation.

## 1.6—REFERENCES

AASHTO. *Guide for Commonly Recognized (CoRe) Structural Elements*, CORE-1. With 2002 and 2010 Interim Revisions. American Association of State Highway and Transportation Officials, Washington, DC, 1997.

AASHTO. *Movable Bridge Inspection, Evaluation, and Maintenance Manual*, Second Edition, MBI-2. American Association of State Highway and Transportation Officials, Washington, DC, 2017.

AASHTO. *Standard Specifications for Highway Bridges*, 17th Edition, HB-17. American Association of State Highway and Transportation Officials, Washington, DC, 2002.

AASHTO. *Guide Specifications for Horizontally Curved Girder Highway Bridges*, Fourth Edition, GHC-4, Interim GHC-4-I1-OL available online. American Association of State Highway and Transportation Officials, Washington, DC, 2003.

AASHTO. *Guide for Maximum Dimensions and Weights of Motor Vehicles*, Fifth Edition, GSW-5. American Association of State Highway and Transportation Officials, Washington, DC, 2016.

AASHTO. “PONTIS” Release 4.4, *User’s Manual*. American Association of State Highway and Transportation Officials, Washington, DC, 2006. Obsolete; superseded by AASHTOWare Bridge Management (BrM).

AASHTO. *AASHTO LRFD Bridge Design Specifications*, Eighth Edition, LRFD-8. American Association of State Highway and Transportation Officials, Washington, DC, 2017.

AASHTO. *AASHTO LRFD Movable Highway Bridge Design Specifications*, Second Edition, LRFDMOV-2-M. With 2008, 2010, 2011, 2012, 2014, 2015, and 2018 Interim Revisions. American Association of State Highway and Transportation Officials, Washington, DC, 2007.

ACI. *Building Code Requirements for Masonry Structures and Commentary*, ACI 530-05. American Concrete Institute, 2005.

AISC. *Iron and Steel Beams 1873 to 1952*. American Institute of Steel Construction, 1990.

AISC. *Steel Construction Manual*, 13th Edition. American Institute of Steel Construction, 2005.

Brown, J. D., D. J. Lubitz, Y. C. Cekov, and K. H. Frank. *Evaluation of Influence of Hole Making Upon the Performance of Structural Steel Plates and Connections*, Report No. FHWA/TX-07/0-4624-1. University of Texas at Austin, Austin, TX, 2007.

CSA. *Existing Bridge Evaluation—Supplement to Design of Highway Bridges*, CAN/CSA-S6-88—1990. Canadian Standards Association, Mississauga, ON, Canada, 1990.

Department of Transport, U.K. “The Assessment of Highway Bridges and Structures,” *Design Manual for Roads and Bridges*. Department of Transport, London, England, Vol. 3, Sec. 4, Pt. 4, BA 16/93, January 1993.

FHWA. *Manual on Uniform Traffic Control Devices* with Revisions No. 1 and No. 2. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2009.

FHWA. *Technical Advisory—Revisions to the National Bridge Inspection Standards (NBIS)*, T5140.21. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1988.

FHWA. *Bridge Management Systems*, Demonstration Project 71, FHWA-DP-71-01R. Federal Highway Administration, U.S. Department of Transportation Washington, DC, 1989.

FHWA. *Underwater Inspection of Bridges*, FHWA-DP-80-1. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1989.

FHWA. *Technical Advisory—Evaluating Scour at Bridges*, T5140-23. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1991.

FHWA. *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges*, FHWA-PD-96-001. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1995.

FHWA. *Seismic Retrofitting Manual for Highway Bridges*, FHWA-RD-94-052. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1995.

FHWA. *Bridge Inspector’s Reference Manual*, FHWA-NHI-03-001. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2002.

FHWA. *Revisions to Items 63-66 to Support Load Rating by Rating Factor*, Policy Memorandum, March 22, 2004. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2004.

FHWA. *Load Rating Guidance and Examples For Bolted and Riveted Gusset Plates In Truss Bridges*, FHWA-IF-09-014, U.S. Department of Transportation, Washington, DC, 2009.

Galambos, T. V., ed. *Guide to Stability Design Criteria for Metal Structures*, Fifth Edition, John Wiley and Sons, Inc., New York, NY, 1998.

Higgins, C., A. Hafner, O. Turan, and T. Schumacher. “Experimental Tests of Truss Bridge Gusset Plate Connections with Sway-Buckling Response,” *Journal of Bridge Engineering*, Vol. 18, No. 1, American Society of Civil Engineers, Reston, VA, 2013, pp. 980-991.

Kulak, G. L., J. W. Fisher, and J. H. A. Struik. *Guide to Design Criteria for Bolted and Riveted Joints*, Second Edition. John Wiley and Sons, Inc., New York, NY, 1987.

NCHRP. *Manual for Condition Evaluation and Load Rating of Highway Bridges Using Load and Resistance Factor Philosophy*, NCHRP Web Document 28, NCHRP Project 12-46, Final Report. Transportation Research Board, National Research Council, Washington, DC, 2000.

NCHRP. *Distribution of Wheel Loads on Highway Bridges*, NCHRP Project 12-26 (1) and (2), Final Report, Transportation Research Board, National Research Council, Washington, DC, 1993.

NCHRP. “BRIDGIT” *Bridge Management System Users Manual and Technical Manual*, NCHRP Project 12-28 (A and B1), Transportation Research Board, National Research Council, Washington, DC, 1999.

NCHRP. *Development of Site-Specific Load Models for Bridge Ratings*, NCHRP Project 12-28 (11), Final Report, Transportation Research Board, National Research Council, Washington, DC, 1998.

NCHRP. *Dynamic Impact Factors for Bridges*, Synthesis Report 266, Transportation Research Board, National Research Council, Washington, DC, 1998.

NCHRP. *Guidelines for Evaluation and Repair of Damaged Steel Bridge Members*, NCHRP Report 271, Transportation Research Board, National Research Council, Washington, DC, 1984.

NCHRP. *Strength Evaluation of Existing Reinforced Concrete Bridges*, NCHRP Report 292, Transportation Research Board, National Research Council, Washington, DC, 1987.

NCHRP. *Fatigue Evaluation Procedures for Steel Bridges*, NCHRP Report 299, Transportation Research Board, National Research Council, Washington, DC, 1987.

NCHRP. *Bridge Management Systems*, NCHRP Report 300. Transportation Research Board, National Research Council, Washington, DC, 1987.

NCHRP. *Load Capacity Evaluation of Existing Bridges*, NCHRP Report 301, Transportation Research Board, National Research Council, Washington, DC, 1987.

NCHRP. *Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges*, NCHRP Report 333, Transportation Research Board, National Research Council, Washington, DC, 1990.

NCHRP. *Distortion Induced Fatigue Cracking in Steel Bridges*, NCHRP Report 336, Transportation Research Board, National Research Council, Washington, DC, 1990.

NCHRP. *Inelastic Rating Procedures for Steel Beam and Girder Bridges*, NCHRP Report 352, Transportation Research Board, National Research Council, Washington, DC, 1993.

NCHRP. *Redundancy in Highway Superstructures*, NCHRP Report 406, Transportation Research Board, National Research Council, Washington, DC, 1998.

NCHRP. *Calibration of LRFD Bridge Design Code*, NCHRP Report 368, Transportation Research Board, National Research Council, Washington, DC, 1999.

NCHRP. *Calibration of Load Factors for LRFR Bridge Evaluation*, NCHRP Report 454, Transportation Research Board, National Research Council, Washington, DC, 2001.

NCHRP. “Manual for Bridge Rating through Load Testing,” *NCHRP Research Results Digest*, No. 234. Transportation Research Board, National Research Council, Washington, DC, 1998.

NFPA. *National Design Specification for Wood Construction*, National Forest Products Association, Washington, DC, 2005.

Ocel. *Guidelines for the Load and Resistance Factor Design and Rating of Welded, Riveted and Bolted Gusset-Plate Connections for Steel Bridges*, NCHRP Web-Only Document 197. Transportation Research Board, National Research Council, Washington, DC, 2013.

Ritter, Michael A. *Timber Bridges—Design Construction, Inspection, and Maintenance*, EM 7700-8. Forest Service, U.S. Department of Agriculture, Washington, DC., 1990.

Sheikh-Ibrahim, F. I. “Design Method for the Bolts in Bearing-Type Connections with Fillers,” *AISC Engineering Journal*, Vol. 39, No. 4, American Institute of Steel Construction, Chicago, IL, 2002, pp. 189–195.

U.S. Government. *National Bridge Inspection Standards, Code of Federal Regulations*, Title 23, Part 650. U.S. Government Printing Office, Washington, DC, December 2004.

Yamamoto, et al. “Buckling Strengths of Gusseted Truss Joints,” *Journal of Structural Engineering*, Vol. 114. American Society of Civil Engineers, Reston, VA, 1998.

Yura, J. A., K. H. Frank, and D. Polyzois. *High-Strength Bolts for Bridges*, PMFSEL Report No. 87-3. University of Texas, Austin, TX, May 1987.

Yura, J. A., M. A. Hansen, and K.H. Frank. “Bolted Splice Connections with Undeveloped Fillers,” *Journal of the Structural Division*, Vol. 108, No. ST12. American Society of Civil Engineers, New York, NY, December 1982, pp. 2837–2849.

**SECTION 2: BRIDGE FILES AND DOCUMENTATION**

**TABLE OF CONTENTS**

2.1—INTRODUCTION ..... 2-1

2.2—PROVISIONS TO SUPPORT THE NBIS REQUIREMENTS ..... 2-1

    2.2.1—General File Information..... 2-2

    2.2.2—Field Inspection Information..... 2-3

    2.2.3—Critical Findings and Actions Taken ..... 2-3

    2.2.4—Waterway Information ..... 2-3

    2.2.5—Significant Correspondence ..... 2-4

    2.2.6—Other Inspection Procedures or Requirements ..... 2-4

    2.2.7—Load Rating Documentation ..... 2-4

    2.2.8—Posting Documentation ..... 2-5

    2.2.9—Scour Assessment ..... 2-5

    2.2.10—Scour Plan of Action..... 2-5

2.3—SUPPLEMENTAL DOCUMENTATION IN BRIDGE FILE ..... 2-5

    2.3.1—General..... 2-5

    2.3.2—Plans and Drawings ..... 2-5

    2.3.3—Construction Documentation ..... 2-6

    2.3.4—Original Design Documentation ..... 2-6

    2.3.5—Unique Considerations..... 2-6

    2.3.6—Utilities and Ancillary Attachments..... 2-7

    2.3.7—Maintenance and Repair History ..... 2-7

    2.3.8—Additional Waterway Documentation ..... 2-7

    2.3.9—Traffic Data..... 2-7

TABLE OF CONTENTS

3.1—INTRODUCTION ..... 3-1

3.2—OBJECTIVES OF BRIDGE MANAGEMENT SYSTEMS ..... 3-2

3.3—COMPONENTS OF A BRIDGE MANAGEMENT SYSTEM ..... 3-2

    3.3.1—Information Management ..... 3-2

        3.3.1.1—Bridge Inventory, General Condition Ratings, and Bridge Element Ratings ..... 3-3

            3.3.1.1.1—Bridge Inventory..... 3-3

            3.3.1.1.2—General Condition Ratings ..... 3-3

            3.3.1.1.3—Bridge Element Ratings..... 3-3

        3.3.1.2—Agency Performance Measures ..... 3-4

        3.3.1.3—Preservation and Improvement Action Data..... 3-7

        3.3.1.4—Cost Data and Financial Plans ..... 3-7

    3.3.2—Data Integration ..... 3-8

        3.3.2.1—Data Analysis..... 3-8

        3.3.2.2—Risk Assessment..... 3-9

        3.3.2.3—Agency Rules..... 3-11

        3.3.2.4—Cost/Benefit Analysis ..... 3-12

            3.3.2.4.1—Condition Driven Cost/Benefit Analysis ..... 3-12

            3.3.2.4.2—Improvement Cost/Benefit Analysis..... 3-12

            3.3.2.4.3—Lifecycle Cost/Benefit Analysis..... 3-13

        3.3.2.5—Prioritization and Optimization ..... 3-14

            3.3.2.5.1—Multi-Objective Optimization ..... 3-15

    3.3.3—Decision Support ..... 3-16

3.4—REFERENCES ..... 3-16

SECTION 4: INSPECTION PROCEDURES

TABLE OF CONTENTS

4.1—INTRODUCTION..... 4-1

4.2—PROVISIONS TO SUPPORT THE NBIS REQUIREMENTS ..... 4-1

    4.2.1—Bridge Inspection Organization..... 4-1

    4.2.2—Qualifications of Personnel ..... 4-2

    4.2.3—Inspection Types ..... 4-2

        4.2.3.1—Initial Inspection ..... 4-3

        4.2.3.2—Routine Inspection ..... 4-3

        4.2.3.3—In-Depth Inspection..... 4-4

        4.2.3.4—Fracture-Critical Member Inspection ..... 4-4

        4.2.3.5—Underwater Inspection ..... 4-5

        4.2.3.6—Special Inspection ..... 4-5

        4.2.3.7—Damage Inspection..... 4-6

    4.2.4—Inspection Interval..... 4-6

        4.2.4.1—Initial Inspection Interval ..... 4-7

        4.2.4.2—Routine Inspection Interval ..... 4-7

        4.2.4.3—In-Depth Inspection Interval ..... 4-7

        4.2.4.4—Fracture-Critical Member Inspection Interval..... 4-7

        4.2.4.5—Underwater Inspection Interval..... 4-8

        4.2.4.6—Special Inspection Interval..... 4-8

        4.2.4.7—Damage Inspection Interval ..... 4-8

    4.2.5—Inspection Procedures ..... 4-9

        4.2.5.1—General..... 4-9

        4.2.5.2—Initial Inspection Procedures ..... 4-10

        4.2.5.3—Routine Inspection Procedures..... 4-10

        4.2.5.4—In-Depth Inspection Procedures ..... 4-11

        4.2.5.5—Fracture-Critical Member Inspection Procedures ..... 4-11

        4.2.5.6—Underwater Inspection Procedures..... 4-12

        4.2.5.7—Special Inspection Procedures..... 4-12

        4.2.5.8—Damage Inspection Procedures ..... 4-12

        4.2.5.9—Complex Bridge Inspection Procedures ..... 4-13

    4.2.6—Collection of Element Level Data ..... 4-13

4.3—NONREGULATORY INSPECTION PRACTICES..... 4-13

    4.3.1—General ..... 4-13

    4.3.2—Safety ..... 4-14

        4.3.2.1—Safety for Inspectors ..... 4-14

        4.3.2.2—Public Safety ..... 4-15

    4.3.3—Planning, Scheduling, and Equipment..... 4-15

        4.3.3.1—Planning ..... 4-15

        4.3.3.2—Scheduling..... 4-16

        4.3.3.3—Equipment..... 4-17

            4.3.3.3.1—Access Methods and Equipment ..... 4-17

            4.3.3.3.2—Inspection Methods and Equipment..... 4-18

4.3.4—Inspection Forms and Reports .....	4-18
4.3.4.1—Field Notebooks .....	4-18
4.3.4.2—Reports .....	4-19
4.3.5—Inspection Techniques .....	4-19
4.3.5.1—Field Measurements .....	4-20
4.3.5.2—Cleaning .....	4-21
4.3.5.3—Condition Rating Inspection of Bridges .....	4-22
4.3.5.4—Critical Inspection Findings .....	4-22
4.3.5.5—Decks.....	4-23
4.3.5.5.1—Concrete Decks .....	4-23
4.3.5.5.2—Prestressed Concrete Deck Panels.....	4-24
4.3.5.5.3—Steel Decks.....	4-25
4.3.5.5.4—Timber Decks.....	4-26
4.3.5.5.5—Expansion Joints .....	4-26
4.3.5.5.6—Railings, Sidewalks, and Curbs.....	4-28
4.3.5.5.7—Drainage.....	4-28
4.3.5.5.8—Lighting.....	4-29
4.3.5.5.9—Deck Overlays.....	4-29
4.3.5.6—Superstructure .....	4-29
4.3.5.6.1—Steel Beams, Girders, and Box Sections .....	4-29
4.3.5.6.2—Reinforced Concrete Beams, Girders, and Box Sections .....	4-30
4.3.5.6.3—Prestressed Concrete Beams, Girders, and Box Sections.....	4-31
4.3.5.6.4—Timber Systems .....	4-32
4.3.5.6.5—Floor Systems.....	4-32
4.3.5.6.6—Trusses .....	4-33
4.3.5.6.7—Cables.....	4-34
4.3.5.6.8—Diaphragms and Cross-Frames .....	4-35
4.3.5.6.9—Lateral Bracing, Portals, and Sway Frames .....	4-35
4.3.5.6.10—Rivets, Bolts, and Welded Connections .....	4-35
4.3.5.6.11—Pins and Hangers.....	4-36
4.3.5.6.12—Bearings .....	4-38
4.3.5.6.13—Paint .....	4-39
4.3.5.6.14—Utilities.....	4-40
4.3.5.6.15—Arches .....	4-41
4.3.5.7—Substructure .....	4-41
4.3.5.7.1—Abutments .....	4-41
4.3.5.7.2—Retaining Walls.....	4-42
4.3.5.7.3—Piers and Bents.....	4-43
4.3.5.7.4—Bridge Stability and Movements.....	4-45
4.3.5.8—Scour and Waterway Inspections .....	4-46
4.3.5.8.1—Substructure/Culvert Scour Inspection.....	4-46
4.3.5.8.2—Underwater Inspection .....	4-47
4.3.5.8.3—Inspection of Waterways.....	4-48
4.3.5.8.4—Channel Protection Features—Dolphins and Fenders.....	4-49
4.3.5.9—Box Culverts as Bridges.....	4-49
4.3.5.10—Corrugated Metal Plate Structures .....	4-50
4.3.5.11—Approaches.....	4-51

4.3.5.11.1—Approach Slabs .....	4-51
4.3.5.11.2—Approach Pavement .....	4-51
4.3.5.11.3—Drainage .....	4-52
4.3.5.11.4—Traffic Safety Features .....	4-52
4.3.5.11.5—Embankment Slopes .....	4-53
4.3.5.12—Encroachments .....	4-53
4.3.5.13—Signs .....	4-53
4.3.6—Complex Bridge Inspections .....	4-54
4.3.6.1—Movable Bridges .....	4-55
4.3.6.2—Suspension Bridges .....	4-55
4.3.6.3—Cable-Stayed Bridges .....	4-56
4.3.6.4—Tied Arch Bridges .....	4-56
4.3.6.5—Prestressed Concrete Segmental Bridges .....	4-56
4.3.7—Fatigue-Prone Details and Fracture-Critical Members .....	4-57
4.3.7.1—Fatigue-Prone Details .....	4-57
4.3.7.2—Fracture-Critical Members .....	4-58
4.3.8—Data Collection for Load Rating .....	4-59
4.3.8.1—Field Data Collection .....	4-59
4.3.8.2—Observation under Traffic .....	4-60
4.3.8.3—Loading Determination .....	4-61
4.4—REFERENCES .....	4-62

SECTION 5: MATERIAL TESTING

TABLE OF CONTENTS

5.1—GENERAL..... 5-1

5.2—FIELD TESTS ..... 5-1

    5.2.1—Concrete Field Tests ..... 5-1

        5.2.1.1—Strength Methods..... 5-2

        5.2.1.2—Sonic Methods ..... 5-3

        5.2.1.3—Ultrasonic Techniques ..... 5-3

        5.2.1.4—Magnetic Methods ..... 5-4

        5.2.1.5—Electrical Methods ..... 5-4

        5.2.1.6—Nuclear Methods..... 5-5

        5.2.1.7—Thermography ..... 5-5

        5.2.1.8—Radar..... 5-6

        5.2.1.9—Radiography..... 5-6

        5.2.1.10—Endoscopes ..... 5-6

    5.2.2—Steel Field Tests..... 5-6

        5.2.2.1—Radiography..... 5-7

        5.2.2.2—Magnetic Particle Examination..... 5-8

        5.2.2.3—Eddy Current Examination ..... 5-9

        5.2.2.4—Dye Penetrant Examination ..... 5-10

        5.2.2.5—Ultrasonic Examination ..... 5-11

    5.2.3—Timber Field Tests ..... 5-11

        5.2.3.1—Penetration Methods ..... 5-12

        5.2.3.2—Electrical Methods ..... 5-12

        5.2.3.3—Ultrasonic Techniques ..... 5-13

5.3—MATERIAL SAMPLING..... 5-14

5.4—LABORATORY TESTS..... 5-15

5.5—INTERPRETATION AND EVALUATION OF TEST RESULTS ..... 5-16

5.6—TESTING REPORTS ..... 5-18

5.7—REFERENCES ..... 5-18

<b>TABLE OF CONTENTS</b>
--------------------------

6.1—SCOPE .....	6-1
6.1.1—Assumptions .....	6-1
6.1.2—Condition of Bridge Members .....	6-2
6.1.3—Evaluation Methods .....	6-3
6.1.4—Bridges with Unknown Structural Components .....	6-3
6.1.5—Component-Specific Evaluation .....	6-4
6.1.5.1—Decks .....	6-4
6.1.5.2—Substructures.....	6-4
6.1.6—Evaluation of Complex Structures .....	6-4
6.1.7—Nonredundant Structures.....	6-4
6.1.8—Qualifications and Responsibilities.....	6-5
6.1.9—Documentation of Load Rating.....	6-5
6.1.10—References.....	6-5
 PART A—LOAD AND RESISTANCE FACTOR RATING .....	 6-6
6A.1—INTRODUCTION .....	6-6
6A.1.1—General.....	6-6
6A.1.2—Scope.....	6-7
6A.1.3—Philosophy.....	6-7
6A.1.4—Application of <i>AASHTO LRFD Bridge Design Specifications</i> .....	6-7
6A.1.5—Load and Resistance Factor Rating .....	6-8
6A.1.5.1—Design Load Rating .....	6-8
6A.1.5.2—Legal Load Rating.....	6-8
6A.1.5.3—Permit Load Rating .....	6-9
6A.2—LOADS FOR EVALUATION .....	6-9
6A.2.1—General.....	6-9
6A.2.2—Permanent Loads and Load Factors .....	6-9
6A.2.2.1—Dead Loads: <i>DC</i> and <i>DW</i> .....	6-9
6A.2.2.2—Permanent Loads Other Than Dead Loads: <i>P</i> .....	6-9
6A.2.2.3—Load Factors .....	6-10
6A.2.3—Transient Loads.....	6-10
6A.2.3.1—Vehicular Live Loads (Gravity Loads): <i>LL</i> .....	6-10
6A.2.3.2—Application of Vehicular Live Load .....	6-10
6A.2.3.3—Dynamic Load Allowance: <i>IM</i> .....	6-12
6A.2.3.4—Pedestrian Live Loads: <i>PL</i> .....	6-12
6A.2.3.5—Wind Loads: <i>WL</i> and <i>WS</i> .....	6-12
6A.2.3.6—Temperature Effects: <i>TG</i> and <i>TU</i> .....	6-12
6A.2.3.7—Earthquake Effects: <i>EQ</i> .....	6-12
6A.2.3.8—Creep and Shrinkage: <i>CR</i> and <i>SH</i> .....	6-12
6A.3—STRUCTURAL ANALYSIS .....	6-12
6A.3.1—General.....	6-12

6A.3.2—Approximate Methods of Structural Analysis .....	6-13
6A.3.3—Refined Methods of Analysis .....	6-14
6A.3.4—Analysis by Field Testing .....	6-15
6A.4—LOAD-RATING PROCEDURES .....	6-15
6A.4.1—Introduction .....	6-15
6A.4.2—General Load-Rating Equation .....	6-16
6A.4.2.1—General .....	6-16
6A.4.2.2—Limit States .....	6-17
6A.4.2.3—Condition Factor: $\phi_c$ .....	6-18
6A.4.2.4—System Factor: $\phi_s$ .....	6-19
6A.4.3—Design-Load Rating .....	6-20
6A.4.3.1—Purpose .....	6-20
6A.4.3.2—Live Loads and Load Factors .....	6-21
6A.4.3.2.1—Live Load .....	6-21
6A.4.3.2.2—Live Load Factors .....	6-21
6A.4.3.3—Dynamic Load Allowance .....	6-21
6A.4.4—Legal Load Rating .....	6-21
6A.4.4.1—Purpose .....	6-21
6A.4.4.2—Live Loads and Load Factors .....	6-22
6A.4.4.2.1—Live Loads .....	6-22
6A.4.4.2.1a—Routine Commercial Traffic .....	6-22
6A.4.4.2.1b—Specialized Hauling Vehicles .....	6-23
6A.4.4.2.2—Live Load Factors .....	6-25
6A.4.4.2.3—Generalized Live Load Factors: $\gamma_L$ .....	6-25
6A.4.4.2.3a—Generalized Live Load Factors for Routine Commercial Traffic .....	6-25
6A.4.4.2.3b—Generalized Live Load Factors for Specialized Hauling Vehicles .....	6-30
6A.4.4.3—Dynamic Load Allowance: $IM$ .....	6-31
6A.4.4.4—Rating in Tons .....	6-31
6A.4.5—Permit Load Rating .....	6-32
6A.4.5.1—Background .....	6-32
6A.4.5.2—Purpose .....	6-32
6A.4.5.3—Permit Types .....	6-33
6A.4.5.3.1—Routine (Annual) Permits .....	6-33
6A.4.5.3.2—Special (Limited Crossing) Permits .....	6-33
6A.4.5.4—Live Load and Load Factors .....	6-33
6A.4.5.4.1—Live Load .....	6-33
6A.4.5.4.2—Load Factors .....	6-34
6A.4.5.4.2a—Routine (Annual) Permits .....	6-34
6A.4.5.4.2b—Special (Limited-Crossing) Permits .....	6-35
6A.4.5.4.2c—Permit Checks Using Refined Analysis .....	6-36
6A.4.5.5—Dynamic Load Allowance: $IM$ .....	6-36
6A.4.5.6—Exterior Beams .....	6-36
6A.4.5.7—Continuous Spans .....	6-37
6A.5—CONCRETE STRUCTURES .....	6-37
6A.5.1—Scope .....	6-37
6A.5.2—Materials .....	6-37

6A.5.2.1—Concrete .....	6-37
6A.5.2.2—Reinforcing Steel .....	6-37
6A.5.2.3—Prestressing Steel .....	6-38
6A.5.3—Resistance Factors .....	6-38
6A.5.4—Limit States .....	6-38
6A.5.4.1—Design-Load Rating .....	6-39
6A.5.4.2—Legal Load Rating and Permit Load Rating .....	6-39
6A.5.4.2.1—Strength Limit State .....	6-39
6A.5.4.2.2—Service Limit State .....	6-39
6A.5.4.2.2a—Legal Load Rating .....	6-39
6A.5.4.2.2b—Permit Load Rating .....	6-40
6A.5.5—Maximum Reinforcement .....	6-40
6A.5.6—Minimum Reinforcement .....	6-40
6A.5.7—Evaluation for Flexural and Axial Force Effects .....	6-41
6A.5.8—Evaluation for Shear .....	6-41
6A.5.9—Secondary Effects from Prestressing .....	6-42
6A.5.10—Temperature, Creep, and Shrinkage Effects .....	6-42
6A.5.11—Rating of Segmental Concrete Bridges .....	6-43
6A.5.11.1—Scope .....	6-43
6A.5.11.2—General Rating Requirements .....	6-43
6A.5.11.3—Application of Vehicular Live Load .....	6-43
6A.5.11.4—Design-Load Rating .....	6-43
6A.5.11.5—Service Limit State .....	6-44
6A.5.11.5.1—Legal Load Rating .....	6-44
6A.5.11.5.2—Permit Load Rating .....	6-44
6A.5.11.6—System Factors: $\phi_s$ .....	6-44
6A.5.11.7—Evaluation for Shear and Torsion .....	6-47
6A.5.12—Rating of Reinforced Concrete Box Culverts .....	6-47
6A.5.12.1—Scope .....	6-47
6A.5.12.2—General Rating Requirements .....	6-48
6A.5.12.3—Structural Analysis of Box Culverts .....	6-48
6A.5.12.4—Load Rating Equation for Box Culverts .....	6-49
6A.5.12.5—Limit States .....	6-50
6A.5.12.6—Resistance Factors .....	6-50
6A.5.12.7—Condition Factor: $\phi_c$ .....	6-50
6A.5.12.8—System Factor: $\phi_s$ .....	6-51
6A.5.12.9—Materials .....	6-51
6A.5.12.10—Loads for Evaluation .....	6-51
6A.5.12.10.1—Dead Loads .....	6-51
6A.5.12.10.2—Earth Pressure .....	6-51
6A.5.12.10.2a—Vertical Earth Pressure: EV .....	6-51
6A.5.12.10.2b—Lateral Earth Pressure: EH .....	6-51
6A.5.12.10.2c—Uniform Surcharge Loads: ES .....	6-51
6A.5.12.10.3—Live Loads .....	6-52
6A.5.12.10.3a—Live Load Distribution .....	6-52
6A.5.12.10.3b—Dynamic Load Allowance: IM .....	6-53
6A.5.12.10.3c—Live Load Surcharge: LS .....	6-53

6A.6—STEEL STRUCTURES.....	6-55
6A.6.1—Scope.....	6-55
6A.6.2—Materials.....	6-55
6A.6.2.1—Structural Steels .....	6-55
6A.6.2.2—Pins.....	6-56
6A.6.2.3—Wrought Iron.....	6-56
6A.6.3—Resistance Factors .....	6-56
6A.6.4—Limit States.....	6-57
6A.6.4.1—Design-Load Rating .....	6-57
6A.6.4.2—Legal Load Rating and Permit Load Rating .....	6-57
6A.6.4.2.1—Strength Limit State .....	6-57
6A.6.4.2.2—Service Limit State.....	6-57
6A.6.5—Effects of Deterioration on Load Rating .....	6-59
6A.6.6—Tension Members.....	6-62
6A.6.6.1—Links and Hangers.....	6-62
6A.6.6.2—Eyebars.....	6-62
6A.6.7—Noncomposite Compression Members.....	6-63
6A.6.8—Combined Axial Compression and Flexure .....	6-64
6A.6.9—I-Sections in Flexure.....	6-64
6A.6.9.1—General.....	6-64
6A.6.9.2—Composite Sections .....	6-65
6A.6.9.3—Non-Composite Sections.....	6-66
6A.6.9.4—Encased I-Sections .....	6-66
6A.6.9.5—Cross-Section Proportion Limits .....	6-66
6A.6.9.6—Riveted Members .....	6-66
6A.6.9.7—Diaphragms and Cross-Frames.....	6-66
6A.6.10—Evaluation for Shear .....	6-67
6A.6.11—Box Sections in Flexure.....	6-67
6A.6.12—Evaluation of Critical Connections.....	6-67
6A.6.12.1—General.....	6-67
6A.6.12.2—Bearing-Type Connections.....	6-68
6A.6.12.3—Slip-Critical Connections .....	6-68
6A.6.12.4—Pinned Connections.....	6-68
6A.6.12.5—Riveted Connections .....	6-68
6A.6.12.5.1—Rivets in Shear .....	6-68
6A.6.12.5.2—Rivets in Shear and Tension.....	6-70
6A.6.12.6—Gusset Plates .....	6-70
6A.6.12.6.1—Resistance Reduction for DL/LL Ratio .....	6-71
6A.6.12.6.2—Fastener Shear Resistance .....	6-71
6A.6.12.6.3—Bolt Slip Resistance .....	6-73
6A.6.12.6.4—Bearing Resistance at Fastener Holes .....	6-74
6A.6.12.6.5—Multilayered Gusset and Splice Plates .....	6-74
6A.6.12.6.6—Gusset Plate Shear Resistance.....	6-75
6A.6.12.6.7—Gusset Plate Compressive Resistance .....	6-76
6A.6.12.6.8—Gusset Plate Tensile Resistance .....	6-78
6A.6.12.6.9—Chord Splices.....	6-80
6A.6.12.6.10—Edge Slenderness .....	6-82

6A.6.12.6.11—Refined Analysis .....	6-83
6A.7—WOOD STRUCTURES .....	6-86
6A.7.1—Scope .....	6-86
6A.7.2—Materials .....	6-86
6A.7.3—Resistance Factors .....	6-86
6A.7.4—Limit States .....	6-86
6A.7.4.1—Design-Load Rating .....	6-86
6A.7.4.2—Legal Load Rating and Permit Load Rating .....	6-87
6A.7.5—Dynamic Load Allowance .....	6-87
6A.7.6—Evaluation of Critical Connections .....	6-87
6A.8—POSTING OF BRIDGES .....	6-87
6A.8.1—General .....	6-87
6A.8.2—Posting Loads .....	6-87
6A.8.3—Posting Analysis .....	6-88
6A.8.4—Regulatory Signs .....	6-90
6A.8.5—Speed Limits .....	6-90
6A.9—SPECIAL TOPICS .....	6-91
6A.9.1—Evaluation of Unreinforced Masonry Arches .....	6-91
6A.9.1.1—General .....	6-91
6A.9.1.2—Method of Analysis .....	6-91
6A.9.1.3—Allowable Stresses in Masonry .....	6-91
6A.9.2—Historic Bridges .....	6-92
APPENDIX A6A—LOAD AND RESISTANCE FACTOR RATING FLOW CHART .....	6-93
APPENDIX B6A—LIMIT STATES AND LOAD FACTORS FOR LOAD RATING .....	6-94
APPENDIX C6A—LRFD DESIGN LIVE LOAD (HL-93) (LRFD DESIGN ARTICLE 3.6.1) .....	6-96
APPENDIX D6A—AASHTO LEGAL LOADS .....	6-97
APPENDIX E6A—LIVE LOAD MOMENTS ON LONGITUDINAL STRINGERS OR GIRDERS (SIMPLE SPAN) .....	6-100
APPENDIX F6A—VARIATION IN MOMENT RATIO WITH SPAN LENGTH .....	6-102
APPENDIX G6A—RATING OF CONCRETE COMPONENTS FOR COMPRESSION PLUS BENDING .....	6-103
APPENDIX H6A—RATING OF STEEL MEMBERS FOR COMPRESSION PLUS BENDING .....	6-104
APPENDIX I6A—RATING OF STEEL COMPRESSION MEMBERS WITH ECCENTRIC CONNECTIONS (SECANT FORMULA METHOD) .....	6-106
PART B—ALLOWABLE STRESS RATING AND LOAD FACTOR RATING .....	6-108
6B.1—GENERAL .....	6-108
6B.1.1—Application of Standard Design Specifications .....	6-108
6B.2—RATING LEVELS .....	6-109

6B.2.1—Inventory Rating Level.....	6-109
6B.2.2—Operating Rating Level.....	6-109
6B.3—RATING METHODS.....	6-109
6B.3.1—Allowable Stress: <i>AS</i> .....	6-109
6B.3.2—Load Factor: <i>LF</i> .....	6-109
6B.4—RATING EQUATION .....	6-110
6B.4.1—General .....	6-110
6B.4.2—Allowable Stress.....	6-111
6B.4.3—Load Factor .....	6-111
6B.5—NOMINAL CAPACITY: <i>C</i> .....	6-111
6B.5.1—General .....	6-111
6B.5.2—Allowable Stress Method.....	6-111
6B.5.2.1—Structural Steel .....	6-112
6B.5.2.1.1—Combined Stresses .....	6-132
6B.5.2.1.2—Batten Plate Compression Members .....	6-132
6B.5.2.2—Wrought Iron.....	6-132
6B.5.2.3—Reinforcing Steel.....	6-133
6B.5.2.4—Concrete .....	6-133
6B.5.2.4.1—Bending.....	6-133
6B.5.2.4.2—Columns .....	6-134
6B.5.2.4.3—Shear (Diagonal Tension).....	6-135
6B.5.2.5—Prestressed Concrete .....	6-135
6B.5.2.6—Masonry.....	6-135
6B.5.2.7—Timber .....	6-137
6B.5.3—Load Factor Method .....	6-138
6B.5.3.1—Structural Steel .....	6-138
6B.5.3.2—Reinforced Concrete.....	6-140
6B.5.3.3—Prestressed Concrete .....	6-140
6B.6—LOADINGS.....	6-142
6B.6.1—Dead Load: <i>D</i> .....	6-142
6B.6.2—Rating Live Load .....	6-142
6B.6.2.1—Wheel Loads (Deck).....	6-143
6B.6.2.2—Truck Loads .....	6-143
6B.6.2.3—Lane Loads .....	6-144
6B.6.2.4—Sidewalk Loadings .....	6-145
6B.6.2.5—Live Load Effects: <i>L</i> .....	6-145
6B.6.3—Distribution of Loads.....	6-145
6B.6.4—Impact: <i>I</i> .....	6-145
6B.6.5—Deflection .....	6-146
6B.6.6—Longitudinal Loads.....	6-146
6B.6.7—Environmental Loads.....	6-146
6B.6.7.1—Wind.....	6-146
6B.6.7.2—Earthquake.....	6-146
6B.6.7.3—Temperature, Creep, and Shrinkage .....	6-146

6B.6.7.4—Stream Flow .....	6-147
6B.6.7.5—Ice Pressure .....	6-147
6B.6.7.6—Permanent Loads Other Than Dead Loads.....	6-147
6B.7—POSTING OF BRIDGES.....	6-147
6B.7.1—General .....	6-147
6B.7.2—Posting Loads .....	6-148
6B.7.3—Posting Analysis .....	6-153
6B.7.4—Regulatory Signs .....	6-153
6B.7.5—Speed Limits.....	6-154
6B.8—PERMITS.....	6-154
6B.8.1—General .....	6-154
6B.8.2—Routine Permits .....	6-154
6B.8.3—Controlled Permits .....	6-154
6B.8.4—Escorted Permits.....	6-155
APPENDIX A6B .....	6-156
APPENDIX B6B .....	6-157
APPENDIX C6B—LIVE LOAD MOMENTS ON LONGITUDINAL STRINGERS OR GIRDERS .....	6-158
APPENDIX D6B—STRINGER LIVE LOAD REACTIONS ON TRANSVERSE FLOOR BEAMS AND CAPS (INTERMEDIATE TRANSVERSE BEAMS) (SIMPLE SPAN ONLY) .....	6-160
APPENDIX E6B—STRINGER LIVE LOAD REACTIONS ON TRANSVERSE FLOOR BEAMS AND CAPS (END TRANSVERSE BEAMS) (SIMPLE SPAN ONLY) .....	6-162
APPENDIX F6B—FORMULAS FOR MAXIMUM SHEAR <sup>A</sup> AT ANY PANEL POINT (NO IMPACT INCLUDED) (SIMPLE SPAN ONLY) .....	6-164
APPENDIX G6B—FORMULAS FOR MAXIMUM SHEAR AT ANY POINT ON SPAN (NO IMPACT INCLUDED) (SIMPLE SPANS ONLY) .....	6-165
APPENDIX H6B—FORMULAS FOR MAXIMUM SHEAR AT ANY POINT ON SPAN (NO IMPACT INCLUDED) (SIMPLE SPANS ONLY) .....	6-166
APPENDIX I6B—FORMULAS FOR MOMENT SHEAR AT ANY POINT ON SPAN (NO IMPACT INCLUDED) (SIMPLE SPANS ONLY) .....	6-167
APPENDIX J6B—FORMULAS FOR MAXIMUM MOMENT AT ANY POINT ON SPAN (NO IMPACT INCLUDED) (SIMPLE SPANS ONLY) .....	6-168
APPENDIX K6B—FORMULAS FOR STEEL COLUMNS <sup>A</sup> .....	6-169
APPENDIX L6B—FORMULAS FOR THE CAPACITY, C, OF TYPICAL BRIDGE COMPONENTS BASED ON THE LOAD FACTOR METHOD.....	6-171
L6B.1—GENERAL.....	6-171
L6B.2—CAPACITY OF STEEL MEMBERS (PART D, STRENGTH DESIGN METHOD) .....	6-171
L6B.2.1—Sections in Bending .....	6-171
L6B.2.1.1—Compact, Braced, Noncomposite .....	6-171

L6B.2.1.2—Compact, Composite .....	6-171
L6B.2.1.3—Noncompact, Noncomposite .....	6-172
L6B.2.1.4—Noncompact, Composite, Positive Moment Section .....	6-172
L6B.2.1.5—Noncompact, Composite, Negative Moment Section.....	6-173
L6B.2.2—Sections in Shear .....	6-173
L6B.2.3—Sections in Shear and Bending (Article 10.48.8.2) .....	6-173
L6B.2.4—Compression Members.....	6-183
L6B.2.4.1—Centrally Loaded Members .....	6-183
L6B.2.4.2—Combined Axial Load and Bending.....	6-183
L6B.2.5—Capacity Based on Overload Provisions of Article 10.57 .....	6-183
L6B.2.5.1—Noncomposite Beams .....	6-183
L6B.2.5.2—Composite Beams .....	6-183
L6B.2.5.3—Web Compressive Stress.....	6-184
L6B.2.6—Gusset Plates .....	6-184
L6B.2.6.1—Fasteners .....	6-184
L6B.2.6.2—Multilayered Gusset and Splice Plates .....	6-185
L6B.2.6.3—Gusset Plate Shear Resistance.....	6-185
L6B.2.6.4—Gusset Plate Compressive Resistance .....	6-187
L6B.2.6.5—Gusset Plate Tensile Resistance .....	6-188
L6B.2.6.6—Chord Splices.....	6-189
L6B.2.6.7—Edge Slenderness .....	6-191
L6B.2.6.8—Refined Analysis .....	6-192
L6B.3—REINFORCED CONCRETE MEMBERS (ARTICLE 8.16) .....	6-192
L6B.3.1—Sections in Bending.....	6-192
L6B.3.1.1—Rectangular Sections with Tension Reinforcement Only.....	6-192
L6B.3.1.2—Tee Section (Flanged) with Tension Reinforcement Only .....	6-192
L6B.3.1.2.1—Compression Zone within Flange Area.....	6-192
L6B.3.1.2.2—Compression Zone Includes Both Flange Area and a Portion of the Web.....	6-192
L6B.3.2—Sections in Compression .....	6-192
L6B.3.3—Sections in Shear.....	6-192
L6B.4—PRESTRESSED CONCRETE MEMBERS (SECTION 9) .....	6-192
L6B.4.1—Sections in Bending.....	6-192
L6B.4.1.1—Rectangular Sections without Nonprestressed Reinforcement .....	6-192
L6B.4.1.2—Tee (Flanged) Sections without Nonprestressed Reinforcement.....	6-193
L6B.4.1.2.1—Compression Zone within Flange Area.....	6-193
L6B.4.1.2.2—Compression Zone Includes Flange Area and Part of Web .....	6-193
L6B.4.2—Sections in Shear .....	6-193

## TABLE OF CONTENTS

7.1—LOAD-INDUCED VERSUS DISTORTION-INDUCED FATIGUE.....	7-1
7.2—LOAD-INDUCED FATIGUE DAMAGE EVALUATION.....	7-1
7.2.1—Application .....	7-1
7.2.2—Estimating Stress Ranges .....	7-2
7.2.2.1—Calculating Estimated Stress Ranges .....	7-2
7.2.2.1.1—For Determination of Evaluation or Minimum Fatigue Life .....	7-3
7.2.2.1.2—For Determination of Mean Fatigue Life .....	7-4
7.2.2.2—Measuring Estimated Stress Ranges.....	7-4
7.2.2.2.1—For Determination of Evaluation or Minimum Fatigue Life .....	7-5
7.2.2.2.2—For Determination of Mean Fatigue Life .....	7-5
7.2.3—Determining Fatigue-Prone Details.....	7-5
7.2.4—Infinite-Life Check.....	7-5
7.2.5—Estimating Finite Fatigue Life.....	7-6
7.2.5.1—General .....	7-6
7.2.5.2—Estimating the Number of Cycles per Truck Passage .....	7-7
7.2.6—Fatigue Serviceability Index.....	7-8
7.2.6.1—Calculating the Fatigue Serviceability Index.....	7-8
7.2.6.2—Recommended Actions Based on Fatigue Serviceability Index .....	7-9
7.2.7—Strategies to Increase Fatigue Serviceability Index.....	7-9
7.2.7.1—General .....	7-9
7.2.7.2—Recalculate Fatigue Serviceability Index .....	7-9
7.2.7.2.1—Through Accepting Greater Risk .....	7-9
7.2.7.2.2—Through More Accurate Data .....	7-10
7.2.7.2.3—Through Truncated Fatigue Life Distribution .....	7-10
7.2.7.3—Retrofit .....	7-12
7.3—DISTORTION-INDUCED FATIGUE EVALUATION .....	7-12
7.3.1—Methods to Assess Distortion-Induced Cracking .....	7-13
7.3.2—Retrofit Options for Distortion-Induced Fatigue Cracking.....	7-13
7.4—FRACTURE-CONTROL FOR OLDER BRIDGES .....	7-14
7.5—ALTERNATE ANALYSIS METHODS.....	7-14
7.6—REFERENCES .....	7-15

SECTION 8: NONDESTRUCTIVE LOAD TESTING

TABLE OF CONTENTS

8.1—INTRODUCTION ..... 8-1

    8.1.1—General..... 8-1

    8.1.2—Classification of Load Tests..... 8-1

8.2—FACTORS WHICH INFLUENCE THE LOAD-CARRYING CAPACITY OF BRIDGES ..... 8-1

    8.2.1—General..... 8-1

    8.2.2—Unintended Composite Action..... 8-2

    8.2.3—Unintended Continuity/Fixity ..... 8-2

    8.2.4—Participation of Secondary Members ..... 8-2

    8.2.5—Participation of Nonstructural Members ..... 8-3

    8.2.6—Portion of Load Carried by Deck..... 8-3

8.3—BENEFITS OF NONDESTRUCTIVE LOAD TESTS ..... 8-3

    8.3.1—Unknown or Low-Rated Components ..... 8-3

    8.3.2—Load Distribution ..... 8-3

    8.3.3—Deteriorated or Damaged Members ..... 8-4

    8.3.4—Fatigue Evaluation ..... 8-4

    8.3.5—Dynamic Load Allowance ..... 8-4

8.4—TYPES OF NONDESTRUCTIVE LOAD TESTS ..... 8-4

    8.4.1—Static Tests..... 8-4

        8.4.1.1—Diagnostic Tests ..... 8-4

        8.4.1.2—Proof Tests ..... 8-5

    8.4.2—Dynamic Tests ..... 8-6

        8.4.2.1—Weigh-In-Motion Testing..... 8-6

        8.4.2.2—Dynamic Response Tests..... 8-6

        8.4.2.3—Vibration Tests ..... 8-6

8.5—LOAD TEST MEASUREMENTS ..... 8-7

8.6—WHEN NOT TO LOAD TEST ..... 8-7

8.7—BRIDGE SAFETY DURING LOAD TESTS ..... 8-8

8.8—LOAD RATING THROUGH LOAD TESTING ..... 8-8

    8.8.1—Introduction..... 8-8

    8.8.2—Diagnostic Load Tests ..... 8-8

        8.8.2.1—Introduction ..... 8-8

        8.8.2.2—Approach ..... 8-8

        8.8.2.3—Application of Diagnostic Test Results ..... 8-9

            8.8.2.3.1—Determining *K* ..... 8-9

    8.8.3—Proof Load Tests..... 8-11

        8.8.3.1—Introduction ..... 8-11

        8.8.3.2—Approach ..... 8-11

        8.8.3.3—Target Proof Loads ..... 8-12

            8.8.3.3.1—Selection of Target Live-Load Factor..... 8-12

8.8.3.3.2—Application of Target Live-Load Factor, $X_{pA}$ .....	8-13
8.8.3.3.3—Load Capacity and Rating.....	8-14
8.9—USE OF LOAD TEST RESULTS IN PERMIT DECISIONS.....	8-15
8.10—SERVICEABILITY CONSIDERATIONS.....	8-15
8.11—REFERENCES.....	8-16
APPENDIX A8—GENERAL LOAD-TESTING PROCEDURES.....	8-17
A8.1—GENERAL.....	8-17
A8.2—STEP 1: INSPECTION AND THEORETICAL LOAD RATING.....	8-17
A8.3—STEP 2: DEVELOPMENT OF LOAD TEST PROGRAM.....	8-17
A8.4—STEP 3: PLANNING AND PREPARATION FOR LOAD TEST.....	8-17
A8.5—STEP 4: EXECUTION OF LOAD TEST.....	8-17
A8.6—STEP 5: EVALUATION OF LOAD TEST RESULTS.....	8-18
A8.7—STEP 6: DETERMINATION OF FINAL LOAD RATING.....	8-18
A8.8—STEP 7: REPORTING.....	8-18

**APPENDIX A: ILLUSTRATIVE EXAMPLES**

**TABLE OF CONTENTS**

Example	Bridge Summary			Rating Live Loads	Limit States for Evaluation	Rating Methods	Page
	Span	Type	Rated Members				
A1	Simple Span 65 ft	Composite Steel Stringer Bridge (Interior and Exterior Stringers)	Interior and Exterior Stringer	Design	Strength I Service II Fatigue	LRFR  ASR and LFR	A-1
				Legal	Strength I Service II		A-39
				Permit	Strength II Service II		
A2	Simple Span 26 ft	Reinforced Concrete T-Beam Bridge	Interior Beam	Design	Strength I	LRFR  ASR and LFR	A-53
				Legal	Strength I		A-71
				Permit	Strength II Service I		
A3	Simple Span 80 ft	Prestressed Concrete I-Girder Bridge	Interior Girder	Design	Strength I Service III	LRFR	A-87
				Permit	Strength II Service I		
A4	Simple Span 17 ft 10 in.	Timber Stringer Bridge	Interior Stringer	Design	Strength I	LRFR  ASR and LFR	A-121
				Legal	Strength I		A-129
A5	Four-Span Continuous 112 ft 140 ft 140 ft 112 ft	Welded Steel Plate Girder Bridge	Interior Girder	Design	Strength I Service II	LRFR	A-137
				Legal	Strength II		
				Permit	Strength II		
A6	Single Span 175 ft	Steel Through Pratt Truss Bridge	Top Chord, Bottom Chord, Diagonal, Vertical	Design	Strength I	LRFR	A-165
A7	Simple Span 21 ft 6 in.	Reinforced Concrete Slab Bridge	Interior and Exterior Strips	Design	Strength I	LRFR	A-181
				Legal	Strength I		
A8	Simple Span 94 ft 8 <sup>1</sup> / <sub>4</sub> in.	Two-Girder Steel Bridge	Intermediate Floorbeam and Main Girder	Design	Strength I Service II	LRFR	A-189
A9	Simple Span 70 ft	Prestressed Concrete Adjacent Box-Beam Bridge	Interior Beam	Design	Strength I Service III	LRFR	A-213
				Permit	Strength II Service I		
A10	Rigid Frame 31.5 ft	Reinforced Concrete Box Culvert	Roof Slab, Walls, and Floor	Design	Strength I	LRFR	A-229
				Legal			
A11	Single span 420.0 ft	Through Truss	Gusset Plates	Design	Strength I	LRFR  ASR and LFR	A-255
							A-272

A1—SIMPLE SPAN COMPOSITE STEEL STRINGER BRIDGE.....	A-1
PART A—LOAD AND RESISTANCE FACTOR RATING METHOD .....	A-1
A1A.1—Evaluation of an Interior Stringer.....	A-1
A1A.1.1—Bridge Data .....	A-1
A1A.1.2—Section Properties.....	A-1
A1A.1.2.1—Noncomposite Section Properties .....	A-1
A1A.1.2.2—Composite Section Properties (LFRD Design 4.6.2.6.1) .....	A-3
A1A.1.2.3—Summary of Section Properties at Midspan .....	A-4
A1A.1.2.3a—Steel Section Only.....	A-4
A1A.1.2.3b—Composite Section—Short Term, $n = 9$ .....	A-4
A1A.1.2.3c—Composite Section—Long Term, $3n = 27$ .....	A-4
A1A.1.3—Dead-Load Analysis—Interior Stringer .....	A-5
A1A.1.3.1—Components and Attachments, $DC$ .....	A-5
A1A.1.3.1a—Noncomposite Dead Loads, $DC_1$ .....	A-5
A1A.1.3.1b—Composite Dead Loads, $DC_2$ .....	A-5
A1A.1.3.2—Wearing Surface.....	A-6
A1A.1.4—Live Load Analysis—Interior Stringer (LFRD Design Table 4.6.2.2.1-1) .....	A-6
A1A.1.4.1—Compute Live Load Distribution Factors (Type (a) cross section).....	A-6
A1A.1.4.1a—Distribution Factor for Moment, $g_m$ (LFRD Design Table 4.6.2.2.2b-1) .....	A-6
A1A.1.4.1b—Distribution Factor for Shear, $g_v$ (LFRD Design 4.6.2.2.3a).....	A-7
A1A.1.4.2—Compute Maximum Live Load Effects.....	A-7
A1A.1.4.2a—Maximum Design Live Load (HL-93) Moment at Midspan .....	A-7
A1A.1.4.2b—Maximum Design Live Load Shear at Beam Ends .....	A-8
A1A.1.4.2c—Distributed Live Load Moments and Shears .....	A-8
A1A.1.5—Compute Nominal Resistance of Section at Midspan .....	A-9
A1A.1.5.1—Classify Section (LFRD Design 6.10.7 and Figure C6.4.5-1).....	A-10
A1A.1.5.1a—Check Web Slenderness (LFRD Design 6.10.6.2.2) .....	A-11
A1A.1.5.1b—Check Ductility Requirement (LFRD Design 6.10.7.1.2).....	A-11
A1A.1.5.2—Plastic Moment, $M_p$ .....	A-11
A1A.1.5.3—Nominal Flexural Resistance, $M_n$ (LFRD Design 6.10.7.1.2) .....	A-12
A1A.1.5.4—Nominal Shear Resistance, $V_n$ (LFRD Design 6.10.9.2).....	A-12
A1A.1.5.5—Summary for Interior Stringer.....	A-12
A1A.1.6—General Load-Rating Equation.....	A-13
A1A.1.7—Evaluation Factors (for Strength Limit States).....	A-13
A1A.1.8—Design Load Rating (6A.4.3) .....	A-13
A1A.1.8.1—Strength I Limit State (6A.6.4.1).....	A-13
A1A.1.8.1a—Inventory Level .....	A-13
A1A.1.8.1b—Operating Level .....	A-14
A1A.1.8.2—Service II Limit State (6A.6.4.1).....	A-14
A1A.1.8.2a—Inventory Level.....	A-14
A1A.1.8.2b—Operating Level .....	A-15
A1A.1.8.3—Fatigue State (6A.6.4.1) .....	A-15
A1A.1.8.3a—Load Distribution for Fatigue.....	A-16
A1A.1.8.3b—Calculation of Remaining Fatigue Life.....	A-16
A1A.1.9—Legal Load Rating.....	A-18

A1A.1.9.1—Strength I Limit State.....	A-18
A1A.1.9.2—Service II Limit State .....	A-19
A1A.1.9.3—Summary.....	A-19
A1A.1.10—Permit Load Rating .....	A-21
A1A.1.10.1—Strength II Limit State .....	A-21
A1A.1.10.2—Service II Limit State (Optional) .....	A-21
A1A.2—Evaluation of an Exterior Stringer .....	A-24
A1A.2.1—Section Properties .....	A-24
A1A.2.1.1—Noncomposite Section Properties .....	A-24
A1A.2.1.2—Composite Section Properties .....	A-24
A1A.2.1.3—Summary of Section Properties at Midspan.....	A-25
A1A.2.2—Dead Load Analysis—Exterior Stringer .....	A-26
A1A.2.2.1—Components and Attachments, $DC$ .....	A-26
A1A.2.2.1a—Noncomposite Dead Loads, $DC_1$ .....	A-26
A1A.2.2.1b—Composite Dead Loads, $DC_2$ (same as interior) .....	A-26
A1A.2.2.2—Wearing Surface .....	A-26
A1A.2.3—Live Load Analysis—Exterior Stringer .....	A-26
A1A.2.3.1—Compute Live Load Distribution Factors .....	A-26
A1A.2.3.1a—Distribution Factor for Moment, $g_m$ (LRFD Design Table 4.6.2.2.2d-1) .....	A-26
A1A.2.3.1b—Distribution Factor for Shear, $g_v$ (LRFD Design Table 4.6.2.2.3b-1).....	A-27
A1A.2.3.1c—Special Analysis for Exterior Girders with Diaphragms or Cross-Frames (LRFD Design 4.6.2.2.2d).....	A-27
A1A.2.3.1d—Summary of Distribution Factors for the Exterior Girders .....	A-27
A1A.2.3.2—Compute Maximum Live Load Effects for HL-93 .....	A-28
A1A.2.3.2a—Distributed Live Load Moments and Shears.....	A-28
A1A.2.4—Compute Nominal Resistance of Section at Midspan .....	A-28
A1A.2.4.1—Classify Section .....	A-29
A1A.2.4.1a—Check Web Slenderness.....	A-29
A1A.2.4.1b—Check Ductility (LRFD Design 6.10.7.1.2).....	A-29
A1A.2.4.2—Plastic Moment, $M_p$ .....	A-30
A1A.2.4.3—Nominal Flexural Resistance, $M_n$ (LRFD Design 6.10.7.1.2).....	A-30
A1A.2.4.4—Nominal Shear Resistance, $V_n$ .....	A-30
A1A.2.4.5—Summary for Exterior Stringer .....	A-30
A1A.2.5—General Load-Rating Equation .....	A-31
A1A.2.6—Evaluation Factors (for Strength Limit State).....	A-31
A1A.2.7—Design Load Rating (6A.4.3).....	A-31
A1A.2.7.1—Strength I Limit State (6A.6.4.1) .....	A-31
A1A.2.7.1a—Inventory Level.....	A-31
A1A.2.7.1b—Operating Level .....	A-31
A1A.2.7.2—Service II Limit State (6A.6.4.1).....	A-32
A1A.2.7.2a—Inventory Level.....	A-32
A1A.2.7.2b—Operating Level .....	A-32
A1A.2.7.3—Fatigue Limit State.....	A-32
A1A.2.8—Legal Load Rating (6A.6.4.2) .....	A-32
A1A.2.8.1—Strength I Limit State (6A.6.4.2.1) .....	A-33
A1A.2.8.2—Service II Limit State (6A.6.4.2.2).....	A-34
A1A.2.8.3—Summary (6A.4.4.4) .....	A-34

A1A.2.9—Permit Load Rating (6A.6.4.2).....	A-34
A1A.2.9.1—Strength II Limit State (6A.6.4.2.1) .....	A-35
A1A.2.9.2—Service II Limit State (Optional).....	A-35
A1A.3—Summary of Rating Factors for Load and Resistance Factor Rating Method .....	A-37
PART B—ALLOWABLE STRESS AND LOAD FACTOR RATING METHODS.....	A-39
A1B.1—EVALUATION OF AN INTERIOR STRINGER .....	A-39
A1B.1.1—Bridge Data.....	A-39
A1B.1.2—Section Properties .....	A-39
A1B.1.2.1—Noncomposite Section Properties.....	A-39
A1B.1.2.2—Composite Section Properties.....	A-40
A1B.1.3—Dead Load Analysis—Interior Stringer .....	A-42
A1B.1.3.1—Dead Loads (Includes an Allowance of Six Percent of Steel Weight for Connections) .....	A-42
A1B.1.3.2—Superimposed Dead Loads (AASHTO 3.23.2.3.1.1) .....	A-42
A1B.1.4—Live Load Analysis—Interior Stringer.....	A-42
A1B.1.5—Allowable Stress Rating (6B.3.1, 6B.4.2, and 6B.5.2) .....	A-43
A1B.1.5.1—Impact (Use Standard AASHTO) (6B.6.4, AASHTO 3.8.2.1) .....	A-43
A1B.1.5.2—Distribution (Use Standard AASHTO) (6B.6.3, AASHTO 3.23.2.2, and Table 3.23.1) .....	A-43
A1B.1.5.3—Inventory Level (Bottom Tension Controls) (6B.5.2.1, Table 6B.5.2.1-1) .....	A-43
A1B.1.5.4—Operating Level (6B.5.2.1, Table 6B.5.2.1-2).....	A-44
A1B.1.5.5—Summary of Ratings for Allowable Stress Rating Method .....	A-44
A1B.1.6—Load Factor Rating (6B.5.4.2, 6B.5.5.3, and 6B.5.6.3).....	A-44
A1B.1.6.1—Impact (Use Standard AASHTO) (6B.6.4) .....	A-44
A1B.1.6.2—Distribution (Use Standard AASHTO) (6B.6.3) .....	A-45
A1B.1.6.3—Capacity of Section, $M_R$ (6B.5.3.1) .....	A-45
A1B.1.6.4—Inventory Level (6B.4.1 and 6B.5.3).....	A-47
A1B.1.6.5—Operating Level (6B.4.3).....	A-47
A1B.1.6.6—Check Serviceability Criteria .....	A-47
A1B.1.6.6a—At Inventory Level (Bottom Steel in Tension Controls) .....	A-47
A1B.1.6.6b—At Operating Level.....	A-49
A1B.1.6.7—Summary of Ratings for Load Factor Rating Method .....	A-49
A1B.1.7—Load Factor Rating—Rate for Single-Unit Formula B Loads.....	A-49
PART C—SUMMARY .....	A-51
A1C.1—Summary of All Ratings for Example A1 .....	A-51
A1C.2—References .....	A-52
A2—REINFORCED CONCRETE T-BEAM BRIDGE: EVALUATION OF AN INTERIOR BEAM .....	A-53
PART A—LOAD AND RESISTANCE FACTOR RATING METHOD .....	A-53
A2A.1—Bridge Data .....	A-53
A2A.2—Dead-Load Analysis—Interior Beam.....	A-53
A2A.2.1—Components and Attachments, $DC$ .....	A-53
A2A.2.2—Wearing Surface, $DW$ .....	A-53
A2A.3—Live-Load Analysis—Interior Beam.....	A-55
A2A.3.1—Compute Live-Load Distribution Factor .....	A-55
A2A.3.1.1—Distribution Factor for Moment, $g_m$ (LRFD Design Table 4.6.2.2.2b-1).....	A-55

A2A.3.1.2—Distribution Factor for Shear, $g_v$ (LRFD Design Table 4.6.2.2.3a-1).....	A-55
A2A.3.2—Compute Maximum Live Load Effects.....	A-56
A2A.3.2.1—Maximum Design Live Load (HL-93) Moment at Midspan.....	A-56
A2A.3.2.2—Maximum Design Live Load Shear (HL-93) at Critical Section .....	A-56
A2A.3.2.3—Distributed Live Load Moments.....	A-56
A2A.4—Compute Nominal Flexural Resistance.....	A-56
A2A.4.1—Compute Effective Flange Width, $b_e$ (LRFD Design 4.6.2.6.1).....	A-56
A2A.4.2—Compute Distance to Neutral Axis, $c$ .....	A-56
A2A.5—Maximum Reinforcement (6A.5.5).....	A-57
A2A.6—Minimum Reinforcement (6A.5.6).....	A-58
A2A.7—Compute Nominal Shear Resistance .....	A-59
A2A.8—Summary for Interior Concrete T-Beam .....	A-61
A2A.9—General Load Rating Equation.....	A-61
A2A.10—Evaluation Factors (for Strength Limit States).....	A-61
A2A.11—Design Load Rating (6A.4.3).....	A-61
A2A.11.1—Strength I Limit State.....	A-61
A2A.11.2—Inventory Level (6A.5.4.1) .....	A-61
A2A.11.3—Operating Level .....	A-62
A2A.12—Legal Load Rating (6A.5.4.2) .....	A-62
A2A.12.1—Strength I Limit State (6A.5.4.2.1) .....	A-63
A2A.12.2—Summary .....	A-64
A2A.13—Permit Load Rating (6A.4.5).....	A-64
A2A.13.1—Strength II Limit State (6A.5.4.2.1) .....	A-65
A2A.13.2—Service I Limit State (Optional) (6A.5.4.2.2b) .....	A-67
A2A.13.2.1—Simplified Check Using $0.75M_n$ (C6A.5.4.2.2b).....	A-67
A2A.13.2.2—Refined Check Using $0.9f_y$ .....	A-68
A2A.14—Summary of Rating Factors for Load and Resistance Factor Rating Method.....	A-70
 PART B—ALLOWABLE STRESS AND LOAD FACTOR RATING METHODS .....	 A-71
A2B.1—Bridge Data .....	A-71
A2B.2—Section Properties.....	A-71
A2B.3—Dead-Load Analysis—Interior Beam.....	A-71
A2B.4—Live-Load Analysis—Interior Beam.....	A-72
A2B.5—Allowable Stress Rating (6B.3.1, 6B.4.2, and 6B.5.2).....	A-72
A2B.5.1—Impact (Use standard AASHTO) (6B.6.4, AASHTO 3.8.2.1).....	A-72
A2B.5.2—Distribution (Use standard AASHTO) (6B.6.3, AASHTO 3.23.2.2 and Table 3.23.1) .....	A-72
A2B.5.3—Inventory Level (6B.4.2, 6B.5.2.4) .....	A-72
A2B.5.4—Operating Level (6B.5.2) .....	A-75
A2B.6—Load Capacity Based on Allowable Stress.....	A-75
A2B.7—Capacity (Alternate Approach) .....	A-76
A2B.8—Allowable Stress Rating—Rate for AASHTO Legal Loads .....	A-78
A2B.9—Summary of Ratings for Allowable Stress Rating Method .....	A-79
A2B.10—Load Factor Rating (6B.3.2, 6B.4.3, 6B.5.3) .....	A-79
A2B.10.1—Impact (Use standard AASHTO) (6B.6.4, AASHTO 3.8.2.1).....	A-79
A2B.10.2—Distribution (Use standard AASHTO) (6B.6.3, AASHTO 3.23.2.2 and Table 3.23.1) .....	A-80
A2B.10.3—Capacity of Section (6B.5.3.2).....	A-80
A2B.10.4—Inventory Level (6B.4.1, 6B.5.3) .....	A-81

A2B.10.5—Operating Level (6B.4.1, 6B.5.3) .....	A-81
A2B.10.6—Summary of Ratings for Load Factor Rating Method .....	A-81
A2B.10.7—Load Factor Rating—Rate for AASHTO Legal Loads .....	A-82
A2B.10.8—Load Factor Rating—Rate for Single-Unit Formula B Loads .....	A-82
PART C—SUMMARY .....	A-84
A2C.1—Summary of All Ratings for Example A2 .....	A-84
A2C.2—References .....	A-85
A3—SIMPLE SPAN PRESTRESSED CONCRETE: I-GIRDER BRIDGE EVALUATION OF AN INTERIOR A-GIRDER (LRFR ONLY) .....	A-87
A3.1—Bridge Data .....	A-87
A3.2—Summary of Section Properties .....	A-89
A3.3—Dead Load Analysis—Interior Girder .....	A-90
A3.3.1—Components and Attachments, $DC$ .....	A-90
A3.3.1.1—Noncomposite Dead Loads, $DC_1$ .....	A-90
A3.3.1.2—Composite Dead Load, $DC_2$ .....	A-90
A3.3.2—Wearing Surface, $DW$ .....	A-91
A3.4—Live Load Analysis—Interior Girder .....	A-91
A3.4.1—Compute Live Load Distribution Factors, $g$ .....	A-91
A3.4.1.1—Distribution Factor for Moment, $g_m$ (LRFD Design Table 4.6.2.2.2b-1) .....	A-92
A3.4.1.2—Distribution Factor for Shear, $g_v$ (LRFD Design Table 4.6.2.2.3a-1) .....	A-92
A3.4.2—Compute Maximum Live Load Effects .....	A-93
A3.4.2.1—Maximum Design Live Load (HL-93)—Moment at Midspan .....	A-93
A3.5—Compute Nominal Flexural Resistance at Midspan .....	A-93
A3.6—Maximum Reinforcement .....	A-94
A3.7—Minimum Reinforcement .....	A-95
A3.7.1—Determine Effective Prestress Force, $P_{pe}$ .....	A-96
A3.7.1.1—Loss Due to Elastic Shortening and/or External Loads, $\Delta f_{pES}$ .....	A-96
A3.7.1.2—Approximate Lump Sum Estimate of Time-Dependent Losses, $\Delta f_{pLT}$ .....	A-97
A3.7.1.3—Total Prestress Losses, $\Delta f_{pT}$ .....	A-98
A3.8—Compute Nominal Shear Resistance at First Critical Section .....	A-99
A3.9—Maximum Shear at Critical Section Near Supports .....	A-101
A3.10—Compute Nominal Shear Resistance .....	A-101
A3.10.1—Simplified Approach .....	A-102
A3.10.2—MCFT Approach .....	A-103
A3.10.3—Check Longitudinal Reinforcement (LRFD Design 5.7.3.5) .....	A-107
A3.11—Compute Nominal Shear Resistance at Stirrup Change/ Quarter Point (6A.5.8) .....	A-108
A3.12—Maximum Shear at Stirrup Change .....	A-109
A3.12.1—Simplified Approach .....	A-110
A3.12.2—MCFT Approach .....	A-111
A3.12.3—Check Longitudinal Reinforcement (LRFD Design 5.7.3.5) .....	A-112
A3.12.4—Summary .....	A-113
A3.13—General Load Rating Equation (6A.4.2) .....	A-113
A3.13.1 Evaluation Factors (for Strength Limit State) .....	A-114
A3.13.1.1—Resistance Factor, $\phi$ (LRFD Design 5.5.4.2.1) .....	A-114
A3.13.1.2—Condition Factor, $\phi_c$ (6A.4.2.3) .....	A-114

A3.13.1.3—System Factor, $\phi_s$ (6A.4.2.4).....	A-114
A3.13.2—Design Load Rating (6A.4.3).....	A-114
A3.13.2.1—Strength I Limit State (6A.5.4.1).....	A-114
A3.13.2.1a—Inventory Level.....	A-114
A3.13.2.1b—Operating Level.....	A-115
A3.13.2.2—Service III Limit State (Inventory Level) (6A.5.4.1).....	A-115
A3.13.3—Legal Load Rating (6A.4.4).....	A-116
A3.13.4—Permit Load Rating (6A.4.5).....	A-116
A3.13.4.1—Strength II Limit State (6A.5.4.2.1).....	A-117
A3.13.4.1a—Flexure.....	A-117
A3.13.4.1b—Shear (Using MCFT).....	A-117
A3.13.4.2—Service I Limit State (Optional) (6A.5.4.2.2b).....	A-118
A3.13.4.2a—Simplified Check Using $0.75M_n$ (C6A.4.2.2.2).....	A-118
A3.13.4.2b—Refined Check Using $0.9f_y$ .....	A-118
A3.14—Summary of Rating Factors.....	A-120
A3.15—References.....	A-120
A4—TIMBER STRINGER BRIDGE: EVALUATION OF AN INTERIOR STRINGER.....	A-121
PART A—LOAD AND RESISTANCE FACTOR RATING METHOD.....	A-121
A4A.1—Bridge Data.....	A-121
A4A.2—Dead Load Analysis—Interior Stringer in Flexure.....	A-121
A4A.2.1—Components and Attachments, $DC$ .....	A-121
A4A.2.2—Wearing Surface.....	A-121
A4A.3—Live Load Analysis—Interior Stringer in Flexure.....	A-122
A4A.3.1—Distribution Factor for Moment and Shear.....	A-122
A4A.3.2—Compute Maximum Live Load Effects.....	A-122
A4A.3.2.1—Maximum Design Live Load (HL-93) Moment at Midspan.....	A-122
A4A.3.2.2—Distributed Live-Load Moments.....	A-122
A4A.4—Compute Nominal Flexural Resistance.....	A-123
A4A.4.1—LRFD Design.....	A-123
A4A.5—General Load-Rating Equation (6A.4.2).....	A-123
A4A.6—Evaluation Factors (for Strength Limit State).....	A-123
A4A.7—Design Load Rating (6A.4.3).....	A-124
A4A.7.1—Strength I Limit State (6A.7.4.1).....	A-124
A4A.7.1.1—Inventory Level.....	A-124
A4A.7.1.2—Operating Level.....	A-124
A4A.7.1.3—Shear (Horizontal Shear) (LRFD Design 8.7).....	A-124
A4A.7.1.4—Compute Maximum Shear at Critical Section (14 in. = 1.17 ft).....	A-124
A4A.7.1.4a—Dead Load Shear.....	A-124
A4A.7.1.4b—Live Load Shear (HL-93).....	A-125
A4A.7.1.5—Compute Nominal Shear Resistance.....	A-125
A4A.7.1.5a—LRFD Design.....	A-125
A4A.7.1.5b—Inventory Level.....	A-126
A4A.7.1.5c—Operating Level.....	A-126
A4A.8—Legal Load Rating (6A.4.4).....	A-126
A4A.8.1—Strength I Limit State (6A.7.4.2).....	A-126
A4A.8.1.1—Shear Capacity.....	A-127

A4A.8.2—Summary .....	A-127
A4A.9—Summary of Rating Factors for Load and Resistance Factor Rating Method .....	A-127
PART B—ALLOWABLE STRESS RATING METHOD .....	A-129
A4B.1—Bridge Data.....	A-129
A4B.2—Section Properties .....	A-129
A4B.3—Dead Load Analysis—Interior Stringer.....	A-129
A4B.4—Live Load Analysis—Interior Stringer.....	A-129
A4B.5—Allowable Stress Rating (6B.3.1, 6B.4.2, 6B.5.2) .....	A-130
A4B.5.1—Impact (Use Standard AASHTO) (6B.6.4).....	A-130
A4B.5.2—Distribution (Use Standard AASHTO) (6B.6.3) .....	A-130
A4B.5.3—Stresses to be Used (Use NDS, <i>National Design Specification for Wood Construction</i> , 2005 Edition) .....	A-130
A4B.5.3.1—Inventory Level Stresses (6B.5.2.7) .....	A-131
A4B.5.3.2—Operating Level Stresses (Use Standard AASHTO) (6B.5.2.7).....	A-131
A4B.5.4—Inventory Level Rating for Flexure .....	A-131
A4B.5.5—Operating Level Rating for Flexure.....	A-131
A4B.5.6—Check Horizontal Shear.....	A-132
A4B.5.7—Inventory Level Rating for Shear .....	A-133
A4B.5.8—Operating Level Rating for Shear.....	A-134
A4B.5.9—Summary of Ratings for Allowable Stress Rating Method .....	A-134
A4B.6—Load Factor Rating.....	A-134
PART C—SUMMARY .....	A-135
A4C.1—Summary of All Ratings for Example A4 .....	A-135
A4C.2—References .....	A-135
A5—FOUR-SPAN CONTINUOUS STRAIGHT WELDED PLATE GIRDER BRIDGE: EVALUATION OF AN INTERIOR GIRDER .....	A-137
A5.1—Bridge Data .....	A-137
A5.1.1—Girder Bracing.....	A-137
A5.1.2—Girder Section Properties .....	A-137
A5.1.3—Girder Sections.....	A-138
A5.2—Dead Load Analysis—Interior Girder.....	A-138
A5.2.1—Components and Attachments, DC .....	A-138
A5.2.2—Wearing Surface, DW .....	A-138
A5.3—Dead Load Effects .....	A-139
A5.3.1—Maximum Positive Moment at Span 1 (at 0.4L = 44.8 ft) .....	A-139
A5.3.2—Maximum Positive Moment at Span 2 (at 0.5L = 182 ft) .....	A-139
A5.3.3—Maximum Negative Moment at Pier 2 (252 ft).....	A-140
A5.3.4—Maximum Shear left of Pier 1 (112 ft).....	A-140
A5.3.5—Negative Moments at Pier 1 .....	A-140
A5.4—Live Load Distribution Factors .....	A-140
A5.4.1—Positive Flexure and Shear to the Left of Pier 1.....	A-140
A5.4.1.1—Interior Girder .....	A-140
A5.4.2—Negative Flexure .....	A-141
A5.4.2.1—Interior Girder .....	A-142
A5.5—Live Load Effects.....	A-142
A5.5.1—Maximum Positive Moment at Span 1 (at 0.4L) .....	A-142

A5.5.1.1—Design Live Load (HL-93).....	A-142
A5.5.1.2—Legal Loads .....	A-142
A5.5.2—Maximum Positive Moment at Span 2 (at 0.5L).....	A-143
A5.5.2.1—Design Live Load (HL-93).....	A-143
A5.5.2.2—Legal Loads (Use Only Truck Loads).....	A-143
A5.5.3—Maximum Negative Moment at Pier 2.....	A-143
A5.5.3.1—Calculate Maximum Negative Moment at Pier 2.....	A-145
A5.5.3.1a—Design Live Load (HL-93).....	A-145
A5.5.3.1b—Legal Loads (Truck Loads and Lane-Type Load).....	A-145
A5.5.4—Maximum Shear at Pier 1 (Left of Support).....	A-146
A5.5.4.1—Design Live Load (HL-93).....	A-146
A5.5.4.2—Legal Loads .....	A-146
A5.6—Compute Nominal Flexural Resistance of Section (Positive and Negative Moment).....	A-147
A5.6.1—Noncomposite Symmetric Section.....	A-147
A5.6.1.1—Check Web for Noncompact Slenderness Limit.....	A-147
A5.6.2—Regions B and H—Positive Moment Sections with Continuously Braced Compression Flanges.....	A-147
A5.6.2.1—Calculate Plastic Moment, $M_p$ (LRFD Design D6.1).....	A-148
A5.6.3—Region E—Negative Moment Sections with Discretely Braced Compression Flange (LRFD Design A6.1.1).....	A-150
A5.6.3.1—Calculate Local Buckling Resistance (LRFD Design A6.3.2).....	A-150
A5.6.3.2—Calculate Lateral Torsional Buckling Resistance (LRFD Design A6.3.3).....	A-151
A5.7—General Load Rating Equation (6A.4.2).....	A-155
A5.8—Design Load Rating .....	A-155
A5.8.1—Strength I Limit State.....	A-155
A5.8.1.1—Flexure at Span 1, 0.4L.....	A-155
A5.8.1.2—Flexure at Span 2, 0.5L.....	A-155
A5.8.1.3—Flexure at Pier 2.....	A-156
A5.8.2—Service II Limit State (6A.6.4.1).....	A-156
A5.8.2.1—At Span 1, 0.4L.....	A-156
A5.8.2.2—At Span 2, 0.5L.....	A-157
A5.8.2.3—At Pier 2.....	A-157
A5.8.3—Legal Load Rating (6A.4.4).....	A-157
A5.8.3.1—Strength I Limit State (6A.6.4.2.1).....	A-157
A5.8.3.1a —Flexure at Span 1, 0.4L.....	A-157
A5.8.3.1b —Flexure at Span 2, 0.5L.....	A-157
A5.8.3.1c —Flexure at Pier 2.....	A-157
A5.8.3.2—Service II Limit State (6A.6.4.2.2).....	A-157
A5.8.3.2a—At Span 1, 0.4L (Type 3-3 Truck Governs).....	A-158
A5.8.3.2b—At Span 2, 0.5L (Type 3-3 Truck Governs).....	A-158
A5.8.3.2c—At Pier 2 (Lane-Type Load Governs).....	A-158
A5.9—Shear Evaluation.....	A-158
A5.9.1—Shear Resistance at Pier 1.....	A-158
A5.9.2—Shear Resistance for Interior Panel.....	A-159
A5.10—Shear Rating at Pier 1.....	A-160
A5.10.1—Design Load Rating.....	A-161
A5.10.2—Legal Load Rating (Type 3-3 Governs).....	A-161

A5.10.3—Permit Load Rating (6A.4.5).....	A-161
A5.10.3.1—Flexure at Span 1, 0.4L .....	A-162
A5.10.3.2—Flexure at Span 2, 0.5L .....	A-163
A5.10.3.3—Flexure at Pier 2 .....	A-163
A5.11—Summary of Rating Factors.....	A-163
A5.12—Reference.....	A-163
<b>A6—THROUGH PRATT TRUSS BRIDGE: DESIGN LOAD CHECK OF SELECTED TRUSS MEMBERS ...</b>	<b>A-165</b>
A6.1—Bridge Data .....	A-165
A6.2—Member Properties .....	A-165
A6.3—Dead Load Analysis .....	A-165
A6.4—Live Load Analysis (Design Load Check) .....	A-166
A6.4.1—Live Load Distribution Factors .....	A-167
A6.4.1.1—One Lane Loaded (See Figure A6.4.1-1) .....	A-167
A6.4.1.2—Two Lanes Loaded (See Figure A6.4.1-1) .....	A-167
A6.4.1.3—Three Lanes Loaded (See Figure A6.4.1-1).....	A-167
A6.4.2—Live Load Force Effects (Due to HL-93).....	A-167
A6.4.2.1—Member TC4 (See Figure A6.3-1).....	A-167
A6.4.2.2—Member BC4.....	A-168
A6.4.2.3—Member D1 .....	A-169
A6.4.2.4—Member V1 .....	A-169
A6.5—Compute Nominal Resistance of Members .....	A-169
A6.5.1—Top Chord TC4 (Compression Member) .....	A-169
A6.5.2—Bottom Chord Member BC4 (Tension Member).....	A-172
A6.5.2.1—Limit State: Yielding over Gross Area (in the Shank of the Eyebar).....	A-172
A6.5.2.2—Limit State: Fracture at the Eyebar Head.....	A-172
A6.5.3—Diagonal Member D1 .....	A-172
A6.5.3.1—Limit State: Yielding over Gross Area (in the Shank of the Eyebar).....	A-172
A6.5.3.2—Limit State: Fracture at the Eyebar Head.....	A-173
A6.5.4—Vertical Member V1 .....	A-173
A6.5.4.1—Limit State: Yielding over Gross Area.....	A-174
A6.5.4.2—Limit State: Fracture at Net Area (at Rivet Holes).....	A-174
A6.6—General Load Rating Equation .....	A-175
A6.7—Evaluation Factors (for Strength Limit States).....	A-175
A6.7.1—Resistance Factor, $\phi$ .....	A-175
A6.7.2—Condition Factor, $\phi_c$ .....	A-175
A6.7.3—System Factor, $\phi_s$ .....	A-175
A6.8—Design Load Rating (6A.4.3) .....	A-175
A6.8.1—Top Chord TC4 .....	A-176
A6.8.2—Bottom Chord BC4 .....	A-176
A6.8.3—Diagonal D1 .....	A-176
A6.8.4—Vertical V1 .....	A-176
A6.9—Summary of Rating Factors.....	A-177
A6.10—Rating of Steel Compression Member (TC4) with Eccentric Connections.....	A-177
A6.10.1—Cross Section of Top Chord.....	A-177
A6.11—References.....	A-180
<b>A7—REINFORCED CONCRETE SLAB BRIDGE DESIGN AND LEGAL LOAD CHECK .....</b>	<b>A-181</b>

A7.1—Bridge Data .....	A-181
A7.2—Dead Load Analysis .....	A-181
A7.2.1—Interior Strip—Unit Width .....	A-181
A7.2.1.1—Components, DC .....	A-181
A7.2.1.2—Wearing Surface, DW .....	A-181
A7.3—Live Load Analysis (Design Load Check) .....	A-182
A7.3.1—One Lane Loaded .....	A-182
A7.3.2—More than One Lane Loaded .....	A-183
A7.3.2.1—Midspan Live Load Force Effects (HL-93) .....	A-184
A7.4—Compute Nominal Resistance .....	A-184
A7.5—Minimum Reinforcement (6A.5.6) .....	A-185
A7.6—Maximum Reinforcement (6A.5.5) .....	A-186
A7.7—Shear .....	A-186
A7.8—General Load-Rating Equation (6A.4.2) .....	A-187
A7.9—Evaluation Factors (for Strength Limit States) .....	A-187
A7.9.1—Resistance Factor, $\phi$ (LRFD Design 5.5.4.2) .....	A-187
A7.9.2—Condition Factor, $\phi_c$ (6A.4.2.3) .....	A-187
A7.9.3—System Factor, $\phi_s$ (6A.4.2.4) .....	A-187
A7.10—Design Load Rating (6A.4.3) .....	A-187
A7.10.1—Strength I Limit State (6A.5.4.1) .....	A-187
A7.10.2—Service Limit State .....	A-187
A7.11—Legal Load Rating (6A.4.4) .....	A-187
A7.11.1—Strength I Limit State .....	A-188
A7.11.2—Service Limit State .....	A-188
A7.11.3—Shear .....	A-188
A7.11.4—Summary .....	A-188
A7.12—Summary of Rating Factors .....	A-188
A7.13—Reference .....	A-188
A8—TWO-GIRDER STEEL BRIDGE: DESIGN LOAD RATING OF GIRDER AND FLOORBEAM .....	A-189
A8.1—Bridge Data .....	A-189
A8.2—Rating of Intermediate Floorbeam .....	A-189
A8.3—Dead Load Force Effects .....	A-189
A8.4—Live Load (HL-93) Force Effects .....	A-192
A8.4.1—Live Load (HL-93) Reactions on Intermediate Floorbeam .....	A-192
A8.4.2—Live Load (HL-93) Maximum Positive Moment .....	A-192
A8.4.3—Live Load (HL-93) Maximum Shear .....	A-193
A8.4.4—Live Load (HL-93) Maximum Negative Moment .....	A-194
A8.5—Summary of Live Load (HL-93) Force Effects in Floorbeam .....	A-195
A8.6—Compute Nominal Resistance of Floorbeam .....	A-196
A8.6.1—Positive Moment Section—Noncomposite Construction .....	A-196
A8.6.2—Negative Moment Section .....	A-198
A8.6.3—Nominal Shear Resistance (unstiffened web) .....	A-201
A8.7—General Load-Rating Equation (6A.4.2) .....	A-201
A8.7.1—Evaluation Factors (for Strength Limit States) .....	A-201
A8.7.1.1—Resistance Factor, $\phi$ (LRFD Design 6.5.4.2) .....	A-201
A8.7.1.2—Condition Factor, $\phi_c$ (6A.4.2.3) .....	A-201

A8.7.1.3—System Factor, $\phi_s$ (6A.4.2.4).....	A-201
A8.7.2—Design Load Rating (6A.4.3) .....	A-202
A8.7.2.1—Strength I Limit State (6A.6.4.1) .....	A-202
A8.7.2.1a—Flexure at 8.17 ft from West Girder (Max. Positive Live Load Moment) .....	A-202
A8.7.2.1b—Flexure at East Girder (Max. Negative Moment) .....	A-202
A8.7.2.1c—Shear at East Girder .....	A-202
A8.7.2.2—Service II Limit State .....	A-202
A8.7.2.2a—At 8.17 ft from West Girder .....	A-203
A8.7.2.2b—At East Girder .....	A-203
A8.8—Rating of East Girder (G1) .....	A-204
A8.9—Dead Load Force Effects.....	A-204
A8.10—Live Load Analysis .....	A-205
A8.11—Compute Nominal Flexural Resistance of Section .....	A-207
A8.11.1—Local Buckling Resistance .....	A-207
A8.11.2—Lateral Torsional Buckling Resistance (LRFD Design 6.10.8.2.3) .....	A-208
A8.12—General Load-Rating Equation (6A.4.2) .....	A-209
A8.12.1—Evaluation Factors (for Strength Limit States).....	A-209
A8.12.1.1—Resistance Factor, $\phi$ .....	A-209
A8.12.1.2—Condition Factor, $\phi_c$ .....	A-209
A8.12.1.3—System Factor, $\phi_s$ .....	A-209
A8.12.2—Design Load Rating (6A.4.3) .....	A-209
A8.12.2.1—Flexure .....	A-210
A8.12.2.1a—Strength I Limit State .....	A-210
A8.12.2.1b—Service II Limit State .....	A-210
A8.12.2.2—Shear .....	A-210
A8.12.2.2a—Strength I Limit State .....	A-210
A8.13—Summary of Rating Factors.....	A-212
A8.14—References .....	A-212
A9—P/S CONCRETE ADJACENT BOX-BEAM BRIDGE: DESIGN LOAD AND PERMIT LOAD RATING OF AN INTERIOR BEAM.....	A-213
A9.1—Bridge Data .....	A-213
A9.1.1—Section Properties .....	A-213
A9.2—Dead Load Analysis—Interior Beam .....	A-213
A9.2.1—Components and Attachments, $DC$ .....	A-213
A9.2.2—Wearing Surface and Utilities, $DW$ .....	A-215
A9.3—Live Load Analysis—Interior Girder .....	A-215
A9.3.1—Compute Live Load Distribution Factors for an Interior Beam (LRFD Design Table 4.6.2.2.2b-1).....	A-215
A9.3.1.1—Distribution Factor for Moment .....	A-216
A9.3.2—Maximum Live Load (HL-93) Moment at Midspan .....	A-216
A9.4—Compute Nominal Flexural Resistance .....	A-216
A9.5—Maximum Reinforcement (C6A.5.5) .....	A-218
A9.6—Minimum Reinforcement .....	A-218
A9.6.1—Determine Effective Prestress Force, $P_{pe}$ .....	A-219
A9.6.1.1—Loss Due to Elastic Shortening, $\Delta f_{pES}$ (LRFD Design 5.9.3.2.3a).....	A-219
A9.6.1.2—Approximate Lump Sum Estimate of Time-Dependent Losses, $\Delta f_{pLT}$ (LRFD Design 5.9.3.3) .....	A-220

A9.6.1.3—Total Prestress Losses, $\Delta f_{pT}$ .....	A-222
A9.7—General Load-Rating Equation (6A.4.2).....	A-223
A9.7.1—Evaluation Factors for Strength Limit States .....	A-223
A9.7.1.1—Resistance Factor, $\phi$ .....	A-223
A9.7.1.2—Condition Factor, $\phi_c$ .....	A-223
A9.7.1.3—System Factor, $\phi_s$ .....	A-223
A9.7.2—Design Load Rating (6A.4.3).....	A-223
A9.7.2.1—Strength I Limit State (6A.5.4.1) .....	A-223
A9.7.2.1a—Flexure at Midspan .....	A-223
A9.7.2.2—Service III Limit State for Inventory Level (6A.5.4.1).....	A-223
A9.7.3—Legal Load Rating (6A.4.4) .....	A-224
A9.7.4—Permit Load Rating (6A.4.5) .....	A-224
A9.7.4.1—Strength II Limit State .....	A-225
A9.7.4.2—Service I Limit State .....	A-225
A9.7.4.2a—Simplified check using $0.75M_n$ .....	A-225
A9.7.4.2b—Refined check using $0.90f_y$ .....	A-226
A9.8—Summary of Rating Factors .....	A-228
A9.8—Reference .....	A-228
A10—LRFR RATING OF A REINFORCED CONCRETE BOX CULVERT .....	A-229
A10.1—Culvert Data .....	A-229
A10.2—Dead Load Analysis, $DC$ (6A.5.12.10.1) .....	A-229
A10.3—Wearing Surface, $DW$ .....	A-230
A10.4—Earth Load: Vertical, $EV$ (6A.5.12.10.2a).....	A-230
A10.5—Earth Load: Horizontal, $EH$ (6A.5.12.10.2b).....	A-231
A10.6—Surcharge Earth Load: Horizontal, $ES$ (6A.5.12.10.2c).....	A-231
A10.7—Live Load Analysis, $LL$ (6A.5.12.10.3) .....	A-231
A10.7.1—Design Load: HL-93 Tandem .....	A-233
A10.7.2—Design Load: HL-93 Truck.....	A-234
A10.7.3—Legal Load: Type 3.....	A-234
A10.7.4—Legal Load: SU-4.....	A-235
A10.7.5—Surcharge Live Load, $LS$ (6A.5.12.10.3c) .....	A-235
A10.8—Structural Analysis of Box Culvert (6A.5.12.3).....	A-235
A10.9—Nominal Flexural Resistance .....	A-237
A10.9.1—Top Slab Center .....	A-237
A10.9.2—Top Slab Corner.....	A-238
A10.9.3—Bottom Slab Center.....	A-238
A10.9.4—Bottom Slab Corner .....	A-239
A10.9.5—Sidewall: Top–Center–Bottom .....	A-239
A10.10—Nominal Shear Resistance .....	A-240
A10.10.1—Top Slab Corner.....	A-240
A10.10.2—Bottom Slab Corner .....	A-241
A10.10.3—Sidewall Top–Center–Bottom .....	A-241
A10.11—Axial Thrust Resistance .....	A-242
A10.12—Calculate Rating Factors, $RF$ .....	A-243
A10.12.1—Load Factors for Culvert Load Rating (Table 6A.5.12.5-1) .....	A-243
A10.12.2—Strength I Limit State: Design Load Rating Factor Calculation for Flexure.....	A-243

A10.12.3—Strength I Limit State: Design Load Rating Factor Calculation for Shear.....	A-245
A10.12.4—Strength I Limit State: Design Load Rating Factor Calculation for Axial Thrust.....	A-247
A10.12.5—Strength I Limit State: Legal Load Rating for Flexure .....	A-248
A10.12.6—Strength I Limit State: Legal Load Rating for Shear.....	A-249
A10.12.7—Strength I Limit State: Legal Load Rating for Axial Thrust .....	A-250
A10.13—Rating Summary.....	A-250
A10.14—Capacity Check for Permanent Loads .....	A-251
A11—THROUGH TRUSS BRIDGE: GUSSET PLATE RATING.....	A-253
A11.1—Bridge and Member Data .....	A-253
PART A—LOAD AND RESISTANCE FACTOR RATING METHOD .....	A-255
A11A.1—Load and Resistance Factor Rating of Gusset Plates.....	A-255
A11A.2—Check the Tension Resistance of M1 .....	A-255
A11A.3—Check the Chord Splice Resistance .....	A-258
A11A.4—Check Tension Resistance of M2 .....	A-261
A11A.5—Check the Compression Resistance of M3 .....	A-263
A11A.6—Check the Compression Resistance of M4 .....	A-266
A11A.7—Check Horizontal Shear Capacity of the Gusset Plate.....	A-270
A11A.8—Check Vertical Shear Capacity of the Gusset Plate.....	A-271
A11A.9—Summary of LRFR Load Rating Factors.....	A-272
PART B—LOAD FACTOR RATING METHOD .....	A-272
A11B.1—Load Factor Rating of Gusset Plates.....	A-272
A11B.2—Check the Tension Resistance of M1 .....	A-273
A11B.3—Check the Chord Splice Resistance .....	A-274
A11B.4—Check Tension Resistance of M2 .....	A-275
A11B.5—Check the Compression Resistance of M3 .....	A-276
A11B.6—Check the Compression Resistance of M4 .....	A-277
A11B.7—Check Horizontal Shear Capacity of the Gusset Plate.....	A-278
A11B.8—Check Vertical Shear Capacity of the Gusset Plate.....	A-279
A11B.9—Summary of LFR Load Rating Factors.....	A-280