Load Rating Steel Beam Bridges

Tim Keller, PE

Session: 4-A
Agenda – Day 1

8:00 am – 8:15 am  Introductions and House Keeping
8:15 am – 8:45 am  Session 1: Load Rating Basics
8:45 am – 9:30 am  Session 2: Basic Load Rating Calculations
9:30 am – 9:45 am  Break
9:45 am – 11:45 am Session 3: Example – Load Rating Concrete Slab Bridge
11:45 am – 12:00 pm Questions
12:00 pm – 1:00 pm  Lunch
1:00 pm – 2:30 pm  Session 4: Example – Load Rating Steel Beam Bridges
2:30 pm – 2:45 pm  Break
2:45 pm – 3:45 pm  Session 4: Example – Load Rating Steel Beam Bridges (Con’t)
3:45 pm – 4:00 pm  Questions
Example – Simple Span Non-Composite Steel Beam Bridge

Steps to Follow to Load Rate Bridge

1. Get Geometry of Bridge
2. Calculate Capacity of Beams
3. Calculate Dead Loads
4. Calculate Live Loads
5. Calculate Rating Factors
Example – Simple Span Non-Composite Steel Beam Bridge

Step 1

Determine Bridge Geometry
Bridge Geometry

Need the following information:

1. Deck Cross Section
   a. Deck thickness and build up
   b. Type of guardrail / barrier
   c. F/F guardrail / barrier dimension
   d. Beam size and spacing
   e. Cross frame size and spacing

2. Span length
Given: Beam Size: W30 x 132 spaced at 8'-0" c/c
Cross Frames: L3 x 3 x 9/16 spaced at 15'-0" c/c
Railing: Twin Steel Tube (TST)
Span: 50'-0" c/c Brgs.

Transverse Section
Example – Simple Span Non-Composite Steel Beam Bridge

Step 2

Calculate Capacity of Beam
Determine Capacity of Beam

Calculating the Capacity (C) for Simple Span Non-Composite Steel Beam

Need the following Steel Beam information:
1. Yield Stress of Steel $F_y$
2. Section properties of the beam
The following equations are for calculating the bending moment capacity of a single-span steel beam or girder with a non-composite concrete deck

AASHTO Standard Specifications
For Highway Bridges
17th Edition
Compact or Noncompact Section?

What is a “compact” section?

A compact section in positive flexure satisfies specific steel grade, web slenderness and ductility requirements and is capable of developing a *capacity exceeding the moment at first yield*, but not to exceed the plastic moment.
Compact section in more basic terms:

• Compact sections are permitted to achieve higher stresses because they have:
  – Compression flanges that satisfy specified width-thickness ratio limits.
  – Webs that satisfy specified depth-thickness ratio limits.

• Compact sections have a high resistance to local buckling.

• Note that the following compactness equations are dependent upon both the dimensions of the section and the steel yield strength.
Compact sections must satisfy Article 10.48.1.1

Compression flange width-thickness ratio

\[
\frac{b}{t} \leq \frac{4,110}{\sqrt{F_y}} \quad (10-93)
\]

\( b = \text{flange width (in.)} \)
\( t = \text{flange thickness (in.)} \)
\( F_y = \text{specified yield point of the steel (psi)} \)
Compact sections must satisfy Article 10.48.1.1

Web depth-thickness ratio

\[
\frac{D}{t_w} \leq \frac{19,230}{\sqrt{F_y}} \quad (10-94)
\]

\( D = \) clear distance between the flanges (in.)
\( t_w = \) web thickness (in.)
Sections meeting Article 10.48.1.1 qualify as **compact** and the bending capacity is computed as

\[ M_u = F_y Z \quad (10-92) \]

\[ Z = \text{plastic section modulus (in}^3\text{)} \]

AISC Manual of Steel Construction has Z listed for W and S shaped beams.

AASHTO 17\textsuperscript{th} Edition, Appendix D, shows the method of computing Z
Calculating the plastic section modulus (Z)

The plastic section modulus is the statical first moment of one half-area of the cross section about an axis through the centroid of the other half-area.

Total area = $A = A_T + A_B$
$A_T$ (shaded) = $A_B$ (clear) = $A / 2$
$\bullet$ = centroid of $A_T$ or $A_B$
$a$ = distance between centroid of $A_T$ and $A_B$
$Z = aA_T = aA_B$

Values of $Z$ for rolled sections are listed in the AISC Manual of Steel Construction.
Example calculation

Assume built in 1920

\[ F_y = 30,000 \text{ psi} \]

Section Number
B12
12x6 ½
25 lb/ft
Check for compact section:

\[
\frac{b}{t} = \frac{6.495''}{0.342''} = 18.99
\]

\[
\frac{4,110}{\sqrt{F_y}} = \frac{4,110}{\sqrt{30,000}} = 23.73
\]

18.99 < 23.73

Compression flange meets Equation (10 - 93)

\[
D = 11.87 - 2 \times 0.485 = 10.90
\]

\[
\frac{D}{t_w} = \frac{10.90''}{0.240''} = 45.42
\]

\[
\frac{19,230}{\sqrt{30,000}} = 111.02
\]

45.42 < 111.02

Web meets Equation (10 - 94)

Section qualifies as compact
Calculate $Z$

$$\sum A = 3.689 \quad \sum \bar{y} = 17.232$$

$$\bar{y} = \frac{\sum A \bar{y}}{\sum A} = \frac{17.232 \text{ in}^3}{3.689 \text{ in}^2} = 4.671$$

Distance between centroids of half areas = $a = 2(4.671") = 9.342"$

Plastic section modulus = $Z = (3.689 \text{ in}^2)(9.342"') = 34.46 \text{ in}^3$

* = Ignore
Calculate capacity:

\[
M_u = F_y Z = (30,000 \text{ psi})(34.46 \text{ in}^3) = 1,033,800 \text{ lb-in} = 86.15 \text{ k-ft}
\]

\[
M_u = \text{Capacity of Beam (C)} = 86.15 \text{ ft. k.}
\]
Sections not meeting Article 10.48.1.1 are noncompact and the bending capacity is computed as

\[ M_u = F_y S_{xt} \quad (10-98) \]

\( S_{xt} \) = section modulus with respect to tension flange (in\(^3\))

For a single-span, non-composite steel beam or girder, \( S_{xt} = S \)

- Values of \( S \) for rolled sections are listed in the AISC Manual of Steel Construction and for older beams in Appendix B.

- The compression flange of a single-span beam or girder is considered fully braced by the concrete slab, with or without shear studs, provided that the deck is in contact with the beam or girder.
$M_u$ as computed using equations (10-92) or (10-98), whichever applies, is the capacity ($C$) in the equation

\[
RF = \frac{M_u}{C-A_1D} \div \frac{A_2L(1+I)}{}
\]
Sample Calculation for Capacity of Beam

Beam = W30 x 132

Bridge Built in 1975 and has an $F_y = 36,000$ psi

From AISC Manual for W30 x 132:

- $b_f = 10.545$ in.
- $t_f = 1.0$ in.
- $D = 28.31$ in. (30.31 - 2(1.0) = 28.31)
- $t_w = 0.615$ in.
- $Z = 437$ in $^3$ (Plastic Section Modulus)
- $S = 380$ in $^3$ (Elastic Section Modulus)

FYI: $437 / 380 = 1.15$
Sample Calculation for Capacity of Beam

Check for Compact Section:

1. \( \frac{b_f}{t_f} < \frac{4110}{F_y}^{\frac{1}{2}} \)
   \[
   \frac{10.545}{1.0} < \frac{4110}{36,000}^{\frac{1}{2}}
   \]
   \[10.545 < 21.66 \text{ Satisfies}\]

2. \( \frac{D}{t_w} < \frac{19230}{F_y}^{\frac{1}{2}} \)
   \[
   \frac{28.31}{0.615} < \frac{19230}{36000}^{\frac{1}{2}}
   \]
   \[46.03 < 101.35 \text{ Satisfies}\]

Beam is Compact therefore:

\[
\Mu = F_y \times Z
\]
\[
\Mu = 36 \text{ ksi} \times 437 \text{ in}^3 \times 1/12 = 1311 \text{ ft. k}
\]

Beam Capacity (C) = 1311 ft. k
Example – Simple Span Non-Composite Steel Beam Bridge

Step 3

Calculate Dead Loads
Given: Beam Size: W30 x 132 spaced at 8'-0" c/c
Cross Frames: L3 x 3 x 9/16 spaced at 15'-0" c/c
Railings: Twin Steel Tube
Span: 50'-0" c/c Brgs.

Transverse Section

4F1 Track (See Figure 909 of the Ohio Bridge Design Manual)
Calculate Dead Load (DL)

Slab:
\[ \frac{8.5''}{12''/\text{ff}} \times (8.0') \times (0.150 \text{ kcf}) = 0.85 \text{ klf} \]

Haunch:

**W30 x 132**

Flange Thickness: \( t_f = 1'' \)

Cross Frames: \( L3 \times 3 \times 5/16'' \) spaced at 15'-0" c/c

**W30 x 132**: \( d = 30'' \), \( t_f = 1'' \)

\[ h = 30'' - 2(1'') - 2(2'') - 2\left(\frac{3''}{2}\right) - 21'' = 1.75'' \]

Total Length of \( L \)'s Per Bay = \[ 2 \left( \sqrt{(8.0')^2 + (1.75')^2} \right) + 8.0' = 24.4' \]
Weight of Cross Frames:
\[ \frac{\text{weight of } 1.3 \times 3 \times 5/8}{24.4 \text{ ft} \times (6.10 \text{ lb/ft})} = 0.01 \text{ k/lft} \]
\( \text{cross frame spacing} \)

TS7 Rating:
\[ \frac{0.08 \text{ k/lft}}{\text{left & right \ (2 sides)}} = 0.04 \text{ k/lft} \]
\( \# \text{ of beam lines} \)

Total = 0.95 k/lft

W/L (int.) = 0.95 k/lft + Beam Weight = 0.95 k/lft + 0.132 k/lft = 1.08 k/lft

Calculate Dead Load (DL) - Exterior Beam

Slab: \[ \frac{8.5'}{12'} \times 0.150 \text{ kcf} \]

Haunch:
\[
\begin{align*}
\text{W30 x 132:}  \\
bf = 10.5'  \\
tf = 1''
\end{align*}
\]

Area 1:
\[ \frac{1}{2} \left( 9'' \times (2'' + tf) \right) = 13.5 \text{ in}^2 \]

Area 2:
\[ (2'')(bf) = 21.0 \text{ in}^2 \]

Area 3:
\[ (2'' + tf) \left[ 24'' - \frac{bf}{2} \right] = 56.25 \text{ in}^2 \]
Area \(4\) : \((24'')(18'' - 8.5'' - 2'' - tf)\) = 156.0 \(\text{in}^2\)

\[
\text{Total} = 246.75 \text{ in}^2
\]

\[
\frac{246.75 \text{ in}^2}{144 \text{ in}^2/\text{ft}^2} = 0.170 \text{ kcf}
\]

Cross-frames: \(\frac{1}{2}\) (interior beam) = 0.005 klf

TSS Railing: = 0.04 klf

\[
\text{Total} = 0.95 \text{ klf}
\]

WDL (ext.) = 0.95 klf + Beam Weight = 0.95 klf + 0.132 klf = 1.08 klf

\[
M_{DL} (\text{int.)} = M_{DL} (\text{ext.)} = \frac{(1.08 \text{ klf})(50')^2}{8} = 337.5 \text{ k-ft}
\]
Example – Simple Span Non-Composite Steel Beam Bridge

Step 4

Calculate Live Loads
Given: Beam Size: W30 x 132 spaced at 8'-0" c/c
Cross Frames: L3 x 3 x 7/16 spaced at 15'-0" c/c
Railing: Twin Steel Tube (TST)
Span: 50'-0" c/c Brgs.

Transverse Section
Calculate Live Load Moments

Axle Live Load (LL) Moments: (see Appendix C)

L = 50 ft.

HS 20 LL Moment = 18L – 280 + 392/L = 627.9 ft. k
2F1 LL Moment = 7.5L + 83.33/L – 49.95 = 326.7 ft. k
3F1 LL Moment = 11.5L + 14.696/L – 94 = 481.3 ft. k
4F1 LL Moment = 13.5L + 130.67/L -140 = 537.6 ft. k
5C1 LL Moment = 11.5L + 31.391/L -106 = 469.6 ft. k
Calculate Live Loads

Calculate Impact factor
L = 50 ft.

\[ I = \frac{50}{L + 125} \]
\[ I = \frac{50}{50 + 125} = 0.29 < 0.30 \]
\[ I = 29\% \]
Calculate Live Loads

Calculate Live Load Distribution Factor (LLDF)

LLDF \underline{Interior} Beam:
Number of Lanes on Bridge = 28’ / 12’ = 2.3 = 2 lanes
Concrete deck
Beam Spacing = 8.0 ft.
Therefore from AASHTO Standard Specification for Highway Bridges Table 3.23.1:

\[\text{LLDF} = \frac{S}{5.5} = \frac{8.0}{5.5} = 1.45 \text{ wheels}\]
Calculate Live Loads

Calculate Live Load Distribution Factor (LLDF)

**LLDF Exterior Beam:**

\[ EM_b = \frac{2}{3} P + \frac{6}{3} P = 1.25P \]

**LLDF Exterior Beam** = 1.25 \text{ wheel}
Calculate Live Loads

Calculate Live Load Distribution Factor (LLDF)

**LLDF Exterior Beam:**

Check LLDF Min.

\[
\text{LLDF Min.} = \frac{S}{(4 + (0.25 \times S))}
\]

\[
\text{LLDF Min.} = \frac{8}{(4 + (0.25 \times 8))} = 1.33 \text{ (controls)}
\]
Calculate Live Load Moments

\[ M_{LL+I} = M_{LL} \times \frac{1}{2} \times (1+I) \times LLDF \]

\(\frac{1}{2}\) factor gets moments in terms of wheels

Calculate \(M_{LL+I}\) for **Interior** Beams:

- HS 20 \(M_{LL+I}\): \(627.9 \times \frac{1}{2} \times 1.29 \times 1.45 = 587.2\) ft. k.
- 2F1 \(M_{LL+I}\): \(326.7 \times \frac{1}{2} \times 1.29 \times 1.45 = 305.5\) ft. k.
- 3F1 \(M_{LL+I}\): \(481.3 \times \frac{1}{2} \times 1.29 \times 1.45 = 450.1\) ft. k.
- 4F1 \(M_{LL+I}\): \(537.6 \times \frac{1}{2} \times 1.29 \times 1.45 = 502.8\) ft. k.
- 5C1 \(M_{LL+I}\): \(469.6 \times \frac{1}{2} \times 1.29 \times 1.45 = 439.2\) ft. k.
Calculate Live Load Moments

\[ M_{\text{LL+I}} = M_{\text{LL}} \times \frac{1}{2} \times (1+I) \times \text{LLDF} \]

\(\frac{1}{2}\) factor gets moments in terms of wheels

Calculate \( M_{\text{LL+I}} \) for **Exterior** Beams:

- **HS 20** \( M_{\text{LL+I}} \): \(627.9 \times \frac{1}{2} \times 1.29 \times 1.33 = 538.6 \text{ ft. k.}\)
- **2F1** \( M_{\text{LL+I}} \): \(326.7 \times \frac{1}{2} \times 1.29 \times 1.33 = 280.3 \text{ ft. k.}\)
- **3F1** \( M_{\text{LL+I}} \): \(481.3 \times \frac{1}{2} \times 1.29 \times 1.33 = 412.9 \text{ ft. k.}\)
- **4F1** \( M_{\text{LL+I}} \): \(537.6 \times \frac{1}{2} \times 1.29 \times 1.33 = 461.2 \text{ ft. k.}\)
- **5C1** \( M_{\text{LL+I}} \): \(469.6 \times \frac{1}{2} \times 1.29 \times 1.33 = 402.8 \text{ ft. k.}\)
Example – Simple Span Non-Composite Steel Beam Bridge

Step 5

Calculate Rating Factors
Calculate Rating Factors

RF = \frac{\text{Capacity} - A_1 \cdot \text{(DL)}}{A_2 \cdot (\text{LL} + I)}

<table>
<thead>
<tr>
<th>Rating Type</th>
<th>A_1 = \text{Factor for dead loads}</th>
<th>A_2 = \text{Factor for live load}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory</td>
<td>1.3</td>
<td>2.17</td>
</tr>
<tr>
<td>Operating</td>
<td>1.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Calculate Rating Factors

Capacity = 1311 ft. k (W30 x 132)

Dead Load Moment

Interior Beam = 337.5 ft. k.
Exterior Beam = 337.5 ft. k (not normally same)

$M_{LL+I}$:

**Interior Beam**

<table>
<thead>
<tr>
<th>Load Level</th>
<th>$M_{LL+I}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS 20</td>
<td>587.2 ft. k.</td>
</tr>
<tr>
<td>2F1</td>
<td>305.5 ft. k.</td>
</tr>
<tr>
<td>3F1</td>
<td>450.1 ft. k.</td>
</tr>
<tr>
<td>4F1</td>
<td>502.8 ft. k.</td>
</tr>
<tr>
<td>5C1</td>
<td>439.2 ft. k.</td>
</tr>
</tbody>
</table>

**Exterior Beam**

<table>
<thead>
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<th>Load Level</th>
<th>$M_{LL+I}$</th>
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</table>

Revised by AW 3/18/2010
Calculate Rating Factors

\[
RF = \frac{\text{Capacity} - A_1 \times (DL)}{A_2 \times (LL + I)}
\]

Inventory Rating for Interior Beam – HS Rating

\[
RF = \frac{1311 - 1.3 \times (337.5)}{2.17 \times (587.2)} = 0.685
\]

HS Load Rating = 0.685 x 20 = HS13.7 (Inventory)
Rating in tons = 0.685 x 36 tons = 24.7 tons (Inventory)
Calculate Rating Factors

\[
RF = \frac{\text{Capacity} - A_1 \cdot (DL)}{A_2 \cdot (LL + I)}
\]

Operating Rating for Interior Beam – HS Rating

\[
RF = \frac{1311 - 1.3 \cdot (337.5)}{1.3 \cdot (587.2)} = 1.143
\]

HS Load Rating = 1.143 \times 20 = HS22.8 (Operating)
Rating in tons = 1.143 \times 36 \text{ tons} = 41.1 \text{ tons (Operating)}
Calculate Rating Factors

\[ RF = \frac{\text{Capacity} - A_1 (DL)}{A_2 (LL + I)} \]

Operating Rating for Interior Beam – Ohio Legal

4F1 Truck: (largest \(M_{LL+I}\))

\[ RF = \frac{1311 - 1.3 (337.5)}{1.3 (502.8)} = 1.334 \]

Percent Legal Load = 1.334 x 100 = 133% say 135%
Rating in tons = 1.334 x 27 tons = 36.0 tons
Calculate Rating Factors

\[ RF = \frac{\text{Capacity} - A_1 (DL)}{A_2 (LL + I)} \]

Operating Rating for Interior Beam – Ohio Legal

2F1 Truck: RF = 2.196  Load Rating = 32.9 tons
3F1 Truck: RF = 1.491  Load Rating = 34.3 tons
5C1 Truck: RF = 1.528  Load Rating = 61.1 tons
Calculate Rating Factors

Prepare a Summary Report:

Figure 908 in BDM has one example
### Sample Load Rating Report

<table>
<thead>
<tr>
<th>BRIDGE LOAD RATING REPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOR PROPOSED BRIDGE PROJECT No.:</td>
</tr>
<tr>
<td>BRIDGE NO.</td>
</tr>
<tr>
<td>SFN</td>
</tr>
</tbody>
</table>

#### Bridge Description
Three span continuous composite steel beam over Sunfish Creek. Originally built in 1956.

#### Work Details
New deck slab. Used existing beams.

#### Spans (C/C Bearings)
56'-70'-56'

#### Bridge Plan Information
New plans submittal to ODOT District 9 (2003)...
Ex. Bridge plans: 1954, @ ODOT Central Office

#### Material Strengths
$\frac{f_c}{f_y} = 4500$ psi, $F_y$ (steel beams) = 33 ksi, $F_y$ (rebars) = 60 ksi

#### Rating Method
Load Factor

- Live Load Distribution Factor for the exterior beam: 1.54
- (AASHTO: Section 3.23.2.3.1.2)
- (Placement of wheel load 2\* from the edge of deck slab)

#### Rating Software
BARS-PC

#### Special Assumptions

#### Structure Rating Summary

<table>
<thead>
<tr>
<th>Structure Rating Summary</th>
<th>Rating</th>
<th>Member</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory HS</td>
<td>24</td>
<td>Exterior (S01)</td>
<td>Middle of span 2</td>
</tr>
<tr>
<td>Operating HS</td>
<td>40</td>
<td>Exterior (S01)</td>
<td>Middle of span 2</td>
</tr>
<tr>
<td>OHC Legal Loads (%)</td>
<td>241%</td>
<td>Exterior (S01)</td>
<td>Middle of span 2</td>
</tr>
</tbody>
</table>

- 2F1 (Tons): 59 Exterior (S01) | Middle of span 2
- 3F1 (Tons): 62 Exterior (S01) | Middle of span 2
- 4F1 (Tons): 65 Exterior (S01) | Middle of span 2
- 5F1 (Tons): 111 Exterior (S01) | Middle of span 2

#### Rated by
John Doe, P.E.

#### Company
John Doe & Associates
123 Main Street
Columbus, OH 43223
Phone: (614)123-4567  E-mail: john.doe@johndoeassociates.com
Fax: (614)123-4567

#### Date
9/10/2001

Figure 908
Congratulations - you have load rated a single span steel beam bridge