## Table of Contents

**Table of Contents**
(Continued)

# Chapter Eleven

# GENERAL

Volume II "Structural Design" of the **MDT Structures Manual** presents the Department's criteria for the structural design of bridges and other structures. Chapter Eleven presents general information which applies to all of Volume II.

## 11.1 BASIC APPROACH

The following describes the basic approach used to develop Volume II of the **Manual**:

1. Application. The **MDT Structures Manual** is intended to be an application-oriented product.

2. Theory. The **Manual** is not intended to be a structural design theory resource nor a research document. The **Manual** will only provide background information as absolutely necessary so that the user will understand the basis for the Department's structural design criteria and application.

3. Example Problems. Where beneficial to explain the intended application, the **Manual** will provide example problems to demonstrate the proper procedure for structural design.

4. Details. Where beneficial, the **Manual** will provide structural design details (i.e., figures and tables) for the various structural components.

5. Coordination with **LRFD Bridge Design Specifications**. A crucial element to **Manual** development is the **Manual's** coordination with the LRFD Specifications. The **MDT Structures Manual** is basically a Supplement to the LRFD Specifications which:

   a. in general, does not duplicate, unless absolutely necessary for clarity, information in the AASHTO Specifications;

   b. elaborates on specific articles of the Specifications;

   c. presents interpretative information, where required;

   d. modifies sections from the Specifications where the Department has adopted a different practice;

   e. where the AASHTO Specifications presents more than one option, indicates the Department's preference; and

   f. indicates structural design elements presented in the AASHTO Specifications but which are not typically used in Montana.

6. Acknowledgement of 16th Edition of **Standard Specifications for Highway Bridges**. This **Manual** has been prepared with the expectation that the **LRFD Bridge Design Specifications** will replace the 16th Edition of the AASHTO **Standard Specifications for Highway Bridges**. The reality is that the implementation of the LRFD Specifications is a transitional process. Much design is still being prepared using the 16th Edition and will be for some time. If a bridge design is being prepared using the 16th Edition of the Standard Specifications, the information and guidance provided in this **Manual** needs to be considered in conjunction with the requirements of that publication and used as appropriate.

## 11.2 STRUCTURAL DESIGN LITERATURE

Section 11.2 discusses the major national publications available in the structural design literature. It provides 1) a brief discussion on each publication, and 2) the status and application of the publication by the Department. Section 11.2 is not all inclusive of the structural design literature; however, it does represent a hierarchy of importance. In all cases, the designer must ensure that he/she is using the latest edition of the publication, including all interim revisions to date.

### 11.2.1 LRFD Bridge Design Specifications

#### 11.2.1.1 Description

The AASHTO **Load and Resistance Factor Design (LRFD) Bridge Design Specifications** are intended to serve as the national standard or guide for use by bridge engineers or for the development of a transportation agency's own structural specifications. The Specifications establish minimum requirements, consistent with current nationwide practices, which apply to common highway bridges and other structures such as retaining walls and culverts; large-span structures may require design provisions in addition to those presented in the LRFD Specifications**.** Because of the continually changing nature of structural design, interim revisions are issued and, periodically, AASHTO publishes a completely updated edition, historically at four-year intervals.

The LRFD Specifications take a fundamentally different approach to design theory than the AASHTO **Standard Specifications for Highway Bridges**. The information in the LRFD Specifications supersedes, partially or completely, the following AASHTO structural design publications:

1. **Standard Specifications for Alternate Load Factor Design Procedures for Steel Beam Bridges Using Braced Compact Sections**,
2. **Guide Specifications for Strength Design of Truss Bridges**,
3. **Standard Specifications for Seismic Design of Highway Bridges**,
4. **Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members**,
5. **Guide Specifications — Thermal Effects in Concrete Bridge Superstructures**,
6. **Guide Specifications for Fatigue Design of Steel Bridges**,
7. **Guide Specifications for Bridge Railings**,
8. **Guide Specifications for Design and Construction of Segmental Concrete Bridges**, and
9. **Guide Specification and Commentary for Vessel Collision Design of Highway Bridges**.

The LRFD Specifications present a load and resistance factor methodology for the structural design of bridges, which replace the load factor and allowable stress methodologies of the previous AASHTO Standard Specifications. The LRFD Specifications apply live load factors which are lower than the traditional AASHTO load factors but balance this reduction with an increase in vehicular live load which more accurately models actual loads on our nation’s highways. Basically, the LRFD methodology requires that bridge components be designed to satisfy four sets of limit states: strength, service, fatigue and extreme-event limit states. Through the use of statistical analyses, the provisions of the LRFD Specifications reflect a uniform safety index for all structural elements, components and systems.

A few significant features of the LRFD Specifications are:

1. The Specifications are supplemented with a comprehensive commentary placed immediately adjacent to the Specifications provisions in a parallel column.
2. The vehicle live load is designated HL-93. This live load model retains a truck

configuration similar to the HS-20 design truck and a tandem slightly heavier than the traditional military loading, but it has been modified to include simultaneously applied lane loading over full or partial span lengths to produce extreme force effects.

3. Alternative load factors have been introduced for permanent loads that must be used in combination with factored transient loads to produce extreme force effects.

4. Fatigue loading consists of a single truck with axle weights and spacings that are the same as an HS-20 truck with a constant 9-m spacing between the 142-kN axles which can be located anywhere on the bridge deck to produce the maximum stress range.

5. In addition to regular load combinations, two design trucks are used for negative moments and internal pier reactions in combination with the lane load, the distance between the rear and front axles of the trucks cannot be less than 15 m, and the combined force effect is reduced by 10%.

6. The Specifications include an empirical design for concrete bridge deck slabs, which allows for reduced deck reinforcement.

7. The Specifications allow for relatively easy and more precise estimates of live-load distribution by tabulated equations.

8. The Specifications allow the optional use of deflection criteria. See Section 11.3.4 for Departmental guidance.

9. The Specifications allow for the more frequent use of compact steel sections.

10. The method of shear design in concrete has been revised; compression field theory and strut-and-tie models are used.

11. The Specifications recognize the detrimental effect of salt-laden water seeping through deck joints and promote the notion of reducing the number of such joints to an absolute minimum.

#### 11.2.1.2 Department Application

The Montana Department of Transportation has adopted the use of the AASHTO **LRFD Bridge Design Specifications** as the preferred document for the structural design of highway bridges in Montana. Volume II of the **Montana Structures Manual** presents the Department's specific application of the LRFD Specifications to structural design, which modify, replace, clarify or delete information from the AASHTO LRFD Specifications for MDT's application.

The AASHTO **Standard Specifications for Highway Bridges** are still valid and may be used with the approval of the Bridge Area Engineer. This **Manual** contains significant information on Department design policies and procedures and must be referenced for designs prepared based on the **Standard Specifications for Highway Bridges**.

Where conflicts are observed in the structural design literature, the following hierarchy of priority shall be used to determine the appropriate application:

1. **Montana Structures Manual**,

2. **LRFD Bridge Design Specifications** or **Standard Specifications for Highway Bridges,** and

3. all other publications.

### 11.2.2 ANSI/AASHTO/AWS Bridge Welding Code (1996 Edition) D1.5

#### 11.2.2.1 Description

The **Bridge Welding Code** presents current criteria for the welding of structural steel in bridges. The Code superseded the 1981 AASHTO **Standard Specifications for Welding of**

**Structural Steel Highway Bridges** and the 1980 **Structural Welding Code, AWS D1.1.**

**11.2.2.2 Department Application**

The Department has adopted the use of the 2002 **Bridge Welding Code D1.5** for the design and construction of structural steel highway bridges. However, the D1.5 Code does not cover welding on reinforcing steel or welding on existing structures. For these items, refer to the current edition of ANSI/AWS D1.1, ANSI/AWS D1.4 and ANSI/AWS D1.1, respectively.

**11.2.3 Standard Specifications for Seismic Design of Highway Bridges (1994 Edition)**

**11.2.3.1 Description**

The AASHTO Seismic Specifications present design criteria for the seismic design of highway bridges to, within reason, limit significant structural damage or structural failure of a highway bridge during an earthquake. The AASHTO Seismic Specifications are applicable throughout the United States, with varying levels of risk assigned to different areas of the nation based upon seismicity. It is based upon the observed performance of bridges during earthquakes and upon research which has been conducted worldwide.

As noted in Section 11.2.1, the AASHTO LRFD Specifications have incorporated and supersede the Seismic Specifications. However, the Seismic Specifications contain useful information discussing background and methods of analysis, and they provides worked examples which are by nature not incorporated into the LRFD Specifications.

In 1999, AASHTO published the **Guide Specifications for Seismic Isolation Design** (Second Edition), which was supplemental to the **Standard Specifications for Seismic Design of Highway Bridges**. The LRFD Specifications do not specifically address seismic isolators; therefore, these Specifications may be used in conjunction with the LRFD Specifications.

**11.2.3.2 Department Application**

The AASHTO **Standard Specifications for Seismic Design of Highway Bridges** may be used by the designer for informational purposes. The **Guide Specifications for Seismic Isolation Design** should be used, where applicable, in conjunction with the LRFD Specifications.

**11.2.4 Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members (1996 Edition)**

**11.2.4.1 Description**

The AASHTO Guide Specifications provide recommended requirements for identifying, fabricating, welding and testing of fracture critical, non-redundant steel bridge members whose failure would be expected to cause a bridge to collapse. The AASHTO Guide Specifications include specifications on welding requirements which are in addition to those in the ANSI/AASHTO/AWS **Bridge Welding Code**. The Guide also discusses the need for proper identification of fracture critical members on plans.

As noted in Section 11.2.1, the AASHTO LRFD Specifications have incorporated and supersede the Guide Specifications. See Article 6.6.2. However, the Guide Specifications contain useful information addressing background, example problems, etc., which are not included in the LRFD Specifications.

**11.2.4.2 Department Application**

The AASHTO Guide Specifications may be used by the designer for informational purposes.

### 11.2.5 Guide Specifications for Horizontally Curved Highway Bridges (2002 Edition)

#### 11.2.5.1 Description

The AASHTO Guide Specifications present specifications and methodologies for the design of steel beams and steel box girder bridges which are on a horizontal curve. The Guide is applicable to simple and continuous spans, composite or non-composite structures of moderate length employing either rolled or fabricated sections. The design methodology is based on both working stress and load factor principles and, therefore, is not compatible with the LRFD Specifications.

#### 11.2.5.2 Department Application

The Department has adopted the AASHTO Guide Specifications as standard practice; therefore, they shall be used for the design of horizontally curved steel members.

### 11.2.6 Guide Specifications For Bridge Railings (1989 Edition)

#### 11.2.6.1 Description

The AASHTO Guide Specifications contain three bridge railing performance levels and associated crash tests and performance requirements in addition to guidance for determining the appropriate railing performance level for a given bridge site.

As noted in Section 11.2.1, the AASHTO LRFD Specifications have incorporated and supersede the Guide Specifications. However, the Guide Specifications contain useful information addressing background, example problems, etc., which are not included in the LRFD Specifications.

#### 11.2.6.2 Department Application

The AASHTO Guide Specifications may be used by the designer for informational purposes.

### 11.2.7 Guide Specifications for Structural Design of Sound Barriers (1989 Edition)

#### 11.2.7.1 Description

The AASHTO Guide Specifications provide criteria for the structural design of sound barriers to promote the uniform preparation of plans and specifications. The AASHTO Guide Specifications allow the design of masonry sound barriers in addition to concrete, wood, steel, synthetics and composites, and aluminum.

#### 11.2.7.2 Department Application

Use the AASHTO Guide Specifications for all sound barrier designs.

### 11.2.8 Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals (1994 Edition with Interim Revisions)

#### 11.2.8.1 Description

The AASHTO Standard Specifications present structural design criteria for the supports of various roadside appurtenances. The publication presents specific criteria and methodologies for evaluating dead load, live load, ice load and wind load. The AASHTO Standard Specifications also include criteria for several types of materials used for structural supports such as steel, aluminum, concrete and wood.

#### 11.2.8.2 Department Application

The Department has adopted the use of the AASHTO **Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals**. The MDT Traffic Engineering Section is primarily responsible for these supports, and the Department has developed standard designs which will apply in most cases.

### 11.2.9 LRFD Manual of Steel Construction

#### 11.2.9.1 Description

The **LRFD Manual of Steel Construction**, published by the American Institute of Steel Construction (AISC), provides dimensions, properties and general design guidance for structural steel for various applications. The Manual contains AISC criteria for steel buildings. However, the properties of the rolled structural shapes are useful for designing bridge structures.

#### 11.2.9.2 Department Application

The designer may use the **AISC LRFD Manual of Steel Construction** for informational purposes.

### 11.2.10 Timber Construction Manual

#### 11.2.10.1 Description

The **Timber Construction Manual**, published by the American Institute of Timber Construction (AITC), provides comprehensive criteria for the design of timber structures, including bridges. The Manual contains information for both sawn and laminated timber.

#### 11.2.10.2 Department Application

The designer should use the AITC **Timber Construction Manual** to supplement the AASHTO publications on the design of timber bridges.

### 11.2.11 Uniform Building Code

#### 11.2.11.1 Description

The **Uniform Building Code** (UBC), published by the International Conference of Building Officials (ICBO), provides criteria for the design of buildings throughout the United States and abroad. They are intended to be used directly by an agency or to be used in the development of an agency's own building codes. Contact:

Building Codes Bureau
MT Department of Labor and Industry
PO Box 200517
Helena, MT 59620-0517
(406) 841-2056

to determine which version of the UBC to use as a reference.

#### 11.2.11.2 Department Application

Buildings for which the Department is responsible for their design (e.g., at rest areas) shall be designed based on the **Uniform Building Code.**

### 11.2.12 AREMA Manual

#### 11.2.12.1 Description

The **AREMA Manual**, published by the American Railroad Engineering and Maintenance-of-Way Association (AREMA), provides detailed structural specifications for the design of railroad bridges. The AREMA specifications have approximately the same status for railroad bridges as the LRFD Specifications have for highway bridges; i.e., the structural design of railroad bridges shall meet the AREMA requirements.

#### 11.2.12.2 Department Application

In some cases, MDT is responsible for the design of railroad bridges over highways. The specifications of the **AREMA Manual** must be met, except as modified by railroad companies operating in Montana.

### 11.2.13 Other Structural Design Publications

The structural design literature contains many other publications which may, on a case-by-case basis, be useful. These may be used at the discretion of the designer. The following briefly

describes several other structural design publications:

1. **Prestressed Concrete Institute (PCI) Design Handbook**. This publication includes information on the analysis and design of precast and/or prestressed concrete products in addition to a discussion on handling, connections and tolerances for prestressed products. It contains general design information, specifications and standard practices.

2. **Post-Tensioning Institute (PTI) Post-Tensioning Manual**. This publication discusses the application of post-tensioning to many types of concrete structures, including concrete bridges. The publication also discusses types of post-tensioning systems, specifications, the analysis and design of post-tensioned structures and their construction.

3. **Concrete Reinforcing Steel Institute (CRSI) Handbook**. This publication meets the ACI Building Code Requirements for Reinforced Concrete. Among other information, it provides values for both design axial load strength and design moment strength for tied columns with square, rectangular or round cross sections, and it provides pile cap designs.

4. **National Steel Bridge Alliance (NSBA) Highway Structures Design Handbook.** This document addresses many aspects of structural steel materials, fabrication, economy and design. Recently updated with LRFD examples in both US customary units and SI units, the general computational procedure is helpful to designers using the **LRFD Bridge Design Specifications.**

5. **United States Department of Agriculture (USDA) Forest Service Timber Bridge Manual**. This is a comprehensive document covering all aspects of traditional timber bridge construction plus the latest developments in laminated deck systems using adhesives or prestressing forces.

6. **Western Lumber Grading Rules**. This publication contains information on how lumber and timbers are graded, and it has stress tables for various species, grades and sizes.

7. **West Coast Lumber Grading Rules**. This publication contains information on how lumber and timbers are graded, and it has stress tables for various species, grades and sizes.

8. **American Concrete Institute (ACI) — Analysis and Design of Reinforced Concrete Bridge Structures.** This publication contains information on various concrete bridge types, loads, load factors, service and ultimate load design, prestressed concrete, substructure and superstructure elements, precast concrete, reinforcing details and metric conversion.

9. **CRSI Manual of Standard Practice**. This publication explains generally accepted industry practices for estimating, detailing, fabricating and placing reinforcing bars and bar supports. MDT requires that reinforcing steel shall be detailed as shown in the CRSI Manual as modified by MDT practices.

10. **PTI — Post-Tensioned Box Girder Bridges.** This publication contains information on economics, design parameters, analysis and detailing, installation, prestressing steel specifications, post-tensioning tendons, systems and sources.

11. **United States Navy — Design Manual for Soil Mechanics, Foundations and Earth Structures.** This is a comprehensive document covering embankments, exploration and sampling, spread footings, deep foundations, pressure distributions, buried substructures, special problems, seepage and drainage analysis, settlement analysis, soil classifications, stabilization, field tests and measurements, retaining walls, etc. Its use is strongly recommended. Note that the loading sections of the Manual are superseded by the LRFD Specifications.

12. **Seismic Design and Retrofit Manual for Highway Bridges**, Report No. FHWA-IP-87-6. This Manual contains information concerning basic seismology, bridge dynamics, design concepts, loads, forces and displacements in addition to design examples, retrofitting and comparative analyses.

13. **Seismic Design of Bridges**, Report No. FHWA-SA-97-007. This is a series of seven worked examples on seismic design. Each volume contains one worked example.

## 11.3 GENERAL STRUCTURAL DESIGN CRITERIA

### 11.3.1 General

Reference: None

The girders should be designed, where practical, so that exterior and interior girders will be similar to allow for the possibility of future widening. This also reduces fabrication costs and the probability for misplacement.

### 11.3.2 Continuity

Reference: LRFD Article 2.5.2.4

Continuity within bridge structures is a very desirable objective because, among many other advantages, the number of deck joints decreases with deck continuity.

Article 2.5.2.4 contains strong wording on using bridge approach slabs. These are not normally used on MDT projects. Approach slabs are required where Portland cement concrete pavement (PCCP) is used or for special considerations.

### 11.3.3 Composite Action

Reference: LRFD Article 9.4.1

The Department mandates the use of composite action between the superstructure and the bridge deck on new construction. On a project-by-project basis, investigate the potential benefits or consequences of composite action when rehabilitating existing bridges.

### 11.3.4 Deflection Criteria

Reference: LRFD Article 2.5.2.6.2

The LRFD Specifications make the traditional live-load deflection criteria optional for both bridges with and without sidewalks because static live-load deflection is not a good measure of dynamic excitation. Nonetheless, in the absence of a better criterion and because of concerns on deck life, the MDT believes that it is appropriate to limit deflections.

#### 11.3.4.1 Structures With Sidewalks

Stringers or girders having simple or continuous spans shall be designed so that the deflection due to truck live load plus dynamic allowance shall not exceed 1/1000 of the span. The deflection of cantilever arms due to live load plus dynamic allowance shall be limited to 1/375 of the cantilever arm.

#### 11.3.4.2 Structures Without Sidewalks

The deflection allowance shall not exceed 1/800 of the span length.

### 11.3.5 Semi-Integral Abutments

Reference: None

Semi-integral abutments are the typically preferred abutment type in Montana, because they offer many of the advantages of integral abutments while offering additional advantages in construction and maintenance. In severe seismic applications, integral abutments are preferred. Chapter 19 discusses the advantages of each abutment type and provides MDT practices.

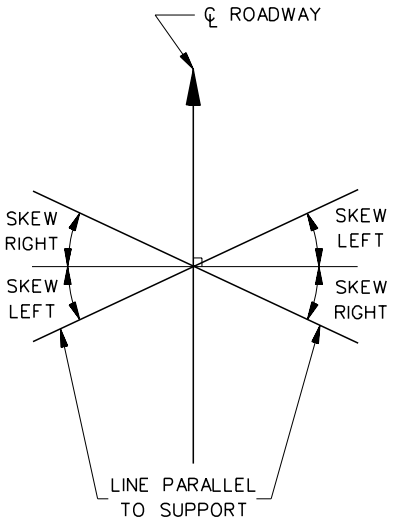
### 11.3.6 Skew

The following applies to skews on bridges:

1. Definition. Skew angle is defined as the angle between a line normal to the highway centerline (or a tangent thereto) and a line parallel to the support (wall, abutment, pier, etc.). The angle is designated left or right, in relation to the normal to the highway centerline. See Figure 11.3A.

2. Snowplows. If possible, avoid matching the angle of a snowplow. The critical angle to avoid is 35° - 37° right.

3. Department Limits. The maximum skew angle on a bridge without approval is 35°. The Bridge Area Engineer must approve the use of greater skew angles.




**SKEW DEFINITION**
**Figure 11.3A**

## 11.4 EXCEPTIONS

Section 11.4 discusses the Department's procedures for identifying, justifying and processing exceptions to the structural design criteria in the **MDT Structures Manual**.

### 11.4.1 Department Intent

The general intent of the Montana Department of Transportation is that all design criteria in this **Manual** and the **LRFD Bridge Design Specifications** or the **Standard Specifications for Highway Bridges** shall be met. This is intended to ensure that the Department will provide a highway system which meets the transportation needs of the State and provides a reasonable level of safety, durability, comfort and convenience for the traveling public. However, recognizing that this may not always be practical, the Department has established a process to evaluate and approve exceptions to its structural design criteria.

### 11.4.2 Procedures

Where the bridge designer proposes a design element which does not meet the requirements of the **MDT Structures Manual**, regardless of whether or not it satisfies the provisions of the **LRFD Bridge Design Specifications** or the **Standard Specifications for Highway Bridges**, the following procedure will apply:

1. Documentation. The bridge designer will document any proposed exceptions from the Department's structural design criteria in the Scope of Work Report, if known at this stage of project development. The designer will present the justification for the exception, which may include:

    a. site constraints,
    b. construction costs,
    c. environmental impacts, and/or
    d. right-of-way impacts.

2. Approval. All proposed exceptions must be approved by the Bridge Design Engineer or Bridge Engineer.