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SECTION 1: INTRODUCTION

1.1. OVERVIEW OF MANUAL

Accurate and current load ratings are needed as part of providing information to the National Bridge Inventory (NBI) and are used for many other purposes such as bridge management, prioritization, and identification of maintenance and rehabilitation needs. Thus, it is important that accurate load ratings be maintained and properly reflect the latest conditions of the structure.

This manual establishes the criteria for load rating and load posting of bridges and culverts. Methods of Load and Resistance Factor Rating (LRFR), Load Factor Rating (LFR), and to a lesser extent Allowable Stress Rating (ASR) are covered herein. Methods of load rating for routine bridges are the primary focus of this manual. Information is also given for topics such as load rating of complex bridges and load rating of bridges for which plans are not available. The intent of the manual is to provide a standardized procedure for determining the load rating of bridges.

This manual can be found on the MnDOT Bridge Office website at: http://www.dot.state.mn.us/bridge/index.html.

The use of this manual does not relieve the load rating engineer of responsibility for the rating of a bridge or structural component. Although Bridge Office policy is presented here for numerous situations, the content of this manual is not intended to be all-inclusive. Therefore, use of this manual must be tempered with sound engineering judgment.

1.1.1. Scope and Organization

This manual provides guidance for the load rating of most bridges in Minnesota including bridges on both the state and local road systems. For bridges that are not covered by the guidance provided in this manual, the *AASHTO Manual for Bridge Evaluation* governs. Where this manual is silent, the current versions of the following documents shall govern, in descending order of authority:

- *MnDOT LRFD Bridge Design Manual*
- *AASHTO Manual for Bridge Evaluation*
- *AASHTO LRFD Bridge Design Specifications (LRFR Only)*
- *AASHTO Standard Specifications (LFR and ASR Only)*

For further clarification, please contact the bridge owner for assistance. This publication consolidates and updates many existing MnDOT policies and procedures. These include: *LRFD Bridge Design Manual* Section 15 (deleted with the publication of this manual), elements of Section 8 of the *LRFD Bridge Design Manual*, and various draft documents including the 2013 draft *Implementation Guidelines for Load and Resistance Factor Rating (LRFR) of Highway Bridges*, draft Bridge Load Rating QC/QA guidance, AASHTOWare BrR (previously Virtis) guidelines, and selected portions of the *Bridge and Structure Inspection Program Manual*.

The manual is organized as follows:

- Section 1 provides general information.
- Section 2 discusses the various data elements that are required to complete a load rating. It covers topics such as when a load rating is needed, what elements should be load rated, when load posting or closure is required, and generally describes the overall process of load rating bridges in Minnesota.
- Section 3 describes the general methodologies of load rating. Covered are methods such as LRFR, LFR and, ASR. The general approach to load rating routine and complex bridges is provided along with a discussion of special topics such as the load rating of bridges with unknown components. Special topics such as load testing and physical inspection rating are briefly introduced.
- Section 4 is an in-depth presentation of the application of the LRFR methods for bridge load rating. In this section, the specific MnDOT exceptions and clarifications to the *AASHTO Manual for Bridge Evaluation* guidance are presented.
- Section 5 is similar to Section 4 but addresses the use of LFR and ASR which are still used for some existing bridges. It covers the topics that were previously contained in the LRFD Bridge Design Manual, Section 15 (now removed).
- Section 6 addresses the fatigue evaluation of steel bridges.
- Section 7 covers special topics such as the assessment and load rating of wood structures and masonry bridges, historic bridges, physical inspection rating and nondestructive load testing.
- Section 8 relates to the use of routine and special analysis software for bridge load rating.
- Section 9 addresses quality assurance/quality control (QA/QC).
- Section 10 discusses the use of specific MnDOT forms for compiling the load rating results.
- Section 11 provides the submission requirements for load rating reports.
- Section 12 contains load rating examples.
- Appendices include a glossary, copies of standard forms, guidance for bridge load posting, and descriptions of standard load rating vehicles.

1.1.2. Updates to the Manual

There is no specific timetable for performing updates to this manual, though its content will be updated periodically to reflect changes in AASHTO LRFD / LRFR or MnDOT practices. Visit the MnDOT Bridge Office website for the most current version of this manual, found at: http://www.dot.state.mn.us/bridge/index.html. Contact the bridge owner regarding AASHTO or MnDOT policies which require clarification for a specific bridge load rating project.

1.1.3. Format of the Manual and References

Each section of this manual contains general information at the start of the section. The general content is divided into articles that are identified with numerical labels. Within the body of the text, references to other articles of this manual are directly cited (e.g. Article 10.1). References to other documents are as follows:

- *AASHTO LRFD Bridge Design Specifications:* LRFD Specifications
- *AASHTO Manual for Bridge Evaluation:* MBE
- *AASHTO Standard Specifications for Highway Bridges:* Standard Specifications

- *MnDOT Bridge and Structure Inspection Program Manual:* BSIPM
  - Found here: https://www.dot.state.mn.us/bridge/inspection.html
- *MnDOT Bridge Preservation and Improvement Guidelines:* BPIG
  - Found here: https://www.dot.state.mn.us/bridge/construction.html
- *MnDOT LRFD Bridge Design Manual:* BDM
  - Found here: http://www.dot.state.mn.us/bridge/lrfd.html
- *Minnesota Manual for Uniform Traffic Control Devices:* MN MUTCD
  - Found here: http://www.dot.state.mn.us/trafficeng/publ/mutcd/index.html

SECTION 2: LOAD RATING POLICIES AND PRACTICES

2.1. WHAT IS A BRIDGE LOAD RATING?

The *MBE* defines load rating as "the determination of the live-load carrying capacity of an existing bridge." As such it reflects the current capacity of a bridge including various factors such as the current condition of the structure as well as changes in loading over time. It involves the determination of the capacity to carry live loads that are frequently very different in overall size and weight / force effects as compared to the live load conditions of the original design.

Load ratings are based on information about the bridge type and configuration. This data is taken from the bridge design plans and is supplemented by information gathered from field inspections or field testing. The load rating provides a basis to determine the safe operating conditions of the bridge and is also used to support maintenance, rehabilitation, or replacement decisions. Load ratings are a Federal requirement as a component of reporting bridge data to the National Bridge Inventory (NBI). Load rating calculations are used to support load posting and overweight permitting as well.

Bridge load ratings are administered and performed by the Bridge Rating Unit of the MnDOT Bridge Office. Bridge load ratings may also be performed by other qualified engineers such as consulting engineers working on behalf of MnDOT or local agencies.

2.2. WHY IS A LOAD RATING NEEDED?

Various Federal and State statutes govern aspects of bridge inspection, load rating, and bridge management. Some of these are described in Article 2.2.1 and Article 2.2.2.

In addition to statutory requirements at the Federal and State levels, it is important to know the capacity of each bridge to carry loads for several reasons, including (but not limited to) the following:

- To determine which structures have substandard load capacities that may require load posting or other remedial action
- To assist in the most effective use of available resources for rehabilitation or replacement
- To assist in the overload permit review process
- To assess potential changes in legal loads, i.e. agricultural vehicle weight limits, new classes of exempt vehicles, etc.

2.2.1. Federal Requirements

Federal law (23 CFR 650 Subpart C) requires that all bridges, defined as structures over 20 feet in length, be inspected and subsequently be load rated in accordance with procedures specified in the *MBE*. The National Bridge Inspection Standards (NBIS) requires that the individual charged with overall responsibility for the load rating of bridges must be a registered professional engineer. The federal requirements for bridge inspection, load rating, and bridge management are further elaborated on in the *Metrics for the Oversight of the National Bridge Inspection Program* (FHWA, 2013). Specifically, Metric #4 – Load Rating Engineer, Metric #13 – Load Rating, and Metric #14 – Post or Restrict, provide guidance for selected elements of bridge load rating.

The federal law *Fixing America's Surface Transportation Act* (Pub. L. No. 144-94), known as the FAST Act, introduced mandated legal loads on the Interstate Highway System. Section 1410 of the law defines a series of emergency vehicles that can operate on and within reasonable access to the Interstate Highway System without requiring a permit.

2.2.2. State Statutes

At the state level, all bridges in Minnesota open to the public, carrying cars and trucks, and having spans of 10 feet or more require a load rating. Minnesota statute 165.01 defines the span of a bridge as an "opening measured horizontally along the center of the roadway… between undercopings of abutments, between the spring line of arches, or between the extreme ends of openings for multiple boxes." This is more stringent than the 20-foot span federal requirement. This includes all county, township, city, and private bridges. Railroad bridges are rated by the operating railroad. Bridges that carry pedestrians or recreational traffic are rated only in special cases.

Minnesota Statutes Chapter 169 prescribes weights of vehicles and thus has a bearing on the load rating requirements described herein. A summary of the gross weight vehicles for regular operations, as required by the State's tire weight limits, axle weight limits, and seasonal weight increases is provided in Table 2.2.2-1. These trucks are in addition to the federally required emergency vehicles.

Table 2.2.2-1: Truck Weight Limits for Non-Permit Vehicles

Description	Weight Limit
Single Axle	10,000 lbs. per single tire 20,000 lbs.
Tandem Axle	34,000 lbs.
Tridem Axle	42,000 lbs.
Gross Weight	80,000 lbs.
Others	There are several exemptions, including for fire trucks, implements of husbandry, increases in allowed weight for winter operations, special considerations for utility vehicles, and exemptions for tow trucks.

Additionally, there are numerous special permit requirements for the shipment of specific commodities. These permits include limits on weight, number of axles, and certain route and seasonal restrictions. These permissions and restrictions change over time and are fully detailed in the State of Minnesota statutes 169.80 through 169.88.

Other restrictions and requirements related to bridges, load ratings, inspections, vehicles, trucks, and weights include *Minnesota Statutes*, Chapters 163, 165, and 168, and *Minnesota Rules*, Chapters 8810 and 8820. A more complete list of Minnesota State Rules and Statutes can be viewed on the provided website link and include the following:

https://www.revisor.leg.state.mn.us/pubs/ (2018)

- Minnesota Statute 165.03 – Strength of Bridge; Inspection
  - Subdivision 3 – County Inventory and Inspection Records and Reports
  - Subdivision 4 - Municipal Inventory and Inspection Records and Reports
  - Subdivision 6 – Other Bridges
  - Subdivision 6a – Bridge Load Rating and Posting
- Minnesota Statute 165.12 – Maintenance of Bridge on Town Road
- Minnesota Statute 169.80 – Size, Weight, Load
- Minnesota Statute 169.801 – Implement of Husbandry
- Minnesota Statute 169.81 – Height and Length Limitations
- Minnesota Statute 169.822 – Weight Limitations; Definitions
- Minnesota Statute 169.824 – Gross Weight Schedule
- Minnesota Statute 169.826 – Gross Weight Seasonal Increases
- Minnesota Statute 169.8261 – Gross Weight Limitations; Forest Products
- Minnesota Statute 169.84 – Load Limit on Bridge
- Minnesota Statute 169.86 – Special Permit to Exceed Height, Width, or Load; Fees
- Minnesota Statute 169.863 – Special Pulpwood Vehicle Permit
- Minnesota Statute 169.864 – Special Paper Products Vehicle Permit
- Minnesota Statute 169.865 – Special Farm Products Permits
- Minnesota Statute 169.866 – Special Canola-Hauling Vehicle Permit
- Minnesota Statute 169.869 – Road Construction Materials Special Permit
- Minnesota Statute 169.87 – Seasonal Load Restrictions; Route Designation
- Minnesota Statute 169.871 – Excess Weight; Civil Penalty
- Minnesota Statute 169.88 – Damages; Liability
- Minnesota Administrative Rule Chapter 8810 – Trunk Highway System
- Minnesota Administrative Rule Chapter 8820 – Local State-Aid Route Standards, Financing

2.2.3. Other MnDOT Guidance

In addition to this manual, there are other MnDOT publications that provide information on bridge design, rehabilitation, inspection, and maintenance that relate to load rating decisions and conclusions.

The *BDM* provides additional coverage of important topics such as: loads and load factors; structural analysis and evaluation; concrete, steel and wood structures; decks; substructures; buried structures; and prior to the writing of this stand-alone manual included Section 15 on load rating. The prior Section 15 provisions were related to the use of ASR, LFR, and LRFR methods. The guidance pertaining to ASR and LFR methods has been included in Section 5 of this manual to document past MnDOT practices and the practices that still relate to many existing bridge load ratings.

The *BSIPM Section A.8* also covers aspects of load rating. It focuses on the condition assessment of structures as part of the gathering of information needed to update the load ratings. The need to document the condition of primary elements and the relationship of those conditions to capacity is emphasized. Other important inspection activities such as determining if additional dead loads have been added and verifying the presence of load posting signs are discussed.

The *BPIG* assists Bridge Office and District personnel in prioritizing bridge preservation and improvement needs. As such the condition and load rating of bridges are required elements of this

decision making. There are various references to the minimum required load rating capacities of bridges that are to be provided at the conclusion of a bridge preservation or improvement project.

2.3. WHEN IS A LOAD RATING NEEDED?

As mentioned previously, all bridges in Minnesota open to the public, carrying cars and trucks, and having spans of 10 feet or more are load rated. This includes all county, township, city, and private bridges. Railroad bridges are load rated by the operating railroad. Bridges that carry pedestrians or recreational traffic are rated only in special cases. Culverts, with spans of 10 feet or more, are also rated. See Article 7.5 for more information for the rating of culverts.

2.3.1. Load Rating Responsibility

The bridge owners are responsible for the load rating of their bridges. MnDOT rates the bridges on the trunk highway (TH) system (Interstate, U.S. highways, and Minnesota state highways). Counties, cities, etc. each rate their own bridges. Where there are privately owned bridges on public roads, the owners are responsible for the load ratings.

MnDOT does not rate bridges that are owned by railroads. The railroad is to perform necessary load ratings for their bridges since they control railroad loads. For railroad bridges, MnDOT only records the design railroad load in the AASHTOWare Bridge Management (BrM) database bridge inventory.

All bridges are rated, whether the bridge is temporary or permanent. Similarly, overweight truck permits for temporary bridges are evaluated in the same manner as for permanent bridges.

See Section 10 and Section 11 for information regarding forms, documentation, and submittal.

2.3.2. New Structures

Load rate all new bridges by the LRFR method using the live load models defined in Section 4 of this manual. The bridge engineer must provide load ratings for the Design (HL-93), Emergency Vehicle (EV), and MN Permit Live Load Models. The load ratings for the Legal (MnDOT) Live Load Models may also be required, and are dependent on the results of the Design load rating and if the bridge is on a trunk highway (TH). Check all applicable limit states and provide the controlling load rating factors and locations. Do not include the future wearing surface as a dead load in the evaluation, as it is not part of the existing condition.

Load rate new bridges prior to final plan completion and finalize with as-built information prior to the bridge opening to traffic. Provide the HL-93 operating rating in the bridge plans within the Design Data block. Compute additional overweight permit vehicle load ratings for all trunk highway (TH) bridges and on other routes where local agencies allow overweight permit loads.

The field inspector should report any changes made to the bridge during construction to the Regional Bridge Construction Engineer. The Regional Bridge Construction Engineer then determines if the changes are sufficient to require an updated rating and reports the findings to the Bridge Ratings Unit (or the local bridge owner for bridges not owned by MnDOT). Changes that merit consideration include, but are not limited to, strand pattern changes for prestressed beams, different dead loads applied than were originally designed for (i.e. a change in deck thickness due to profile adjustments),

or other structural modifications. The Bridge Rating Unit updates the load rating to reflect the as-built conditions on the load rating forms.

Provide the appropriate LFR information needed for use in the permit load system in the BrR input files for new bridges designed and rated using the LRFD / LRFR provisions.

2.3.3. Existing Structures

For existing structures, a prior load rating should already be on file. These load ratings must reflect the condition of the bridge including any changes in loading that have occurred over time. If conditions have not changed since the last time the load rating was updated, there is typically no need to re-rate the bridge. However, ensuring that changes in condition are properly documented and those results communicated to the load rating engineers is essential. Refer to *BSIPM Section A.8* for additional guidance on the collection of inspection data useful for load rating.

2.3.3.1. Updating Existing Load Ratings

Structures must be re-rated, using LRFR methodology, when it is determined that a meaningful change has occurred in the condition of the structure. Review, and if necessary, update load ratings when there is an increase to the allowable legal load using the structure. Some examples of situations that would necessitate a new load rating include:

- A modification that changes the dead load on the bridge. (For example: a new concrete, asphalt, or polymer overlay; removal and replacement of an overlay, additional sidewalk, etc.)
- Damage that alters the structural capacity of the bridge. (For example: being hit by an errant vehicle, flooding damage, etc.). For significantly damaged members it is not recommended that a load rating be computed since the applicability and accuracy of such calculations is questionable. More severe damage must be repaired up to and including selected member replacement in part or in total.
- Deterioration that alters the structural capacity of the bridge. (For example: section loss from corrosion or rot in timber members).
- Settlement, movement, or scour of a pier or abutment.
- Repairs or remodeling.
- An upgrading of the load rating software with significant changes that will affect load rating calculations.
- A change in state and federal laws regulating truck weights.

A common reason for load ratings to change is a change in condition of the main structural components. NBI condition ratings for deck (Item 58), superstructure (Item 59), substructure (Item 60) and culvert (Item 62) describe the overall physical condition of the structure. They can be a useful tool for determining if a new load rating is required. Follow the ensuing general rule when reviewing the NBI ratings during each inspection cycle:

- If an NBI condition rating falls to 4 or below ("poor" or "serious" condition), review the bridge inspection report and existing load rating to determine if a new load rating is required.

As it pertains to element level inspection data, while any structural element rated at the worst condition state should be reviewed by the Program Administrator, use the following general rules followed when reviewing the structural element condition ratings during each inspection cycle:

- If any portion of a primary structural element is rated in the worst condition state, review the existing load rating and inspection notes (along with any photographs, sketches, or measurements) to determine if a new load rating is required. See *BSIPM Section B.3* for rating descriptions for the Structural Element Condition Ratings.
- Section loss due to corrosion is a frequent problem on steel bridges in Minnesota. Review the section loss element (Element #881). Review the existing load rating and inspection notes (along with any photographs, sketches, or measurements) if Element 881 is rated as condition "4" to determine if a new load rating is required.

Generally, follow the LRFR procedures outlined in Section 4 when a new load rating is necessary. For structures with significant deterioration and section loss, repair or rehabilitation may be required.

2.3.3.2. Repaired Structures

BPIG Chapter 8 as well as in *BDM Article 4.6.2* detail the procedures for re-rating bridges as part of a major bridge preservation or bridge rehabilitation project. Therein, the guidelines describe that although eventually all bridges will have updated LRFR load ratings, a bridge repair project is a time to update older load ratings as well. The *BPIG* requires that for bridge major preservation projects that significantly increase the dead load, (i.e. railing replacement or overlays) that the effect of the work be analyzed using LRFR. For more extensive bridge rehabilitation projects such as deck replacements, widening, major repairs, etc., both the design and subsequent load rating are to be carried out using LRFD and LRFR methods.

Rehabilitation planning must be more comprehensive than just providing a remedy for superstructure deficiencies. While specific attention is given to continuous steel beams and concrete beams in shear, deficiencies in substructure elements such as concrete pier caps must also be identified using LRFD / LRFR procedures.

Specific guidance is given in the *BPIG* for the following topics:

- Prestressed beam concrete shear
- Retrofit or replacement of fatigue prone components
- Fracture critical bridges
- Type W bridge culverts

In accordance with the above guidance, coordinate with the Bridge Office on repair projects to ensure that substandard elements do not remain or, as a minimum, that the new controlling element is identified since it may no longer be a superstructure element. Repair projects that add material to address section loss (i.e. deterioration), are rated using only the original section properties, i.e. as if the repair restored the section to its original condition. Repairs that are intended to strengthen the structure can consider the additional material in the calculations of the section properties.

When updated load ratings are computed as part of a bridge repair project, provide the load rating results on the bridge plan within the Design Data block.

During project planning and when requested, calculate a new trunk highway (TH) load rating for a proposed repair project. This type of load rating is kept on temporary hold until the Bridge Rating Unit is informed that the project has been completed.

For repaired bridges designed and rated using the LRFD / LRFR provisions, provide the appropriate LFR or ASR information needed for use in the permit load system in the BrR input files.

2.4. WHAT ELEMENTS SHOULD BE LOAD RATED?

Only those structural elements that are in the direct load path (from the vehicle down to the supporting earth) affect the bridge load rating. Typically, only elements of the superstructure are load rated. These include the primary load carrying elements for a steel, prestressed concrete, or timber beam bridge. Similarly, a new concrete or timber slab bridge, culvert, etc. are all required to have an as-designed load rating. Investigate decks or substructures only in unusual circumstances such as severe deterioration. Unusually heavy permit loads may also require investigation of the deck and substructures. Load rating includes analysis of the following typical items:

- All superstructure elements defined as "primary members" as well as stringer-floorbeam framing systems;
- Gusset plate connection elements of non-redundant steel truss bridges;
- Other connections of non-redundant systems;
- Concrete bridge decks that are specially designed (i.e. not designed by *BDM Table 9.2.1.1* or *BDM Table 9.2.1.2*);
- Timber and metal bridge decks;
- Concrete slabs on concrete box beams;
- Fracture critical steel pier caps.

For existing structures, elements that would otherwise not be load rated may need to be rated in certain circumstances. Such circumstances include elements that have significant deterioration or appear to be in distress. This could include pier caps, piles in pile bents, integral or otherwise critical substructures, i.e. cross girders or straddle bents. The need to load rate these elements will typically be the result of a finding during the field inspection. In such cases, estimate the dimensions, reinforcement, the extent of deterioration, etc. using the best available information. Load rating of these atypical elements may require the use of analysis tools and methods different than those typically applied to superstructure elements.

Also consider:

- For more complex bridges such as trusses, arches, etc., load rate those elements that, for the specific structure type, are part of the superstructure load path.
- For bridges composed of various elements such as stringers, floorbeams, chords, etc., load rate all primary load carrying elements and report the controlling load rating for each element along with detailed information as to the position of loads, method of load distribution, etc.
- For complex bridges, discuss the format and required elements of the complex load rating with MnDOT during design as to provide the appropriate information.

The engineer must furnish the load rating and computer files as part of the bridge design submissions as detailed in Section 10 and Section 11.

2.4.1. Superstructures

Superstructure components (girders, beams, arches, trusses, floorbeams, stringers, etc.) must always be load rated. This includes slab bridges. The load rating must be kept up-to-date and reflect the current inspected condition of the bridge. Similarly, inspectors must be aware of, monitor, and report the latest conditions of the critical elements on the controlling members of a specific bridge. Changes in condition to members that were not the controlling member may also change the load rating of the bridge.

For slab on girder bridges, when possible, rate the entire bridge superstructure in the BrR software program and include a load rating of both interior and exterior girders. In general, complete the load rating so that all unique elements in the bridge cross-section are analyzed and their load rating computed.

2.4.1.1. Decks

It is not necessary to analyze concrete bridge decks on redundant stringers/girders that are designed based on the *BDM* or were based on prior standard designs. Concrete decks that have significant deterioration or were custom designed (i.e. designs that differ from current or past MnDOT standard design details), along with other deck types such as steel grid decks or timber decks must be load rated. See Article 3.6.1 for further guidance on the evaluation decks that may require a load rating.

2.4.2. Substructures

Substructures are not normally load rated. Load rating may be required, at the judgment of the engineer, in these circumstances:

- Significant additional loads are being added to the bridge
- An unusually heavy truck applies for a permit
- Inspections reveal there is substantial damage or deterioration to a substructure, including large section loss
- An increase in the unbraced column length, possibly due to rehabilitation, repair, or scour
- If, for any other reason, the capacity for the usual legal and permit traffic is questioned
- When required as part of a bridge repair project (See Article 3.6.2.1)

See Article 3.6.2 for guidance on the evaluation of substructures that may need a load rating of substructures.

2.4.3. Buried Structures

Culverts are required to be rated. See Article 3.9.2 and Article 7.5.

2.5. SOURCES OF INFORMATION USED FOR LOAD RATING

Base bridge load rating calculations upon all relevant information in the bridge file. Sources of information for a new load rating or a re-rating include the original plan, as-built plan, reconstruction or repair plan(s), existing load rating, bridge inventory data, shop drawings, and inspection reports. Consider traffic data, any structural modifications which have increased the dead load on the bridge,

and the existing structural condition based upon the most recent inspection. Use the specified material strengths as given on the design plan or on the mill certification from the records (if available) unless specific materials testing as described in Article 2.5.4 is conducted. If there is no plan information on material strengths or grades, and no other source is available, select appropriate presumptive strengths from the values given in the *MBE* based on the year of construction.

2.5.1. Plan Data Sources

2.5.1.1. Design Plans

The design plans contain information on the overall bridge geometry, details, reinforcing, materials used for design, assumptions of existing loading, and most of the information needed for constructing the baseline load rating.

2.5.1.2. As-Built Plans

In some cases, modifications to the original design occurred as a result of fabrication or construction changes. As-built plans are contract design plans which have been modified to reflect changes made during construction. Use as-built plans to refine the loads, bridge geometry, and section and material properties.

2.5.1.3. Shop Drawings

Shop drawings and other fabrication plans can be an extremely valuable source of information when performing a load rating. Shop drawings and fabrication plans are probably the most accurate documentation of what members and materials were actually used during construction, and may contain information not found in the design plans. Although MnDOT has an inventory of shop drawings and fabrication plans, they do not exist for every bridge. Contact the State Bridge Load Rating Engineer for assistance if shop drawings and/or fabrication plans are required to accurately perform the load rating.

2.5.1.4. Bridges Without Plans

Plans may not exist for some bridges. In these cases, complete field measurements are required. Certain structures or components of structures are built from standard drawings. These standard drawings may have been changed and revised over time. The specific standard drawings used for construction are generally identified in the roadway plans for the project under which the bridge was built. Review other appropriate bridge history records, testing reports, repair or rehabilitation plans to determine their relationship to the load carrying capacity of the structure.

2.5.2. Traffic Data

LRFR live load factors for use with legal loads and permit loads are selected based upon the Average Daily Truck Traffic (ADTT) / Heavy Commercial Average Daily Traffic (HCADT) available or estimated for the bridge site. MnDOT uses the term HCADT, but is equivalent in application to ADTT. FHWA requires an ADTT to be recorded on the Structure Inventory and Appraisal (SI&A) form for all bridges. In cases where site traffic conditions are unavailable from the bridge file, contact the MnDOT Transportation Data and Analysis (TDA) office for current HCADT information for the route carried by the bridge or routes with a similar functional classification. ADTT may also be estimated from

Annual Average Daily Traffic (AADT) data for the site. Record the ADTT information on the appropriate load rating form.

2.5.3. Roadway Roughness and Condition

MnDOT has included a data item in the bridge inspection forms for inspectors to document the surface roughness. Only use the surface roughness in special situations to reduce the dynamic load allowance for load rating evaluations using the LRFR methodology. See Article 4.2.3.3 for further guidance.

2.5.4. Material Testing

In some cases, material testing may be warranted as part of assessment and load rating. There are two common instances: (a) to judge the capacity or integrity of materials that appear to be decaying and (b) to extract samples from older materials to verify the in-situ strength as compared to assumed or specified material strengths. In each case, the intent is to use the actual material test results to produce a more informed load rating.

Numerous field test procedures are available for concrete, steel, and timber structures. Many of these procedures are nondestructive, while others result in some removal or damage of the material.

Tests which require the removal of material from the structure should be used only when a particular piece of information is desired, and only when the results can provide something useful in the overall evaluation of the bridge. A few common material sampling standards are shown in *MBE Table 5.3-1*.

Remove samples from those areas of a bridge subjected to low stress levels as determined by the Engineer. Obtain an adequate number of samples to provide results representative of the entire structure evaluated. Normally, a minimum of three samples would be required.

The removal of material from a structure will leave a hole or void in one or more members. Readily make repairs to concrete, masonry, steel, and timber members. As the first option, try to locate material removal in locations that will not require a subsequent repair. If repairs to a steel structure are required, it is preferable to make the repairs using high strength bolted connections. Use field welding as the last option after ensuring the base metal is weldable, that possible fatigue or fracture problems initiation sites are not introduced via the repair, and only when designed and constructed by experienced personnel.

To supplement field tests and observations, there are many standardized laboratory tests used routinely in the evaluation of materials used in bridges. *MBE Tables 5.4-1*, *5.5-1*, and *5.5-2* list the ASTM and AASHTO standards governing the laboratory testing of concrete, steel, and timber components, respectively. These tests should be conducted by testing laboratories familiar with the AASHTO, ASTM, and MnDOT standards to be employed. It is common to find a great deal of scatter in material test results, particularly for concrete tests. The scatter will need to be interpreted when deciding what nominal values to use for load rating, i.e. how to determine what value of f'_c to use for concrete or F_y to use for steel specimens.

2.6. INCORPORATION OF FIELD INSPECTION DATA IN LOAD RATINGS

Use up-to-date inspection and condition data for bridge load rating. *BSIPM Section A.8* details the guidance for bridge inspection and the collection of data for load rating. This guidance is paraphrased herein to emphasize the link between bridge inspection, load rating, and overall bridge management.

During a bridge inspection, verify the accuracy of existing plans or sketches with field measurements when it is apparent modifications have been made to the original structure. It is especially important to measure and document items that may affect the load capacity, such as dead loads and section deterioration and damage. Only consider sound material in determining the nominal resistance of the deteriorated section.

Where present, field verify utilities, attachments, depth of fill, and wearing surface thickness at the time of inspection. Wearing surface thicknesses are highly variable. Use multiple measurements at curbs and roadway centerline to determine an average wearing surface thickness. The load factor for wearing surface dead load at the strength limit state may be taken as 1.25 where thickness has been field measured.

For bridges without plans, load ratings are based upon field measurements. The load rating will only be as accurate as the field measurements. Prior to performing a new load rating, confirm the size and spacing of the structural members. Promptly report any discrepancies with plan dimensions, or the dimensions indicated on the load rating calculations to the Program Administrator.

Note if any observed conditions would suggest that the structural steel members present on a bridge are older than the construction date listed on the structure inventory report. Over the years, steel trusses and beams have frequently been salvaged from an older bridge and moved to a new location. In some cases, the age of the salvaged steel may not have been considered in the existing load rating. Note the presence of salvaged structural members on the bridge inspection report. If the age of salvaged structural elements can be determined, note it on the bridge inspection report. If the inspector suspects that the structural steel on the bridge is older or in some other way different than what was assumed in the load rating calculations, promptly report it to the Program Administrator.

For corroded steel members, deteriorated concrete members, or decayed timber members, determine the loss in cross-sectional area as accurately as reasonably possible. Measure and document misaligned, bent, or kinked members (particularly compression members). Thoroughly document distressed or deteriorated connections. As the inspection notes alone may not be enough to convey this information, additional measurements, sketches, or photographs may be required. Obtaining and documenting adequate information during the initial inspection may eliminate the need for a follow-up inspection.

2.7. QUALIFICATIONS AND RESPONSIBILITIES

The following positions are integral to a successful load rating:

- Program Manager (PM) – The individual in charge of the program, that has been assigned or delegated the duties and responsibilities for bridge inspection, reporting, and inventory. The

Program Manager provides overall leadership and is available to inspection team leaders to provide guidance.

- Program Administrator (PA) – A registered Professional Engineer in the state of Minnesota appointed by an agency or jurisdiction to oversee the bridge inspection program and have QC responsibilities as delegated by the Project Manager.
- State Bridge Engineer (SBE) – The individual responsible for the overall management of the QC/QA program in the Bridge Office.
- State Bridge Load Rating Engineer (SBLRE) – The individual responsible for the overall management of the load rating program in the Bridge Office
- Load Rating Engineer (LRE) – A person who signs the Bridge Rating and Load Posting Forms. The individual must be a registered Professional Engineer in the state of Minnesota, and have expertise required to properly evaluate the structure being rated.
- Load Rater (LR) – A graduate engineer with at least three years of experience in bridge rating and/or design.

The engineering expertise necessary to properly evaluate a bridge varies widely with the type of the structure. Complex or non-redundant bridges may require specialized engineering knowledge. Evaluation in accordance with this manual shall be performed and checked by suitably qualified engineers in the type of bridges being load rated. It is expected that load rating engineers using LRFR will also have a working knowledge of the *LRFD Specifications*. Load rating analysis is an engineering evaluation that will be dated and signed by a registered Professional Engineer in the state of Minnesota.

The load rating engineer (LRE) shall provide quality control of all load ratings by requiring that all load rating calculations be checked by an engineer, other than the load rater (LR), prior to submittal to the state. Place initials of the checker on each sheet of the calculations and second sheet of the load rating form. Failure to do this will be grounds for rejection of the submittal by MnDOT. Guidelines for quality control and quality assurance are provided in Section 9.

MnDOT Bridge Office - Load Rating Unit: The MnDOT Bridge Office Load Rating Unit performs load capacity ratings for Minnesota trunk highway (TH) bridges (with some exceptions), develops the load rating report forms, and provides data to the MnDOT Office of Freight and Commercial Vehicle Operations (OFCVO) to route overweight permit loads on state trunk highways (TH).

The MnDOT Bridge Office Load Rating Unit will perform load ratings on new trunk highway (TH) bridges, existing repaired trunk highway (TH) bridges, or when a MnDOT District requests a new load rating due to structural damage of deterioration. After being contacted by a MnDOT District that a bridge requires a new load rating, the State Bridge Load Rating Engineer will perform a preliminary evaluation. The time frame for calculating a new load rating will depend upon the level of importance determined from the preliminary evaluation. The final load rating (if necessary) should be completed within 45 days of the preliminary evaluation.

While the MnDOT Bridge Office Load Rating Unit does not perform load ratings for county, township, and city bridges, they are available for technical assistance.

Load ratings for trunk highway (TH) culvert structures that meet the state definition of a bridge are the shared responsibility of the MnDOT Bridge Office and the District. The District is responsible for monitoring culvert conditions and consulting with the MnDOT Bridge Office Load Rating Unit if changes in condition indicate that a new load rating may be needed.

MnDOT Bridge Office – Bridge Inventory Management Unit (BIMU): The BIMU files a copy of the load rating report for any bridge (trunk highway, county, township, city, etc.) which carries vehicular traffic.

The BIMU is responsible for updating load rating items in the structure inventory database and reporting load rating information to the FHWA.

The NBIS requires that load rating information for state trunk highway (TH) bridges be updated within 90 days of the load rating date, and that load rating information for county, township, and city bridges be updated within 180 days of the load rating date.

For newly constructed trunk highway (TH) culverts, the BIMU will fill out Form 90 and enter the corresponding operating and inventory load ratings in the MnDOT database

County, Township, and City Bridges: Load ratings for county, township, and city bridges and culverts are the responsibility of the agency with inspection jurisdiction over the bridge. Counties and cities will typically hire consultants to perform some (or all) of their load ratings.

Railroad Bridges: The Federal Railroad Administration (FRA) guidelines to railroads for the inspection and management of railroad bridges are outlined in 49CFR 213, Appendix C. The railroad owner is responsible for ensuring that the bridge is capable of safely carrying all railroad traffic operated on that track, and for specifying the maximum loads that may be operated over the bridge. Load ratings for railroad bridges are performed according to the American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering. Load ratings for railroad bridges are not generally filed by MnDOT. Load rating information for a railroad bridge is not entered in the MnDOT database, and is not reported to the FHWA.

2.8. CONSIDERATIONS FOR LOCALLY OWNED STRUCTURES

The County or City Engineer will typically serve as the Program Administrator. Cities that do not employ an engineer may elect to designate a private consulting engineer as the Program Administrator. Responsibilities of a Program Administrator related to load rating include, but are not limited to, the following:

- Verify that load capacity ratings have been performed on all vehicular bridges on the agency roster.
- Review the inspection reports and structure inventory reports during each inspection cycle to determine if changes in condition or dead loads indicate that a new load rating should be performed.
- Review the online report "Load Posting & Rating Review" on an annual basis. This report lists bridges that require load postings, bridges without a load rating date, and bridges that may require a new load capacity rating. Report any errors or discrepancies to the BIMU.
- Ensure that any required load ratings are promptly performed, and that the appropriate load rating form is submitted to the BIMU to update the structure inventory. Many agencies will hire a consulting engineer to perform bridge load ratings, most culvert load ratings can be performed by the agency using Form 90.
- Verify that load posting signage (if required) is in place, accurate, and readable. Promptly notify township or municipalities if load restriction signage is incorrect, missing or damaged. Perform a follow-up inspection to verify that the load posting signage has been corrected,

repaired or replaced. If a new load rating requires that a bridge must be posted (or that an existing posting be revised), install load posting signs as soon as reasonably possible, but no more than 30 days after the load rating date. Significant changes in the posted limit may warrant installation of temporary load posting signs until permanent load posting signs can be installed.

- County and City Program Administrators should be aware of Minnesota Statute 165.03, Subdivisions 3 & 4, which requires an annual report of the inspections, filed on or before February 15th of each year. The report must contain recommendations for the correction of, or legal posting of load limits on any bridge or structure that is found to be under strength or unsafe. See the applicable statue subdivisions for the complete requirements.
- Contact the railroad if inspections determine that damage or deterioration to a railroad bridge is sufficient to reduce the load carrying capacity of the structure (registered mail is preferred).

2.9. RESULTS REPORTING AND ACTIONS

For all load ratings based on the LRFR methodology, report the load rating data to the NBI as a Rating Factor for items 63, 64, 65 and 66 using the HL-93 loadings. Report existing load ratings as an HS equivalency when based on ASR or LFR methods.

2.9.1. Bridge Load Posting / Load Restrictions

Some load rating calculations will result in a finding that a bridge requires load posting. The detailed procedures for load posting are provided in Article 4.8 for LRFR and Article 5.8 for LFR / ASR procedures.

Bridges that are determined not capable of carrying 3 tons shall be closed.

2.9.2. Overweight Permitting

Refer to Article 4.4.6 and Article 5.9 for a detailed discussion on the overweight permitting process. Since the issuance of permits is a MnDOT or local function, the load rating engineer only needs to be aware of the overweight permitting process and not the specifics of permit issuance and compliance.

SECTION 3: LOAD RATING METHODOLOGY

3.1. GENERAL

This section briefly introduces the various methods of load rating and describes their use. Among the topics covered are various AASHTO and MnDOT methods for load rating, the load rating of routine and complex bridges, and the load rating of specific elements requiring special attention. The text provided in this section is general in nature, most topics are covered in greater detail in later sections of the manual.

3.2. LOAD RATING PRACTICES

Load rating is the calculation of a safe live load capacity for various vehicles such as design loads, state-specific or national legal loads, and overweight permit loads. It involves the calculation of member resistance as well as permanent and transient force effects. For common bridges like slab-on-girder, T-beam, slab bridges, etc., the rating is usually computed for shear and for bending moment, which are the dominant force effects. These force effects are computed at common locations such as the tenth points of each span and at special points of interest such as where the member resistance changes, i.g. at a cover plate termination for a steel bridge. Other points are rated as needed, for example at locations of significant deterioration. For other bridge types, i.g. a truss or arch, the rating involves other force effects such as axial force demand and sometimes includes a combination of forces such as axial load and bending forces.

When load rating a bridge, the final overall bridge load rating is the load rating at the weakest point of the weakest member within the whole bridge. This load rating is recorded on the cover sheet of the load rating form. This member is called the controlling member (controlling load rated member) of the bridge.

The controlling location may change with different rating vehicles. This is because rating vehicles of different weights, axle spacing, and/or lengths have different effects on different members and spans. The identification of the controlling member, location, and limit state for each rated vehicle is recorded on page two (or a subsequent page) of the load rating forms.

3.3. LRFR / LFR / ASR (HOW AND WHEN TO USE)

The three methodologies for load rating are Load and Resistance Factor Rating (LRFR), Load Factor Rating (LFR), and Allowable Stress Rating (ASR). Most new or updated load ratings will be computed using LRFR, as LFR and ASR are mostly historical but are still used in certain situations. For an existing bridge that must be reevaluated for a new legal or exclusion vehicle implemented through a policy change, rate the structure using the methodology used during the most recent evaluation.

Use LRFR as follows:

- All new structures
- Any structure originally designed using LRFD
- Most major preservation or bridge rehabilitation projects (See Article 2.3.3)

Use LFR as follows:

- With overweight permit load evaluation of most existing structures (exception is only for structures that require ASR)
- Any structures originally designed using LFR that require re-evaluation of a bridge component due to
    - Condition change
    - Collision damage / impact

Only use ASR for certain structures, such as:

- Timber structures built before 2007 for design load and legal load evaluations
- All timber structures for permit load evaluation
- Masonry structures

For structure types that do not have guidance provided in the *MBE*, contact the MnDOT Bridge Office Load Rating Unit to determine the appropriate methodology to use.

The remaining articles of this section discuss items that apply to all three load rating methodologies.

Procedures unique to evaluating structures using LRFR are given in Section 4 of this manual, while Section 5 provides historic reference to methods for LFR and ASR.

3.4. MEMBER CONDITION

Regular inspection and the accompanying inspection reports include information on the condition of the bridge members. The accompanying load ratings are based on the as-inspected condition of the structure. The load rating evaluation assumes that construction is of satisfactory quality and that materials meet the design strengths unless information to the contrary is available. Adjustments to the design capacity due to member or structure condition are permitted and should be assigned as provided in this manual and the *MBE*. The adjustments, through condition factors for LRFR or safety factors for ASR and LFR, may be modified according to judgment and the findings from the inspection report.

While there are factors that can be applied to the member capacity to account for member condition, these are general and do not replace an assessment of the cross-section of the member itself. Determine the as-inspected cross-sectional properties when there is a significant loss of section. Loss of section may be a result of corrosion, deterioration, or decay. Also consider stress concentrations caused by gouges, nicks, or other such defects as these can affect long term fatigue performance or susceptibility to fracture.

Other important factors include the presence of bolts and rivets in the net area for tension members. Account for misalignments, bends, or kinks in compression members, as the load-carrying capacity of the member and structure may be greatly affected. For connections at compression members, also consider eccentricities in the connection.

3.5. BRIDGES WITH UNKNOWN COMPONENTS

For structures that lack sufficient detail for analysis, physical inspections may be necessary to approximate a load rating. See Article 7.4.

3.6. COMPONENT SPECIFIC EVALUATION

3.6.1. Decks

The most common bridge deck type is a cast-in-place reinforced concrete bridge deck. These are found on most bridges in Minnesota regardless of superstructure type. However, other bridge deck types are present including timber and metal grid decks. When load rating of a deck is required, the *Standard Specifications* and *LRFD Specifications* each provide accepted approaches to the estimation of live load force effects in various deck types. The LRFD provisions are more modern and cover a wider variety of deck types and scenarios.

The load rating of decks is not covered explicitly in the *MBE*. Use the live load distribution methods for deck design from the *BDM* and *LRFD Specifications* along with the load combinations and vehicles from the MBE.

Deck deterioration may have an effect on the load carrying capacity of a bridge. This may be a concern on timber decks, concrete slab spans, composite structures, or bridges with an integral deck and superstructure (such as cast-in-place concrete or prestressed T-beam bridges). The deterioration of the deck may affect the capacity of the deck as well as the capacity of the beam for composite beam-and-slab systems. The inspection report will indicate if the deck condition is deteriorated to the point where rating is required. Consider the effect of the deck deterioration in the load rating.

3.6.1.1. Concrete

Stringer-supported concrete deck slabs under normal traffic do not typically require evaluation for load rating. A concrete deck is a highly redundant structural element and though it may be subject to local deterioration, the longitudinal and transverse reinforcing steel engage substantial portions of the deck and provide for a greater system response to loading. Arching, or membrane action, produces additional capacity but is not traditionally considered in the strip method design used for most decks. The deck will therefore generally not be a controlling element due to various sources of stiffness and strength not usually accounted for. However, decks should be inspected regularly to verify performance and to determine those cases where an evaluation of the deck capacity might be advised.

3.6.1.2. Timber

Timber decks with excessive deformations or deflections often control the load rating and therefore must be evaluated. Horizontal shear is frequently the controlling action of the timber plank decks.

3.6.2. Substructures

Substructures typically do not need to be rated. A check of substructure elements is typically only performed if there is reason to believe that the substructure could govern the capacity of the entire

bridge. Some situations that might warrant an investigation into the load carrying capacity of a substructure include deterioration of main load carrying elements (i.e. significant loss of reinforcing steel in a pier cap or section loss in a pile bent), other damage such as from impact, knowledge from existing plans or otherwise that the substructure capacity may not be adequate for anticipated loads, or other obvious concerns of the load rating engineer. When there is concern about deterioration or damage, perform an inspection of the substructure to support the load rating calculations. Inspect the substructure (piers and abutments) for deterioration, as well as damage from ice flows or flood debris. Inspect the substructure for evidence of instability (settlement, tipping, misalignment, or undermining) or section loss that would affect the load-carrying capacity of the bridge.

A prescribed procedure for addressing the severity of damage or deterioration that triggers an analysis and load rating of a substructure is not provided herein. Given the many factors that influence this decision it is left to the discretion of the engineer to decide when a substructure element may in fact become a controlling element.

3.6.2.1. Substructure Load Rating for Bridge Repair Projects

Existing bridges may have deficient load carrying capacity due to deterioration or larger modern design loads. In some cases, the deterioration of the superstructure or some other change is a cause for repair. When an existing bridge is repaired, determine if the controlling load rating is now governed by some other element such as a substructure pier cap, a pile bent, etc. Refer to *BDM Article 4.6.2* and *BPIG Chapter 6 and 8* for further information on the assessment and load rating of structures as part of bridge repair projects.

3.6.3. Nonredundant Members

Nonredundant members are those elements which, if failure were to occur, would result in the collapse of the bridge. Failure may be brittle or ductile, and can be a result of excessive loads, fatigue, brittle fracture, or collisions. Follow the guidance provided in the *MBE* when evaluating nonredundant members.

3.7. LOAD RATING OF ROUTINE BRIDGES

The text of this manual focuses primarily on the load rating of routine bridges. Routine bridges are broadly defined as those that are composed of elements that can be input to the AASHTOWare Bridge Rating (BrR) software program (See Section 8 for guidance on analysis software). Some complex bridges present in Minnesota are discussed in Article 3.8. Any guidance in the remaining articles of this manual should be considered to apply only to routine bridges, unless specifically noted.

3.8. LOAD RATING OF COMPLEX BRIDGES

Some types of bridges cannot be rated by the currently available version of the load rating software BrR (see Article 8.1 for types of elements that can be analyzed in BrR). However, because the capabilities of BrR are constantly evolving, with new bridge types being added over time, do not consider the definition of "complex" in this manual to be a static definition. For these types of bridges, a load rating is still required however.

For a bridge being designed but that will not fit in the various standard bridge types covered by BrR for future load rating, compute the load ratings using the original design software. For trunk highways (TH), in addition to load rating, procedures are needed to evaluate trucks that apply for overload permits. When designing new complex bridges, rate for the MN Permit Live Load Models (see Appendix F) and record the lowest or controlling load rating factor for each truck.

If custom trucks cannot be run in the design software, one solution is to provide the capacity along with the influence line for the critical points. Load rating information is needed for the critical locations of negative and positive moment. If shear is or could be critical at any point in a member, provide data for that also. For members in which axial load is the dominant force effect, provide the appropriate capacities and force effects. The information needed for each location is the moment (or shear or axial force) capacity, dead load effects, secondary prestress effects (if applicable), and other permanent force effects to determine the capacity remaining for live load along with the live load influence line. For a beam member, equate these to the width of one beam spacing. For other members receiving load from multiple lanes, discuss an appropriate presentation of the load rating tables with MnDOT during design. State the applied load factors, capacity reduction factors, and live load distribution factors.

The complete submittal is to include plan sheets necessary to convey the essential information used in the load rating. This includes the general plan and elevation, the deck cross section, the framing plan, and the beam elevation.

Direct any questions about this procedure to the State Bridge Load Rating Engineer.

3.8.1. Curved and Skewed Steel Bridges

Curved and skewed bridges exhibit behaviors that are more complex than a traditional straight bridge with no to moderate skew. This is because of the differential displacement of adjacent beams caused by skew and curvature. Article 4.3.3.2 specifies when to use refined analysis methods to load rate curved and skewed steel bridges instead of traditional line girder analysis.

BrR can load rate curved and skewed steel girder bridges using the bridge system approach. In this refined model, the engineer provides all the information to describe the longitudinal beams as well as the transverse bracing, i.e. diaphragms and crossframes. A load rating is provided for all the beams and crossframes. In load rating of curved and skewed steel bridges, many different approaches may have been used in the design as the design policies have changed and evolved over the years. For skewed line girders, in the past, engineers frequently ignored any effects of skew despite the fact they can be significant, particularly as the skews exceed 20 degrees from a right bridge. Curved girder design policy has also evolved significantly over time transitioning from very approximate methods such as the V-load approach, to various versions of the AASHTO ASD and LFD Specifications including companion guide specifications for curved girders to more modern designs completed using LRFD. The modern version of BrR relies on the latest AASHTO LRFD and LRFR techniques and allows for a comprehensive evaluation of skewed and curved girders. As it pertains to the evaluation of crossframes and diaphragms, the *MBE* does not require such an evaluation, it is left to the discretion of the engineer when to consider load rating the bracing members. Since a steel girder bridge is highly redundant, commonly containing many diaphragms and crossframes, it is not required to load rate these members unless there is evidence from the inspection of overload, i.e. a buckled crossframe for instance. Otherwise it is understood that the design of crossframes is a conservative approach both with respect to the estimation of design loads

and the calculation of member capacity. Evaluation and load rating of the bracing members is therefore not required.

For general guidance on the modeling of curved and skewed steel girder bridges, refer to *LRFD Specifications Article 4.6.3.3* with specific attention drawn to the guidance on considering warping and lateral flange bending in *Article 4.6.3.3.2*, the modifications to crossframe axial stiffness in *Article C4.6.3.3.4*, and the provisions of *LRFD Specifications Section 6* that consider the combined action of primary and lateral flange bending and their effect on member capacity.

3.8.2. Segmental Box Girders (Cast-in-Place and Precast)

Guidance on the load rating of segmental concrete bridges is provided in *MBE Article 6A.5.11.* For information regarding the analysis of segmental bridges, *AASHTO LRFD 4.6.2.9* provides recommendations.

There are several significant differences between segmental bridges and traditional prestressed concrete structures.

Segmental concrete bridges require a load rating analysis in both the longitudinal and transverse directions (*MBE 6A.5.11.2*). The longitudinal analysis is the traditional flexure, shear, and torsion analysis of the main beam (box) itself whereas the transverse analysis is a check of the top slab for the direct application of wheel loads. The use of finite element analysis or recognized nomographs and charts is needed for the analysis of the top slab since its behavior is not analogous to the slab-on-girder strip methods provided in the *LRFD Specifications*.

Specific guidance on the application of vehicular live load is provided in *MBE Article 6A.5.11.3*. This includes changes to multiple presence factors. Changes to the required and optional limit states and location and number of loaded lanes for design load rating are covered in *MBE Article 6A.5.11.4*. Treatment of the Service Limit State is covered in *MBE Article 6A.5.11.5* and sub articles with unique requirements for legal and permit load rating.

Because segmental concrete box girder bridges frequently consist of a single cell with two webs, AASHTO provides a suggested system factor, φ_s, to account for common configurations that recognize conditions such as simple span or continuous units, balanced cantilever versus span-by-span erection, cast-in-place versus precast, differing joint types, numbers of tendons in webs, etc. (*MBE Article 6A.5.11.6*). Each of these has a different impact on the suggested redundancy factor. An increase in the system redundancy factors of 0.10 applied to all the tabular values is permitted for box girder bridges with three or more webs, i.g. twin cell box girders.

MBE Article 6A.5.11.7 requires an analysis of flexure, shear and torsion for box girder bridges for all load ratings.

3.8.2.1. MnDOT Segmental Box Girder Policy

The MnDOT policy for live load placement and allowable tension is given below for post-tensioned segmental box girders. These requirements supersede any other guidance in this manual provided for more conventional prestressed concrete structures.

Longitudinal load rating – allowable stresses

- At top of slab:
  - Tension limit = 0.095 $\sqrt{f'_c}$ for load combinations involving permit loads and thermal gradient loading, TG
  - Tension limit = 0 psi for all other loads and load combinations
- Elsewhere:
  - Tension limit = 0.095 $\sqrt{f'_c}$ for all cast-in-place post-tensioned segmental bridges
  - Tension limit = 0.095 $\sqrt{f'_c}$ for permit load evaluation (precast segmental bridges)
  - Tension limit = 0 for other loads (precast segmental bridges)

Transverse load rating – allowable stresses

- At top of slab:
  - Tension limit = 0.095 $\sqrt{f'_c}$ for load combinations involving permit loads and thermal gradient loading, TG
  - Tension limit = 0 for all other loads and load combinations
- Elsewhere:
  - Tension limit = 0.095 $\sqrt{f'_c}$ for all loads and combinations

For load rating segmental box girder bridges, the following policy applies to the number of loaded lanes used. In the table below the text "# of design lanes" implies a load rating is performed assuming that the number of design lanes, i.e. the integer portion of 12-ft. standard lanes that can fit on the bridge deck, is used. The text "# of striped lanes" implies the number of lanes is limited to the striped lane condition. However, as required by the MBE, these lanes must be allowed to float across the width of the deck to create extreme force effects, i.e. the lanes are not in a static position as the physical striping might exist at the time the rating is performed. The discussion of striped versus design lanes presupposes a refined analysis in which the number of lanes and their position can be chosen. For analysis using distribution factors and line girder methods, this level of refinement is not available.

Table 3.8.2.1-1 Lane Placement for Segmental Box Girder Load Rating

Segmental Box	Design Loading, IN		Design Loading, OP		Legal		Routine Permit	
Longitudinal	Str I	# of design lanes	Str I	# of design lanes	Str I	# of design lanes	Str II	# of design lanes
	Ser I	# of design lanes	Ser I	# of striped lanes	Ser I	# of striped lanes	Ser I	# of striped lanes
	Ser III	# of design lanes	Ser III	# of striped lanes	Ser III	# of striped lanes	Ser III	# of striped lanes
Transverse	Str I	# of design lanes	Str I	# of design lanes	Str I	# of design lanes	Str II	# of design lanes
	Ser I	# of design lanes	Ser I	# of striped lanes	Ser I	# of striped lanes	Ser I	# of striped lanes
	Ser III	# of design lanes	Ser III	# of striped lanes	Ser III	# of striped lanes	Ser III	# of striped lanes

3.8.3. Post-Tensioned Concrete Slab Bridges

The load rating of post-tensioned concrete slab bridges is performed with the following allowable stress limits and for the number of design and striped lanes as follows.

Longitudinal load rating

- At top of slab:
  - Tension limit = 0.095 $\sqrt{f'_c}$ for permit loads
  - Tension limit = 0 psi for all other loads
- Elsewhere:
  - Tension limit = 0.095 $\sqrt{f'_c}$ for design loads and 0.19 $\sqrt{f'_c}$ for permit loads

Table 3.8.3-1 Lane Placement for Post-tensioned Concrete Slab Bridge Load Rating

Design Loading, IN		**Design Loading, OP**		**Legal**		**Routine Permit**	
Str I	# of design lanes	Str I	# of design lanes	Str I	# of design lanes	Str II	# of design lanes
Ser I	# of design lanes	Ser I	# of striped lanes	Ser I	# of striped lanes	Ser I	# of striped lanes
Ser III	# of design lanes	Ser III	# of striped lanes	Ser III	# of striped lanes	Ser III	# of striped lanes

The discussion of striped versus design lanes presupposes a refined analysis in which the number of lanes and their position can be chosen. For analysis using equivalent strip methods for slab live load distribution, this level of refinement is not available.

3.8.4. Arches

For load ratings of deck arch bridges, include ratings of the arch rib, spandrel columns, floor systems, and connections between these elements. The arch rib bending moments computed by analysis software are sensitive to the boundary conditions at the base of the arch. If the arch is supported on piers, include the piers in the analysis model. If the foundations at the base of the arch are flexible, include equivalent spring stiffness values representing the flexibility in the analysis model.

Consider whether AASHTO moment magnification can accurately account for second-order effects in the arch ribs and spandrel columns of the bridge being load rated. If not, conduct a second-order geometric nonlinear analysis of the arch following the provisions of Article 4.3.3.2 and Article 4.3.3.3.

Apply the appropriate HL-93 double truck loading to panels of deck arch bridges for which the arch rib has negative moments due to total unfactored DC loads. Also consider the HL-93 double truck loadings for continuous floor systems and spandrel columns supporting continuous floor systems.

For load ratings of tied arch bridges, include ratings of the arch rib, tie girder, hangers, and floor system. Apply the appropriate HL-93 double truck loading to portions of the arch rib and tie that have negative moments due to total unfactored DC loads. Also consider the appropriate HL-93

double truck loading for the stringers, floorbeams, and hangers of tied arch bridges with continuous floor systems.

Unbraced deck and tied arches shall be assessed for global stability following the provisions of Article 4.3.3.2 and Article 4.3.3.3.

For the evaluation of the capacity of solid web steel arches, the provisions of *LRFD Specifications Article 6.14.4* apply. However, these provisions may be unnecessarily conservative, and it is possible that existing steel arch ribs will have web and flange slenderness limits that are outside what is permissible by LRFD and hence LRFR. Work is ongoing (as of 2018) to completely rewrite these provisions and instead replace them in AASHTO with provisions for noncomposite box shaped sections of more general proportions. If a low load rating is obtained for a solid arch rib or if a rib has flange or web slenderness limits outside the limits allowed by AASHTO, contact the MnDOT Load Rating Engineer and Bridge Office for guidance.

3.8.5. Trusses

In addition to axial forces, truss member bending moments may need to be considered in the load rating. Truss member bending moments may be divided into two categories: primary and secondary bending moments. Primary bending moments are required to maintain equilibrium at the Strength limit state. Primary moments of concern are those caused by loads that are applied to truss members away from panel point workpoints, when the worklines of intersecting truss members do not meet at a single point (this can occur in regions of complex geometry at the joints between adjacent truss units), and when the worklines and centroids of truss members do not coincide. In this last case, the primary moment will be equal to the axial force in the truss member multiplied by the distance between the workline and member centroid.

Secondary bending moments develop when rotations of truss members are restrained by rigid riveted or bolted connections between members. Secondary moments are not required to maintain equilibrium at the Strength limit state, and may dissipate under ultimate loads through localized yielding of steel at the connections, and displacements of the connection fasteners.

Consider primary moments for all load rating limit states. Secondary moments may be neglected at the Strength limit state by considering the members to have pinned end-conditions in the plane of the truss. Due to the traditional practice of cambering trusses for dead load, i.e. intentionally shortening and lengthening some members during fabrication, the bending moments due to joint rigidity tend to be minimized under a fully erected condition and thus even trusses with apparently rigid joints composed of riveted and bolted gusset plates are generally considered to be pin-ended. In unique cases, i.g. fatigue evaluation, evaluation of a truly pinned truss with frozen pins or consideration of secondary bending effects due to live load may be required. This is to be considered on a case-by-case basis but in general a traditional pinned end model such as used in BrR and consistent with the longstanding theory of the analysis of trusses is an appropriate level of detail.

Conduct the truss bridge structural analysis using general purpose finite element software if BrR is not capable of accurately including the primary moments in the bridge being load rated (if deemed significant) or if consideration of secondary effects is warranted.

Use the system factors specified in *MBE Article 6A.4.2.4* for truss bridges, with the following exception. If it can be shown that a riveted truss member in bridge with two parallel trusses is internally redundant, then then system factor may be increased from 0.90 to 0.95.

Apply the appropriate HL-93 double truck loading to panels of truss bridges for which the top chord is in tension under total unfactored DC loadings.

Compute load ratings for gusset plates, pins, hangers, and uplift tiedowns for truss bridges in addition to truss member load ratings.

At MnDOT's discretion, long-span truss bridges may be analyzed for wind loadings. For these analyses, the second order effects can be estimated by a traditional column slenderness and moment magnification factor approach or a more general second order analysis a second-order analysis conforming to the provisions of Article 4.3.3.2 and Article 4.3.3.3.

Determine the capacity of gusset plates using the latest *MBE* provision. In the case of a low rating for a chord splice, an alternate approach is allowed and the elastic Method 1 provisions of NCHRP 12-84 may be used in place of the *MBE* provisions. In all cases, apply the system and condition factors specified by the *MBE* when determining connection capacity.

3.8.6. Cable Supported Bridges

Cable-stayed bridges and suspension bridges shall be analyzed using methods that account for cable stiffness reduction due to cable sag.

3.9. SPECIAL METHODS

In some cases, a method other than a calculated load rating will be required. Instances when a special method may be required include if there is not enough information available, the structure cannot be analyzed by typical means, or when a calculated load rating provides an unrealistic result. These methods provide the load rating engineer with additional means of providing a load rating, though they should be used only when calculated load ratings are not possible or unrealistic.

3.9.1. Physical Inspection Rating

Use a Physical Inspection Rating (PIR) when the capacity cannot readily be calculated because of one or more of these reasons:

- No bridge plans are available.
- The steel reinforcement of a concrete bridge is unknown.
- The superstructure has deterioration or damage which cannot be quantitatively measured, but has obviously reduced the load carrying capacity of the bridge.
- The substructure has deterioration, shifting, tipping or misalignment which obviously reduced the load carrying capacity of the bridge, but the extent of the reduction cannot be readily calculated.
- The culvert has an NBI culvert rating of 4 ("poor" condition) or lower.
- The culvert is posted with less than legal loads.

Article 7.4 of this manual provides detailed guidance on this method.

3.9.2. Assigned Load Ratings (i.e. Culverts)

Culverts that have been designed based on MnDOT Standard Design Plans and tables can be assigned ratings in place of evaluating the culvert according to the procedures prescribed in the *MBE*. See Article 7.5 for the procedures for assigning a rating to culverts.

3.9.3. Load Testing

Load testing is the rating method where a controlled test is conducted on a bridge to calibrate computer models for a more accurate load rating. Load testing is not commonly performed due to cost considerations but has been used to demonstrate the live load distribution and apparent capacity of many different bridge types.

Use load testing when the bridge cannot be rated by ordinary methods or when the ordinary methods give very conservative results. See *MBE Section 8: Nondestructive Load Testing* and Article 7.6 of this manual.

SECTION 4: LOAD AND RESISTANCE FACTOR RATING (LRFR)

4.1. INTRODUCTION

4.1.1. General

The load and resistance factor rating (LRFR) procedures of this section provide a methodology consistent with load and resistance factor design (LRFD). Conduct all load ratings following the procedures outlined in this section, except for those cases outlined in Article 5.1. New structures will have been designed according to the *BDM*. Those bridges will still require a load rating following the procedures provided in this section. The load rating of bridges using the LRFR methods relies heavily on materials found in the *BDM* and for that reason this manual does not repeat all the information needed to perform a load rating.

4.1.2. Scope

This section of the manual is organized as follows:

- Article 4.1 provides a general introduction and philosophy of LRFR.
- Article 4.2 discusses the permanent and transient loads applied for load rating.
- Article 4.3 provides guidelines for analysis.
- Article 4.4 presents procedures for load rating bridges for the LRFD design loading, Minnesota legal loads, and overweight permit loads.
- Article 4.5 provides guidance specific to the analysis for concrete structures.
- Article 4.6 provides guidance specific to the analysis for steel structures.
- Article 4.7 provides guidance specific to the analysis for wood structures.
- Article 4.8 presents the procedures for load posting structures.

4.1.3. Philosophy

Load and Resistance Factor Rating (LRFR) is consistent with the *LRFD Specifications* in using a reliability-based limit states philosophy and extends the provisions of the *LRFD Specifications* to the areas of load rating, load posting, permit truck evaluation, remaining fatigue life evaluation, and load testing of existing bridges. The LRFR methodology has been developed to provide more uniform reliability in bridge load ratings, load postings and permit decisions. The LRFR procedures provide load and resistance factors calibrated to provide a more uniform level of reliability and that are based on structural reliability theory to achieve a minimum target reliability for the strength limit state. The LRFR approach differs in many ways from the design approach using LRFD. Various other vehicles are introduced as are checks for various loading levels such as design, legal, and permit loads. The load rating engineer must be familiar with the LRFR provisions, their relationship to the LRFD design specification, and to the MnDOT procedures and requirements described herein.

The target reliability index for load ratings, and thus the load factors and combinations, differ from those used during design. The *LRFD Specifications* prescribe a set of notional design loads and associated load combinations to provide a level of reliability, or safety, associated with a 75-year exposure period. A way of thinking of this is that it attempts to envelope nearly all possible load combinations that could occur in the 75-years after the bridge is designed. For load rating, the task

is different. The bridge capacity merely needs to be safely determined for the next several years, until a future inspection. Also, a load rating engineer is using actual information about the condition of a specific bridge (structural condition, traffic condition, etc.) after it has been recently inspected. The shorter exposure period and use of as-inspected conditions allows for greater flexibility in load rating than in the design of a new bridge. It is for these reasons that load rating has a greater number of load combinations, separate levels (inventory and operating) for the design loads, and special legal and permit load evaluation methods.

The calculation of load ratings involves a determination of the capacity to carry design loads (generally the same loads used in the original design), legal loads (loads legally allowed to operate in MN), and permit loads (special loads allowed to cross a single or limited number of times). As the level of uncertainty decreases from Design → Legal → Permit, so too is there a general decrease in the magnitude of the load factor and the number of lanes assumed to be loaded.

Load rating involves the evaluation of a structure for both its strength (Strength Limit State) as well as the need to meet certain criteria that are consistent with long term durability and survival of the bridge (Service Limit State). The Strength Limit State load factors have generally been calibrated to meet certain safety or reliability levels. The Service Limit State load factors were originally established based on past practice, though recent research by the Transportation Research Board, NCHRP and AASHTO has validated the appropriateness of the presumptive values used since LRFD was introduced by AASHTO in 1994. Some changes in the service limit state and fatigue design procedures were introduced in AASHTO as a result of the service limit state calibration process.

4.1.4. Application of LRFD and MnDOT LRFD BDM

This section of the manual is consistent with the current *LRFD Specifications* and the *BDM*. Any instances where this manual does not provide guidance are governed by the two aforementioned documents, with the provisions in the *BDM* superseding those of the *LRFD Specifications*.

Deviation from the specifications is permissible when the observed behavior of a member is not as predicted by the specifications. This may be in the case of visible distress or excessive deformation. Material sampling, instrumentation, and load testing may be utilized to establish a components behavior and provide information needed to determine the load capacity in such instances. Any decisions to change the evaluation criteria must be documented and have approval of the State Bridge Load Rating Engineer.

4.1.5. Load and Resistance Factor Rating

There are three levels of load evaluation defined in the *MBE* for load and resistance factor rating, Design, Legal, and Permit, each serving a distinct purpose. Additionally, the FAST Act also introduced additional load rating requirements related to emergency vehicles (EV). These requirements are also included herein. Each level of load rating uses different live load models and evaluation criteria. These procedures are summarized below. Analysis procedures for each are found in Article 4.4. The ratings are generally considered to be hierarchical. Design load rating is the most stringent. It evaluates the bridge for its capacity to carry modern design loads. These values are computed primarily to provide a single standard for load rating reporting to the NBI database since the same notional load is used nationwide. The regulatory aspect of load rating happens when computing the rating factors for legal loads and emergency vehicles allowed to operate in Minnesota, and when checking permit loads. *MBE Article 6A.1.5* provides a more detailed description of this process.

4.1.5.1. Design Load Rating

Design load rating is the evaluation of a bridge based on HL-93 loading and applying LRFD design standards. It is the first level of load rating and is generally viewed as a screening tool. Bridges that have an adequate load rating factor, i.e. greater than or equal to 1.0 at the IN level will generally have adequate capacity for legal loads. This is equivalent to saying the bridge has a capacity equivalent to what is required of a new structure designed in accordance with LRFD. It is common for older bridges to not possess this capacity since they were designed using older AASHTO Specifications, less stringent loading, etc. Having a rating less than 1.0 for design loading at the IN level is of no specific concern. It is, as mentioned before, used to report the bridge load rating to the NBI but has no regulatory impact on bridge operations. A more liberal value of capacity is provided by computing the load rating at the OP level.

Design load rating includes both strength and service load considerations. This is because not all critical limits are related purely to strength. Steel bridges are checked for certain service limits related to yielding under a specified loading. Concrete bridges (prestressed and reinforced) include service limit state checks related to cracking. So, it is important to realize that load rating is a check of several important limits, not just load carrying capacity under factored strength limit loads.

As mentioned, a design load rating can be used to determine if a bridge might have adequate capacity for legal loads. A strength limit evaluation that produces a satisfactory rating factor (RF ≥ 1.0 at the IN level or RF ≥ 1.15 at the OP level) is considered able to safely carry all MnDOT legal load models. However, non-trunk highway bridges must be load rated for legal loads, regardless of the design load rating factor.

See Article 4.4.3 for design load rating analysis procedures.

4.1.5.2. Legal Load Rating

Legal load rating is used to make decisions regarding load posting and bridge strengthening. A design load rating less than 1.0 at the inventory level does not necessarily require load posting or rehabilitation. Such a rating factor simply indicates that the load rater must evaluate the structure for the legal loads. This is a result of different (less severe) load models and load combinations. Furthermore, a rating factor less than 1.10 for the legal loads indicates action may be required. A value of 1.10 is used in Minnesota rather than the value of 1.00 prescribed in the *MBE*, as there are allowable increases in gross vehicle weight of 10% in the winter, along with special harvest season increases, special allowances for timber haulers, and other exceptions. Therefore, action must be considered once the legal load rating factor is less than 1.10. The legal load rating applies to Minnesota legal loads.

See Article 4.4.4 for legal load rating analysis procedures.

4.1.5.3. Emergency Vehicle Load Rating

Emergency vehicle (EV) load rating is used to satisfy the requirements of the FAST Act. The live load models have a target reliability index that is similar to the legal load rating vehicles, and are also used to make decisions regarding load posting and bridge strengthening. However, due to different requirements as to when the emergency vehicle load rating is to be evaluated, as well as

different procedures if a posting is required, it is considered a separate evaluation than the legal load rating.

See Article 4.4.5 for emergency vehicle load rating analysis procedures.

4.1.5.4. Permit Load Rating

Permit load rating is used to evaluate the safety and serviceability of structures for vehicles that are above legally established weight limitations. A permit load rating can be performed for an annual permit truck or for a single trip permit truck. A structure can only be evaluated for a permit load rating if there is sufficient capacity (typically RF ≥ 1.10) for Minnesota legal loads.

Permit trucks are also used as part of the scoping process for repair projects to determine if improvements to an existing bridge are needed. The *BPIG* provides guidance on how permit ratings affect the scoping process. These guidelines require that preservation activities should not result in new or more restrictive permit load restrictions. Also included is the direction that any bridges that carry high overweight permit traffic, or are on the Interstate Highway System or Over Size Over Weight (OSOW) Superload Corridors must have repairs that result in a structure with no restrictions for adjacent traffic or speed for standard permit classes A, B, and C and an LRFR inventory rating factor of at least 0.9.

See Article 2.2.2 for the Minnesota statutes governing permit trucks.

See Article 4.4.6 for permit load rating analysis procedures.

4.2. LOADS

4.2.1. General

This article discusses permanent and typical transient loads (i.e. live loads), as they are usually the only loads that need to be considered to establish a load rating. Other loads, such as wind, temperature, and earthquake are typically not considered and have not been included in this manual. Refer to *MBE Article 6A.2* if conditions warrant their inclusion.

4.2.2. Permanent Loads

Use the existing conditions, as verified with inspection reports and field measurements, to compute dead load effects (DC and DW) on the structure. Dead loads should account for the conditions of the bridge at the time of the analysis, and must include utilities, any attachments, and the thickness of wearing surface. Use the minimum unit weights of materials in accordance with *BDM Table 3.3.1* in computing dead loads, unless more precise information is available.

Do not include in the load rating the allowance for future dead loads such as a wearing course if included in the design, until they are actually placed.

Consider secondary effects (PS) from post—tensioning applied to statically indeterminate structures to be permanent loads (P).

4.2.2.1. Modeling of Composite Concrete Decks

Minnesota has two common types of concrete bridge decks, those poured for their full thickness and those comprised of a 7-inch base deck with a subsequent second pour of an additional 2-inch low slump wearing course. For bridge design, it is assumed that the full 9 inches of concrete is placed at once. This results in the largest possible load on the non-composite beams and is a conservative assumption for design. However, for load rating, the bridge is load rated based on how the deck was constructed (when known).

Use the following approach when modeling a two-course deck placement in BrR.

- Apply the first 7-inch concrete deck along with other non-composite loads to the girder section.
- Apply the load of the additional 2-inch low slump wearing course, all subsequent composite dead loads, i.e. barrier rails, and live load, to the full thickness deck less the 0.5 inches.

This approach results in some differences between MnDOT policy and software application in terms of how loads are applied to specific resisting sections. MnDOT has determined this difference is acceptable to accommodate commonly available programs and their capabilities.

To model the stool height, assume a stool height of 1.5 inches as an offset of the slab and beam for bridges designed from 1990 to the present and use 1 inch for older structures. This is for purposes of computing the section properties of the composite beam, for providing a standard allowance for the weight of the stool, and to provide an allowance for variations in camber, deck cross slope, deviations in superelevation, etc. When it is known that the in-place stool height is greater than the assumed 1.0 or 1.5 inches, include the increased height in the calculation of additional non-composite dead loads, but do not include the greater height in the computation of the section properties.

4.2.2.2. Utilities

Unless otherwise confirmed by inspection, include a dead load for utilities of 2 psf of deck area in rural areas and 3 psf in cities and urban areas for all bridges. Higher loads may be required if heavier utilities are shown on the plan or are known to exist. When existing utilities are present, estimate their effects and apply them to the appropriate supporting bridge components, i.e. a duct bank of conduits, water / sewer lines, etc.

4.2.2.3. Steel

For typical multi-beam steel bridges, account for the extra dead loads such as splices, connection plates, etc. by calculation. Do not use an allowance for detailing since this allowance varies widely for various bridges. Increase the computed value by 1.5% to account for welds and minor weight contributions. This is consistent with the practice for bridge design found in *BDM Article 6.2*.

For other steel bridge types, i.e. trusses, arches, etc., a more rigorous assessment of detail weight is needed. The weight of "details" on truss and arch members including items such as lacing, diaphragm plates, gusset plates, etc. can be 20% of the member cross-section weight. Determine the additional dead load in a rational way.

4.2.3. Transient Loads

4.2.3.1. Vehicular Live Loads

The nominal live loads to be used in the evaluation of bridges are dependent on evaluation type.

- **Design Load Rating:** HL-93 Design Load per the *BDM Article 3.4* and as specified in Article 4.4.3.2
- **Legal Load Rating:** Minnesota legal loads, as specified in Article 4.4.4.2.
- **EV Load Rating:** Emergency vehicle loads, as specified in Article 4.4.5.2.
- **Permit Load Rating:** Permit Trucks, as specified in Article 4.4.6.3

The vehicle force effects, including impact, are the most common transient loads used in bridge rating. For curved bridges, include the effects of centrifugal loads as well. Consider the effects of longitudinal braking forces only when there are concerns about the longitudinal stability of the structure.

4.2.3.2. Application of Vehicular Live Load

Assign the number of traffic lanes and place the wheel lines in accordance with the *LRFD Specifications*, and the following:

- Roadway widths less than 18 feet carry only one traffic lane.
- Roadway widths from 18 to 20 feet have two traffic lanes, each equal to one half the roadway width.
- Do not place the center of any wheel load closer than 2.0 feet from the edge of a traffic lane or face of the curb.
- The distance between wheel lines in adjacent lanes is not to be less than 4.0 feet.
- The standard gage width is 6.0 feet, unless specified otherwise.

The actual usage of the bridge may have striped lanes that do not match the design lane placement according to the *LRFD Specifications*. The design lane considers the possibility of a truck placed at the face of a barrier, including in the shoulder areas, whereas a striped lane considers the actual expected location of traffic. The use of design lanes results in a conservative estimation of live load force effects. Design lanes are especially conservative where the live load distribution factor is determined using the lever rule method. Instances of when the lever rule may be used include for exterior girders in multi-beam bridges, two-girder bridges, and other two-element systems such as truss, arches, etc. where load are shifted to extreme locations to determine their relative distribution. The rater may consider normal operating conditions, with placement of truck loads only within the striped lanes, only with prior approval of the State Bridge Load Rating Engineer. Include placement of the transverse location of the load on the lane stripe. Typical instances of when the striped lane location can be used include service limit states of design and legal load ratings, the design load operating ratings, and permit load rating evaluations. This allowance may also be used when checking fatigue since fatigue rating, and accumulated damage, is a function of the normal operating condition of the bridge, not an extreme shifted location as might be of concern for strength. The placement of the striped lanes must be field verified and documented in the inspection report. Report the use of striped lanes rather than design lanes on the load rating forms. The allowance for placing traffic in striped lanes is further described in the *MBE Article 6A.2.3.2.* Similar language is provided for load rating using the LFR method in *MBE Article 6B.6.2.2*.

For design load rating of structures with sidewalks, consider two scenarios where (1) the HL-93 loading extends onto the sidewalk and (2) where the HL-93 is within the lanes and there are pedestrians on the sidewalk. For permit load evaluations, however, assume the permit trucks remain within the lanes, and that there are no pedestrians on the sidewalk.

4.2.3.3. Dynamic Load Allowance

The dynamic load allowance accounts for the dynamic interaction between a structure and moving vehicles. The amplification of the live load response is affected by riding surface discontinuities at expansion joints, bumps, pavement roughness, and the dynamic characteristics of truck suspensions. The LRFD dynamic load allowance (IM) of 33% reflects conservative conditions that may prevail under certain distressed approach and bridge deck conditions. The *MBE* provides reductions in the dynamic load allowance for bridges with less severe approach and deck surface conditions based on field observations. However, MnDOT policy does not allow for a reduction. Therefore, use 33% for dynamic load allowance. Do not apply the dynamic load allowance to wood components. Single trip permit trucks that require a speed reduction to less than 10 MPH can use 5% as the dynamic load allowance. Any other instance where a value other than 33% is desired must receive prior approval from the MnDOT Bridge Office.

4.2.3.4. Pedestrian Loads

Do not include pedestrian loads in the design load rating and legal load rating of the bridge, unless there is an expectation that significant pedestrian loading will occur simultaneously with maximum vehicular loading. See *BDM Article 4.2.3* for application of pedestrian loads in conjunction with vehicular loads.

4.3. ANALYSIS

Routine load ratings consist of computations made using data from the design plans, as-built drawings, field measurements, and inspection reports. Review the original design plans as the first source of information for material strengths and assumed allowable stresses. If the material strengths are not explicitly stated on the design plans, review the MnDOT construction and material specifications applicable at the time of the bridge construction. This may require investigations into old ASTM or AASHTO Material Specifications active at the time of construction. The *MBE* also provides guidance and data on older bridge types and materials for the evaluation of existing bridges without original plans or material specifications.

4.3.1. General

Use the methods of structural analysis described in *LRFD Specifications Section 4*, the *BDM*, and in this Section.

Rate all bridges using the LRFD load distribution factors. Refined analysis for bridges that could otherwise be load rated using empirical distribution factors will only be accepted when it is necessary and with the prior approval of the State Bridge Load Rating Engineer.

Load ratings may require the use of refined methods of analysis such as 2-D grillage or 3-D finite element models for bridges in which the live load effects are not easily quantified using empirical distribution factor approaches. Refined methods of analysis are also justified when the results can

be used to avoid load posting or to ease restrictions on the flow of permitted overweight trucks. Some newer more complex structures (segmental bridges, curved girders, integral bridges, cable-stayed, etc.) have been designed using sophisticated analysis methods. Therefore, a sophisticated level of analysis will be required to rate these structures. Older curved and skewed bridges were designed using various non-refined analysis approaches that were acceptable at the time. The design approaches may have been suitable at the time but they do not allow for different live loads such as newer legal loads, or special permit loads, to be considered. Thus, a refined 2-D or 3-D analysis will generally be needed for an updated load rating of curved and skewed bridges.

Load ratings may consist of routine computations adjusted for actual material properties as determined from field sampling and tests of the materials.

4.3.2. Approximate Methods of Analysis

Unless specified otherwise within this manual, use the following *LRFD Specifications* for approximate methods of analysis.

- **Existing straight bridges:** *LRFD Specifications Article 4.6.2*
- **Steel box-girder bridges:** *LRFD Specifications Article 4.6.2 and 6.11*
- **Horizontally curved steel bridges:** *LRFD Specifications Article 4.6.2.2.4*

Ignore the effects of curvature for major-axis bending moments for horizontally curved steel I-girder and box-girder bridges if conditions in *LRFD Specifications Articles 4.6.1.2.4b and 4.6.1.2.4c*, respectively, are met.

Do not use the multiple presence factor of 1.2 when checking fatigue. It is already directly included in the AASHTO distribution factor equations but is not appropriate for the evaluation of fatigue. Thus, when using the AASHTO single lane distribution factors for fatigue, divide the computed result by 1.2. This is clarified further both in the *LRFD Specifications* as well as the *MBE*. See Article 4.4.6.3.1, Article 4.4.6.3.2, and Article 4.4.6.5 for the use of the multiple presence factor for permit loads.

4.3.3. Refined Methods of Analysis

A refined analysis is a bridge load rating done by more rigorous methods than usual. Some of these methods include: finite element analysis, yield line theory, strut and tie analysis, three-dimensional modeling and analysis, or load testing to obtain measured responses. Although not common practice, bridge load raters have the option to perform a refined analysis to improve the load rating if the project meets certain criteria. The criteria include: the avoidance of load posting a bridge, improving the load rating for overweight permit trucks, improving the capacity to qualify for repair work, and at the District's request. All listed criteria require prior approval by the State Bridge Load Rating Engineer.

The use of refined analysis is limited. The increased time, effort, and cost of the analysis must be balanced against the workload of the staff and the potential benefits.

4.3.3.1. Bridges Requiring Refined Analysis

Some bridge types will by default receive a refined analysis. Examples are curved steel girders, steel girder bridges with large skews, non-uniform beam spacing (i.e. flared beams), segmental concrete boxes and cable stayed bridges. These bridges are designed with software developed specifically for these complex structures. Load rating requires similar analytical tools to assess the dead load and live load distribution. In general, a bridge superstructure will require refined analysis if the live load design forces cannot be accurately determined using AASHTO LRFD distribution factors or the lever rule in conjunction with a line girder or 2D planer structural analysis.

4.3.3.2. Modeling Considerations

When refined analysis is required, the bridge shall be modeled with sufficient accuracy to determine dead load and live load forces. Use of general purpose finite element packages which include moving load analysis for AASHTO LRFD and user-specified vehicles is preferred. Model with sufficient detail to accurately compute the design forces required to perform the load rating.

4.3.3.2.1. Skewed and Curved Steel Bridges

The following provisions specify when to utilize refined analysis for load ratings of skewed and curved steel girder superstructures. *LRFD Specifications Articles 4.6.3.3.2* defines a *skew index* for skewed steel girder bridges, and a *connectivity index* for curved steel girder bridges.

The skew index is defined as:

$I_s = w_g \tan\phi / L_s$

where:

w_g = Width of the bridge measured between fascia girders

ϕ = Skew angle measured from a line perpendicular to the tangent of the bridge centerline. In bridges with unequal skew of their bearing lines, ϕ is taken as the angle of the bearing line with the largest skew.

L_s = Span length at the bridge centerline.

The connectivity index is defined as:

$I_c = 15000 / R(n_{cf} + 1)m$

where:

R = Minimum radius of curvature at the centerline of the bridge cross-section in feet throughout the length of the bridge.

n_{cf} = Number of intermediate cross-frames in the span

m = A constant taken equal to 1 for simple-span bridges and 2 for continuous-span bridges.

In bridges with multiple spans, I_c is taken as the largest value obtained from any of the spans.

Analyze straight skewed bridges with a skew index above 0.30 and curved steel bridges without skew with a connectivity index above 1.0 using refined analysis methods. Analyze skewed steel girder bridges with curvature using refined analysis methods if the connectivity index is above 0.5 and the skew index is above 0.1.

Model girder flange lateral bending stresses and report cross-frame forces for skewed and curved steel girder bridges for which refined analysis is required. Consider in-plane moment, in-plane shear, and flange lateral bending moment in the girder load rating. Cross frame forces will be provided by a refined analysis but they need not be rated. To avoid an overly-conservative cross-frame analysis, consider the influence of the out-of-plane eccentricity of the cross-frames. See *LRFD Specifications Article 4.6.3.3.4* and its commentary for information on the modeling of crossframes including a reduction in effective stiffness for common crossframe types.

When analyzing curved steel structures using refined analysis, carefully consider which directions of superstructure movement at bearings are guided, and which are fixed. It may be necessary to include the stiffness of the substructures in the analysis models when there are multiple fixed piers.

4.3.3.2.2. Concrete Bridge Considerations

Analyze post-tensioned concrete structures by software that includes time-dependent effects such as prestress losses, creep, and shrinkage. Include these time-dependent effects in the analysis, and integrate with the construction staging analysis. Calculate in the software the effects of both primary and secondary prestressing moments of indeterminant post-tensioned concrete structures. Primary prestress moments are defined as the time-dependent prestressing force multiplied by the net eccentricity of the prestressing tendons from the cross-section's neutral axis, while secondary prestress moments are the moments induced in indeterminant structures by the restraint of deformations from the prestressing force.

Losses in pretensioned concrete girders may be computed by following the *LRFD Specifications* provisions without the use of a time-dependent software analysis.

Material-nonlinear moment-curvature analysis may be used to load rate reinforced concrete arch bridges. The stiffness of the concrete elements may alternatively be reduced following the cracked moment of inertia provisions contained in the *LRFD Specifications*. For earth-filled concrete arches, use analysis methods that appropriately distribute loads applied to the deck through the fill to the arch rib.

4.3.3.2.3. Second Order Effects and Stability

Carefully consider second-order moment amplification (P-delta) effects in complex structures. If approximate methods such as AASHTO moment magnification are found to be incapable of computing second-order effects accurately, compute the total bending moments including both first-order and second-order effects directly by the analysis software using geometric-nonlinear analysis. Develop geometric-nonlinear models of steel structures following the provisions for member

stiffness reduction and initial imperfections contained in the current edition of the AISC *Specification for Structural Steel Buildings (ANSI/AISC 360)*.

Consider whether the global stability of a structure is a potentially controlling limit state for load rating. Assess for global stability the laterally unbraced arch ribs using analysis software with linear buckling (eigenvalue) or geometric-nonlinear analysis capabilities.

4.3.3.2.4. Construction Sequence Effects

The dead load force effects present in segmental concrete boxes, cable stayed bridges, suspension bridges, and spliced prestressed concrete girder bridges will be dependent on the construction sequence used to build these structures. Analyze these bridge types by software that includes construction staging capabilities. Model the original sequence used to construct the bridge with sufficient detail to accurately determine current dead load force effects. Include alterations made to the structure after completion of the original construction in the analysis model. Model the construction staging for other complex structure types for which the current dead load forces are dependent on the original bridge construction sequence.

4.3.3.3. Software Selection

Use software for refined analysis that meets the requirements specified in Article 4.3.3.2 for the structure type being rated. At MnDOT's discretion, the engineer may be required to demonstrate that the selected software package produces accurate results for benchmark problems of MnDOT's choosing prior to being used to conduct the load rating. When geometric-nonlinear or linear buckling (eigenvalue) analysis is undertaken for load rating, show that the software can produce accurate results for the benchmark problems in the AISC *Specification for Structural Steel Buildings (ANSI/AISC 360),* Appendix A, published July 7, 2016.

4.3.3.4. Reporting of Results for New and Existing Bridges

It is not required that MnDOT have a license of the software package selected for the load rating structural analysis. However, input files for the software analysis model must be provided as part of the load rating calculation package that clearly define the geometry, material properties, section properties, boundary conditions, and loads used within the model. Complete the reporting forms listed in Section 10 of this manual. For structures requiring refined analysis, also provide a written report that describes the structural model, the refined analysis techniques that were utilized, and which includes a discussion of the load rating results. List the live load factors used to provide load ratings for legal and permit vehicles, and document how many lanes were loaded simultaneously with these vehicles in the analysis model.

For both new and existing bridges, clearly document any assumptions used in the development of the analysis models. If complete information is unavailable for existing bridges, (such as actual construction sequence information), document what assumptions were made in place of the missing information.

4.4. LOAD RATING PROCEDURES

4.4.1. Introduction

Perform load ratings in a sequential manner. First, evaluate all bridges for design loads (HL-93). Then determine the legal load rating. The legal load rating is not required for trunk highway (TH) bridges in instances where the design load inventory rating is greater than 1.00 or the design load operating rating is greater than 1.15. After completing the legal load rating (when required), evaluate the emergency vehicles. Evaluate all interstate highway bridges, all non-trunk highway (non-TH) bridges, and any trunk highway (TH) bridge within 1 mile of an interstate for the emergency vehicles. Finally, evaluate overweight permit loads. Overweight permits are only allowed if a bridge does not require posting after the legal load and emergency vehicle evaluations. The evaluation procedure is outlined below.

1. Design Load Rating (Figure D-1 and *BDM Article 3.4*)
    a. Compute the inventory rating factor for HL-93 design loading
    b. Compute the operating rating factor for HL-93 design loading
2. Legal Load Rating
    a. Do not evaluate the legal load rating if each of the following is true:
        i. The bridge is on a trunk highway (TH).
        ii. The design load inventory rating factor is greater than 1.00 or design load the operating rating factor is greater than 1.15.
    b. Otherwise, sequentially compute the legal load rating factors, as illustrated in Figure 4.4.1-1.
        i. Type M3, Type M3S2-40, and Type M3S3-40 trucks (Figure E-1).
        ii. Specialized Hauling Vehicles SU4, SU5, SU6, and SU7 (Figure E-2).
        iii. Legal lane loads (Figure E-3)
            1. Spans greater than 200 feet.
            2. Negative moment regions and reactions at internal supports.
3. Emergency Vehicle Rating (Figure E-4)
    a. Compute the rating factor for the EV2 and EV3 trucks, for the following cases:
        i. All interstate highway bridges
        ii. Trunk highway (TH) bridges within 1 mile of an interstate
        iii. All non-trunk highway (TH) bridges
4. Permit Vehicle Rating
    a. For trunk highway (TH) bridges, compute the rating factor for the following permit trucks:
        i. Standard permit trucks G-80 (Figure F-1 and Figure F-2).
        ii. Standard permit trucks G-07, for non-BrR rated bridges (Figure F-3 and Figure F-4)
    b. For non-trunk highway (non-TH) bridges, compute the rating factor for the following permit trucks:
        i. Standard permit trucks G-07 (Figure F-3 and Figure F-4), except the C198.23 truck
        ii. 6-axle and 7-axle permit trucks (Figure F-5)

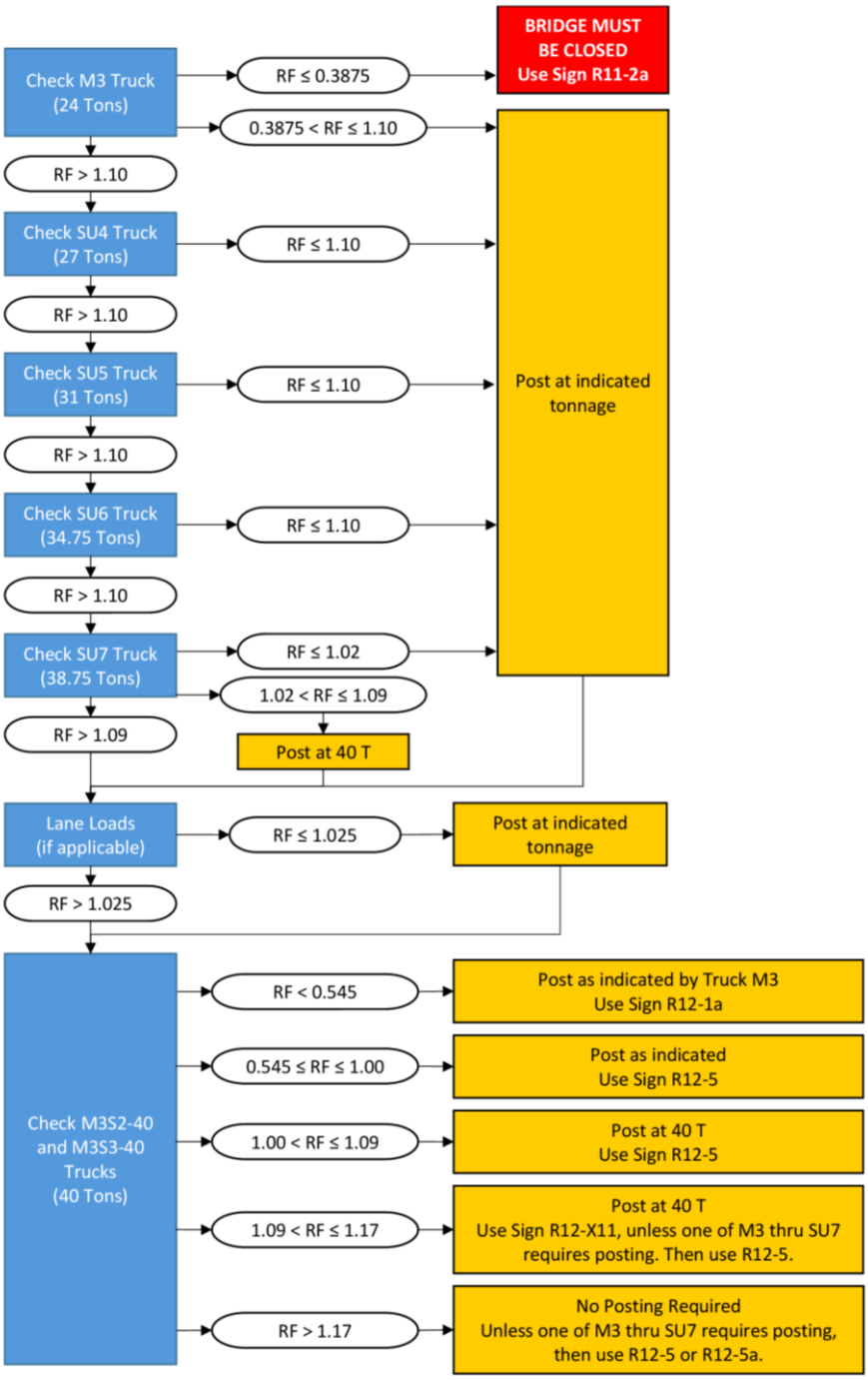


Figure 4.4.1-1: LRFR Legal Load Rating Flowchart

4.4.2. General Load Rating Equation

4.4.2.1. General

The general load rating equation in LRFR (*MBE Eq. 6A.4.2.1-1*) is given as:

$$RF = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_P)(P)}{(\gamma_{LL})(LL + IM)}$$

where:

RF = Rating Factor

C = Member capacity

For Strength Limit States

$C = \phi_c \, \phi_s \, \phi \, R_n$

Where, the following lower limit shall apply:

$\phi_c \, \phi_s \geq 0.85$

For Service and Fatigue Limit States, member capacity is given as:

$C = f_R$

R_n = Nominal member resistance (as inspected)

f_R = Resistance, in terms of stress, as specified in the *LRFD Specifications*

ϕ_c = Condition Factor (Article 4.4.2.3)

ϕ_s = System Factor (Article 4.4.2.4)

ϕ = LRFD Resistance Factor

DC = Dead load effect due to structural components and attachments

DW = Dead load effect due to wearing surface and utilities

P = Permanent loads other than dead loads (secondary prestressing effects, etc.)

LL = Live load effect of the rating vehicle

IM = Dynamic load allowance (Article 4.2.3.3)

γ_{DC} = LRFD load factor for structural components and attachments

γ_{DW} = LRFD load factor for wearing surfaces and utilities

γ_p = LRFD load factor for permanent loads other than dead loads

γ_{LL} = LRFD live load factor for the chosen limit state and rating vehicles (Article 4.4.3.3, Article 4.4.4.3, Article 4.4.5.3,and Article 4.4.6.4)

Use the resistance factor, ϕ, as specified in the *LRFD Specifications* for new construction. The condition factor, ϕ_c, is a reduction factor based on member condition. Apply the condition factor to the resistance of degraded members. The condition factor is discussed further in Article 4.4.2.3. An increased reliability index is maintained for deteriorated and non-redundant bridges by using condition and system factors in the load rating equation.

4.4.2.2. Limit States and Load Factors

Table 4.4.2.2-1 provides the dead load factors used in LRFR load rating evaluation.

Table 4.4.2.2-1: Dead Load Factors for Load Rating

Limit States	**Component Dead Load γ_{DC}**	**Wearing Surface Dead Load γ_{DW}**
Strength I, II ②	1.25	1.50 ①
Service I, II, III ②	1.00	1.00

Notes:

① Load factor for DW at the strength limit state may be taken as 1.25 when the thickness of the overlay has been field measured.

② Use 1.00 as the load factor, γ_P, for permanent loads other than dead load for any secondary effects of post-tensioning.

The limit states and live load factors to use in the analysis are dependent on the type of load rating being evaluated. The live load factors for each load rating type can be found in the following articles:

- **Design Load Rating:** Article 4.4.3.3
- **Legal Load Rating:** Article 4.4.4.3
- **EV Load Rating:** Article 4.4.5.3
- **Permit Load Rating:** Article 4.4.6.4

Currently MnDOT does not require fatigue limit state load evaluation. See Section 6 for guidance on when a fatigue evaluation is appropriate.

4.4.2.3. Condition Factor

The condition factor provides a reduction to account for the increased uncertainty in the resistance of deteriorated members and the likely increased future deterioration of these members during the period between inspection cycles. Current MnDOT policy is to set this factor equal to the values presented in *MBE Table 6A.4.2.3-1* and *MBE Table C6A.4.2.3-1*.

The condition factor, ϕ_c, does not account for section loss but is rather used in addition to section loss. If section properties are obtained accurately by actual field measurement of losses rather than by an estimated percentage of losses, the values specified for in the *MBE* tables may be increased by 0.05 but must remain less than or equal to 1.00. For instance, a concrete member may receive a poor condition rating of 4 (condition factor of 0.85) due to heavy cracking and spalling or due to the deterioration of the concrete matrix. Such deterioration of concrete components may not necessarily reduce their calculated flexural resistance but it is appropriate to apply the reduced condition factor of 0.85 in the LRFR analysis. If there are also losses in the reinforcing steel of this member, they should be measured and accounted for in the load rating. The condition factor of 0.90 (0.85 increased by 0.05) in the LRFR load rating analysis is used, even when the as-inspected section properties are used in the load rating as this reduction by itself does not fully account for the impaired resistance of the concrete component.

4.4.2.4. System Factor

System factors are multipliers applied to the nominal resistance to reflect the level of redundancy of the complete superstructure system. Bridges that are less redundant will have their member capacities reduced, and, accordingly, will have lower load ratings. The aim of the system factor is to provide reserve capacity for bridges with lesser degrees of redundancy. Current MnDOT policy is to use the system factors provided in *MBE Table 6A.4.2.4-1* when load rating for flexural and axial effects for steel members and non-segmental concrete members. When rating prestressed concrete beams for shear, set the system factor equal to 1.0. Do not penalize subsystems that have redundant members if the overall system is non-redundant (i.e. multi stringer deck framing members on a two-girder or truss bridge). For instance, a two-girder bridge with floorbeams and stringers may have stringers that qualify as load path redundant with floorbeams and main girders classified as nonredundant. Use the system factor with all live load models.

4.4.3. Design Load Rating

4.4.3.1. Purpose

The design load rating (or HL-93 rating) assesses the performance of existing bridges utilizing the LRFD HL-93 design loading and design standards. Dimensions and properties for the bridge are the as-inspected condition. Design load rating is a measure of how the bridge rates relative to the design loading contained in the *LRFD Specifications*. The design load rating produces inventory and operating level rating factors for the HL-93 loading.

Report the results of the HL-93 rating to the NBI as a Rating Factor. For example, “RF = 1.11” and “RF = 1.99,” respectively for inventory and operating.

4.4.3.2. Live Loads

Use the LRFD design live load, HL—93. See Figure D-1 and *BDM Article 3.4*. Do not apply the dynamic load allowance to the lane loads.

4.4.3.3. Load Factors

Use the evaluation load factors given in Table 4.4.3.3-1.

Regarding the live load factors for prestressed concrete used in the Service III Limit State, AASHTO provides two choices, a value of 0.8 or 1.0. Historically, i.e. for bridges designed using ASD, LFD, and even early versions of LRFD, engineers used a method of beam design that computed stresses based on the gross section of the concrete beam and used methods of prestress loss computation that are defined in the current AASHTO LRFD as "approximate". When LRFD was introduced, the Service III Limit State load factor was chosen as 0.8 so that beams designed using LRFD would require a similar number of strands as those designed using the Standard Specifications and using HS-20. This was an acknowledgement that prestressed beams do not exhibit systematic cracking at the service load level and reflected the higher live load force effects from HL-93 as compared to HS-20. It removed a perceived penalty against prestressed concrete beam designs that empirically do not have a history of cracking under routine force effects.

Since LRFD was first introduced, AASHTO has included additional options for prestressed beam analysis. Instead of using gross section properties for stress analysis, AASHTO allows use of the more liberal transformed section properties, the result of which is a fewer number of strands and a reduction in computed stresses due to the increased efficiency of the section. In addition, AASHTO has introduced more complex prestress loss calculations but which generally result in a smaller total prestress loss value. These two changes in practice resulted in AASHTO modifying the Service III Limit. It requires that if designers choose to use the refined loss methods including the allowance for elastic gains that the load factor of 0.8 no longer applies and the stresses must be computed with a live load factor of 1.0.

For load rating, either method may be used. Load rating programs (and load raters) must simply apply the methods correctly.

- Use the 0.8 factor when the stresses are based on gross section beam properties and when simplified methods of loss calculations are employed.
- Use the 1.0 factor when the refined loss calculations are used including the effects of elastic gains.

Since either method is permitted by AASHTO, the load rater can choose either to evaluate the structure. MnDOT policy is to first use the simplified method, i.e. the 0.8 load factor, and if a satisfactory rating is not obtained, the engineer can reevaluate the section based on the requirements to use the 1.0 factor. It is not a given that the refined method will always provide a better load rating than the approximate method so in the case of an inadequate load rating, both can be checked and the higher rating factor may be used.

Table 4.4.3.3-1: Live Load Factors for Design Load Rating

Bridge Type	Limit State	Design Load	
		Inventory γ_{LL}	Operating γ_{LL}
Steel	Strength I	1.75	1.35
	Service II	1.30	1.00
	Fatigue I / II ①	0.75	—
Reinforced Concrete	Strength I	1.75	1.35
Prestressed Concrete (non-segmental)	Strength I	1.75	1.35
	Service III	Table 4.4.3.3-2	—
Wood	Strength I	1.75	1.35

Notes:

① The fatigue limit state is not a required limit state. See Section 6 for guidance on fatigue evaluation.

Table 4.4.3.3-2: Service III Live Load Factors for Design Load Rating of Prestressed Concrete

Prestressed Concrete	Service III Load Factor
Prestressed concrete components rated using the refined estimates of time-dependent losses, as specified in *LRFD Specifications Article 5.9.5.4* in conjunction with taking advantage of the elastic gain	1.0
All other prestressed concrete components	0.8

4.4.4. Legal Load Rating

4.4.4.1. Purpose

Legal load rating assesses the ability to safely carry state-specific legal loads and identifies bridges that may need load posting or strengthening. Bridges that have sufficient capacity for design load rating will have sufficient capacity for Minnesota legal loads. A single safe load capacity in tons is given for a legal load rating (e.g. 40 tons). MnDOT also requires the rating factor be reported for legal load ratings (e.g. RF = 1.15). The capacity produced in the analysis considers redundancy and bridge condition, with a level of reliability that corresponds to an operating level of reliability.

4.4.4.2. Live Loads

4.4.4.2.1. Routine Commercial Traffic

Use the Type M3, Type M3S2-40, and Type M3S3-40 trucks for the legal load evaluation of routine commercial traffic (See Figure E-1).

4.4.4.2.2. Specialized Hauling Vehicles

The trucking and construction industry operate single unit Specialized Hauling Vehicles (SHV) with closely-spaced multiple axles that make it possible for these short wheelbase trucks to carry a maximum load of up to 80,000 lbs. and still meet Federal Bridge Formula B and the axle weight limits. Because of the higher load effects of these vehicles, especially on short span bridges, AASHTO has adopted a rating live load model of four single unit trucks as legal loads for bridge load rating and posting.

Use the SU4, SU5, SU6, and SU7 trucks for the legal load evaluation of Specialized Hauling Vehicles (See Figure E-2).

4.4.4.2.3. Lane-type Legal Loads

Use the lane-type legal load models (Figure E-3) for simple span structures in excess of 200 feet and for continuous span structures regardless of span length, to obtain the critical load effect. It is unnecessary to use a lane load or to place more than one vehicle in a lane for simple span structures up to 200 feet because the LRFR live load factors provided have been selected for this possibility.

Apply the dynamic load allowance to the truck live loads, but not to the lane loads when used.

4.4.4.3. Load Factors

Use the load factors given in Table 4.4.4.3-1.

Table 4.4.4.3-1: Live Load Factors for Legal Load Rating

Bridge Type	**Limit State**	**Legal Load γ_{LL}**
Steel	Strength I	Table 4.4.4.3-2
	Service II	1.30
Reinforced Concrete	Strength I	Table 4.4.4.3-2
Prestressed Concrete (non-segmental)	Strength I	Table 4.4.4.3-2
	Service III ①	1.00
Wood	Strength I	Table 4.4.4.3-2

Notes:

① The Service III limit state does not need to be evaluated for the Specialized Hauling Vehicles (SU4, SU5, SU6, SU7). See Article 4.4.6.7.

Table 4.4.4.3-2: Strength I Live Load Factors for Legal Load Rating

Bridge Type	**Limit State**	**Traffic Volume (One direction)**	**Legal Load γ_{LL}**
All Types	Strength I	Unknown	1.45 ①
		ADTT ≥ 5000	1.45 ①
		ADTT ≤ 1000	1.30 ①

Notes:

① If the engineer believes an increase to the live load factor is justified, the value may be increased, up to the value multiplied by 1.3. Receive approval from the SBLRE prior to increasing the load factor.

Linear interpolation of the factor is allowed for an ADTT between 1,000 and 5,000.

4.4.4.4. Load Rating in Tons

When reporting results, round the load rating down to the next even integer. Load ratings of 3 Tons and 5 Tons are acceptable for the Type M3 truck. The equivalent vehicle weight is assumed to be 40 Tons when a lane-type load model governs the load rating, i.e. a rating factor of 0.8 based on lane type loading implies a capacity of 0.8 x 40 = 32 tons.

4.4.5. Emergency Vehicle Load Rating

4.4.5.1. Purpose

Emergency vehicle (EV) load rating assesses the need for load posting bridges for emergency vehicles. The federal law *"Fixing America's Surface Transportation Act (FAST Act)"* revised the weight limits for emergency vehicles on the Interstate System. According to the federal law, all bridges must be rated for the new emergency vehicles that are on or within reasonable access to the Interstate System. MnDOT has adopted the policy that all bridges on the Interstate System and all non-trunk highway (non-TH) bridges be load rated for the emergency vehicles, and that any bridge on a trunk highway (TH) within one mile of the Interstate System be load rated as well.

4.4.5.2. Live Loads

FHWA developed two emergency vehicle (Figure E-4) configurations that produce an envelope of force effects of the emergency vehicles specified in the FAST Act. Only evaluate the emergency vehicle in a single lane operating in one direction of the bridge when it is possible for the engineer to control the number of vehicles assumed for load distribution.

4.4.5.3. Load Factors

Use a live load factor of 1.30.

4.4.5.4. Load Rating in Tons

Contact the MnDOT Bridge Office if an emergency vehicle governs the rating factor. A special load posting sign may be needed in such an instance. Refer to the FHWA Memorandum "*Load Rating for the FAST Act's Emergency Vehicles"* for additional information.

4.4.6. Permit Load Rating

4.4.6.1. Purpose

MnDOT issues permits that allow passage of vehicles that exceed the legal weight limit. These permits are issued as either routine (annual) permits or special (single trip) permits. Standard permit vehicles represent classes of overweight trucks most frequently used to carry loads requiring a routine or single trip permit. For any bridge re-rating, analyze the standard permit vehicles as additional live load models. The results will be available for informational and future permit management and operations purposes. For non-trunk highway (non-TH) bridges, the permit vehicle evaluation must include three results for each permit truck. These instances include no permit vehicles restrictions (Restriction Code 1), permit vehicle must straddle two lanes (Restriction Code 2), and the permit vehicle must reduce speed to no more than 10 MPH (Restriction Code 3).

For most future permit load investigations, the results of the standard permit vehicles will provide a sound basis for screening the load for bridge safety without the need for a reanalysis. For specific single trip permit applications where the truck may not fit the standard permit configurations, use the actual truck configuration described in the permit to analyze all pertinent structures.

4.4.6.2. Permit Types

4.4.6.2.1. Routine (Annual) Permits

Routine permits are issued for the movement of overweight vehicles over a specified route or within a restricted area. The duration of the permit is valid for one year beginning from the date the application is approved, and the movements must be made during the hours specified in the permit. The routine permit vehicle may mix in the traffic stream and move at normal speeds without any restrictions.

4.4.6.2.2. Special (Single Trip) Permits

Special permits are issued for the movement of an overweight vehicle for a one-way or round-trip route. Additional restrictions may be imposed for excessively heavy loads to reduce the live load effect. These permits are valid only for the specific date, time, vehicle, and route designated in the permit.

4.4.6.3. Live Loads

4.4.6.3.1. Routine (Annual) Permits

Determine the live load force effects using two-lane distribution factors for both interior and exterior beams as defined in the *MBE*. The *MBE* does not define a required check or recommend a method for analysis of exterior beams loaded by a single lane. See Article 4.4.6.5 for MnDOT policy on the evaluation for exterior beams.

Standard Permit Truck A, B, and C of MnDOT Standard Permit Trucks G-80 (Figure F-1) define Standard Annual Permits for MnDOT. For non-trunk highway (non-TH) bridges, the 6-axle and 7-axle trucks (Figure F-5) are also required to be analyzed.

For spans up to 200 feet, consider only the permit vehicle to be present in the lane. For spans more than 200 feet and when checking negative moments in continuous span bridges of any span length, apply an additional lane load taken as 0.2 klf in all lanes. Apply the lane load to those portions of the span(s) where lane loading effects add to the permit vehicle load effects.

4.4.6.3.2. Special (Single Trip) Permits

Standard Permit Truck P411 and P413 of Figure F-2 and all trucks shown on Minnesota Standard Permit Trucks G-07 of Figure F-3 and Figure F-4 define MN standard single-trip permit trucks. In the future, MnDOT may define additional standard permit vehicles based upon the frequency of such permits and their potential to induce load effects outside the envelope of the other standard permit vehicles.

Perform single trip permit analysis for a single lane loading. Single lane loading is used because these permit loads are infrequent and are likely the only heavy loads on the structure during the crossing. When the one-lane LRFD distribution factor is used, divide out the built-in 1.2 multiple presence factor. (That is, divide the computed one-lane distribution factor by 1.2 before using in the permit load rating.) Place the permit vehicle laterally on the bridge to produce maximum stresses in the critical member under consideration. In special cases, the dynamic load allowance may be

reduced to 5%, provided that the maximum vehicle speed can be reduced to 10 MPH prior to crossing the bridge.

For girder bridges, check the interior and exterior girders to determine which governs. For single trip permit vehicles, it is important to note that the vehicle could traverse the bridge in any lane, making it necessary to investigate whether the exterior girder controls the load rating.

4.4.6.4. Load Factors

Use the evaluation load factors given in Table 4.4.6.4-1.

In some cases, the special permit truck may be escorted across the bridge with no other vehicles allowed on the bridge during the crossing. If this is the case, then reduce the live load factor to the value given in Table 4.4.6.4-2.

Table 4.4.6.4-1: Live Load Factors for Permit Load Rating

Bridge Type	**Limit State**	**Permit Load γ_{LL}**
Steel	Strength II	Table 4.4.6.4-2
	Service II	1.00
Reinforced Concrete	Strength II	Table 4.4.6.4-2
	Service I	1.00
Prestressed Concrete (non-segmental)	Strength II	Table 4.4.6.4-2
	Service I ①	1.00
	Service III (Standard MnDOT permit trucks)	1.00
Wood	Strength II	Table 4.4.6.4-2

Notes:

① Use Service I to check the 0.9 F_y stress limit in reinforcing steel. See Article 4.4.6.7.

Table 4.4.6.4-2: Strength II Live Load Factors for Permit Load Rating

Permit Type	**Frequency**	**Loading Condition**	**Distribution Factor**	**ADTT (one direction)**	**Load Factor by Permit Weight Ratio (kip/ft.)**		
					< 2.0	**> 2.0 < 3.0**	**> 3.0**
Routine (Annual)	Unlimited Crossings	Mix with traffic (other vehicles may be on the bridge)	Two or more lanes	>5000	1.40	1.35	1.30
				=1000	1.35	1.25	1.20
				<100	1.30	1.20	1.15
					All Weights		
Special (Single Trip)	Single-Trip	Escorted, no other vehicles on bridges	One lane	N/A	1.10		
	Single-Trip	Mix with traffic (other vehicles may be on the bridge)	One lane	All ADTTs	1.20		

where:

Permit Weight Ratio = GVW / AL

GVW = Gross Vehicle Weight

AL = Front axle to rear axle length, using only axles on the bridge

Linear interpolation may be used for live load factors between ADTTs.

If a refined analysis is used in the evaluation, modify the live load factors according to the guidance found in Article 4.4.6.7.

4.4.6.5. Exterior Beams

The live load factors for permit loads, given in Article 4.4.6.4 (Table 4.4.6.4-2), are applied to both interior and exterior beams. The required corresponding distribution factor (one, or more than one lane loaded) is also specified as it relates specifically to permit loads. For design and legal loading, the approach in the *LRFD Specifications* and *MBE* is clear that single and multiple lane loaded checks are to be performed. For routine permits, the *MBE* is also clear that the required check is for two lanes loaded only. MnDOT policy is to require an additional check of a single lane. When checking for a single lane using the AASHTO empirical distribution factor equations, there is a built in multiple presence factor of 1.2 applied. The 1.2 factor accounts for force effects from other load contributions from an adjacent lane beside the loading under consideration. However, for routine permit loads, this scenario of side-by-side loading is conservatively addressed in the *MBE* by requiring a 2-lane distribution factor approach with permit loads assumed in both lanes. Thus, for the MnDOT single lane check requirement, do not apply the 1.2 factor, since the more appropriate check for side-by-side loading is performed using the multi-lane distribution factor approach in AASHTO. For the

distribution of live load to exterior beams, follow *LRFD Specifications*, with the following modifications:

- For routine permits, evaluate each of the following:
  - Assume multi-lane loaded conditions with permit trucks of equal weights present in each lane including any lane loads or multi-span loading for continuous spans. Apply the "2 or more" lanes loaded distribution factor.
  - Assume a single lane loaded condition but do not apply the multiple presence factor. When using the AASHTO empirical distribution factor formulas, divide the computed value by 1.2. For other methods of exterior beam live load distribution, i.e. lever rule, rigid rotation model, FEA analysis, etc. do not apply the 1.2 factor to the computed result. Apply the computed distribution factor to the force effects of the routine permit including any contributions from lane loading, a second truck for continuous spans, etc.
- For special permits, use a one-lane loaded condition only. Do not apply the multiple presence factor included in AASHTO's empirical DF equations, i.e. divide out the built-in 1.2 factor. If using the lever rule or other methods, do not include the 1.2 multiple presence factor correction.

4.4.6.6. Continuous Spans

Consider the effect of uplift and the effect on bearings when analyzing permit vehicles. Uplift is considered to occur when the upward reaction reduces the total reaction to less than ten percent of the dead load reaction. Uplift must not occur for the vehicle to be permitted.

4.4.6.7. Permit Checks Using Refined Analysis

When evaluating the permit checks using refined analysis, apply and modify the load factors as follows:

- For routine permit checks, increase the load factors in Table 4.4.6.4-2 by 0.10 and apply to the two permit trucks placed in adjacent lanes.
- For special permit trucks that are escorted with no other vehicles on the bridge, apply a load factor of 1.10 to the escorted vehicle.
- For special permits mixed with traffic, apply the following:
  - For new structures, apply a live load factor of 1.10 to both the permit truck and to the design load (HL-93) placed in the adjacent lane. This is a MnDOT policy that differs from the *MBE*. The *MBE* permits a permit load to be placed adjacent to a controlling legal load. Because there are many different legal loads, and defining the controlling load might be difficult, MnDOT conservatively places HL-93 loading in the adjacent lane. When designing a new structure, if an "excessive design" results from the conservative assumption, the engineer has the discretion to identify the controlling legal loading vehicle and redesign and rerate the structure accordingly.
  - For existing structures, the engineer has the option to follow the procedure for a new structure by applying the design load (HL-93) in the adjacent lane. If an adequate load rating result is obtained the analysis is complete. If an inadequate result is obtained, the engineer must then identify the controlling legal loading vehicle and rerate the bridge for the combined permit and legal loads in adjacent lanes.

Additionally, for special permit trucks that are escorted and are required to travel at a reduced speed (< 10 MPH) reduce the dynamic load factor as indicated in Article 4.4.6.3.2.

4.5. CONCRETE STRUCTURES

MnDOT requires that the shear capacity of all reinforced and prestressed concrete bridge members being evaluated by LRFR for the design load, legal loads and permit loads be included. Therefore, select as 'on' the option for evaluation of shear in BrR for all three evaluations.

For prestressed concrete beams, the load rater may consider the following options for the evaluation:

- Increase the concrete strength by up to 20% for beams that are at least 20 years old. See the following research reports by the UMN for background on the allowed increase:
  - http://www.dot.state.mn.us/research/TS/2016/201632.pdf
  - https://www.lrrb.org/pdf/200747.pdf
  - https://www.lrrb.org/pdf/201003.pdf
- Consider the end blocks in BrR, if present
- Use a refined analysis to determine the live load distribution factor

The Service III limit state is provided to check for cracking of the precompressed tensile zone concrete. The limit state applies to prestressed concrete bridges (segmental included) and is provided in LRFD to limit concrete tensile stresses under service loads. The allowable tensile stress in the pre-compressed tensile zone for the inventory level design load check, legal load, and MnDOT standard permit truck ratings is $0.19\sqrt{f_c'}$ in ksi units. For segmental bridges a special check of principal tension is required. Refer to the *MBE* for additional details.

The Service I limit state is provided to check for possible inelastic deformations in the reinforcing steel. This check is applied to permit load checks and has a limiting criterion of $0.9F_y$ in the extreme tension reinforcement. Limiting the steel stress to $0.9F_y$ is intended to ensure that there is elastic behavior and that cracks in reinforced or prestressed beams that develop during the passage of overweight vehicles will close once the vehicle is removed. It also ensures that there is reserve ductility in the member. For MnDOT standard permit loads, a crack control check is required as described above so it is anticipated that this yielding check will not control. However, for special permit loads, a crack control check is not enforced and thus cracking may occur. Therefore, for special permits, use the yielding check described in this paragraph to determine if elastic behavior is expected after passage of the heavy vehicle.

Use the values provided in Table 4.5-1 for the evaluation of concrete structures.

Table 4.5-1: Concrete Properties

Parameter	Equation/Value
Unit Weight	Reinforced Concrete Elements: w_c = 0.145 kcf for calculation of E_c w_c = 0.150 kcf for dead load calculation Pretensioned and Post-tensioned Elements: w_c = 0.150 kcf for calculation of E_c (except for pretensioned beams) w_c = 0.155 kcf for dead load calculation
Modulus of Elasticity	Pretensioned Beams: E_c (ksi) = $120{,}000 \cdot K_1 \cdot w_c^{2.0} \cdot f'_c{}^{0.33}$ where $f'_c \leq 6$ ksi E_c (ksi) = $1265 \cdot \sqrt{f'_c} + 1000$ where $f'_c > 6$ ksi All Other Concrete Elements: E_c (ksi) = $120{,}000 \cdot K_1 \cdot w_c^{2.0} \cdot f'_c{}^{0.33}$

4.6. STEEL STRUCTURES

4.6.1. General

Steel structures shall satisfy the overload permanent deflection check under the Service II load combination for design load, legal load, and permit load ratings. The maximum steel stress is limited to 95% and 80% of the yield stress for composite and non-composite girders respectively. During an overweight permit review, the specified truck weight is used, so a 1.00 live load factor is used.

4.6.2. Truss Gusset Plates

4.6.2.1. Background

As a result of the failure of the I-35W bridge, the FHWA issued Technical Advisory T5140.29. It recommends that during future recalculations of load capacity on existing non-load path redundant steel trusses that the capacity of gusset plates be checked to reflect changes in condition or dead load, to make permit or load posting decisions, or to account for structural modifications or other alterations that result in significant changes in stress levels. Previous load ratings should also be reviewed for trusses which have been subjected to significant changes in stress levels, either temporary or permanent, to ensure that the capacities of gusset plates were adequately considered. Gusset plates and connection elements of existing non-load path redundant steel bridges that have not undergone a load capacity evaluation in the past shall be checked for compliance with Technical Advisory T5140.29.

In the past, MnDOT had several documents that addressed the load rating of guest plates. They included: the MnDOT Truss Bridge Gusset Plate Design Review Procedure, MnDOT Interpretation of

Truss Bridge Gusset Plate Review Results, Excel spreadsheets, and sample calculations. These documents, spreadsheets, and examples are no longer current and are not to be used. The required practice for gusset plates is defined below.

4.6.2.2. Current practice

The 2014 Interim Revisions to the *MBE* completely replaced the prior procedures mentioned above and supersede the prior FHWA guidance. They are based on research performed by the FHWA and NCHRP. *MBE Article 6A.6.12.6 – Gusset Plates* was introduced to cover the LRFR load rating of gusset plates. A companion article (*MBE Appendix L6B.2.6*) covers LFD aspects of gusset plate load rating though the text of *MBE Appendix L6B* clearly states the gusset plate provisions were only developed considering LRFR and that the load factors used for LFD are not rigorously determined. Accordingly, MnDOT's policy is that any truss requiring an updated load rating must use the LRFR provisions for all elements, including the gusset plate evaluation.

The 2014 interim provisions introduce a requirement that gusset plates be checked for the applicable combinations of shear, tension, compression. The provisions are applicable for design, legal, and permit loads. Because corrosion is not uncommon on older trusses, guidance is provided in *MBE Article C6A.6.5* on how to treat the presence of corrosion on gusset plate capacities.

The *MBE* contains an example problem (Example A11) to demonstrate the gusset plate analysis. The example problem includes provisions of both the LRFR and LFR methodologies. It is MnDOT policy that only the LRFR provisions are applicable for any gusset plate load ratings that are to be updated.

4.7. WOOD STRUCTURES

For wood structures built from 2007 to the present, load rate these using the LRFR methodology. For the permit load evaluation, provide the LRFR results on the load rating forms. However, the current version of BrR only allows ASR evaluation and therefore the ASR input file must also be provided.

Evaluate wood structures built prior to 2007 for the design load and legal load ratings using ASR methodology.

The evaluation of wood structures is presented in Article 7.1.

4.8. LOAD POSTING OF BRIDGES

4.8.1. Load Posting Requirements for Bridges

NBIS regulations (23 CFR Part 650) require the load rating of each bridge as to its safe loading capacity in accordance with the *MBE* and the load posting of the bridge in accordance with this document or in accordance with state law, when the maximum unrestricted legal loads or state routine permit loads are exceeded. If a bridge is not capable of carrying statutory loads, it is posted for a lesser load limit. The decision to load post a bridge will be made by the bridge owner based on the agency's load posting practice. The LRFR guidelines are provided to assist MnDOT and local bridge owners for establishing load posting weight limits.

The strength limit state is used for checking the capacity of structural members and is the primary limit state utilized by MnDOT for determining load posting needs. Service and fatigue limit states are utilized to limit stresses, deformations, and cracking under regular service conditions. In LRFR, Service and Fatigue limit state checks are optional in the sense that a load posting or permit decision does not have to be dictated by the result. MnDOT policy, however, requires the evaluation of the Service limit state. These serviceability checks provide valuable information for the engineer to use in the decision process.

A concrete bridge with unknown reinforcement details need not be posted for restricted loading if it has been carrying normal traffic and shows no distress (see Article 3.9.1 and Article 7.4).

4.8.2. Reliability-Based Load Posting

The goal of the LRFR methodology is to maintain target uniform reliabilities in all load ratings and load postings. In LRFR, the method of load posting is different than past practices of simply multiplying the rating factor (unmodified) times a vehicle tonnage. For a posted bridge there is a greater probability of vehicles exceeding the posted limit compared to numbers exceeding the legal limit on an un-posted bridge. The *MBE* provides guidance on how to translate LRFR rating factors less than 1.0 into load posting values that maintain the criteria of uniform reliability, especially for the low-rated bridges. This is achieved through a load posting analysis equation, *MBE Eq. 6A.8.3-1* (and provided in Article 4.8.3) and a load posting graph given in the *MBE* that presents load posting weights for different vehicle types as a function of LRFR rating factors.

4.8.3. Load Posting Analysis

Use the following equation to establish the LRFR posting load for the governing legal load truck if the rating factor is greater than 0.3:

$$Safe\ Posting\ Load = \frac{W}{0.7}[(RF) - 0.3]$$

where:

RF = Legal load rating factor

W = Weight of rating vehicle (Tons)

It is the responsibility of the Load Rating Engineer to make a recommendation as to the need for load posting and must include the weight limit should load posting be required. When the RF for any vehicle type falls below 0.3, then that vehicle type should not be allowed on the bridge. Other vehicle types with RF > 0.3 may continue to use the bridge, provided the safe posting load is at least 3 tons. Add load posting recommendations to the Load Rating Summary sheet.

Close bridges that do not possess a 3-ton minimum capacity.

4.8.4. Signing

Regulatory signs shall conform to the requirements of the *"MN MUTCD"* and the *"Standard Signs and Markings Manual"*. These manuals include load posting signs, supplemental signs, advance warning signs, other related bridge signs, and instructions on their use.

The *MN MUTCD* can be found here:

http://www.dot.state.mn.us/trafficeng/publ/mutcd/

The *Standard Signs and Marking Manual* can be found here:

http://www.dot.state.mn.us/trafficeng/publ/signsmanual/index.html

The regulatory signs to use for load posting are shown in Table 4.8.4-1 and can also be found in Appendix G:

Table 4.8.4-1: Load Posting Signs

Load Posting Sign	Example	Usage
R12-1a		Lower load posting weights and shorter bridges, typically used when the posting tonnage is a single digit
R12-5		Most load postings at or below 40 tons
R12-5a		If only the single unit truck requires load posting, and the posting tonnage is two digits
R12-X11		Where higher limits are required due to seasonal or permit loads (45 tons only)
R11-2a		Bridge Closed (Capacity less than 3 tons)

For Sign R12–5, post the two combination vehicles (M3S2-40 and M3S3-40) at the same tonnage. Use the lesser of the two calculated tonnages. When using this sign, all three vehicles must be posted. The maximums for this sign are “40T” for all three vehicles.

When a bridge is closed, erect signs and traffic barriers to provide warning and protection to the traveling public. Install measures to prevent pedestrian use of the bridge shall be installed if pedestrian use is to be restricted. Signs and barriers shall be inspected periodically to ensure their continued effectiveness.

4.8.5. Speed Limits

A lower speed limit is an allowable posting avoidance option in the *MBE*, as a lower speed limit may reduce impact loads to an extent where a load posting may not be required. However, due to posting loads typically being a capacity issue, coupled with the difficulty in enforcing a reduced speed, MnDOT does not allow for a reduced speed as a posting avoidance option.

4.8.6. Notification

When a load rating is completed and indicates a bridge is to be posted, it is mandatory that the bridge be posted unless the bridge owner elects to provide expedited repairs to strengthen the bridge to carry legal loads. Notify the permit office immediately of any new trunk highway (TH) bridge load posting.

On trunk highways (TH), the State Bridge Engineer sends a load posting notification memo to the District Engineer. The load posting signs must be erected within 30 days after notification of their requirement. If there are significant changes in the bridge condition or in the posted weight, erect temporary signs in the interim.

The district office must inform the MnDOT Bridge Inventory Management Unit when the load posting signs are in place. After the bridge is posted by the District, they are to report back to the Bridge Office of their action through a memorandum. The Bridge Office should be notified of the District's action within 30 days of receipt of the weight restriction recommendations.

Verification of the posting (or non-posting) shall be confirmed through the bridge inspection reporting. Weight limit signs shall conform to the requirements stated in the *MBE*.

SECTION 5: LOAD FACTOR RATING (LFR) AND ALLOWABLE STRESS RATING (ASR)

5.1. PREFACE

It is MnDOT's policy that all new load ratings and the updating of existing load ratings be computed using LRFR methods with several exceptions, which are discussed in Article 3.3.

Most of the text in this section is taken from *BDM Section 15* (now removed) and relates to the historic practices of MnDOT and the application of LFR and ASR methods. This information is still important as it will be some time before all load ratings are converted to LRFR. Thus, the text in this section defines the policies and practices used to compute many existing load ratings.

5.2. GENERAL

This section focuses on the use of load factor (LFR) and allowable stress (ASR)methods of analysis. Historically all bridges were initially designed and then subsequently load rated using allowable stress methods. As the *Standard Specifications* evolved over time, load factor methods were introduced and these were used for both design and then later for load rating. These methods were previously covered in the *AASHTO Manual for Condition Evaluation of Bridges (MCE)*, which was subsequently incorporated into the more recent *AASHTO Manual for Bridge Evaluation (MBE)*. It is true in Minnesota and other states that as of this writing (2018) most bridges in the inventory continue to have their current load ratings in LFR format; only newer bridges tend to have LRFR ratings. There is no national requirement to re-rate existing bridges using the LRFR methods, so there continues to be many bridges load rated with older methods such as ASR and LFR, the focus of this Section.

The use of LFR and ASR load ratings is not considered incorrect or in any way unsafe, rather they are older methods, not statistically calibrated, and therefore do not provide uniform reliability such as is the basis for LRFR. For that reason, LFR and ASR ratings have been replaced in recent years with the LRFR approach. In Minnesota, most bridges continue to have current load ratings using these older methods. This is acceptable and complies with Federal requirements for reporting the safe capacity of bridges.

The use of the ASR methods is typically reserved for timber bridges, unreinforced masonry, or other structures that do not have guidance provided in the *MBE*. It is possible to rate timber bridges using ASR or LRFR methods. Guidance on when to use ASR or LRFR for timber structures is given in Article 5.7.7 and Article 7.1.

The LFR load rating of bridges is consistent with past practice for most bridge types, i.e. steel beams, prestressed concrete beams, concrete slab bridges, trusses, etc. Bridges with an existing ASR / LFR load rating may remain that way until such time that the load rating must be updated. Any major changes to the bridge trigger a re-rating and this new load rating must be done using the LRFR methods. Section 2 discusses the conditions which will require the load rating to be updated.

5.2.1. Application of the Standard Specifications

The *MBE* load rating provisions include separate sections for the use of the LRFR method as well as for ASR / LFR load ratings. The ASR / LFR load ratings are covered in Part B – Allowable Stress Rating and Load Factor Rating of Section 6. In either case of ASR / LFR ratings, the *MBE* contains provisions that amend or supersede the *Standard Specifications* typically used for design. However, there are many instances in which a load rating engineer must refer to the *Standard Specifications* for guidance and reference. Thus, the use of the *MBE* is not complete in and of itself. The various provisions of Part B provide the exceptions and changes to the design specifications but otherwise those portions not changed in some way apply for load rating.

5.3. LOAD RATING METHOD – ALLOWABLE STRESS AND LOAD FACTOR

The load rating of bridges following the ASR method is a historic and traditional expression of structural safety. The code-specified live loads are applied to produce maximum force effects in the specific bridge members. These loads are combined with dead load and other permanent force effects, generally without any additional factoring, and compared to a capacity which is considered to be a safe working or allowable stress. The allowable stress is some portion of the member's limiting strength / stress as a function of the capacity of the member in tension, compression, bending, or shear, the traditional means of expressing member capacity. In the ASR methods, all uncertainties associated with variations in loading and member strength are lumped in a single factor of safety. For this reason, not all bridges have the same level of safety since variations in dead load to live load ratio, variations in the confidence in predicting member strength, etc. are all lumped in a single value.

In load factor rating, the loads are first factored before combining them. Separate factors apply for dead load and live load, reflecting the variability of one compared to the other. These factors also vary with respect to the prediction of safe capacities at what are referred to as inventory and operating levels, each representing a different level of safety or risk in the load rating calculation. The loads, thus factored and combined, are then compared to the member's capacity but without the aforementioned factors of safety used in the ASR method. Some member strengths are given in the *MBE*, others come from the *Standard Specifications*. Generally, the strength of the member is expressed in force units, i.e. kips or kip-feet, but certain stress-based checks still apply such as the cracking of a prestressed concrete section.

5.4. LOAD RATING EQUATION

The basic load rating equations for ASR and LFR ratings is as follows:

$$RF = \frac{C - A_1 D}{A_2 L(1 + I)}$$

In this equation, the terms are defined in *MBE Article 6B.4.1* as

RF = the rating factor for live load

C = the capacity of the member including applicable capacity reduction factors (See Article 5.6 and Article 5.7)

D = the dead load effect on the member

L = the live load effect on the member

I = the impact factor to be used with the live load effect

A_1 = a factor for dead loads

A_2 = a factor for live loads

When this equation is used for ASR, the factors A_1 and A_2 become unity and the equation is simplified. In general, the rating factor, RF, is simply the reserve member capacity after taking out the effects of dead loads (or permanent loads in general) divided by the live load demand. A rating factor of 1.0 or greater indicates a specific rating live load can be safely carried. A value less than 1.0 indicates the live load does not meet the requirements of the load rating checks.

5.4.1. Rating Levels

Bridges are rated at two different stress levels, inventory level and operating level. Design load ratings (inventory or operating) are calculated and reported in terms of the HS-20 design load. For example, if the calculated rating factor is 1.15, the load rating is recorded as HS-23.0.

5.4.1.1. Inventory Rating

Inventory ratings are computed such that the load rating calculation assumes an unlimited number of crossings could be carried safely at a specific level. Effectively, the inventory rating factors are as if the bridge is reverse-engineered using the same rules as applied to a new structure.

5.4.1.2. Operating Rating

The operating level is used to allow a greater amount of live load on the bridge but for more limited numbers of crossings. The operating rating level is used in Minnesota for load posting and for evaluation of overweight permits.

5.5. LOADINGS

Loading of the structure will primarily need to consider the dead load, rating live load, distribution of live load, and impact loads. Only consider the effect of live load deflection in special cases. Consider longitudinal loads only at the operating level. Environmental loads will rarely control the load rating and do not need to be considered except for unusual cases when, in the opinion of the load rating engineer, locked in force effects (i.e. from method of construction) or transient effects such as thermal loading, creep, shrinkage, etc. influence the load rating.

5.5.1. Dead Load

All procedures for the determination of dead load for ASR and LFR are the same as for LRFR (See Article 4.2.2), except that dead load distributions are calculated according to the *Standard Specifications*. Railings, sidewalks, utilities, and medians may be divided uniformly among all beams

if they are located symmetrically on the deck cross section. If the items are not located symmetrically then the aforementioned items may not be divided uniformly among all the beams.

5.5.2. Rating Live Load

Calculate and report the load ratings in terms of the HS-20 design load.

When load rating for overweight permits, apply the permit truck to the lane that has the greatest effect on that member when members meet the following requirements:

- Member supports more than one traffic lane
- The engineer can position the loaded lanes
- The engineer can determine a distribution factor using statical assumptions (simple beam / lever rule assumptions)

Trusses, two-girder systems, floor beams, etc., are instances where the above conditions are likely to apply. Do not assume a permit load is present in each lane.

A similar approach can be taken if determining live load force effects using software tools that allow for differing loads in adjacent lanes. Apply the design load (HS-20) to the adjacent lanes. In the load rating equation, apply the adjacent lane loads as a negative term in the numerator (as a deduction) so that the ability to carry the permit loads is directly assessed. Limit the placement of mixed live loads to the traffic lanes.

When load rating for load posting, apply the loads to the lanes in the same manner as is used for design.

When load rating a bridge with a sidewalk, use the pedestrian loads provided in the *Standard Specifications*. In the load rating equation, apply the sidewalk dead and live loads as negative terms in the numerator.

5.5.3. Distribution of Loads

Use the *Standard Specifications* for lateral distribution of live loads.

5.5.4. Impact

Use the *Standard Specifications* for addition of impact to live load. Impact may be reduced to 5% when a permit vehicle is required to substantially reduce speed in crossing the structure (<10 MPH).

5.6. NOMINAL CAPACITY – LFR

5.6.1. General

Determine the nominal capacity using the load factor sections of the *Standard Specifications*. Take into consideration the observable effects of deterioration, such as loss of concrete or steel cross-sectional area, loss of composite action or corrosion.

A structure condition capacity reduction factor accounts for an increased uncertainty in resistance of deteriorated members. Apply the factor to the bridge, or to the member whose condition led to the NBI condition code.

Table 5.6.1-1: Capacity Reduction Factor

NBI Superstructure Condition (SCC)	Capacity Reduction Factor
6 of higher (Good or Satisfactory)	1.00
5 (Fair)	0.95
4 or lower (Poor)	0.85

The factors may be modified if inspection reports clearly show different factors are appropriate for load rating, i.e., if the condition is clearly documented with measured section losses that can be incorporated into the load rating calculations. Do not use these reduction factors if the reason for the reduced condition rating is not in the direct load path of the bridge support system.

5.6.2. Structural Steel

In the past, most continuous steel beam spans have been designed as non-composite in the negative moment region. Rate them the same way. Conversely, if the beam was designed for composite action in the negative moment region, rate it as composite and with the longitudinal slab rebars included in the section properties.

Load rating engineers have the option of using the plastic capacity of steel per *Standard Specifications Article 10.50* for single trip permit operating check only.

Use the overload requirements of *Standard Specifications Article 10.57* when performing steel beam load ratings.

5.6.2.1. Truss Gusset Plates

Truss bridge gusset plates must be rated using LRFR methodology. Do not rate gusset plates using LFR methodology.

In response to the collapse of the I35W Bridge over the Mississippi River, the MnDOT Bridge Office developed two documents in October 2008 to use as guidelines for load rating and analyzing plates. The Memo to Designers (2008-02): Truss Bridge Gusset Plate Analysis, included the two documents, which were titled *MnDOT Truss Bridge Gusset Plate Design Review Procedure* and *MnDOT Interpretation of Truss Bridge Gusset Plate Review Results*. Additionally, Excel spreadsheets and a sample calculation were developed and could be obtained by request from the Bridge Rating Engineer. These documents and Excel spreadsheets are now out-of-date and must not be used.

The 2014 Interim Revisions to the *MBE* introduced significant guidance regarding the analyzing and load rating of gusset plates. These provisions now supersede the guidance provided in the Memo to Designers (2008-02) and should be used instead. An example of load rating gusset plates by the Load Factor Method is found in *MBE Appendix A11, Part B*. The *MBE* provides guidance on both LFR

and LRFR methodologies. However, it is MnDOT policy to only evaluate gusset plates using the LRFR methodology.

5.6.3. Reinforced Concrete

See *MBE Article 6B.5.3.2*. When strength of the reinforcing steel is unknown, Table 5.6.3-1 may be used.

Table 5.6.3-1: Yield Strength of Reinforcing Steel (MBE Table 6B.5.3.2-1)

Reinforcing Steel	**Yield Point, F_y, (psi)**
Unknown steel (prior to 1954)	33,000
Structural Grade	36,000
Billet or Intermediate Grade and Unknown after 1954 (Grade 40)	40,000
Rail or Hard Grade (Grade 50)	50,000
Grade 60	60,000

5.6.4. Prestressed Concrete

Load rate prestressed concrete members in accordance with the strength requirements of the *Standard Specifications*. At inventory level, the load rating must consider the allowable stresses at service load as specified in the *Standard Specifications*.

For LFR, the shear capacity of prestressed concrete beams is required to be considered only if inspection of the bridge indicates there are shear cracks present on the beam. The shear capacity must be reduced based on the beam condition, and load posting the bridge may be necessary when shear controls and shear cracks are present. The load rating forms must be filled out using the values with shear evaluation 'on' in BrR.

If the beams do not have shear cracks present, consideration of the shear capacity of prestressed concrete beams is not required. The load rater may choose to turn shear evaluation 'off' in BrR for the evaluation of the design load rating and legal load ratings. However, the load rating forms must include results for both the shear evaluation 'on' and 'off', and the BrR input model that is submitted must have the shear evaluation 'on'.

For prestressed concrete beams without shear cracks present, the load rater may consider the following options for the evaluation:

- Increase the concrete strength by up to 20% for beams that are at least 20 years old. See the following research reports by the UMN for background on the allowed increase:
  - http://www.dot.state.mn.us/research/TS/2016/201632.pdf
  - https://www.lrrb.org/pdf/200747.pdf
  - https://www.lrrb.org/pdf/201003.pdf

- Consider the end blocks in BrR, if present
- Use a refined analysis to determine the live load distribution factor

Use a capacity reduction factor of 0.91 for flexure of prestressed concrete in load factor rating. Historically, this value has been used by MnDOT in the LFR methodology without issue. Refer to the *Standard Specifications* for the factors to use for other materials and stresses.

A summary of the strength and allowable stress load rating equations is presented in *MBE Article 6B.5.3.3*.

5.7. NOMINAL CAPACITY – ASR

5.7.1. General

Unlike LRFR or LFR, ASR does not apply reduction factors. In the Allowable Stress method, the capacity of a member is based on the rating level evaluated: Inventory level Allowable Stress, or Operating level Allowable Stress. Allowable stress and strength formulas should be those provided in this manual, in the *MBE*, or those contained in the *Standard Specifications*.

5.7.2. Structural Steel

The allowable unit stresses used for determining safe load capacity depend on the type of steel used in the structural members. Refer to *MBE Article 6B.5.2.1* when information on specifications of the steel is not available. *MBE Article 6B.5.2.1* also includes information on the effective length of compression members, combined stresses, and batten plate compression members.

5.7.3. Wrought Iron

See *MBE Article 6B.5.2.2*.

5.7.4. Reinforced Concrete

See *MBE Article 6B.5.2.3*. When strength of the reinforcing steel is unknown, Table 5.7.4-1 may be used.

Table 5.7.4-1: Allowable Unit Stresses for Reinforcing Steel (MBE Table 6B.5.2.3-1)

	Stresses (psi)		
	Inventory Rating	**Operating Rating**	**Yield**
Structural or unknown grade prior to 1954	18,000	25,000	33,000
Structural Grade	20,000	27,000	36,000
Grade 40 billet, intermediate, or unknown grade (after 1954)	20,000	28,000	40,000
Grade 50 rail or hard	20,000	32,500	50,000
Grade 60	24,000	36,000	60,000

Unit stresses in concrete may be determined in accordance with the Service Load Design Method of *Standard Specifications Article 8.15* or be based on the tables in *MBE Article 6B.5.2.4*.

5.7.5. Prestressed Concrete

All procedures for ASR for prestressed concrete are the same as for LFR, except the capacity reduction factor is not applied. See Article 5.6.4.

5.7.6. Masonry

Consider the condition of the masonry unit and mortar when assigning an allowable stress. Evaluate masonry components only at the inventory level. See *MBE Article 6B.5.2.6* for guidance on the minimum allowable stresses to use in the evaluation. See Article 7.2 of this manual for additional guidance on unreinforced masonry arches.

5.7.7. Timber

Evaluate wood structures built after 2007 using LRFR. For wood structures built prior to 2007, evaluate using ASR. The evaluation of wood structures is presented in Article 7.1.

5.8. LOAD POSTING OF BRIDGES

5.8.1. General Procedure

On occasion, a bridge is unable to carry a prescribed loading. Specifically, when the legal load cannot be carried at a prescribed level, the bridge must be posted, or weight restricted, accordingly.

Minnesota Statutes provide for many exceptions to the basic legal loads. Due to these exceptions, the threshold to require a load posting is not a 1.00 rating factor, but something higher. There are increases of 10% in the winter, harvest increases, the "Timber Haulers Bill", and other exceptions. Due to the legal load exceptions, check any bridge with an operating rating factor of less than 1.35 (HS-27) to see if load posting is required. Perform all calculations for load posting in accordance with the *MBE*, and at the operating rating level.

5.8.2. Load Posting Analysis

When the operating rating is less than HS-27 as mentioned above, check the bridge to see if load posting is required. For the evaluation of load posting, the Minnesota Posting Trucks are the Type M and Type SU trucks described in Appendix E (Figure E-1 and Figure E-2).

The load posting requirements are provided below. Analysis begins with the Type M truck and then proceeds through the Type SU trucks. Also check the truck and trailer combination vehicles. See Figure 5.8.2-1 for the workflow.

Calculate the safe load capacity of the bridge in tons as follows:

$$RT = RF \times W$$

where:

RT = Load rating in tons for truck used in computing live load effect

RF = Rating Factor

W = Weight in tons of truck used in computing live load effect

The load posting sign type and weights that are to be placed on the posting sign are entered on the front page of Form RC–CL or Form RC-TH. Form PW must also be filled in completely if load posting is required and becomes the third sheet of the load rating documents. Round the calculated posting tonnages down to the nearest even ton. (Exception: 3 T or 5 T may be used on sign R12-1a.)

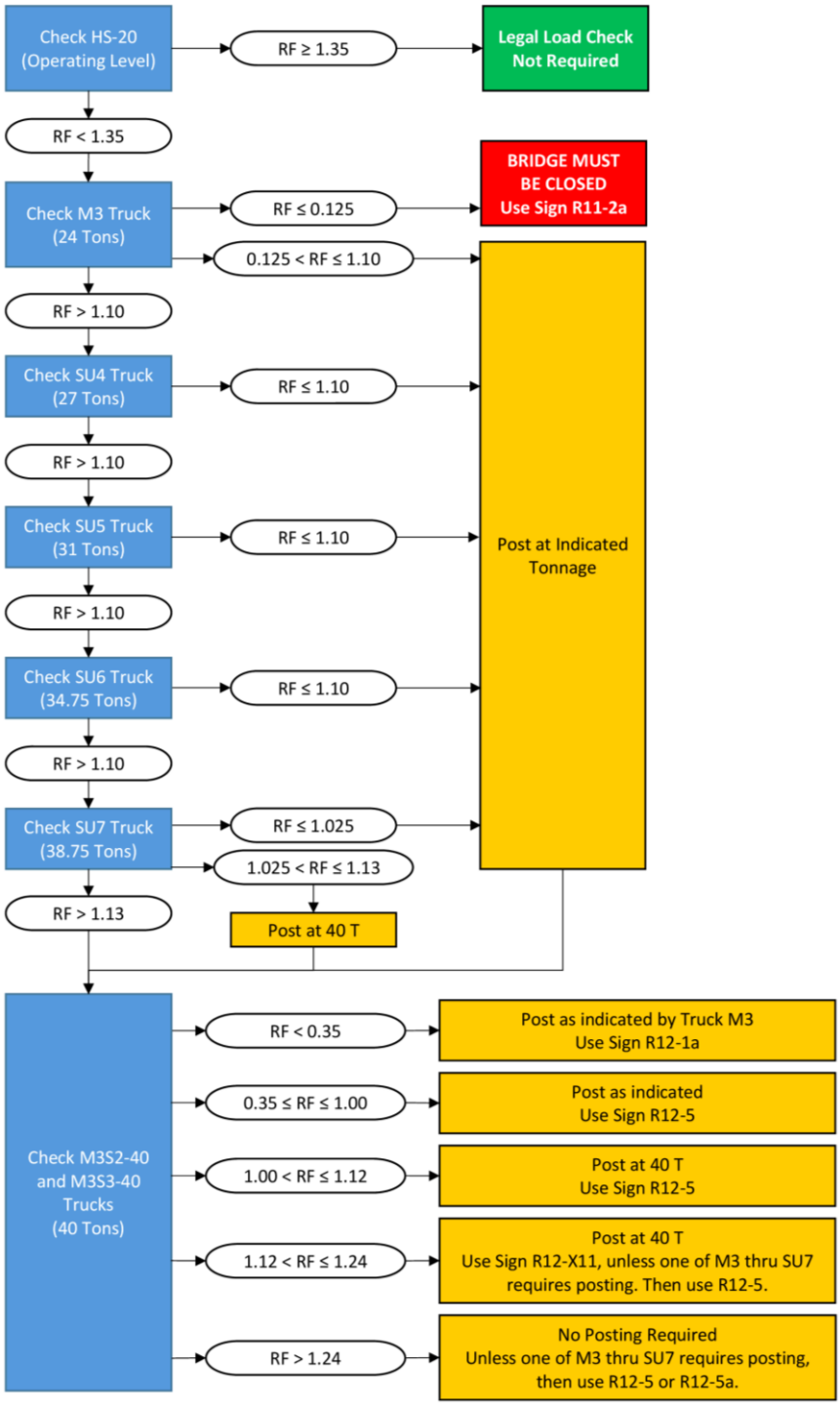


Figure 5.8.2-1: ASR/LFR Load Posting Procedure

5.8.3. Signing

The policy for signing for LFR and ASR evaluation is the same as for LRFR. See Article 4.8.4.

5.8.4. Speed Limits

The policy for speed limits for LFR and ASR evaluation is the same as for LRFR. See Article 4.8.5.

5.8.5. Notification

The policy for notification for LFR and ASR evaluation is the same as for LRFR. See Article 4.8.6.

5.9. PERMIT LOAD EVALUATION

This article applies to state trunk highways (TH) only. Consult with bridge owner for permit load requirements for bridges not on the trunk highway (TH) system.

Maximum vehicle weights are defined in Minnesota Statutes. Under certain conditions, trucks may obtain permits to travel at greater weights. Such permits are either annual permits or single trip permits.

5.9.1. Annual Permits

The Office of Freight and Commercial Vehicle Operations (OFCVO) issues annual permits for trucks weighing up to a maximum of 159,000 pounds. A holder of an annual permit may make an unlimited number of trips during the year of the permit.

Minnesota Standard Permit Trucks G-80, are shown in Appendix F. Of these, the Type A, B, and C vehicles (Figure F-1) are considered routine or annual permits. Use these standard vehicles to rate and thus screen bridges for various weights and dimensions of overweight vehicles. Record rating factors and restriction codes on the load rating forms for these trucks.

5.9.2. Single Trip Permits

The OFVCO also issues single trip permits. There is no maximum weight for single trip permits other than bridge capacity. All permit trucks have weight limits for single axles, and for certain axle groups.

Minnesota Standard Permit Trucks G-07 are shown in Figure F-3 and Figure F-4. These are a new generation of permit trucks and are all considered to be special permits. The P411 and P413 trucks from the G-80 chart (Figure F-2) are also special permits given their excessive weight.

5.9.3. Permit Load Analysis

For the evaluation of routine permits, assume that the permit truck may be alongside another heavy vehicle. If the initial Rating Factor is less than 1.0, restrictions may be required for the truck to cross the bridge. Restrictions may include: the truck being required to be escorted, reduced speed, prescribed lane position, or some combination. The MnDOT Overweight Permit Restrictions are given in Appendix C. The structure can be analyzed to reflect any restrictions that will be imposed.

The standard gage width (also called tread width) is 6.0 feet, in accordance with the *Standard Specifications*. For overweight permits treat gages of up to 6.5 feet as though they are 6.0 feet. Trucks with gage widths wider than this and with more than 4 tires may be evaluated at a reduced equivalent weight. The reduced weight may vary between bridges, depending on the applicable live load distribution formula for each bridge.

BrR allows the analysis of non-standard gages. This feature can be used in lieu of the approximate methods described above.

A truck traveling under an overweight permit is by law prohibited from crossing a load posted bridge.

SECTION 6: FATIGUE EVALUATION

6.1. INTRODUCTION

A procedure for fatigue evaluation of steel bridges is included in *MBE Section 7*. Fatigue evaluations are not typically performed as part of steel bridge load rating but can be useful when determining the remaining life of specific welded, bolted, or riveted details on a bridge and as a tool for determining if specific details have adequate remaining life when undertaking a rehabilitation project. This analysis can be used as a tool to determine what means of service life extension will be needed as part of the rehabilitation project and should be used for rehabilitation projects for structures that have Category D, E, and E' details. For example, a fatigue evaluation may be useful when contemplating redecking a steel bridge containing rolled girders with cover plates, plate girders with longitudinal stiffeners or lateral bracing system connection plates, or other sensitive details. *BPIG Chapter 8* contains additional information on the retrofit and replacement of fatigue prone components.

Fatigue evaluation has been included in the LRFR provisions since the first edition of the *MBE*. The method has been updated several times, most recently in 2015 when it was completely revised. It is important to note that only through the LRFR provisions is a method available for determining the remaining fatigue life. Because of how the *Standard Specifications*, and thus the ASD / ASR and LFD / LFR provisions are formulated, there is no comparable way to use those methods for fatigue assessment. Thus, for fatigue evaluation only, an LRFR method is provided in the *MBE*. These LRFR provisions are applicable to bridges of any vintage, designed by any specification.

6.2. IDENTIFYING FATIGUE PRONE DETAILS

Not all details are likely to be of concern for the long-term fatigue performance of steel structures. This is because a number of details, generally described as Category A, B, C, and C' details in the *LRFD Specifications* have a high tolerance for stress range that frequently exceed that which is expected in service. Generally, a structure having only these details and having been properly proportioned for fatigue at the time of design, will have adequate fatigue life throughout its service. However, many older bridges, and even some newer bridges, use details with a lower permissible stress range. Examples of such details include lateral bracing connection plates attached near tension flanges, longitudinal stiffeners terminating in areas of tension or reversal, welded cover plates on the tension flanges of rolled shapes, and some other lesser-performing details. Structures containing these details should be subject to greater scrutiny as part of the load rating and remaining life assessment.

It is important to stress that the methods described herein do not apply to structures with active cracking. When cracks are large enough to be visible, many details have exceeded or are near the end of their useful life and the calculations for fatigue life are no longer valid. The significance of the cracking must be addressed some other way, such as a more complicated fracture mechanics approach, or preferably a retrofit.

Additionally, the methods of remaining fatigue life assessment only apply to details where the cracking is classified as load-induced. Load-induced cracking may occur, for example, at the ends of cover plates and longitudinal stiffeners, at connection plates for lateral bracing, and at some

transverse intermediate stiffeners. These are the types of cracks stemming from stresses that can be computed by an engineer. These are only a portion of the cracks that may form on steel structures. Many steel bridge fatigue cracks do not come from load-induced sources but rather come from distortion-induced sources; these cannot be assessed by the methods herein. Examples of distortion-induced cracks include cracks at diaphragm and cross-frame connection plates that are cut short or otherwise not welded to the girder flanges. Distortion-induced cracks cannot be assessed using remaining fatigue life analysis and should be retrofitted instead.

6.2.1. Specific Detail Evaluation

Some details commonly found on existing structures have been difficult to evaluate in the past due to lack of available or consistent guidance. These are briefly discussed below.

6.2.1.1. Tack Welds

Tack welds are commonly found on older riveted structures. They were frequently used to temporarily hold individual components together so that riveting could be completed. *MBE Article 7.2.1* indicates that small tack welds, such as those used to temporarily hold components in place, can be evaluated as Category C details based on prior laboratory testing.

6.2.1.2. Riveted Connections

The base metal at riveted connections can be taken as Category C for existing structures as opposed to Category D which would be used for new structures having non-pretensioned fasteners. Category D corresponds to a conservative prediction of first cracking at a single location and this conservative definition of fatigue strength is used for new designs. Category C is more representative of the fatigue resistance of a connection where cracking has progressed to a size that would be critical for the strength of the member.

6.2.1.3. Inspection Hatches and Fabrication / Erection Handholes

Built-up sections commonly contain penetrations or perforations for inspection access or to facilitate member fabrication. An example is shown in Figure 6.2.1.3-1.

Figure 6.2.1.3-1: Inspection Access / Perforated Cover Plate Example

These open holes are not specifically addressed in the *LRFD Specifications*, rather the provisions for plates with holes are more in line with the treatment of small holes in infinitely wide plates, the origin of the Category D designation. Studies by Dr. Robert Connor of Purdue using finite element analysis have shown that elongated access holes such as those shown above and larger diameter round holes, say for a hatch, may be more in line with Category C. He examined 15 in., 18 in. and 24 in. wide plates with 1 in. diameter, 12 in. diameter and 12 in. x 18 in. access holes with rounded ends like the one shown in Figure 6.2.1.3-1. The general conclusion is that the 12-in. diameter round access hole and elongated hole detail are consistent with Category C; Category D appears to be too severe. This conclusion assumes that there are no mitigating factors such as a poorly prepared hole. A ballot item was introduced in August 2017 to modify the fatigue detail categories table in the *LRFD Specifications* and classify these larger perforations as Category C details. Since the proposed item, if accepted, will not be published until the *AASHTO LRFD Bridge Design Specifications* 9th edition, estimated to be printed in 2020, this manual will classify these details ahead of time based on the proposed language expected to be adopted by AASHTO.

6.3. FATIGUE LIFE EVALUATION

The *MBE* approach to fatigue life evaluation begins with a determination of whether a detail is fatigue prone or not. Details are only susceptible to cracking if they can be loaded to a state of net tension, i.e. the tensile portion of live load is sufficient to overcome the compression stress. In the *2015 MBE Interim Revisions*, this criteria is stated as:

$$2(\Delta f)_{tension} > f_{dead-load\ compression} \quad \textit{(MBE Eqn. 7.2.3-1)}$$

For this equation, $(\Delta f)_{tension}$ is defined in the *MBE* as the "tensile portion of the effective stress range as specified in Article 7.2.2" where the effective stress range is defined as the stresses resulting from the Fatigue II Limit State. This Limit State historically included a load factor of 0.75. In 2016, AASHTO voted to increase this load factor to 0.80 in the *LRFD Specifications*. It also voted to raise the load factor for Fatigue I, used for infinite life, from 1.50 to 1.75. In the equation above, the value "2" is simply the ratio of the maximum stress range (from Fatigue I) to the effective stress

range (from Fatigue II) which was historically a value of 1.50 / 0.75 = 2. The *MBE* has not been updated (as of this writing in 2018) to capture these changes. If the ratio of the new load factors is carried forward to the *MBE* as is expected, the *MBE* equation will be as follows:

$$2.1875(\Delta f)_{tension} > f_{dead-load\ compression}$$

Where the value of 2.1875 is the ratio of 1.75 / 0.80 and can be rounded to

$$2.2(\Delta f)_{tension} > f_{dead-load\ compression}$$

Thus, until such time that the *MBE* is updated, base the check for whether a fatigue evaluation needs to be conducted this modified equation. If a detail is determined to be fatigue prone per this check, a check of the fatigue life is required.

6.3.1. Estimating Fatigue Stress Ranges

A check of fatigue life requires that the total range of stress be estimated. The discussion in Article 6.3, above, only relates to the tensile portion of the range, not the total stress range. The stress range used for fatigue life evaluation can be estimated in three ways:

- By direct application of *LRFD Specifications* and the *MBE*,
- From measured strains, or,
- From a truck-weight survey.

Use direct application of the *LRFD Specifications* and the *MBE* as the first attempt. Collection of measured strains is a secondary option if the findings of the fatigue evaluation reveal inadequate life and it is important that a component remain in service for a period exceeding the computed life. The use of truck weight survey data is likely not an option in many instances due to the lack of accurate site-specific data.

The approach to fatigue life evaluation in the *LRFD Specifications* and the *MBE* includes a check for infinite life as well as a check for remaining fatigue life in the cases where infinite life is not provided. These are described in the following articles.

6.3.1.1. Infinite Life – Maximum Stress Range

The first step is to determine if a detail has infinite life. Theoretically, a detail will experience little or no fatigue damage during its 75-year design life if all stress ranges experienced by the detail are less than the constant-amplitude fatigue threshold (CAFT). Since bridge details are not subject to constant loading, but rather variable amplitude loading, occasional higher amplitude stress ranges are of concern in assuring that all stress ranges experienced by the detail are less than the CAFT.

Thus, the detail under evaluation is said to have infinite fatigue life when the following check is satisfied:

$$(\Delta f)_{max} \leq (\Delta F)_{TH} \quad \textit{(MBE Eqn. 7.2.4-1)}$$

where:

$(\Delta f)_{max}$ = the calculated stress range for the Fatigue I limit state multiplied by a multiple presence factor, R_p (*MBE Article 7.2.2.1*), or

= 2.2 $(\Delta f)_{eff}$ when the effective stress range is calculated using a truck survey, weigh-in-motion (WIM) study, or measured strains with R_s = 1.0. *Note – in the MBE this is shown as 2.0 $(\Delta f)_{eff}$ because the MBE has not yet adopted the new LRFD fatigue load factors.*

$(\Delta F)_{TH}$ = constant-amplitude fatigue threshold (CAFT) given in *LRFD Specifications Table 6.6.1.2.5-3*

If this check is satisfied, the life is said to be infinite and no further check is needed. If the above check is not satisfied, which is common, then the detail does not possess infinite life. In that case, compute the finite life as shown in the following article.

6.3.1.2. Finite Life – Effective Stress Range

When the detail does not have infinite life, calculate the finite life using the effective stress range. The effective stress range can be thought of as a weighted average over the life of the detail and is computed using the Fatigue II load combination. The effective stress range is computed as:

$$(\Delta f)_{eff} = R_p R_s (\Delta f)_{LRFD} \quad \textit{(MBE Eqn. 7.2.2-1)}$$

where:

R_p = multiple presence factor defined in the *MBE*

R_s = stress-range estimate partial load factor specified in the *MBE*

$(\Delta f)_{LRFD}$ = calculated stress range due to the Fatigue II limit state

For the usual approach of using conventional *LRFD Specifications* methods of line girder analysis, the standard *MBE* fatigue loading, etc., the value for R_s is taken as 1.0. For more refined methods of determining the loading, the value for R_s is less than 1.0, a credit for the refinement. The value for R_p is frequently nearly 1.0 as well.

6.3.1.3. Remaining Fatigue Life – General Approach

When a detail has finite life, compute the total life of a detail, N (in cycles), subjected to constant loading using the following equation:

$$N = \frac{R_R A}{[(\Delta f)_{eff}]^3}$$

where:

A = detail category constant (defines the resistance of the detail)

$(\Delta f)_{eff}$ = effective stress range

R_R = resistance factor related to risk and the probability of cracking

The equation demonstrates that the life is related to the detail constant and is inversely proportional to the cube of the effective stress range. This equation predicts the total life of the detail. For the determination of the R_R value, the *MBE* contains four possible estimates of fatigue life: Minimum, Evaluation 1, Evaluation 2, and the Mean. Each of these has a different probability of cracking being statistically possible in the evaluation timeframe.

The Minimum Life estimate, which as the name implies is the shortest life, i.e. most conservative, is a 98% confidence that the computed life can be attained. Since there is a high degree of confidence a structure will survive this long without cracking, the life is the shortest of all possible predictions. This life is the same as the life expectation for new structures. The use of Minimum Life estimates is not recommended for the assessment of existing structures.

The Evaluation 1 and 2 estimates are less conservative and are generally considered to be reasonable estimates of safe remaining life. Evaluation 1 provides an 84% chance of survival and Evaluation 2 a 67% chance of survival for the computed life. These two estimates are generally considered as reasonable for fatigue evaluation since they assume a greater risk but they also coincide with ongoing inspection and assessment.

The Mean Life estimate assumes the possibility of a 50% chance of cracking during the computed life. This is the longest life, but also assumes a higher possibility that cracking will occur. An instance in which this life might be used is for a bridge nearing the end of its life and in which cracking would not necessarily be critical.

There is no firm guidance on when to use the various possible lives. Rather the *MBE* provides a range of possible lives that an owner can consider when evaluating whether or not to retrofit specific details to achieve a target remaining life.

Not all steel bridges are required to have a remaining fatigue life analysis performed even when the load rating is updated. MnDOT will direct when such an analysis is to be performed. When performing a remaining fatigue life analysis, compute the remaining life based on the Evaluation 1 resistance factors. This is required for details having Category D, E, or E' classification. Present the results as part of an updated load rating or as part of rehabilitation planning documents. The Department will

use this information to make a determination on how this information affects the long-term continued operation of the steel bridge.

6.3.1.4. Remaining Fatigue Life – MBE Approach

The following equation from the *MBE* also computes the total life of the detail, using years instead of cycles, as the value "Y". This equation is a more complex form of the version above since it includes the growth in traffic volumes over time as a parameter in predicting the life in years. When used with the current age of the bridge, an estimate of remaining life can be made. The *MBE* uses this form of the finite life equation to capture the growth rate of traffic over the life of the bridge, the term "g", and using current traffic count data.

$$Y = \frac{\log\left[\frac{R_R A}{365n[(ADTT)_{SL}]_{PRESENT}[(\Delta f)_{eff}]^3} g(1+g)^{a-1} + 1\right]}{\log(1+g)} \qquad \textit{(MBE Eqn. 7.2.5.1-1)}$$

To use this equation there are several important clarifications and caveats to ensure that reasonable results are obtained.

The *MBE* states that the growth rate assumed for traffic growth be expressed as a percentage but this is incorrect. For a growth rate of 3%, the engineer is not to use "3" as the value for "g" but rather 0.03. The equation is otherwise mathematically correct but unusual results can be obtained. An explanation follows.

6.3.1.5. Remaining Fatigue Life – MnDOT Approach

The equation in the *MBE* assumes that the bridge carries a current volume of truck traffic given by the value $ADTT_{SL\ PRESENT}$. As importantly, it assumes that this traffic will grow in the future at a rate "g" and that it has been growing at this rate since the bridge was opened. Because of this idea, that the growth has been and will be constant, and is unbounded, the results can be erroneous.

Consider the issue of growth. Shown in Figure 6.3.1.5-1 are four different growth scenarios: no growth (i.e. a flat volume), and descending values reflecting 2%, 4% and 6% prior growth per year for each year in the past going back 50 years. This is the assumed relationship between volume and number of years since bridge opening assumed in the *MBE* formula. Defining the flat traffic volume as the baseline, the 2%, 4% and 6% descending curves only account for 64%, 45% and 33% of the baseline volumes. This plot demonstrates that, counterintuitively, higher growth rates may be an unconservative / unrealistic assumption for older bridges since they predict lower cumulative cycles to date than flatter or constant traffic volumes.

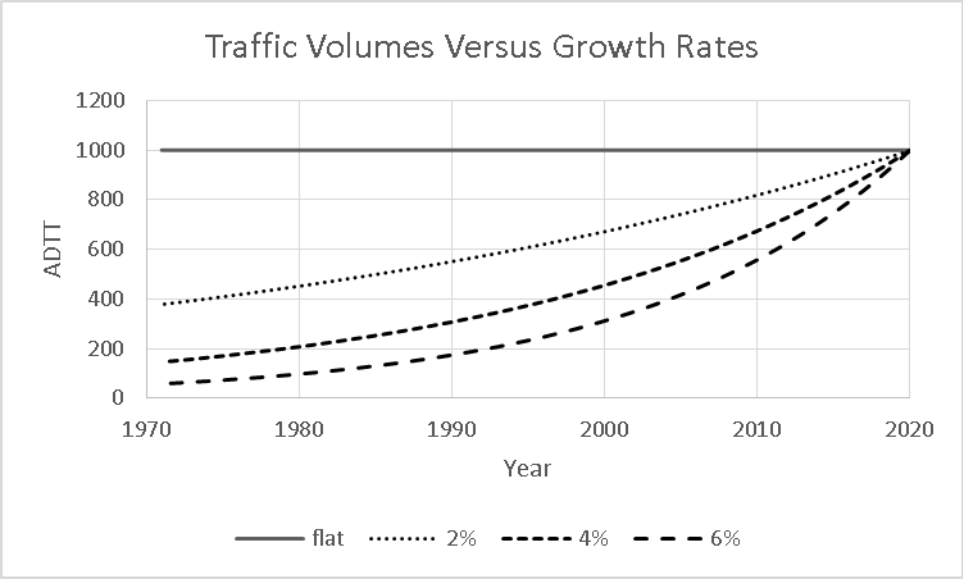


Figure 6.3.1.5-1: Theoretical Traffic Volume Growth Curves

The load rating engineer must exercise caution given the above. It is likely that traffic has not grown at a uniform rate throughout the life of the bridge. The engineer should instead make a calculation, using whatever historic traffic data is available, that estimates the accumulated cycles to date. It is usually conservative to assume all prior years have the current traffic volumes though this may be unnecessarily conservative.

The converse to the above discussion of past growth is also true. For a facility with a high current traffic volume but significant remaining life, the volume cannot grow unbounded in the future. It is well known that there are limiting volumes, per lane, that can be accommodated. *LRFD Specifications Article 3.6.1.4.2* indicates that the maximum volume per lane, of all vehicles combined, is approximately 20,000 vehicles per day. They also estimate the truck percentage based on the classification of the roadway. Consultation with a traffic / highway engineer is useful when trying to determine bounding or limiting volumes for a bridge being assessed. The term $ADTT_{limit}$ is used herein to define the limiting volume.

Given these anomalies in the *MBE* approach, MnDOT provides the following procedure:

Step 1: Compute the total life of the detail, $N_{available}$, in cycles:

$$N_{available} = \frac{R_R A}{[(\Delta f)_{eff}]^3}$$

where:

R_R = resistance factor for fatigue life, *MBE Table 7.2.5.1-1*

A = Detail Category Constant, *LRFD Specifications Table 6.6.1.2.5-1*

$(\Delta f)_{eff}$ = the effective stress range, *MBE Article 7.2.2*

Step 2: Estimate the total number of cycles to date using available traffic information or some other methods. This is called N_{prior}.

Step 3: Compute the remaining life:

$$N_{remaining} = N_{available} - N_{prior}$$

Step 4: If the life has been exhausted, i.e. $N_{remaining}$ is negative or a small value, there is no appreciable remaining life. Otherwise, compute the remaining fatigue life as follows:

$$Y_{remaining} = \frac{\log\left[\left(\frac{g_{fut}}{1+g_{fut}}\right)\left(\frac{N_{remaining}}{365nADTT_{Present}}\right)+1\right]}{\log(1+g_{fut})}$$

where: g_{fut} = future growth rate expressed as a decimal, i.e. 3% = 0.03

Step 5: Ensure that the traffic volumes in year $Y_{remaining}$ from the present day due not exceed the limiting value, $ADTT_{limit}$. Calculate the volume in year $Y_{remaining}$ as:

$$ADTT_{Y.remaining} = ADTT_{present}\,(1+g_{fut})^{Y_{remaining}-1}$$

If the value of $ADTT_{Y.remaining}$ exceeds the $ADTT_{limit}$, modify the result as follows:

- Determine the number of years of forward growth from $ADTT_{present}$ until the limit is reached.

  $$ADTT_{present}(1+g_{fut})^{x-1} = ADTT_{limit}$$

  Solve the above equation for "x", the number of years from the present at which point the limiting ADTT will be reached. Solving for "x" yields the following:

  $$x = \frac{\log\left(ADTT_{limit}/ADTT_{present}\right)}{\log(1+g_{fut})} + 1$$

In this equation, the value for "x" will generally not be an integer value. For convenience, round this value, either up or down, to the nearest integer value.

- Sum the number of cycles in those years. The summation is given by the following using the rounded value for "x"

  $$N_{growth} = \frac{365nADTT_{present}(1-(1+g_{fut})^{x})}{1-(1+g_{fut})}$$

- The remaining number of cycles that will now be consumed by constant volume, limited, traffic is now given by:

$$N_{limited} = N_{remaining} - N_{growth}$$

- Determine how many additional years of life at the limiting ADTT volume, $ADTT_{limit}$ are available. That defines the final exhaustion of the fatigue life.

$$Y = \frac{N_{limited}}{365nADTT_{limit}}$$

6.3.1.6. Remaining Fatigue Life Example Problem

Assume the following:

- Category E detail, A = 11 x 10^8 (*LRFD Specifications Table 6.6.1.2.3-1*)
- Δ_{feff} = 3 ksi
- n = 1 cycle of loading per passage
- Structure age = 50 years
- Assumed cycles to date = 22 million
- Current volume, $ADTT_{present}$ = 1500 trucks per day
- $ADTT_{limit}$ = 2000 trucks per day
- R_R = 1.2 for Evaluation 1 (the MnDOT recommended evaluation life)
- g_{fut} = 3%, i.e. 0.03

The first step is to compute the total life of the detail in terms of number of cycles.

$$N_{available} = \frac{R_R A}{[(\Delta f)_{eff}]^3} = \frac{1.2 * (11 * 10^8)}{3^3} = 48.9 \text{ million cycles}$$

For a total life of 48.9 million cycles, and the engineer's estimate of 22 million cycles to date, the remaining life, in cycles, is found to be:

$$N_{remaining} = N_{available} - N_{prior} = 48.9 \text{ x } 10^6 - 22.0 \text{ x } 10^6 = 26.9 \text{ x } 10^6$$

The number of remaining cycles is converted to a life, in years, as follows. This is based on an unbounded growth rate of 3% for all future years.

$$Y_{remaining} = \frac{\log\left[\left(\frac{g_{fut}}{1+g_{fut}}\right)\left(\frac{N_{remaining}}{365nADTT_{Present}}\right)+1\right]}{\log(1+g_{fut})} \approx 30 \text{ years}$$

The traffic volume 30 years in the future is computed using the following:

$$ADTT_{Y.remaining} = ADTT_{present}\,(1 + g_{fut})^{Y_{remaining}-1} = 3{,}534 \text{ trucks per day in 30 years}$$

Now that the projected volume is found, it must be compared to the limiting volume provided by the traffic engineer. The limit of 2,000 trucks per day per lane is significantly exceeded. Thus, the

idea that the life is 30 years, and predicated on constantly growing traffic volumes, is incorrect. The actual life will be even longer.

Find the number of years where traffic growing at 3% per year will reach the limiting value of 2,000 trucks per day per lane

$$x = \frac{\log\left(\mathrm{ADTT_{limit}}/\mathrm{ADTT_{present}}\right)}{\log(1+g_{fut})} + 1 = 10.7 \text{ years, say 11 years}$$

Thus, the number of cumulative cycles in the 11 years that the traffic grows to the limiting value is given by the following expression

$$N_{growth} = \frac{365nADTT_{present}(1-(1+g_{fut})^{x})}{1-(1+g_{fut})} \approx 7 \text{ million}$$

And the number of available remaining cycles when the limiting volume is reached is found as

$$N_{limited} = N_{remaining} - N_{growth} = (26.9-7)\text{ x }10^{6} = 19.9 \text{ million cycles}$$

Therefore, the number of remaining cycles after the traffic growth is capped is 19.9 million cycles. The number of years required to exhaust this number of remaining cycles is

$$Y = \frac{N_{limited}}{365nADTT_{limit}} = 27 \text{ years}$$

Therefore, the total remaining life is approximately 38 years, 11 years of which correspond to the traffic growth phase and an additional 27 years at a constant volume.

As a comparison, if the *MBE* equation is used,

$$Y = \frac{\log\left[\frac{R_R A}{365n[(ADTT)_{SL}]_{PRESENT}[(\Delta f)_{eff}]^3} g(1+g)^{a-1} + 1\right]}{\log(1+g)}$$

The predicted total life would have been computed as 97 years. Of this, 50 years would be consumed and the equation would predict 47 years remaining life as compared to 38 years from the above. The reason for the discrepancy is that the *MBE* equation assumed traffic growth rates from year zero to the present volume of 1,500. This would result in cumulative volumes of only 14.5 million cycles to date as compared to the engineer's estimate of 22 million. Thus, the difference results in an extended life. It also results in unbounded traffic volumes. Thus, the approach recommended herein is provided and required for remaining life evaluation.

6.3.2. Strategies to Improve Fatigue Life

When the calculation of the remaining life provided above is inadequate there are various approaches available. These include:

- Recompute the stress range using refined analysis – If the stress ranges were computed using standard *LRFD Specification* empirical rules for live load distribution, i.e. the load distribution approaches using line girder methods, simple beam analysis, etc., it is usually beneficial to recompute the stresses using a refined analysis for live load. There are two benefits. First, the stress ranges are typically lowered by using a refined analysis. Since finite life is a function of the cube of the effective stress range, even slight reductions in stress have significant positive benefits on remaining life. Additionally, because the refined analysis method is used, the *MBE* also lowers the partial load factor, R_s, to a value of 0.95, less than the default value of 1, an additional benefit.

  An additional tool for refined analysis is referred to in the *LRFD Specifications* as the "local structural stress" method and by some as the "hot spot" stress analysis method. Application of this method requires a detailed finite element analysis of specific details and adherence to various modeling and mesh refinement guidelines. The advantage of the method is that it can be applied to details of any type, including those that do not fit in any of the AASHTO detail categories. It also does not require that any specific detail category be applied or understood. Because the method of analysis captures the geometric stress concentration of the detail being modeled, this replaces the general concept of AASHTO Detail Categories. Some guidance on the use of the local structural stress method is found in the *LRFD Specifications* in the discussion of orthotropic decks. Guidance on the use of the method is also found in the FHWA / NHI Publication *Design and Evaluation of Steel Bridges for Fatigue and Fracture*, available free online from the FHWA, as well as in the *LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. This approach will be rarely applied. If it is deemed necessary or of interest for specific projects, it should be discussed and approved in advance and in conjunction with the Bridge Rating Engineer and the State Bridge Construction and Maintenance Engineer.

- Measure the strains directly – The installation of strain gages near the critical details will likely reveal that the stress ranges measured in the field are substantially less than predicted by analysis. This is a common finding. There are two benefits to this approach. First, a detail-specific stress is directly measured, typically resulting in a lowering of the stress. Second, the partial load factor is reduced from 1.0 to 0.85 to reflect the engineer's efforts to collect the best possible information.

- Retrofit selected details – it is common that a detail with inadequate remaining life is not a pervasive problem but exists at isolated locations along the structure where, due to the specific section properties and loading, the stress ranges are particularly high. Study the possibility of retrofitting only these selected details. This is discussed in Article 6.4.

6.4. FATIGUE CRACKING RETROFIT

For information on retrofit of fatigue cracking there are several valuable resources. These include:

- The online resource entitled *Fatigue And Fracture Library for the Inspection, Evaluation, and Repair of Vehicular Steel Bridges* by Fish, Schroeder, Connor and Sauser, available online at http://dx.doi.org/10.5703/1288284315520,
- The NCHRP publication *Maintenance Actions to Address Fatigue Cracking in Steel Bridge Structures* by Connor and Lloyd, and

- The FHWA's *Manual for Repair and Retrofit of Fatigue Cracks in Steel Bridges* by Dexter and Ocel.

Each of these provides extensive coverage on fatigue cracking and its remedy whether from load or distortion-induced cracking.

Discuss options for fatigue cracking retrofit with the Regional Bridge Construction Engineer.

SECTION 7: SPECIAL TOPICS

7.1. WOOD STRUCTURES

7.1.1. General

For definitions, and common Minnesota longitudinal and transverse wood decks and timber bridge superstructure types, see *BDM Section 8*.

For wood structures built from 2007 to the present, perform load rating using the LRFR methodology, including the permit load evaluation. Also, model these structures in BrR using the ASR method to facilitate overweight permitting evaluation.

For wood structures built prior to 2007, load rate using the ASR methodology. For structures which have a combination of wood and other materials, use the LRFR methodology.

A thorough inspection of an existing wood structure is a very important part of a load rating. Evaluate the condition of all members and elements, including the substructure.

7.1.2. Material Properties

7.1.2.1. General

Use the design stresses from the plan when plans are available. Additional guidance is provided if the member is sawn lumber or is glued laminated timber.

For bridges built in the years 1991 to 2006, refer to the *Standard Specifications* and the *1991 National Design Specification for Wood Construction (NDS) (ASD)*. Check the plans for species and grade. The reference design stresses represent the inventory level rating, therefore increase the design stresses by 33% for the operating level rating.

For bridges built in the years 2007 to the present, refer to the current edition of the *LRFD Design Specifications*. Check the plans for species and grade.

For bridges built prior 1991, if the plans are not available or the design stresses are not given on the plans, refer to Table 7.1.2.1-1.

Table 7.1.2.1-1: Allowable Stress Guidance for Sawn Timber Components

Year Built ⑥	Bridge Type		Grade	Design Stresses (psi)			
				Bending F_b	Shear F_v	Bearing F_{cp}	Compressive F_c
Prior to 1961	Longitudinal Nail Laminated		1200#f	1200 ①	100 ①	325 ②	Not Available
	Timber-Deck Bridges	Girder, Solid Sawn	1600#f	1600 ①	100 ①	345 ②	Not Available
		Transverse Nail Laminated Deck	1200#f	1200 ①	100 ①	325 ②	Not Available
	Posts & Timbers		1200#c	Not Available	Not Available	345 ②	1200 ⑤
1961-1963	Longitudinal Nail Laminated		No. 1	1450 ①	120 ①	390 ②	1200 ⑤
	Timber-Deck Bridges	Girder, Solid Sawn	Select Structural	1600 ①	120 ①	415 ②	1450 ⑤
		Transverse Nail Laminated Deck	No. 1	1450 ①	120 ①	390 ②	1200 ⑤
	Posts & Timbers		Select Structural	Not Available	Not Available	415 ②	1450 ⑤
1964-1990	Longitudinal Nail Laminated		No. 1	1500	143 ③	385 ②	1250 ⑤
	Timber-Deck Bridges	Girder, Solid Sawn	Select Structural	1600	128 ③	385 ②	1100 ⑤
		Transverse Nail Laminated Deck	No. 1	1500	143 ③	385 ②	1250 ⑤
	Posts & Timbers		Select Structural	1500	128 ③	258 ④	1092 ④

Notes:

① Do not modify values for condition of use (moisture content)

② Reduce values for bearing stress, F_{cp}, by one-third if material in the bearing zone is saturated with moisture

③ Value has been adjusted for split equal to ¾ X Wide face: F_v multiplier = 1.5 per 1973 AASHTO

④ Value has been adjusted for wet conditions per 1973 AASHTO

⑤ Reduce values by 10% if the wood is continuously wet or submerged

⑥ For timber piles, prior to 1960, the maximum design load for 12" diameter timber piling was 15 to 20 tons and the effect of any bending in the pile was considered. From 1961 to 1963, the compression parallel to grain was 1200 psi for timber piles designed as structural columns. The maximum design load for 12" diameter timber pile was 15-20 tons through the 1970's. From 1964 to 1973, AASHTO prescribed piles to be designed for safe bearing and for column action.

7.1.2.2. Sawn Lumber

Evaluate sawn lumber beams (member size 5"x5" and larger) using the following guidance:

- The application of a moisture factor for bending and shear is not required.
- For horizontal shear, if the beams are in good condition without excessive splitting, use a higher shear value so that it does not govern the rating. If inspection indicates there is a concern with shear, then use judgment.
- Apply a one-third reduction to the design stress for compression perpendicular to grain if the bearing areas are wet and/or there is concern for crushing.

Apply the following guidance to the evaluation of sawn lumber slabs and decks:

- The application of a moisture factor for bending and shear is not required.
- Apply a one-third reduction to the design stress for compression perpendicular to grain if the bearing areas are wet and/or there is concern for crushing.

Use the following guidance for the evaluation of sawn lumber planks:

- Apply a one-third reduction to the design stress for compression perpendicular to grain if the bearing areas are wet and/or there is concern for crushing.
- When the design stresses are not provided on the original plan and cannot be determined from any other source, a design bending stress, F_b, of 1500 psi may be used, with an assumed species of Douglas Fir-Larch. Refer to the appropriate *AASHTO Standard Specifications for Highway Bridges* covering the year built, and on a line corresponding to the F_b given for the assumed species Douglas Fir-Larch to determine the other stress categories.

7.1.2.3. Glued Laminated Timber

Girders, transverse decks, and longitudinal decks may all be composed of glued laminated timber. Experience has shown older girder designs commonly used wet use values but not size or volume factors. Therefore, it is recommended to use wet use values and to not apply size and volume factors. Only apply a size factor if a conservative result is needed based on engineering judgment. For long spans, shear typically does not govern. Use engineering judgment to assign a design shear value that does not govern the load rating. For compression perpendicular to grain, apply a one-third reduction in design stress if the bearing areas are wet and/or there is concern for crushing.

When the original plan is not available, and the original design stresses cannot be determined from any other source, use the following for F_b (assume species is Douglas Fir-Larch):

- Transverse decks: 1500 psi
- Longitudinal decks: 1400 psi
- Girders: 2000 psi and assume it as wet use

For the other stress categories such as shear, bearing, etc. refer to the appropriate *AASHTO Standard Specifications for Highway Bridges* for the year built and corresponding to the F_b given above for the assumed species Douglas Fir-Larch. For compression perpendicular to grain, apply a one-third reduction in design stress if the bearing areas are wet and/or there is concern for crushing.

7.1.3. Superstructure

Within the Minnesota bridge inventory are bridges that are a combination of timber and other structural materials such as steel and concrete. For example, wood decking on steel beams, or a precast concrete superstructure on timber abutments. For these types of bridges, use the LRFR method when load rating the bridge regardless of the bridge built date.

A thorough inspection of an existing timber bridge or a bridge with timber components is a very important part of a load rating. The inspection should include evaluation of the condition of all members and elements, not limited to just the superstructure. In many cases a timber substructure can control the load rating.

There are several approaches to incorporating timber section loss from internal rot and decay. For critical areas and when a less conservative load rating is desired, employ the use of advanced timber bridge inspection tools to quantify section loss. Refer to the *BSIPM* on non-destructive testing of timber, and the bridge inspection website on timber bridge inspection and maintenance (http://www.dot.state.mn.us/bridge/inspection.html).

For a more conservative approach, assume the members with rot and decay are inadequate for carrying loads, and determine the redistribution of loads due to the ineffective member. This approach serves well when decay is very difficult to quantify, and even more difficult to predict its progression. Engineering judgment plays a bigger role in load rating timber bridges because of the many factors, change in grading rules over time, and difficulty in precisely quantifying decay, etc.

Do not apply impact to timber structures per the *LRFD Specifications*. Always check the horizontal shear, as it can often control the ratings. Account for imperfections and deterioration of the members for bending and shear capacity rating calculations by reducing the species grade and/or structural section. Check vertical shear, even though it does not typically control the rating.

See *BDM Article 8.8* for load rating examples completed by the LRFR methodology of a longitudinal spike laminated timber deck, glulam beam superstructure, transverse spike laminated deck, and a transverse glued laminated deck. Note, these examples load rate the superstructure elements in the design examples of *BDM Article 8.7*.

7.1.4. Substructure

Rate pile abutments and bents when there is deterioration, damage, or tipping. Also rate the pile abutments and bents when there has been enough soil loss by scour or other means around the piles sufficient enough that buckling could be an issue or there is inadequate geotechnical support of the pile in friction.

Any decay or damage will result in the reduction of the load-carrying capacity based on a loss of cross-sectional area (for shear and compression) or in a reduction of the section modulus (for moment). Base the capacity of damaged timber bents on the remaining cross-sectional area of the pile and the column stability factor (C_p) using "d", the least remaining dimension of the pile. Determine the reductions based on field measurements. Consider the lateral earth pressure and redundancy when load rating timber piles with significant deterioration and/or tipping. Assume piles to be fixed 6 feet below the stream bed or ground line and pinned at their tops.

Load rate the abutment and pier caps if there is deterioration or other structural issues present that would influence the capacity of the cap. If there is an isolated fully decayed pile, compute the cap capacity without that pile support. If there are several fully decayed piles, the reduced capacity of the entire substructure unit may need to be estimated.

7.2. UNREINFORCED MASONRY ARCHES

The most common type of unreinforced masonry bridge is the filled spandrel arch. Regardless of type, load rate unreinforced masonry arches by the Allowable Stress Rating method. As of this writing (2018), neither LFR nor LRFR methods have been developed for the load rating of masonry structures. The minimum allowable compressive stress for masonry assemblies is given in *MBE Article 6B.5.2.6*. The values provided are empirically based and are conservative. More accurate values may be used if the masonry has been evaluated.

Base the load rating on the limitation of the tensile and compressive stresses developed in the extreme fiber when axial and bending stresses are combined, and on failure modes due to instability. Consider the arch to be an elastic, redundant structure. Investigate the three following types of failure:

- Overturning of adjacent masonry units
- Sliding or shear failure
- Compressive failure of the masonry

Approximate analysis methods may not provide adequate results, which therefore necessitate a more refined analysis. For filled spandrel arch bridges, the arch ring and surrounding fill provide structural capacity. For a refined analysis, consider the soil-structure interaction, including lateral earth pressure. The passive restraint of the fill limits the distortion of the arch under live load, and provides additional composite stiffness.

7.3. HISTORIC BRIDGES

In 1966, Congress enacted the National Historic Preservation Act to help preserve historical and archaeological sites. The MnDOT Historic Bridge program was created because of this act and works to preserve historic bridges in Minnesota. The program is administered by MnDOT's Cultural

Resources Unit, State Aid Division, and Bridge Office. The *Management Plan for Historic Bridges in Minnesota* provides information on applicable laws, funding options, rehabilitation alternatives, and Minnesota's innovative collaborative approach, where engineers and historians collaborate to find solutions to rehabilitating bridges.

Information about the MnDOT Historic Bridge program can be found at the following site, which includes a list of the over 200 historic bridges in Minnesota:

http://www.dot.state.mn.us/historicbridges/

See *MBE Article 6A.9.2* for further guidance.

7.4. PHYSICAL INSPECTION RATINGS

Use a Physical Inspection Rating (PIR) when the capacity cannot readily be calculated. Reasons that the structure cannot be calculated include:

- No bridge plans are available
- The steel reinforcement for a concrete bridge is unknown
- The superstructure has deterioration or damage which cannot be quantitatively measured, but has obviously reduced the load carrying capacity of the bridge
- The substructure has deterioration, shifting, tipping or misalignment which obviously reduced the load carrying capacity of the bridge, but the extent of the reduction cannot be readily be calculated
- The culvert has an NBI culvert rating of 4 ("poor" condition) or lower
- The culvert is posted with less than legal loads

Additionally, there are bridges for which common analytical methods are not adequate to determine a load rating. For bridges where necessary details, such as reinforcement in a concrete bridge, are not available from plans or field measurements, use knowledge of the live load used in the original design, the current condition of the structure and live load history to provide a basis for assigning a safe load capacity. A concrete bridge with unknown details need not be posted for restricted loading if it has been carrying normal traffic and shows no distress. Nondestructive proof load tests can be helpful in establishing the safe load capacity for such structures. In these circumstances, use the MnDOT load rating summary form to document the recommendation that the bridge does not need to be load tested or load rated.

A PIR must be conducted by a registered Professional Engineer in the state of Minnesota thoroughly familiar with the bridge.

Use careful consideration of all available information, including bridge condition (corrosion, spalling, damage, deflection, settlement, cracking, etc.), age, type of construction, redundancy, ADTT, loading (past, present, and future), etc. to determine the load rating. Use engineering judgment or a combination of calculations, experience, and judgment.

Owners should schedule inspections for bridges rated by physical inspection at intervals of 12 months or less.

Re-rate bridges or culverts rated by this method after each inspection if there is a change in the superstructure condition code stemming from a problem in the direct load path.

All overweight permits are prohibited from bridges rated using the PIR method, unless the bridge has a documented history of carrying heavier trucks with no evidence of distress beneath the traffic lanes.

7.5. ASSIGNED LOAD RATINGS (I.E. CULVERTS)

Standard culvert designs have been used since the 1930s. Standard designs have an inventory rating at least equal to their design load. Operating ratings can be estimated to be at least 1.5 times higher than the inventory rating. Typically, culverts have been designed as two-dimensional structures. When analyzed in three dimensions, especially when fully considering soil-structure interaction, culverts have significantly higher load carrying capacity than indicated by standard design loads.

Assign load ratings for culverts and other soil-structure interaction structures in good condition based on their type, design load, and year of construction, as shown in Table 7.5-1. The assigned load ratings shown in the table have been in use since 1990 and are based primarily on design loads used to develop MnDOT Standard Design Plans and tables for culvert and soil-structure interaction structures, and also on historical performance for structures that are in fair or better condition (NBI greater than 4).

This table is also found on Form 90 (Culvert Rating Form). Table 7.5-1 and Form 90 recommended load ratings do not apply if the NBI Culvert Condition Rating is 4 or less. After the culvert reaches an NBI rating of 4 or less, a new load rating calculation or a new Physical Inspection Rating must be made (See Article 7.4 of this manual). A new load rating must also be performed if cracking or distortion occurs beneath traffic lanes. Cracking or physical distortion under traffic lanes indicates current permit or legal truck weights should be restricted or limited.

Rate box culverts with a clear span of 20 feet or more as bridges, ***not*** with Form 90. However, precast concrete arches on footings (type 512) with spans up to 43 feet, may be rated as culverts using Form 90.

See Article 10.2 for guidelines pertaining to load rating documentation of culverts using Form 90 or Form PIR.

In most cases the bridge type will indicate if the structure is a culvert or a bridge. This may not be true for the BrM bridge types: concrete arch, steel arch, and prestress arch. For these types, check the barrel length or span length.

Box culverts of the design "Type W" were built mostly in the era of 1929 to 1944. They had a single layer of reinforcement and were designed as simple span elements on all sides. For this reason, they are rated lower. Pre-1929 box culverts may be included with this category.

See the FHWA Bridge Inspector's Reference Manual (BIRM), Chapter 14, for further guidance on the characteristics, inspection, and evaluation of culverts.

Table 7.5-1: Load Rating Guidelines

Material	Culvert Type	Structure Type Code	Inventory Load Rating	Operating Load Rating
Cast-in-place Concrete ①	Box	113	HS-22.0	HS-33.0
	Type W Box (1930 era)	113	HS-16.0	HS-24.0
	Footing Supported Arch	112	HS-20.0	HS-30.0
Precast Concrete ①, ②	Box	513	HS-24.0	HS-36.0
	Footing Supported Arch	512	HS-20.0	HS-30.0
	Round Pipe	514	HS-24.0	HS-36.0
	Pipe-Arch	515	HS-22.0	HS-33.0
Aluminum	Box	913	HS-14.0	HS-21.0
Metal	Footing Supported Arch	312	HS-12.0	HS-18.0
	Round Pipe	314	HS-16.0	HS-24.0
	Pipe-Arch	315	HS-16.0	HS-24.0
	Elliptical	316	HS-16.0	HS-24.0
Timber	Box	713	HS-14.0	HS-21.0
Masonry	Footing Supported Arch	812	HS-18.0	HS-27.0
① **Structures with Load Factor HS-25 Design**			**HS-25.0**	**HS-42.0**
② **Structures with LRFD HL 93 Design using Standard Plans – Precast Concrete Box Culvert**			**RF=1.0**	**RF=1.3**

7.6. NONDESTRUCTIVE LOAD TESTING

The actual performance of most bridges is more favorable than conventional theory dictates. If directed by MnDOT, the safe load capacity for a structure can be determined from full scale nondestructive field load tests, which may be desirable to establish a higher safe load carrying capacity than calculated by analysis. A nondestructive load test may also be necessary if the bridge cannot be rated by ordinary methods.

During a nondestructive load test, the bridge is monitored with strain gages and other instruments. Normal traffic is stopped and calibrated test trucks are driven across the bridge. Extensive

calculations are required before and after the test. A computer model is "calibrated" to the load test results. The calibrated computer model is used to determine a safe load capacity for the structure. Refer to the *MBE Section 8* for information on conducting nondestructive load tests and using the results to establish a new or updated load rating.

The nondestructive load testing rating method will only be accepted with the express written consent of MnDOT. No investigations of this nature should be undertaken without the prior approval of the State Bridge Load Rating Engineer. Due to safety considerations, nondestructive load testing is not typically recommended.

SECTION 8: ANALYSIS SOFTWARE

8.1. REQUIRED SOFTWARE FOR ROUTINE BRIDGES

Standard analysis tools applicable to MnDOT bridge inventory can maximize efficiency, provide consistency, and facilitate future revisions of Load Ratings by different parties. To this end, MnDOT has specified the AASHTOWare Bridge Rating (BrR) software program as the acceptable load rating software to be used. If a bridge is capable of being defined within the parameters of BrR, it must be rated using BrR. As of this writing (BrR Version 6.8.2) the software can analyze the following structure types:

- Girder System or Girder Line Superstructures
    - Reinforced concrete decks on steel, concrete, or timber beams
    - Transverse nail-laminated or plank timber decks on timber or steel beams
    - Corrugated metal decks on steel, concrete, or timber beams
    - Generic decks on steel, concrete, or timber beams
    - Steel girder, including:
        - Rolled shapes
        - Plate girders
        - Built-up sections
        - Non-detailed sections
    - Prestressed concrete, including:
        - I-beams
        - I-beams with a top flange that acts as a deck
        - I-beams with no top flange
        - Box beams with circular voids
        - Box beams with rectangular voids
        - Tee beams
        - Tee beams with a top flange that acts as the deck
        - U-beams
    - Reinforced concrete, including:
        - I-beams
        - T-beams
        - Slab
    - Timber beams, including:
        - Rectangular sawn timber beams
- Floor System or Floor Line Superstructures
    - Reinforced concrete decks on steel beams
    - Corrugated metal decks on steel, concrete, or timber beams
    - Steel girders, including:
        - Rolled shapes
        - Plate girders
        - Built-up sections
    - Floor trusses
- Truss System or Truss Line Superstructures
    - Steel longitudinal truss members, including:
        - Rolled shapes

        - Built-up sections
        - Channel box sections
        - Angle box sections
        - Non-detailed sections
    - Steel transverse truss members, including:
        - Floor trusses
    - Steel floorbeam and stringer
- Reinforced Concrete Slab System Superstructures
    - Reinforced concrete slab
- Concrete Multi-Cell Box Superstructures
    - Post-tensioned concrete multi-cell box
    - Reinforced concrete multi-cell box
- Culverts
    - Reinforced concrete box culverts

Any type of structure that is not listed above, or included in later versions of BrR is to be considered a complex bridge. Regardless of BrR capabilities, note that curved steel girders are considered a complex structure type. Complex bridges have additional analysis and quality control/quality assurance requirements. See Article 8.3 and Section 9.

Use of other analysis software such as STAAD, LUSAS, MDX, CONSPAN, MATHCAD, Excel, Influence Line Programs, etc. is subject to the consent of MnDOT, and must follow the quality process defined in *BDM Section 4.1*.

8.2. MODELING GUIDANCE FOR ROUTINE BRIDGES

Bridges entered in BrR shall use the "Girder System Definition" whenever the bridge geometry will fit within the limitations of BrR.

When using the "Girder Line Superstructure Definition", rate an interior beam under a vehicle traffic lane. When it is unclear whether an interior or exterior beam governs the load rating, or some unique circumstance such as damage or corrosion exists the engineer is responsible to rate the typical interior beam and the exterior or other potentially controlling element.

See Appendix H for additional load rating instructions specific to BrR.

8.3. ANALYSIS GUIDANCE FOR COMPLEX BRIDGES

See Article 4.3.3 for guidance on the analysis of complex bridges, and Article 4.3.3.4 for guidance on reporting the load rating from complex analysis.

Consult with MnDOT prior to undertaking a refined analysis to discuss the need for as well as benefits and costs of the refined analysis.

SECTION 9: QUALITY CONTROL AND QUALITY ASSURANCE

9.1. INTRODUCTION

Quality has two components, quality control (QC) and quality assurance (QA). In general QC involves the detailed checking of the load rating work products while QA is an audit and overall quality and consistency check of the load rating program. The NBIS provides specific definitions that are useful in defining QC and QA.

> **Quality control (QC)**. Procedures that are intended to maintain the quality of a bridge inspection and load rating at or above a specified level.
>
> **Quality assurance (QA)**. The use of sampling and other measure to assure the adequacy of quality control procedures to verify or measure the quality level of the entire bridge inspection and load rating program.

QC/QA is both a part of MnDOT practice and a federal requirement as part of 23 CFR 650.313(g).

23 CFR 650.313(g) states the requirements for QC/QA as:

Assure systematic quality control (QC) and quality assurance (QA) procedures are used to maintain a high degree of accuracy and consistency in the inspection program. Include periodic field review of inspection teams, periodic bridge inspection refresher training for program managers and team leaders, and independent review of inspection reports and computations.

Thus, there is a federal oversight requirement that includes a review of MnDOT QC/QA practices and the qualifications of individuals involved in inspection and load rating. Quality control of the inspection and load ratings and quality assurance of the overall process is therefore essential. The FHWA 23 Metrics further emphasizes this point when in Metric #20: Inspection Procedures – QC/QA, it states:

This metric evaluates if the QC/QA process meets the intent of the NBIS, verifies that the reviews are performed and review results are being used to maintain a high degree of accuracy and consistent in the inspection program.

Thus, it is the intent of this section to implement a QC/QA procedure that is consistent with the CFR requirements as well as MnDOT's own standards.

9.2. QUALITY CONTROL

Quality control procedures are intended to maintain the quality of the bridge load ratings and are performed continuously within the load rating teams/units when the load ratings are performed by the MnDOT bridge rating unit. When consultants perform load ratings, the consultant shall have quality control procedures in place to assure the accuracy and completeness of the load ratings. All load rating calculations shall be checked by a qualified engineer other than the load rating engineer. Upon completion, place the initials of the checker on every sheet of the calculations.

Conduct quality control checks on every load rating product. The quality control expectations are described in more detail in *BDM Article 4.1* and *BSIPM Chapter E – Quality Control (QC)/Quality Assurance (QA)*. As discussed in Article 8.1, BrR is considered a validated software program for routine bridges.

When computer programs are used, perform necessary independent checks to validate the accuracy of the load rating results generated by the program. The checker's responsibilities include verifying all input data, verifying that the summary of load capacity information accurately reflects the analysis, and being satisfied with the accuracy and suitability of the computer program.

Consultants are responsible for being familiar with MnDOT Bridge Load Rating policies and procedures. Consultants performing bridge load ratings for Bridge Owners are responsible for QC on their work for accuracy and completeness.

9.2.1. Load Rating of New Bridges

Load rating a bridge requires a Load Rating Engineer (LRE) and either a second LRE or a Load Rater (LR). One will perform the load rating and fill out the load rating forms in a manner as described in Section 10. The LRE who signs the forms must be a registered Professional Engineer in the state of Minnesota.

A second engineer will perform an independent check of the load rating and forms and initial the forms at the completion of this check. The checker should be as or more experienced than the originator. An originator or a checker can sign the rating forms.

Include the following in the check:

- Examine overall load rating concepts.
- Examine assumptions made for the modeling and load rating of the bridge.
- Check that correct material strengths are used.
- Check that the applied dead loads (including deck thickness, overlays, railings, diaphragms, etc.) are correct.
- Check live load distribution factors.
- When using BrR, check "hidden" factors such as engine settings, points of interest, etc.
- For complex bridges, refer to the direction for "Intermediate" and "Complex" levels of checking in *BDM Article 4.1*.
- Verify critical elements.
- Check that the final documentation is correct and complete.

9.2.2. Re-rating Existing Bridges

The requirements for personnel, load rating, and documentation are similar to those described in Article 9.2.1. Base the re-rating on the original load rating and include changes that have occurred since the previous load rating. Preserve the original input (computer) file, and apply the changes to a copy.

The check will be similar to that of new bridge load ratings as described above except that it should be focused primarily on the changes that have occurred since the previous load rating. All inputs should be checked, particularly if the rating is switching from LFR or ASR to LRFR.

9.2.3. Bridge Load Posting

Calculations made that demonstrate a need for load posting require the work be performed by a LRE and a second LRE or a LR serving as a checker. This work also requires review and approval from the Program Manager (PM) and the State Bridge Engineer (SBE). The rating will be performed as described in Article 9.2.2. A memo will be prepared from the SBE to the District Engineer summarizing the load rating and load posting actions. The PM will review the load rating/load posting and advise the SBE. The SBE will then review and sign the memo that accompanies the load rating.

9.3. QUALITY ASSURANCE

The MnDOT Bridge Load Rating Unit is responsible for Quality Assurance of bridge load ratings. The Bridge Load Rating Unit is responsible for reviewing state owned bridge load rating reports. MnDOT also audits bridge load rating reports for bridges owned by local or other agencies that carry public transportation.

For bridges that are not state owned, the Program Administrator (PA) is responsible to review their own bridge load rating reports.

Quality assurance procedures are used to verify the adequacy of the quality control procedures to meet or exceed the standards established by the agency or the consultant performing the load ratings. These QA procedures apply to load ratings performed by MnDOT personnel, local agencies, and consultants. Quality assurance is performed independent of the load rating QC. Further guidance on the QA procedure for MnDOT bridge inspection and load rating is found in *BSIPM Section A.8.4.1* and *BSIPM Section E.5*.

SECTION 10: FORMS AND DOCUMENTATION

10.1. GENERAL GUIDANCE

When the load ratings are complete, compile the load rating calculations and documentation into a comprehensive report to facilitate updating the information and calculations in the future. Completely document the load rating including all background information such as field inspection reports, material and load test data, all supporting computations, and a clear statement of all assumptions used in calculating the load rating. Provide sketches to document section losses incorporated in the analysis. Reference the inspection reports, testing reports, and other information relied on to compute the load rating. When refined methods of analysis or load testing are used, include live load distribution factors for all rated members. For complex structures where computer models are used in the analysis, provide a copy of the computer models with documentation to MnDOT. For new, replaced and rehabilitated bridges designed using LRFD, compute the LRFR load ratings at the time of design and show the operating rating factor on the structural drawings in the Design Data block.

Submit an electronic version of the load rating report, including the input data file and any computer models used in the analysis, to MnDOT.

Fully document the loading conditions used for the load rating. This includes changes from the original plan, deck replacements or thickness modifications, railing modifications or replacements, bridge widening, unusual loading conditions, and damage or deterioration incorporated in the load rating. List the condition or event, its key details, and the date of the event. In documenting the deck changes, list thicknesses of: 1) the original deck, 2) the amount milled, 3) the overlay, and 4) the final configuration.

Enter the NBI Condition Rating values, which are sometimes called condition codes. For new bridges, these will all be 9. For re-rating old bridges, the current load ratings are found on the MnDOT Structure Inventory Report.

Document load rating considerations given for damage or deterioration. A bridge in a deteriorated condition will require more detail and explanation in the load rating.

Clearly document assumptions used in the load rating calculations or structural modeling. If the information is readily found in the computer files (BrR or other software), it need not be repeated.

10.2. REPORTING FORMS

Summarize the results of a bridge load rating analysis on a bridge load rating and load posting report form. MnDOT load rating forms can be found on the MnDOT Bridges and Structures website under the heading "Bridge Rating" (see link below):

http://www.dot.state.mn.us/bridge/datamanagement.html

These are the MnDOT load rating and load posting report forms. Hard copies are found in Appendix B but the website will always contain the most up-to-date version of all forms.

- Form RC-TH & RD-TH (Bridge Rating and Load Posting Report for Trunk Highways)
- Form RC-CL & RD-CL (Bridge Rating and Load Posting Report for County and Local Agencies)
- Form PIR-TH (Bridge Rating and Load Posting Report for Trunk Highways – Physical Inspection Rating)
- Form PIR-CL (Bridge Rating and Load Posting Report for County and Local Agencies – Physical Inspection Rating)
- Form 90 (Culvert Rating Form)
- TrussR (supplemental load rating worksheet for truss members)
- Form PW (supplemental load posting worksheet)

10.2.1. Form RC-TH and RD-TH (Minnesota Trunk Highway Bridges)

Form RC-TH / RD-TH is the load rating, load rating details, and load posting report for Minnesota trunk highway (TH) bridges. This form and any load rating calculations are retained in the MnDOT Load Rating Engineer files. If the analysis type requires the inclusion of the G-07 permit vehicles, append the table on the form to include these additional vehicles. Forward a copy of Form RC-TH to the MnDOT Bridge Inventory Management Unit (BIMU) to update the structure inventory report. This will be retained in the files of the BIMU. Load rating reports for most trunk highway (TH) bridges are now available through the MnDOT Electronic Document Management System (EDMS) to allow MnDOT Districts to view, download or print load rating reports.

10.2.2. Form RC-CL and RD-DL (County, Township, and City Bridges)

Form RC-CL / RD-CL is the load rating, load rating details, and load posting report for County, Township, and City bridges. This form (along with all load rating calculations) must be retained in the files of the Bridge Owner. Submit a copy of Form RC-CL to the BIMU to update the structure inventory report. This will be retained in the files of the BIMU.

10.2.3. Form PIR-TH or Form PIR-CL (Physical Inspection Rating Form)

In situations where a load rating cannot readily be calculated, an evaluation by an engineer based upon the most recent inspection may be used to approximate the inventory and operating ratings. Physical Inspection Ratings are discussed in Article 7.4, and require Form PIR (Physical Inspection Rating) to be used.

The numbers in the load rating should follow the approximate ratio given in Table 10.2.3-1, where "T" is the posting tonnage.

Table 10.2.3-1: PIR Load Rating Guideline

Single Weight Posting Sign (R12-1a)	Posting Sign (R12-5)		Rating	
	Single Vehicle	Combination Vehicles	Inventory	Operating
T	T	1.6 x T	HS (0.6 x T)	HS (T)

For bridges that carry a large percentage of Specialized Hauling Vehicles (SHV), contact the MnDOT Bridge Office Load Rating Unit to determine acceptable alternatives if Table 10.2.3-1 results in posting loads that are excessively restrictive.

On this form, for "Type of Analysis" check "Other" and write in "PIR". For "Method of Rating" check "Field Eval./Doc. Engineering Judgment/PIR".

Form PIR must be retained in the files of the Bridge Owner. A copy of Form PIR should be submitted to the BIMU to update the structure inventory report. These will be retained in the files of the BIMU.

Bridges rated using Form PIR should have all overweight permits prohibited, unless the bridge has a documented history of carrying heavier trucks with no evidence of distress beneath the traffic lanes.

10.2.4. Form 90 (Culvert Rating Form):

Any culvert which carries vehicular traffic and is defined as a "bridge" under Minnesota state law (total structure length of 10 feet or greater), must have a load rating. New culverts, or culverts in fair or better condition with no evidence of distress due to normal traffic loads, can be rated using Form 90. Form 90 includes a table from which the inventory and operating ratings can be selected based upon the culvert design and material type. The inventory ratings shown in the table are based upon the minimum original design load, regardless of original capacity.

Before using the table on Form 90, the most recent bridge inspection report must be reviewed to confirm that the NBI culvert rating (NBI Item 62) is condition 5 or greater. If the NBI culvert rating is 4 ("poor" condition) or lower, Form 90 cannot be used. Form PIR should then be used to determine a reduced level for these ratings.

Some other guidelines for using Form 90 include:

- If the Form 90 table guidelines are not followed in determining the inventory and operating ratings, provide an explanation.
- Box culverts with a clear span 20 feet or greater cannot be rated using Form 90 - they must be rated as a "bridge" (use Form RC-CL or RC-TH instead).
- If a culvert is comprised of more than one culvert type or material, the segment with the lowest inventory and operating ratings will govern (this should be noted on Form 90).

Cast-in-place concrete box culverts are typically classified as either type "W" (generally constructed in 1944 and earlier) or type "C" (generally constructed after 1944). Type "W" culverts typically have less steel reinforcement, and therefore will have lower inventory and operating ratings.

The Culvert Rating Form 90 should be retained in the files of the Bridge Owner. Submit a copy of Form 90 to the BIMU to update the structure inventory report. This will be retained in the files of the BIMU.

10.2.5. Form TrussR

Form TrussR contains the load rating details for the main components of a truss: stringers, floorbeams, truss members, and joints. For each of these element groupings, list the member designation as well as the IN and OP rating factors. Provide details in the Location / Comments section to describe the specific conditions that affect the load rating. For the stringers, rate the interior and exterior stringers and provide each value. Rate each unique floorbeam type and provide the controlling value. Rate the truss members and gusset plates / connections using the provisions herein and found in the *MBE*. For all load rated elements, clarify the position and number of traffic lanes assumed in the rating. This is important to distinguish load rating results for design and legal loads as compared to rating results for permit loads that could for instance, be the only vehicle on the bridge and located transversely on the deck so as to achieve a more favorable rating result.

10.2.6. Form PW

Form PW is used to provide the information needed for bridge posting. Record the RF and equivalent TON information for each Minnesota posting vehicle on this form. See Article 4.8 and Article 5.8 for additional details on load posting analysis.

10.2.7. Summary

Any questions related to performing load ratings or filling out the MnDOT load rating and load posting report forms should be directed to the State Bridge Load Rating Engineer. Immediately after a load rating is performed, a copy of the appropriate MnDOT load rating and load posting report form(s) should be submitted to the MnDOT Bridge Inventory Management Unit to update the structure inventory.

Bridge Inventory Management Unit
MnDOT Bridge Office
3485 Hadley Avenue North
Oakdale, MN 55128-3307

SECTION 11: SUBMITTAL

The original copy of the load rating should be retained in the files of the bridge owner. For trunk highway (TH) bridges these are the files of the MnDOT Bridge Ratings Unit.

Deliver copies of all load ratings (township, county, city, state, etc.) to:

Bridge Inventory Management Unit
MnDOT Bridge Office
3485 Hadley Avenue North
Oakdale, MN 55128-3307

The copies are kept on file and selected information will be entered in Structure Information Management System (SIMS). From there annual reports are prepared and sent to the FHWA.

Copies of MnDOT bridge load ratings will be scanned and entered in EDMS. From there, they can be accessed by bridge inspectors.

SECTION 12: LOAD RATING EXAMPLES

Examples will be provided in the future.

APPENDIX A: GLOSSARY

AASHTO --- American Association of State Highway and Transportation Officials

ADTT --- Average Daily Truck Traffic. (In BrM, this is called HCADT)

Allowable Stress Design (ASD) --- The original AASHTO design method. The safety factors are applied to the material strength portion of the structure capacity. Also called working stress design (WSD).

Allowable Stress Rating (ASR) --- The load rating version of ASD

Annual Average Daily Traffic (AADT) --- The theoretical estimate of the total number of vehicles using a specific segment of roadway (in both directions) on any given day of the year. This estimate represents the total number of cars per year divided by 365 and is developed using factors to adjust for season, day of the week, and vehicle type.

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

Average Daily Traffic (ADT) --- A 24-hour traffic volume that should be qualified by stating a time period.

BDM --- *MnDOT LRFD Bridge Design Manual*

BIMU --- MnDOT Bridge Inventory Management Unit

BrR --- AASHTOWare Bridge Rating software

BrM --- AASHTOWare Bridge Management software. See SIMS.

BPIG --- *Bridge Preservation and Improvement Guidelines*

BSIPM --- *Bridge and Structure Inspection Program Manual*

CAFT --- constant-amplitude fatigue threshold

Dead Load --- Those loads that are constant in magnitude, fixed in location, and remain in place permanently or for a long period of time.

Dynamic Load Allowance (in LRFD, abbreviated as IM) --- An increase in the applied static force effects to account for the dynamic interaction between the bridge and moving vehicles. The additional live load is expressed as a percent increase of the vehicle live load. It represents the vertical forces due to vibrations and bouncing of a vehicle as it passes over a bumpy bridge deck. AASHTO specifies the methods of calculation. It is always applied with the vehicle live load unless a specific reason is given otherwise.

EDMS --- Electronic Document Management System

FHWA --- Federal Highway Administration

***FRA* ---** Federal Railroad Administration

***Gross Vehicle Weight (GVW)* ---** Total weight of the vehicle including the empty weight plus all variable loads such as freight, passengers, fuel, etc. (See also Minn Stat 169.01, Subd. 46.)

***Heavy Commercial Annual Average Daily Traffic (HCAADT)* ---** The theoretical estimate of the number of heavy commercial vehicles using a specific segment of roadway (in both directions) on any given day of the year. This estimate represents the total number of heavy commercial vehicles per year divided by 365 and is developed using factors to adjust for season. See AADT.

***Heavy Commercial Average Daily Traffic (HCADT)* ---** A 24-hour heavy commercial truck volume that should be qualified stating a time period. See ADT and ADTT.

***Impact (IM)* ---** See Dynamic Load Allowance

***Inventory Rating Level* ---** As defined by AASHTO, it is equivalent to the design level of stress. A bridge subjected to no more than this stress level can be expected to safely function for a life of 75 or more years.

***Kip or k* ---** A weight of 1000 pounds

***Legal Load* ---** The maximum GVW a truck may have without a permit. Minnesota Statute 169 defines this.

***Legal Trucks* ---** These are the model trucks used to determine load postings on bridges. The MBE defines standard loadings and Minnesota has adopted variations of them as given in Appendix E. (Sometimes called Posting Trucks.)

***Live Loads* ---** Loads that remain in place for a relatively short time. These are mainly vehicle loads: cars, busses, trucks, etc. Bridge load rating is usually concerned with only the truck live loads. Other live loads are: construction equipment, pedestrian, wind, stream flow, and several others as given in the AASHTO *LRFD Bridge Design Specifications*.

***Load and Resistance Factor Design (LRFD)* ---** *AASHTO LRFD Bridge Design Specifications* introduced in 1994. It has been gradually implemented by designers over the approximate period of 1996 to 2005. Safety factors are applied to both the bridge capacity and to the loads to achieve a system of ratings with uniform reliability.

***Load and Resistance Factor Rating (LRFR)* ---** The load rating version of LRFD.

***Load Factor Design (LFD)* ---** The AASHTO design method used for bridges from approximately 1975 to 1995. Separate load factors (or safety factors) are applied to the dead load, and to the live load.

***Load Factor Rating (LFR)* ---** The load rating version of LFD.

***Load Rater (LR)* ---** A graduate engineer with at least three years of experience in bridge rating and/or design.

Load Rating Engineer (LRE) --- A person who signs the Bridge Rating and Load Posting Forms. The individual must be a registered Professional Engineer in the state of Minnesota, and have expertise required to properly evaluate the structure being rated.

Load Rating --- The determination of the safe live load carrying capacity of a new or an existing bridge. This is calculated using existing bridge plans supplemented by information gathered from a field inspection. The basic equation is given in MBE Equation 6A.4.2.1-1. (This is sometimes known as "Capacity Rating.") Load Ratings may be subdivided into specific types depending on which live load is used in the denominator of load rating equation. Some of these types are:

> ***Design Load Rating ---*** The AASHTO Design Loading (HL-93) is used for the live load. The final load rating is expressed as a rating factor.
>
> ***Legal Load Rating ---*** The live load is one or more of the "legal trucks." If the RF is less than 1.00 (or another specified amount), the bridge will be posted. (Sometimes called Posting Rating.)
>
> ***Annual Permit Load Rating ---*** The live load model used represents a possible truck or class of trucks that may operate under an annual overweight permit.
>
> ***Single Trip Permit Load Rating ---*** The specific overweight permit truck model is used in the denominator of the load rating equation.

Load Rating Equation --- Equation 6A.4.2.1-1 of the MBE.

LRFD Specifications –-- *AASHTO LRFD Bridge Design Specifications*, See Load and Resistance Factor Design (LRFD)

Manual for Bridge Evaluation. (MBE) --- The second edition was published in 2011 by AASHTO. Its use should also include all interims as added in 2013, 2014, 2015, and 2016. The MBE replaced both the MCE and the *AASHTO Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges*.

Manual for Condition Evaluation of Bridges (MCE) --- The second edition was published in 1994 by AASHTO. Its use should also include all interims as added in 1995, 1998, 2000, 2001, and 2003. The MCE was replace by the MBE.

MN MUTCD --- *Minnesota 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 NBIS.

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

Office of Freight and Commercial Vehicle Operations (OFCVO) --- Issuing permits for overweight and overdimension vehicles is one of the functions of this office. They are in the Modal Planning and Program Management Division of MnDOT. Their website: http://www.dot.state.mn.us/cvo/index.html

Operating Rating Level --- As defined by AASHTO. The maximum permissible live load stress level to which a structure may be subjected. Allowing an excessive volume of vehicles to use a bridge at Operating Level may shorten the life of the bridge.

Permit Office --- The unit of the Office of Freight and Commercial Vehicle Operations (OFCVO) that issues overweight / overdimension permits.

PIR --- Physical Inspection Rating

Program Administrator (PA) --- A registered Professional Engineer in the state of Minnesota appointed by an agency or jurisdiction to oversee the bridge inspection program and have QC responsibilities as delegated by the Project Manager.

Program Manager (PM) --- The individual in charge of the program, that has been assigned or delegated the duties and responsibilities for bridge inspection, reporting, and inventory. The Program Manager provides overall leadership and is available to inspection team leaders to provide guidance.

Posted --- The maximum loads allowed on a bridge are indicated by signs erected at each end of the bridge. Also known as Load Posted or Load Posting.

Quality Assurance (QA) --- 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 rating program.

Quality Control (QC) --- Procedures that are intended to maintain the quality of a bridge load rating at or above a specified level.

Rating --- See Load Rating. (Another type of bridge rating is called "appraisal rating" or "condition rating." It is based on the Condition Codes of a bridge. Refer to the Bridge Inspectors Manual for more information on this.)

Rating Factor (RF) --- The result of calculating the load rating equation, MBE 6A.4.2.1-1. Generally a RF ≥ 1.0 indicates that the member or bridge has sufficient capacity for the applied live load and is acceptable; and a RF < 1.0 indicates overstress and requires further action. A RF is always associated with a particular live load.

Standard Specifications --- AASHTO *Standard Specifications for Highway Bridges*, Seventeenth Edition-2002

State Bridge Engineer (SBE) --- The individual responsible for the overall management of the QC/QA program in the Bridge Office.

State Bridge Load Rating Engineer (SBLRE) --- The individual responsible for the overall management of the load rating program in the Bridge Office.

Structures Information Management System (SIMS) --- The database that includes information on all bridges in Minnesota. It is maintained by the Bridges Office's Bridge Inventory Management Unit. Bridge load ratings are part of that information. The "MnDOT Structure Inventory Report" contains a summary of the information.

SI&A --- Structure Inventory and Appraisal

SHV --- Specialized Hauling Vehicles

Standard Permit Trucks --- Model trucks used to determine the capacity of bridges for a broad group of overweight trucks. See diagrams in Appendix F.

TDA --- Traffic and Data Analysis

Trunk Highway (TH) --- This consists of all highways under the jurisdiction of the State of Minnesota, including Interstate highways, U.S. highways and Minnesota state highways.

Type --- Bridge type refers to a brief description of the bridge superstructure. The names and numerical codes for these are found in Appendix 2-A of the BDM.

APPENDIX B: LOAD RATING FORMS

This appendix includes the load rating forms. These forms include:

1. Form RC-TH & RD-TH (Bridge Rating and Load Posting Report for Trunk Highways)
2. Form RC-CL & RD-CL (Bridge Rating and Load Posting Report for County and Local Agencies)
3. Form PIR-TH (Bridge Rating and Load Posting Report for Trunk Highways – Physical Inspection Rating)
4. Form PIR-CL (Bridge Rating and Load Posting Report for County and Local Agencies – Physical Inspection Rating)
5. Form 90 (Culvert Rating Form)
6. TrussR (supplemental load rating worksheet for truss members)
7. Form PW (supplemental load posting worksheet)

FORM RC-TH
Revised July 2016

MnDOT BRIDGE RATING AND LOAD POSTING REPORT
FOR TRUNK HIGHWAYS

Bridge Location and Description

Bridge No. _____

Hwy. No. _____ Over ☐ Under ☐ _____

Year Built _____ Year Remodeled _____ Replaces Br. _____

Type _____ County _____ Ref. Pt. _____

Description _____

Location _____

Data for Basis of Report (Check all that apply)

☐ Bridge Inventory File
☐ Previous Bridge Rating and Load Posting Report
☐ Bridge Plans
  ☐ New ☐ Overlay
  ☐ Repair/Reconstruction _____
  ☐ Other Dead Load Modifications
☐ Bridge Inspected by _____ ,date _____
  ☐ Damaged Component _____
  ☐ Deteriorated Component

Types of Analysis:
☐ Manual ☐ AASHTOWare BrR, V.____ ☐ Computer* ☐ Other*
* _____

NBI Condition Ratings
Deck _____
Superstructure
Substructure _____
ADTT _____

Method of Rating (Check appropriate box)

☐ Load Factor (LF) ☐ Assigned LF Rating
☐ Allowable Stress (AS) ☐ Assigned LRFR
☐ Load & Resistance Factor (LRFR)
☐ Load Testing
☐ Field Eval./Doc. Engineering Judgment

Design Load

Design Method _____

Summary of Rating and Load Posting Analysis

Load Posting
Required ☐
Not Required ☐

Sign	TONS		
R12-1A ☐			
R12-5a ☐			
R12-5 ☐	M3	M3S2	M3-3
R12-x11 ☐		45	

Bridge Rating

Inventory	Operating
HS ☐ RF ☐ _____	HS ☐ RF ☐ _____

Overweight Permit Codes

A _____ B _____ C _____

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Signature: _____ Date: _____

(Typed or Printed) Name: _____ License No. _____

(Typed or Printed) Employed by (☐Agency/☐Firm): _____

FORM RD-TH
Revised Oct. 2011

BRIDGE RATING DETAILS

Bridge Type _____ Bridge No. _____
Rating Method _____ Design Load: _____
Roadway Width _____ Inventory Rating: _____
☐ Curved ☐ Tapered Operating Rating: _____
Beam Spacing _____ Rated _____ Checked _____
☐ Live Load Distribution Factor Date: _____
Single _____ Multiple _____ Sheet _____ of _____
☐ Finite/Grid Element Analysis

BEAM ELEVATION [2]
Show span lengths, structure/beam depths.

Truck	Rating Factor	Span/ Pier	Location	Limit State [1]	Notes/Comments
HS 20 Inventory					
HS 20 Operating					
Standard A [3]					
Standard B [3]					
Standard C [3]					
Standard P411 [3]					
Standard P413 [3]					

1 Choose from: service or ultimate; shear or moment
2 Elevation may be on back or another sheet if it won't fit here
3 If the bridge needs posting, change these trucks to the posting trucks.

FORM RC-CL
Revised July 2016

MnDOT BRIDGE RATING AND LOAD POSTING REPORT
FOR COUNTY AND LOCAL AGENCIES

Bridge Location and Description

Bridge No. _____

Hwy. No. _____ Over ☐ Under ☐ _____

Year Built _____ Year Remodeled _____ Replaces Br. _____

Type _____ County _____ Ref. Pt. _____

Description _____

Location _____

Data for Basis of Report (Check all that apply)

- ☐ Bridge Inventory File
- ☐ Previous Bridge Rating and Load Posting Report
- ☐ Bridge Plans
  - ☐ New ☐ Overlay
  - ☐ Repair/Reconstruction _____
  - ☐ Other Dead Load Modifications _____
- ☐ Bridge Inspected by _____ Date _____
  - ☐ Damaged Component
  - ☐ Deteriorated Component

Types of Analysis:
☐ Manual ☐ AASHTOWare BrR, V.____ ☐ Computer* ☐ Other*
* _____

NBI Condition Ratings
Deck
Superstructure
Substructure
ADTT _____

Method of Rating (Check appropriate box)
- ☐ Load Factor (LF)
- ☐ Allowable Stress (AS)
- ☐ Load & Resistance Factor (LRFR)
- ☐ Load Testing
- ☐ Field Eval./Doc. Engineering Judgment
- ☐ Assigned Load Ratings
- ☐ Assigned LRFR

Design Load _____

Design Method _____

Summary of Rating and Load Posting Analysis

Load Posting
Required ☐
Not Required ☐

Sign	TONS		
R12-1a ☐			
R12-5A ☐			
R12-5 ☐	M3	M3S2	M3S3
R12-X11 ☐		45	
R11-2a ☐	**BRIDGE CLOSED**		

Bridge Rating

Inventory	Operating
HS ☐	HS ☐
RF ☐ ____	RF ☐ ____

Overweight Permit Codes

A _____ B _____ C _____

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Signature: _____ Date: _____

(Typed or Printed) Name: _____ License No. _____

(Typed or Printed) Employed by (☐Agency/☐Firm): _____

My signature below indicates that I have read and fully agreed with the load rating report.

Program Administrator's Signature: _____ Date: _____

FORM RD-CL Revised Dec. 2015	BRIDGE RATING DETAILS

Bridge Type _____ Bridge No. _____

Rating Method _____ Design Load: _____

Roadway Width _____ Inventory Rating: _____

☐ Curved ☐ Tapered Operating Rating: _____

Beam Spacing _____ Rated _____ Checked _____

☐ Live Load Distribution Factor Date _____

Single _____ Multiple _____ Sheet _____ of _____

☐ Finite/Grid Element Analysis

BEAM ELEVATION [2]

Show span lengths, structure/beam depths.

Truck		Rating Factor	Span/ Pier	Location	Limit State [1]	Notes/Comments
☐ HS20 ☐ HL93	Inventory					
☐ HS20 ☐ HL93	Operating					
Post, M3						
Post, M3S2						
Post, M3S3						
Type SU4						
Type SU5						
Type SU6						
Type SU7						

1 Choose from: service or ultimate; shear or moment

2 Elevation may be on back or another sheet if it won't fit here.

FORM RD-CL Revised Dec. 2015	BRIDGE RATING DETAILS

Annual/Routine Permit	No Restriction	Straddle Two Lanes	5% Impact	Notes/Comments
	Rating Factor	Rating Factor	Rating Factor	
STD. A				
STD. B				
STD. C				
6-axle, 90k-99k				
7-axle, 97k-99k				

Special/Single Permit	No Restriction	Straddle Two Lanes	5% Impact	Notes/Comments
	Rating Factor	Rating Factor	Rating Factor	
P411		**		
P413		**		
C152		**		
C174b		**		
C214b		**		
C237b		**		
C256b		**		
CPM200j		**		

OVERWEIGHT PERMIT RESTRICTIONS FOR LOCAL BRIDGES

Restriction Code	Restriction Description	Special/ Single Permit	Annual/ Routine Permit	Detailed Restriction Description	Bridge Check Operation
1	None	YES	YES	No Restriction to cross bridge	Normal
2	Straddle Two Lanes	YES	YES	Drive on the centerline between two lanes, in a manner that prevents any other vehicle from occupying a part of either lane on either side of the permit vehicle. Drive in the center of a single lane bridge.	The AASHTO "Single Lane" live load distribution is used. *This operation applies to all permit vehicles when performing LFR method or only to annual permit vehicles when performing LRFR method.*
3	Maximum speed of 10 mph	YES ①	YES ①	Drive at a speed of 10 mph or less	The impact factor is reduced from the AASHTO impact to 5%
X	DENIED	YES	YES	The overweight permit vehicle is **NOT ALLOWED** on this bridge	Used when requirements for restriction 1 thru 3 are not met

① Not allowed where there is a posted minimum speed.

** "N/A", Does not apply when performing LRFR method, ref. AASHTO MBE Table 6A.4.5.4.2a-1

FORM PIR-TH
Revised July 2016

MnDOT BRIDGE RATING AND LOAD POSTING REPORT
FOR TRUNK HIGHWAYS

Bridge Location and Description

Bridge No. _____

Hwy. No. _____ Over ☐ Under ☐ _____

Year Built _____ Year Remodeled _____ Replaces Br. _____

Type _____ County _____ Ref. Pt. _____

Description _____

Location _____

Data for Basis of Report (Check all that apply)

☐ Bridge Inventory File
☐ Previous Bridge Rating and Load Posting Report
☐ Bridge Plans
  ☐ New ☐ Overlay
  ☐ Repair/Reconstruction _____
  ☐ Other Dead Load Modifications _____
☐ Bridge Inspected by ,date
  ☐ Damaged Component
  ☐ Deteriorated Component

Types of Analysis:
☐ Manual ☐ AASHTOWare BrR, V.____ ☐ Computer* ☐ Other*
*

NBI Condition Ratings

Deck _____
Superstructure
Substructure _____
Culvert
ADTT _____

Method of Rating (Check appropriate box)

☐ Load Factor (LF) ☐ Assigned LF Rating
☐ Allowable Stress (AS) ☐ Assigned LRFR
☐ Load & Resistance Factor (LRFR)
☐ Load Testing
☐ Field Eval./Doc. Engineering Judgment

Design Load _____

Design Method _____

Summary of Rating and Load Posting Analysis

Load Posting	Required ☐ Not Required ☐			**Bridge Rating**	
Sign	TONS			Inventory	Operating
R12-1A ☐				HS ☐ RF ☐	HS ☐ RF ☐
R12-5a ☐					
R12-5 ☐	M3	M3S2	M3-3	**Overweight Permit Codes**	
R12-x11 ☐		45		A _____	B _____ C _____

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Signature: _____ Date: _____

(Typed or Printed) Name: _____ License No. _____

(Typed or Printed) Employed by (☐Agency/☐Firm): _____

FORM PIR-TH Revised Feb. 2014	MINNESOTA DEPARTMENT OF TRANSPORTATION PHYSICAL INSPECTION RATING (Per AASHTO - the Manual for Bridge Evaluation,6.1.4)

Bridge No. _____ Rated By _____ Checked By _____

Problem leading to this physical inspection rating:

Describe bridge: Spans, lengths, widths, depths, deck, wearing course, etc.

Describe Bridge Condition:

Other Remarks:

Bridge Sketch

FORM PIR-CL Revised July. 2016	**MnDOT BRIDGE RATING AND LOAD POSTING REPORT FOR COUNTY AND LOCAL AGENCIES**

Bridge Location and Description

Hwy. No. _____ Over ☐ Under ☐ _____ **Bridge No.** _____

Year Built _____ Year Remodeled _____ Replaces Br. _____

Type _____ County _____ Ref. Pt. _____

Description _____

Location _____

Data for Basis of Report (Check all that apply)

- ☐ Bridge Inventory File
- ☐ Previous Bridge Rating and Load Posting Report
- ☐ Bridge Plans
  - ☐ New ☐ Overlay
  - ☐ Repair/Reconstruction _____
  - ☐ Other Dead Load Modifications
- ☐ Bridge Inspected by _____ Date _____
  - ☐ Damaged Component
  - ☐ Deteriorated Component

Types of Analysis:
☐ Manual ☐ AASHTOWare BrR, V.____ ☐ Computer* ☐ Other*
*

NBI Condition Ratings

Deck
Superstructure
Substructure _____
Culvert
ADTT

Method of Rating (Check appropriate box)

- ☐ Load Factor (LF) ☐ Assigned Load Ratings
- ☐ Allowable Stress (AS) ☐ Assigned LRFR
- ☐ Load & Resistance Factor (LRFR)
- ☐ Load Testing
- ☐ Field Eval./Doc. Engineering Judgment

Design Load

Design Method

Summary of Rating and Load Posting Analysis

Load Posting Required ☐ Not Required ☐

Sign	TONS		
R12-1a ☐			
R12-5A ☐			
R12-5 ☐	M3	M3S2	M3S3
R12-X11 ☐		45	
R11-2a ☐	**BRIDGE CLOSED**		

Bridge Rating

Inventory	Operating
HS ☐	HS ☐
RF ☐ ____	RF ☐ ____

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Signature: _____ Date: _____

(Typed or Printed) Name: _____ License No. _____

(Typed or Printed) Employed by (☐Agency/☐Firm): _____

My signature below indicates that I have read and fully agreed with the load rating report.

Program Administrator's Signature: _____ Date: _____

FORM PIR-CL Revised Aug. 2014	MINNESOTA DEPARTMENT OF TRANSPORTATION PHYSICAL INSPECTION RATING (Per AASHTO - the Manual for Bridge Evaluation, 6.1.4)

Bridge No. _____ Rated By _____ Checked By _____

Problem leading to this physical inspection rating: _____

Describe bridge: Spans, lengths, widths, depths, deck, wearing course, etc.

Describe Bridge Condition: _____

Other Remarks: _____

Bridge Sketch

Form 90
Revised: Feb. 14

Culvert Rating Form

Bridge Number:	Year Built:	Year Remodeled:
County:	Bridge Owner:	
Route:	Feature Crossed:	
Culvert Type:		
Structure Type Code:	Culvert Dimensions:	
No. of Barrels:	Barrel Length:	

Rating Guidelines

Material	Culvert Type	Structure Type Code	Inventory Load Rating	Operating Load Rating
Cast-in-place Concrete	Box	113	HS 22.0	HS 33.0
	Type W Box (1930 era)	113	HS 16.0	HS 24.0
	Footing Supported Arch	112	HS 20.0	HS 30.0
Precast Concrete	Box (prior to 1989)	513	HS 24.0	HS 36.0
	Box (1989 – 2010) *	513	HS 25.0	HS 42.0
	Box (2011 & after) **	513	RF=1.0	RF=1.3
	Footing Supported Arch	512	HS 20.0	HS 30.0
	Round Pipe	514	HS 24.0	HS 36.0
	Pipe-Arch	515	HS 22.0	HS 33.0
Aluminum	Box	913	HS 14.0	HS 21.0
Metal	Footing Supported Arch	312	HS 12.0	HS 18.0
	Round Pipe	314	HS 16.0	HS 24.0
	Pipe-Arch	315	HS 16.0	HS 24.0
	Elliptical	316	HS 16.0	HS 24.0
Timber	Box	713	HS 14.0	HS 21.0
Masonry	Footing Supported Arch	812	HS 18.0	HS 27.0

✶ Structures with Load Factor HS 25 Design

✶✶ Structures with LRFD HL 93 Design using Standard Plans – Precast Concrete Box Culvert

The above table may be used as a guideline to the culvert rating.

Inventory Rating	

Operating Rating	

NBI Condition Rating: Culvert _____
If the culvert condition rating is 4 or less, do not use this form.
Instead, rate by Physical Inspection Rating (Form_PIR).

(Typed or Printed) Name: _____ Date: _____

(Typed or Printed) Title: _____

(Typed or Printed) Employed by (Agency / Firm): _____

Form TrussR Apr 2007	Bridge Rating Details		Bridge No:
		Rated	Date
		Checked	Sheet of

Member	Inventory	Operating	Location / Comments
Stringer			
Floor Beam			
Truss Members and Joints			
L 0 – L 1			
Joint L 0			

Form PW Dec 2015	Posting Worksheet	
		Bridge No
		Rated by
		Date

Truck	Wgt, TON	Rating Factor	Location	Limit State	Notes/Comments
T M 3					
T M 3S2-40					
T M 3S3					
SU4					
SU5					
SU6					
SU7					
NRL					

APPENDIX C: OVERWEIGHT PERMIT RESTRICTIONS

Restriction Code	Restriction Description	Allowed		Detailed Restriction Description	Bridge Check Operation
		Single Trip Permit	Annual Permit		
1	None	YES	YES	No restrictions to drive over bridge.	Normal
2	Straddle two lanes	YES	YES	Drive on the centerline between two lanes, in a manner that prevents any other vehicle from occupying a part of either lane on either side of the permit vehicle. Drive in the center of a single lane bridge.	The AASHTO "Single Lane" live load distribution is used.
3	Maximum speed of 10 miles per hour	YES ①	YES ①	Drive at a speed of 10 miles per hour or less.	The impact factor is reduced from the AASHTO impact, to 5%.
5	Drive in center of bridge	YES	YES	Similar to restriction 2, but used for one lane bridges.	The AASHTO "Single Lane" live load distribution is used.
6	See specific MnDOT instructions	YES ②	NO	More specific instructions must be attached.	Depends on the individual situation.
7	Need MnDOT District Engineer approval	YES	NO	More specific instructions must be attached.	Depends on the individual situation.
X	DENIED	YES	YES	The overweight permit vehicle is **NOT ALLOWED** on this bridge.	Used when requirements for restrictions 1 thru 7 are not met.

① Not allowed where there is a posted minimum speed, such as most interstate mainline routes.

② Minimum escort: police at the front of permit vehicle.

APPENDIX D: LRFD DESIGN LIVE LOAD (HL-93)

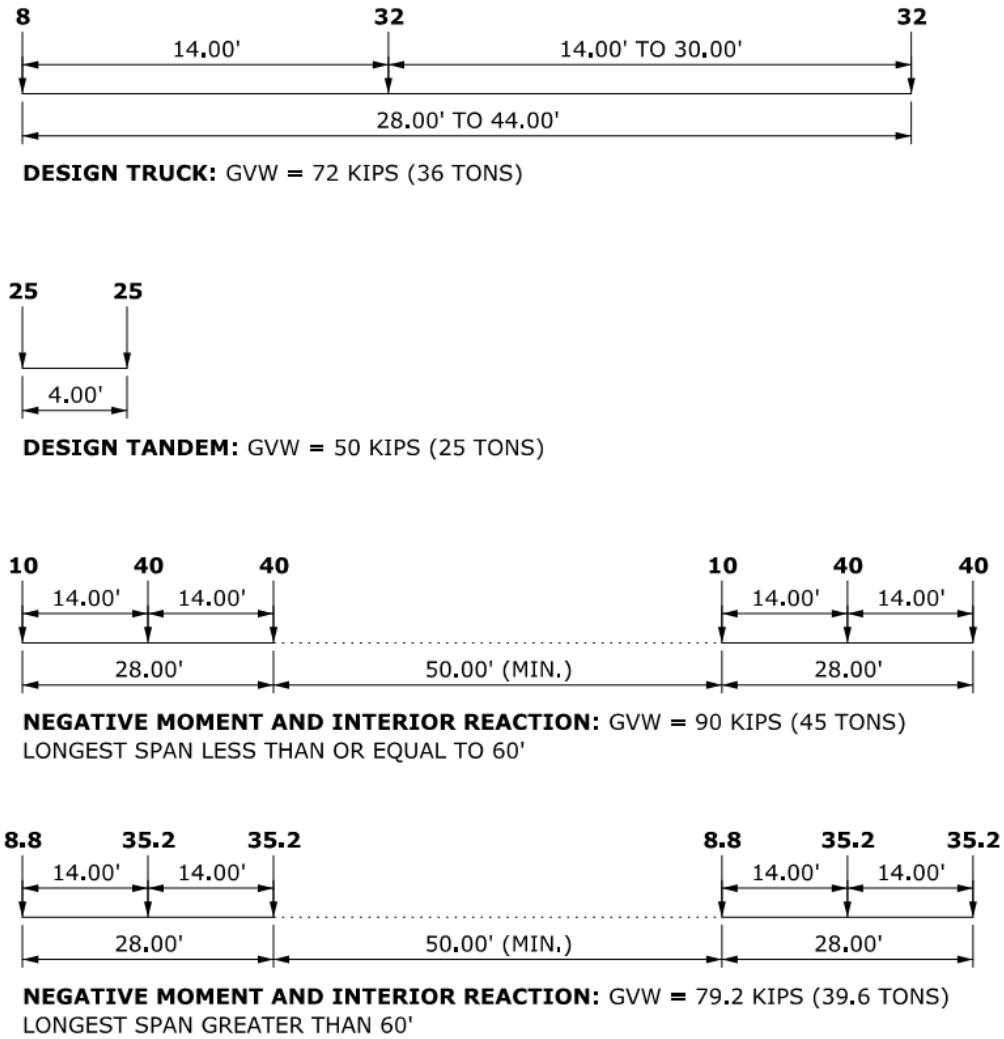


Figure D-1: Axle Load (in Kips) of LRFD Design Loads (HL-93), add Design Lane Load of 0.64klf

APPENDIX E: MINNESOTA LEGAL LOADS

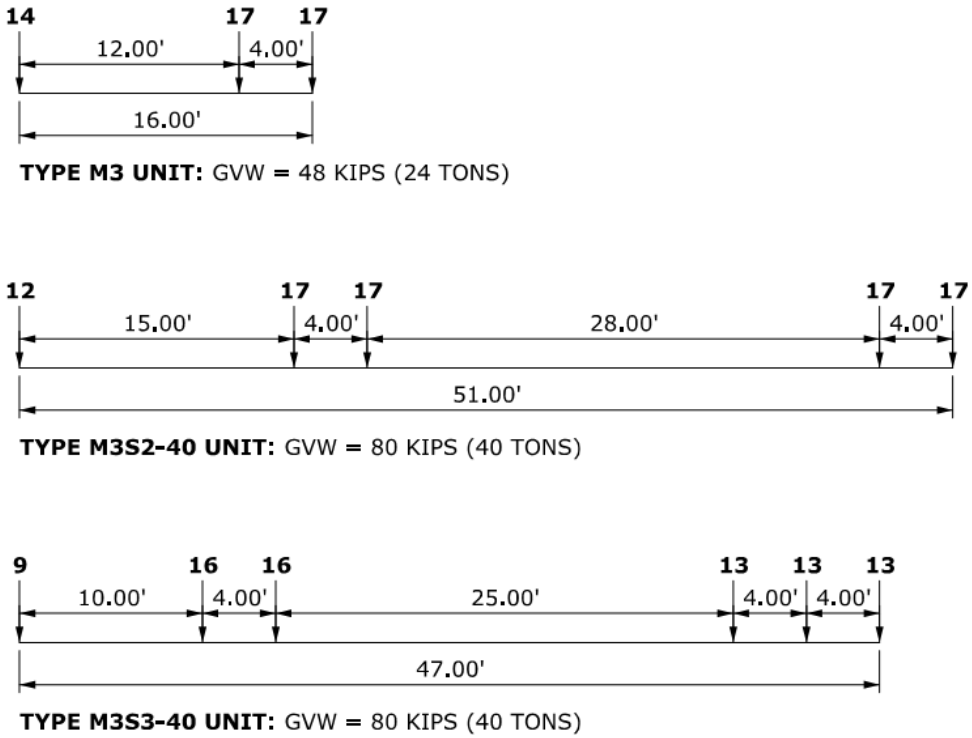
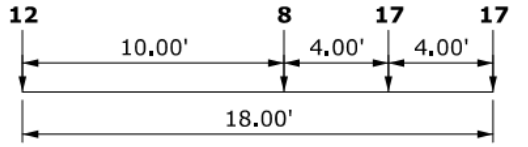
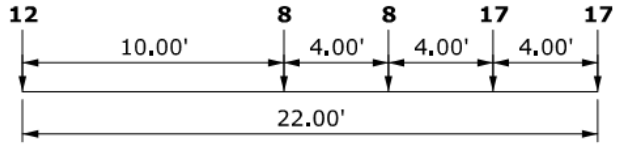


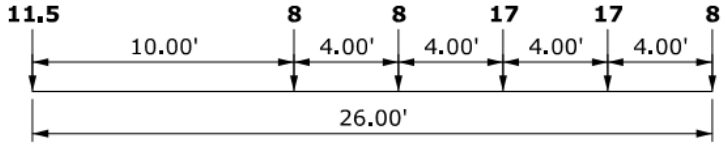
Figure E-1: Axle Load (in Kips) of Routine Single and Combination Vehicles



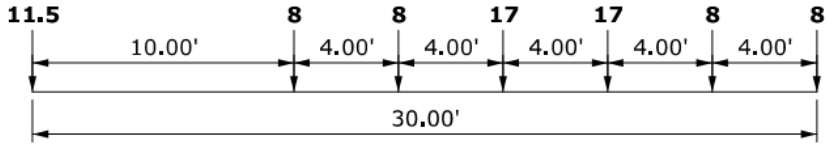
TYPE SU4 UNIT: GVW = 54 KIPS (27 TONS)



TYPE SU5 UNIT: GVW = 62 KIPS (31 TONS)



TYPE SU6 UNIT: GVW = 69.5 KIPS (34.75 TONS)



TYPE SU7 UNIT: GVW = 77.5 KIPS (38.75 TONS)

Figure E-2: Axle Load (in Kips) of Single-Unit Specialized Hauling Vehicles

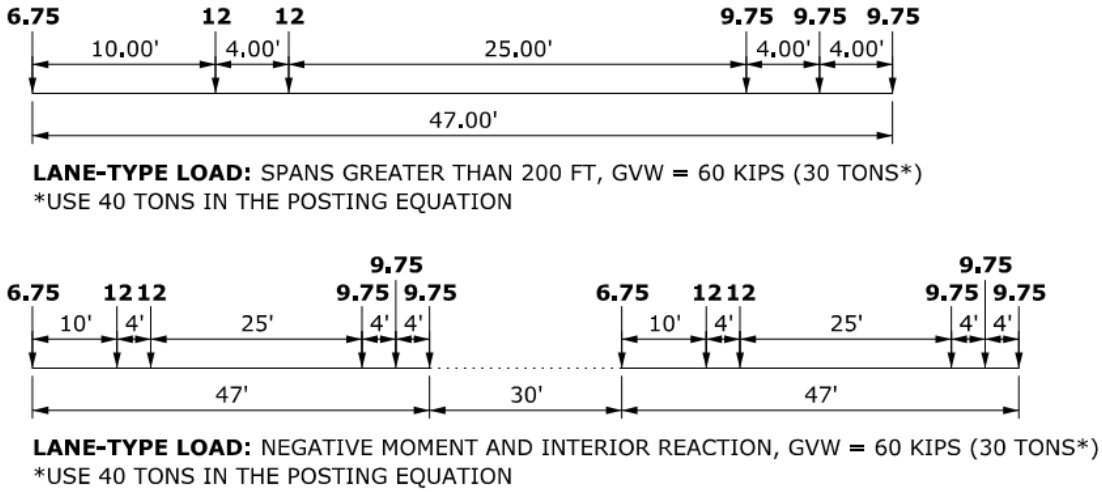


Figure E-3: Axle Load (in Kips) of Lane Load Vehicles, Include Legal Lane Weight of 0.2klf

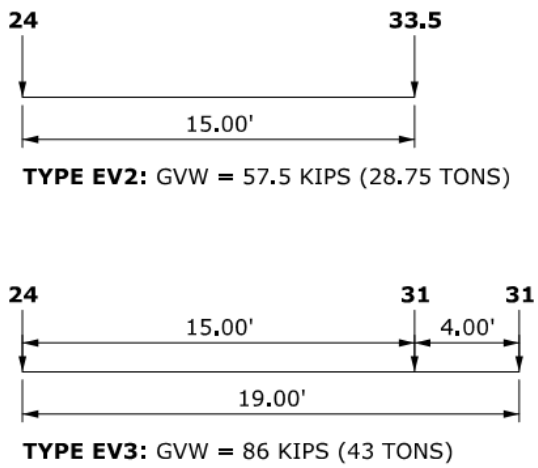


Figure E-4: Axle Load (in Kips) of Emergency Vehicles

APPENDIX F: MN PERMIT LIVE LOAD MODELS

MINNESOTA STANDARD PERMIT TRUCKS – G-80 MODELS

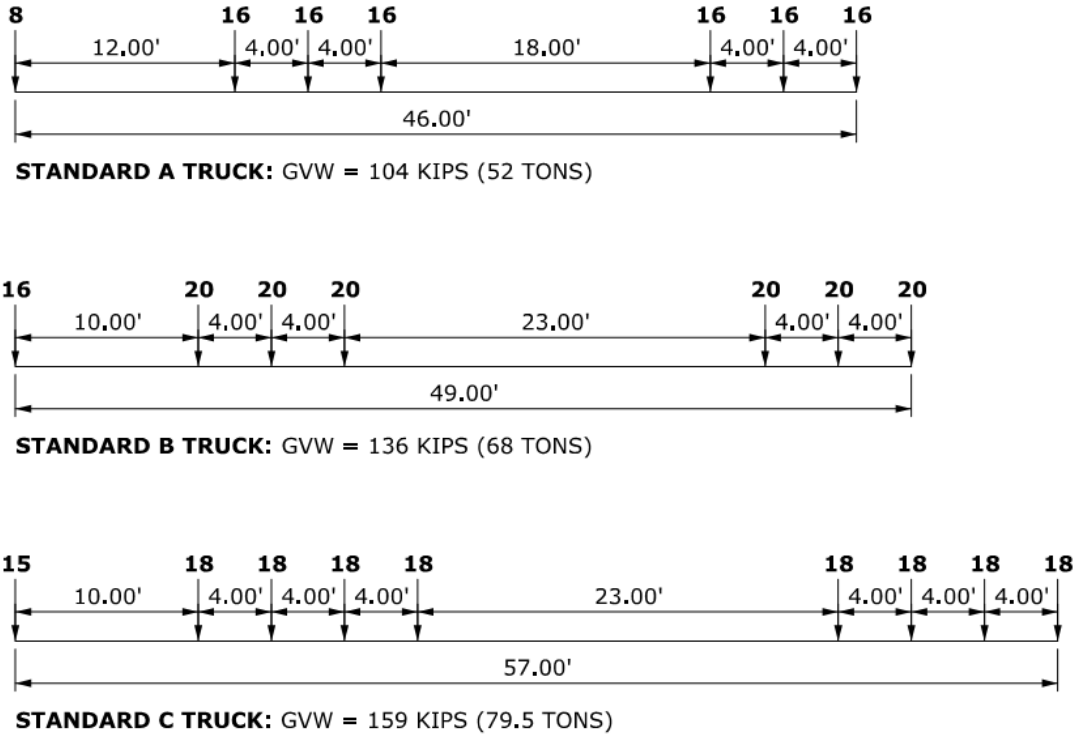
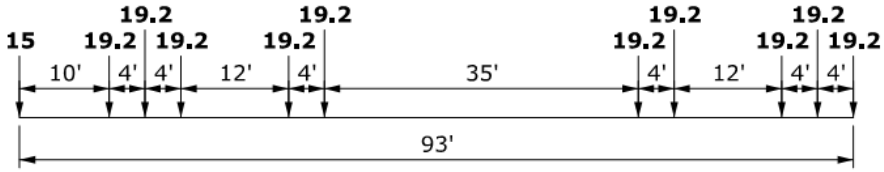
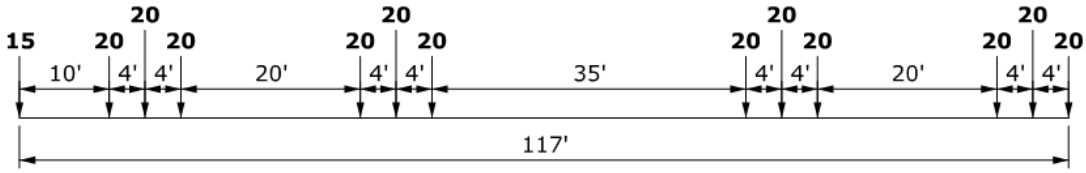


Figure F-1: Axle Load (in Kips) of Standard G-80 Annual Permit Trucks



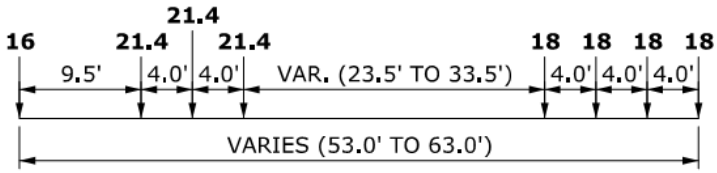
P411 TRUCK: GVW = 207 KIPS (103.5 TONS)



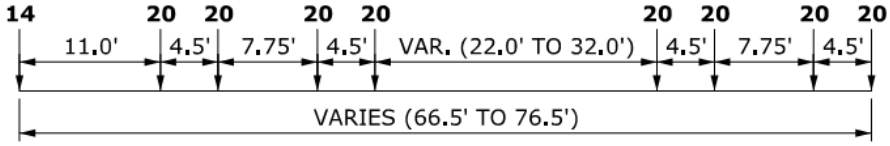
P413 TRUCK: GVW = 255 KIPS (127.5 TONS)

Figure F-2: Axle Load (in Kips) of Standard G-80 Single Trip Permit Trucks

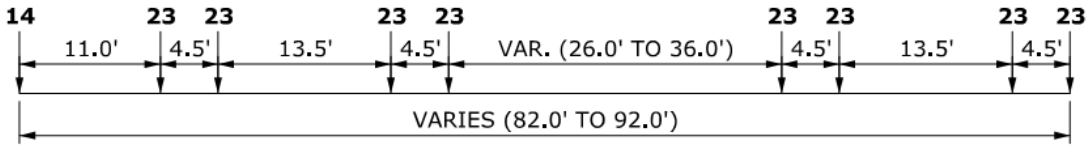
MINNESOTA STANDARD PERMIT TRUCKS – G-07 MODELS



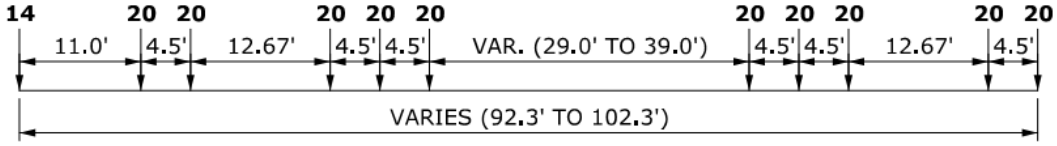
STANDARD C152b: GVW = 152.2 KIPS (76.1 TONS)



STANDARD C174b: GVW = 174 KIPS (87 TONS)

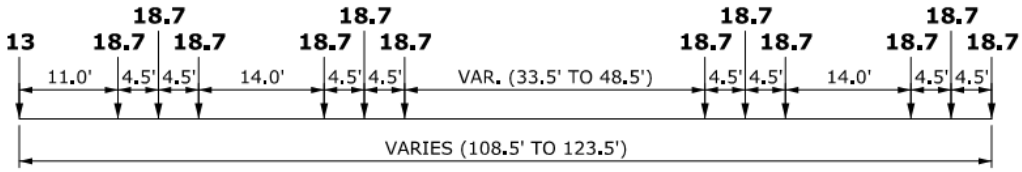


STANDARD C198.23: GVW = 198 KIPS (99 TONS)

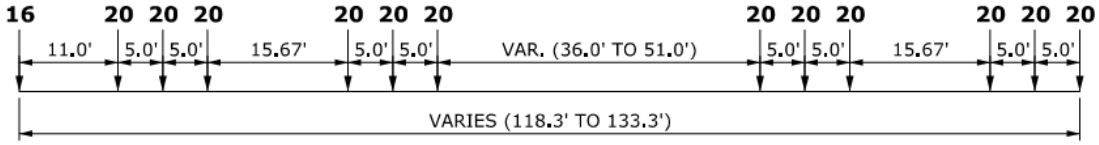


STANDARD C214b: GVW = 214 KIPS (107 TONS)

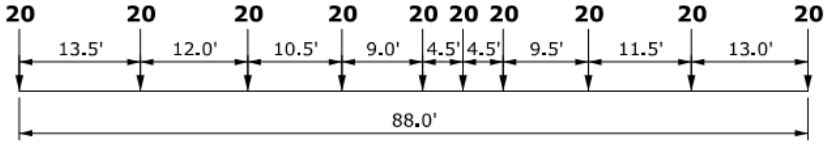
Figure F-3: Axle Load (in Kips) of Standard G-07 Single Trip Permit Trucks (1 of 2)



STANDARD C237b: GVW = 237.4 KIPS (118.7 TONS)



STANDARD C256b: GVW = 256 KIPS (128 TONS)



STANDARD C200j: GVW = 200 KIPS (100 TONS)

Figure F-4: Axle Load (in Kips) of Standard G-07 Single Trip Permit Trucks (2 of 2)

MINNESOTA STANDARD PERMIT TRUCKS – 6-AXLE AND 7-AXLE MODELS

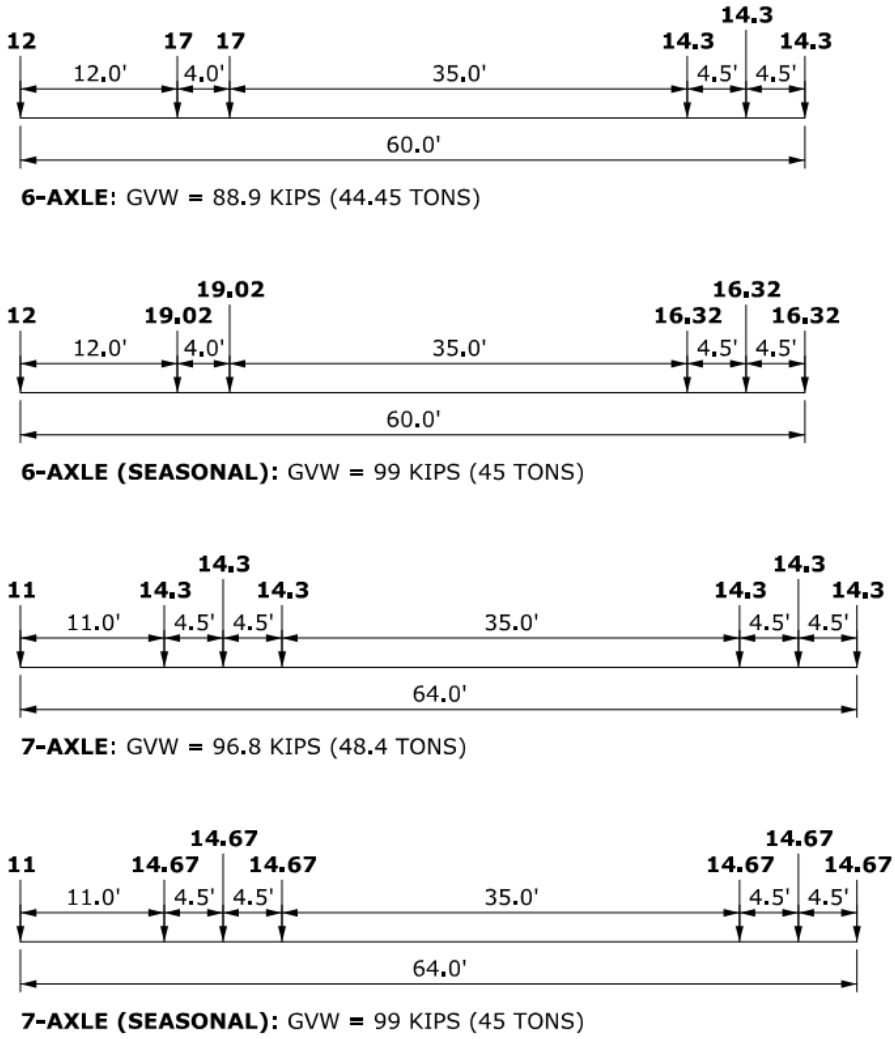


Figure F-5: Axle Load (in Kips) of Standard 6-Axle and 7-Axle Permit Trucks (non-TH Only)

APPENDIX G: MnDOT LOAD POSTING SIGNS

Figure G-1: R12-1a

Figure G-2: R12-5

Figure G-3: R12-X11

Figure G-4: R12-5a

Figure G-5: R11-2a

APPENDIX H: AASHTOWare BrR GUIDELINES

Resources for Rating Information

- This manual
- Original plan
- Repair plan
- As-built plan
- Existing rating
- Bridge Inventory data
- Inspection reports

Select Tolerances

Prior to beginning the analysis, set the program tolerances as follows (*Configuration Browser* > *System Defaults* > *Tolerance*):

Units	Tolerance
ft.	0.01
in.	0.05
mi.	0.010

Enter Bridge Information

The following table outlines the information that should be input at the beginning of an analysis after selecting "Create New Bridge" from the Bridge Explorer.

Input Name	Tab Name	Input Description / Examples
Bridge ID	N/A	Bridge number (usually 5 digits). Enter space(s) at the start if the bridge only has 3 or 4 digits.
NBI Structure ID (8)	N/A	Same as Bridge ID
Bridge Completely Defined	N/A	Check this box to indicate if the bridge superstructure (members and spans) is completely defined in this BrR file.
Name*	Description	Enter the three-digit bridge type. See Appendix 2-A of the *BDM*. If there is more than one type in the bridge, enter the type of the controlling span and add the suffix, m, for multiple.
Year Built	Description	Year of construction

Input Name	Tab Name	Input Description / Examples
Description	Description	[*Select those that apply from this list, add others if needed.]* • "This Bridge was copied from its twin, Br #####." • "Twin to Br #####." • Number of spans. • Other bridge types if multiple types in one bridge. • Note if different ratings apply to each side of bridge or direction of traffic • Note if bridge has one way traffic. • Note if flare or curve is present. • Skew angle. • Describe dead load distribution: Sidewalks, medians, rails, etc. • Describe, in detail, if for any reason the computer model deviates from the plan. • "(Does/Does not) have end blocks." [For prestressed beam bridges] • "Replaces Bridge #####." • Initials of person rating and date completed.
Location	Description	City or Township name
Length	Description	Bridge length, in feet
Facility Carried (7)	Description	Facility carried **over** the bridge. Use the highway abbreviation without periods. If the bridge carries one way traffic, add this as a suffix. Examples: I 94, I 35 SB, US 12, US 2 WB, MN 36, CSAH 44, CR 88. If no highway number exists, use the street name/number, etc.
Route Number	Description	Often the same as Facility Carried. If a minor road crosses over a major highway, enter the major highway number. May be a second highway no. over/under. Omit Prefixes (I, US, MN, CSAH, etc.)
Feat. Intersected (6)	Description	Highway, river, or feature **under** the bridge.
Mi. post	Description	Leave blank.
Default Units	Description	English preferred

Input Name	Tab Name	Input Description / Examples
District (2)	Description (cont'd)	Select from pull-down menu
County	Description (cont'd)	Select from pull-down menu
Owner (22)	Description (cont'd)	Select from pull-down menu
Maintainer	Description (cont'd)	Select from pull-down menu. Usually same as owner.
Admin. Area*	Description (cont'd)	Select from the pull down menu. This is used for sorting into folders.
NHS Indicator	Description (cont'd)	Leave blank.
Functional Class	Description (cont'd)	Leave blank.
Recent ADTT	Traffic	Enter the current truck traffic volume. This is called HCADT on the MnDOT Structure Inventory and Appraisal form. If the HCADT is blank on the form, use 12 % of the ADT.

* This field is being used for an alternate purpose, as defined by the MnDOT Bridge Rating Section

Enter Materials

Use the material strengths as given on the plan. If there is no plan and no other source is available, select from the values given in this manual or the *MBE* based on the year of construction.

When selecting reinforcing steel for concrete structures, check the box if epoxy coated reinforcement is used. (*Bridge Workspace > Materials > Reinforcing Steel*)

Enter Structure Definitions

Run the "Superstructure Definition Wizard" (*Bridge Workspace > SUPERSTRUCTURE DEFINITIONS*).

- General
  - Use the girder system method whenever possible or practical.
  - Let the system define effective widths.
- Deck
  - For new bridges use a concrete deck strength of 4 ksi. (Class C)
  - For "Actual deck thickness",
    - Girder System Superstructure: include the actual wearing surface thickness
    - Girder Line Superstructure: the wearing course is calculated manually and entered as a weight per foot in the member loads. (The effective width and depth for composite action is entered elsewhere.)
  - For "Structural deck thickness", enter the depth of the initial deck pour.

  - See Article 4.2.2.1 for additional MnDOT policies regarding composite decks and two-course decks
- Load
  - The Composite Dead Load (DL2) needs to be separated into two (or more) items (lines). This is because LRFR will use different load factors for each of them.

    The default Load Case Description may be selected and modified to fit MnDOT criteria.

Load Case Name	Type	Acting on	Stage	Items
DC1	D, DC	Non-Composite	1	(set by default)
DC2	D, DC	Composite (long term)	2	Original wearing course, railings, median, sidewalk, etc.
Util + WC	D, DW	Composite (long term)	2	Future wearing course, Utilities,

  - The default setting for transverse distribution of DL2 is uniformly to all beams. This is the preferred method when the loading is symmetrical across the bridge width. When the load is not symmetrical, another distribution method may be chosen, or a dummy load may be added to make it symmetrical.
  - Enter utility loads in the Member Loads section.
  - BrR does not calculate the excess weight in the stool due to residual camber and deck cross slope. These may be entered in Member Alternative, Additional Self Load, kip/ft.
- Parameter Names
  - Whenever BrR prompts the engineer to select a name for a parameter, select a name that is short and descriptive. Some examples are:

Parameter Full Name	Short name
Bridge Alternatives	Br Alt 1
Stress limits – concrete	PS Conc 7.5
Stirrups for prestressed beam	# 4 Inv U
Prestressed Properties – strands	Strd 0.5 in

Completion of Rating

Compare new bridge ratings calculated with BrR to any old rating that may exist, and resolve any major discrepancies.

Verify that the bridge rating can be run from the Bridge Explorer.

Prestressed Concrete

See Appendix I for an example inputs and analysis of a simple span prestressed concrete structure.

Follow the guidance for shear as presented in Article 4.4.6.7 for LRFR methodology, and Article 5.6.4 for LFR methodology.

For LFR, set shear calculation limits to comply with *AASHTO Standard Specifications Article 9.20.2*. The setting is in *MEMBER ALTERNATIVES*. Configure the engine properties to BRASS LFD within the *"Engine" Tab*. Within *PROPERTIES*, select the "*Miscellaneous" Tab*, and then select "*no limit on* M_{cr}/M_{max}*".*

For LFR, if the rating is controlled by shear at the end of the beam, follow these steps:

- First, turn off the BrR set tenth point checks. (*SUPERSTRUCTURE DEFINITIONS > MEMBERS > (GIRDER) > MEMBER ALTERNATIVES > "Control Options" Tab).* Then add points of interest at h/2, 1/10, 2/10, 3/10, and 5/10.
- If shear still controls the rating, also check and record the rating with shear turned off and record the subsequent Rating Factor in the notes column of the table in the Bridge Rating form.

For bridges that have their prestress losses given in the plan (This began in 2009) use these losses for the BrR rating. The plan will usually list two numbers, for elastic and long term losses. Sum these two values and enter them as the Final loss. The BrR location is under *SUPERSTRUCTURE DEFINITIONS > Prestress Properties.* Select the named prestressed material, then select the "Loss Data - Lump Sum" tab.

For bridges other than as described in the above paragraph, use the AASHTO method for calculation of prestress losses (that is the default).

Concrete Slab Spans

For concrete slab spans, the following guidance should be implemented:

- Enter a strip of slab one unit wide.
- Use a slab depth of the full depth, less 0.5 inches
  - Thus, considering the wearing course as fully composite with the base slab and of the same strength.
  - Apply the remaining 0.5 inches as a member load, in weight per foot.
- Ensure the ignore shear box is selected

Reinforced Concrete Deck Girders (T beams) Types 106 & 206

The following has been verified for the girder system method:

- BrR calculates the dead load and the section properties from the information in *MEMBERS > MEMBER ALTERNATIVES > Cross Sections*.
- Under the Structure Typical Section screen, BrR does not use the "Total deck thickness." BrR does use the "Wearing Surface" information, for dead load only.

Steel Beams, Composite

The following guidance for composite steel beams should be used:

- The girder schedule is the preferred method to enter beam sizes.
- Items not required to enter:
    - welds
    - bolts
    - splices
    - rebar in the slab (unless specifically designed for this).
- If the beam was designed for composite action in the negative moment region, rate it the same way and with the longitudinal slab reinforcement included.
- The contraflexure points must be entered in as a percentage of span. You can get these from either the girder elevation plan sheet or the dead load moments in BrR.
- For LFR, BrR does not include the 10% redistribution that is allowed in *Standard Specifications Article 10.48.1.3*.

Additional items to aware of for steel beams includes:

- Be careful to input correct stool height.
- Verify diaphragms and stiffener locations on elevation view.
- If diaphragms are straight on a skewed bridge make sure to account for two stiffeners and diaphragms close together.
- BRASS calculates plastic capacity for simple spans. It does not if the girder is a hybrid.
- Check to see that critical locations are not artificially low at contraflexure points. If so then adjust contraflexure points in the engine tab so this won't control.
- Use elastic rating for continuous steel rating.
- Do not let bearing stiffeners control the final rating.
- Floor beams and stringers could be rated beginning with BrR version 5.3.1.

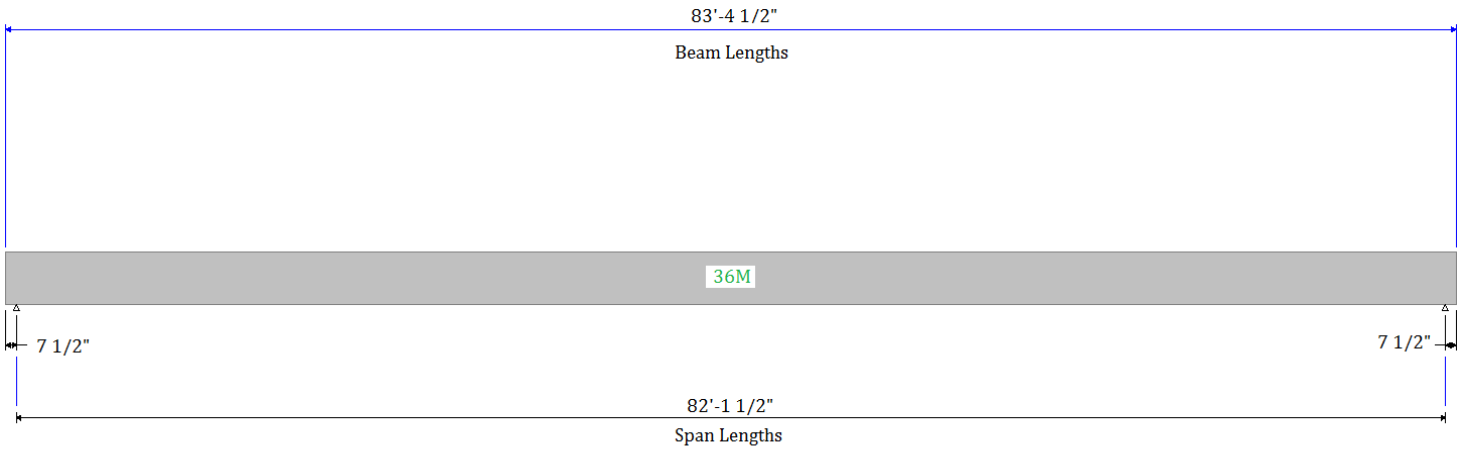
Timber

BrR can rate timber decks for moments and shear.

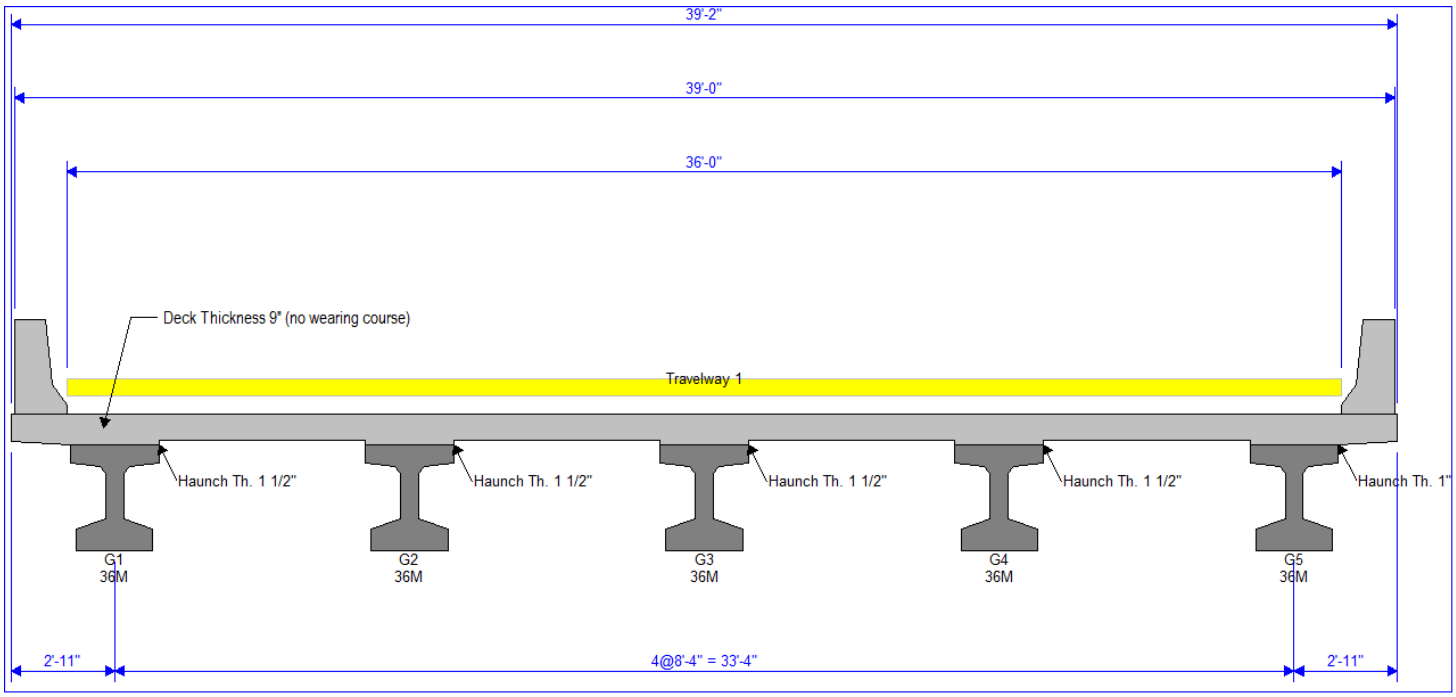
APPENDIX I: AASHTOWare BrR EXAMPLE

The following pages present an example input for a simple span prestressed I-beam.

AASHTOWare BrR - SIMPLE SPAN PRESTRESSED I BEAM EXAMPLE - BR 76015



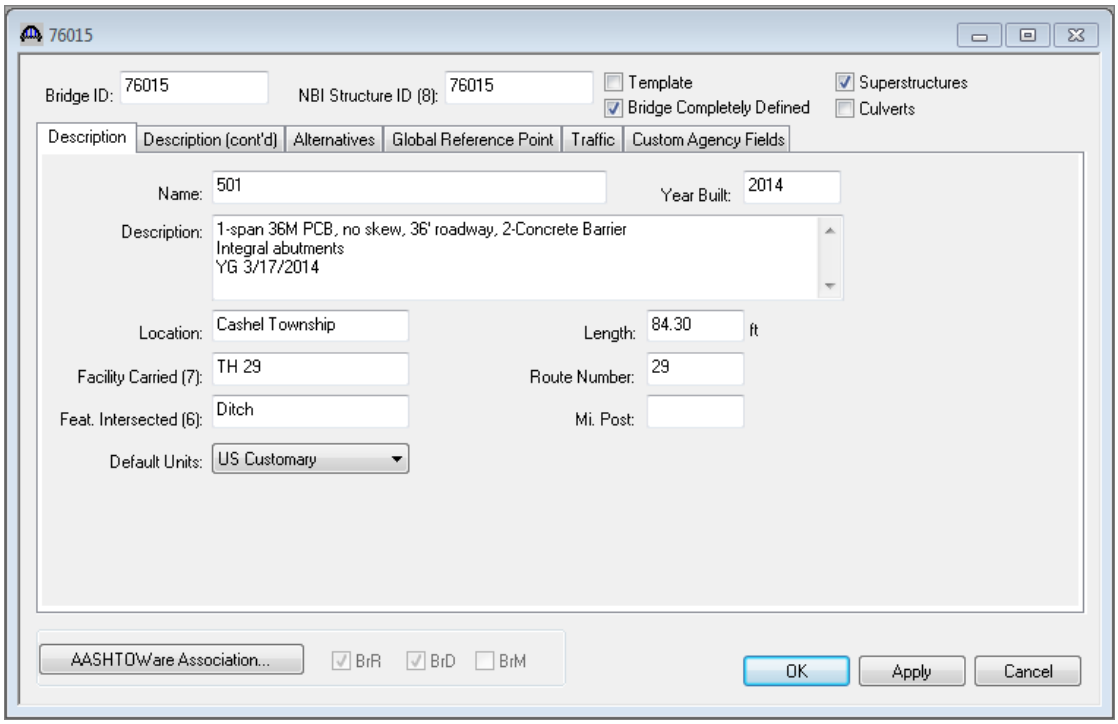
ELEVATION



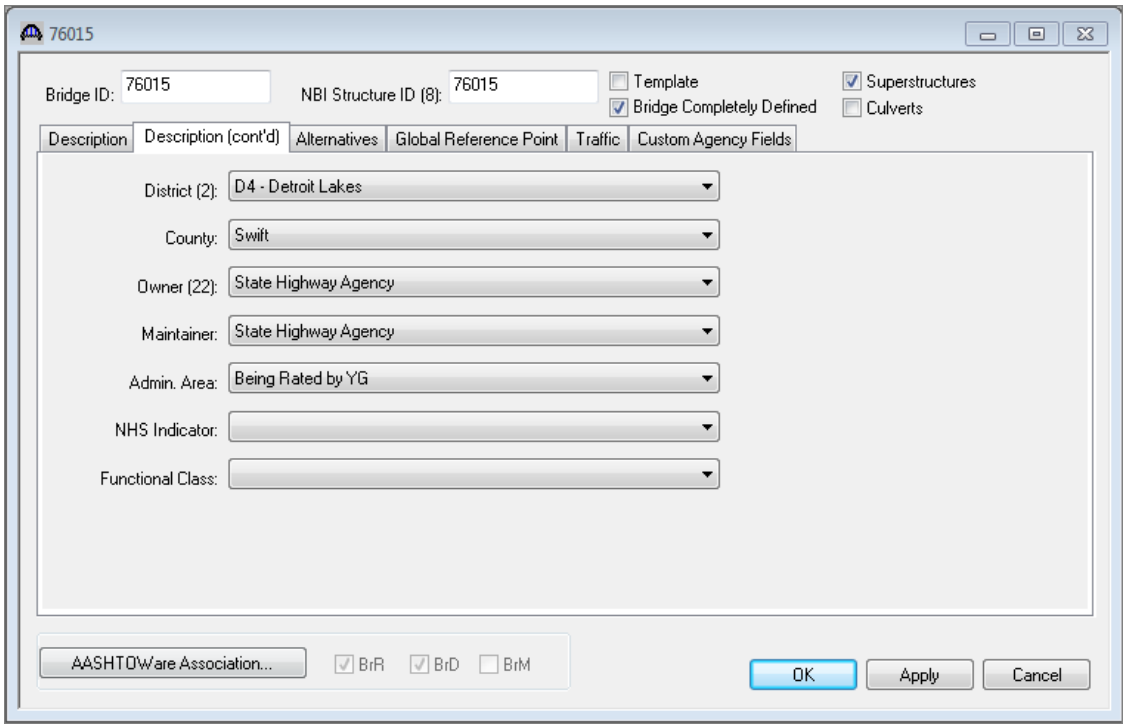
TYPICAL SECTION

PS1 - Simple Span Prestressed I Beam Example (BrR 6.7.1)

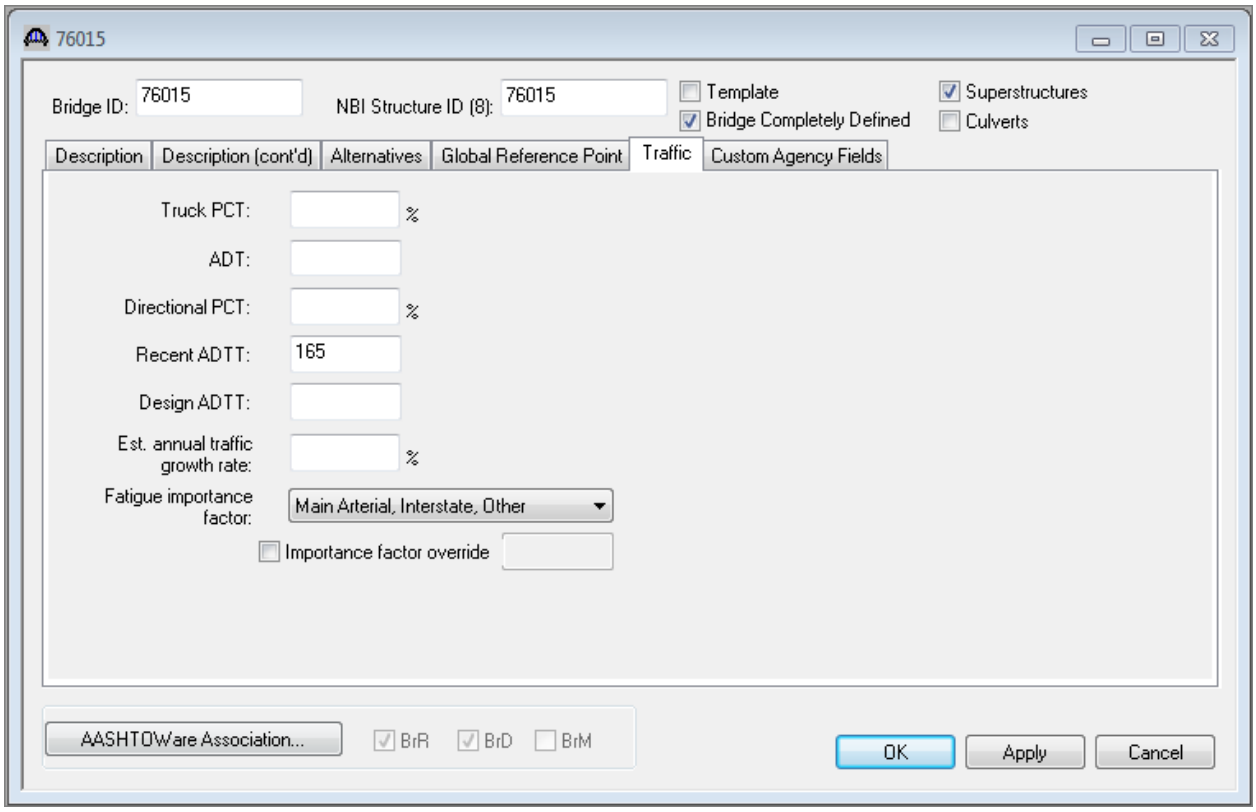
1. From the Bridge Explorer create a new bridge and enter the following description data:
    a. Bridge ID – Enter Bridge number (usually 5 digits). For bridges with only 3 or 4 digits, enter space(s) then enter the bridge number, e.g., __123, _1234
    b. NBI Structure ID – Same as Bridge ID
    c. Bridge Completely Define – Check this box to indicate whether or not the bridge superstructure (members and spans) is completely defined in this BrR file.
    d. Name – Enter the three digit bridge type. (see Bridge LRFD Design Manual, Appendix 2-A). If there is more than one type in the bridge, enter the type of the main span (or lowest rated ?) and add suffix, m (for multiple).
    e. Year Built – Year of construction
    f. Description – select those that apply from list below, add others if needed
        - This Bridge was copied from its' twin, Br xxxxx
        - Twin to Br xxxxx
        - Number of spans
        - Other bridge types if multiple types in one bridge
        - Note if different ratings apply to each side of bridge or direction of traffic or if bridge has one way traffic
        - Flare or curve, note if present
        - Skew angle
        - Describe dead load distribution: Sidewalks, medians, rails, etc.
        - Describe in detail if for any reason the computer model deviates from the plan
        - Does / does not have end blocks, (For prestressed beam bridges)
        - Replaces Bridge xxxx
        - Initials of person rating and date completed
    g. Location – City or Township name
    h. Length – XXXX feet
    i. Facility Carried – Facility carried over the bridge. Use the highway abbreviation without periods. If the bridge carries one way traffic, add this as a suffix. Examples: I 94, I 35 SB, US 12, US 2 WB, MN 36, CSAH 44, CR 88. If no highway number exists, use the street name/number, etc.
    j. Route number - Often the same as Facility carried. If a minor road crosses over a major highway, enter the major highway number. May be a second highway no. over/under. Omit Prefixes (I, US, MN, CSAH, etc.)
    k. Feature intersected - Highway, river, stream or feature under the bridge.
    l. Mile post – Leave blank
    m. Units – English preferred



2. Enter the following description (cont'd)…
    a. District – Select from pull-down menu
    b. County – Select from pull-down menu
    c. Owner – Select from pull-down menu
    d. Maintainer – Select from pull-down menu (usually the same as owner)
    e. Administrative Area – Select from pull down menu
    f. NHS Indicator – Leave blank
    g. Functional Class – Leave blank

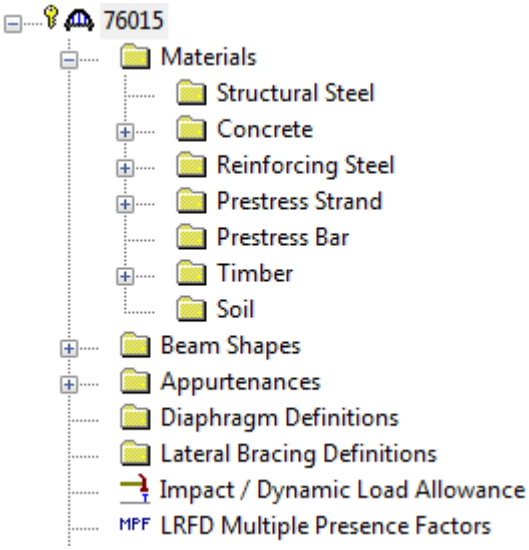


3. Enter the following Traffic information:
    a. Recent ADTT - Enter the current truck traffic volume. This is called HCADT on the MnDOT Structure Inventory Report. If the HCADT is blank on the Inventory Report, use 12 % of the ADT.

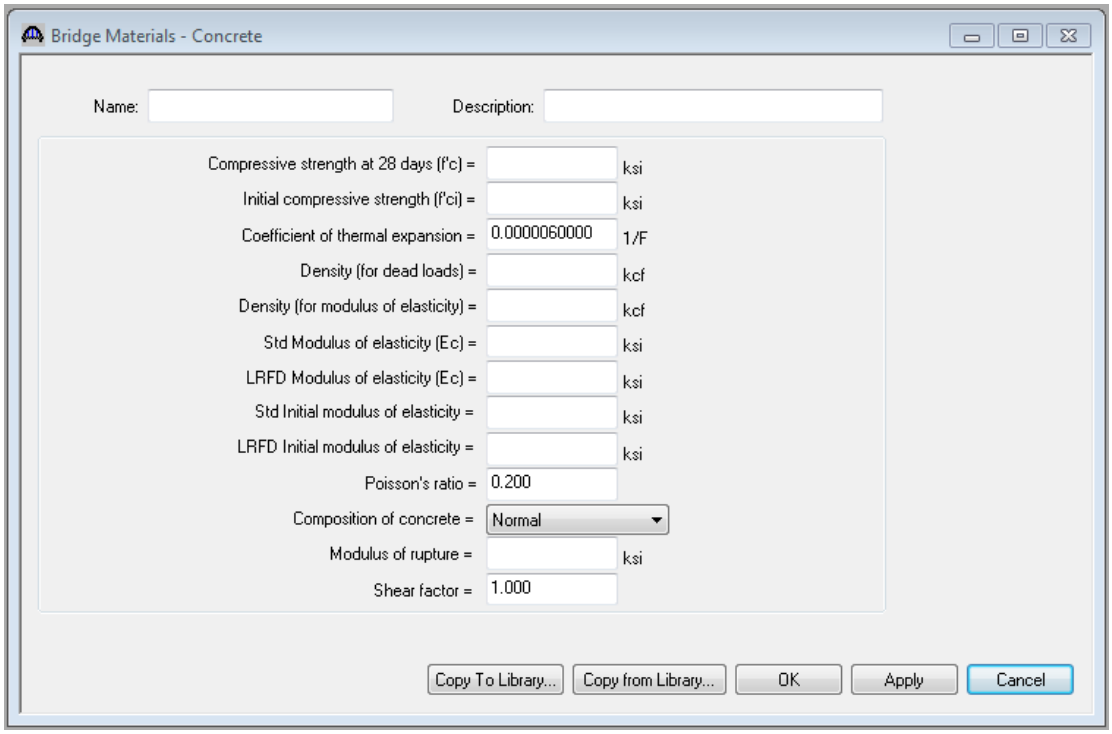


Close the window by clicking OK. This saves the data to memory and closes the window.

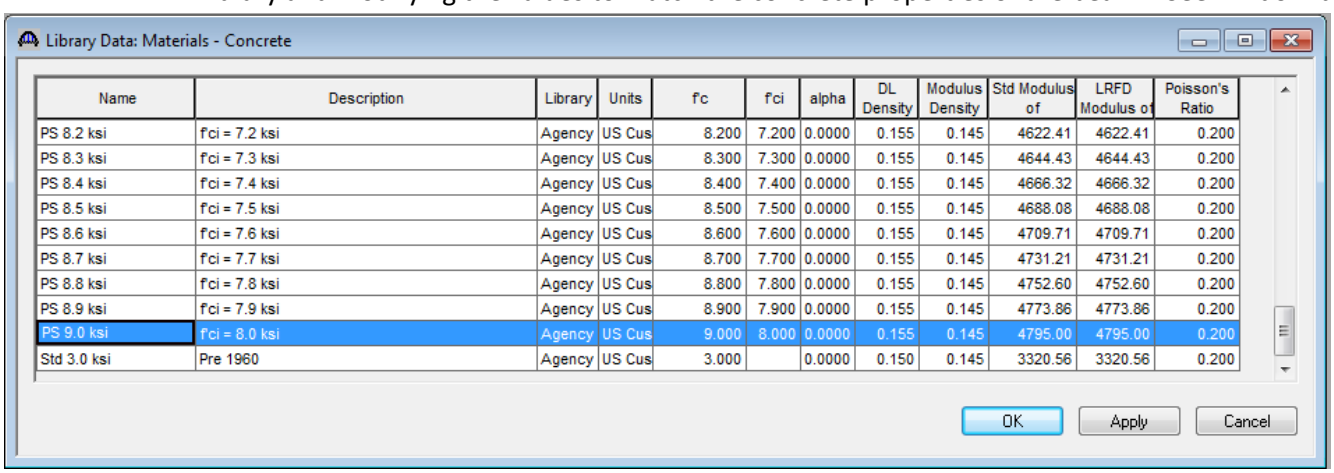
4. To enter the materials to be used by members of the bridge, click on the plus sign icon to expand the tree for on the Materials. The tree with the expanded Materials branch is shown below:



a. To add a new concrete material for the beam, click on Concrete in the tree and select File/New from the menu (or double click on Concrete). The window shown below will open.



b. Add the concrete material "PS 9.0 ksi" by copying the closest concrete material properties from the Library and modifying the values to match the concrete properties of the beam. See window below.



Name	Description	Library	Units	f'c	f'ci	alpha	DL Density	Modulus Density	Std Modulus of	LRFD Modulus of	Poisson's Ratio
PS 8.2 ksi	f'ci = 7.2 ksi	Agency	US Cus	8.200	7.200	0.0000	0.155	0.145	4622.41	4622.41	0.200
PS 8.3 ksi	f'ci = 7.3 ksi	Agency	US Cus	8.300	7.300	0.0000	0.155	0.145	4644.43	4644.43	0.200
PS 8.4 ksi	f'ci = 7.4 ksi	Agency	US Cus	8.400	7.400	0.0000	0.155	0.145	4666.32	4666.32	0.200
PS 8.5 ksi	f'ci = 7.5 ksi	Agency	US Cus	8.500	7.500	0.0000	0.155	0.145	4688.08	4688.08	0.200
PS 8.6 ksi	f'ci = 7.6 ksi	Agency	US Cus	8.600	7.600	0.0000	0.155	0.145	4709.71	4709.71	0.200
PS 8.7 ksi	f'ci = 7.7 ksi	Agency	US Cus	8.700	7.700	0.0000	0.155	0.145	4731.21	4731.21	0.200
PS 8.8 ksi	f'ci = 7.8 ksi	Agency	US Cus	8.800	7.800	0.0000	0.155	0.145	4752.60	4752.60	0.200
PS 8.9 ksi	f'ci = 7.9 ksi	Agency	US Cus	8.900	7.900	0.0000	0.155	0.145	4773.86	4773.86	0.200
PS 9.0 ksi	f'ci = 8.0 ksi	Agency	US Cus	9.000	8.000	0.0000	0.155	0.145	4795.00	4795.00	0.200
Std 3.0 ksi	Pre 1960	Agency	US Cus	3.000		0.0000	0.150	0.145	3320.56	3320.56	0.200

Note: AASHTOWare BrR only computes modulus of elasticity using AASHTO LRFD Equation 5.4.2.4-1. For f'c > 6ksi, MnDOT uses ACI 363 equation.

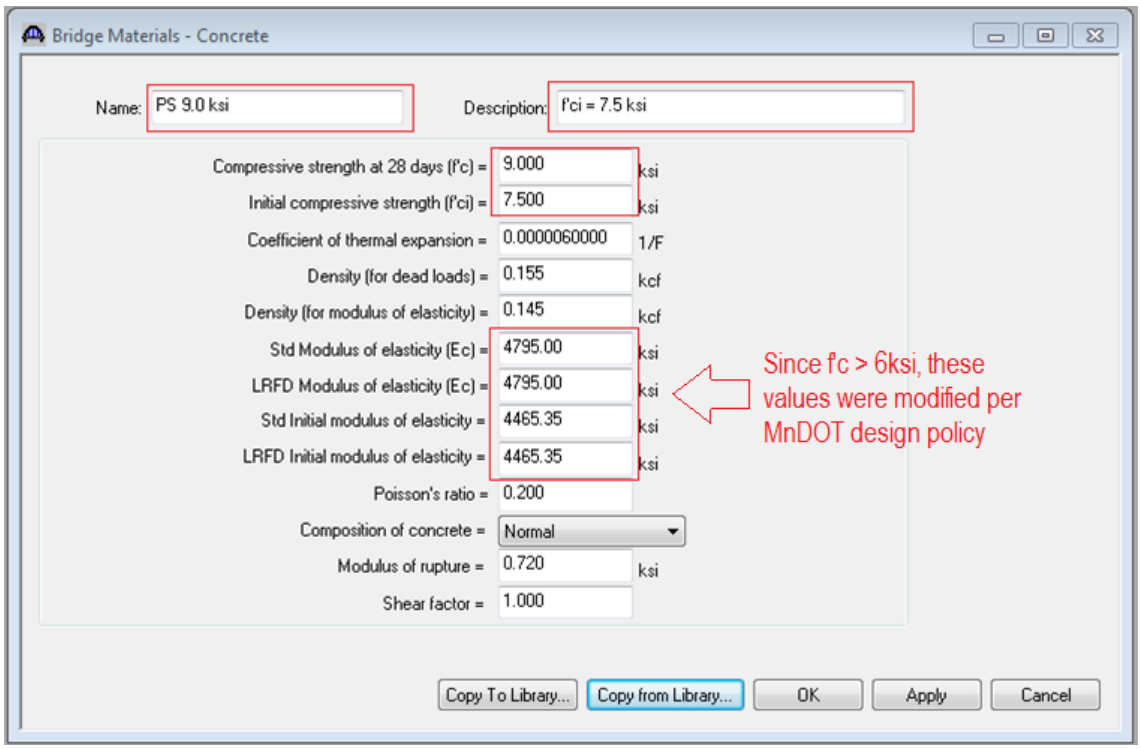
MnDOT Design Policy Item:

For pretensioned beams (M, MN, MW, and RB) fabricated with highstrength concrete (greater than 6.0 ksi), compute the modulus of elasticity with the ACI 363 equation below:

$$E_c = 1265 * \sqrt{f'_c} + 1000 \quad (where\ f'_c\ and\ E_c\ are\ in\ ksi)$$

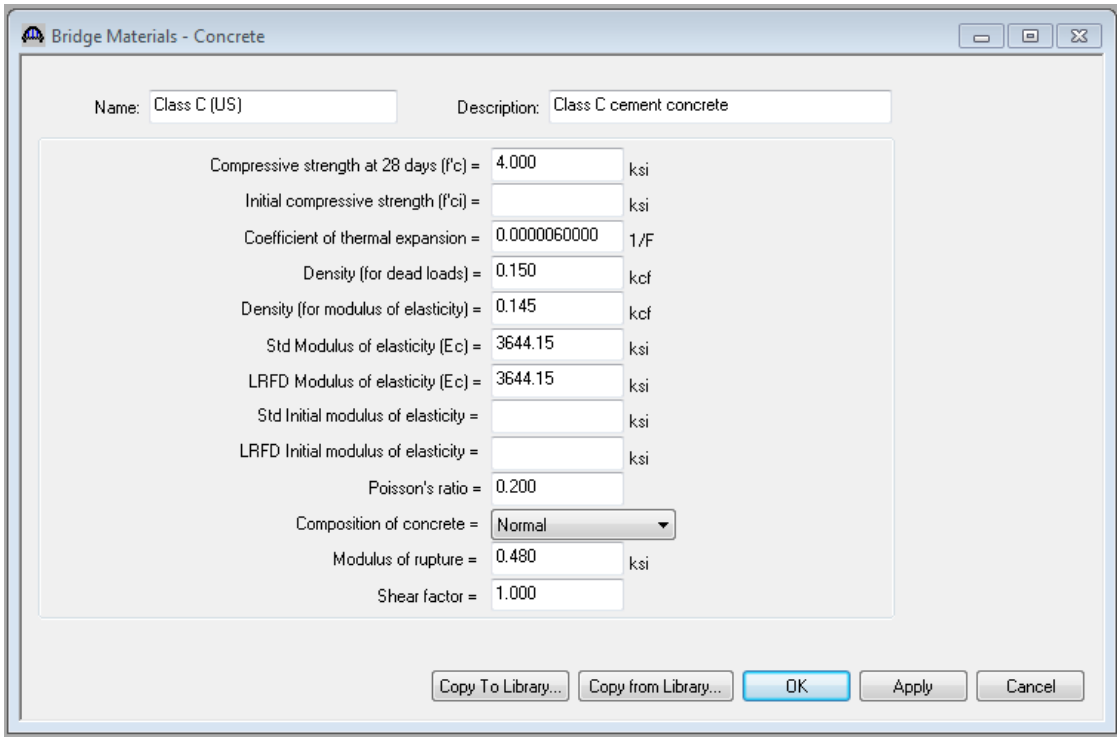
For all other pretensioned and post-tensioned elements, compute the modulus of elasticity using AASHTO LRFD Equation 5.4.2.4-1, with K_1 = 1 and w_c = 0.150 kcf.

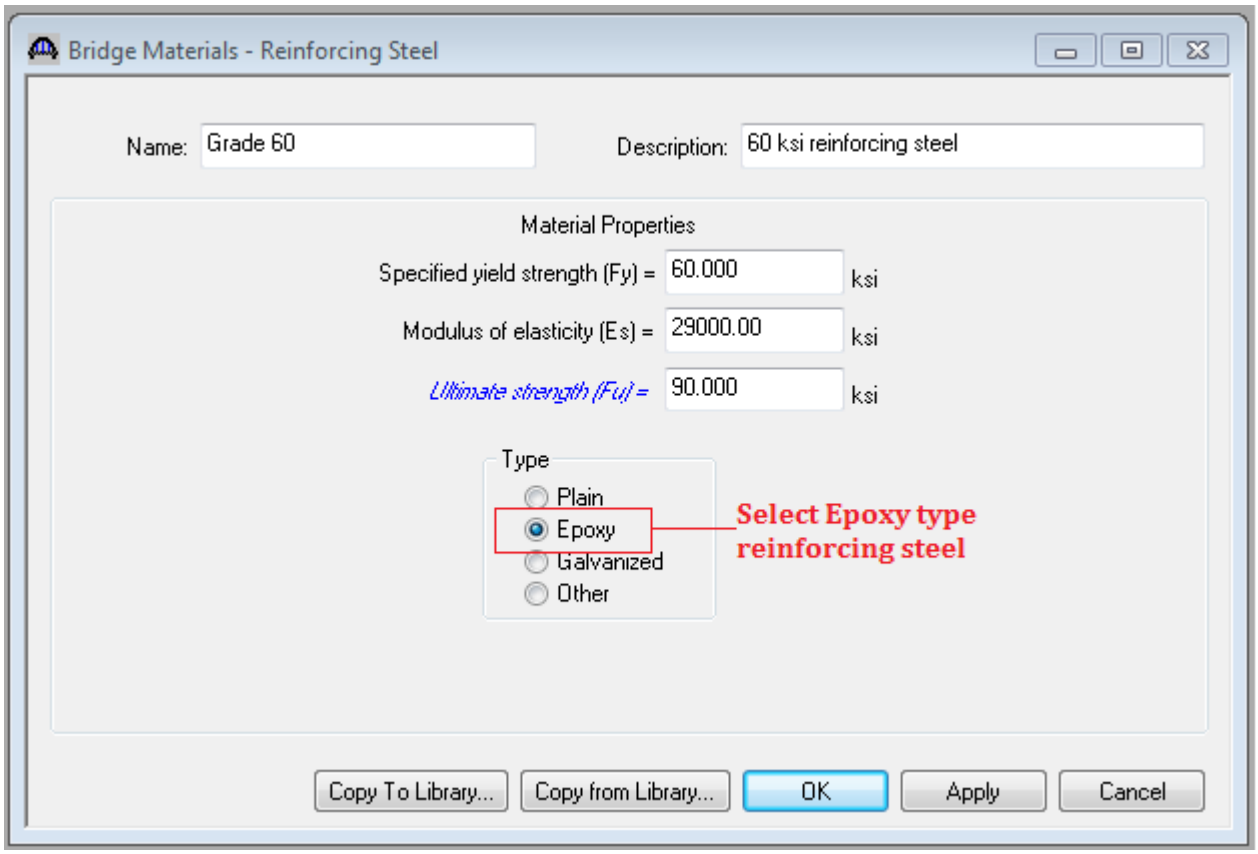
c. Enter appropriate name and description and modify the concrete section property values. See window below:

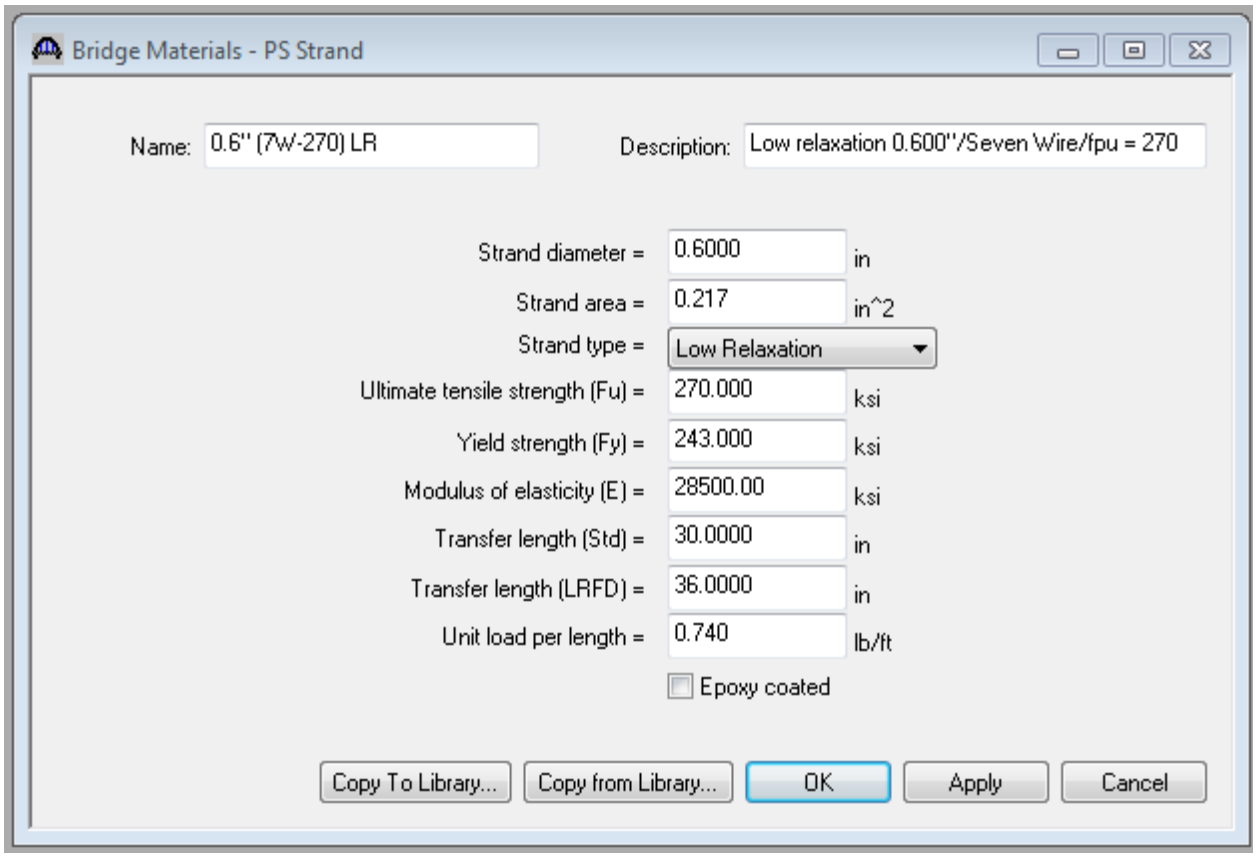


Click OK to save the data to memory and close the window.

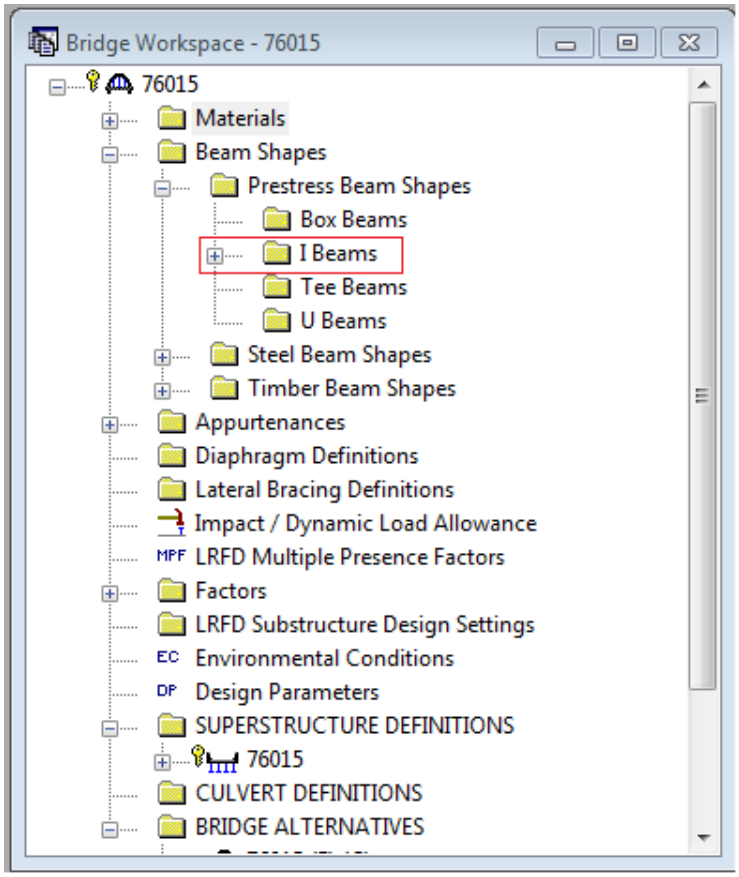
d. Add a concrete material for the deck, reinforcement material and prestress strand using the same techniques by copying from the library. Verify values for accuracy. The windows will look like shown below:



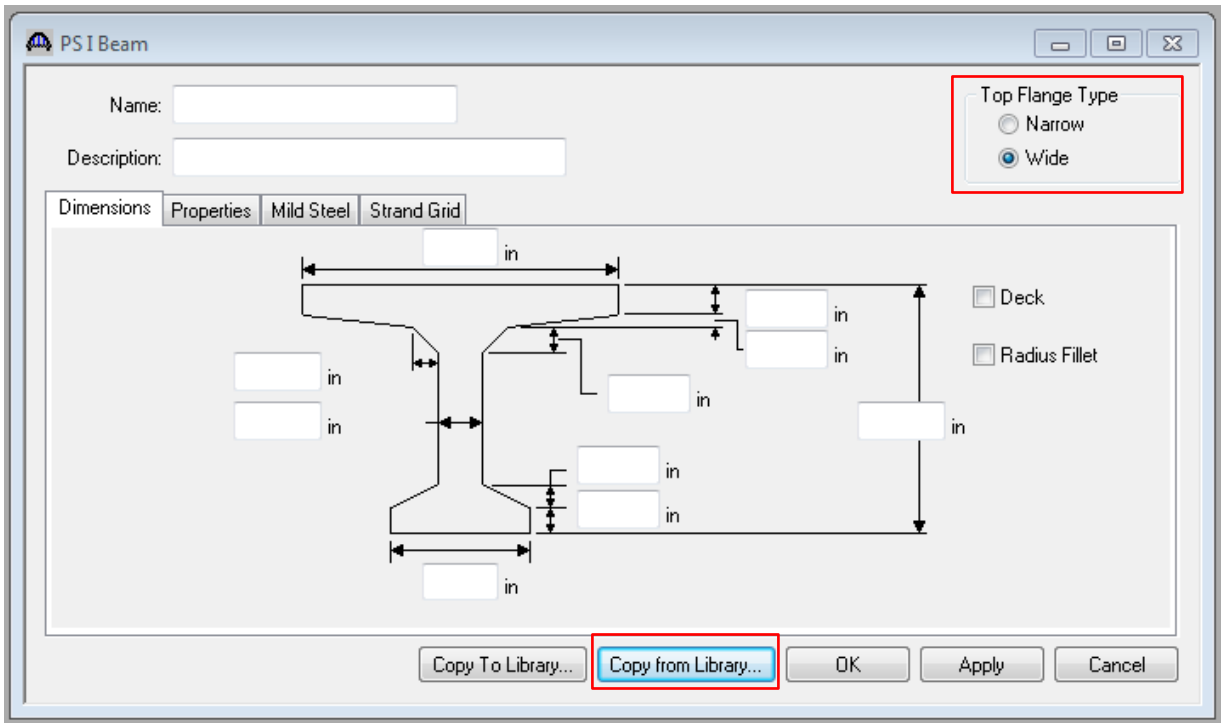

Bridge Materials - Reinforcing Steel
Name: Grade 60
Description: 60 ksi reinforcing steel
Material Properties
Specified yield strength (Fy) = 60.000 ksi
Modulus of elasticity (Es) = 29000.00 ksi
Ultimate strength (Fu) = 90.000 ksi
Type
Plain
Epoxy
Galvanized
Other
Select Epoxy type reinforcing steel
Copy To Library...
Copy from Library...
OK
Apply
Cancel


Bridge Materials - PS Strand
Name: 0.6" (7W-270) LR
Description: Low relaxation 0.600"/Seven Wire/fpu = 270
Strand diameter = 0.6000 in
Strand area = 0.217 in^2
Strand type = Low Relaxation
Ultimate tensile strength (Fu) = 270.000 ksi
Yield strength (Fy) = 243.000 ksi
Modulus of elasticity (E) = 28500.00 ksi
Transfer length (Std) = 30.0000 in
Transfer length (LRFD) = 36.0000 in
Unit load per length = 0.740 lb/ft
Epoxy coated
Copy To Library...
Copy from Library...
OK
Apply
Cancel

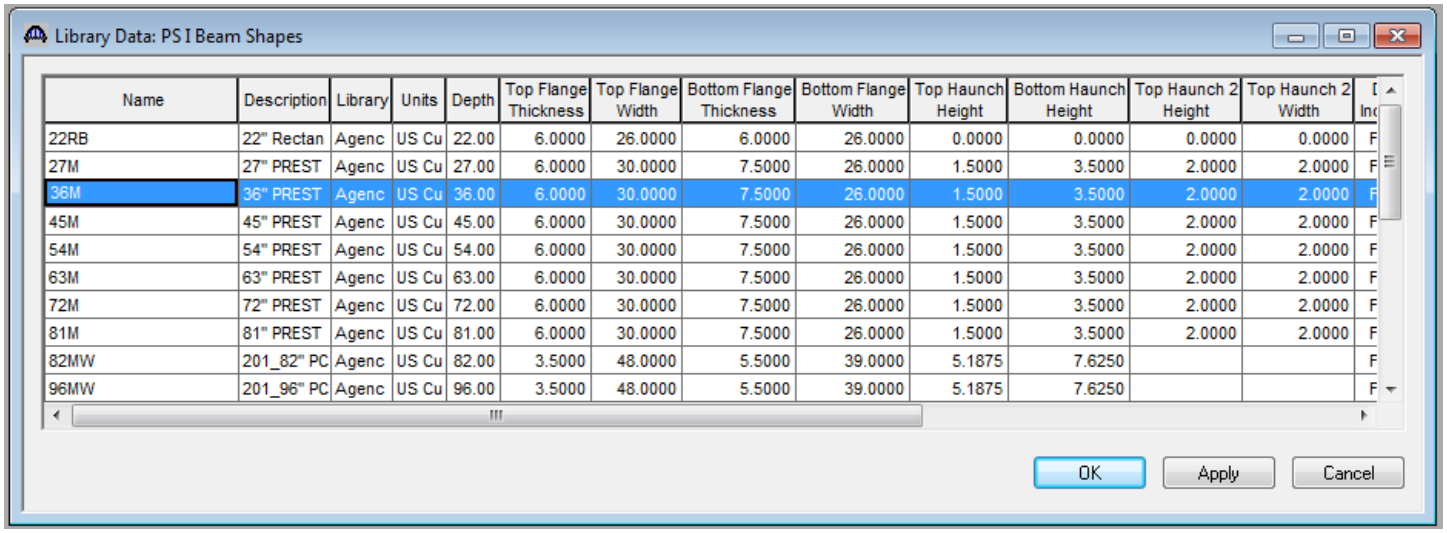
5. To enter a prestress beam shape to be used in this bridge, expand the tree labeled Beam Shapes as shown below:



   a. Click on I Beams in the tree and select File/New from the menu (or double click on I Beams in the tree). The window shown below will open.

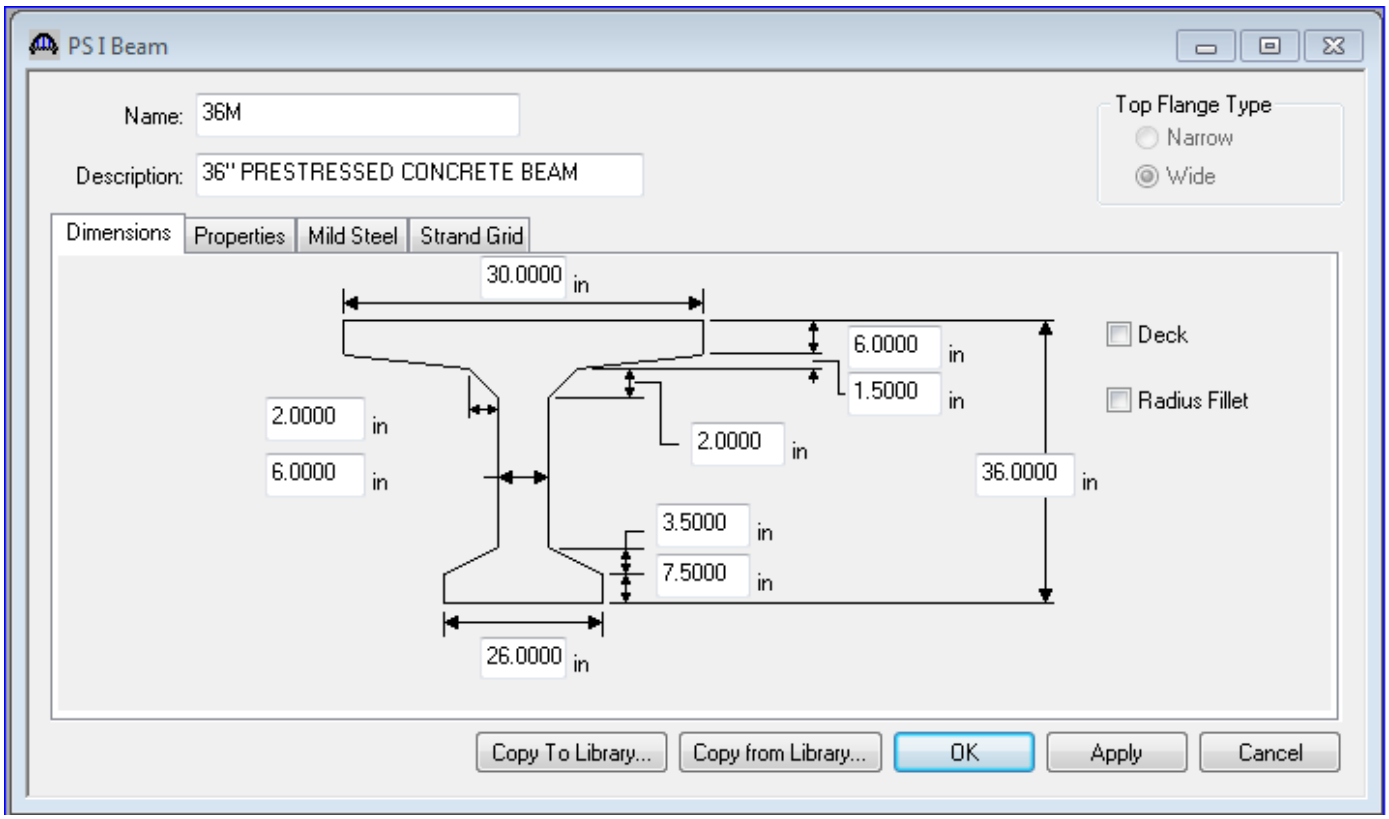


b. Select the Top Flange Type as "Wide" and click on the copy from Library button. Select 36M and click OK.



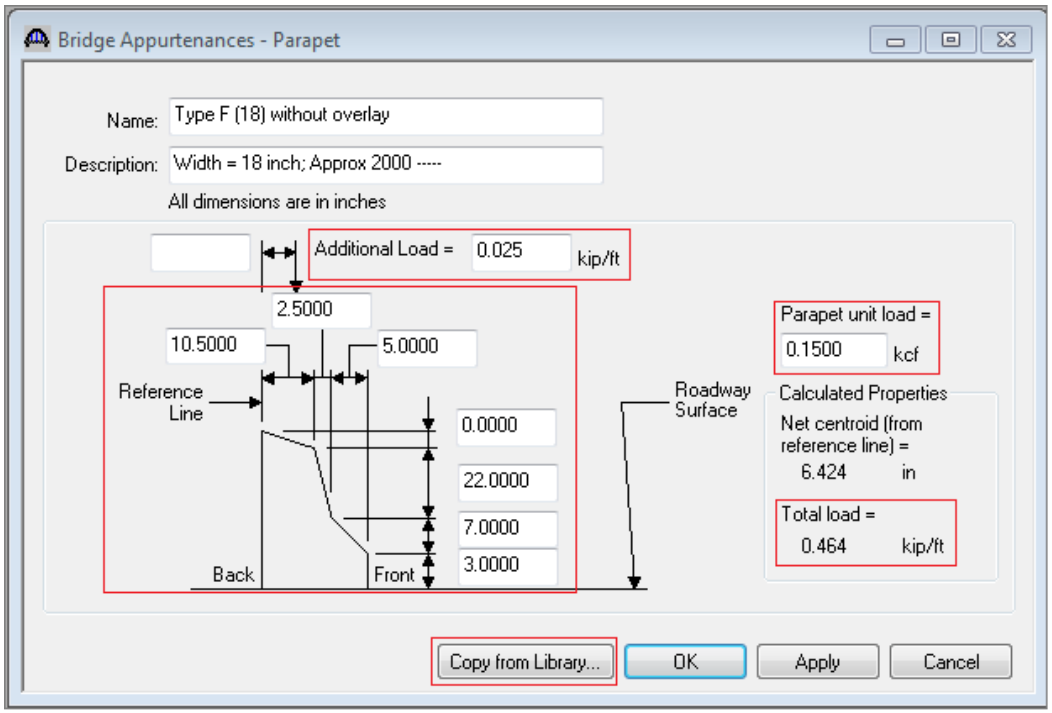
Name	Description	Library	Units	Depth	Top Flange Thickness	Top Flange Width	Bottom Flange Thickness	Bottom Flange Width	Top Haunch Height	Bottom Haunch Height	Top Haunch 2 Height	Top Haunch 2 Width
22RB	22" Rectan	Agenc	US Cu	22.00	6.0000	26.0000	6.0000	26.0000	0.0000	0.0000	0.0000	0.0000
27M	27" PREST	Agenc	US Cu	27.00	6.0000	30.0000	7.5000	26.0000	1.5000	3.5000	2.0000	2.0000
36M	36" PREST	Agenc	US Cu	36.00	6.0000	30.0000	7.5000	26.0000	1.5000	3.5000	2.0000	2.0000
45M	45" PREST	Agenc	US Cu	45.00	6.0000	30.0000	7.5000	26.0000	1.5000	3.5000	2.0000	2.0000
54M	54" PREST	Agenc	US Cu	54.00	6.0000	30.0000	7.5000	26.0000	1.5000	3.5000	2.0000	2.0000
63M	63" PREST	Agenc	US Cu	63.00	6.0000	30.0000	7.5000	26.0000	1.5000	3.5000	2.0000	2.0000
72M	72" PREST	Agenc	US Cu	72.00	6.0000	30.0000	7.5000	26.0000	1.5000	3.5000	2.0000	2.0000
81M	81" PREST	Agenc	US Cu	81.00	6.0000	30.0000	7.5000	26.0000	1.5000	3.5000	2.0000	2.0000
82MW	201_82" PC	Agenc	US Cu	82.00	3.5000	48.0000	5.5000	39.0000	5.1875	7.6250		
96MW	201_96" PC	Agenc	US Cu	96.00	3.5000	48.0000	5.5000	39.0000	5.1875	7.6250		

c. The beam properties are copied to the I Beam window as shown below.

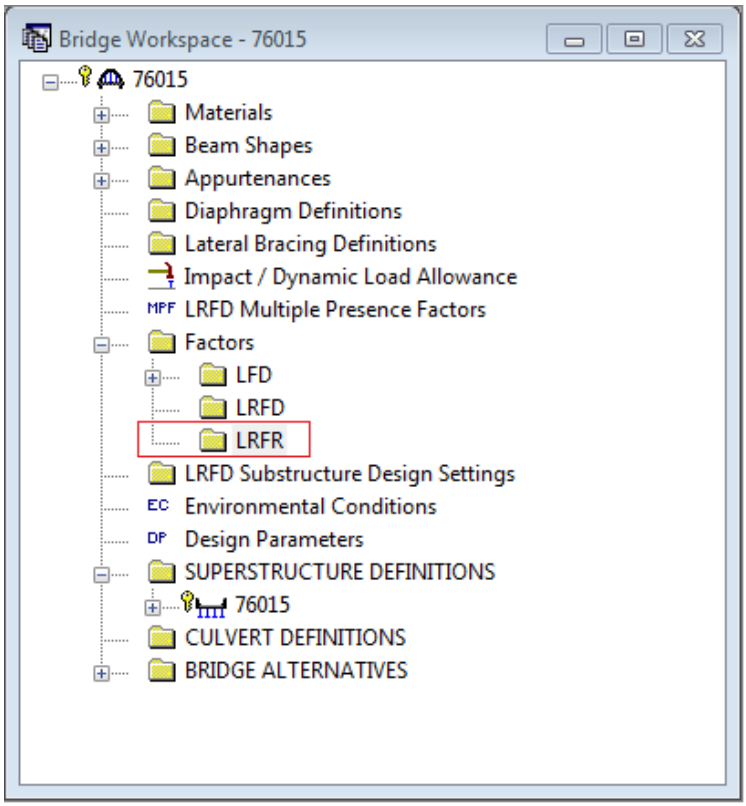


d. Click OK to save the data to memory and close the window

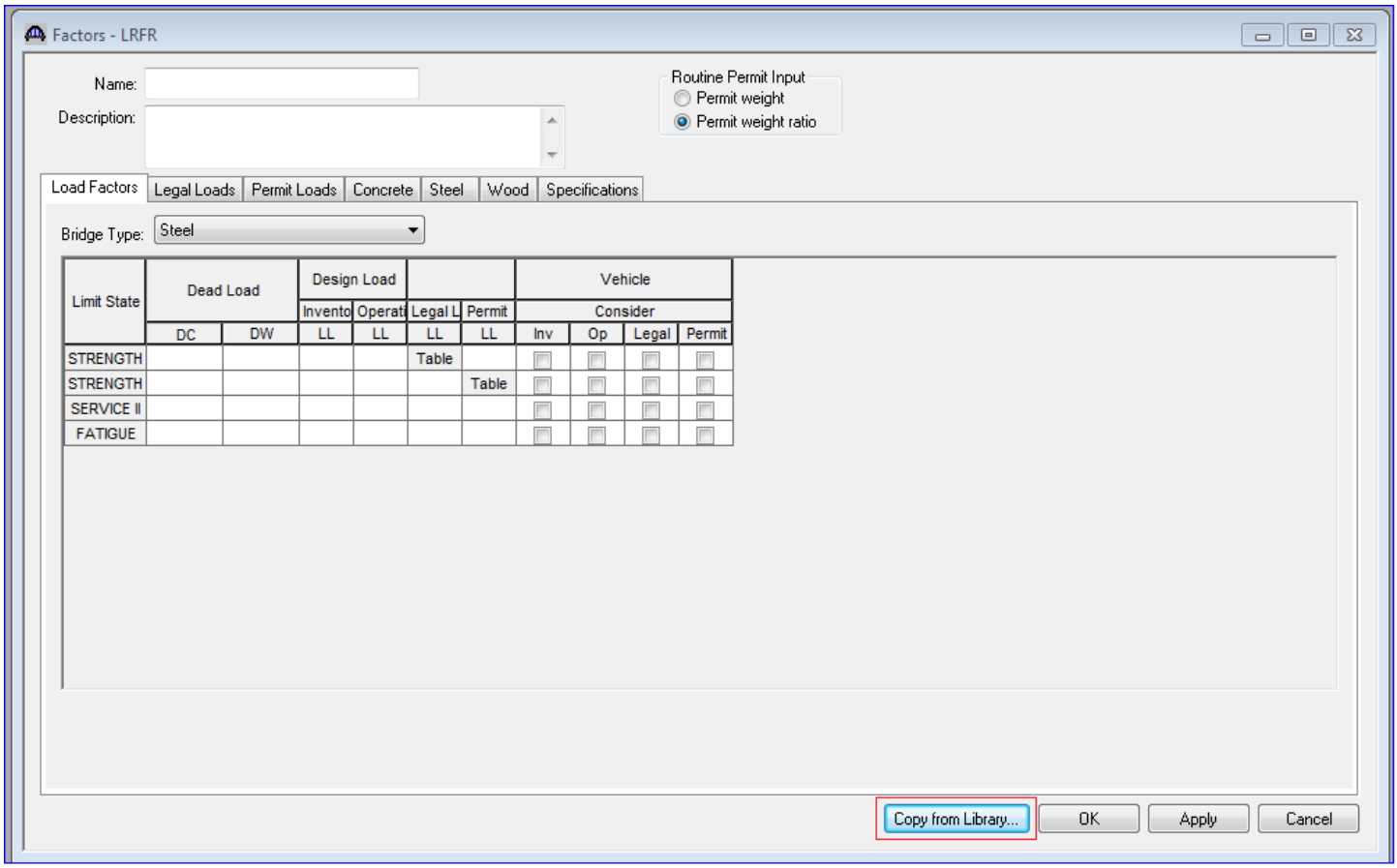
6. To enter the appurtenances to be used within the bridge, expand the tree branch labeled Appurtenances. To define a parapet double click on Parapet in the tree and input the parapet dimensions or click on "Copy from Library" as shown below. Modify values to match dimensions and Total load. Concrete total load is calculated from dimensions given in the diagram below and parapet unit load (concrete unit weight). User may add or subtract (enter negative value) load from Total load in Additional Load box. Click OK to save the data to memory and close the window.



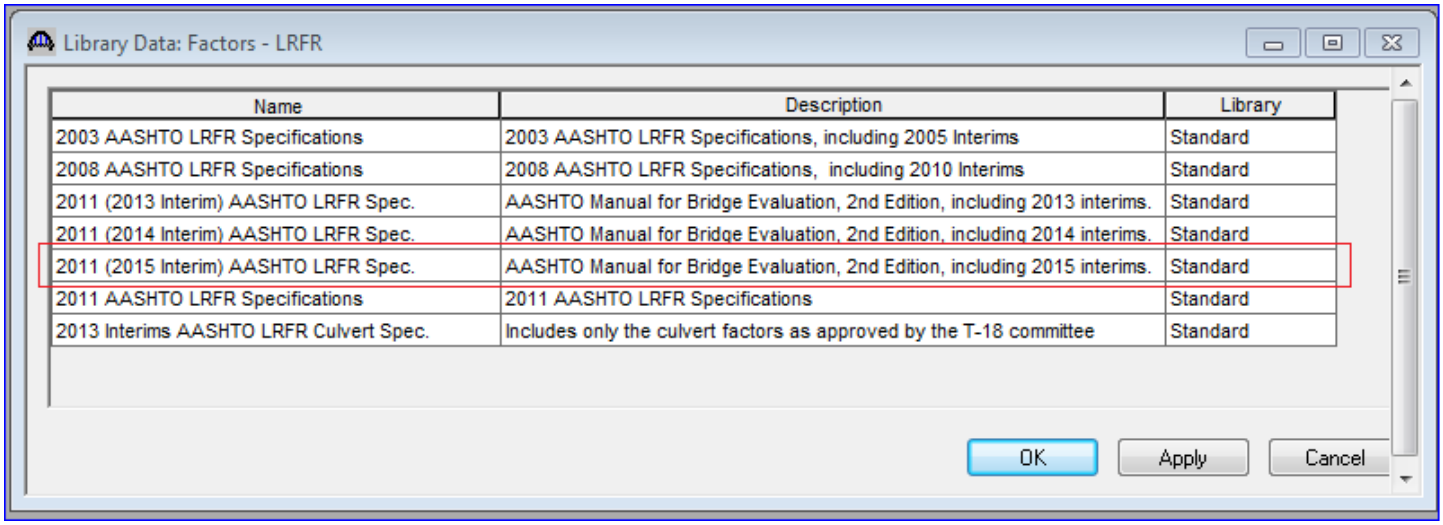
7. If applicable, raised median can be entered on median tab, expand the tree branch labeled Median. To enter information, follow step 6.
8. The default Standard impact factors will be used.
9. To enter LRFR factors, expand the tree branch labeled Factors. Double click on LRFR in the tree to open the Factors window.



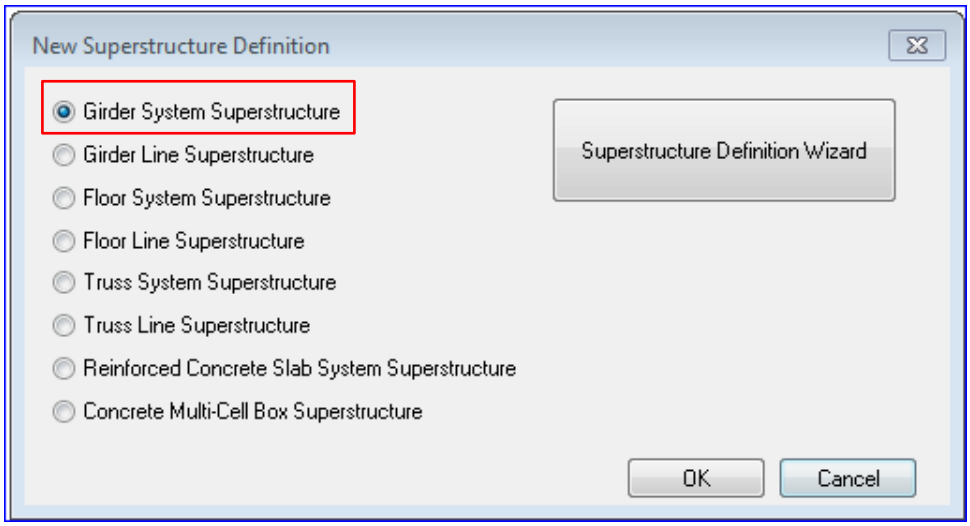
a. Click on “Copy from Library” button as shown below. This will open the window for Factors library data.



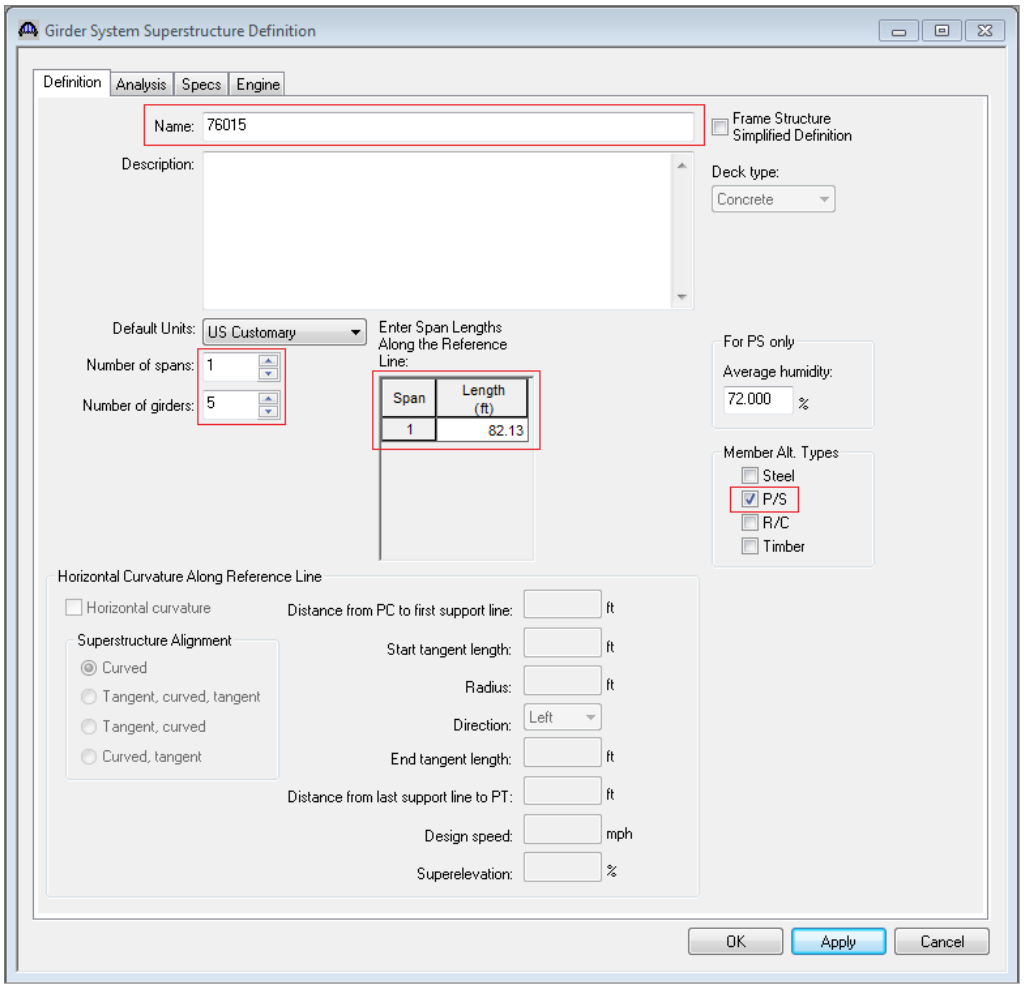
b. Select the most current AASHTO Specifications, "*AASHTO Spec, 2011 (2015 Interim) AASHTO LRFR Spec.*" as shown below. Click OK to save the data to memory and close the window.



10. To create the superstructure type for the bridge, double click on SUPERSTRUCTURE DEFINITIONS (or click on SUPERSTRUCTURE DEFINITIONS and select File/New from the menu or right mouse click on SUPERSTRUCTURE DEFINITIONS and select New from the popup menu) to create a new structure definition. The following dialog will open.

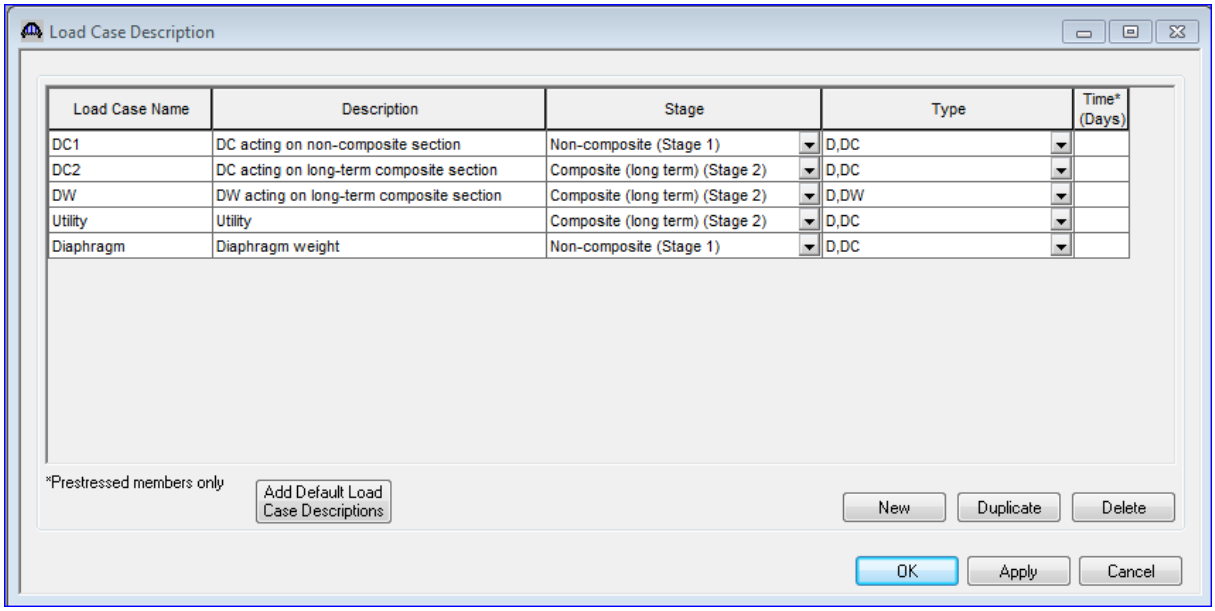


a. Select Girder System and click OK and the Structure Definition window will open. Enter the appropriate data as shown below and check P/S box (for PCB). Click on OK to save the data to memory and close the window.

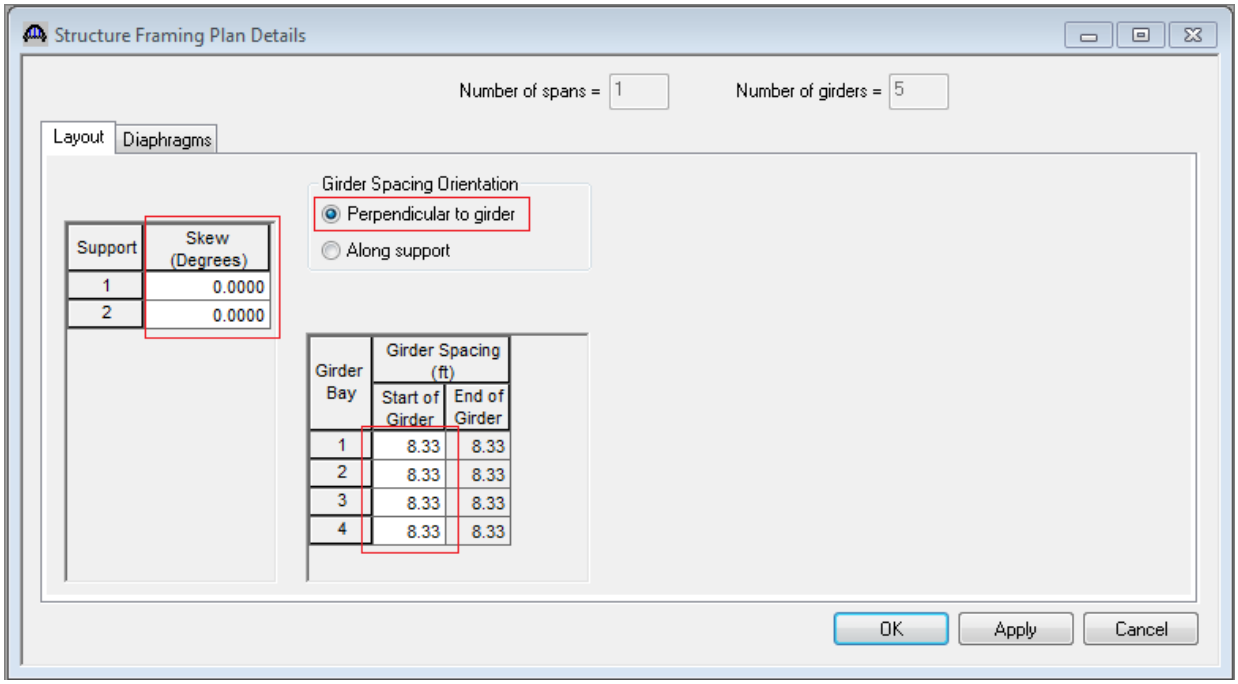


11. Click Load Case Description to define the dead load cases. The composite Dead Load (DL2) needs to be separated into two (or more) items (lines). This is because LRFR will use different load factors for each of the items.
    -D, DC includes the original wearing course, railings, median, sidewalk, etc…
    -D, DW includes utilities.

Enter the required information and click the OK button. The completed Load Case Description window is shown below.

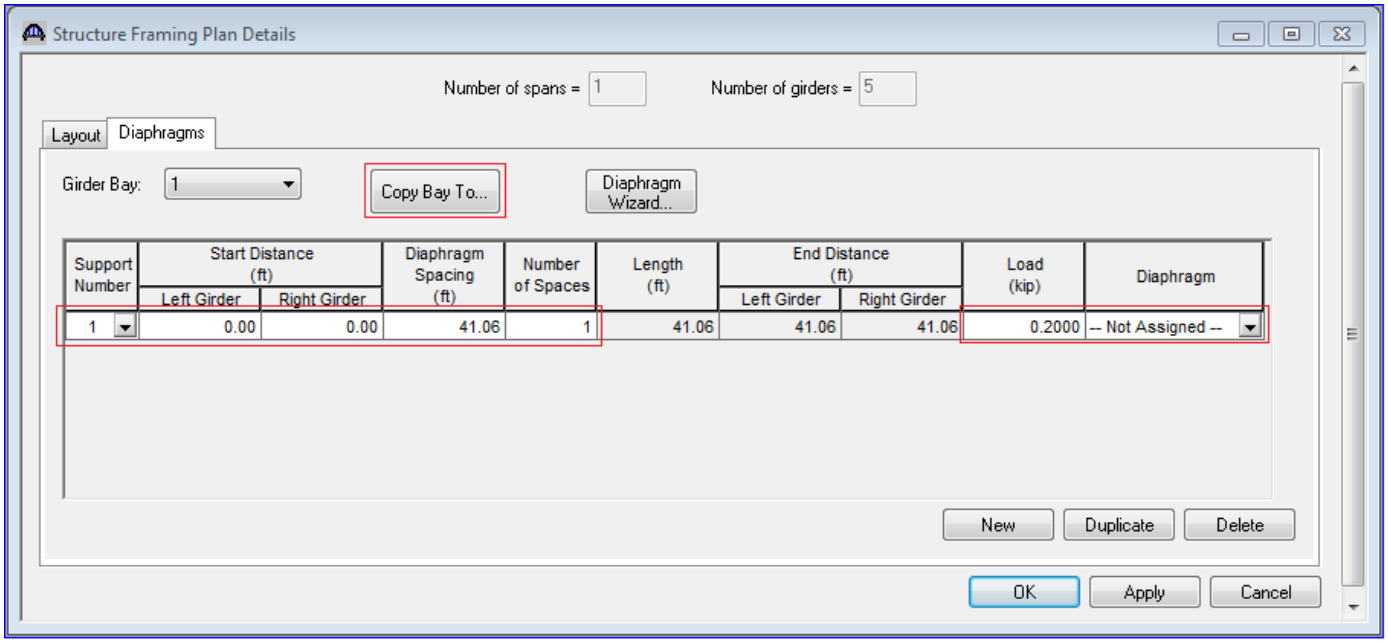


12. Double-click on Framing Plan Detail to describe the framing plan. Enter the appropriate data as shown below.



a. Switch to the Diaphragms tab to enter diaphragm spacing. Click New and enter the following diaphragm information in the dialog shown below. Click on Copy Bay To button to copy diaphragm bracing information from Girder Bay 1 to other bays.

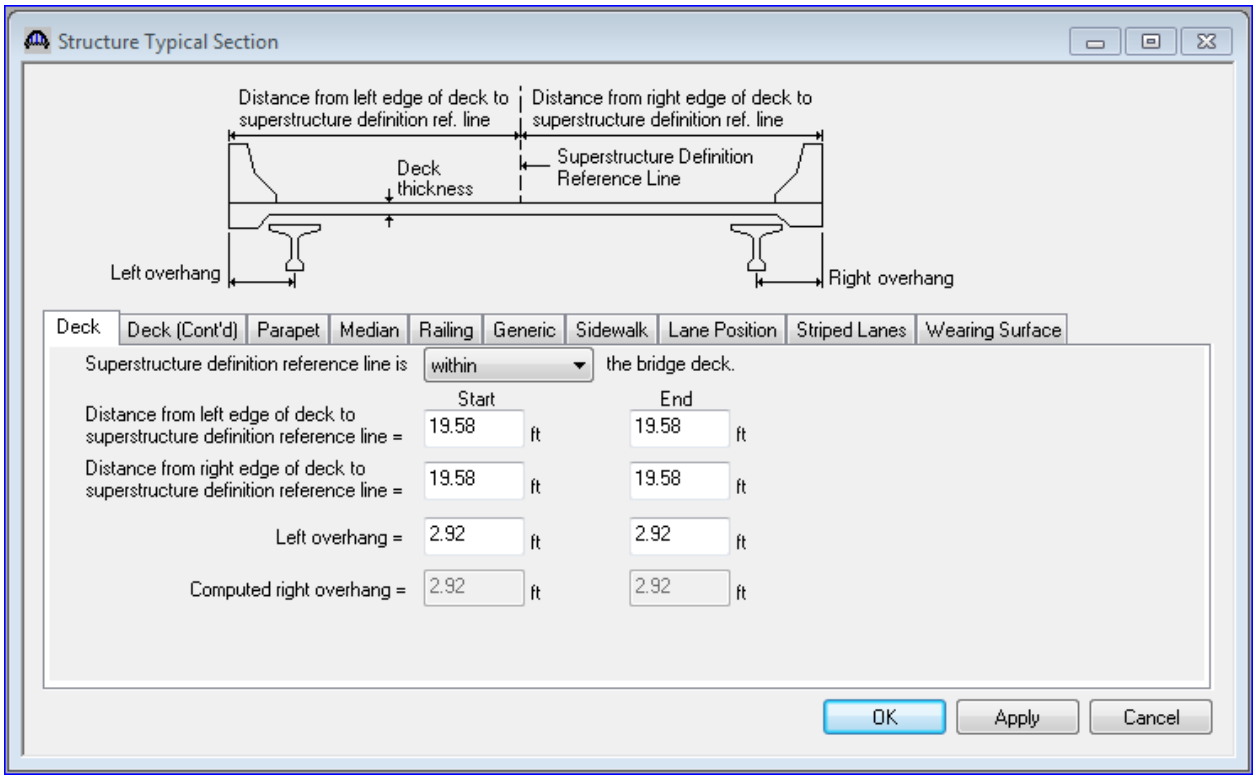
Note: Another option for entering diaphragm load is in the tree branch labeled MEMBERS. For each girder that is created, a point load can be entered in the Concentrated tab in the Member Loads element. See step 19



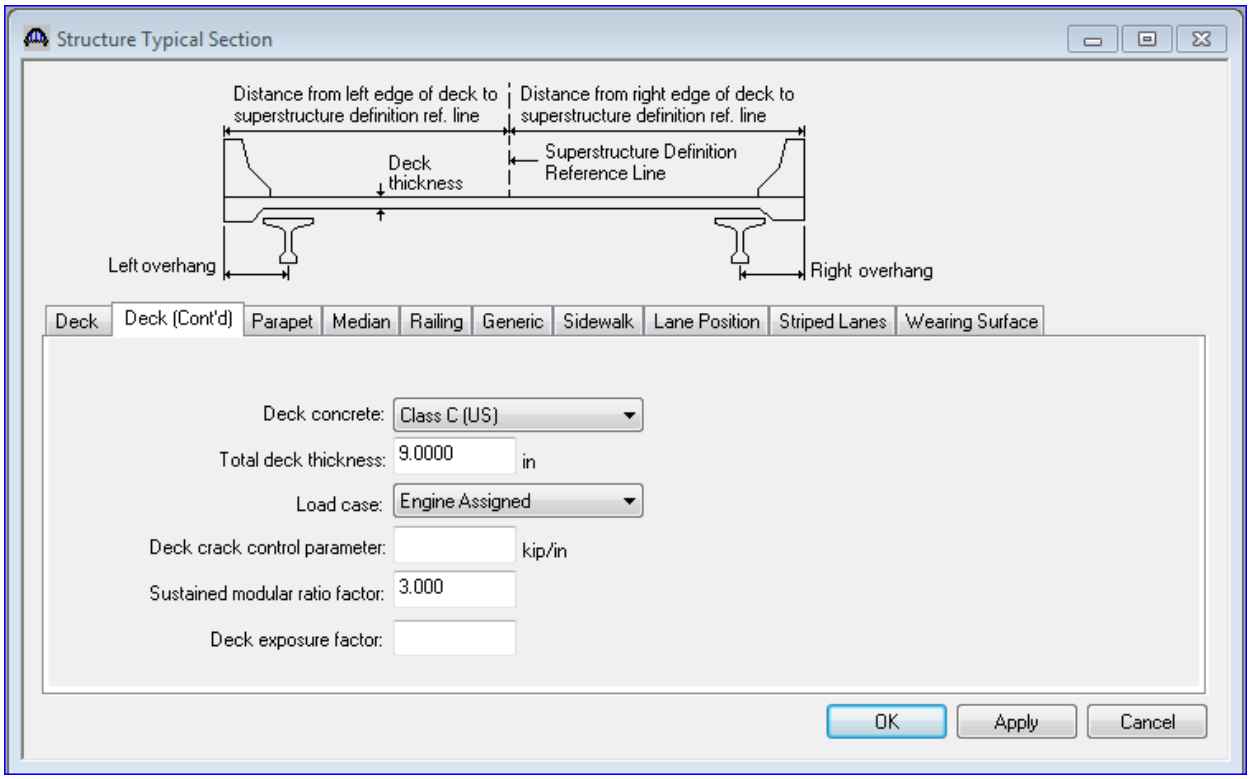
b. Select OK to close the window

13. Next define the structure typical section by double-clicking on Structure Typical Section in the Bridge Workspace tree. If applicable, User can enter typical section information related to the deck, parapets, median, railings, generic barrier, sidewalk, lane position, and wearing surface. Input the data describing the typical section as shown below.

Basic deck geometry:

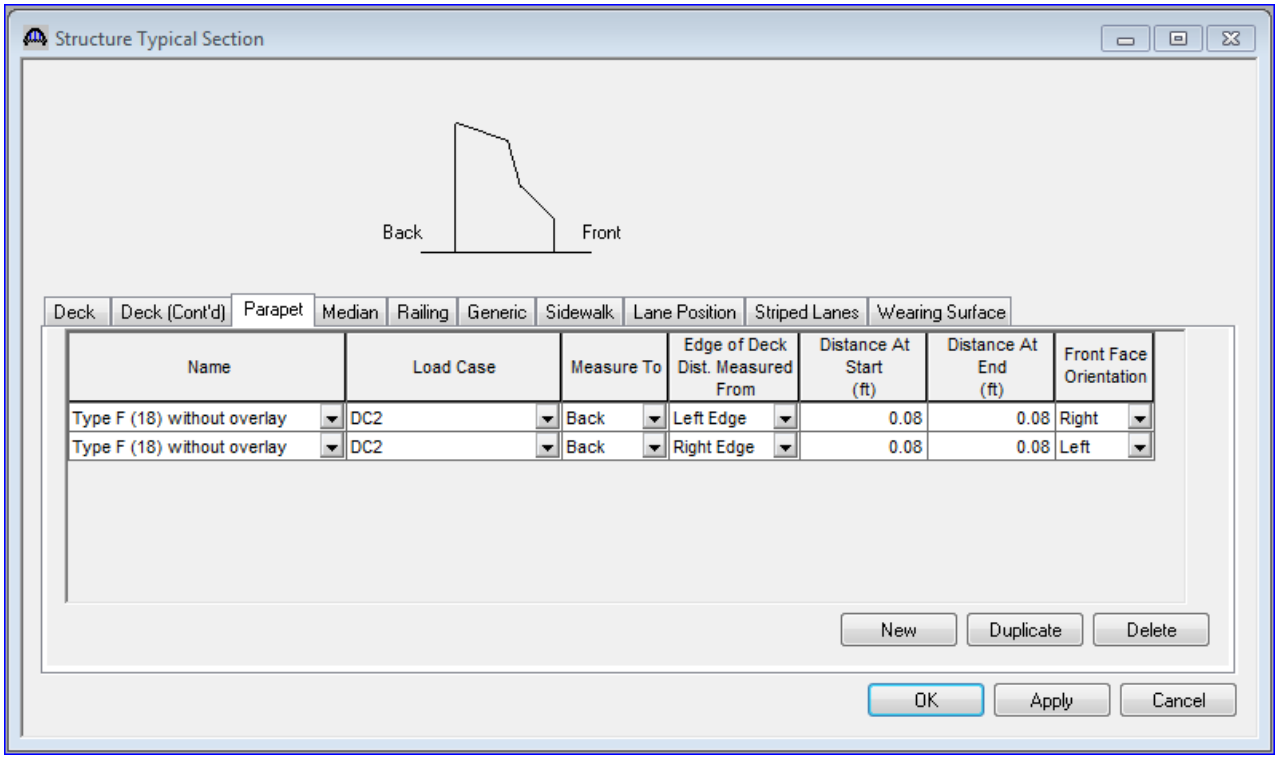


a. The Deck (cont'd) tab is used to enter information about the deck concrete and thickness. Enter total deck thickness as indicated in the plan (no deduction for wearing surface).


Structure Typical Section
Distance from left edge of deck to superstructure definition ref. line
Distance from right edge of deck to superstructure definition ref. line
Deck thickness
Superstructure Definition Reference Line
Left overhang
Right overhang
Deck
Deck (Cont'd)
Parapet
Median
Railing
Generic
Sidewalk
Lane Position
Striped Lanes
Wearing Surface
Deck concrete:
Class C (US)
Total deck thickness:
9.0000
in
Load case:
Engine Assigned
Deck crack control parameter:
kip/in
Sustained modular ratio factor:
3.000
Deck exposure factor:
OK
Apply
Cancel

Parapets:

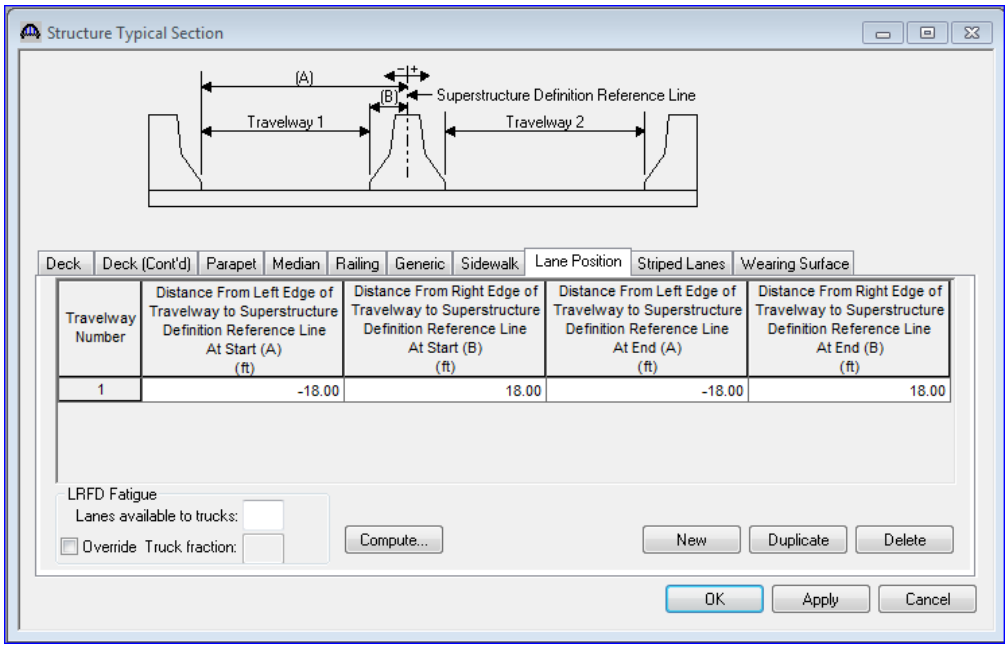
14. Add two parapets as shown below.



Name	Load Case	Measure To	Edge of Deck Dist. Measured From	Distance At Start (ft)	Distance At End (ft)	Front Face Orientation
Type F (18) without overlay	DC2	Back	Left Edge	0.08	0.08	Right
Type F (18) without overlay	DC2	Back	Right Edge	0.08	0.08	Left

Lane Positions:

15. Select the Lane Position tab and use the Compute… button to compute the lane positions. A dialog showing the results of the computation opens. Click Apply to apply the computed values. The Lane Position tab is populated as shown below.

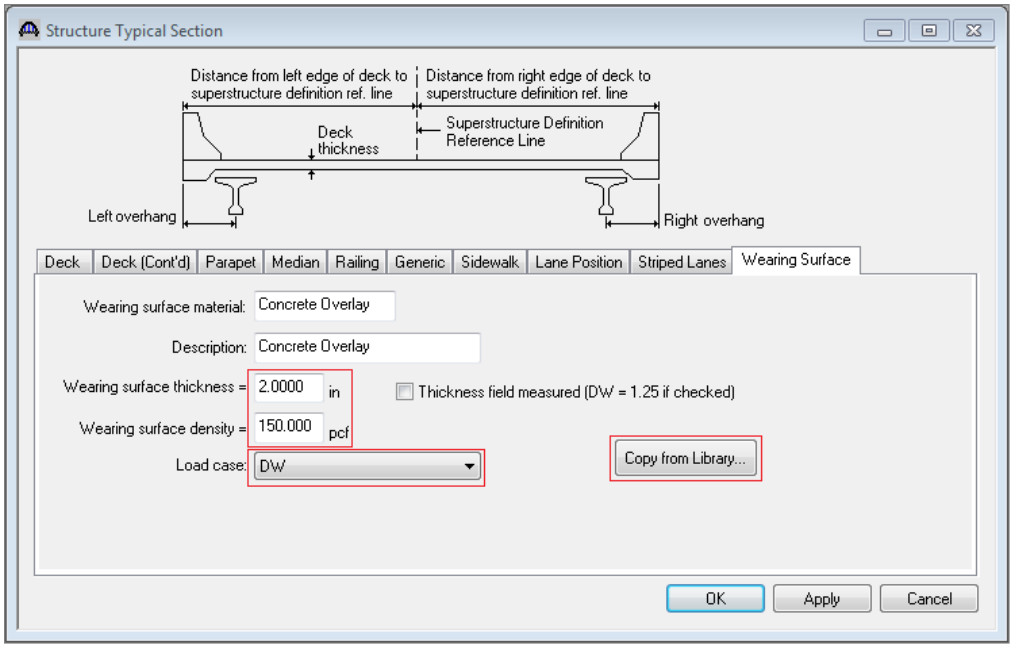


Striped Lanes:

16. Ignore this tab

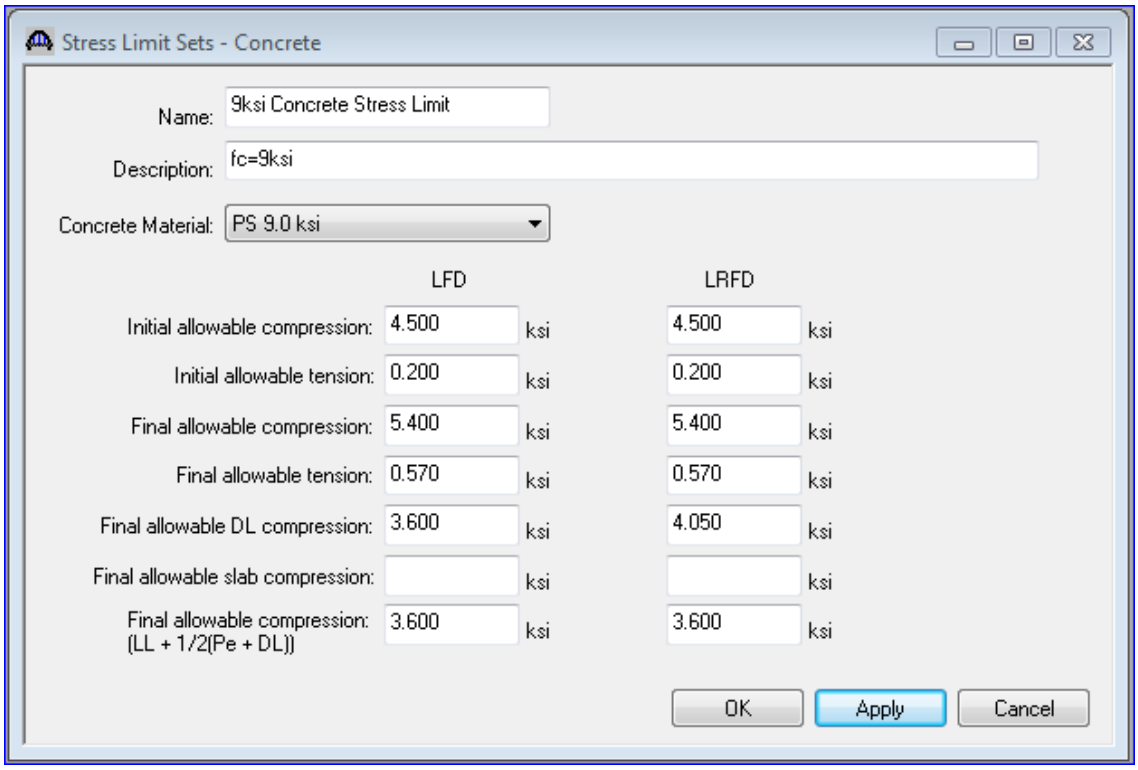
Wearing Surface:

17. Since the plan calls for no wearing surface, it is not required that this tab is filled out. To show how a User would complete the section, data were entered as shown below.



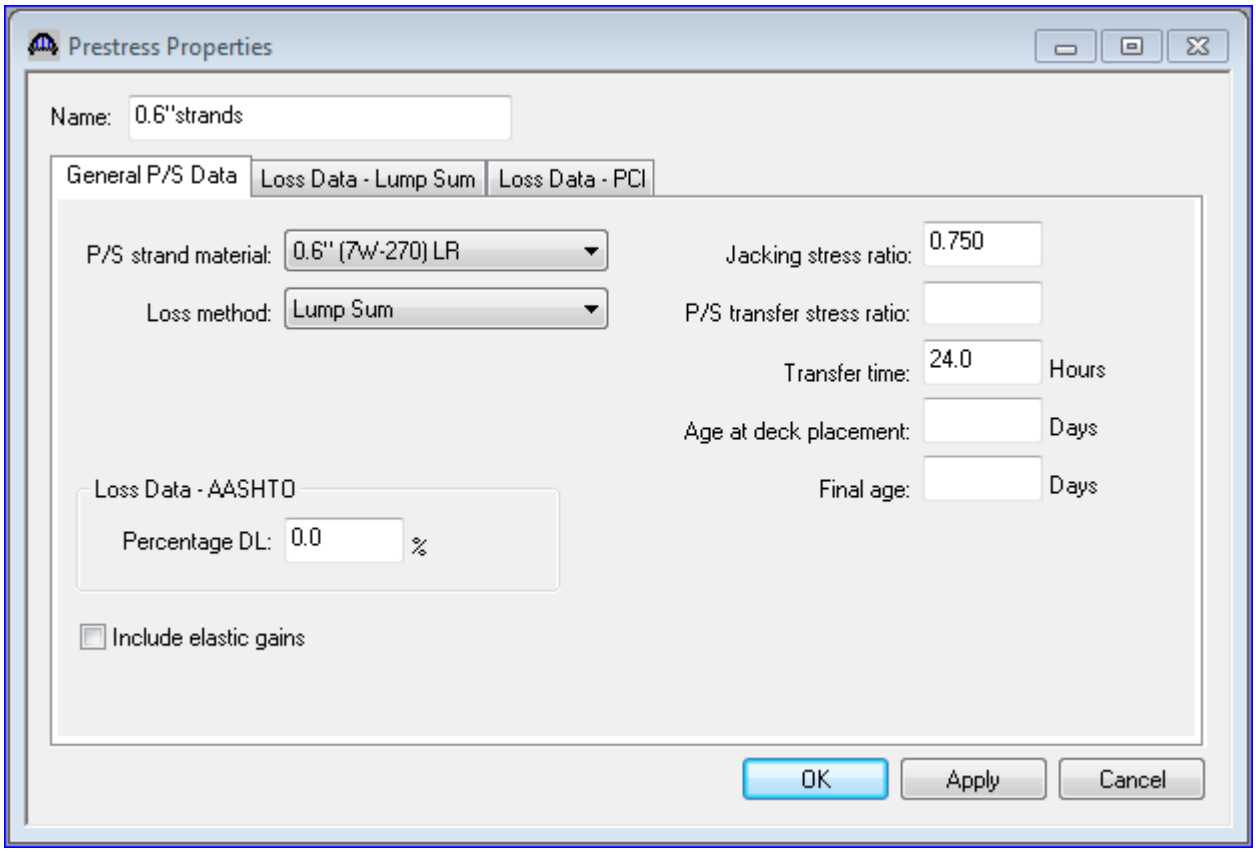
   a. Click OK to save the data to memory and close the window.

18. Now define a Stress Limit. A Stress Limit defines the allowable concrete stresses for a given concrete material. Double click on the Stress Limits tree item to open the window. Select the “PS 9.0 ksi” concrete material. Default values for the allowable stresses will be computed based on this concrete and the AASHTO Specifications. A default value for the final allowable slab compression is not computed since the deck concrete is typically different from the concrete used in the beam. Click OK to save this information to memory and close the window.

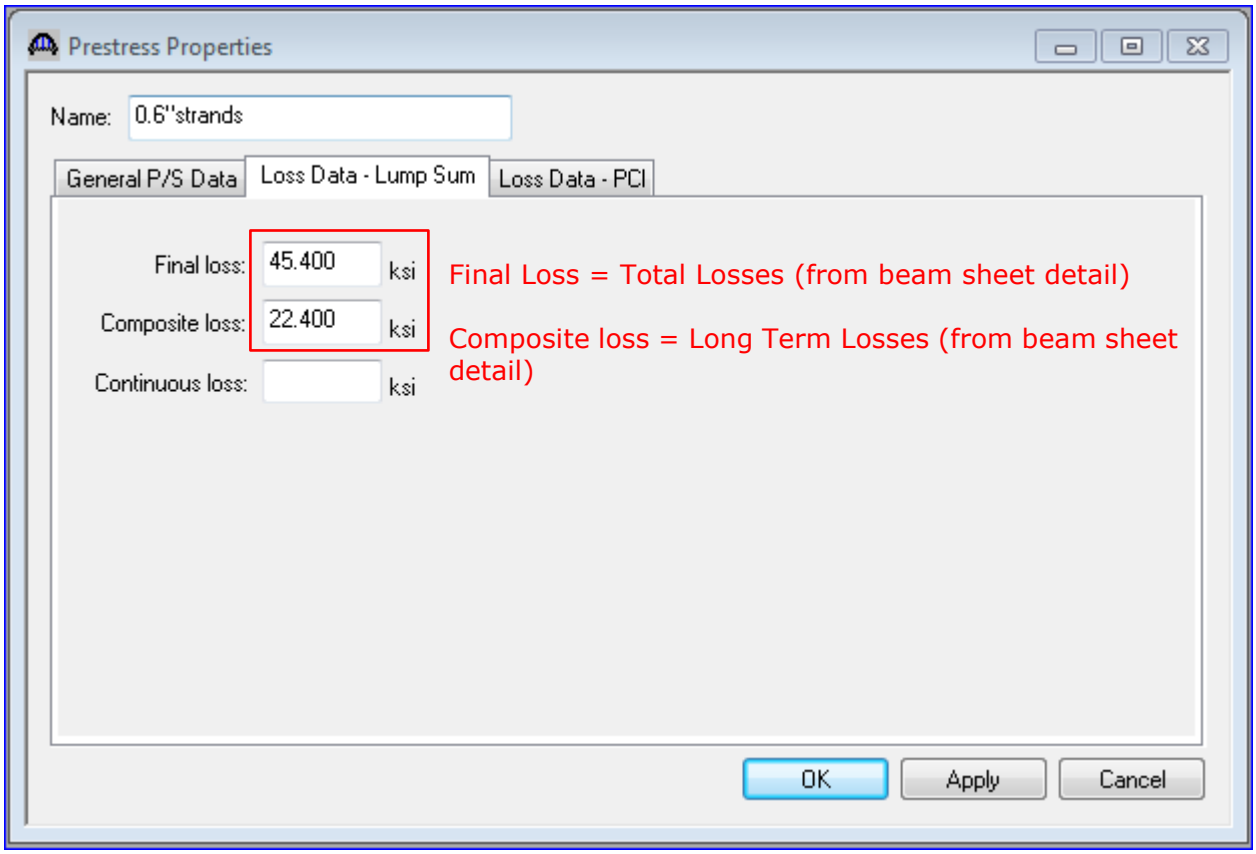


19. Double click on the Prestress Properties tree item to open a window in which to define the prestress properties for this structure definition. Define the Prestress Property as shown below. MnDOT uses the Lump Sum Method to compute losses so both "General P/S Data" and "Loss Data – Lump Sum" tabs are visited.

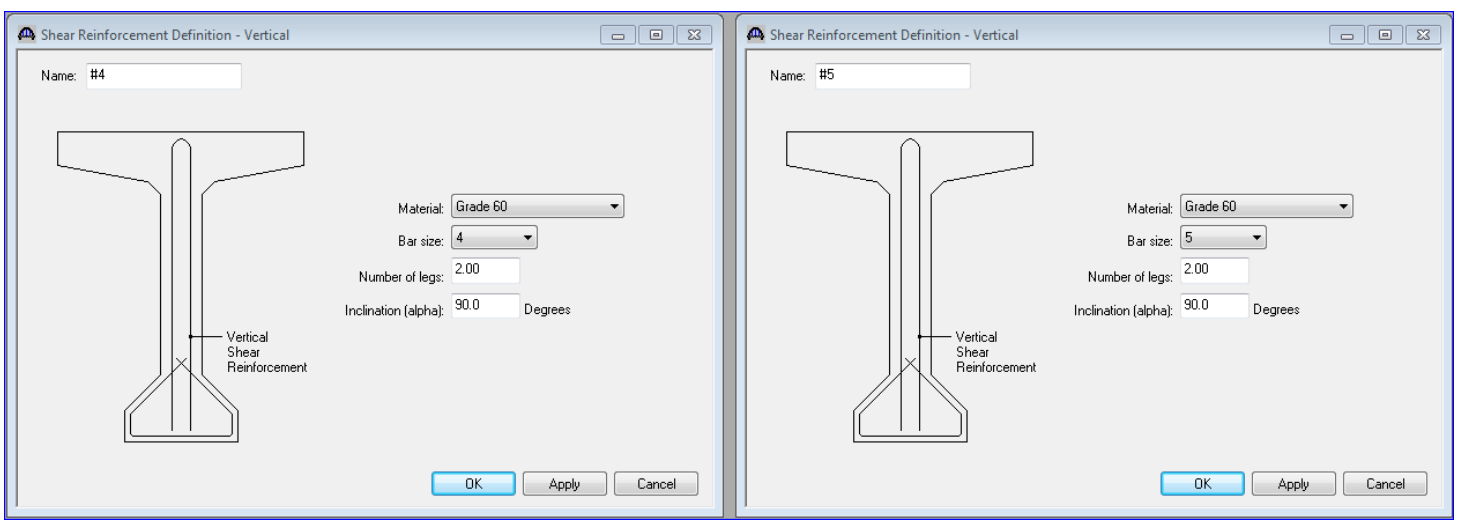
Note: Bridges built prior to Oct. 2009 are rated using LFR method. For this method of analysis, MnDOT uses the AASHTO Approximate method to compute losses so the "General P/S Data" tab is the only tab that User will have to visit. For bridges build on or after Oct. 2009, Lump Sum Method should be used.



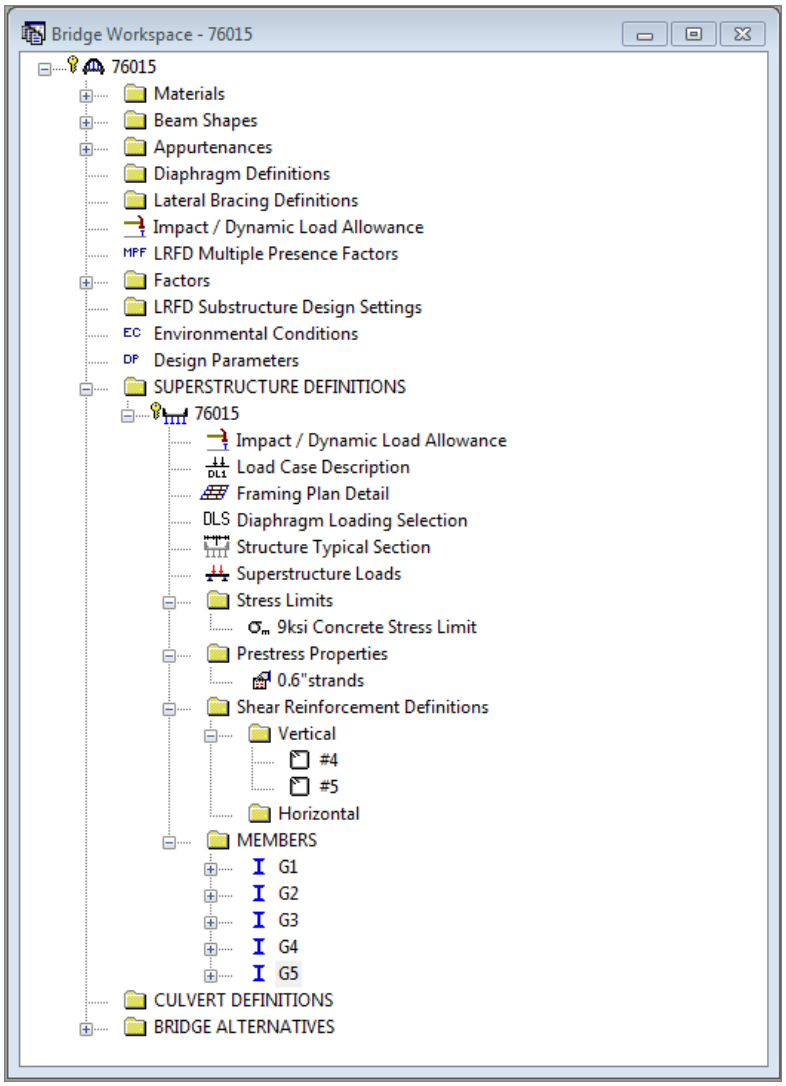
a. For the Loss Data – Lump Sum tab, enter the Final loss and Composite loss values from the beam detail section of the bridge plan. See image below. Click OK to save to memory and close the window.



20. Now define the vertical shear reinforcement by double clicking on Vertical (under Shear Reinforcement Definitions in the tree). Define the reinforcements (#4 and #5) as shown below. Click OK to save to memory and close the window.

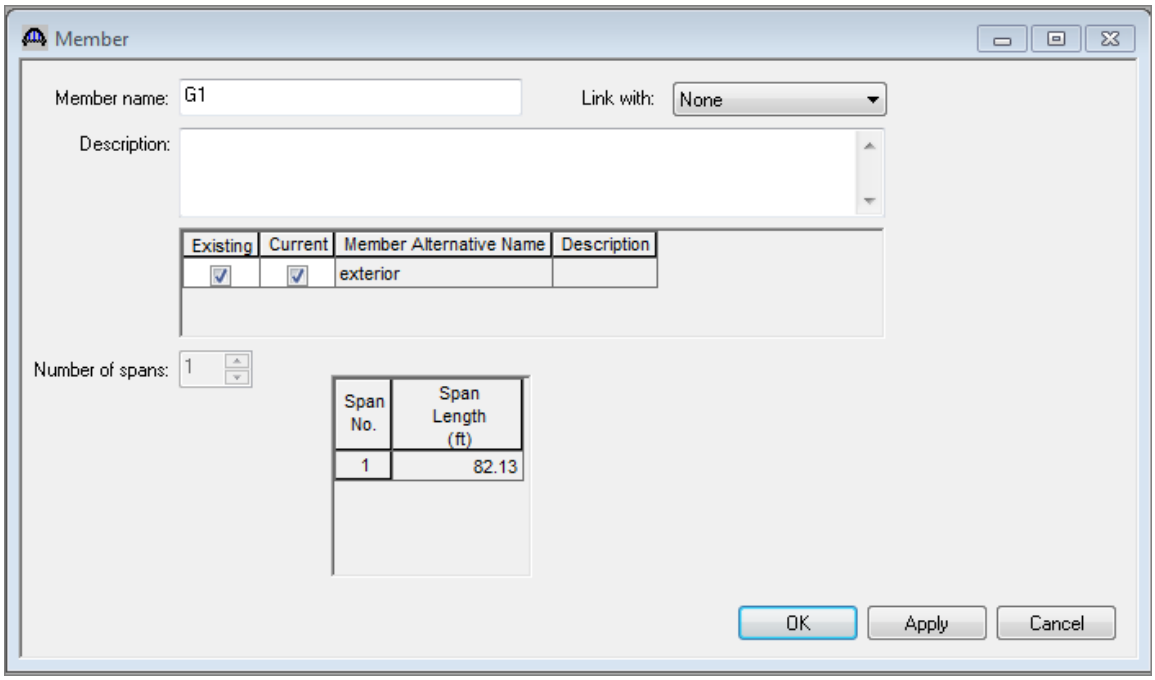


A partially expanded Bridge Workspace is shown below.



Describing a member: Exterior Beam

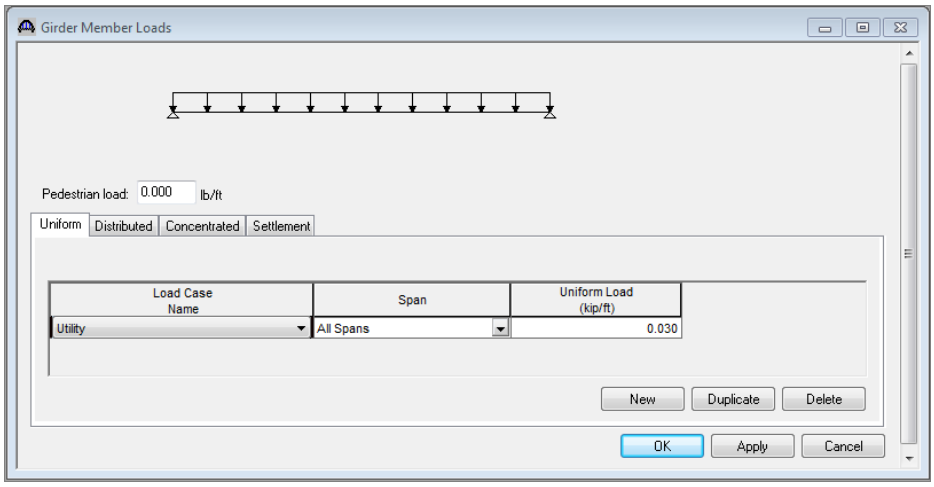
21. The G1 member window (see image below) shows the data that was generated when the structure definition was created. No changes are required at this time. The first Member Alternative that we create will automatically be assigned as the Existing and Current Member alternative for this Member.



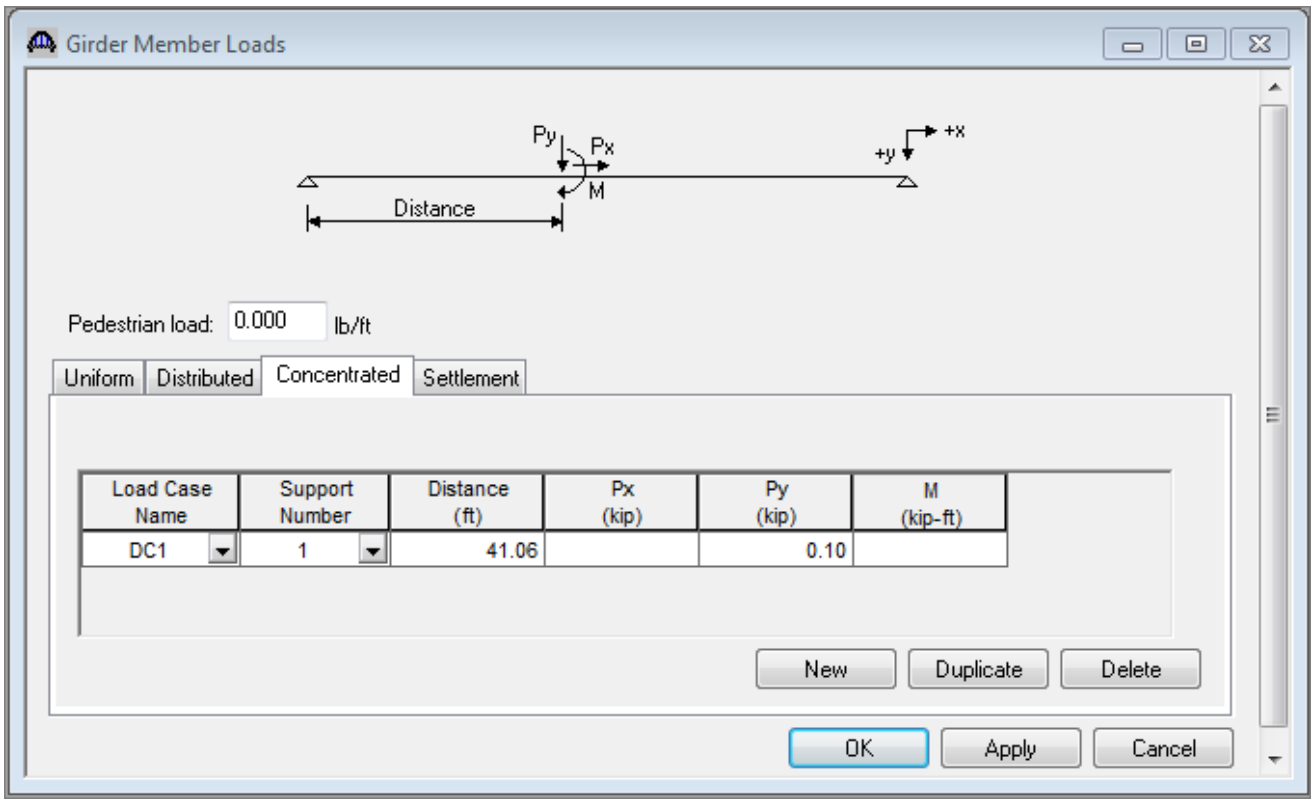
22. Utility load is entered in the Member Loads section under the G1 member in the tree. Double-click Member Loads in the tree to open the window. Under the Uniform tab, select load case that is to be applied, select the span(s) for which the uniform load is to be entered and enter the magnitude of the uniform load as shown below.

MnDOT Design Policy Item:

Note: Unless otherwise confirmed by inspection, include a dead load for utilities of 2 psf of deck area in rural areas and 3 psf in cities and urban areas. Higher loads may be required if heavier utilities are shown on the plan or are known to exist.

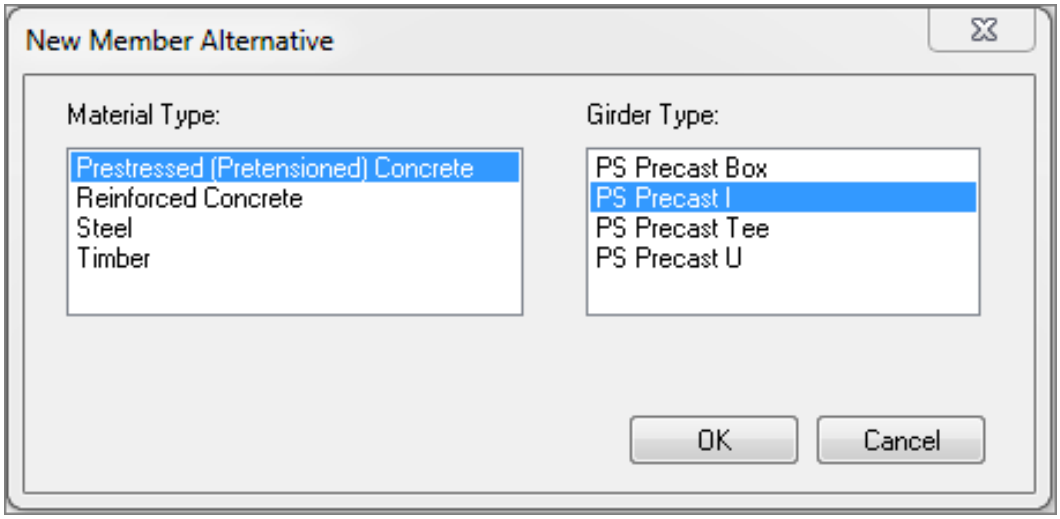


23. As stated earlier (see step 10-a), User has the option of entering Diaphragm load as a concentrated load to act on a member. The Concentrated Tab will allow the User to define the load acting on a member. A sketch is presented illustrating the load type for the selected tab. To show how a User would complete the section, data were entered as shown below. Click OK to save to memory and close the window.



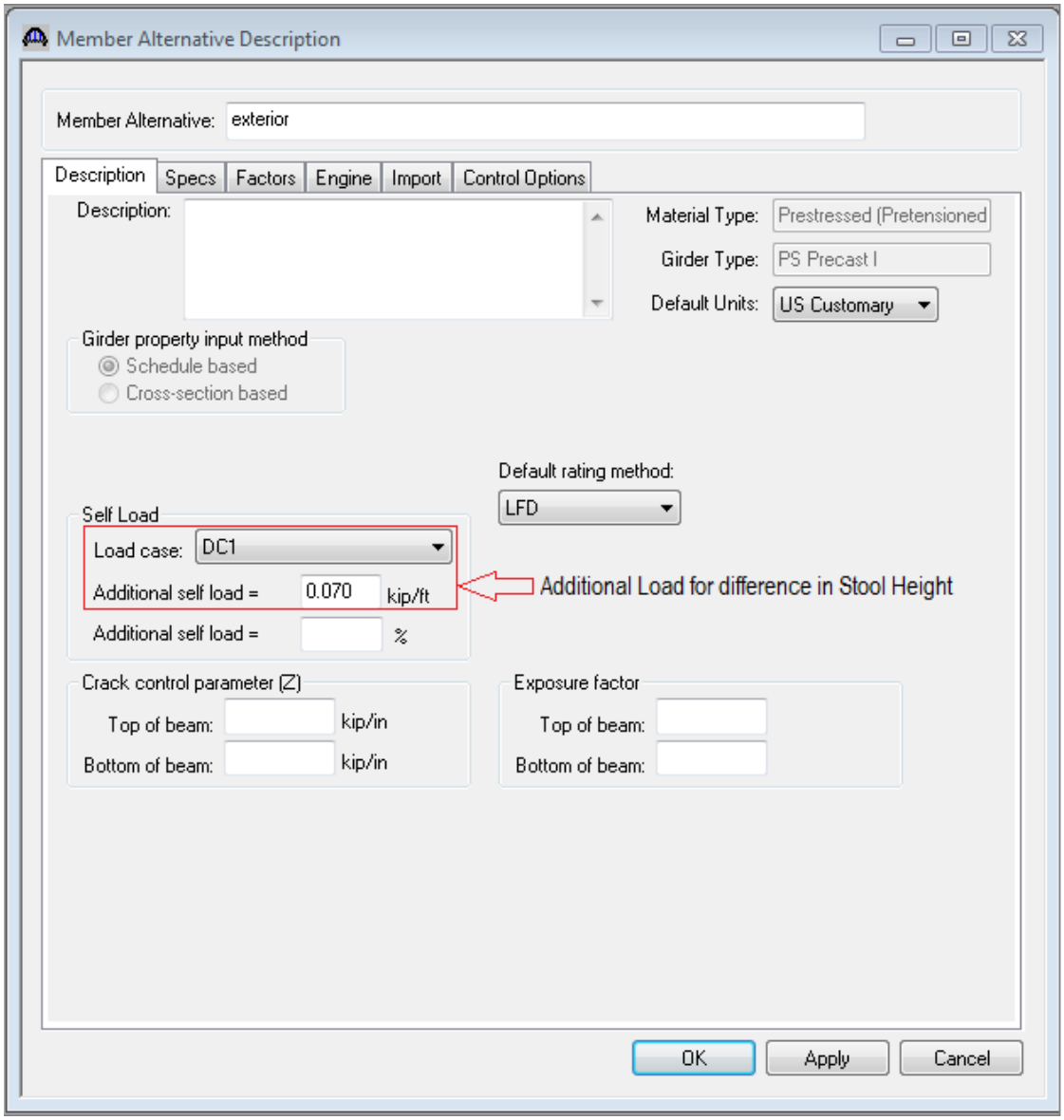
Defining a Member Alternative:

24. Expand the G1 member in the tree. Double-click MEMBER ALTERNATIVES in the tree to create a new alternative. The New Member Alternative dialog shown below will open. Select Prestressed (Pretensioned) Concrete for the Material Type and PS Precast I for the Girder Type.



a. Click OK to close the dialog and create a new member alternative.

25. The Member Alternative Description window will open. Enter the appropriate data as shown below. The Schedule-based Girder property input method is the only input method available for a prestressed concrete beam. To account for the weight of additional stool, residual camber, slope of the deck, super elevation, etc. weight is added in the Self Load section of the Member Alternative Description window as uniform dead load as shown below.



a. Click on the Control Options Tab. For modeling prestressed concrete beams in BrR, select the following LFD and LRFR control options.

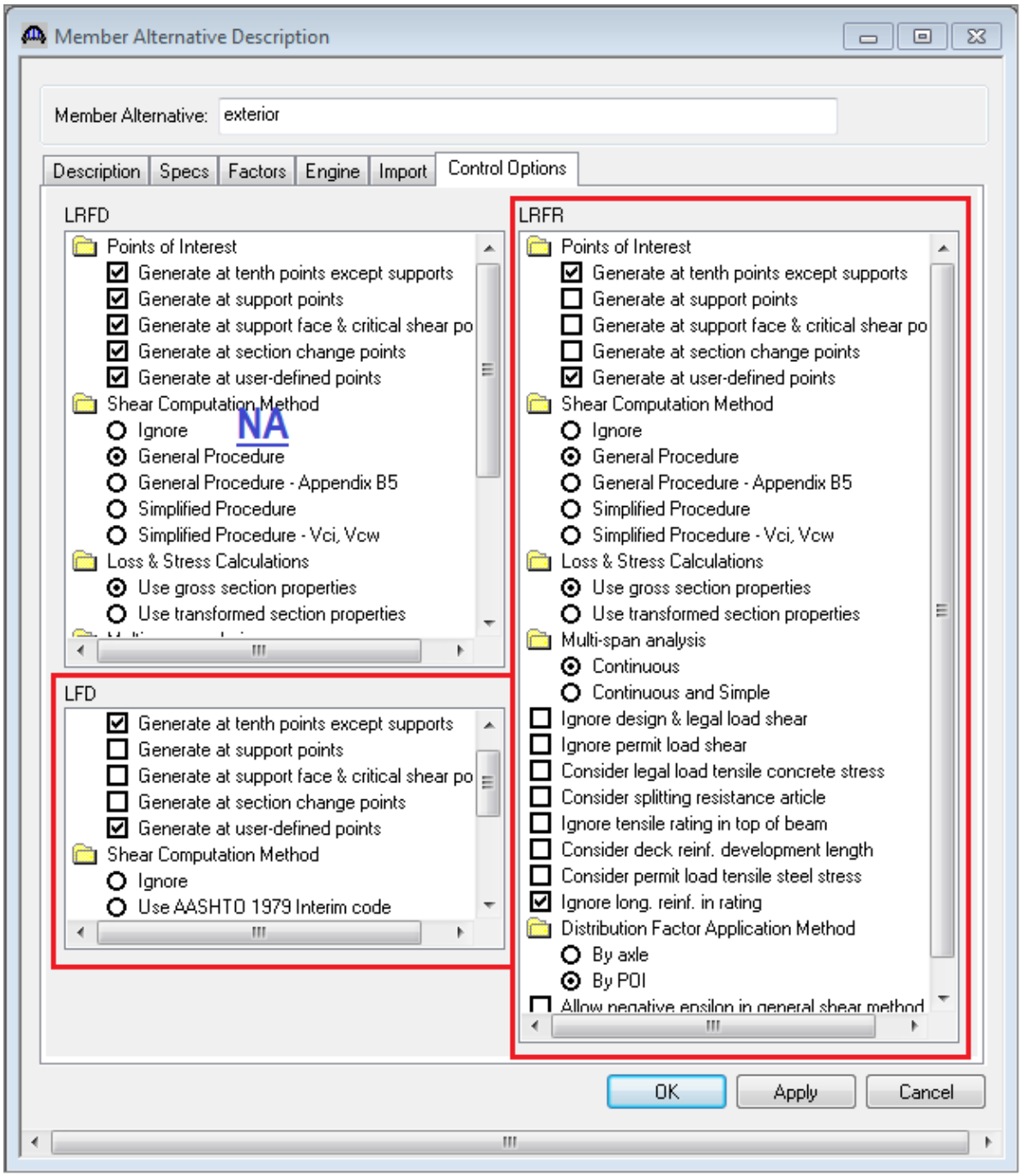
For LFD control options (see image below):

- Points of Interest (POI)

  - Generate at tenth points except supports
  - Generate at user defined points
- Shear Computation Method
  - Use current AASHTO

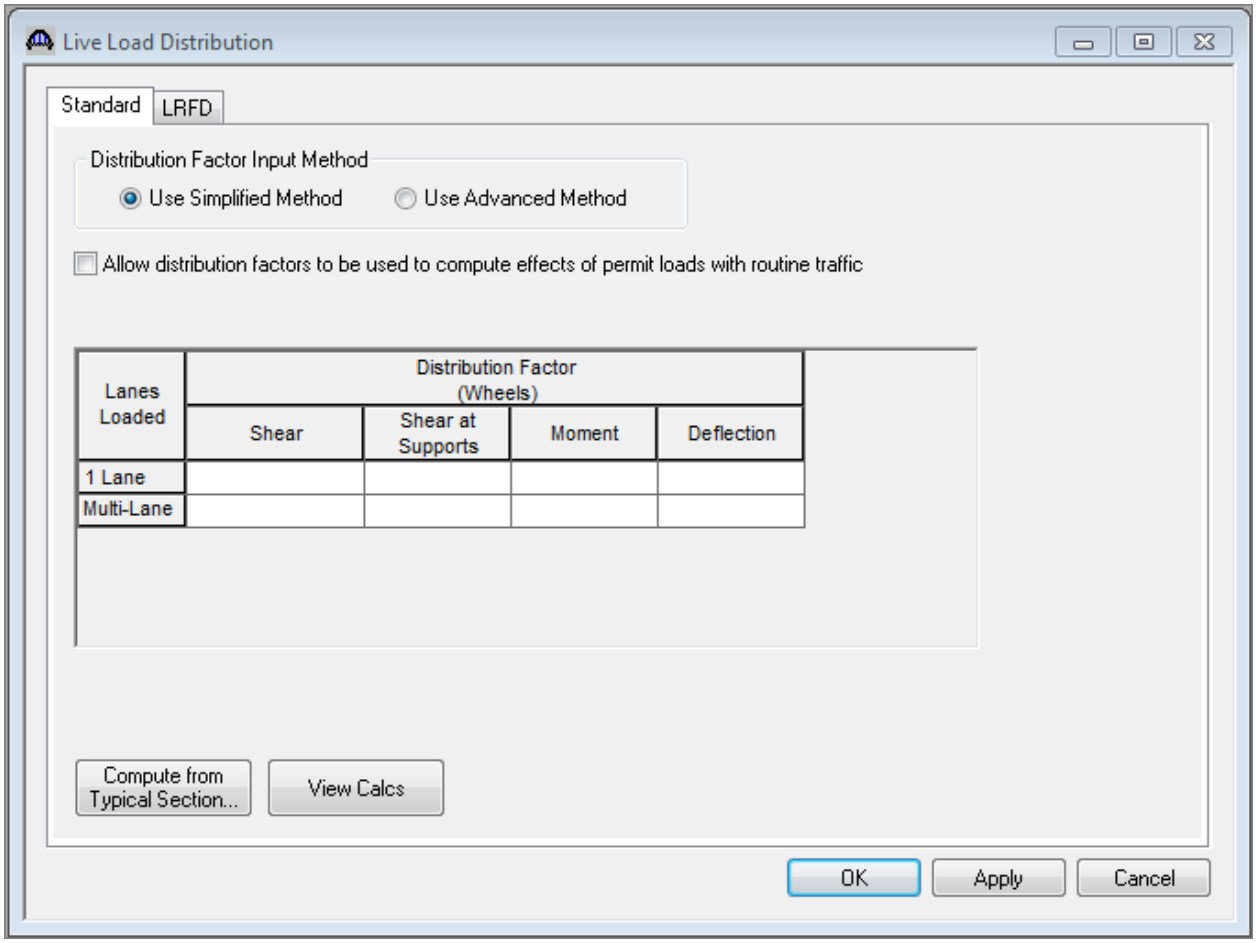
For LRFR control options (see image below):

- Points of Interest (POI)
  - Generate at tenth points except supports
  - Generate at user-defined points
- Shear Computation Method
  - General Procedure
- Multi-span analysis
  - Continuous
  - Ignore long. reinf. in rating

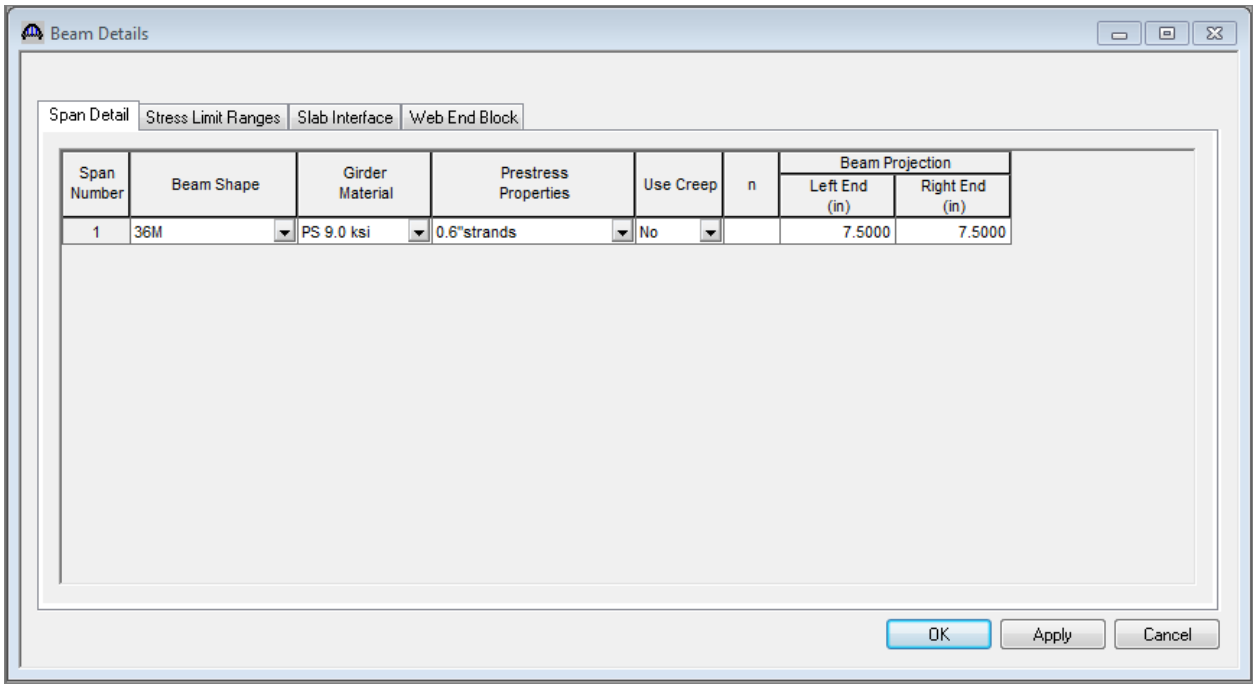


26. Double-click Live Load Distribution in the tree to compute the distribution factors from typical section. Standard tab is use for bridges that are Allowable Stress and Load Factor Design. LRFD tab is for bridges that are Load and Resistance Factor Design. If the User tries to use the Compute from Typical Section button on the Standard or LRFD tab to populate the live load distribution factors for this member alternative without

creating the rest of adjacent members, you will receive a message that AASHTOWare BrR cannot calculate the distribution factors because beam shapes are not assigned to adjacent member alternatives. This is due to the fact that program does not yet know if we have adjacent prestressed concrete beams. After all members in your superstructure have been created in member alternatives, we can revisit this window to compute the live load distribution factors using the Compute from Typical Section button.

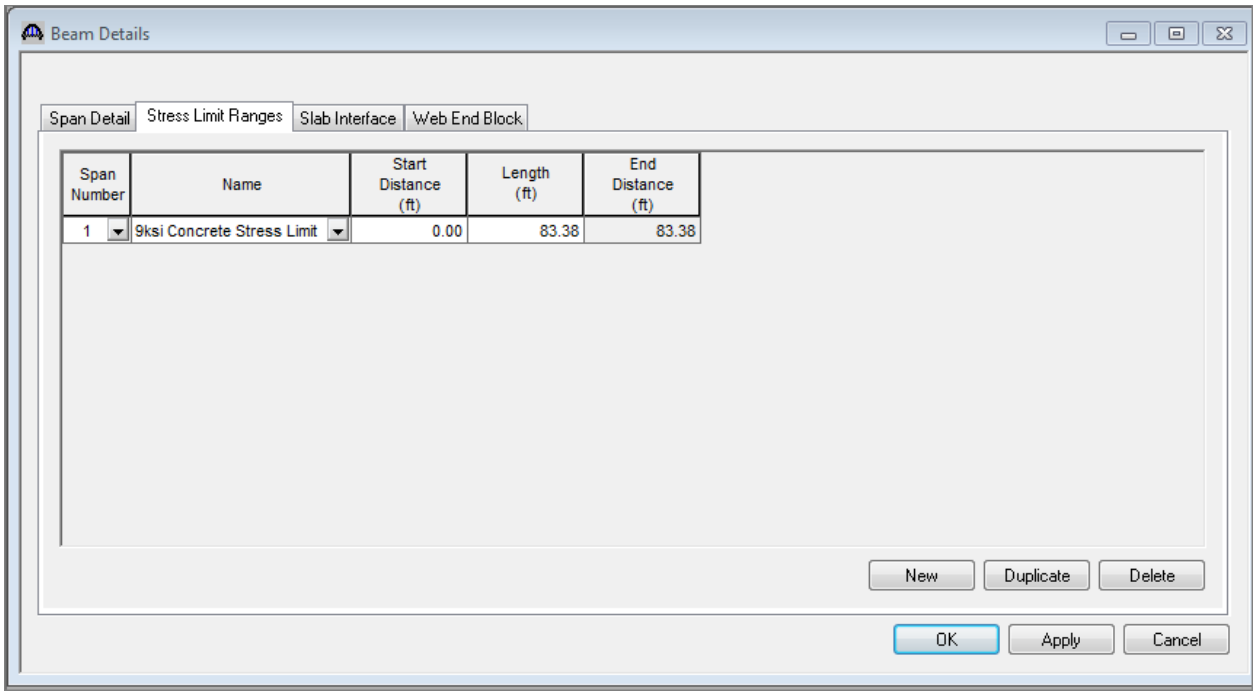


27. Next is to describe the beam by double clicking on Beam Details in the tree. Enter the required information for the beam as shown below. Beam projection is the distance from the end of the beam to the centerline of bearing.

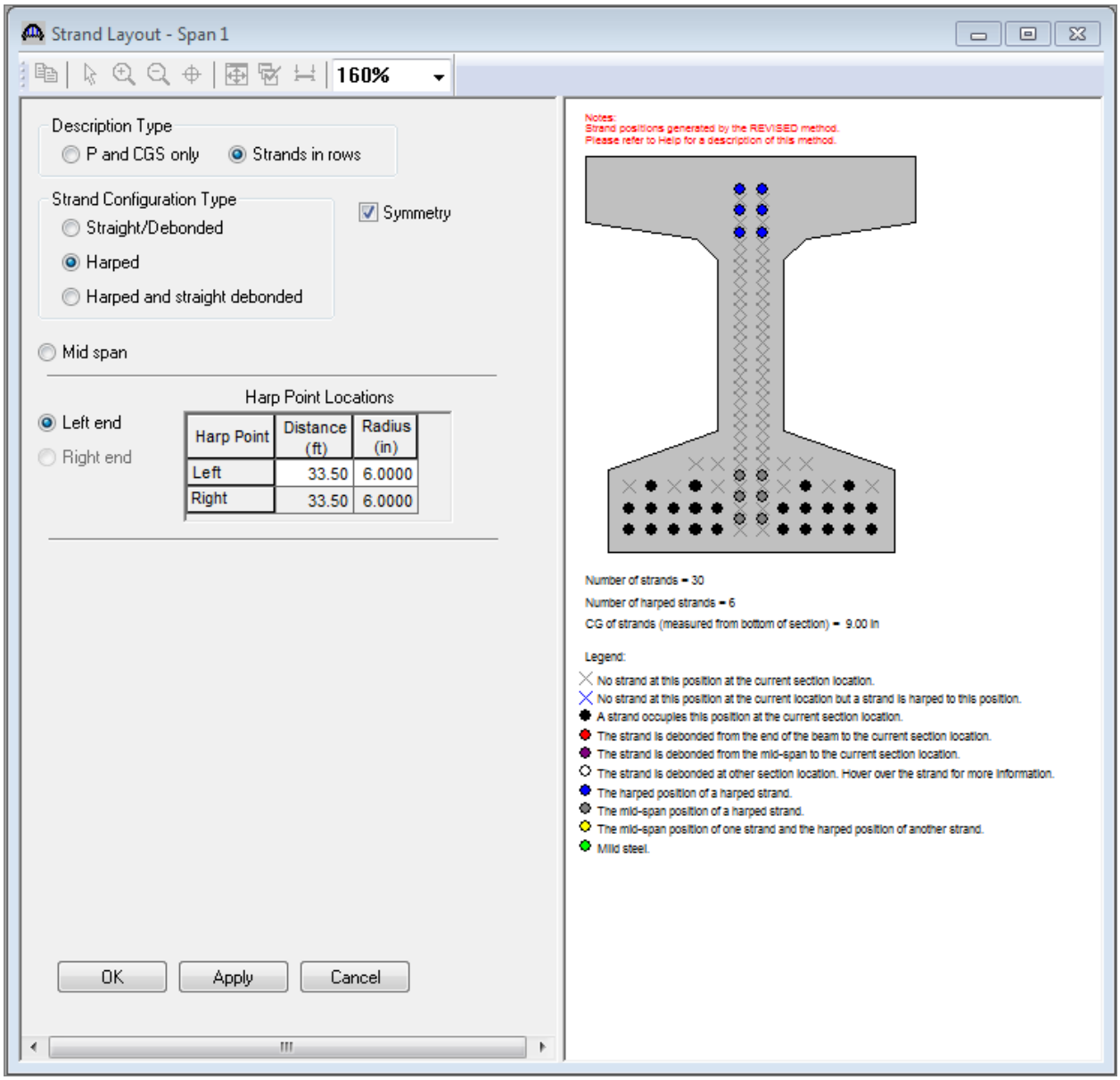


a. Click on the next tab," Stress Limit Ranges", and complete the required information as shown below. Click OK to save to memory and close the window.

Note: Stress Limit Ranges are defined over the entire length of the precast beam, including the projections of the beam past the centerline of bearing which were entered on the Span Detail tab.



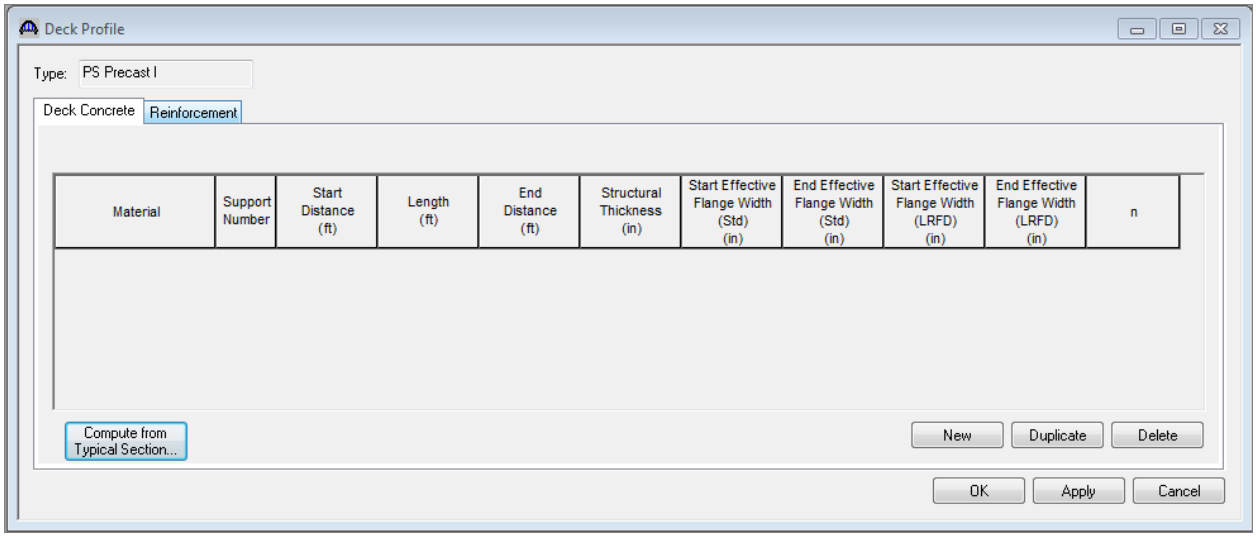
28. Expand the tree under Strand Layout and open the Span 1 window. Place the cursor in the schematic view on the right side of the screen. The toolbar buttons in this window will become active. Select the Zoom button to shrink the schematic of the beam shape so that the entire beam is visible.
    a. Select the Description Type as Strands in rows and the Strand Configuration Type as Harped. The Mid span radio button will now become active. You can now define the strands that are present at the middle of the span by selecting strands in the right hand schematic. Select the bottom 30 strands in the schematic so that the CG of the strands is 3.80 inches.
    b. Now select the Left end button to enter the following harped strand locations at the left end of the precast beam. Place the cursor in the schematic view on the right side of the screen. You can now define the strands that are present at the left end of the span by selecting strands in the right hand schematic. Select the top, third and fifth row 2 strands in the schematic so that the CG of the strands is 31 inches. Enter Harp Point Locations information. Close the window by clicking OK. This saves the data to memory and closes the window.



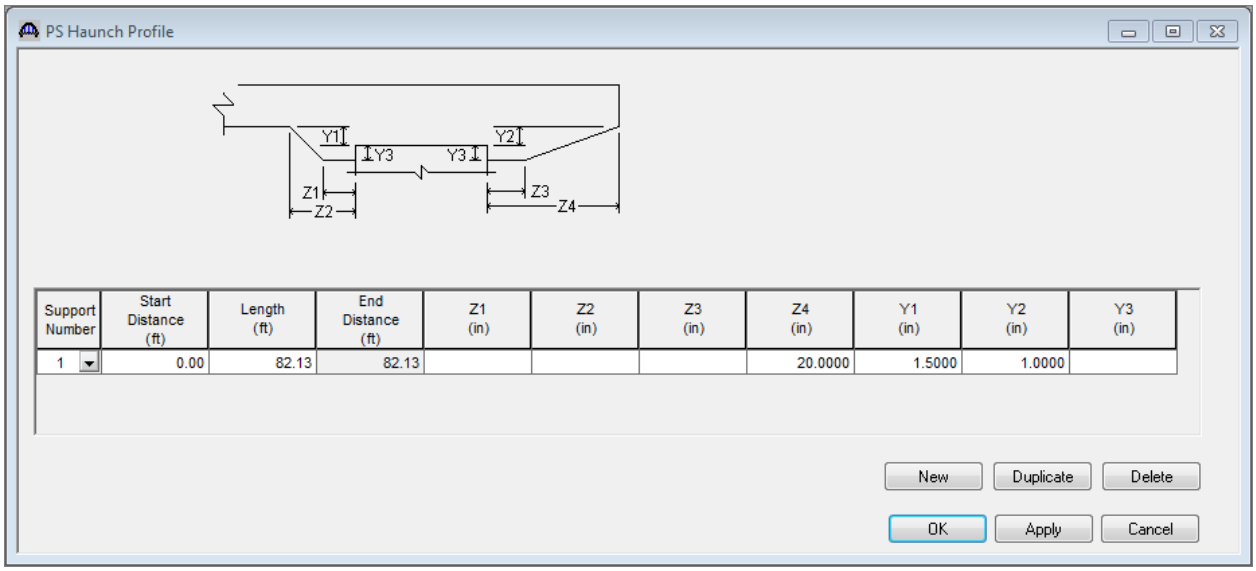
29. Double-click Deck Profile in the tree to describe the structural properties of the deck. If the User tries to use the Compute from Typical Section button to describe the deck profile for this member alternative without creating the rest of adjacent members, we will receive a message that AASHTOWare BrR cannot compute from Typical Section because beam shapes are not assigned to adjacent member alternatives. After all members in your superstructure have been created in member alternatives, we can revisit this window.

MnDOT Design Policy Item:

The topmost 0.5 inch of the wearing course or slab is not considered to be effective for composite action or section properties.

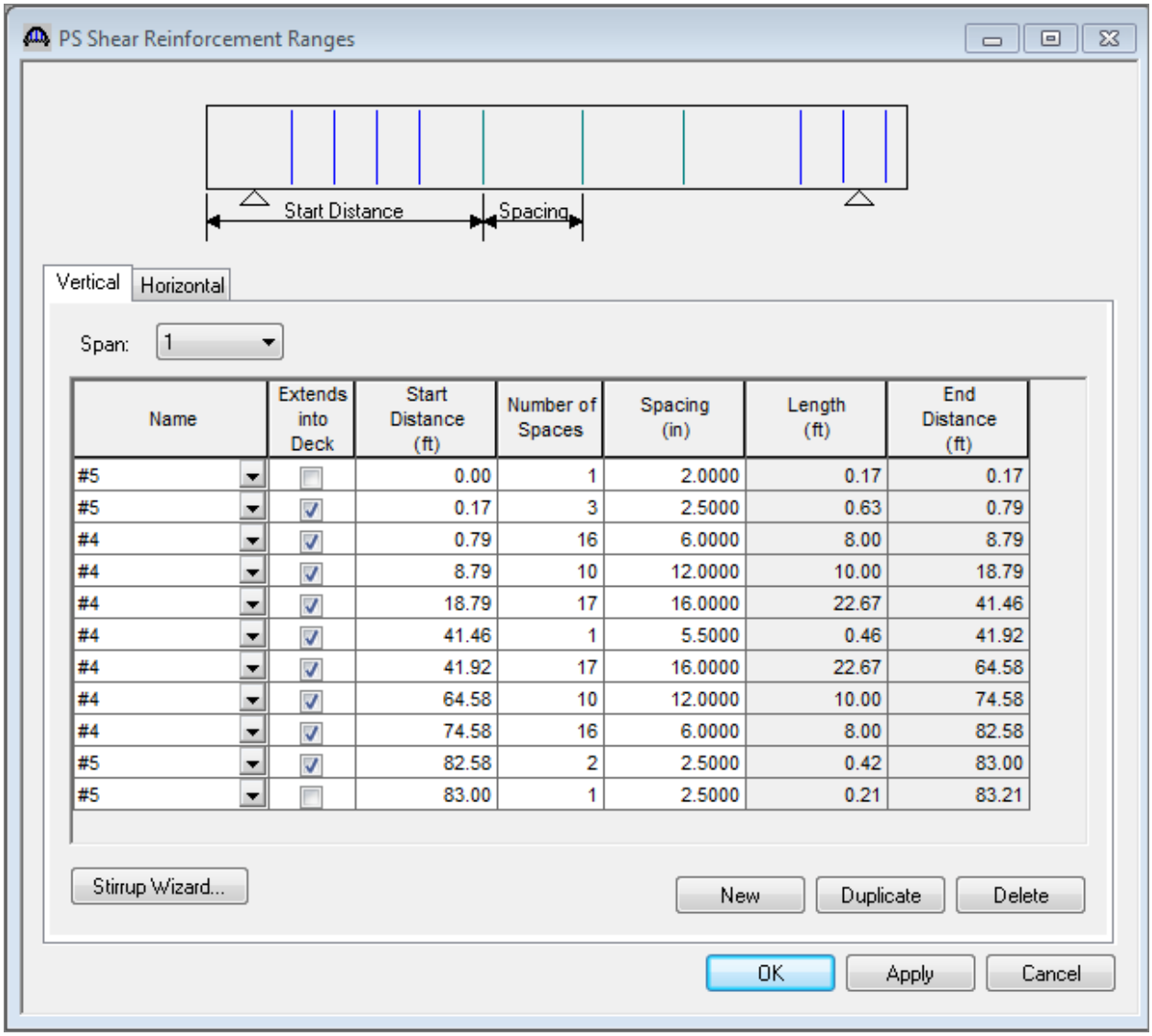


30. The haunch profile is defined by double clicking on Haunch Profile in the tree. Enter the required information. The window is shown below.



31. The Shear Reinforcement Ranges are entered by double clicking on Shear Reinforcement Ranges in the tree. The vertical shear reinforcement is defined as extending into the deck on this tab. This indicates composite action between the beam and the deck. Data does not have to be entered on the Horizontal tab to indicate

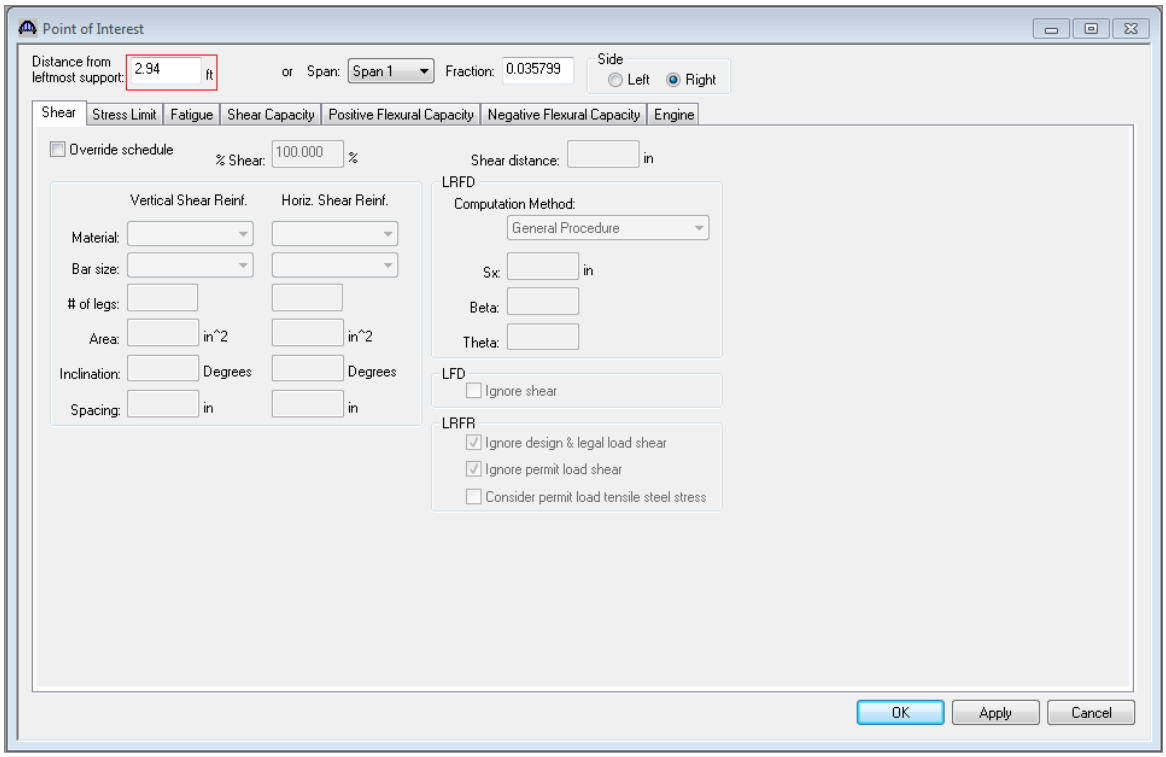
composite action since we have defined that by extending the vertical bars into deck. Enter the required information and click the OK button. The window is shown below.



Name	Extends into Deck	Start Distance (ft)	Number of Spaces	Spacing (in)	Length (ft)	End Distance (ft)
#5	☐	0.00	1	2.0000	0.17	0.17
#5	☑	0.17	3	2.5000	0.63	0.79
#4	☑	0.79	16	6.0000	8.00	8.79
#4	☑	8.79	10	12.0000	10.00	18.79
#4	☑	18.79	17	16.0000	22.67	41.46
#4	☑	41.46	1	5.5000	0.46	41.92
#4	☑	41.92	17	16.0000	22.67	64.58
#4	☑	64.58	10	12.0000	10.00	74.58
#4	☑	74.58	16	6.0000	8.00	82.58
#5	☑	82.58	2	2.5000	0.42	83.00
#5	☐	83.00	1	2.5000	0.21	83.21

32. Double-click Points of Interest in the tree to define a point of interest on a beam. Enter points of interest at 0.72h. ***Note: For LFR analysis, enter points of interest at h/2***. "h" is the distance from the top of the deck to the bottom of the beam at the centerline of bearing.

$$h = 9\text{in}+4\text{in}+36\text{in}=49\text{in} \qquad 0.72\text{h} = 0.72\left(\frac{49in}{12\frac{in}{ft}}\right) = 2.94\ \text{ft}$$

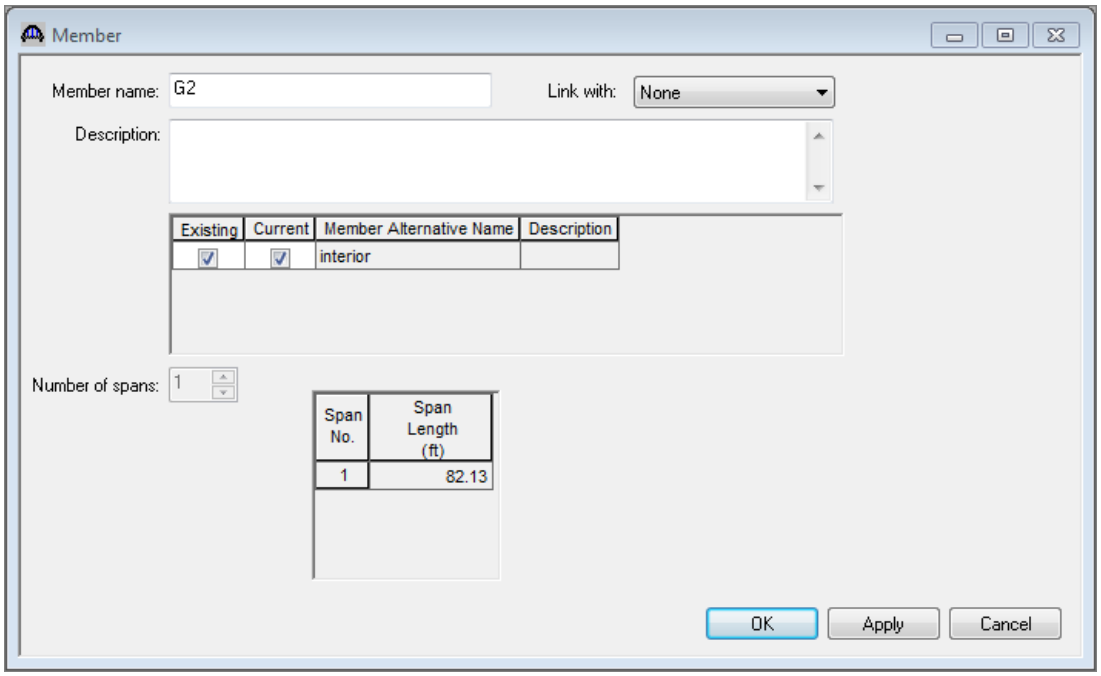


a. Click Apply and then click OK to save to memory and close the window.

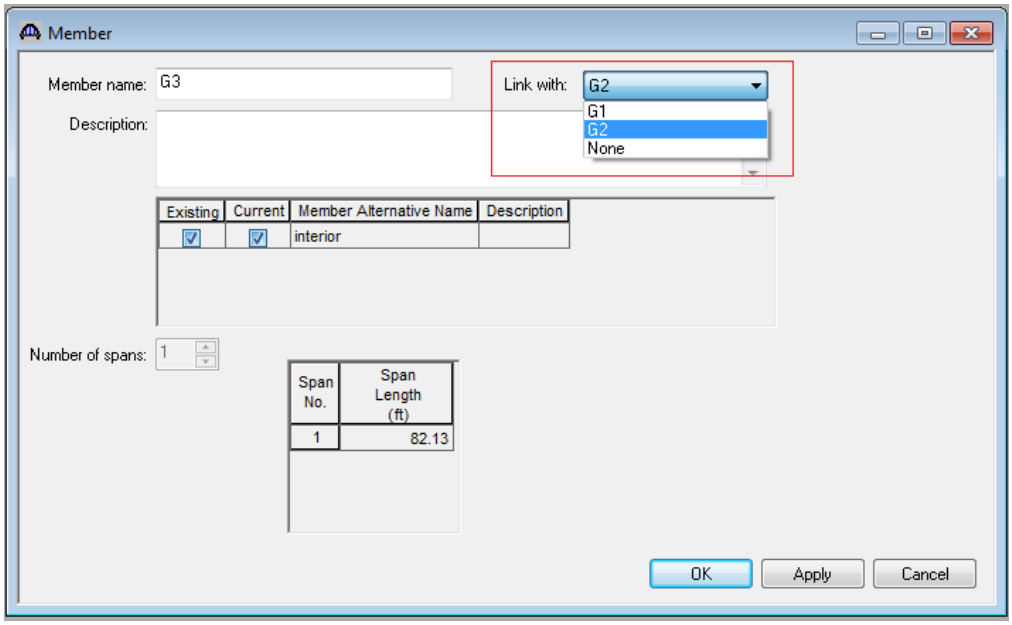
The description of the exterior beam for this structure definition is complete.

Describing a member: Interior Beam

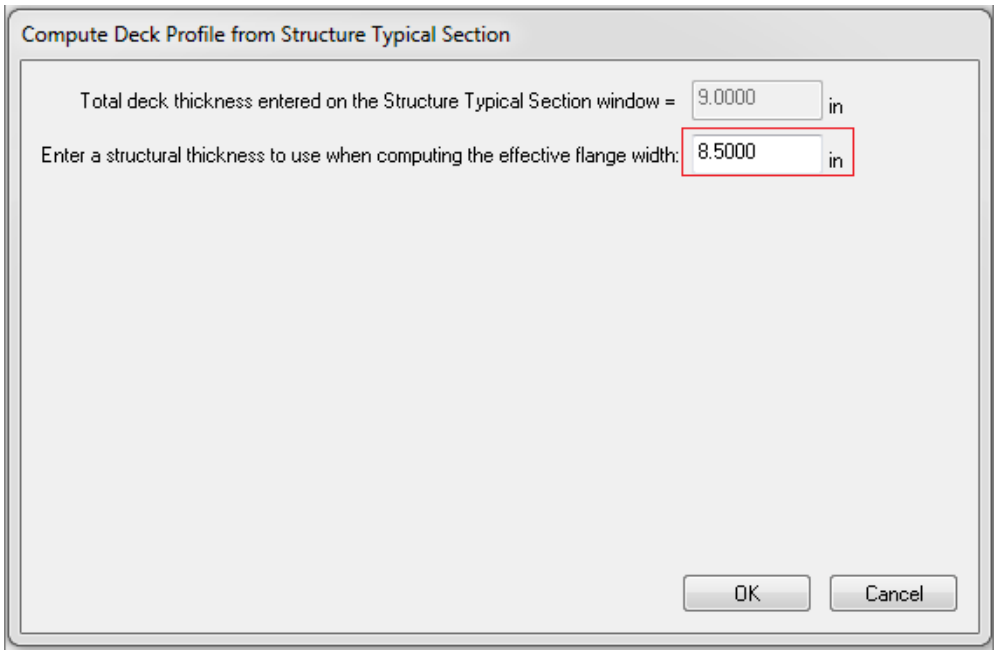
33. The G2 member window (see image below) shows the data that was generated when the structure definition was created. No changes are required at this time. The first Member Alternative that we create will automatically be assigned as the Existing and Current Member alternative for this Member.



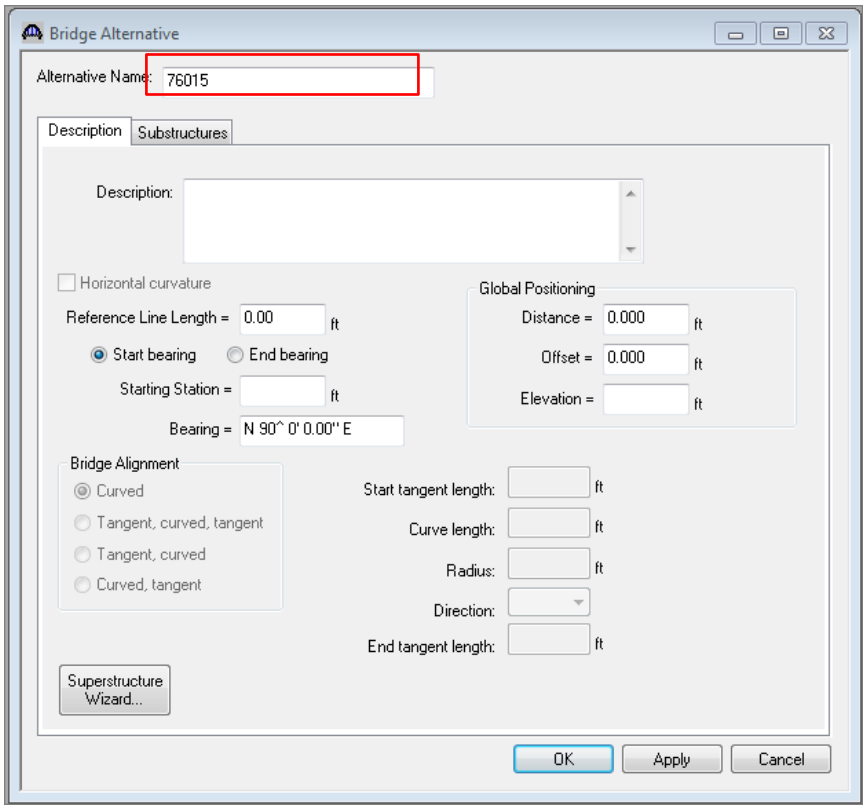
34. Follow steps 21 through 32 to completely define the interior beam (G2).
35. To define the rest of the remaining interior beams and exterior beam, one by one, expand G3, G4 & G5 member in the tree, select from the "Link with" pull down menu to which this member is to be linked as highlighted below. G3 and G4 will be linked with G2 and G5 will be linked with G1. If two members are linked, they share the same definition and any revision to one member affects the other member. If there are any differences between two members, then they should not be linked with one another.



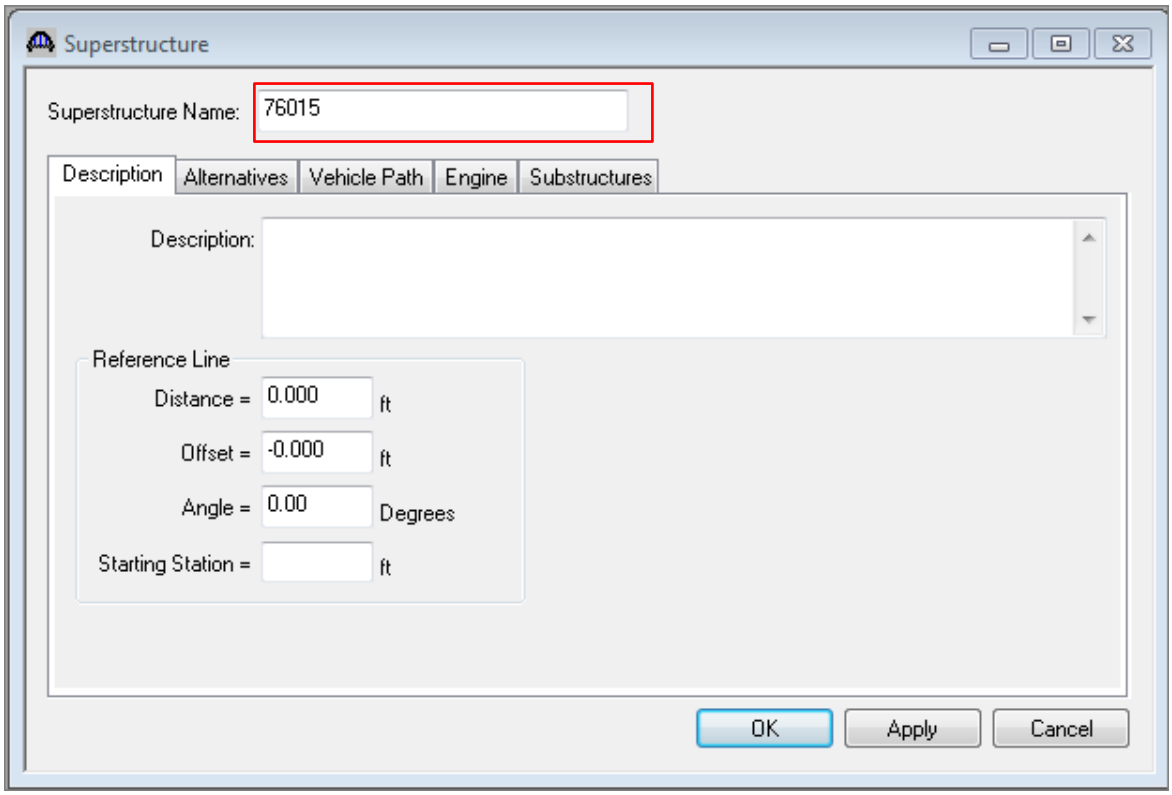
36. Compute LRFD live load distribution factors for the exterior (G1) and interior girders (G2) by double-clicking Live Load Distribution in the tree. Click on Compute from Typical Section button to calculate LRFD live load distribution factors. Click OK to save to memory and close the window.
37. Define deck properties for the exterior (G1) and interior girders (G2) by double-clicking Deck Profile in the tree. Click on Compute from Typical Section button and enter a slab depth of the full depth minus 0.5 inch as shown below. Click OK twice to save to memory and close the window.



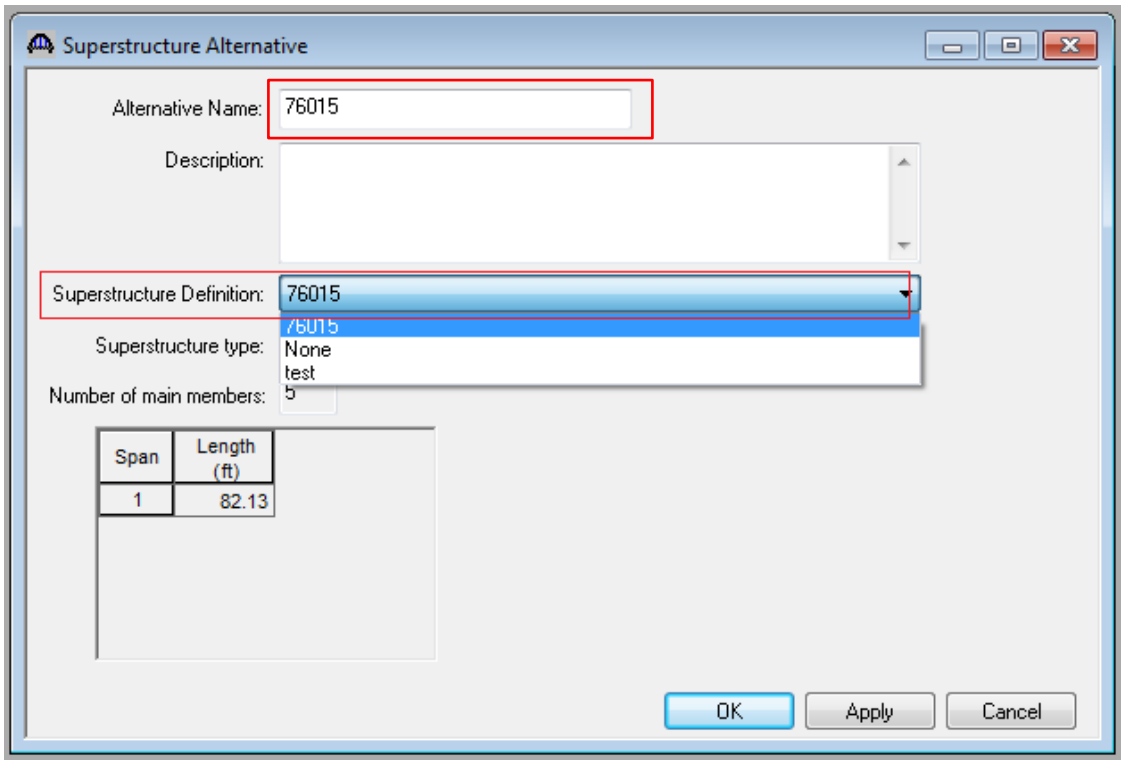
38. From the bridge workspace, double-click on Bridge Alternatives and enter an Alternative Name as shown below. Click OK to save to memory and close the window.



a. Double-click on superstructure folder in the tree and enter a superstructure name as shown below. Click OK to save to memory and close the window.



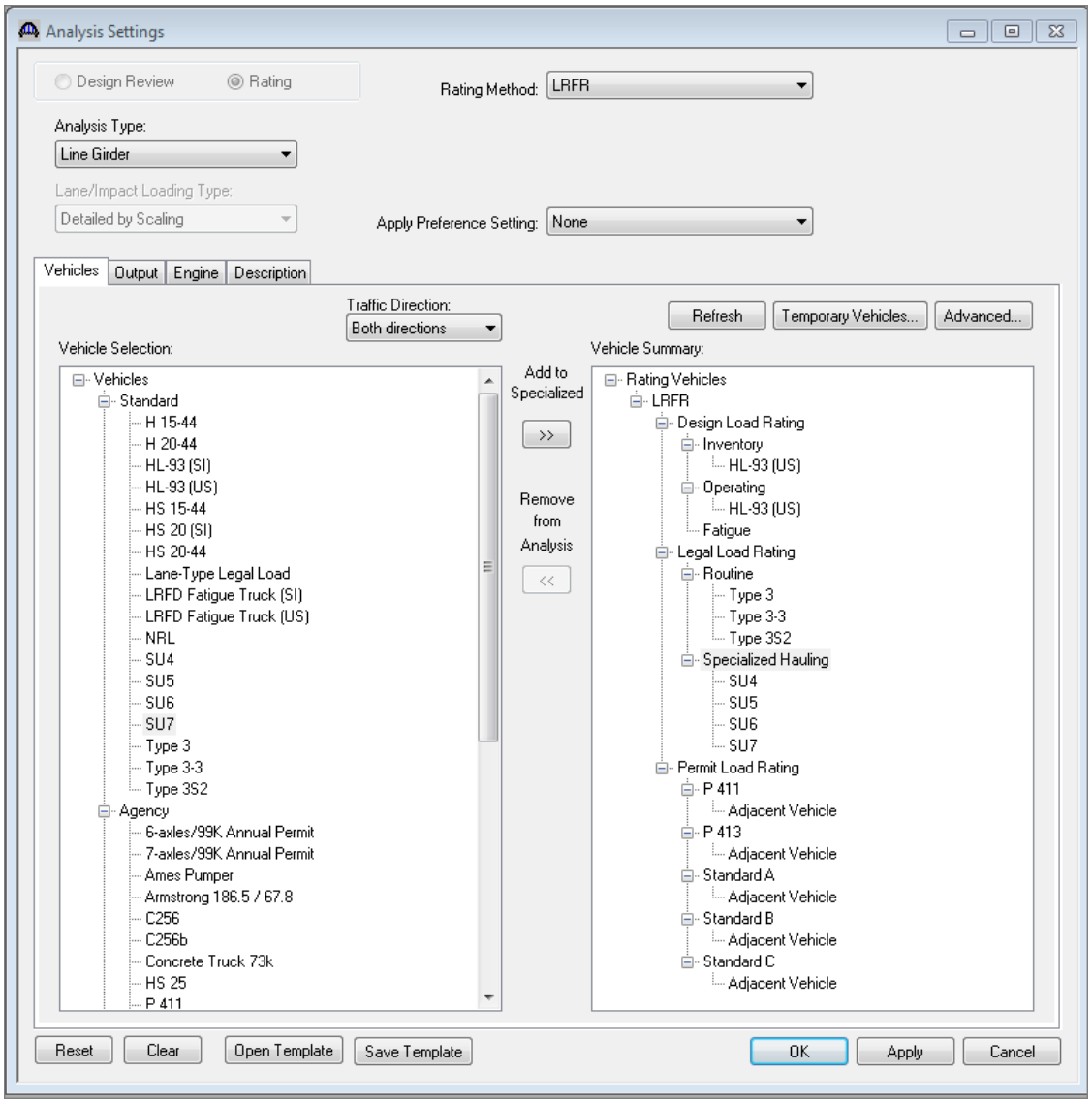
b. Double-click on Superstructure Alternatives folder in the tree. Enter a name and select the bridge that was created earlier under the superstructure definitions as shown below. Click OK to save to memory and close the window.



The AASHTOWare BrR file can now be analyzed.

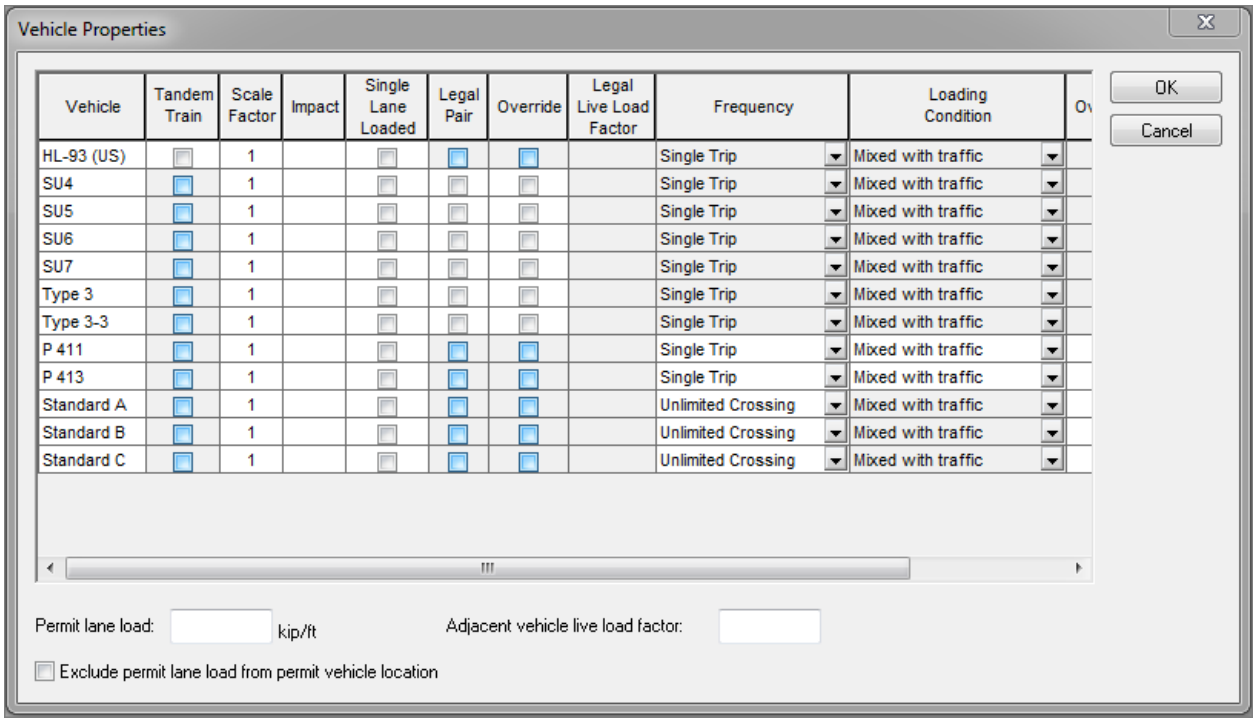
39. To perform LRFR rating, click the Analysis Settings button, , on the toolbar to open the window shown below. Select the following event setting listed below:
    - -Rating Method: LRFR
    - -Analysis Type: Line Girder
    - -Lane/Impact Loading Type: As Requested
    - -Apply Preference Setting: None
    - -Traffic Directions: Both Directions

    a. Add vehicles under the Vehicle Summary. To add vehicles under the Vehicle Summary, first select the Inventory under Design Load Rating. Then under Vehicle Selection select the HL-93 (US) vehicle and click on Add to Operating arrow button. Do the same procedure for the Operating under the Design Load Rating. Repeat the same process to add legal loads and permit vehicles to the Vehicle Summary as shown below.



b. Click on the **Advanced** button in the Analysis Settings window to take you to Vehicle Properties window. This window allows you to override vehicle properties entered in the previous windows. The correct Frequencies and Loading Conditions for the legal and permit vehicles are shown below.

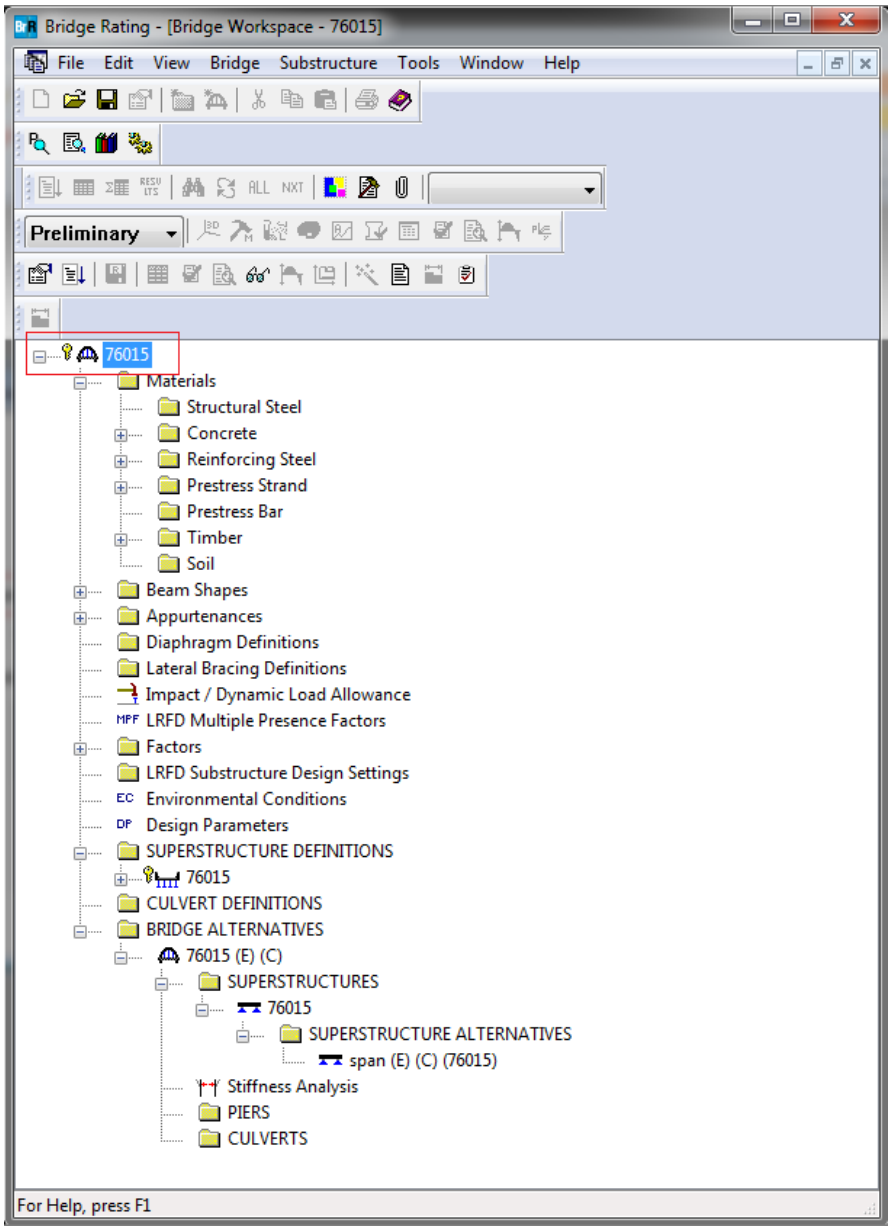
c. To save the setting, click on the **Save Template** button and enter the desired template name and click **Save**. This Template can be used for future load rating analysis.

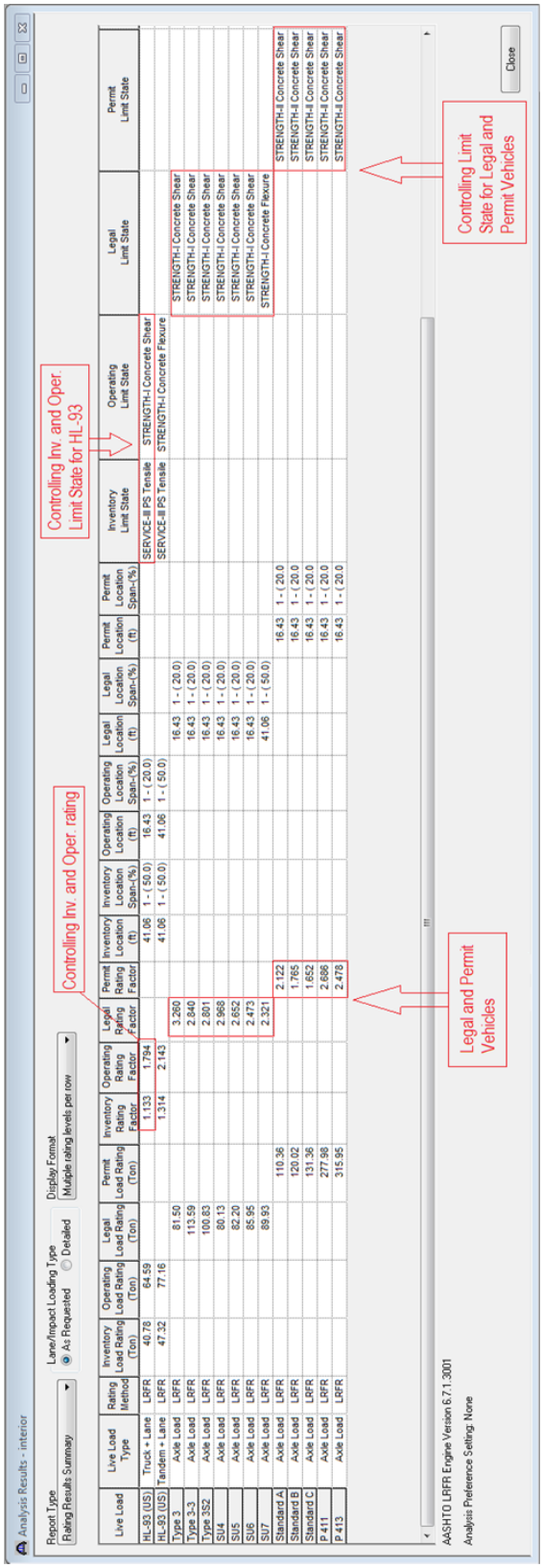


Vehicle	Tandem Train	Scale Factor	Impact	Single Lane Loaded	Legal Pair	Override	Legal Live Load Factor	Frequency	Loading Condition
HL-93 (US)		1						Single Trip	Mixed with traffic
SU4		1						Single Trip	Mixed with traffic
SU5		1						Single Trip	Mixed with traffic
SU6		1						Single Trip	Mixed with traffic
SU7		1						Single Trip	Mixed with traffic
Type 3		1						Single Trip	Mixed with traffic
Type 3-3		1						Single Trip	Mixed with traffic
P 411		1						Single Trip	Mixed with traffic
P 413		1						Single Trip	Mixed with traffic
Standard A		1						Unlimited Crossing	Mixed with traffic
Standard B		1						Unlimited Crossing	Mixed with traffic
Standard C		1						Unlimited Crossing	Mixed with traffic

d. Click OK to save to memory and close the window.

e. Select the bridge in the Bridge Workspace as shown below and click on the Analyze button, on the toolbar to perform the rating. When the rating is finished you can review the results by selecting either the exterior girder (G1) or interior girder (G2) under the Member Alternatives folder in the tree and clicking the View analysis Report icon on the toolbar. The window shown below will open (Load rating results shown are for interior girder only).


Bridge Rating - [Bridge Workspace - 76015]
File Edit View Bridge Substructure Tools Window Help
Preliminary
76015
Materials
Structural Steel
Concrete
Reinforcing Steel
Prestress Strand
Prestress Bar
Timber
Soil
Beam Shapes
Appurtenances
Diaphragm Definitions
Lateral Bracing Definitions
Impact / Dynamic Load Allowance
LRFD Multiple Presence Factors
Factors
LRFD Substructure Design Settings
Environmental Conditions
Design Parameters
SUPERSTRUCTURE DEFINITIONS
76015
CULVERT DEFINITIONS
BRIDGE ALTERNATIVES
76015 (E) (C)
SUPERSTRUCTURES
76015
SUPERSTRUCTURE ALTERNATIVES
span (E) (C) (76015)
Stiffness Analysis
PIERS
CULVERTS
For Help, press F1



Live Load	Live Load Type	Rating Method	Inventory Load Rating (Ton)	Operating Load Rating (Ton)	Legal Load Rating (Ton)	Permit Load Rating (Ton)	Inventory Rating Factor	Operating Rating Factor	Legal Rating Factor	Permit Rating Factor	Inventory Location (ft)	Inventory Location Span-(%)	Operating Location (ft)	Operating Location Span-(%)	Legal Location (ft)	Legal Location Span-(%)	Permit Location (ft)	Permit Location Span-(%)	Inventory Limit State	Operating Limit State	Legal Limit State	Permit Limit State
HL-93 (US)	Truck + Lane	LRFR	40.78	64.59			1.133	1.794			41.06	1 - (50.0)	16.43	1 - (20.0)					SERVICE-II PS Tensile	STRENGTH-I Concrete Shear		
HL-93 (US)	Tandem + Lane	LRFR	47.32	77.16			1.314	2.143			41.06	1 - (50.0)	41.06	1 - (50.0)					SERVICE-II PS Tensile	STRENGTH-I Concrete Flexure		
Type 3	Axle Load	LRFR			81.50				3.260						16.43	1 - (20.0)					STRENGTH-I Concrete Shear	
Type 3-3	Axle Load	LRFR			113.59				2.840						16.43	1 - (20.0)					STRENGTH-I Concrete Shear	
Type 3S2	Axle Load	LRFR			100.83				2.801						16.43	1 - (20.0)					STRENGTH-I Concrete Shear	
SU4	Axle Load	LRFR			80.13				2.968						16.43	1 - (20.0)					STRENGTH-I Concrete Shear	
SU5	Axle Load	LRFR			82.20				2.652						16.43	1 - (20.0)					STRENGTH-I Concrete Shear	
SU6	Axle Load	LRFR			85.95				2.473						16.43	1 - (20.0)					STRENGTH-I Concrete Shear	
SU7	Axle Load	LRFR			89.93				2.321						41.06	1 - (50.0)					STRENGTH-I Concrete Flexure	
Standard A	Axle Load	LRFR				110.36				2.122							16.43	1 - (20.0				STRENGTH-II Concrete Shear
Standard B	Axle Load	LRFR				120.02				1.765							16.43	1 - (20.0				STRENGTH-II Concrete Shear
Standard C	Axle Load	LRFR				131.36				1.652							16.43	1 - (20.0				STRENGTH-II Concrete Shear
P 411	Axle Load	LRFR				277.98				2.686							16.43	1 - (20.0				STRENGTH-II Concrete Shear
P 413	Axle Load	LRFR				315.95				2.478							16.43	1 - (20.0				STRENGTH-II Concrete Shear