Bridge Load Rating Workshop

March 22, 2011
Big Rapids
Agenda

8:30  Check-in
9:00  FHWA & MDOT Rating Summary
10:00 Means and Methods for Superstructure Evaluation
10:30 Break
10:45 Means and Methods for Superstructure Evaluation (continued)
       Additional Considerations for Superstructure Evaluation
12:00 Lunch
1:00  Load Rating Examples (hand calculations)
2:00  Break
2:15 VIRTIS Software Examples and Exercises
4:00  Adjourn
Presenters

Dave Juntunen, P.E.  
Engineer of Bridge Operations  
Michigan Department of Transportation  

Mr. Juntunen has worked for MDOT for 24 years as a bridge designer, structural research engineer, and bridge operations engineer.

Bob Kelley, P.E.  
Bridge Management Engineer  
Michigan Department of Transportation  

Mr. Kelley has a Bachelor of Science degree from Michigan State University in Civil Engineering, 1978. He has worked for 32 years with MDOT, the last 20 years as Bridge Management Engineer.

Chris Gilbertson, P.E.  
Michigan Technological University  

Mr. Gilbertson is a graduate student and instructor for Michigan Technological University. He is currently working toward his PhD in structural engineering, holds a Masters of Science in Civil Engineering and is a licensed professional engineer. His work toward his PhD is focusing on dynamic material testing of wood through the use of a Split Hopkinson Pressure Bar.

Creightyn McMunn, P.E.  
Load Rating Specialist Engineer  
Michigan Department of Transportation  

Ms. McMunn was recently announced as MDOT’s statewide specialist for load rating bridges. She manages consultant contracts for bridge load rating services and serves as a technical consultant and liaison to MDOT Divisions, Regions and local agencies.

Ms. McMunn earned her Bachelor’s and Master’s Degrees in Civil Engineering from the University of Michigan. She previously served as MDOT’s Load Rating Lead Worker and as a Structural Engineer in the Experimental Studies Unit of MDOT’s Construction & Technology Division.

Moderator

John Kiefer, P.E.  
Research Engineer  
Center for Technology & Training (CTT) - MTU  

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Presentation Summary

A recent FHWA Program Review of Load Rating and Posting of Michigan Bridges has found that there is a large backlog of local agency bridges that may not be in compliance with load rating requirements. This workshop is intended to provide local agencies and consultants the necessary information, including procedures and tools, to meet compliance.

Workshop Topics Include:

- Background Information
- FHWA & MDOT Processes for Determining Implementation
- Requirements for Local Agencies
- VIRTIS Software
- Deadlines for Completing Analysis
- ASR, LRFR, and LFR Methods
- Loads & Loading Configurations
- Hands on Exercises (on paper and with VIRTIS)

The National Bridge Inspection Standards (NBIS) Title 23-CFR-650 Section 650.313g requires all states to provide periodic refresher training for persons involved in bridge inspection. As per this requirement, the State of Michigan requires 24 hours of training in the preceding 5 years. With proper documentation, persons who participate in this workshop will receive credit for 6 hours of refresher training; further information regarding documentation will be provided at the workshop.
MDOT Bridge Advisory: Licensing and Use of AASHTOWare Virtis Software

BRIDGE ADVISORY NUMBER: BA-2010-06

DATE: October 4, 2010

SUBJECT: Licensing and use of AASHTOWare Virtis Software

ISSUED BY: Beckie Curtis, Load Rating Engineer

REVIEWED BY: David Juntunen, Bridge Operations Engineer

Contact Information: Beckie Curtis, Load Rating Engineer, 517-322-1186 or curtisre@michigan.gov or mdot-load_rating@michigan.gov

PURPOSE
The recent FHWA Program Review of Load Rating and Posting of Michigan Bridges has found that there is a large backlog of local agency bridges that may not be in compliance with load rating requirements. To address this finding, MDOT is developing, in partnership with CRAM and MML, an action plan to assure local agency load rating compliance with NBIS.

In an effort to standardize load ratings and improve quality control and oversight, MDOT has purchased a super-site license of AASHTOWare Virtis. This license will allow local agencies and/or their consultants to obtain a license of the software at no cost.

BACKGROUND
The NBIS requires that all bridges be load rated for capacity in accordance with the AASHTO Manual for Bridge Evaluation (formerly the Manual for Condition Evaluation of Bridges). Virtis is a comprehensive bridge rating tool developed by AASHTO. For an agencies’ bridge inventory, the product stores detailed bridge descriptions sufficient for structural analysis. Virtis is the tool for rating bridge superstructures in accordance with the AASHTO Manual for Bridge Evaluation. The concept of storing generic bridge descriptions in a database is a powerful one with many user and agency benefits. Among the benefits are:

- Rating a bridge using multiple analysis programs from the same description and input;
- Upgrading and/or replacing components of the system, including the structural analysis engine, specification checking software, and user interface while preserving the basic bridge data;
- Ability to analyze design, legal and permit loads;
- Maintenance of a bridge model that may be easily updated for future specification changes or analyzed under the specifications of design (such as either LFR or LRFR);
- Maintenance of a bridge model to meet NBIS load rating documentation requirements;
For additional information on the capabilities of AASHTOWare Virtis, please refer to the AASHTOWare Catalog:

http://www.aashtoware.org/Documents/FY2011_Catalog_Final-6-4-10.pdf

**LICENSING THE SOFTWARE – BRIDGE OWNER**

The Virtis software may be licensed at no cost by any local agency within Michigan. To license the software, please complete the following steps:

- Complete the Non-Member Software Request Form, included for your use and which may be found at:
- On the line for Purchase Order Number, indicate “Michigan DOT Agency Sponsored License”
- Select the option for “Virtis Special Consultant Option” and change the cost from $2700 to $0
- Submit the form to AASHTO (see page 4 of the software request form for AASHTO contact information)
  - Send a copy to MDOT
    - by email to mdot-virtis-support@michigan.gov
    - by fax to 517-322-5664 Attention: Load Rating
    - by mail to:
      Load Rating  
      8885 Ricks Rd  
      PO Box 30049  
      Lansing, MI 48909
- Complete the supplemental licensing agreement with AASHTO

**LICENSING THE SOFTWARE – CONSULTING ENGINEER**

The Virtis software may be licensed at no cost by a consultant working for a local agency within Michigan. To license the software, please complete the following steps:

- Consultants must submit a letter or email stating their understanding and agreement that the license may only be used on bridges within the State of Michigan. This must be received before AASHTO will license the software.
  - by email to mdot-virtis-support@michigan.gov
  - by fax to 517-322-5664 Attention: Load Rating
  - by mail to:
    Load Rating  
    8885 Ricks Rd  
    PO Box 30049  
    Lansing, MI 48909
- MDOT will notify AASHTO of all authorized consultants on October 29, 2010.
  - Submitting the letter of understanding after this date may result in delay in obtaining MDOT authorization.
• Complete the Non-Member Software Request Form, included for your use and which may be found at:
  o  http://www.aashtoware.org/Documents/FY2011_Non-Member%20Forms.pdf
• On the line for Purchase Order Number, indicate “Michigan DOT Agency Sponsored License”
• Select the option for “Virtis Special Consultant Option” and change the cost from $2700 to $0
• Submit the form to AASHTO (see page 4 of the software request form for AASHTO contact information)
  o  Send a copy to MDOT
    ▪  by email to mdot-virtis-support@michigan.gov
    ▪  by fax to 517-322-5664 Attention: Load Rating
    ▪  by mail to:
      Load Rating
      8885 Ricks Rd
      PO Box 30049
      Lansing, MI 48909
• Complete the supplemental licensing agreement with AASHTO

TRAINING AND SUPPORT

Support regarding installation of the software is available through the AASHTO Contractor. Limited support for use of the software in performing the load rating will be provided by MDOT by emailing mdot-virtis-support@michigan.gov or contacting Beckie Curtis at 517-322-1186.

Tutorials and Virtis files, including the Michigan analysis vehicles, are available on the MDOT Bridge Operations Website, http://www.michigan.gov/mdot/0,1607,7-151-9625_24768--,00.html

Training sessions are currently being scheduled, and information regarding dates and locations of the training will be sent when available.

Note: See References & Resources at the end of this workbook page for the MDOT link to other downloadable MDOT Advisories
Example: Load Factor Rating (LFR)

A load rating needs to be performed on a simply supported bridge with a span length equal to 65ft and with the cross section shown above. The bridge was built in 1965 and has been well maintained with no deterioration reported as of the most recent bridge inspection. The approach and wearing surface are in good condition. Diaphragms are located at mid-span.

The bridge is located in an area which allows designated loading. The design loading was HS-20, which is greater than HS-15. Therefore, the slab does not require analysis (see BAG, Chapter 4). The substructure is in good condition and therefore does not require analysis.

The bridge has been analyzed and the following properties determined:

- Moment capacity: 2,910 ft·k
- Shear capacity: 380 k
- Combined dead load effect
  - moment: 573 ft·k
  - shear: 35.3 k
- Live load effect: to be determined as required for each component of the load rating
- Impact factor: 0.26
- Girder distribution factor (GDF): 0.667
General Load Rating Equation:

\[ RF = \frac{C - A_1D}{A_2(L)(GDF)(1 + I)} \]

Where:
- RF = rating factor
- C = capacity
- D = dead load effect
- L = live load effect
- GDF = girder distribution factor
- I = impact factor
- A_1 = dead load effect factor
- A_2 = live load effect factor

Federal Inventory Rating (Item 66)

The HS-20 truck is used to complete the Federal Inventory Rating. Shear and moment tables for the HS-20 truck over simple spans of varying lengths may be found in the BAG.

- \( A_1 = 1.3 \)
- \( A_2 = 2.17 \)
- \( M_L = 896 \text{ ft}^*k \) (BAG Table 10.9)
- \( V_L = 61.7 \text{ k} \) (BAG Table 10.21)

\[ RF_m = \frac{2910 - 1.3(573.6)}{2.17(896)(0.667)(1 + 0.26)} = 1.32 \]

\[ RF_v = \frac{380 - 1.3(35.3)}{2.17(61.7)(0.667)(1 + 0.26)} = 2.96 \]
Federal Operating Rating (Item 64F)

The HS-20 truck is used to complete the Federal Operating Rating. Shear and moment tables for the HS-20 truck over simple spans of varying lengths may be found in the BAG.

\[ A_1 = 1.3 \]
\[ A_2 = 1.3 \]
\[ M_L = 896 \text{ ft}^*\text{k} \quad \text{(BAG Table 10.9)} \]
\[ V_L = 61.7 \text{ k} \quad \text{(BAG Table 10.21)} \]

\[
RF_m = \frac{2,910 - 1.3 (573.4)}{1.3 (896) (0.667) (1 + 0.26)} = 2.20
\]

\[
RF_v = \frac{380 - 1.3 (35.3)}{1.3 (61.7) (0.667) (1 + 0.26)} = 4.96
\]

Michigan Operating Rating (Item 64M)

The Michigan Legal Loads are used to complete the Michigan Operating Rating. The live load moment and shear effects produced by the Michigan Legal Loads may be found from tables located in the BAG.

\[ A_1 = 1.3 \]
\[ A_2 = 1.3 \]
\[ M_L = 1,550 \text{ ft}^*\text{k} \quad \text{(Truck #17)} \]
\[ V_L = 104 \text{ k} \quad \text{(Truck #17)} \]

\[
RF_{m \ (2 \ unit)} = \frac{2,910 - 1.3 (573.4)}{1.3 (1550) (0.667) (1 + 0.26)} = 1.27
\]

\[
RF_{v \ (2 \ unit)} = \frac{380 - 1.3 (35.3)}{1.3 (104) (0.667) (1 + 0.26)} = 2.93
\]

\[ RF > 1.0 \implies \text{NO posting required} \]
MDOT Overload Class, Item 193

The Overload trucks are used to complete the MDOT Overload Class rating. The live load moment and shear produced by the Overload Trucks are found from tables located in the BAG. Start with Class A load tables, if RF is less than 1.0 then go on to Class B, followed by Class C tables if necessary to achieve RF > 1.0

\[ A_1 = 1.3 \]
\[ A_2 = 1.3 \]
\[ M_L = 2,000 \text{ ft*k} \quad \text{(Trucks #10 & #12) (BAG Table 10.10) (Class A)} \]
\[ V_L = 144 \text{ k} \quad \text{(Truck #12) (BAG Table 10.22) (Class A)} \]
\[ M_L = 1,680 \text{ ft*k} \quad \text{(Truck #12) (BAG Table 10.11) (Class B)} \]

\[ RF_{m(A)} = \frac{2,910 - 1.3 \times 573.4}{1.3 \times 2,000 \times 0.667 \times (1 + 0.26)} = 0.99 \]

\[ RF_v = \frac{380 - 1.3 \times 35.3}{1.3 \times 144 \times 0.667 \times (1 + 0.26)} = 2.12 \]

\[ RF_m < 1.0 \text{ for maximum Class A truck. Check Class B truck.} \]

\[ RF_{m(B)} = \frac{2,910 - 1.3 \times 573.4}{1.3 \times 1,680 \times 0.667 \times (1 + 0.26)} = 1.18 \]

\[ RF_m > 1.0 \implies \text{OVERLOAD CLASS B} \]
Example: Load Factor Rating (LFR) with Deterioration

A load rating needs to be performed on a simply supported bridge with a span length equal to 65ft and with the cross section shown above. The bridge was built in 1965 and shows signs of deterioration as of the most recent bridge inspection. The approach and wearing surface are in good condition. Diaphragms are located at mid-span. The moment and shear capacities of the bridge were updated to reflect the damage observed in the field.

The bridge is located in an area which allows designated loading. The design loading was HS-20, which is greater than HS-15. Therefore, the slab does not require analysis (see Bridge Analysis Guide (BAG), Chapter 4). The substructure is in good condition and therefore does not require analysis.

The bridge has been analyzed and the following properties determined:

- Moment capacity updated to reflect deterioration: 2,066 ft*k
- Shear capacity updated to reflect deterioration: 164 k
- Combined dead load effect
  - moment: 573 ft*k
  - shear: 35.3 k
- Live load effect: to be determined as required for each component of the load rating.
- Impact factor: 0.26
- Girder distribution factor (GDF): 0.667
General Load Rating Equation:

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

Where:

- RF = rating factor
- C = capacity
- D = dead load effect
- L = live load effect
- GDF = girder distribution factor
- I = impact factor
- A_1 = dead load effect factor
- A_2 = live load effect factor

**Federal Inventory Rating (Item 66)**

The HS-20 truck is used to complete the Federal Inventory Rating. Shear and moment tables for the HS-20 truck over simple spans of varying lengths may be found in the BAG.

- \( A_1 = 1.3 \)
- \( A_2 = 2.17 \)
- \( M_L = 896 \text{ ft}^*\text{k} \) \hspace{1cm} (BAG Table 10.9)
- \( V_L = 61.7 \text{ k} \) \hspace{1cm} (BAG Table 10.21)

\[ RF_m = \frac{2,066 - 1.3 (573.6)}{2.17 (896) (0.667) (1 + 0.26)} = 0.81 \]

\[ RF_v = \frac{164 - 1.3 (35.3)}{2.17 (61.7) (0.667) (1 + 0.26)} = 1.05 \]
Federal Operating Rating (Item 64F)

The HS-20 truck is used to complete the Federal Operating Rating. Shear and moment tables for the HS-20 truck over simple spans of varying lengths may be found in the BAG.

\[ A_1 = 1.3 \]
\[ A_2 = 1.3 \]
\[ M_L = 896 \text{ ft}^* \text{k} \quad \text{(BAG Table 10.9)} \]
\[ V_L = 61.7 \text{ k} \quad \text{(BAG Table 10.21)} \]

\[
RF_m = \frac{2,066 - 1.3 \times 573.4}{1.3 \times 896 \times 0.667 \times (1 + 0.26)} = 1.35
\]

\[
RF_p = \frac{164 - 1.3 \times 35.3}{1.3 \times 61.7 \times 0.667 \times (1 + 0.26)} = 1.75
\]
Michigan Operating Rating (Item 64M)

The Michigan Legal Loads are used to complete the Michigan Operating Rating. The live load moment and shear effects produced by the Michigan Legal Loads may be found from tables located in the BAG.

\[ A_1 = 1.3 \]

\[ A_2 = 1.3 \]

\[ M_L = 1,550 \text{ ft*k} \quad \text{(Truck #17)} \]

\[ V_L = 104 \text{ k} \quad \text{(Truck #17)} \]

\[
RF_{m\,(2 \text{ unit})} = \frac{2,066 - 1.3 (573.4)}{1.3 (1550) (0.667) (1 + 0.26)} = 0.78
\]

\[
RF_{v\,(2 \text{ unit})} = \frac{164 - 1.3 (35.3)}{1.3 (104) (0.667) (1 + 0.26)} = 1.04
\]

\[ RF < 1.0 \Rightarrow \text{Posting or repairs must be considered} \]

Calculate Live Load Capacity (live load effect which causes \( RF = 1 \))

\[
L_{Allowed} = \frac{C - 1.3 (D)}{1.3 (RF) (GDF) (1 + I)}
\]

\[
= \frac{2,066 - 1.3(573.4)}{1.3 (104) (0.667) (1 + 0.26)}
\]

\[ = 1,209 \text{ ft*k} \]


**Posting Procedure**

Look at trucks that have a moment effect > 1,209 ft*k

---

**1-unit Trucks**

All 1-unit trucks have \( m < 1,209 \text{ ft}^*\text{k} \), max of 84 k is okay.

Restrict to 42 tons

---

**2-unit Trucks**

<table>
<thead>
<tr>
<th>Truck #</th>
<th>( M_{\text{Truck}} )</th>
<th>( M_{\text{/wt}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>1230</td>
<td>10.4</td>
</tr>
<tr>
<td>13</td>
<td>1250</td>
<td>9.93</td>
</tr>
<tr>
<td>14</td>
<td>1350</td>
<td>10.2</td>
</tr>
<tr>
<td>15</td>
<td>1300</td>
<td>9.05</td>
</tr>
<tr>
<td>16</td>
<td>1470</td>
<td>10.6</td>
</tr>
<tr>
<td>17</td>
<td>1550</td>
<td>10.3</td>
</tr>
<tr>
<td>18</td>
<td>1510</td>
<td>9.81</td>
</tr>
</tbody>
</table>

\[
\frac{1,209 \text{ ft}^*\text{k}}{10.6 \frac{\text{ft}^*\text{k}}{\text{k}}} = 114 \text{ k} = 57 \text{ tons}
\]

Restrict to 57 tons

---
### 3-unit Trucks

<table>
<thead>
<tr>
<th>Truck #</th>
<th>$M_{truck}$</th>
<th>$M_{/wt}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>1260</td>
<td>8.34</td>
</tr>
<tr>
<td>22</td>
<td>1320</td>
<td>8.18</td>
</tr>
<tr>
<td>23</td>
<td>1430</td>
<td>9.3</td>
</tr>
<tr>
<td>25</td>
<td>1400</td>
<td>8.51</td>
</tr>
</tbody>
</table>

\[
\frac{1,209 \text{ ft}^*k}{9.2 \text{ ft}^*k/\text{k}} = 130 \text{ k} = 65 \text{ tons}
\]

Restrict to 65 tons

### Summary

**Posted Limits**

- 1-unit — 42 tons
- 2-unit — 57 tons
- 3-unit — 65 tons
MDOT Overload Class, Item 193

The Overload trucks are used to complete the MDOT Overload Class rating. The live load moment and shear produced by the Overload Trucks are found from tables located in the BAG. Start with Class A load tables, if RF is less than 1.0 then go on to Class B, followed by Class C tables if necessary to achieve RF > 1.0

\[ A_1 = 1.3 \]
\[ A_2 = 1.3 \]
\[ M_L = 2,000 \text{ ft}^*\text{k (Trucks #10 & #12) (BAG Table 10.10) (Class A)} \]
\[ V_L = 144 \text{ k (Truck #12) (BAG Table 10.22) (Class A)} \]

\[ RF_{m(2\text{ unit})} = \frac{2,066 - 1.3 (573.4)}{1.3 (2,000) (0.667) (1 + 0.26)} = 0.60 \]

\[ RF_{v(2\text{ unit})} = \frac{164 - 1.3 (35.3)}{1.3 (144) (0.667) (1 + 0.26)} = 0.74 \]

Calculate Live Load Capacity (live load effect which causes \( RF = 1 \))

\[ L_{\text{Allowed}} = \frac{C - 1.3 (D)}{1.3 (RF) (GDF) (1 + I)} \]

\[ = \frac{2,066 - 1.3(573.4)}{1.3 (1) (0.667) (1 + 0.26)} \]

\[ = 1,209 \text{ ft}^*\text{k} \]
Check Class B and Class C tables for moment effects greater than 1209 ft\(\times\)k. If no moment effect is greater than 1209 ft\(\times\)k in Class B, then the bridge is Class B, otherwise check Class C.

Class B > 1,209 ft\(\times\)k

Class C > 1,209 ft\(\times\)k

**Bridge is Class D:**

- Produce table of allowable axle loads for each of the 10 overload trucks.

**Sample calculations for allowable Class D axle loads:**

Truck #1 under Class A loading produces a moment of 1,150 ft\(\times\)k (BAG Table 10.12) which is less than the maximum allowable of 1,209 ft\(\times\)k, therefore the axial load of 60 kips for Truck #1 does not need to be restricted.

Truck #2 under Class A loading produces a moment of 1,270 ft\(\times\)k (BAG Table 10.12), which, being greater than the 1,209 ft\(\times\)k allowable, will need to be restricted.

\[
\text{Allowable Axle Load} = \frac{L_A \text{ Permit}}{\text{Moment}} \cdot \text{Axle Load}
\]

\[
= \frac{1,209 \text{ ft}^\times\text{k}}{1,270 \text{ ft}^\times\text{k}} = (60 \text{ k}) = 57 \text{ k}
\]

**Restrict Truck #2 to 57 k per axle**
This procedure was used to generate the following table for the remaining overload trucks:

<table>
<thead>
<tr>
<th>Truck</th>
<th>Axle Load (k) from Figure 8.1</th>
<th>Moment Effect for Class A Overload (ft*k) from Table 10.10</th>
<th>Calculated Allowable Axle Load (k) for Class D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>1150</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>1270</td>
<td>57</td>
</tr>
<tr>
<td>3</td>
<td>57</td>
<td>1400</td>
<td>49</td>
</tr>
<tr>
<td>4</td>
<td>49</td>
<td>1550</td>
<td>38</td>
</tr>
<tr>
<td>5</td>
<td>44</td>
<td>1630</td>
<td>32</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>1710</td>
<td>21</td>
</tr>
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<td>7</td>
<td>31</td>
<td>1820</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td>24</td>
<td>1860</td>
<td>15</td>
</tr>
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<td>9</td>
<td>22</td>
<td>1920</td>
<td>13</td>
</tr>
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<td>20</td>
<td>2000</td>
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</tr>
<tr>
<td>11</td>
<td>46</td>
<td>1830</td>
<td>30</td>
</tr>
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<td>31</td>
<td>2000</td>
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<td>22</td>
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<td>14</td>
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<td>16</td>
<td>17</td>
<td>1740</td>
<td>11</td>
</tr>
<tr>
<td>17</td>
<td>17.3</td>
<td>1980</td>
<td>10</td>
</tr>
<tr>
<td>18</td>
<td>24</td>
<td>1710</td>
<td>16</td>
</tr>
<tr>
<td>19</td>
<td>21.5</td>
<td>1770</td>
<td>14</td>
</tr>
<tr>
<td>20</td>
<td>20.5</td>
<td>1750</td>
<td>14</td>
</tr>
</tbody>
</table>
Example: Load Resistance Factor Rating (LRFR)

A load rating needs to be performed on a simply supported 27”x36” prestressed concrete side-by-side box-beam bridge with a span length equal to 50ft and with the cross section shown above. The bridge has been well maintained with no deterioration reported as of the most recent bridge inspection. The approach and wearing surface are in good condition.

The bridge is located in an area which allows designated loading. The design loading was HL-93, therefore the slab does not require analysis (see BAG, Chapter 4). The substructure is in good condition and therefore does not require analysis.

The bridge has been analyzed and the following properties determined:

- Moment Capacity: 991 ft*k
- Shear Capacity: 95.6 k
- $c_b = 18.5$ in (composite shape)
- $I = 92,640$ in$^4$ (composite shape)
- Combined Dead Load Effect
  - Moment: 293 ft*k
  - Shear: 22.1 k
- Live Load Effect: To be determined as required for each component of the load rating.
- IM: 0.26
- Girder Distribution Factor (GDF): 0.26
- ADTT: 5000
General Load Rating Equation:

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

Where:

- \(RF\) = rating factor
- \(C\) = capacity
- \(\gamma_{DC}\) = LRFD load factor for structural components and attachments
- \(DC\) = dead load effect due to structural components and attachments
- \(\gamma_{DW}\) = LRFD load factor for wearing surfaces and utilities
- \(DW\) = dead load effect due to wearing surfaces and utilities
- \(\gamma_P\) = LRFD load factor for permanent loads other than dead loads = 1.0
- \(P\) = permanent loads other than dead loads
- \(\gamma_{LL}\) = evaluation live load factor
- \(LL\) = live load effect
- \(IM\) = dynamic load allowance

From the Manual for Bridge Evaluation:

<table>
<thead>
<tr>
<th>Prestressed Concrete:</th>
<th>Design Load (HL-93)</th>
<th>Other Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength I</td>
<td>Federal Inventory and Operating</td>
<td>MI Operating (Legal Loads)</td>
</tr>
<tr>
<td>Strength II</td>
<td></td>
<td>Permit Loads (Check Shear)</td>
</tr>
<tr>
<td>Service III</td>
<td>Federal Inventory</td>
<td>MI Operating (Legal Loads)</td>
</tr>
<tr>
<td>Service I</td>
<td></td>
<td>Permit Loads (Check Shear)</td>
</tr>
</tbody>
</table>
Federal Inventory Rating (Item 66)

The HL-93 truck is used to complete the Federal Inventory Rating for Strength I and Service III limit states. BAG tables are used to determine the moment produced by the HL-93 truck on the bridge being analyzed. The general load rating equation is utilized for Strength I and Service III.

In load rating, wearing surfaces that have been field verified may be treated as structural components (DC). Therefore, for this bridge, there are no terms for DW or P.

**Strength I Limit State:**

\[ \phi_c = 1.0 \]
\[ \phi_s = 1.0 \]
\[ \phi = 1.0 \]
\[ \gamma_{DC} = 1.25 \]
\[ \gamma_{LL} = 1.75 \]

Moment due to HL-93 on 50 ft span = 1,034 ft\( \cdot \)k (Table E6A-1, AASHTO Manual for Bridge Evaluation)

**Flexure at midspan:**

\[
RF = \frac{\phi_c \phi_s \phi R_n - (\gamma_{DC})(DC)}{(\gamma_{LL})(LL + IM)}
\]

\[
RF = \frac{(1.0)(1.0)(1.0)(991 \text{ ft} \cdot \text{k}) - (1.25)(293 \text{ ft} \cdot \text{k})}{(1.75)(1,034 \text{ ft} \cdot \text{k})(0.26)}
\]

\[ RF = 1.33 \]

Note: Shear need not be checked for design load (HL-93) as the bridge does not show signs of shear distress.
Service III Limit State:

\( \gamma_{DC} = 1.0 \)
\( \gamma_{LL} = 0.80 \)

Moment due to HL-93 on 50 ft span = 1,034 ft*\( k \) (Table E6A-1, AASHTO Manual for Bridge Evaluation)

Tensile stress in concrete:

\[
RF = \frac{f_R - (\gamma_D)(f_D)}{(\gamma_{LL})(f_{(LL+IM)})}
\]

Where:

- \( f_R \) = tensile capacity of concrete (stress due to effective prestressing + allowable tension)
- \( f_D \) = tensile stress in concrete due to dead loads
- \( f_{(LL+IM)} \) = tensile stress in concrete due to live loads

\[
f_R = 1.845 \text{ ksi}
\]
\[
f_D = 0.952 \text{ ksi}
\]
\[
f_{(LL+IM)} = \frac{(M_{truck})(c_b)}{I}
\]
\[
(1,034 \text{ ft } k)(12 \text{ in/ft})(0.26)(18.5 \text{ in})
\]
\[
f_{(LL+IM)} = \frac{92,640 \text{ in}^4}{92,640 \text{ in}^4}
\]
\[
f_{(LL+IM)} = 0.644 \text{ ksi}
\]

\[
RF = \frac{1.845 \text{ ksi} - (1.0)(0.952 \text{ ksi})}{(0.80)(0.644 \text{ ksi})}
\]

\[
RF = 1.73
\]
Federal Operating Rating (Item 64F)

The HL-93 truck is used to complete the Federal Operating Rating for the Strength I limit state. BAG tables are used to determine the moment produced by the HL-93 truck on the bridge.

Strength I Limit State:

\[
\phi_c = 1.0 \\
\phi_s = 1.0 \\
\phi = 1.0 \\
\gamma_{DC} = 1.25 \\
\gamma_{LL} = 1.35
\]

Moment due to HL-93 on 50 ft span = 1034 ft*k (Table E6A-1, AASHTO Manual for Bridge Evaluation)

Flexure at midspan:

\[
RF = \frac{\phi_c \phi_s \phi R_n - (\gamma_{DC})(DC)}{(\gamma_{LL})(LL + IM)}
\]

\[
RF = \frac{(1.0)(1.0)(1.0)(991 \text{ ft} \cdot \text{k}) - (1.25)(293 \text{ ft} \cdot \text{k})}{(1.35)(1,034 \text{ ft} \cdot \text{k})(0.26)}
\]

\[
RF = 1.72
\]

Note: Shear need not be checked for design load (HL-93) as the bridge does not show signs of shear distress.
Michigan Operating Rating (Item 64M)

Note: AASHTO states that legal loads need not be checked if the rating produced with the HL-93 load is above 1.0. This is NOT true of Michigan legal loads as the trucks allowed in MI are larger than the AASHTO legal trucks.

The Michigan Legal Loads are used to complete the Michigan Operating Rating. Moment due to Michigan legal trucks may be found from the BAG tables. $\gamma_{LL}$ value varies according to truck and ADTT and can be found in Table 4a-6 of the BAG. The table below was produced to determine the controlling truck for both Strength I and Service III (note, in Service III, $\gamma_{LL} = 1.0$).

<table>
<thead>
<tr>
<th>Truck</th>
<th>Strength I Load Factor</th>
<th>Service III Load Factor</th>
<th>IM</th>
<th>Moment</th>
<th>Strength I Factored with Impact</th>
<th>Service III Factored with Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>1.33</td>
<td>351</td>
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<td>1.00</td>
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<td>496</td>
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<td>660</td>
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<td>3</td>
<td>1.80</td>
<td>1.00</td>
<td>1.33</td>
<td>542</td>
<td>1298</td>
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<td>1.00</td>
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<td>689</td>
<td>1411</td>
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<td>1.00</td>
<td>1.33</td>
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<td>1.33</td>
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<td>1301</td>
<td>923</td>
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<td>1.00</td>
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<td>1.00</td>
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<td>769</td>
<td>1238</td>
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<td>1.00</td>
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<td>1.00</td>
<td>1.33</td>
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<td>1.00</td>
<td>1.33</td>
<td>879</td>
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<td>1169</td>
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<td>588</td>
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<td>1.33</td>
<td>398</td>
<td>953</td>
<td>529</td>
</tr>
</tbody>
</table>
Strength I Limit State:

\[ \phi_c = 1.0 \]
\[ \phi_s = 1.0 \]
\[ \phi = 1.0 \]
\[ \gamma_{DC} = 1.25 \]
\[ \gamma_{LL} = \text{varies according to truck (already included in value below)} \]

Factored moment due to MI Truck #16 on 50 ft span = 1,634 ft\(^*\)k

Flexure at midspan:

\[
RF = \frac{\phi_c \phi_s \phi R_n - (\gamma_{DC})(DC)}{(\gamma_{LL})(LL + IM)}
\]

\[
RF = \frac{(1.0)(1.0)(1.0)(991 \text{ ft} \cdot \text{k}) - (1.25)(293 \text{ ft} \cdot \text{k})}{(1,634 \text{ ft} \cdot \text{k})(0.26)}
\]

\[
RF = 1.47
\]
Service III Limit State:

\[ \gamma_{DC} = 1.0 \]
\[ \gamma_{LL} = 1.0 \]

Factored moment due to MI Truck #17 on 50 ft span = 1,343 ft*k

Tensile stress in concrete:

\[ RF = \frac{f_R - (\gamma_D)(f_D)}{(\gamma_{LL})(f_{(LL+IM)})} \]

Where:

- \( f_R \) = tensile capacity of concrete (stress due to effective prestressing + allowable tension)
- \( f_D \) = tensile stress in concrete due to dead loads
- \( f_{(LL+IM)} \) = tensile stress in concrete due to live loads

\[ f_R = 1.845 \text{ ksi} \]
\[ f_D = 0.952 \text{ ksi} \]

\[ f_{(LL+IM)} = \frac{(M_{\text{truck}})(c_b)}{I} \]

\[ f_{(LL+IM)} = \frac{(1,343 \text{ ft} \cdot \text{k})(12 \text{ in}/f_t)(0.26)(18.5 \text{ in})}{92,640 \text{ in}^4} \]
\[ f_{(LL+IM)} = 0.837 \text{ ksi} \]

\[ RF = \frac{1.845 \text{ ksi} - (1.0)(0.952 \text{ ksi})}{(1.0)(0.837 \text{ ksi})} \]

\[ RF = 1.06 \]
MDOT Overload Class, Item 193

The Overload trucks are used to complete permit rating. The BAG tables are used to determine the live load moment produced by the Overload Trucks on the bridge then the general load rating equation is used to determine the rating factor. Start with Class A overload vehicles, if RF is less than 1.0 then go on to Class B, followed by Class C if necessary to achieve RF > 1.0

Moment due to Michigan overload trucks may be found from the BAG tables. $\gamma_{LL}$ value varies according to truck, overload class, and ADTT and can be found in Table 4a-4 of the BAG. The table below was produced to determine the controlling truck for Strength II. IM = 1.10 reflects a smooth riding surface.

Note: Service I checks are optional, not shown here.

NOTE: Permit trucks should be checked for shear incrementally along the length of the member, not shown here.

<table>
<thead>
<tr>
<th>Truck</th>
<th>Strength II Load Factor Class A</th>
<th>IM</th>
<th>Moment</th>
<th>Strength II Factored with Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.39</td>
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<td>750</td>
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<td>3</td>
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<td>1.10</td>
<td>960</td>
<td>1468</td>
</tr>
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<td>4</td>
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<td>1.10</td>
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<td>1841</td>
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<td>7</td>
<td>1.28</td>
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<td>1300</td>
<td>1745</td>
</tr>
<tr>
<td>9</td>
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<td>1.10</td>
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<td>1726</td>
</tr>
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<tr>
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<td>1170</td>
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<td>15</td>
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<td>1240</td>
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</tr>
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<tr>
<td>20</td>
<td>1.10</td>
<td>1.10</td>
<td>1210</td>
<td>1464</td>
</tr>
</tbody>
</table>
Strength II Limit State:

\[ \phi_c = 1.0 \]
\[ \phi_s = 1.0 \]
\[ \phi = 1.0 \]
\[ \gamma_{DC} = 1.25 \]
\[ \gamma_{LL} = \text{varies according to truck, class, and ADTT (already included in value below)} \]

Factored moment due to MI Truck #16 on 50 ft span = 1,634 ft*k

Flexure at midspan:

\[ RF = \frac{\phi_c \phi_s \phi R_n - (\gamma_{DC})(DC)}{(\gamma_{LL})(LL + IM)} \]

\[ RF = \frac{(1.0)(1.0)(1.0)(991 \text{ ft} \cdot \text{k}) - (1.25)(293 \text{ ft} \cdot \text{k})}{(1,841 \text{ ft} \cdot \text{k})(0.26)} \]

\[ RF = 1.30 \]

OK for routine permit Class A vehicles

NOTE: Permit trucks should be checked for shear incrementally along the length of the member, not shown here.
Example: MDOT Steel Superstructure with Pin & Hanger
Create a new bridge from the File Menu.

Enter the bridge information under the “Description” tab. The Bridge ID and NBI Structure ID must be unique for each Virtis file created.
Enter the Truck PCT, ADT and Design ADTT on the “Traffic” tab. This is only necessary for LRFR.

By right clicking on the + or – sign, the branches can expand or collapse for easier editing.
Now is a good time to complete the Bridge Assumption Form, based on the information found on the plans.

<table>
<thead>
<tr>
<th>BRIDGE ANALYSIS ASSUMPTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge ID: 25132-524</td>
</tr>
<tr>
<td>Most recent BIR date: Apr 10, 2008</td>
</tr>
<tr>
<td>Is deterioration accounted for in load rating: no</td>
</tr>
<tr>
<td>Stringers rated 7</td>
</tr>
<tr>
<td>Year Constructed/Reconstructed*: 1977</td>
</tr>
<tr>
<td>Work performed: no other significant work</td>
</tr>
</tbody>
</table>

| Superstructure Component: 3 Steel, Simple or Cantilever |
| Fy/fc': 50 / 3 ksi |
| Composite: yes |
| Number of beams: 16 |
| Shop Dwgs verified: yes |
| Size of Beams/Beam #’s and spans: W33x118 Sp 1 & 3, x130 Sp2 NB, x141 Sp 2 SB |
| Deck thickness: 9.5 in fc': 3 ksi Fy: 60 ksi |
| Deck Design load > H15: yes |
| Barrier Type/weight: Type 1 305 plf (L) Median 544 plf (C) Type 1 305 plf (R) |
| Wearing surface material/thickness/unit weight: in/pcf |
| Sidewalks or brush blocks width/thick: in (L)/in (C)/in (R) |
| Clear roadway: 118 ft 4 in |
| Design by LRFD: no Rating Method: LF |
| Additional loads: D1 = (((22in*0.375in)/144in^2/ft^2*490 lb/ft^3)+2*7.2lb/ft)*8.25ft = 350lb |
| D2 = (((22in*0.375in)/144in^2/ft^2*490 lb/ft^3) + 2*7.2lb/ft) * 8.5ft = 365lb |
| D3 = 25 lb/ft * 8.5ft = 215lb |
| Unique factors that affect capacity: Only span 2 is composite, NB and SB are separated by only one median barrier. |

* If the structure has been reconstructed, only include the information from previous constructions that is still relevant. Complete enough forms to identify all relevant information.

Analyzed By- Signature and Date CJI Feb 14, 2011

Checked By- Signature and Date CEM Feb 16, 2011
Now that all of the background data is assembled, reviewed and organized, this information can be entered into Virtis. The typical workflow is to start at the top and work down. Under the “Materials” folder, double click “Structural Steel” and select “Copy from Library.”

Select the steel “ASTM A588 - <= 4”, Fy = 50 ksi”
Select “OK” once to exit the library and again to exit the “Bridge Materials” window.

As there isn’t a “3 ksi concrete” option in the pre-installed library, the user can choose the “Class A (US)” concrete and manually modify the compressive strength to 3 ksi or add this material property to the agency library for future use. Any time a pre-installed library item is modified, it is helpful to rename the property so future reviewers are aware of the change. For this example, create a new material in the Library Explorer.
When copy is selected, a new materials screen will pop up. Change the name, compressive strength (3 ksi), modulus of elasticity (3155.9242 ksi), and modulus of rupture (0.4156 ksi).
Once the new material has been defined, return to the Bridge Workspace and add the 3 ksi concrete to the model. Add the Grade 60 reinforcing steel as well.

Next add the three beam shapes: W33x118, W33x130 and W33x141 from the library.
Enter the Parapet Shapes.

The dimensions of the Type I Barrier can be found on the plans.
Enter the median barrier.
Factors only need to be entered for LRFR bridges. The LRFR factors will be addressed later in the presentation.
Enter the Superstructure Definitions. As there is an open longitudinal joint, the NB and SB spans should be entered separately. “Girder System Superstructure” can be chosen in most cases. In some unique cases of splayed girders, it might be better to use “Girder Line Superstructure”.

This is a 3-span continuous structure with 8 beams. Enter the span lengths and remember the decimal accuracy used. Virtis will compare all future inputs to the lengths entered on this screen so be consistent with the decimal point accuracy. The span lengths are 37.7188-ft and 79.5-ft.
Add load cases. For most structures, adding the default load cases is sufficient. It is helpful to document any loads that you include on the assumption sheet.
Enter the skew and girder spacings on the “Framing Plan Detail”. Entering the skew is important because skew impacts live load distribution for LRFR structures, placement of diaphragms and calculation of reactions at supports. The skew is -12.3 degrees and the girder spacing is 8.25 ft.

While entering the structure framing plan, it may be helpful to see the framing plan created as data is entered. Right click on “Framing Plan Detail” and select “Schematic”. This will work for any of the items that have schematics.
Rearrange the windows so that the “Bridge Workspace,” “Schematic Framing Plan View,” and “Structure Framing Plan Details” windows are all visible. Hit apply in the “Structure Framing Plan Details” window to update the framing plan schematic.

Add diaphragms using the Diaphragm Wizard. Diaphragms for simple steel beams and concrete beams are only used to estimate loads in Virtis. Diaphragms for continuous steel beams are used to calculate bracing of the compression flange so accurate placement of these diaphragms is important. You may want to check the shop drawings.
It is typically assumed that the pin and hanger diaphragms are 1-ft off of the pin and hanger centerline. Enter the loads as shown. Remember to add this info to the assumption sheet.

\[
D_1 = \left(\frac{22\text{in} \times 0.375\text{in}}{144\text{in}^2/\text{ft}^2} \times 490 \text{ lb/ft}^3\right) + 2 \times 7.2\text{lb/ft} \times 8.25\text{ft} = 350\text{lb}
\]

\[
D_2 = \left(\frac{22\text{in} \times 0.375\text{in}}{144\text{in}^2/\text{ft}^2} \times 490 \text{ lb/ft}^3\right) + 2 \times 7.2\text{lb/ft} \times 8.5\text{ft} = 365\text{lb}
\]

\[
D_3 = 25 \text{ lb/ft} \times 8.5\text{ft} = 215\text{lb}
\]
Since the beam spacing and skews for all beams are the same, copy from bay 1 to all of the other bays. This will reduce the time needed to add diaphragms and loads.

Check the schematic.
Enter the Structure Typical Section information.
Since the bridge does not have varying skews or splayed beams, we can set the Virtis reference line to the centerline of the bridge. For oddly configured bridges, it may be helpful to set the reference line elsewhere. The out to out of NB is 60.3125 ft, so the distance to the Virtis reference line = 60.3125/2 = 30.15625 ft. The left overhang is 1.3125 ft.

Enter deck information.
Enter parapet information.

Compute travelway.
There is no wearing surface on this structure, so click ok and check the cross-section schematic.

Next enter a member alternative. Choose the correct member type, which in this case is a rolled steel beam.
It is helpful to enter a name which describes why the member is being entered, for example “Exterior Fascia Beam.” An important note is that bearing lengths change the length of the beam for Concrete Beams but not for Steel Beams.

Compute live load distribution.
Enter hinges at the pin and hangers.

Enter the beam sections.
Enter the bottom cover plate.

Add a 1-in haunch.
Enter lateral support for length of beam.

Now that the fascia beam is fully modeled except for the deck, it can be copied and pasted to the interior beam. This is most useful for similar beam sections. Select the member alternative to be copied, right click and select copy.
Select the member alternative folder that you want to paste to, right click, and select paste.

Rename to “Interior Beam.” The other interior beams can be linked to the one just created as long as the beams are all identical. Click on G2, G3, G5, G6 and G7 and link to G4.
Recalculate the live load distribution factors for the interior beam.

Under “Deck Profile,” first add “Shear Connectors” and then click “Compute from Typical Section” on the “Deck Concrete” tab. If the deck section is computed first, a warning will appear stating that the deck is non-composite.
Repeat this process in the “Deck Profile” section of the exterior fascia beam as well. Now the Exterior Fascia Beam (G1) can be copied to the Interior Fascia Beam (G8). Update the “Live Load Distribution” and “Deck Profile” for the Interior Fascia Beam.

As SB is similar to NB, you can copy the superstructure definition for NB and paste into the superstructure definition folder. Be sure to check for any differences between NB and SB. Examples include cross section changes, beam size changes and updating the haunches and live load distributions.
Now that the superstructure definitions are modeled, Bridge Alternatives must be created. This makes it possible to rate the entire bridge at one time and also perform batch processes in the ‘Bridge Explorer’ workspace, which is important for permitting issues.

For load rating, there will typically be only one Bridge Alternative. Another Bridge Alternative could be created for a proposed bridge or rehabilitation project, but only one bridge alternative should be existing/current at a time. Each superstructure that was entered above now needs its own definition in the Bridge Alternative. Select the superstructure wizard. Enter the number of superstructures. Enter the superstructure and superstructure alternative names and then select the superstructure definition that you want to link to each alternative.
Choose analysis settings then add the appropriate trucks to the Rating Vehicle Summary area. MDOT analyzes each bridge for Michigan legal and overload vehicles. This requires a minimum of three runs – once for HS-20 and standard legal loads, once for the first 10 overload trucks and once for the second 10 overload trucks. The MDOT vehicles are available to download from the Bridge Operations Service Center website.

It is helpful to use templates. Once the trucks are in the window on the right, you can select “Save Template” and then name your selection for ease of use in the future.
To run the analysis, click the Analyze button with the bridge definition highlighted. This will analyze the entire structure. You can also run a single superstructure definition (NB/SB) or a single member alternative (Fascia/Interior) by highlighting the desired location before clicking Analyze.

After analysis completes, choose the Report Tool and select “LFD Analysis Output.”
Uncheck all options except for Overall Summary then select “Generate”.

This will generate an *.xml file that will open in Internet Explorer, which can then be saved as a *.pdf file.
Repeat the previous steps for the Overload Trucks. Overload Trucks are analyzed as single lane loaded. To choose single lane loading, select “Advanced” from the Analysis Settings Window and check the “Single Lane Loaded” option. If you are creating a template, ensure “Single Lane Loaded” is checked before saving the template.

To export the *.xml file from the Bridge Workspace window, choose file\Export and save the file to the desired location.
Complete the summary sheet.

**BRIDGE ANALYSIS SUMMARY**

Bridge ID: 25132-524

The above structure was analyzed using: Virtis

Version or Other: 6.2.0

The analysis is based on field inspection dated: Apr 10, 2008

The controlling component and failure mode are:

Interior NB, Positive Moment Flexural Strength

**NEW INVENTORY CODING**

<table>
<thead>
<tr>
<th>NBI Item 63- Operating Rating Method</th>
<th>6-LF Rating Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBI Item 64F- Federal Operating Rating</td>
<td>2.554 Rating Factor</td>
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<tr>
<td>MDOT Item 64MA- Michigan Operating Method</td>
<td>6-LF Rating</td>
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<tr>
<td>MDOT Item 64MB- Michigan Operating Rating</td>
<td>1.402 Rating Factor</td>
</tr>
<tr>
<td>MDOT Item 64MC and D- Michigan Operating Truck</td>
<td>17 D - Designated</td>
</tr>
<tr>
<td>NBI Item 65- Inventory Rating Method</td>
<td>6-LF Rating Factor</td>
</tr>
<tr>
<td>NBI Item 66- Federal Inventory Rating</td>
<td>1.532 Rating Factor</td>
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<tr>
<td>NBI Item 41- Open Posted Closed</td>
<td>A-Open</td>
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<tr>
<td>NBI Item 70- Bridge Posting</td>
<td>5 - 100% or more</td>
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<tr>
<td>NBI Item 141- Posted Loading</td>
<td>US Tons</td>
</tr>
<tr>
<td>MDOT Item 193A- Michigan Overload Class</td>
<td>A</td>
</tr>
<tr>
<td>MDOT Item 193C- Overload Status</td>
<td>- No Restriction</td>
</tr>
</tbody>
</table>

Analyzed By- Signature and Date: CJL Feb 14, 2011

Checked By- Signature and Date: CEM Feb 16, 2011

Database Updated By- Initials and Date: ____________________________
Example: Modifying the Virtis File for LRFR Analysis

Copy the AASHTO LRFR factors from the Library. These factors apply to the HL-93 vehicle. MDOT Research Report R-1511 determined load factors, $\gamma_{LL}$, specific to Michigan’s standard and overload vehicles. These factors are also listed in the MDOT Bridge Analysis Guide (BAG).

In LRFR, vehicles with a gross vehicle weight (GVW) less than 100 k are considered Legal Vehicles. Vehicles with a GVW greater than or equal to 100 k are considered Permit Vehicles. The "Legal Loads" tab lists the AASHTO legal load factors based on ADTT. These factors can be changed to reflect the load factors, $\gamma_{LL}$, given in the BAG. When modifying the load factors in this manner, only legal trucks with the same load factor, $\gamma_{LL}$, can be analyzed at the same time.
Double-click on “NB Spans 1 thru 3,” go to the Analysis tab and check the LRFR factors. Repeat this step for “SB Spans 1 thru 3.”

Double-click on “Exterior Fascia Beam,” go to the Factors tab and check the LRFR factors. Repeat this step for all of the defined members, including those in the SB spans.
Click analysis settings and add the appropriate trucks to the Vehicle Summary area. MDOT analyzes LRFR structures for all 28 Michigan vehicles as well as the 20 overload vehicles. There is a current research study to determine which trucks control for LRFR. The user must determine whether each Michigan vehicle is considered a Legal Vehicle or a Permit Vehicle based on gross vehicle weight.

Select “Advanced” from the Analysis Settings Window. Change the frequency to “Unlimited Crossing,” leave the loading condition as “Mixed w/ Traffic,” and check Override for the Permit Vehicles. Enter the load factor, $\gamma_{LL}$, as appropriate per the MDOT BAG for all Permit Vehicles. This option is not currently available for Legal Vehicles, but will be available with the Version 6.3 Release of Virtis.
MICHIGAN DEPARTMENT OF TRANSPORTATION

BRIDGE ANALYSIS GUIDE

<table>
<thead>
<tr>
<th>Truck</th>
<th>GVW (kips)</th>
<th>Normal Load Factor, $\gamma_{LL}$</th>
<th>Designated Load Factor, $\gamma_{LL}$</th>
<th>Special Designated Load Factor, $\gamma_{LL}$</th>
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</table>

Table 4a-1
Similar to LFR, it is useful to save the LRFR truck templates. Once the trucks are in “Vehicle Summary” area and the settings have been modified in the “Advanced” tab, you can select “Save Template” for ease of use in the future.

Click “OK,” then analyze the structure. After the analysis is complete, the rating factors for each girder can be viewed by selecting “View Analysis Report” from the toolbar. The Member Alternative must be highlighted in order to select “View Analysis Report.”
Alternately, you could run the bridge from the Bridge Explorer Window. This will present the controlling member rating in a condensed format, showing the lowest rating factors for each vehicle analyzed. To see rating factors for all of the girders, click “View Structure Rating Results” and then “View Member Rating Results.” This option is available when analyzing structures with LFR as well.
Repeat the previous steps for the Overload Trucks. For LRFR, Overload Trucks are NOT single lane loaded but are analyzed similar to the Michigan Trucks. There is an ongoing research project to determine which frequency setting, “Unlimited Crossing” or “Multiple Trips”, is more accurate so this setting may change depending on the results.

**BRIDGE ANALYSIS SUMMARY**

Bridge ID 25132-S24

The above structure was analyzed using: Virtis

Version or Other: 6.2.0

The analysis is based on field inspection dated: Apr 10, 2008

The controlling component and failure mode are:

Interior NB, Positive Moment Flexural Strength

**NEW INVENTORY CODING**

NBI Item 63- Operating Rating Method

NBI Item 64F- Federal Operating Rating

MDOT Item 64MA- Michigan Operating Method

MDOT Item 64MB- Michigan Operating Rating

MDOT Item 64MC and D- Michigan Operating Truck

NBI Item 65- Inventory Rating Method

NBI Item 66- Federal Inventory Rating

NBI Item 41- Open Posted Closed

NBI Item 70- Bridge Posting

NBI Item 141- Posted Loading

MDOT Item 193A- Michigan Overload Class

MDOT Item 193C- Overload Status

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Analyzed By- Signature and Date

Cheked By- Signature and Date

Database Updated By- Initials and Date

CJL Feb 14, 2011

CEM Feb 16, 2011

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INTRODUCTION

Purpose of the Bridge Analysis Guide

The Michigan Bridge Analysis Guide (the Guide) has been prepared to assist engineers with and to promote uniformity in analyzing highway bridges for load-carrying capacity. The process of preparing a bridge load capacity analysis has many discrete steps, including gathering physical data for the specific bridge, selecting the appropriate truck type(s), choosing the correct live load distribution factor and performing the actual analysis. This guide is structured to inform and lead the user through all the required process steps, provide completed examples and list references for further information.

The requirements for load rating of highway bridges can be found in the American Association of State Highway and Transportation Officials (AASHTO) publication, Manual for Condition Evaluation of Bridges, Second Edition, 1994 with Interim Revisions through 2000. This Guide has been prepared using that manual as a primary source of information. The Load Factor (LF) method has been used throughout this Guide.

Purpose of Load Rating

Bridge load capacity analysis is required by federal regulation, the purpose of which is to assure the structure owner, and indirectly the highway user, that each bridge is safe for use by the motoring public. Through load capacity analysis, a bridge may be discovered to be incapable of safely carrying some legal loads. In that circumstance, it may be necessary to publicly “post” the bridge for the reduced safe load, or in the extreme case, to close the bridge. In addition, for those occasions when loads beyond the range of standard legal vehicles (or “permit” loads) need to use a specific structure, load capacity analysis can provide answers about which loads are safely acceptable.

Qualifications and Responsibilities

The individual with overall responsibilities for load rating bridges should be a licensed professional engineer and preferably shall have a minimum of 5 years of bridge design and inspection experience. The engineering skills and knowledge necessary to properly evaluate bridges may vary widely depending on the complexity of the bridge involved. The specialized skills and knowledge of other engineers may be needed to ensure proper evaluation.

Basic Definitions (see Chapter 12 for more definitions)
Inventory Rating. The Inventory Rating represents the normal live load capacity of a bridge using the current load distribution factors, calculated with the current Load Factor Methods, but reflects the existing member and material deterioration. The AASHTO HS loading configuration is the applied live load. The load rating is expressed in terms of HS-type loadings. This load rating is intended to represent the load that can be safely carried by the bridge on a frequently repeated and continuing basis.

Federal Operating Rating. The Operating Rating represents the maximum live load capacity of a bridge calculated as noted above for the Inventory Rating, but with a reduced load factor for Live Load. The AASHTO HS loading configuration is used as the applied load, however the load is reported to MDOT in terms of MS-type loading. (The metric equivalent of HS loading) This load rating is intended to represent loads that can be safely carried by the bridge on an infrequent basis. Allowing unlimited numbers of vehicles to use a bridge at the Operating Level may shorten the life of the bridge.

Michigan Operating Rating. Michigan law allows legal loads that are in excess of the gross weights for standard H and HS-type loads. For the Michigan Operating Rating, bridges are to be analyzed with operating load factors for the ability to carry all Michigan legal loads. The vehicle types to be investigated are the three AASHTO legal vehicles and all Michigan legal vehicles. Michigan legal vehicles include all legal single-unit trucks, two-unit trucks (tractors with a trailer) and three-unit trucks (a tractor with two trailers). The Michigan Operating Rating represents loads that can be safely carried by the bridge on an infrequent basis. This rating may sometimes be referred to as the Legal Load Rating.

Load Posting. When it is discovered that a bridge can not safely carry all Michigan legal loads at the operating level, the bridge is posted with a sign indicating the maximum weight of vehicles of all three types (one-unit, two-unit and three-unit) that can safely use the bridge. Agencies may choose to post bridges for less than the calculated capacity, or to post at the inventory rating level, in order to extend the life of the structure.

Overloads or Permit Loads. Occasionally, vehicles that are heavier than Michigan legal loads, or that have axle configurations or axle loads that are not allowed by Michigan law, may need to use the highways and may cross specific highway bridges. Those vehicles can be said to be “overloads” and are required to obtain a permit from the agency owning the highway and bridges in question. It is prudent to analyze the capacity of the specific bridges to be crossed for their ability to safely carry the overload. Overload analysis is ordinarily done at the Operating level. Permits are then issued or denied based on the bridge analysis.
Federal Regulations that Govern Load Rating

The requirement to analyze highway bridges for capacity stems from federal law and can be found in the National Bridge Inspection Standards (NBIS) October 1988, within the Code of Federal Regulations. Specifically, Title 23, Part 650, Subpart C, 650.303 (c) reads in part, “Each structure. . .shall be rated as to its safe load carrying capacity in accordance with Section 4 of the AASHTO Manual.”

The requirements to maintain records related to bridge inspections and ratings can be found in the NBIS 650.311 (a), which reads in part, “Each State shall prepare and maintain an inventory of all bridge structures. . .” and “. . .certain structure inventory and appraisal data must be collected and retained within the various departments. . .”

When to Perform a Load Rating

In general, load ratings are performed on a bridge when one of five events has occurred: 1) the bridge is new and has not been previously rated, 2) the bridge has had a significant alteration that may affect the capacity of the bridge, 3) the bridge has incurred damage that affects the capacity, 4) a key component of the structure has deteriorated such that the previous load rating is no longer valid or 5) a request has been made to permit an overload vehicle to use the bridge.

New bridges must be load rated in order to comply with the Code of Federal Regulations requirements cited above. Rated capacities for new bridges are submitted to the MDOT and become the first recorded information retained about that topic.

In the second instance, if a bridge element has been repaired, rehabilitated, reconstructed or altered in a significant way, a load rating must be performed. This load rating could be triggered by such items as a deck overlay, the addition of a heavier railing, a new deck, a new superstructure, beam repairs, new beams, widening, significant substructure repair or any other rehabilitation that would affect the ability of the structure to carry load. The analyst must be aware of any changes in dead load that result from the work performed on the bridge.

The third case could be represented by an accident in which a vehicle struck a beam or substructure unit and significant damage occurred. The nature and extent of the damage would need to be included in modeling the structure for the new load rating.

In the fourth instance, a new load rating would be initiated after a field inspection indicated that a key element had deteriorated to a level not represented in the previous
load rating. This would include items such as beam flange or web section loss, deck deterioration, substructure unit section loss or being out of plumb.

In the final instance, a permit application may have been submitted for an overload vehicle to travel over a particular bridge or series of bridges along a proposed route. If a bridge has not been analyzed previously for this particular overload, that task must be completed before a answer to the permit application can be returned.

All load ratings should be performed based on the result of a recent inspection of the bridge and where possible the design and/or as-built plans for the structure must be reviewed.

Michigan’s Heavy Trucks.

A key feature of Bridge Load Ratings in Michigan is the inclusion of all Michigan legal loads. Michigan law allows the use of trucks that far exceed the federal limit of 80,000 lb. Maximum total weights are not directly controlled by Michigan law; however, weights are indirectly controlled by a combination of maximum legal vehicle lengths, maximum legal axle loads and axle spacing. The combined effect of those items yields legal trucks that can weigh as much as 164,000 lb. Individual axle loads and tandem axle loads have a variety of legal limits based on spacing, but the overall maximums are limited to the federal limits for axle weights.

While it should be noted that a small percentage of commercial vehicles in Michigan operates at greater than the federal limit of 80,000 lb, the concentration of these heavy vehicles varies widely throughout the state. Some rural locations may rarely see a vehicle greater than 80,000 lb, while other areas, such as near an aggregate pit or manufacturing facility may experience frequent passage of heavy vehicles. As noted above, Operating Ratings are to be performed with the inclusion of all Michigan legal loads.
Purpose of Load Rating

The safe load carrying capacity of a bridge is determined through the load rating process. The bridge owner and, indirectly, the bridge user must be assured that each structure is being used in a safe and sustainable manner. Through load rating, it may be discovered that a bridge is incapable of safely carrying some legal loads. In that circumstance, it is necessary to publicly “post” the bridge for the reduced safe load or, in the extreme case, to close the bridge. In addition, for those occasions when loads beyond the range of standard legal vehicles (or “permit” loads) need to use a specific structure, load rating can provide answers about which loads are safely acceptable.

The requirement to perform load ratings on highway bridges stems from federal law and can be found in the National Bridge Inspection Standards, October 1988, within the Code of Federal Regulations. Specifically, Title 23, Part 650, Subpart C, 650.303 (c) reads:

“Each structure required to be inspected under the Standards shall be rated as to its safe load carrying capacity in accordance with Section 4 of the AASHTO Manual. If it is determined under this rating procedure that the maximum legal load under state law exceeds the load permitted under the Operating Rating, the bridge must be posted in conformity with the AASHTO Manual or in accordance with State law.”

In this context “AASHTO Manual” refers to Reference 1 (see Chapter 11).

Process Outline for Load Rating

The process of preparing a bridge load rating has many components. Perhaps the most significant items include gathering physical data for the specific bridge, selection of the appropriate truck type(s), choosing the correct live load distribution factor and performing the actual analysis.

Information Gathering

Basic information may be available from a variety of sources. Specific details regarding span length, beam spacing, beam size, material properties and other miscellaneous items is ordinarily available in the original design plans and/or as-constructed plans. If these sources are unavailable, an inspection of the bridge by a qualified inspector to measure pertinent details may be sufficient for an approximate rating. If a more exact rating is required, load tests may be necessary to determine the safe load capacity. Historical information regarding material properties is included in Chapter 10.

The existence, extent and thickness of any overlay on a bridge deck is of great significance when performing load rating calculations. Deck overlays are very common, and they can have a profound effect on that capacity of a structure which remains...
available for carrying live load. It is the responsibility of the bridge analyst to be aware of the details of any overlay which may exist on a structure to be load rated.

The condition of all structural components and extent of deterioration must be considered in the calculation of a load rating. This information may be available in a recent thorough field inspection. Inspections are to be performed as described in Section 3 of the AASHTO Manual for Condition Evaluation of Bridges. The effective area of members used in a capacity analysis must be the original gross area minus the area that can no longer carry load due to deterioration or corrosion.

Analysis Truck Selection

As can be seen in Chapter 2, there is a great variety of legal vehicles that use the roads and bridges in Michigan. Michigan law elaborates loads that fall in three categories: “Normal,” “Designated” and “Special Designated.” It is of primary importance to know whether a particular road or road system has been selected as “Designated” and/or “Special Designated.” Bridges within a system that has no designation can be analyzed for “Normal” loads. A more conservative assumption would be to include all Michigan legal load categories in the analysis.

Tables showing maximum moments and shears caused by all three categories of loads are included in Chapter 10. Also, see Chapter 5 for an expanded discussion of vehicle selection.

LL Distribution factor

When using the Load Factor (LF) method, live load distribution factors vary greatly depending on beam spacing, bridge deck type and beam or girder type. Although this Guide focuses primarily on LF, there may be circumstances when the Load and Resistance Factor Design (LRFD) method will prove useful to the analyst. For more information about live load distribution factors, see Chapter 6.

Calculations

The final element in completing an analysis is performing and documenting the analysis calculations. For several examples of actual calculations, see Chapter 9.

Summary of AASHTO Manuals

Manual for Condition Evaluation of Bridges (Ref 1)

This manual is a very useful and thorough resource. The information contained in this MDOT Bridge Analysis Guide is based in large measure on information available in the AASHTO Manual. A summary of the chapters contained in the AASHTO manual is as follows:
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1 - Introduction</td>
<td>This chapter gives a basic introduction into load rating.</td>
</tr>
<tr>
<td>2 - Bridge File</td>
<td>This chapter summarizes the types of records that should be kept for each bridge by the bridge owner.</td>
</tr>
<tr>
<td>3 - Inspection</td>
<td>Types of inspections are listed as well as frequency of, planning of and equipment for inspection operations.</td>
</tr>
<tr>
<td>4 - Material Testing</td>
<td>Testing of material may be necessary to determine material strength. This chapter describes various methods of testing.</td>
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<tr>
<td>5 - Nondestructive Load Testing</td>
<td>This chapter briefly explains that load testing is an option in lieu theoretical analysis calculations.</td>
</tr>
<tr>
<td>6 - Load Rating</td>
<td>The guiding principles of load rating calculations are contained in this chapter of the AASHTO manual.</td>
</tr>
<tr>
<td>7 - Additional Considerations</td>
<td>Other items such as sign posting, vehicle permits and historic bridges are discussed in this section.</td>
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</table>

**Standard Specifications for Highway Bridges, Sixteenth Edition** (Ref 2)

This AASHTO manual has been used to guide the direction of bridge design in the United States for decades. The purpose of the Standard Specifications is to "standardize" the way bridges are designed in the United States. Both Allowable Stress Design and Load Factor Design are covered in the Standard Specifications.

**Load and Resistance Factor Bridge Design Specifications** (Ref 3)

This newer manual was first published in 1994 and may someday supersede the Standard Specifications. The LRFD Specifications have been adopted by some states as the new "standard" for bridge design. Michigan has not yet adopted LRFD methods. However, much useful information is contained in this manual.
Summary of MDOT Manuals

Standard Specifications for Construction (Ref 9)

Past editions of the Michigan Department of Transportation Standard Specifications for Construction may be very helpful. These specifications may provide information useful in determining the original material properties of concrete, structural steel and steel reinforcement.

Bridge Design Manual and Bridge Design Guides (Refs. 11 and 12)

When existing plans of the subject bridge are unavailable, old editions of the MDOT Bridge Design Manual and Bridge Design Guides may provide useful information regarding the design techniques/criteria common to the year of the bridge.

Specifications for Design of Highway Bridges, 1958 Edition (Ref 30)

A complete description of bridge design practice at MDOT in 1958.

Road and Bridge Standard Plans

Similar to the Bridge Design Manual and Bridge Design Guides, older editions of Standard Plans may also provide helpful information. Old bridge railings are shown in detail in previous editions of the Standard Plans.

Structure Inventory and Appraisal Coding Guide (Ref 10)

This Guide is intended to aid local agencies in completing and submitting the Structure Inventory and Appraisal forms for all bridges in their jurisdiction.

Theoretical Analysis Methods for Load Rating

The three primary analysis methods for load rating bridges include: 1) the Allowable Stress (AS) method, 2) the Load Factor (LF) method and 3) the Load and Resistance Factor (LRF) method. All three will be briefly described. This Guide focuses primarily on the Load Factor Method. An additional method for studying live load distribution, finite element analysis, will be discussed in Chapter 6, Live Load Distribution.

It should be noted that Federal Regulations require that LF methods be used for Federal Inventory and Operating ratings. Michigan Operating and Permit ratings may be performed using any of the above methods.
ASD, sometimes referred to as Working Stress Design is oldest of the three methods introduced above. This was the design philosophy used in the earliest Standard Specification for Highway Bridges, issued by AASHO in 1931. In this method, service (or unfactored) loads are applied to the structure and used to determine stresses. The relationship between stress and strain is always taken as linear. The calculated stresses are then compared to an allowable stress. The allowable stresses are determined by applying a factor of safety to the yield stress or ultimate stress of the material. In ASD, live load is treated with the same importance as dead load.

LFD began to be implemented by AASHTO in the early 1970's. In the LFD methodology, various factors are applied to the loads to increase them based on the predictability of each load type. Load factors for live loads are higher than for dead loads because dead loads can be calculated fairly accurate, whereas, live loads are more unpredictable. In addition, reduction factors are applied to the strength of each structural member. These reduction factors lower the strength of the member based on the probabilities of achieving the planned for material properties and dimensional accuracy of the member, among other potential variables. LFD is also based on the knowledge that members continue to gain capacity beyond the linear stress versus strain stage. Member capacities are calculated with the member at full yield strength. LFD is viewed as a more rational and accurate method than ASD. Both ASD and LFD methods are contained in the current AASHTO Standard Specifications for Highway Bridges; however, LFD is more widely used.

LRFD as the most recent method for design and analysis of highway structures, began to be implemented in the 1990's. This method is an extension of the LFD theory. LRFD is more refined in terms of the use of probability and statistical data for both loads and member capacities. New live load configurations were developed and equations were rewritten to include current research. The AASHTO LRFD Bridge Design Specification is anticipated to someday replace the Standard Specifications that contains the ASD and LFD methods.

Material Sampling for Strength Determination In conjunction with theoretical analysis, field samples may be taken and tests conducted to determine the actual “as-built” strength of the structural components. For structural steel strength measurement, MDOT’s practice has been to take three samples from three different beams, usually from the bottom flange near an end support. Tensile testing should be done in accordance with ASTM A-370. Deck concrete may be cored and tested for compressive strength in accordance with ASTM C-39. A minimum of three cores should be tested.

If the results of these tests indicate that greater than anticipated strength is present, that greater strength can be used for analysis and rating of the bridge. However, if lower than anticipated strength is found, that result can not be ignored, and must be used in the rating process.

Actual steel and concrete strength results may be utilized with any approved analytical technique.
Load Testing Method of Load Rating

Load testing of bridges for load rating purposes is also a useful method in certain circumstances. Some bridges can not be satisfactorily analyzed due to a lack of design plans or because of deterioration that is difficult to quantify. In other cases, unusual structure types may not lend themselves to definitive analysis techniques.

A potential advantage of load testing is that some bridges have been shown to have a higher capacity using this method than that derived by normal calculations. An obvious disadvantage is that load testing is generally significantly more expensive than performing normal calculations. However, the cost of load testing may be acceptable to a bridge owner if faced with the possibility of a more expensive bridge replacement or major bridge rehabilitation.

To be useful in establishing (or proving) maximum safe live load capacity, “proof” load testing should be performed. The test load magnitude should be such that it will cause at least the Operating level of live load effects of the live load that would be allowed to use the bridge. For details regarding load testing procedures and methods of determining proof load test values see the Manual for Bridge Rating through Load Testing (Ref 31) Careful planning of loads needed, load application, instrumentation and personnel requirements should be carried out, prior to testing. A condition survey of the structure and an analysis to identify critical components should be completed as part of the planning. The bridge should be closed to traffic during proof load testing.

MDOT has sponsored load testing of various bridges throughout the state and has reports available. If load testing is appropriate for a given bridge, it may be helpful to obtain this information from MDOT. See Chapter 11 for specific references related to MDOT sponsored load testing.

Judgment Load Ratings

Generally, Judgment Ratings are performed with few or no calculations to support such ratings. An example of a judgment rating can be found in the text of Chapter 7 of the AASHTO Manual for Condition Evaluation of Bridges:

“A concrete bridge need not be posted for restricted loading when it has been carrying normal traffic for an appreciable length of time and shows no distress. This general rule may apply to bridges for which details of the reinforcement are not known. However, until such time as the bridge is either strengthened or replaced, it should be inspected at frequent intervals for signs of distress. In lieu of frequent inspections, a bridge may be load tested to determine its capacity.”

In all cases that a Judgment Rating is performed, it should be after a thorough visual observation of the bridge and with a clear knowledge of the traffic loading using the bridge. However, if signs of distress are observed, normal load rating procedures should be considered.
Judgment Ratings should be accompanied by written documentation that supports the conclusions of the Engineer. These documents should include copies of at least the following items: the inspection report, a detailed technical description of member condition (and damage if any exists), a technical description of the traffic that does or may use the bridge, any calculations made to rate the bridge and a listing of assumptions used as a basis for those calculations. Whenever possible, photographs should be included in the Judgment Rating documentation for further support.

Substructure Considerations

Section 6.1.2 of the AASHTO Manual for Condition Evaluation of Bridges gives guidance regarding substructure ratings. In essence, that section allows the engineer to use his/her judgment in the rating of substructures. If the substructure show no signs of instability or deterioration, then the substructures may be considered to be adequate for the existing traffic. However, if the substructure does show signs of deterioration and/or distress, the engineer should perform a conservative judgement rating.

Deck Considerations

In general, stresses in the deck do not control the load rating except in special cases, as noted in Section 6.7.2.1 of the AASHTO Manual for Condition Evaluation of Bridges. This is easier to understand if one compares the maximum axle load of an HS20 design truck, which is 32 kips, to the maximum normal legal axle load of 18 kips. In addition, bending in two directions, or plate action, is a known behavior of deck slabs that may have been excluded in the original design but does have a significant effect on the capacity of the slab.

However, some bridge deck slabs originally designed for H-15 loading may be over stressed by the tandem axles of Michigan Designated or Special Designated legal vehicles. AASHTO section 3.24.3.1 (ref 2) is based on a spread of the effect of individual wheel loads. Based on a study of the AASHTO method, for bridges with normal beam spacing, the moment effect of the wheels of tandem axles spaced at 3'-6" will overlap, and hence are additive.

It is appropriate to examine the Michigan Operating capacity of bridge decks designed for H-15 loading, which are exposed to Designated or Special Designated Michigan legal vehicles. See Chapter 9 for an example of an H-15 slab analysis. In general, examinations for Inventory Rating and for Federal Operating rating need not be conducted.

Simple Spans Versus Continuous Spans

The majority of bridges throughout Michigan is made up of simple spans. Simple spans have supports that allow the beam ends to rotate freely. Continuous spans have beam members extending over several supports. Continuous bridges have become more popular since deck joints can be eliminated thereby reducing future maintenance problems. All other details remaining constant, continuous beams can carry more load than simply supported beams. Simple span bridges are the general focus of this Bridge
Analysis Guide.

Overview of Computer Software

Available Software

Commercial software is available to aid in load rating calculations. Some of these software packages are available from AASHTO and some are available from private companies. Since computers and software change so rapidly, this Bridge Analysis Guide will not supply great detail with regard to software. Perhaps the best advice is to study the specific details prior to purchasing any software to be confident that the product that is chosen is capable of performing the functions that are desired. Most software manufacturers advertise their products in trade magazines. Each software manufacturer specifies the minimum system requirements that your computer must have to properly run their software. Most manufacturers now require Microsoft Windows 95 or higher, a CD-ROM drive, a mouse or other pointing device, a Pentium processor and a specified amount of hard drive space.

Listed below are some software packages that are currently available:

- **Virtis** is available from AASHTO, and was specifically created to aid in the load rating of highway bridges.

- **STAAD** is a program developed by Research Engineers International. STAAD is an acronym for Structural Analysis And Design and is a general analysis program that can be used for design as well as ratings.

- **SAP2000**, developed by Computers & Structures, Inc.; is another general analysis program that can be used for designing or load rating bridges.

- **DESCUS** is a software package that designs, analyzes and rates curved or straight steel bridge girders. Opti-Mate, Inc. is the company that produces DESCUS.

- **BRASS** is an acronym for Bridge Rating and Analysis of Structural Systems and is available from the Wyoming Department of Transportation.

Spreadsheets

With a few basic equations, an engineer can create a spreadsheet to aid in load rating calculations. Spreadsheets offer an inexpensive method to make use of the computer. An advantage that a spreadsheet has over using commercially available software is that it can be specifically tailored to individual needs and that the formulas, or code, can be easily checked, verified and modified. Spreadsheet concepts and operating details should always be verified by someone other than the originator.
Overview of Hand Calculation Methods

Superposition

The principle of superposition is often used in mechanics of materials and structural analysis. For example, in strength-of-materials studies, the total stress at a point in a material resulting from various applied forces can be obtained by summing the stresses due to each force considered individually. In determining the reactions of a simple beam subjected to a number of loads, the total reaction can be obtained by summing the reactions due to each load considered individually. The principle of superposition can be stated as follows:

**Principle of Superposition**: The total effect at some point in a structure due to a number of loads applied simultaneously is equal to the sum of the effects for the loads applied individually.

For the principle of superposition to be valid there must be a linear relationship among forces, stresses and deflections. There are two conditions for which superposition is not valid:

1. When the structural material does not behave according to Hooke’s law; that is, when the stress is not proportional to the strain.
2. When the deflections of the structure are so large that computations cannot be based on the original geometry of the structure (Ref 15).

Unless otherwise stated, the principle of superposition is assumed to be valid in this Bridge Analysis Guide.

Beam Diagrams and Formulas

Many publications contain common beam loadings that can be used to analyze a variety of bridge superstructure loading scenarios. An example of two of the most common beam diagrams taken from the American Institute for Steel Construction (Ref 5) are shown below in Figure 4.1.

With the principle of superposition in mind, these beam diagrams can be added together in a variety of ways to reproduce dead and live loads for simple spans. An example of superposition can be shown in Figure 4.2.
FIGURE 4.1
Common Beam Diagrams
FIGURE 4.2
Example of Superposition

Example: $9020\text{kft} = 8000\text{kft} + 60\text{kft} + 464\text{kft} + 496\text{kft}$
Various beam diagrams also exist for fixed end moments and continuous spans. Using the same methodology as depicted in Figure 4.2 with superposition in mind, beam diagrams can also be used for continuous superstructures. For continuous spans, the engineer should be aware of the degree of fixity at each support and whether a beam diagram is appropriate. If it is determined that the degree of fixity at each support is such that it cannot be modeled using the standard beam formulas, then a more detailed analysis is needed. The Moment Distribution Method and differential equations are among other hand calculation methods available to the engineer, all of which are beyond the scope of this manual.

**Influence Lines**

Influence lines are another method used to calculate bending moments and shears. Influence lines can be defined as a function whose value at a point represents the value of some structural quantity due to a unit force placed at the point (Ref 15). Consider a three span continuous model. An influence line for determining the negative moment at the left interior support would appear similar to that shown below in Figure 4.3.

![Example of Influence Line](image)

Influence lines require careful forethought in order to understand which points are of significance and how to have the greatest effect on those points. One useful design aid is a publication called *Moments, Shears and Reactions for Continuous Highway Bridges*. This publication is produced by the American Institute of Steel Construction (AISC) and is quite useful for continuous structures. This publication gives influence coefficients that are derived from influence lines. Again, superposition can be used with influence lines. Though this publication was originally published in 1959, it is still available for purchase and can be obtained by contacting AISC or going to the website www.aisc.org.
Critical Locations on Beams

For simple spans, worst case moments will occur at or near midspan and worst case shears will occur at the supports. Evaluations of capacity versus applied midspan moments and end shears are the most important examinations for load rating of simply supported bridges. However, for bridges with continuous spans or with pin and hangers, critical sections are not as obvious and require careful analysis.

On simply supported structures two other circumstances may require an investigation of capacity at a location other than the two most important locations noted in the above paragraph. If a structural section change, such as a cover plate end or flange transition, occurs on a beam or girder, it may be necessary to examine the capacity of the reduced section versus the applied moment at that change location. Also, if significant deterioration has occurred at a location other than at midspan (for moment) or beam end (for shear) it may be necessary to evaluate the capacity of the member at that compromised location. Maximum moment and/or shear at these locations or any other location on a simple beam can be calculated using the AISC diagrams mentioned above. In addition, many currently available computer programs will generate the required information for any location on a beam.

Since the advent of high speed computers, the process of evaluating all appropriate live load configurations and placements has become much simpler. To determine the maximum bending moments and shears, each applicable vehicle must be “rolled” across the bridge. During this process, maximum values for bending moment and shear are recorded along a given span for each vehicle and for each placement. These tabulations of moments and shears for each vehicle are called “envelopes.” An example of moment and shear envelopes is shown in Figure 4.4. Once created, the envelopes for each vehicle can be compared to determine which vehicle produces the most severe loading effects for each span length. These maximums can be compiled into a chart for all applicable span lengths. A complete set of maximum charts is contained in Chapter 10 of this Guide.

Documentation of Load Rating

Reasons for Documentation

Documentation is important in load rating just as it is in most engineering calculations. Calculations create a written record of the basis for the load rating of a given bridge. It is recommended that a copy of all load rating calculations, along with any structure inspection information that formed a basis for the rating, should be maintained in a file for each bridge. This allows individuals in the future to refer to a previous load rating and see the assumptions that were used in that work. This information may also be helpful for future ratings.
FIGURE 4.4
Example of Moment and Shear Envelopes
Documenting Hand Calculations

Hand calculations should be performed by a competent engineer familiar with bridge design. It is important that hand calculations be neat and orderly and accompanied by references to books, manuals, inspection information, test data or anything that was used to aid in the calculations. Assumptions should be noted to provide clarity. Hand calculations should be checked and ultimately sealed by a Professional Engineer licensed in the state of Michigan. A sample hand calculation is shown in Figure 4.5. When reviewing Figure 4.5, please note that the right edge of the paper is reserved for references to manuals and codes. Also note how results are clearly identified, equations are fully written out and units of measure are clearly labeled.

A summary of results should be prepared at the conclusion of all rating calculations. The summary should contain at a minimum: the inventory and operating capacities of the structure, the controlling member, and a description of any posting that may be required.

Documenting Software

Software can be used to significantly aid in the load rating of bridges. Software is especially useful for continuous or complex bridges. It should be noted that the engineer should be familiar with the capabilities and limitations of the software. When documenting software, the following information should be identified as a minimum: Name of software, version, manufacturer’s name and address.

A printout of the final input and output should be included in the file. Important results should be highlighted on the output for easy review. A diskette with the electronic input and output files should be included in the files. Significant limitations that affect the results should be documented.

It is important that the input and output be checked to verify that the software is running correctly. The input should be checked to verify that all parameters are entered correctly. The output should be checked for “reasonableness.” The reasonableness check requires a certain level of experience. Also, rough hand calculations can be performed to approximate output values. Software should not be used blindly.

Documenting Assumptions

Any assumptions that are made during load rating should be clearly identified as being such. When possible, assumptions should be accompanied by a brief statement that substantiates the assumption.
FIGURE 4.5
Hand Calculation Example
LOAD FACTOR RATING AND LOAD AND RESISTANCE FACTOR RATING

Load Rating Methods

There are three methods for performing load ratings. These methods are Allowable Stress Rating (ASR), Load Factor Rating (LFR) and Load and Resistance Factor Rating (LRFR). ASR is considered to be an obsolete code. While certain existing ratings are acceptable to remain in ASR, this method is only used for new Federal Ratings of policy exceptions such as timber and masonry bridges. LFR is being phased out as the preferred Federal Rating method. LRFR is the preferred Federal Rating method, and will be required on all bridges designed by Load and Resistance Factor Design (LRFD) after October 1st, 2010. Please refer to the Federal Highway Administration (FHWA) Bridge Technology website for further details on this policy (http://www.fhwa.dot.gov/bridge/nbis/103006.cfm). NBI Item 70, Bridge Posting, and the Michigan Operating Rating may be computed by LRFR, LFR or ASR. It is preferred that LFR is used for structures designed by Allowable Stress Design (ASD) or Load Factor Design (LFD) and LRFR is used for structures designed by LRFD. ASR may be used for timber and masonry.

Design Live Loads

Design live loads are used during the design of a new bridge, and reconstruction or rehabilitation designs. Design live loads are not legal loads. Generally speaking, design axle loads are more severe than legal axle loads and help to provide reasonable factors of safety for slab designs.

The American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges specifies the HS-20 Live Load as the design live load for bridges designed under Allowable Stress Design (ASD) and Load Factor Design (LFD). Please refer to these specifications for details of this design load. HS-20 is used in Load Rating when calculating the Federal Inventory and Operating Rating for bridges analyzed by Allowable Stress Rating (ASR) or Load Factor Rating (LFR). In 1978, the HS-20 load in Michigan was increased by 25% and named HS-25. HS-25 was used for certain routes in Michigan to account for the stress caused by the heaviest legal loads. HS-25 is a design loading only, and is not used in Load Rating.

The HL-93 Live Load is the design live load for bridges designed under Load and Resistance Factor Design (LRFD). Please refer to the latest edition of the AASHTO LRFD Bridge Design Specifications for details of this design load. HL-93 is used in Load Rating when calculating the Federal Inventory and Operating Rating for bridges analyzed by Load and Resistance Factor Rating (LRFR). In 2008, the HL-93 loading configuration was modified slightly, increased by 20% and renamed HL-93-mod. HL-93-mod is used for certain routes in Michigan to account for the stress caused by the heaviest legal and permit loads. HL-93-mod is a design loading only, and is not used in Load Rating.
State Regulations on Legal Loads

The extension of grandfather rights has allowed the states to continue operation of vehicles on state and interstate highways in excess of the limits mandated by federal regulations. These rights allowed individual states continued control of size and weight limits. As a result, each state has a different weight limit “package” consisting of different mixes of these combinations.

Michigan Regulations on Legal Loads

The three levels of Michigan Legal loads are called Normal, Designated and Special Designated, and are described in detail in Chapter 2 of the BAG. It is the responsibility of the engineer to determine whether Normal, Designated or Special Designated loadings are appropriate for the specific agency/roadway under consideration. As a majority of roadways in Michigan are Designated, only that loading is listed in this interim update in order to simplify the information contained and to avoid confusion. Designated loading is not the most conservative loading and the assumption to use Designated loading should not be made on the presence of the loading in the Condensed Guide.

Figure 2.1 in the Bridge Analysis Guide illustrates common legal vehicles used on Michigan roads (truck numbers 1-28). All of the legal vehicles are used to determine the Michigan Operating Rating and Load Posting Values.

Legal Loads in Other States and Provinces

The engineer should take into account the legal loads in neighboring states and provinces for border bridges. Chapter 3 of the BAG includes information of bordering states and a brief summary of the influence of North America Free Trade Agreement (NAFTA) requirements on bridges.

Load Factor Rating (LFR)

There are four categories of bridge rating for Load Factor Rating (LFR). These four categories use three different groups of live loads.

Federal Inventory Rating

1. HS20 truck or lane load
2. In general, the truck load controls for shorter span lengths and lane load controls for longer lengths
3. For continuous structures, lane loadings may be continuous or discontinuous
4. As many lanes may be loaded as is required to produce the maximum desired effect
5. This rating is performed at the Inventory level
Federal Operating Rating
1. HS20 truck or lane load
2. In general, the truck load controls for shorter span lengths and lane load controls for longer lengths
3. For continuous structures, lane loadings may be continuous or discontinuous
4. As many lanes may be loaded as is required to produce the maximum desired effect
5. This rating is performed at the Operating level

Michigan Operating Rating (Legal or Posting Load Rating)
1. The controlling legal vehicle of the 28 different legal loads. Different vehicles may control different load effects (such as shear or moment). The truck that is recorded should be the truck that produces the lowest load factor for all limit states.
2. As many lanes may be loaded as is required to produce the maximum desired effect
3. Only one standard truck per lane is allowed on a span for spans <200-ft
4. A train of trucks must be applied for spans >200-ft (Chapter 5 of the BAG). A research project is currently in progress to find the appropriate loading configurations for spans between 200-ft and 400-ft and to develop site-specific analysis criteria for spans greater than 400-ft (10-3-2008).
5. The analyst must determine if Normal, Designated, or Special Designated loading applies
6. See Chapter 2 of the BAG for illustrations of the Legal Load vehicle configurations
7. See Chapter 10 of the BAG for tables for all maximum moments and shears for the Legal Load configurations, for simple span lengths between 5-ft and 300-ft
8. If any of the rating factors are below 1, then the lowest tonnage of all vehicles below 1 is the load limit for that Truck Type (1, 2 or 3 Unit)
9. If all vehicles in a particular category (1-unit, 2-unit, 3-unit) can be safely carried by a bridge, the Posting Load will be the largest legal load in that category
10. This rating is performed at the Operating Level

Permit Load Rating (see Chapter 8)
1. This capacity rating is used when a request has been made to transport a load that is not included in the Michigan legal loads
2. The exact load shall be analyzed and that one vehicle placed so as to produce the maximum effect
3. See Chapter 8 of the BAG for a chart illustrating the more common permit type vehicle configurations
4. See Chapter 10 of the BAG for tables for all maximum moments and shears for the more common permit type vehicle configurations, for simple span lengths between 5-ft and 300-ft
5. This rating is performed considering loading of only one lane for Load Factor and Allowable Stress Ratings
6. This rating is performed at the Operating Level
Load and Resistance Factor Rating (LRFR)

Similar to LFR, there are four categories of bridge rating for Load and Resistance Factor Rating (LRFR). These four categories use three different groups of live loads.

Federal Inventory Rating (also called Design Load Rating at Inventory Level)
1. HL-93 loading
2. This load rating is sometimes referred to as a “screening” level for other states, however, some Michigan Legal Loads exceed this design loading and therefore the Legal Load Rating should always be calculated.
3. As many lanes may be loaded as is required to produce the maximum desired effect
4. This rating is performed at the Inventory level

Federal Operating Rating (also called Design Load Rating at Operating Level)
1. HL-93 loading
2. As many lanes may be loaded as is required to produce the maximum desired effect
3. This rating is performed at the Operating level

Michigan Operating Rating (Legal or Posting Load Rating)
1. The controlling legal vehicle of the 28 different legal loads. Different vehicles may control different load effects (such as shear or moment). The truck that is recorded should be the truck that produces the lowest load factor for all limit states.
2. The Live Load Factor, $\gamma_L$, to be used for the Strength I and II Limit States varies based on the Average Daily Truck Traffic (ADTT) of the structure and the weight of the truck being analyzed. See MDOT Research Report R-1511 for more information on the variable load factor. Tables 4a-1 through 4a-3 summarize the Live Load Factors for the Strength I and II Limit States. The Load Factor may be interpolated for a specific ADTT.
3. The Live Load Factor to be used for the Service II Limit State varies based on the weight of the truck being analyzed. Trucks with a Gross Vehicle Weight (GVW) less than 100-kip use a Load Factor of 1.3. Trucks with a GVW greater than or equal to 100-kip use a Load Factor of 1.0 for Service II.
4. As many lanes may be loaded as is required to produce the maximum desired effect.
5. The loading configuration of Legal Loads varies for moments and shear at interior supports as well as for span lengths greater than 200-ft. Table 4a-7 summarizes the loading configurations required to analyze Legal Loads. Spans greater than 400-ft require site-specific analysis. A research project is currently in progress to find the appropriate loading configurations for spans between 200-ft and 400-ft and to develop site-specific analysis criteria for spans greater than 400-ft (10-3-2008).
6. The analyst must determine if Normal, Designated, or Special Designated loading applies.
7. If posting is required, the lightest Posting Loads for each category (1 unit, 2
unit, and 3 unit) must be calculated
8. If all vehicles in a particular category (1-unit, 2-unit, 3-unit) can be safely carried by a bridge, the Posting Load will be the largest legal load in that category

Permit Load Rating
1. This capacity rating is used when a request has been made to transport a load that is not included in the Michigan legal loads
2. There are two levels of Permits identified in LRFR. See Table 6A.4.5.4.2a-1 of the AASHTO Manual for Bridge Evaluation\(^6\) (MBE) for more information. Routine Permits are annual or unlimited permits that are allowed to mix with traffic. Special or Limited Crossings are limited to less than 100 crossings and may or may not be escorted to prevent other vehicles on the structure.
3. Routine Permits should use Strength Limit State Live Load factors, \(\gamma_L\), as identified in MDOT Research Report R-1511 and as given in Tables 4a-4 through 4a-6, based upon ADTT and GVW. The load factor may be interpolated for a specific ADTT. These permits are based on as many lanes loaded as would produce the maximum effect.
4. Special or Limited Crossing Permits may use the Strength Limit State Live Load factors given in Table 6A.4.5.4.2a-1 of the MBE. These permits are based on single lane loading.
5. The Live Load Factor to be used for the Service II Limit State varies based on the weight of the truck being analyzed. Trucks with a Gross Vehicle Weight (GVW) less than 100-kip use a Load Factor of 1.3. Trucks with a GVW greater than or equal to 100-kip use a Load Factor of 1.0 for Service II Limit State.
6. See Chapter 8 of the BAG for a chart illustrating the more common permit type vehicle configurations
7. See Chapter 10 of the BAG for tables for all maximum moments and shears for the more common permit type vehicle configurations, for simple span lengths between 5-ft and 300-ft
8. The loading configuration of Legal Loads varies for moments and shear at interior supports as well as for span lengths greater than 200-ft. Table A-9 summarizes the loading configurations required to analyze Permit Loads. Spans greater than 400-ft require site-specific analysis. A research project is currently in progress to find the appropriate loading configurations for spans between 200-ft and 400-ft and to develop site-specific analysis criteria for spans greater than 400-ft (10-3-2008).
References & Resources

Bridge Conference & Workshop Materials (Handouts & Presentations):


MDOT Advisories:

http://www.michigan.gov/mdot/0,1607,7-151-9625_24768_49104---,00.html


The following are available for purchase at:


https://bookstore.transportation.org/Item_details.aspx?id=51

