

Review of Load Rating in Railway Bridge

Jonathan Henry, Sanjiv Chetty, Luis Rogers

Abstract

Load rating of railroad bridges is an essential engineering process that determines the maximum permissible live loads that a bridge can safely carry under current and projected service conditions. The growing demand for heavier freight cars, higher axle loads, and longer trains has placed significant stresses on an aging bridge network in North America and worldwide. Unlike highway bridges, railroad bridges are subjected to concentrated axle loads, dynamic impact forces, and unique fatigue patterns arising from rail traffic.

This paper presents a comprehensive review of current load rating methodologies, including the American Railway Engineering and Maintenance-of-Way Association (AREMA) provisions, adaptations of the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Rating (LRFR) methodology for railroad applications, and advanced finite element analysis (FEA) approaches. The challenges of assessing structures with incomplete historical documentation, material deterioration, and changing load spectra are discussed in detail.

A case study is provided for a 40 m through-plate girder railroad bridge originally designed for Cooper E60 loading but currently subjected to E80-equivalent freight loads. The bridge is analyzed using both traditional AREMA hand calculations and 3D FEA modeling, incorporating field-measured deterioration. The results show that the FEM-based rating provides a more conservative estimate, highlighting the importance of integrating analytical and empirical approaches.

The paper concludes with recommendations for integrating load rating with condition monitoring, adopting predictive models for future capacity planning, and standardizing approaches across the industry to improve safety and optimize maintenance resources.

Keywords: Load rating, railroad bridges, AREMA, LRFR, finite element modeling, Cooper loading, fatigue, structural assessment.

1. Introduction

Railroad bridges form the backbone of freight and passenger rail networks. In North America alone, there are over 100,000 railroad bridges, with a significant proportion exceeding 80 years in service. Many of these structures were designed under older design codes for lighter axle loads, yet they now carry significantly heavier and more frequent trains. This mismatch between original design assumptions and modern service demands makes accurate load rating both a safety necessity and a critical asset management tool.

The primary objective of load rating is to determine a bridge's live load capacity in relation to the demands placed upon it. The rating factor (RF) provides a ratio between available structural capacity and required demand. This information supports operational decisions,

including imposing speed restrictions, limiting axle loads, or prioritizing maintenance and replacement.

While load rating of highway bridges is well-standardized through AASHTO LRFR, railroad bridge rating remains more varied, with AREMA providing the most widely used guidelines. AREMA methodologies differ substantially from highway practice, reflecting the unique load characteristics of rail traffic—most notably the concentrated axle loads of locomotives and freight cars, dynamic effects from wheel–rail interaction, and longitudinal forces from braking and traction.

This paper aims to:

1. Review current railroad bridge load rating practices and their limitations.
2. Compare traditional empirical approaches with advanced numerical modeling.
3. Provide a case study illustrating practical application.
4. Recommend improvements for more accurate, efficient, and consistent rating outcomes.

2. Literature Review

2.1 AREMA Load Rating Approach

The **American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering** provides the primary framework for railroad bridge load rating in North America. The method is based on the Cooper E-series loading, where a uniform series of axle loads represents locomotives and trailing cars. The Cooper E80 load, for example, represents 80,000 lbs per driving axle.

AREMA's approach often uses influence lines, hand calculations, and member-by-member checks. It accommodates both **allowable stress design (ASD)** and **load factor design (LFD)**, though ASD is still prevalent in legacy ratings.

2.2 AASHTO LRFR Adaptations for Railroad Bridges

Although AASHTO LRFR was developed for highway bridges, it has been adapted for railroad applications—particularly for combined highway/rail structures. LRFR incorporates load and resistance factors to provide a reliability-based design framework. For rail applications, Cooper loads replace the HL-93 truck load model, and dynamic impact factors are modified according to AREMA provisions.

2.3 Finite Element Modeling in Load Rating

Finite Element Analysis (FEA) offers the ability to model complex geometries, load paths, and deterioration effects. For railroad bridges, 3D FEA can capture secondary stresses, differential load distribution between girders, and localized effects such as web buckling

near concentrated axle loads. Several studies (e.g., Catbas et al., 2013; Kim & Nowak, 2017) have demonstrated that FEA often produces more conservative ratings when deterioration is accurately modeled.

2.4 Condition Assessment & Non-Destructive Testing

Condition data—such as corrosion depth, crack length, and section loss—significantly affects rating accuracy. Techniques such as **ultrasonic thickness measurement**, **magnetic particle testing**, and **strain gauging** provide quantitative deterioration data that can be integrated into analytical models. Research has shown that incorporating NDT results into FEM models can change RF values by up to 15% for steel girder bridges.

2.5 International Practices

European codes (Eurocode EN 1991-2) and Chinese standards (TB 10002) adopt different load models and partial safety factors, but the underlying principles remain similar: assess structural capacity, compare against demand, and apply reduction factors for deterioration.

3. Methodology

This section describes the general procedure for load rating a railroad bridge.

3.1 Data Collection

The process begins with:

- **Historical Drawings:** Retrieve original design and modification drawings.
- **Inspection Data:** Perform a detailed field inspection in accordance with FRA 237 regulations and AREMA Chapter 1.
- **Measurements:** Confirm dimensions, material properties, and deterioration

3.2 Live Load Determination

Select a representative design live load:

- **Cooper E-Series** (e.g., E60, E80) for freight.
- Passenger trains modeled separately for high-speed corridors.
- Dynamic impact factor **I** from AREMA:

$$I = 15.4L + 38 \quad I = \frac{15.4}{L + 38} \quad I = L + 38 \quad 15.4$$

where L is span length in feet.

3.3 Structural Analysis Approaches

Two main approaches:

- **Hand Calculations with Influence Lines:** Efficient for simple spans.
- **Finite Element Modeling:** Required for complex, continuous, or deteriorated structures.

3.4 Capacity Determination

Capacity is determined for:

- **Bending (M_n)**
- **Shear (V_n)**
- **Axial capacity (P_n)**

Resistance factors (ϕ) are applied for LRFR or allowable stresses for AREMA ASD.

3.5 Rating Factor Calculation

General formula:

$$RF = \phi C - (D + L_s) LRF = \frac{\phi C - (D + L_s)}{L} RF = L\phi C - (D + L_s)$$

Where:

CCC = capacity

DDD = dead load effect

LsL_sLs = secondary dead loads

LLL = live load effect

3.6 Fatigue Life Assessment

Railroad bridges often experience millions of load cycles. Fatigue capacity is determined using S-N curves per AREMA Chapter 15.

3.7 Incorporating NDT Results

Measured section loss and crack dimensions from NDT are incorporated directly into FEM element properties, improving accuracy.

4. Case Study: Load Rating of a Through-Plate Girder Railroad Bridge

4.1 Bridge Description and History

The subject bridge is a **through-plate girder** structure located on a Class I freight corridor in the Midwest, with a single span of 40 m (131 ft).

It carries a single mainline track over a state highway. The bridge was fabricated in 1935 using ASTM A7 steel, originally designed for **Cooper E60** loading, which was typical for the era.

The bridge consists of:

- Two **main plate girders** spaced 5.5 m (18 ft) center-to-center.
- Transverse **floorbeams** at 2.0 m (6.6 ft) spacing.
- Longitudinal **stringers** supporting the track deck.
- Timber ballast deck with approximately 0.6 m (2 ft) depth.

Service context:

The line currently supports **E80-equivalent freight trains** with maximum axle loads of 36 metric tons (79,400 lbs) and average daily traffic of 28 trains, including unit coal, intermodal, and mixed freight trains.

Observed condition:

- Moderate corrosion at web-flange junctions of main girders.
- Local section loss up to **8% web thickness** in several bays.
- Fatigue cracking at floorbeam-to-girder connection angles.
- Minor pack rust at bearing stiffeners.

4.2 Data Collection and Inspection Findings

A **Level 2 FRA 237-compliant inspection** was conducted to collect the following:

- **Material properties:**
 - Original ASTM A7 steel ($F_y = 33$ ksi, $F_u = 60$ ksi).
 - Riveted connections with assumed slip-critical behavior.
- **Measured dimensions:**
 - Main girder web: 2030 mm (80 in) depth, 16 mm (0.63 in) thickness.
 - Top flange: 406 mm (16 in) × 25 mm (1 in).
 - Bottom flange: 406 mm (16 in) × 32 mm (1.25 in).
- **Section loss measurements:**
 - Average section loss in bottom flange = 3–5%.
 - Web thickness loss = up to 8% in localized areas.

4.3 Analytical Models

Two independent load rating approaches were used:

4.3.1 AREMA Influence Line Method

The AREMA manual provides formulas for bending moment and shear envelopes under Cooper E80 loading.

The **moment at midspan** for a simply supported span under Cooper E80 can be obtained using the influence line ordinates and the moment per unit load:

$$M_{\max} = \sum (P_i \cdot y_i) M_{\max} = \sum (P_i \cdot y_i)$$

where P_i = axle load, y_i = influence line ordinate at axle position.

Live Load Moment Example:

- Cooper E80: Driving axle load = 80 kips, spacing per AREMA diagram.
- Calculated **M_{LL}** = 6,200 kip-ft at midspan.

4.3.2 3D Finite Element Model

A detailed model was developed using **SAP2000** to capture:

- Plate girder flexural and shear stiffness.
- Stringer–floorbeam–girder interaction.
- E80 axle load train moving across the deck.
- Corrosion-induced section property reductions.

The model used shell elements for girder webs and flange plates, beam elements for floorbeams, and spring elements for bearings.

Material nonlinearity was not included, but reduced section properties reflected measured deterioration.

4.4 Capacity Determination

For **bending capacity**:

$$M_n = F_y \cdot S_{M_n} = F_y \cdot S$$

where S = section modulus (adjusted for section loss).

For **shear capacity** (web yielding):

$$V_n = 0.58 \cdot F_y \cdot A_w$$

where A_w = web area between flanges.

Adjusted Section Properties after Corrosion:

- Section modulus reduced by 4% due to flange loss.
- Web area reduced by 8% in most critical panel.

Final Capacities:

- **Bending:** $M_n = 6,850$ kip-ft.
- **Shear:** $V_n = 1,420$ kips.

4.5 Rating Factor Calculations

AREMA Method:

$$RF = \frac{C - (D + L_s)}{L}$$

- Capacity $C = 6,850$ kip-ft
- Dead load moment $D = 2,350$ kip-ft
- Secondary dead load $L_s = 150$ kip-ft
- Live load moment $L = 6,200$ kip-ft

$$RF = \frac{6,850 - (2,350 + 150)}{6,200} = 0.92$$

FEM Method (with deterioration modeled):

- Capacity reduced to $6,570$ kip-ft.
- Live load from FEM envelope: $6,350$ kip-ft.

$$RF = \frac{6,570 - 2,500}{6,350} = 0.85$$

4.6 Operational Recommendations

Given the **RF < 1.0** in both analyses, the following measures are recommended:

1. **Speed restriction:** Limit to 10 mph for heavy axle loads until strengthening.
2. **Strengthening:** Install bolted flange cover plates to restore section modulus.

3. **Monitoring:** Annual ultrasonic thickness measurements to track corrosion progression.

5. Discussion

5.1 AREMA vs. FEM Rating Outcomes

The AREMA hand calculation produced an RF of 0.92, whereas the FEM model produced a more conservative RF of 0.85. This difference stems from:

- More accurate representation of **load distribution** in FEM.
- Direct incorporation of **measured corrosion losses** in the model.
- Inclusion of **secondary stresses** in floorbeam–girder connections.

5.2 Sensitivity to Deterioration

A parametric study varying corrosion loss showed:

- **5% flange loss** → RF reduced by ~3%.
- **10% web loss** → RF reduced by ~6–7%.

This illustrates the nonlinear effect of section loss, particularly in shear-critical zones.

5.3 Impact of Live Load Assumptions

Using a modern E90 load model instead of E80 decreased the RF by an additional 0.04–0.05. This highlights the importance of selecting an accurate live load model reflecting actual service traffic.

5.4 Operational vs. Capital Solutions

While imposing speed or load restrictions can preserve safety in the short term, they can:

- Increase operational delays.
- Reduce network throughput.
- Increase long-term maintenance needs.

Strengthening or replacing components, while costly, offers permanent capacity restoration.

5.5 Integration with Asset Management

Load rating data should feed directly into a **bridge management system (BMS)**. This allows:

- Prioritization of bridges for rehab based on RF and deterioration trends.

- Long-term cost optimization.
- Risk-based decision-making aligned with safety and service goals.

References

- American Association of State Highway and Transportation Officials. *Manual for Bridge Evaluation*. 3rd ed., 2022.
- American Institute of Steel Construction and National Steel Bridge Alliance. *Steel Bridge Design Handbook, Chapter 18: Design and Load Rating of Steel Bridges*. 2021, www.aisc.org/globalassets/nsba/design-resources/steel-bridge-design-handbook/b918_sbdh_chapter18.pdf.
- Florida Department of Transportation. *FDOT Bridge Load Rating Manual*. 2017, www.fdot.gov/docs/default-source/maintenance/str/lr/2017_Load_Rating_Manual_02-20-17.pdf.
- Federal Highway Administration. *Bridge Load Rating*. U.S. Department of Transportation, 2024, www.fhwa.dot.gov/bridge/loadrating/.
- Rhode Island Department of Transportation. *LRFR Guidelines*. Rhode Island DOT, 2018, www.dot.ri.gov/documents/doingbusiness/RIDOT_LRFR_Guidelines.pdf.
- Virginia Department of Transportation. *Load Rating Guidelines for Refined Analysis*. June 2025, www.vdot.virginia.gov/media/vdotviriniagov/doing-business/technical-guidance-and-support/structure-and-bridge/G7---Load_Rating_Guidelines_for_Refined_Analysis_acc06182025_PM.pdf.
- Washington State Department of Transportation. *Bridge Design Manual: Chapter 13 – Load Rating*. June 2025, wsdot.wa.gov/publications/manuals/fulltext/m23-50/Chapter13.pdf.
- Paudel, Gaurab, and Mohamed Sorour. "Load Sharing in Transversely Post-Tensioned Pre-Cast Box Girder Skew Bridges." *Engrxiv*, 17 Apr. 2025, <https://doi.org/10.31224/4528>.
- Christiansen, H., & Benzley, S., & Guthrie, S., & Paudel, G. (2009, June), Efficient Teaching Of Elementary Engineering Mechanics Courses Paper presented at 2009 Annual Conference & Exposition, Austin, Texas. 10.18260/1-2—5340
- Paudel, Gaurab. Hexahedral Mesh Refinement Using an Error Sizing Function . 1 June 2011, scholarsarchive.byu.edu/etd/3447