
4867
BNSF

Steel Railway Bridge Fatigue and the Evolution of Railway Car Loadings

The Current State and Future Challenges of Railway Bridges

Stephen M. Dick, PE, SE, Ph.D.
Hanson Professional Services

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

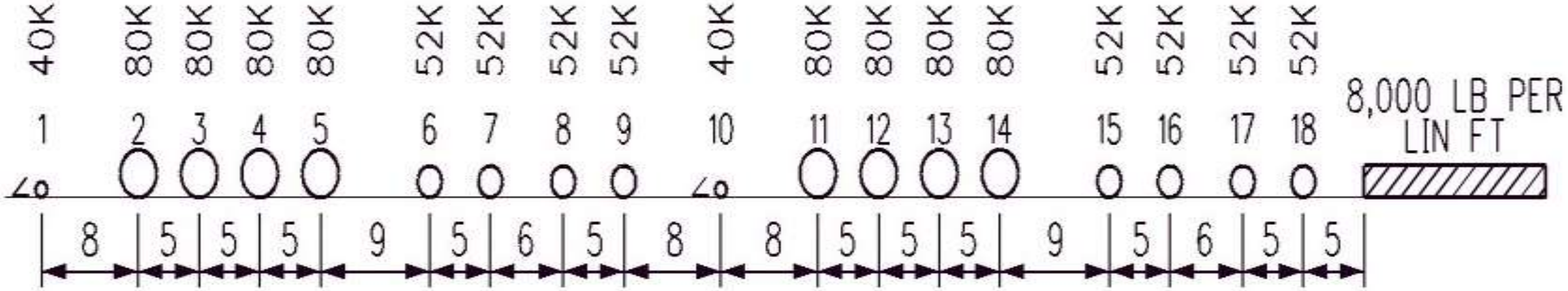
Future trends

- Not really set
- Refinement of existing technologies
- Modern materials have potential
  - durability issues
  - cost

Design parameters

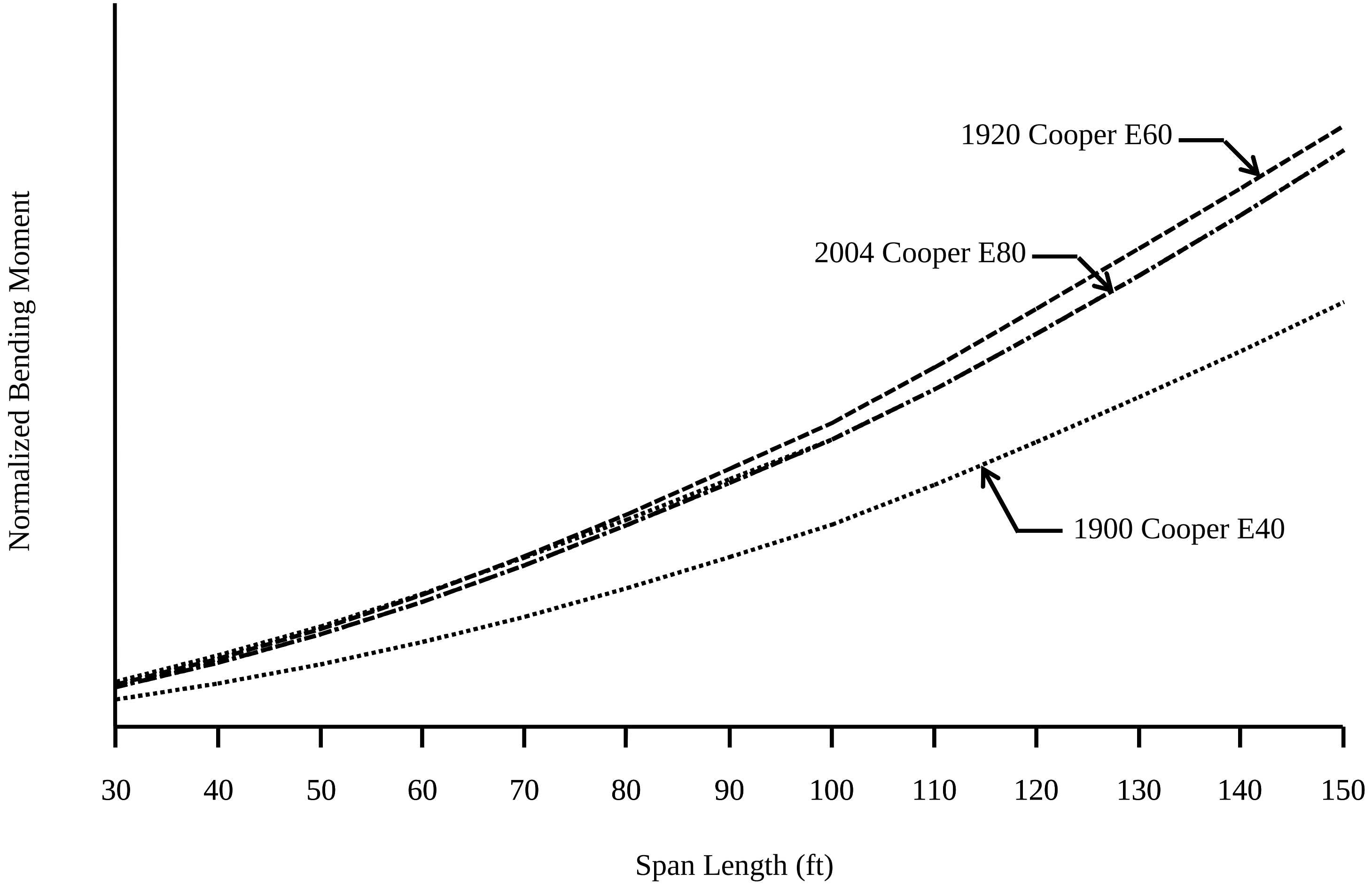
- AREMA Manual
  - Timber – Chapter 7
  - Concrete – Chapter 8
  - Steel – Chapter 15
  - Seismic – Chapter 9
  - Bridge Maintenance – Chapter 10

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

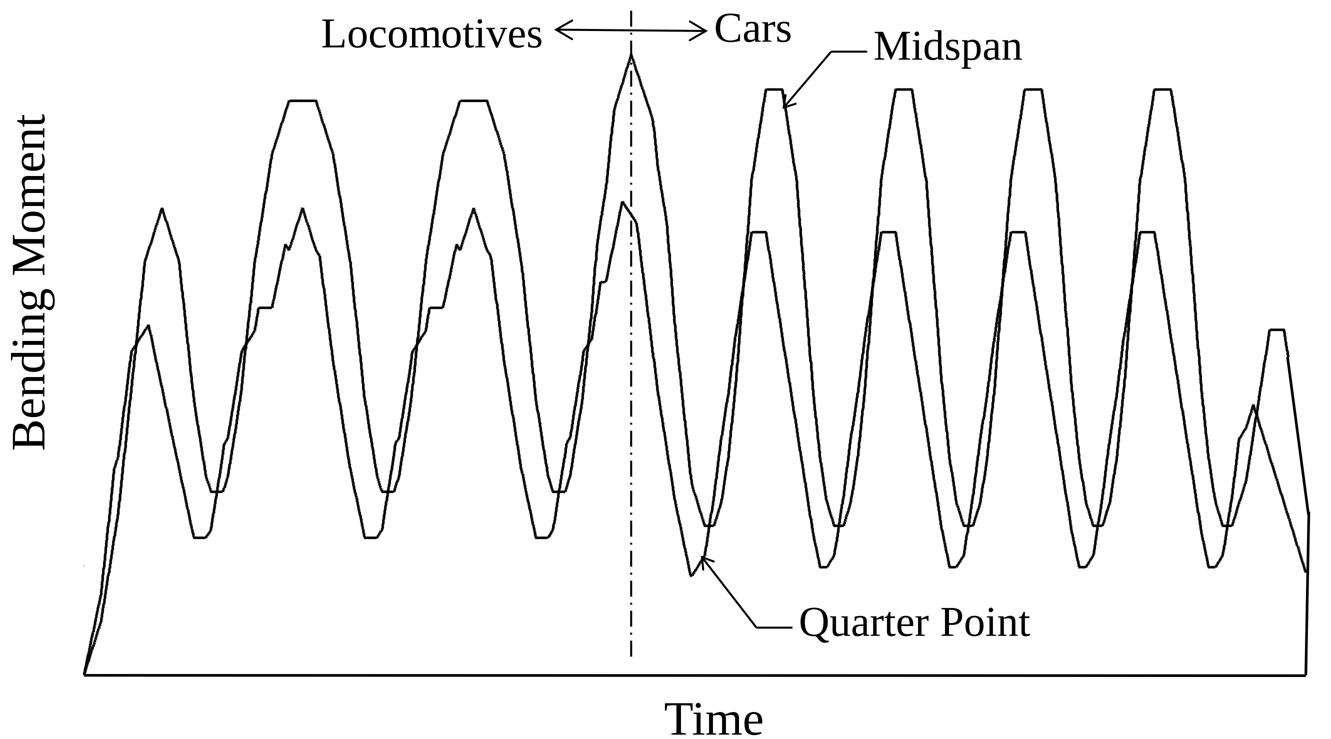
Steel Railway Bridge Fatigue

Steel Railway Bridge Fatigue

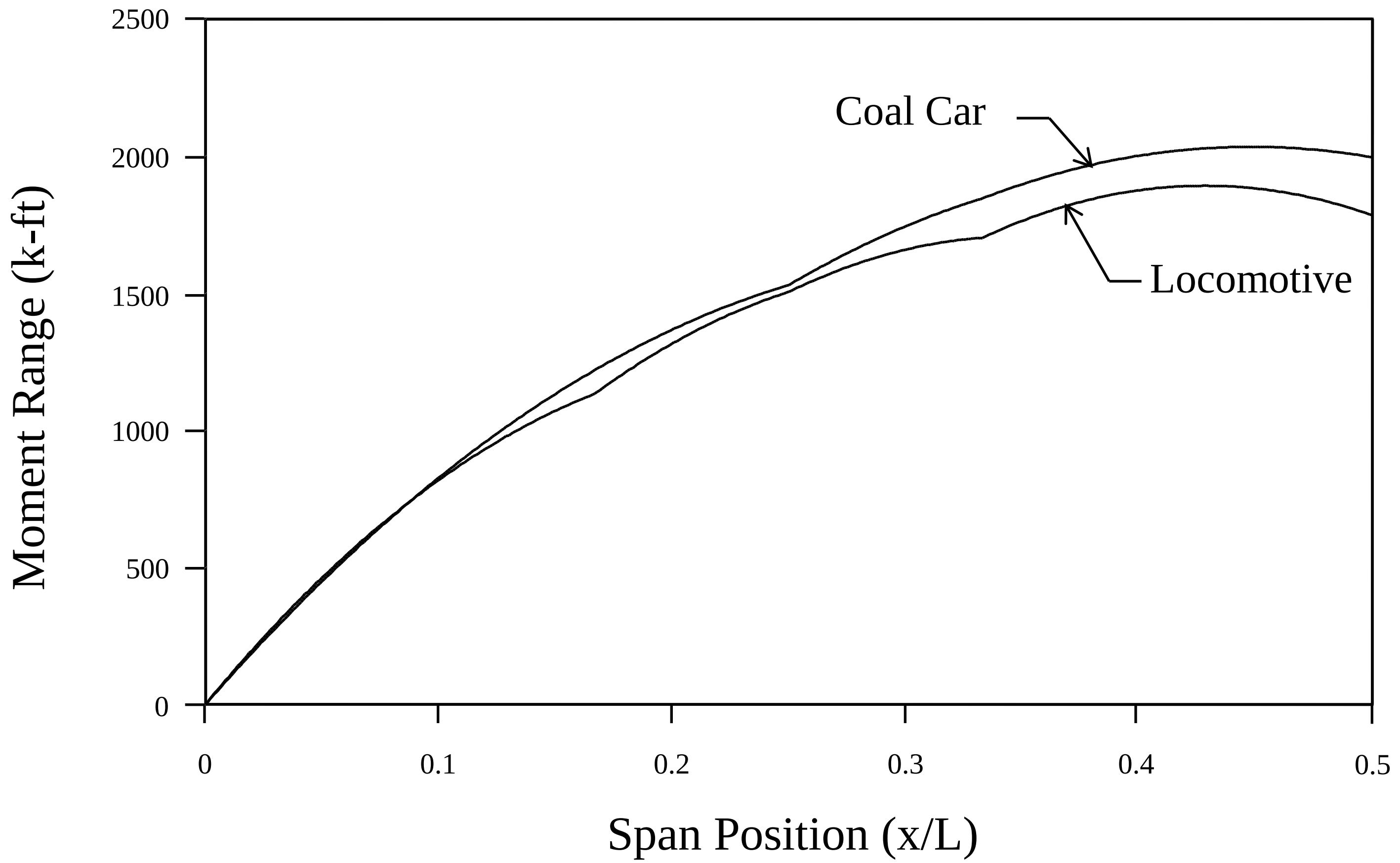
- Number of old steel railway bridges is still very high
- Increased traffic levels on fewer routes are increasing the number of potential cycles
- Increased axle weights are creating higher bending moments and cycle potential

Steel Railway Bridge Fatigue

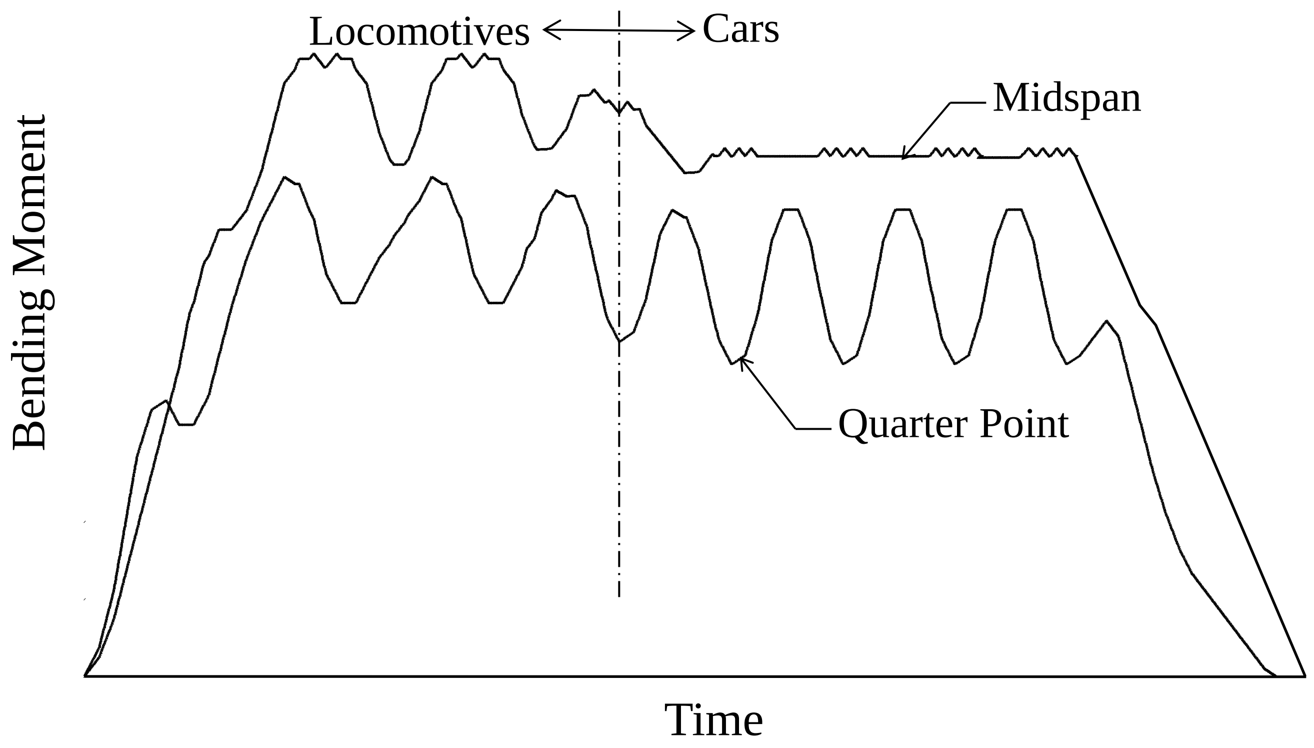
- Multiple cycles are potentially damaging from a train
- Need to examine the potential for all cycles that can occur
- Maximum moment – one overall cycle
- Moment range – one cycle per car



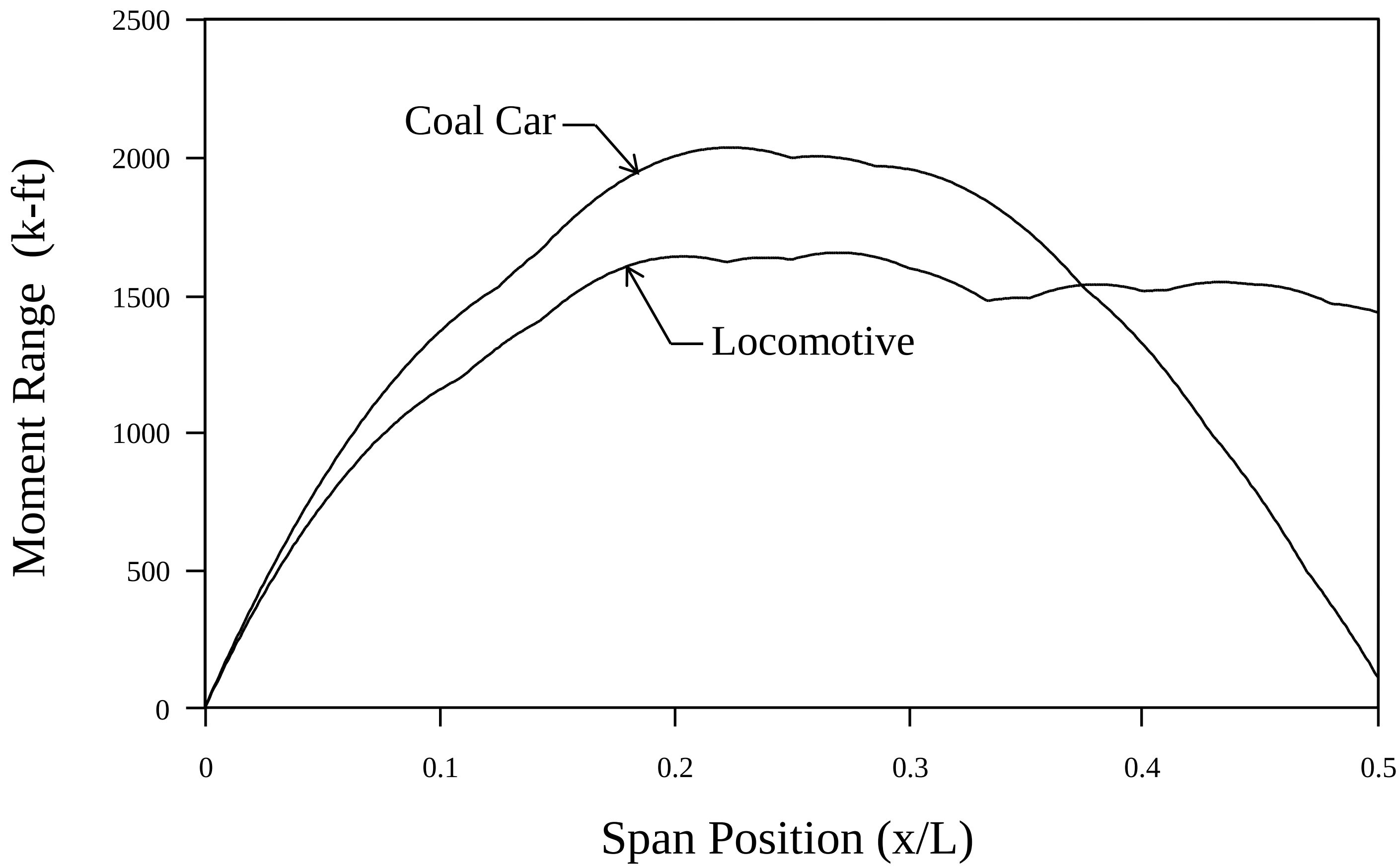
Moment Trace for a Unit Coal Train on a 50-foot Span.



Moment Range versus Span Position on 50-Foot Span

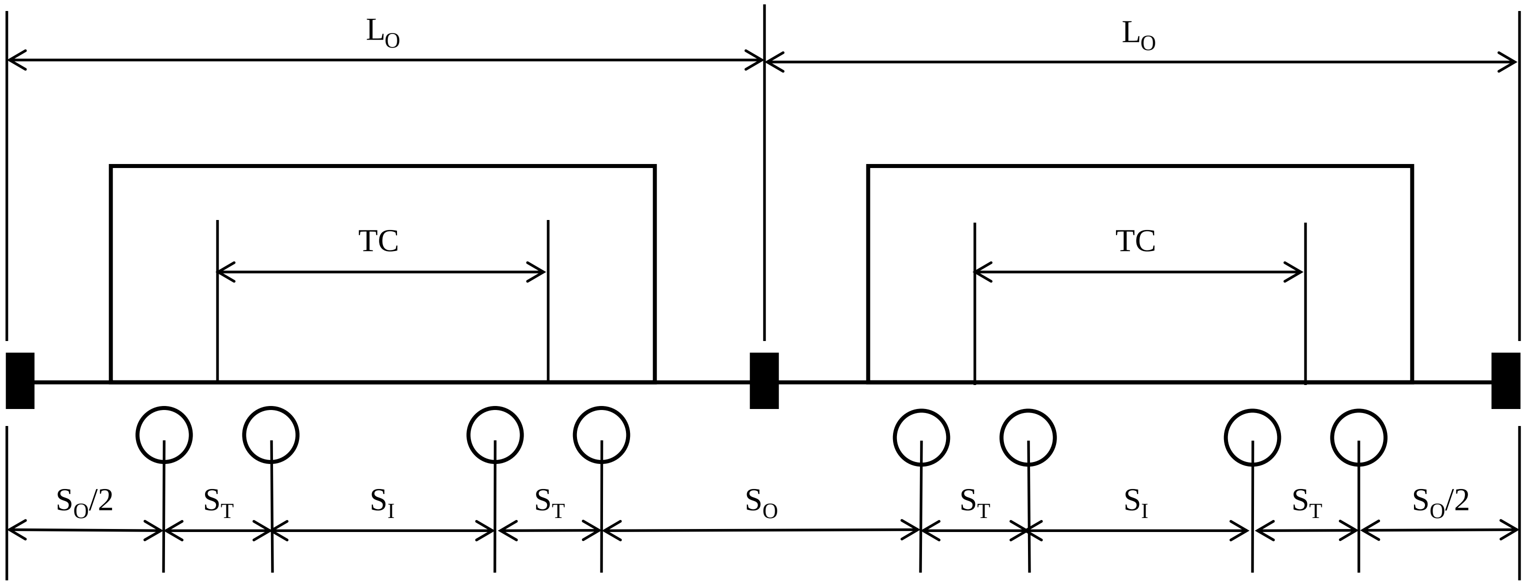


Moment Trace for a Unit Coal Train on a 100-foot Span.

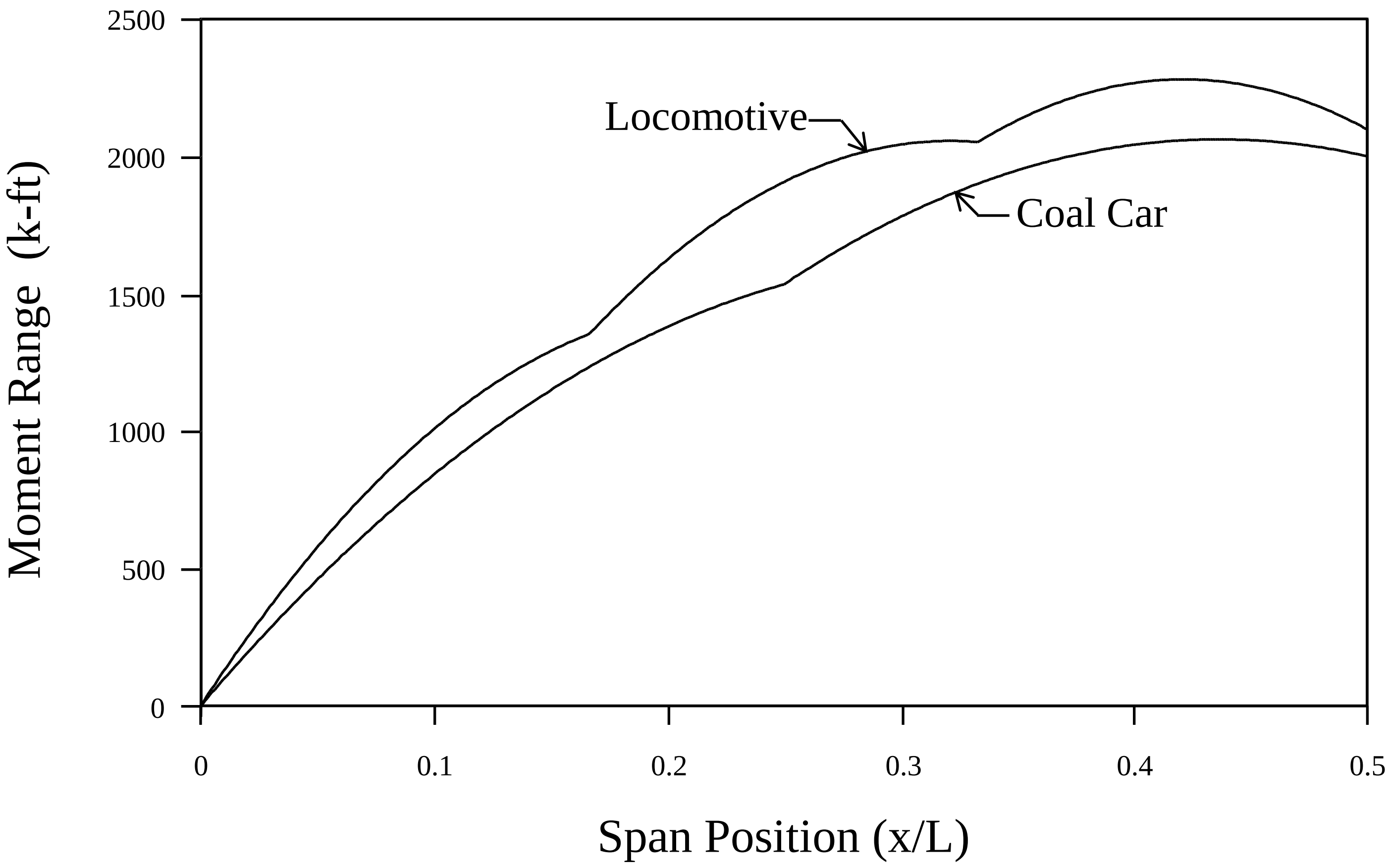


Moment Range versus Span Position on for 100-Foot Span

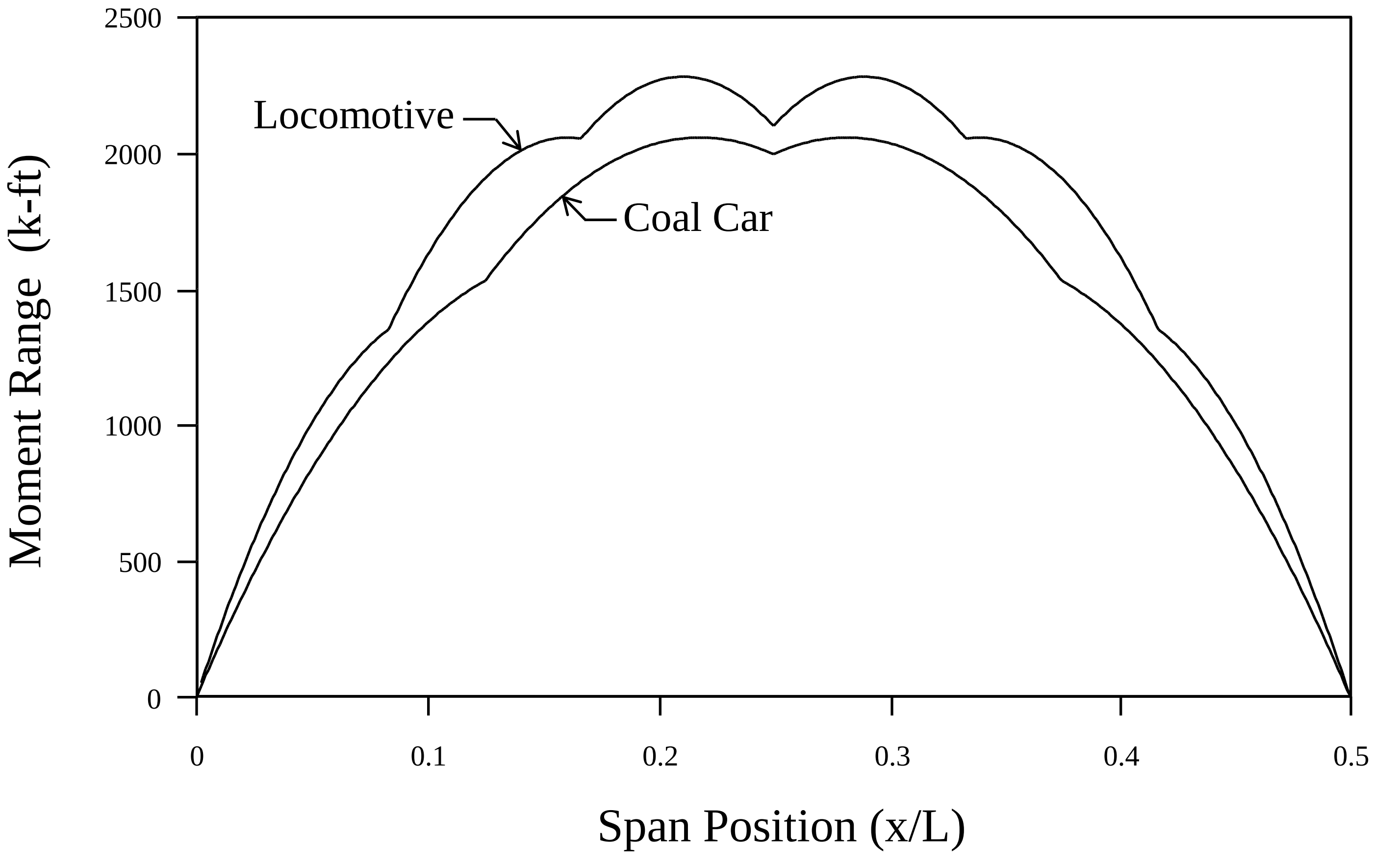
L_O - Overall length of railroad car measured over the pulling face of the coupler.
TC - Length between the center pin on the trucks, known as the truck center distance.
S_I - Inboard Axle Spacing, the distance between the inside axles of the railroad car.



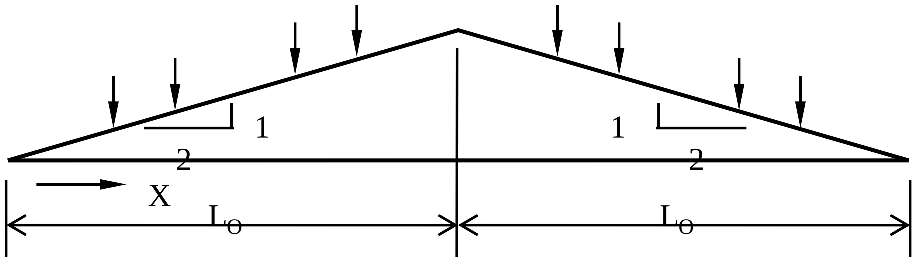
S_O - Outboard Axle Spacing, the distance between the outside axles of the railroad car.
S_T - Truck Axle Spacing, the distance between the adjacent axles of a truck.
n - number of axles
P - axle load



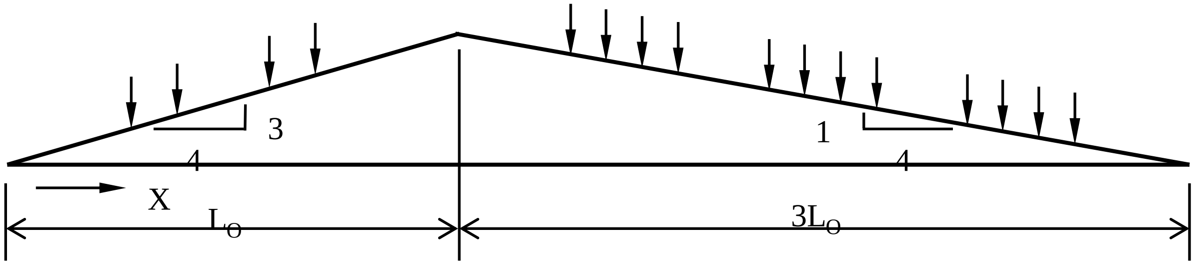
Moment Range versus Span Position on for $L_S/L_O = 1.0$



Moment Range versus Span Position on for $L_S/L_O = 2.0$



Influence 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

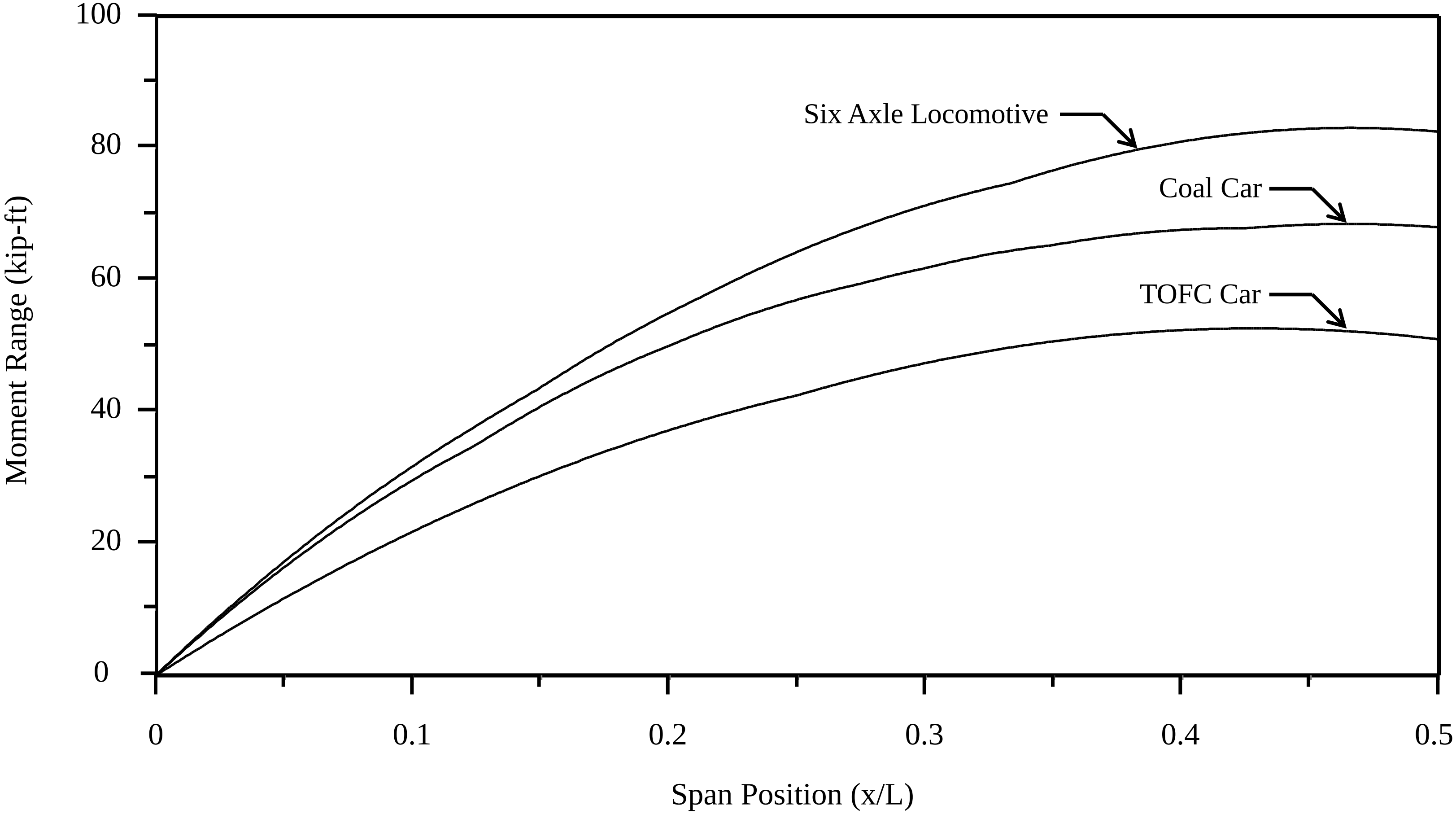
- Cyclical in nature
- Possesses an absolute maximum
- Magnitude can be estimated for integer values of L_S/L_O using a similar sine wave approximation

Moment Range

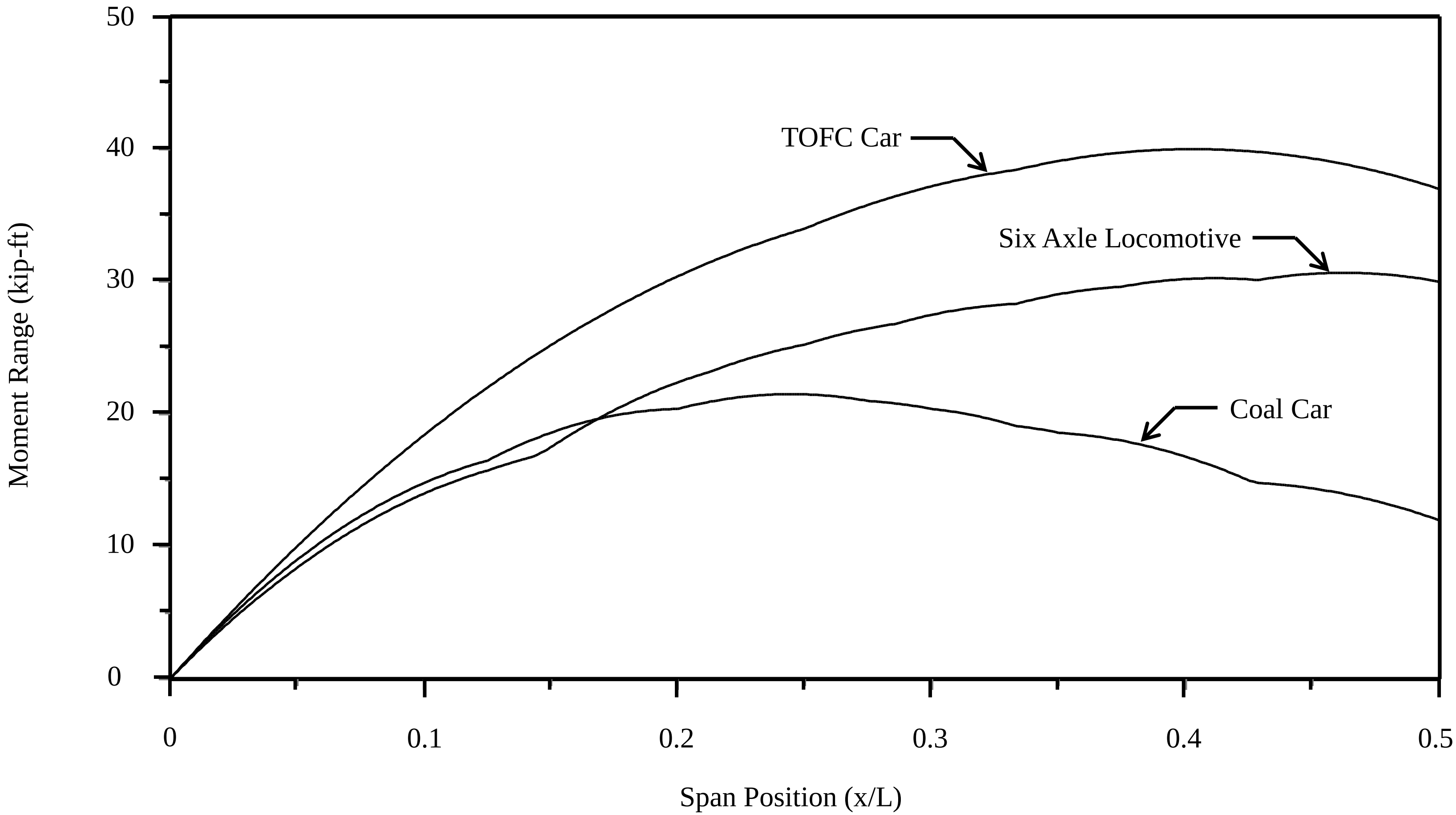
Absolute Maximum Moment Range

$$R_{AM} = nP\left[\frac{S_I}{4} - \frac{S_o}{4} + \frac{S_o{}^2}{4L_o}\right]$$

Equipment Type	Overall Length	L_S/L_O 30' span	L_S/L_O 150' span
SD70	70.00	0.43	2.14
Coal	53.00	0.57	2.83
TOFC	94.00	0.32	1.60
SPDS	71.00	0.42	2.11
APDS - End	65.26	0.46	2.30
APDS - Middle	58.83	0.51	2.55



Maximum Moment vs. Span Position – 80 ft. span



Moment Range vs. Span Position – 80 ft. span

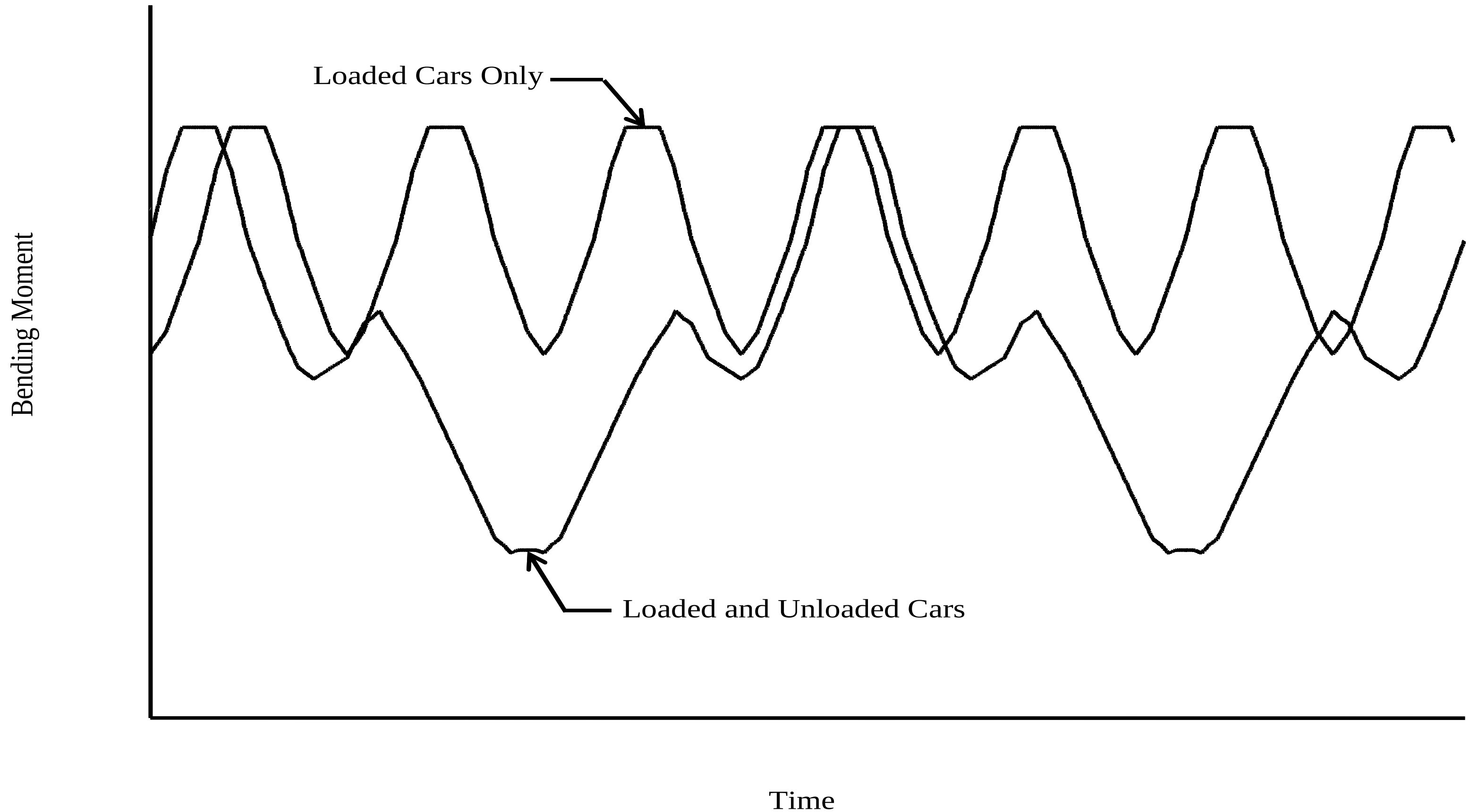


FIGURE 4. Bending Moment Versus Time For Railcar Loadings Over Long-Span Bridges

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


4867
4867
BNSF
BNSF