Steel Railway Bridge Fatigue and the Evolution of Railway Car Loadings

The Current State and Future Challenges of Railway Bridges

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Discussion Items

General bridge features
Railroad car loadings
Steel bridge fatigue
General Bridge Features
Common Features

• Simply supported
  – “Time is money”
    • repairs are easier
    • historical precedent

• Standardized designs
  – applicable to any type of span
    • steel and timber both standardized
    • prestressed concrete very popular
  – standardization creates economies
Historical Bridge Types
(1890 forward)

• Steel
  – rolled multiple beams (up to 30 feet)
  – built-up girders (up to 120 – 150 feet)
  – trusses (longer than 150 feet)

• pin trusses popular early
• riveted (now bolted) trusses
• welding also used
Historical Bridge Types
(1890 forward)

• Steel – riveted and bolted construction
  – rivets common until the 1960’s
  – bolting used for repairs on existing bridges
  – bolting still used extensively
    • truss and girder field erection
    • potential fatigue locations
Historical Bridge Types
(1890 forward)

• Steel – welded construction
  – became generally used in the late 1950’s
  – used in both girders and trusses
  – restrictions on details because of fatigue
Historical Bridge Types
(1890 forward)

• Timber
  – used extensively for trestle bridges
  – span lengths 10 – 15 feet
  – used for ballast decks on steel bridges
  – timber’s use is declining
    • insufficient load capacity for heavier loadings
    • supplies of useful timber are declining
    • creosote treatment has environmental issues
Historical Bridge Types
(1890 forward)

• Timber
  – glulam and hybrid construction is in place for test bridges.
  – results are mixed
Historical Bridge Types
(1890 forward)

• Reinforced Concrete
  – used since early in 20th century
  – used early for arch and box culverts
  – popular in urban areas for grade separations
  – substructures
  – used for large arches and viaducts in various locations
Historical Bridge Types
(1890 forward)

• Prestressed Concrete
  – used heavily in railroad industry
  – replacing timber in trestle construction
  – precasting allows faster field construction
  – standardized spans up to ~ 50 feet
  – Span length limited to ~ 80 – 100 feet
Historical Bridge Types
(1890 forward)

• Foundations
  – stone abutments and piers still in use
  – older concrete
    • many are rubble-filled
    • unreinforced concrete
    • Gravity design without pile foundations
  – newer concrete
    • rely on pilings or drilled shafts
    • heavy use of steel H-piling
Future trends

• Not really set
• Refinement of existing technologies
• Modern materials have potential
  – durability issues
  – cost
Design parameters

• AREMA Manual
  – Timber – Chapter 7
  – Concrete – Chapter 8
  – Steel – Chapter 15
  – Seismic – Chapter 9
  – Bridge Maintenance – Chapter 10
Cooper E80 Design Loading
Cooper E80 Loading

• Loading still used despite its age (1894)
• Still provides adequate overall moments for both short and long spans
• Scaleable
• Not entirely satisfactory as a basis for fatigue checks
Design Moments Normalized for Allowable Stresses
Railway Car Loadings
Actual Loadings

• Steady increases over time
• Total volume increasing dramatically
• Coal
  – 1900  ~ 3,000 pounds per foot
  – 2000  ~ 5,400 pounds per foot
Actual Loadings
Important milestone dates

- 1928 - Wood underframes outlawed
- 1941 - Arch bar trucks outlawed
- 1968 - Roller bearings required

Requirements for interchange only
Actual Loadings
Pre-1940

• Car loads from 30 tons (1900) up to 70 tons (1930)
• Majority of car fleet length 40 feet or less
• Very few freight cars exceeding 60 feet
• Passenger cars often the heaviest cars
Actual Loadings
1940-1960

• Car loads from 70 tons (1940) up to 90 tons (1960)
• Majority of car fleet length 40 feet or less
• Longer car lengths introduced (90 feet)
• Development of railcars for specific commodities beginning
Actual Loadings
Post-1960

- Car loads from 90 tons (1960) up to 110 tons (1995)
- Wide variety of car lengths available for commodity specialization
- Long car lengths very common
- Car weights increasing in general because of specialization of car equipment
Actual Loadings
Total Tonnages

- Tonnage during World War II was highest for the first half-century
  - three to four times the traffic during Great Depression
- Traffic levels not repeated until 1980’s
- Traffic continuing to increase to historic levels
Actual Loadings
Unit Train Weights

• 1930’s – 1500 to 3300 plf
• 1950’s – 1200 to 3200 plf

• Empty weight – 1200 plf
  – consistent over time
Actual Loadings
Unit Train Weights
2004 data

- Manifest – 1500 to 4600 plf
- Grain – 4700 to 5000 plf
- Coal – 5400 plf
- Automobile – 1500 to 2200 plf
- TOFC – 1200 to 2100 plf
- Double Stack – 1300 to 2600 plf
  - empty: assume 900 plf for TOFC/DS/Auto
Steel Railway Bridge Fatigue
Steel Railway Bridge Fatigue

• Number of old steel railway bridges is still very high

• Increased traffic levels on fewer routes are increasing the number of potential cycles

• Increased axle weights are creating higher bending moments and cycle potential
Steel Railway Bridge Fatigue

• Multiple cycles are potentially damaging from a train
• Need to examine the potential for all cycles that can occur
• Maximum moment – one overall cycle
• Moment range – one cycle per car
Moment Trace for a Unit Coal Train on a 50-foot Span.
Moment Range versus Span Position on 50-Foot Span

Moment Range (k-ft)

Span Position (x/L)

Coal Car

Locomotive
Moment Trace for a Unit Coal Train on a 100-foot Span.
Moment Range versus Span Position on for 100-Foot Span
L₀ - Overall length of railroad car measured over the pulling face of the coupler.
TC - Length between the center pin on the trucks, known as the truck center distance.
S₁ - Inboard Axle Spacing, the distance between the inside axles of the railroad car.

S₀ - Outboard Axle Spacing, the distance between the outside axles of the railroad car.
Sₜ - Truck Axle Spacing, the distance between the adjacent axles of a truck.
n - number of axles
P - axle load
Moment Range versus Span Position on for $L_S/L_O = 1.0$
Moment Range versus Span Position on for $L_S/L_O = 2.0$
Influence Lines For Moment Behavior At Midspan And Quarter Point

Influence Line for \( L_S = 2L_O \) at Midspan

Influence Line for \( L_S = 4L_O \) at Quarter Point

Influence Lines For Moment Behavior At Midspan And Quarter Point
Moment Range

General Characteristics

• Cyclical in nature

• Possesses an absolute maximum

• Magnitude can be estimated for integer values of $L_S/L_O$ using a similar sine wave approximation
Moment Range

Absolute Maximum Moment Range

\[ R_{AM} = nP \left[ \frac{S_I}{4} - \frac{S_o}{4} + \frac{S_o^2}{4L_o} \right] \]
<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Overall Length</th>
<th>$L_s/L_o$ 30' span</th>
<th>$L_s/L_o$ 150' span</th>
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<tr>
<td>SD70</td>
<td>70.00</td>
<td>0.43</td>
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<td>TOFC</td>
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<td>0.32</td>
<td>1.60</td>
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<td>SPDS</td>
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<td>0.42</td>
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<tr>
<td>APDS - End</td>
<td>65.26</td>
<td>0.46</td>
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<tr>
<td>APDS - Middle</td>
<td>58.83</td>
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</tr>
</tbody>
</table>
Maximum Moment vs. Span Position – 80 ft. span
Moment Range vs. Span Position – 80 ft. span
FIGURE 4. Bending Moment Versus Time For Railcar Loadings Over Long-Span Bridges

Moment Trace for Mixed Empty/Loaded Railcars
Steel Railway Bridge Fatigue

• Need to “sharpen the pencil” for the number of cycles to expect from each type of train
• Need for quicker calculation of moment range magnitudes other than absolute maximum
Additional Research

• Consideration of R ratio in fatigue life calculations for riveted/bolted members

• Development of very long life fatigue coefficients for riveted members (over 100,000,000 cycles)

• Retrofit strategies that are economical and can take full advantage of bridge members if only details are problematic