Inspection Guidelines and Criteria for Load Rating Box Beams

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Load Rating Engineer, INDOT
Presentation Agenda

- Introduction: INDOT Emphasis
- FHWA Emphasis
- Focus on Box Beams, Box Beam Deterioration
- What is Load Rating?
- Load Rating Specifications & Guidelines
- Computer Software for Load Rating
- Load Rating Formulae & What Matters
- Load Rating & What Affects it
- Inspection for Load Rating
  - Load Rating Request Form
  - Load Rating Check List for Inspection
- Deterioration Inspection (Typical Sketch)
- Load Rating Criteria & Guidelines for Box Beams
- Box Beam Guidelines
- Significance of Corrosion
- Example: PS Box Beams, Rating Summary
- Conclusion/Questions?
Introduction and INDOT

- **Commissioners Directive**
  - **On Time and On Budget** (Deliver with focus on KPI and Performance and Quality Services)
  - **Take Care of What We Have**
    a) Plan to improve Bridge and Pavement Quality
    b) Ensure a Commitment to Safety
    c) Manage Talent to link strategy and operations to results
    d) Culture of Continuous Improvement
  - **Customer Satisfaction**
Box beams have a history of poor performance, premature distress, and failures. Box beams have failed in IL, PA, and IN.

Box beams account for ~5,000 of 19,000 bridges in Indiana.

Purpose:
- To ensure the safety of high risk box beam bridges
FHWA Emphasis

Scope:
- According to 2013 NBI submittal, IN has 24 box beam bridges with a Superstructure Rating of 3 or less
- Review team conducted field review of 13 of these bridges
- An additional 6 bridges had been replaced

Review Team
- FHWA - Keith Hoernschemeyer, Dan Brydl, Mohammad Hajeer, Micah Loesch, Jay DuMontelle
- INDOT - Merril Dougherty, Randy Strain, Bill Dittrich
- IL DOT - Steve Negangard
FINDINGS

- Many deficiencies were noted with the bridges reviewed
  - Longitudinal cracks, delaminations, and spalls with exposed/failed strands are common
  - 30%-50% failure rate of strands in an individual box is not uncommon
  - Large longitudinal structural cracks are not uncommon
  - Condition of individual beams is highly variable on the same structure
  - Leaking longitudinal joints are very common
  - Over the edge deck drainage with no curb is common

- Most had asphalt wearing surface with no membrane

- Many do not function as designed due to poor load distribution caused by deteriorated/non-functioning grout and transverse tensioning rods; limiting redundancy
FINDINGS

- Beams have minimal bottom concrete cover over strands and rebar
- Beams have “straps” (used in fabrication process) with minimal/no concrete cover
- Beams have only single row of strands
- Some beams have as few as 7 strands; thereby providing limited redundancy of the strands
FINDINGS

• Condition/deficiencies of the beams were generally not well documented in the inspection reports
• Review Team noted several critical findings that had not previously been identified – findings were addressed by owners during the review
• Assumptions for most load ratings were not well documented in the bridge file
• INDOT Inspection Manual has minimum guidance regarding condition rating and load rating of box beams
Focus on Box Beams

1. Joint in barrier wall passing through curb slab
2. Close-up of corroded beam
3. Corrosion damage on beam surface
4. Rusty areas on concrete surface
5. Overall view of damaged structure
6. Corrosion levels: Light Pitting, Heavy Pitting, New 7-Wire Stand, Corrosion w/o Pitting
Box Beam Deterioration

Typical asphalt overlay with longitudinal cracking, indicative of poor load distribution amongst adjacent beams and allowing water into joints/beans

Credit: FHWA-Indiana
Non-functioning transverse tie rod, leading to poor load distribution amongst adjacent beams

Credit: FHWA-Indiana
Box Beam Deterioration

Leaking joints contributing to strand corrosion, longitudinal cracking, delaminations, and spalling – starting at edge of beams

Credit: FHWA-Indiana
Box Beam Deterioration

Deck drainage contributing to strand corrosion, longitudinal cracking, delaminations, and spalling – starting at edge of beams

Credit: FHWA-Indiana
Box Beam Deterioration

Corroded/failed strand

Credit: FHWA-Indiana
Box Beam Deterioration

- **Focus Areas**
  - Asphalt Overlay Cracks/Salt Water Ingress
  - Loss of Grout-Single Beam Action (Non Composite)
  - Fabrication Deficiencies (Component Thickness)
Box Beam Deterioration

- **Focus Areas**
  - Inadequate cover/Vent Hole Blocks/Longitudinal Cracks/Spalls
  - Lateral PT Rod Corrosion/Failure
  - Loss of Prestress –Strand Corrosion/Pitting/Exposed Strands
  - Edge Deck Drainage- Spalling/Corrosion
What is Load Rating?

- Load Rating is the task of evaluating the Safe Load Capacity of a Bridge for Live Loads using analytical and other methods to ensure Bridge Safety.
- Load Rating Factor should be preferably greater than 1.0 for the design live load.
- Load Rating Factor is the ratio of the net capacity of the superstructure to the live load demand.
- Load rating is different than condition rating.
- Load rating is usually derived analytically.
- Condition rating is usually derived from subjective judgment based on bridge inspection techniques.
Applicable Codes and guidance

  - Load Rating Guidelines
- AASHTO Standard Specifications for Highway Bridges (17th Edition)
  - LFR or ASD Analysis
- AASHTO LRFD Bridge Design Specifications (6th Edition)
  - LRFR Analysis
- Indiana Bridge Inspection Manual 2013 (being updated)
- FHWA Memorandums
- INDOT Central Office Memorandums
- INDOT Load Rating Practices are undergoing review (Multi-Year Process)
Computer Software for Load Rating

- Preferred software is AASHTOWARE BridgeRating 6.6.0 or BrR 6.6.0 (previously known as VIRTIS)
  - Can rate simple, continuous, steel or concrete, RC and prestressed, straight and curved beams, three sided culverts, RC slabs, plate girders, truss member ratings (not connections) and many others
  - Cannot rate post-tensioned box beams, arch spandrels, simple arches and fill structures, post tensioned slabs, gusset plates
- CANDE for arch and underfill structures
- SMARTCULVERT for arches and conspan type structures
- MIDAS/ABACUS/GT-STRUDL and BrR combo for FEM analysis including secondary effects for steel truss frame analysis as well as post tensioned curved concrete box structures
- Spread sheets and MathCAD sheets for custom development (example for Gusset Plate analysis)
- Conspan and Merlin-DASH also offer some load rating analysis but are not comprehensive.
**Load Rating Formulae & What Matters**

- **LRFR Load Rating Equation (MBE 6A.4.2)**
  - $C =$ Capacity
  - $R_n =$ Nominal Resistance
  - $g =$ Load Factor
  - $j =$ Resistance Factor
  - $j_c =$ Condition Factor
  - $j_s =$ System Factor
  - $g_{LL} =$ Live Load Factor

Inventory Rating = 1.75*
Operating Rating = 1.35 *

* The above factors have been Modified to be less conservative
Per latest NCHRP study adopted By AASHTO to be published in The latest MBE.
Load Rating Formulae & What Matters

- **LRFR Condition Factor, $j_c$**
  Resistance reduction based on SI&A Condition Rating

**Table 6A.4.2.3-1—Condition Factor: $\varphi_c$**

<table>
<thead>
<tr>
<th>Structural Condition of Member</th>
<th>$\varphi_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good or Satisfactory</td>
<td>1.00</td>
</tr>
<tr>
<td>Fair</td>
<td>0.95</td>
</tr>
<tr>
<td>Poor</td>
<td>0.85</td>
</tr>
</tbody>
</table>

**Table C6A.4.2.3-1—Approximate Conversion in Selecting $\varphi_c$**

<table>
<thead>
<tr>
<th>Superstructure Condition Rating (SI &amp; A Item 59)</th>
<th>Equivalent Member Structural Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 or higher</td>
<td>Good or Satisfactory</td>
</tr>
<tr>
<td>5</td>
<td>Fair</td>
</tr>
<tr>
<td>4 or lower</td>
<td>Poor</td>
</tr>
</tbody>
</table>
Load Rating Formulae & What Matters

- **LRFR System Factor, $\varphi_s$**
  - Resistance reduction based on Redundancy and Fatigue Prone Details

Table 6A.4.2.4-1—System Factor: $\varphi_s$ for Flexural and Axial Effects

<table>
<thead>
<tr>
<th>Superstructure Type</th>
<th>$\varphi_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welded Members in Two-Girder/Truss/Arch Bridges</td>
<td>0.85</td>
</tr>
<tr>
<td>Riveted Members in Two-Girder/Truss/Arch Bridges</td>
<td>0.90</td>
</tr>
<tr>
<td>Multiple Eyebar Members in Truss Bridges</td>
<td>0.90</td>
</tr>
<tr>
<td>Three-Girder Bridges with Girder Spacing $\leq 6$ ft</td>
<td>0.85</td>
</tr>
<tr>
<td>Four-Girder Bridges with Girder Spacing $\leq 4$ ft</td>
<td>0.95</td>
</tr>
<tr>
<td>All Other Girder Bridges and Slab Bridges</td>
<td>1.00</td>
</tr>
<tr>
<td>Floorbeams with Spacing $&gt;12$ ft and Noncontinuous Stringers</td>
<td>0.85</td>
</tr>
<tr>
<td>Redundant Stringer Subsystems between Floorbeams</td>
<td>1.00</td>
</tr>
</tbody>
</table>
LFR Load Rating Equations

Manual For Bridge Evaluation 6B.4

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

- C = Capacity
- A1 = 1.3
- A2 = 2.17 for Inventory Rating and 1.3 for Operating Rating
- D = Dead Load Effect
- L = Live Load Effect
- I = Impact Factor (Dynamic)
Load Rating Formulae & What Matters

- Indiana uses LFR (H20/HS20) for older bridges and LRFR (HL 93) for newer bridges
- Bridges in Indiana Posted if H20 inventory rating is less than 16T
- Looking at LRFR and LFR formula above:
  - Desirable condition is Load Rating Factor is > 1.0
  - This is possible if Capacity is higher (C or Rn is higher) or the section of component is higher
  - This is combined with lighter dead loads and wearing surface loads
  - This is also combined with lower live loads actually travelling on the bridge (lower gross weights or axle loads)
  - Lower C or R or deterioration equals lower rating

LRFR

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

For the Strength Limit States:

\[
C = \phi_C \phi_S \phi_{Rn}
\]

LFR

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

- C = Capacity
- A1 = 1.3
- A2 = 2.17 for Inventory Rating and 1.3 for Operating Rating
- D = Dead Load Effect
- L = Live Load Effect
- I = Impact Factor (Dynamic)
Load Rating & What Affects It

FOR BOX BEAMS AND IN GENERAL

FACTORS AFFECTING OR LOWERING LOAD RATING ARE:

- **LOWER C**
  (DETERIORATION/SPALLING/LOSS OF PRESTRESS/NON COMPOSITE)

- **HIGHER D**
  (HIGHER DEAD LOADS-
  OVERLAYS/BARRIER UPGRADES)

- **HIGHER L**
  (HIGHER LIVE LOADS WITH HIGHER IMPACT OR DYNAMIC LOAD ALLOWANCE)

**WORST COMBO WOULD BE LOWEST C AND HIGHEST D AND L**
Inspection for Load Rating

LOAD RATING REQUEST FORM

Download from: http://www.in.gov/dot/div/contracts/design/dmforms/

Application No. 14

All requests for Load Rating must be made using this form. A copy of the form must additionally be attached to the email sent to coordinator 8 with a copy of the same to the INDOT Load Rating Engineer.
Inspection for Load Rating: Check List

- **Check List @**: [http://www.in.gov/dot/div/contracts/design/dmforms/](http://www.in.gov/dot/div/contracts/design/dmforms/)

- **Pre-Planning before inspection:**
  - Gather Plans, make field copies and sketches
  - Review Plans and familiarize with tension zones, critical areas, material types and design loads
  - BIAS Bridge File review for existing load ratings, critical locations and condition ratings, previous section loss areas
  - Prepare tools and see what may be required like callipers, verniers, tilt gage or D-meter

- **During Inspection:**
  - Sketches:
    - Use Pre-prepared sketches or quick line drawings to log deterioration (Lx Wx D or t)
    - All sheets should have structure number, date, name of inspector and indicate span or location
  - Photos:
    - Take at least two clear photos of deterioration, one close up and one long shot (Can print, annotate and scan or use i-pad with some apps for dimensioning)
Inspection for Load Rating: Check List

- Check List @: [http://www.in.gov/dot/div/contracts/design/dmforms/](http://www.in.gov/dot/div/contracts/design/dmforms/)

- What to look for?:
  - Prestressed concrete box beam bridges
  - Identify if Deck is present
  - Identify Asphalt wearing surface and overlays- Look for longitudinal and transverse cracks (Document in detail sketches)
    - Check for longitudinal cracks at bottom and sides of beam (L x W, location, condition)
    - Check for vertical cracks at ends of beam (L x W, location, condition)
    - Check for cracks/spalls/rust stains/water seepage or stains, efflorescence (L x W x D)
    - Check for repeat condition (Are cracks appearing on all beams or focused at ends?)
    - Check for Beam Sag, Check for Rust Stains and Rusted PT Rods and Blocked Vent holes
    - Check for broken rusted strands, vehicle impact and unsound concrete
    - Check for edge spalling
    - Document in notes and sketches
Typical Sketch

Pier 1

Span 1, Beam 6

Pier 2

Spall with 8 exposed strands
Load Rating Criteria for Box Beams

- Current Bridge Inspection Manual Load Rating Chapters being Revised
- Three sources for reference:
  - Illinois DOT Structural Services Manual
  - Pennsylvania Pub. 238, Box Beams
  - ODOT Research Report
Use Engineering Judgment with Inspection data and condition rating. Remove Unsound concrete

Spall : Remove one strand for no exposure/sound concrete

Spall with exposed strands unsound concrete : Remove at least two layers including adjacent strands

Longitudinal Cracks: Remove strand above crack and each adjacent strand

Longitudinal Crack with Rust stains or efflorescence: Remove adjacent strands at least two layers
Significance of Corrosion

- Corrosion rate @ 1 mil/year, 50% section loss in strands occurs five times quicker than rebar.
- Lehigh University team research: Forensic Examination of a Non composite Adjacent Precast Prestressed Concrete Box Beam Bridge (see JOURNAL OF BRIDGE ENGINEERING © ASCE / JULY/AUGUST 2010).
- Presence of Hairline crack on the bottom flange could indicate significant corrosion and pitting of the strand above it.
- Corrosion can spread across adjacent strands without any surface indication of distress. Pitting to strands could reduce tensile strength by over 30%.
- Corrosion typically occurs on the bottom face of the strand. Since the strand consists of six wires wound around the central wire, all six strands are vulnerable to corrosion.
Example: Prestressed Concrete Box Beams

- Inspection Sketch Provided by INDOT
- Markup Copy
- RRI 8/27/14
- Sketch 7/10/2014 by Nicole Pfeiffer

- Not to scale
- Top left corner: 12" long x 3" wide
- Spall: 6" x 6" @ pier 2
- Spall: 3" long x 6" wide
- Spall (size?)
- Spalled
- Corner spall: 1 exposed strand
- Corner spall: 1 broken strand
- Corner spall: 1 broken strand & drop from abutment
- Corner spall: 1 exposed strand
- Corner spall: 1 broken strand & drop from abutment
- Corner spall: 1 exposed strand
- Corner spall: 1 broken strand & drop from abutment
- Corner spall: 1 exposed strand

- West face of pier 2 cap has widespread delamination

- Span A
- Box beams
Prestressed Concrete Box Beam

[Diagram of Prestressed Concrete Box Beam with various annotations and measurements]
Prestressed Concrete Box Beam

Sketch 7/10/2014
by Nate Pfeiffer

Mark up Copy

RR 2 8/24/14

"long" is in direction of beams
"wide" is across beams

not to scale

24" up side of beam
6" above pier cap

corner spill

3" long x 9" wide

spill up to exposed ground

span C

box beams
Prestressed Concrete Box Beams

<table>
<thead>
<tr>
<th>Description:</th>
<th>3 Simple Span Prestressed Concrete Box Beams - Side-by-Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>By:</td>
<td>TLW</td>
</tr>
<tr>
<td>Checked:</td>
<td>DZ</td>
</tr>
<tr>
<td>Date:</td>
<td>9/17/2014</td>
</tr>
</tbody>
</table>

| Load Rating Method: | LFR |
| Load Rating Program: | Virtis 6.5.0 |

| Year Built: | 1966 |
| Year Reconstructed: | N/A |
| Design Loading: | HS-20 |
| Units: | US Customary |

<table>
<thead>
<tr>
<th>Location Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>County:</td>
</tr>
<tr>
<td>District:</td>
</tr>
<tr>
<td>Reference Post:</td>
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<table>
<thead>
<tr>
<th>Bridge Geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spans:</td>
</tr>
<tr>
<td>Girder Spacing:</td>
</tr>
<tr>
<td>O-To-O Coping:</td>
</tr>
<tr>
<td>Clear Roadway:</td>
</tr>
<tr>
<td>Left Overhang:</td>
</tr>
<tr>
<td>Skew:</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Slab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Depth =</td>
</tr>
<tr>
<td>Structural Depth =</td>
</tr>
<tr>
<td>Wearing Surface:</td>
</tr>
<tr>
<td>SIP:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resteel:</td>
</tr>
<tr>
<td>Deck Concrete:</td>
</tr>
<tr>
<td>Beam:</td>
</tr>
<tr>
<td>Beam Concrete:</td>
</tr>
<tr>
<td>Strands:</td>
</tr>
</tbody>
</table>
**Prestressed Concrete Box Beams**

<table>
<thead>
<tr>
<th>Span</th>
<th>Beam</th>
<th>Original Strand</th>
<th>Removed</th>
<th>Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>29</td>
<td>1</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>29</td>
<td>1</td>
<td>28</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>29</td>
<td>6</td>
<td>23</td>
</tr>
</tbody>
</table>

Indicates strand observed in the field as being exposed. This strand was removed from the load rating model.
Prestressed Concrete Box Beams

Span: A Beam: 7
- Original Strand: 29
- Removed: 6
- Remaining: 23

Span: A Beam: 8
- Original Strand: 29
- Removed: 2
- Remaining: 27

Span: A Beam: 9
- Original Strand: 29
- Removed: 1
- Remaining: 28

Indicates strand observed in the field as being exposed. This strand was removed from the load rating model.

Span: B Beam: 1
- Row 1
  - Original Strand: 27
  - Removed: 1
  - Remaining: 26

Span: B Beam: 2
- Row 1
  - Original Strand: 27
  - Removed: 0
  - Remaining: 27

Span: B Beam: 3
- Row 1
  - Original Strand: 27
  - Removed: 7
  - Remaining: 20

Indicates strand observed in the field as being exposed. This strand was removed from the load rating model.
Prestressed Concrete Box Beams

% Removed = 48%

Indicates strand observed in the field as being exposed. This strand was removed from the load rating model.
<table>
<thead>
<tr>
<th></th>
<th>INV. (Location)</th>
<th>OPER. (Location)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H20-44</td>
<td>0.559 (16.92')</td>
<td>1.231 (16.92')</td>
</tr>
<tr>
<td>HS20-44</td>
<td>0.479 (16.92')</td>
<td>1.046 (20.30')</td>
</tr>
<tr>
<td>HL 93</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Fatigue Truck</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>H5 25</td>
<td>0.383 (16.92')</td>
<td>0.837 (20.30')</td>
</tr>
<tr>
<td>Michigan Train #5</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Michigan Train #8</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Military Loading</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SuperLoad - 11 Axles</td>
<td>0.307 (16.92')</td>
<td>0.677 (16.92')</td>
</tr>
<tr>
<td>SuperLoad - 13 Axles</td>
<td>0.360 (16.92')</td>
<td>0.792 (16.92')</td>
</tr>
<tr>
<td>SuperLoad - 14 Axles</td>
<td>0.233 (16.92')</td>
<td>0.513 (16.92')</td>
</tr>
<tr>
<td>SuperLoad - 19 Axles (306k)</td>
<td>0.330 (16.92')</td>
<td>0.727 (16.92')</td>
</tr>
<tr>
<td>SuperLoad - 19 Axles (480k)</td>
<td>0.255 (16.92')</td>
<td>0.562 (16.92')</td>
</tr>
<tr>
<td>Toll Road Truck 126k</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Toll Road Truck 89.6k</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Toll Road Truck 90k</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Box Beam Rating Summary

Recommendation:
1. Post weight limit of 11 tons.
2. Increase inspection frequency, e.g. 6 to 12 months.
3. Replace beams with load rating factors below 0.80.

Remaining Roadway Width = 11.5’
Deck Thickness 5 1/4”

Allow 3’-0” for temporary barrier off beam to be replaced
Travelway 1

H20 INV RF
PSC BB1 (det) CB-17 (4’-0”)
1.025 (20.5 tons)

PSC BB2 CB-17 (4’-0”)
1.223 (24.4 tons)

PSC BB3 (det) CB-17 (4’-0”)
0.885 (17.6 tons)

PSC BB4 (det) CB-17 (4’-0”)
0.936 (18.7 tons)

PSC BB5 (det) (Critical) CB-17 (4’-0”)
0.559 (11.1 tons)

PSC BB6 (det) CB-17 (4’-0”)
0.833 (16.6 tons)

PSC BB7 (det) CB-17 (4’-0”)
0.671 (13.4 tons)

PSC BB8 CB-17 (4’-0”)
1.223 (24.4 tons)

PSC BB9 (det) CB-17 (4’-0”)
0.729 (14.5 tons)

8@4’-1/4” = 32’-2”
Conclusions

- Better inspection leads to better data
- Better data leads to more accurate load ratings
- Accurate load ratings lead to ensuring safety, preventing loss of life and money
Questions?

- **Contact Information**
  - Bridge Inspection Manager: Merril Dougherty (mdougherty@indot.in.gov)
  - Load Rating: Raju R.Iyer (riyer@indot.in.gov)