Load Ratings of Historic Covered Timber Bridges

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National Historic Covered Bridge Program

- Goal is to preserve, restore, and rehabilitate 800+ bridges remaining in USA
- Includes a comprehensive program focused on the historical, research, and educational aspects of covered bridges
- More than 25 research projects currently underway (or completed) by FPL and its various research partners

100 Years of Service Forest Products Laboratory 1910–2010

U.S. Department of Transportation Federal Highway Administration

National Park Service

Acknowledgements

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  - **FPL**: Doug Rammer
  - Numerous City, County, and State employees from Indiana and Vermont who assisted with load testing, provided vehicles and traffic control

Outline

- Introduction
- Methodology
- Cox Ford Bridge
- Field Testing
- Test Results
- Analytical Modeling
- Load Rating

Introduction

- All bridges, including historic covered bridges, open to vehicular traffic are required to be load rated
- No established testing or rating procedures for covered timber bridges currently available
- Load tested bridges often found to perform better than currently assigned ratings
- Need for the development of additional guidance on field testing and load rating procedures for historic covered timber bridges

Methodology

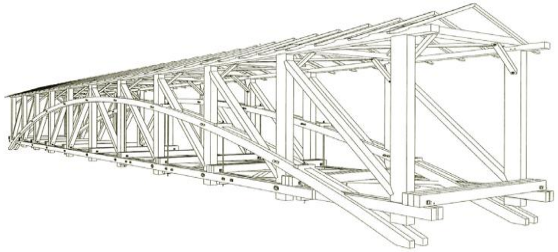
- Live load test selected bridges
- Generate analytical model (2D, simplistic)
- Calibrate model using live load data
- Apply rating vehicles to calibrated model
- **Develop testing and rating manual for covered timber bridges**

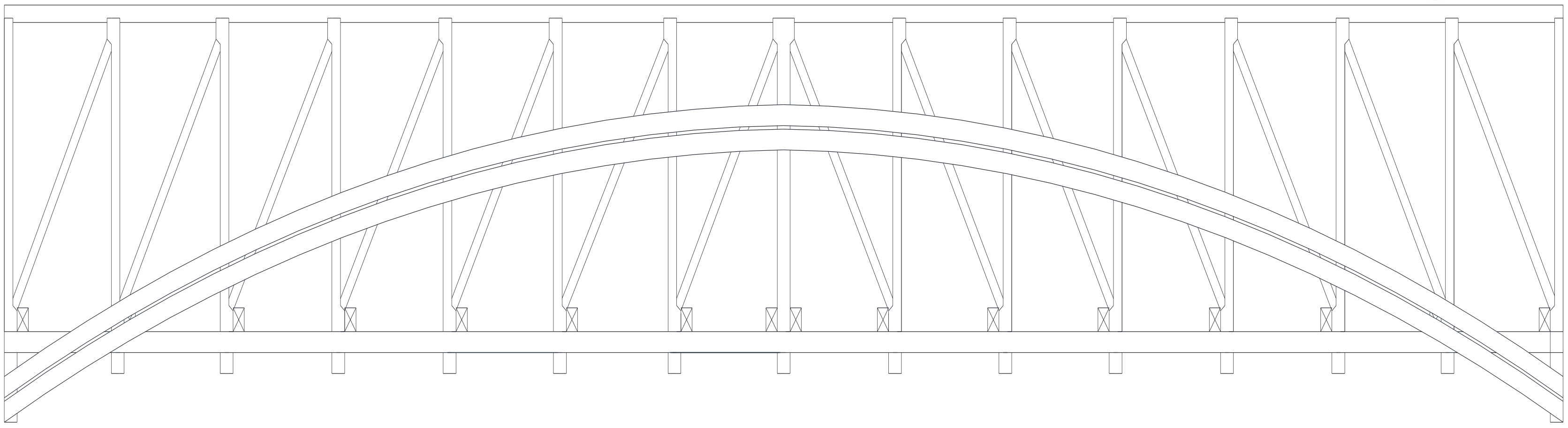
Burr-Arch Trusses

State of Indiana - 2010

Bridge	Span (ft)	Load limit (ton)
Zacke Cox	51	13
Portland Mills	120	13
Cox Ford	183	5

220+ surviving bridges



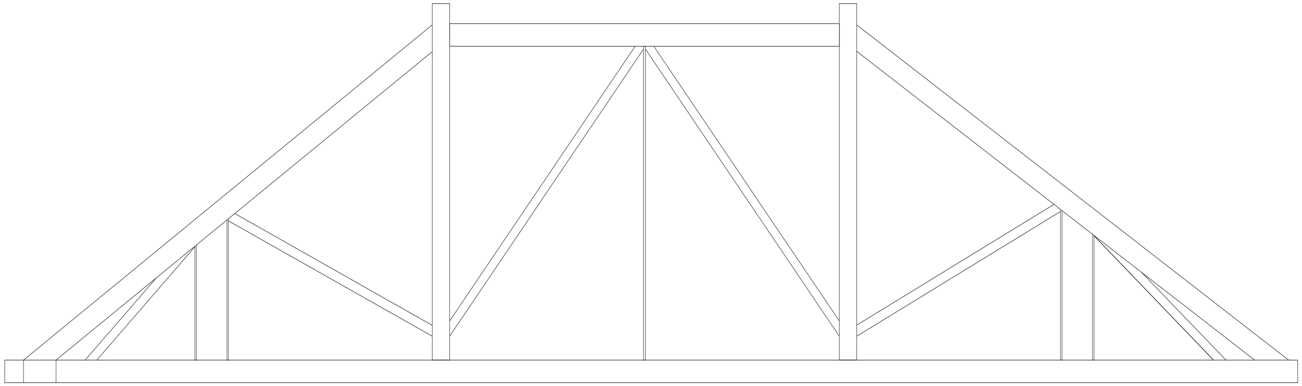


Queen Post Trusses

State of Vermont - 2011

Bridge	Span (ft)	Load limit (ton)
Warren	46	5
Flint	88	3
Moxley	55	4
Slaughterhouse	58	8

100+ surviving bridges



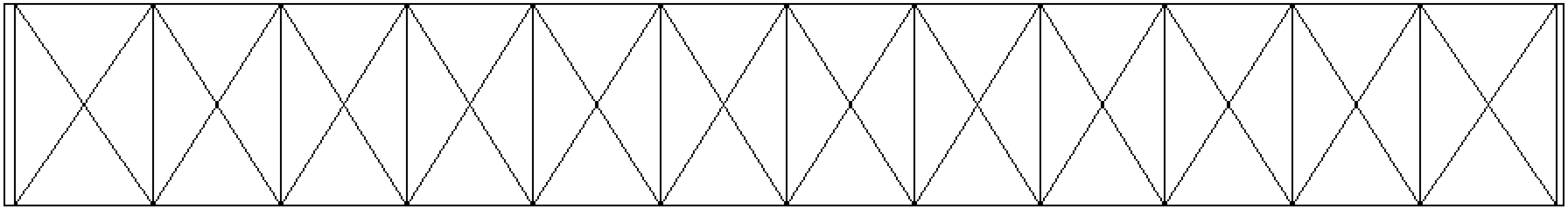
Howe Truss Bridges

State of Indiana - 2012

140+ surviving bridges

Bridge	Span (ft)	Load limit (ton)
James	123	5
Scipio	145	5
Dick Huffman*	129	8
Rob Roy*	112	3

* – 2 simple span trusses supported by intermediate pier



Example - Cox Ford Bridge

- Burr Arch, built 1913
- Parke County, Indiana
- Single, simply supported 192 ft (58.5m) span
- Posted limit - 5 ton

Field Testing

- Static Load
  - Truck 1 (~10,500lb), Truck 2 (~19,000lb)
- Displacement
  - Global
- Strain
  - Member strains (verticals, diagonals, TC, BC, etc)

Truck 1

Truck 2

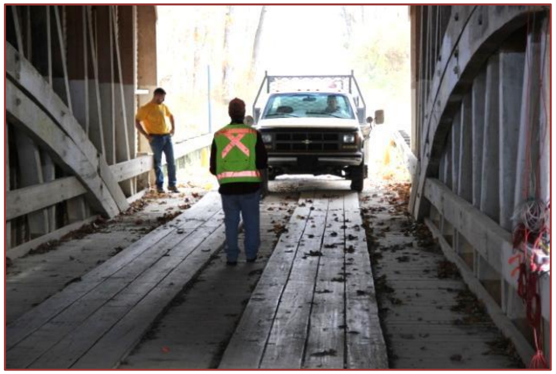
Field Testing Cont.

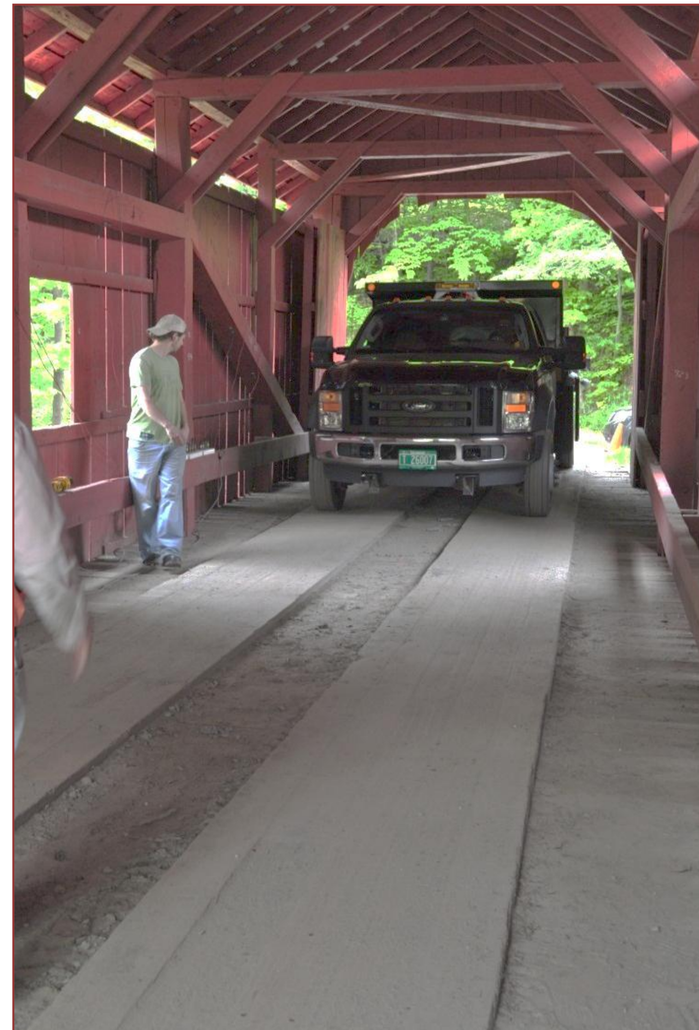
- Typical sensor setup: Deflection and Strain

Field Testing Cont.

Field Testing Cont.

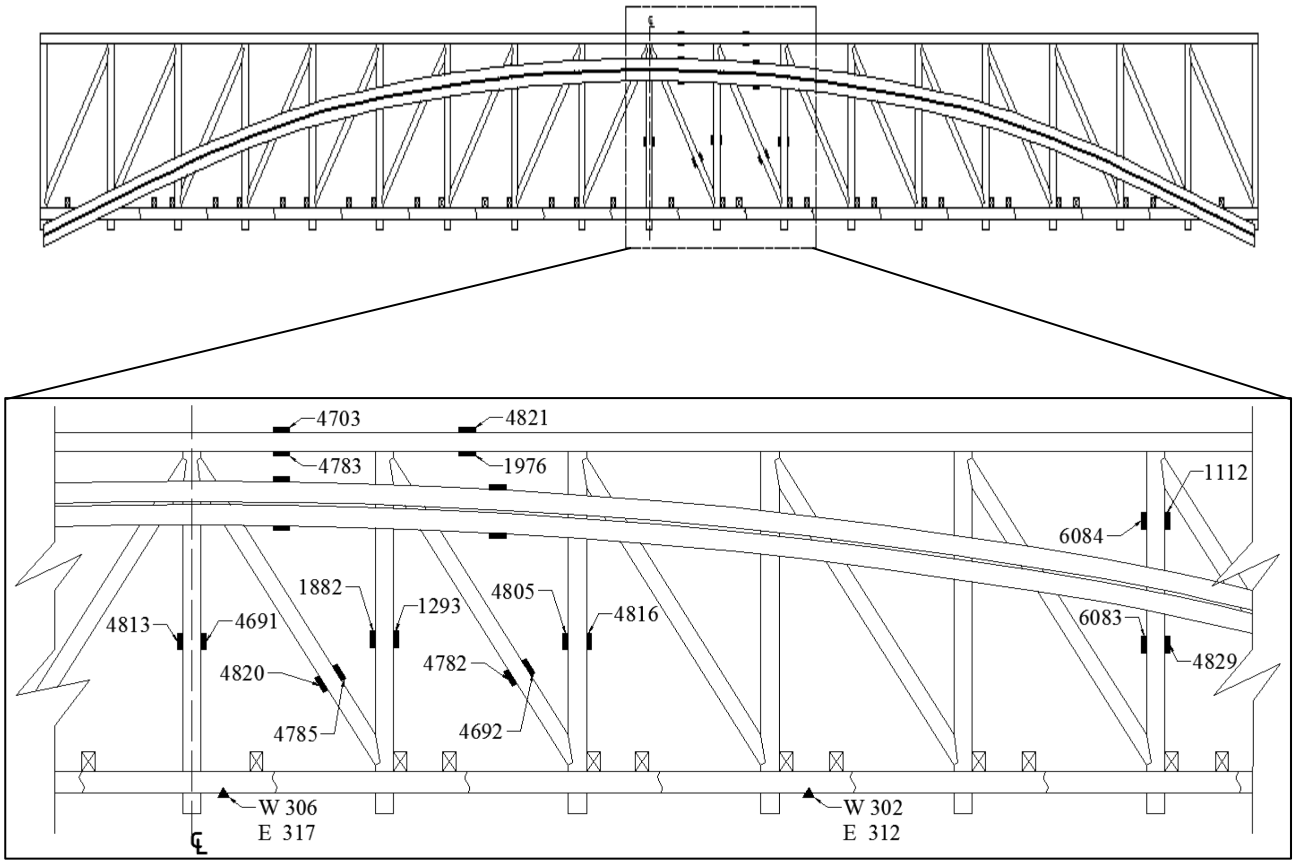
- Static Loading To Collect Deflection & Strain Envelope Data





Field Testing Cont.

- Static Loading To Collect Deflection & Strain Envelope Data

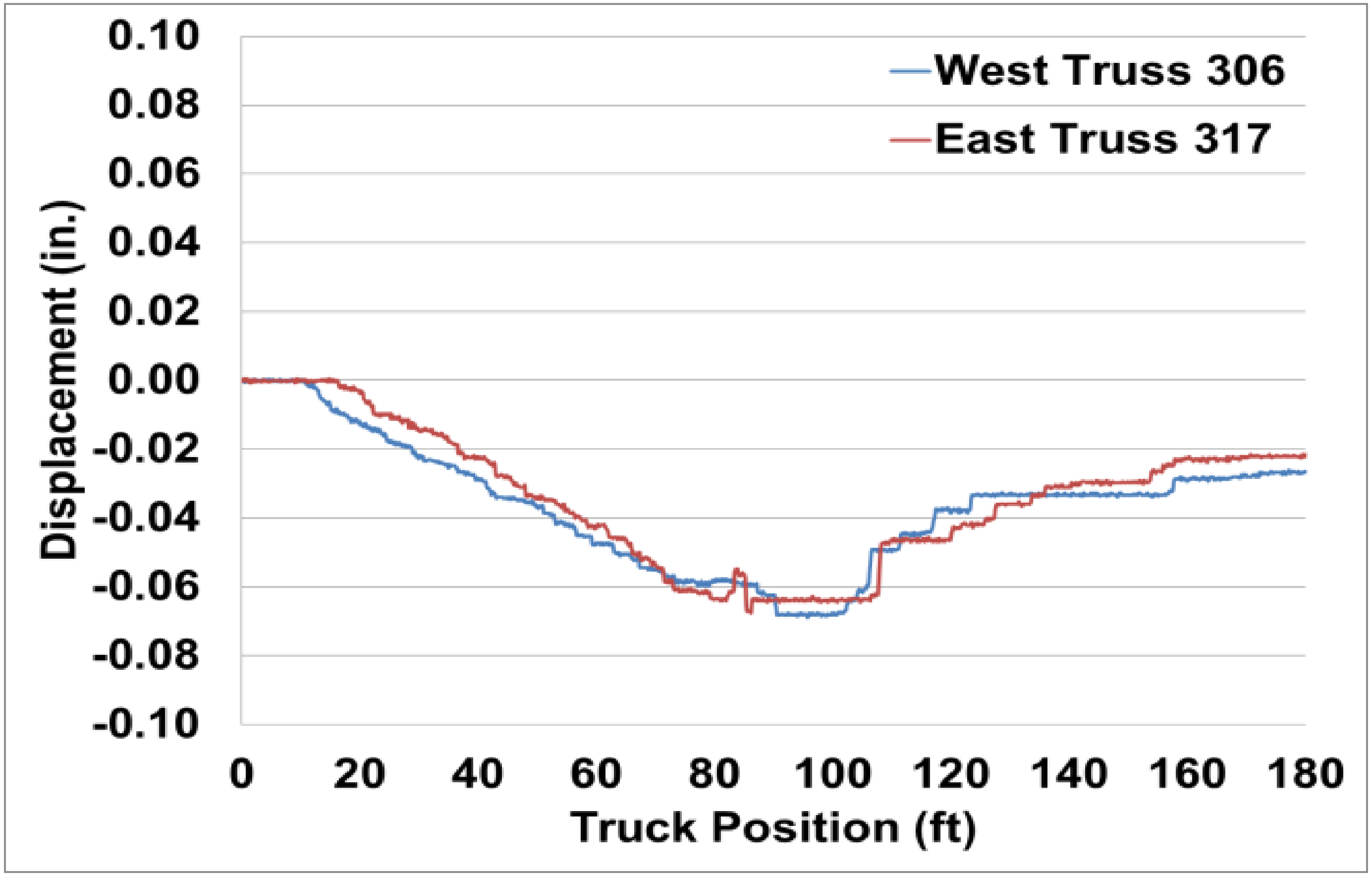


Field Test Results

- Two Key Goals of Collecting Field Data:
  1. Quantitatively AND Qualitatively evaluate response of Structure:
     - Transverse load distribution
     - Elastic response
     - End restraint
     - Truss member response; fixity in member connections
  2. Calibrate analytical model

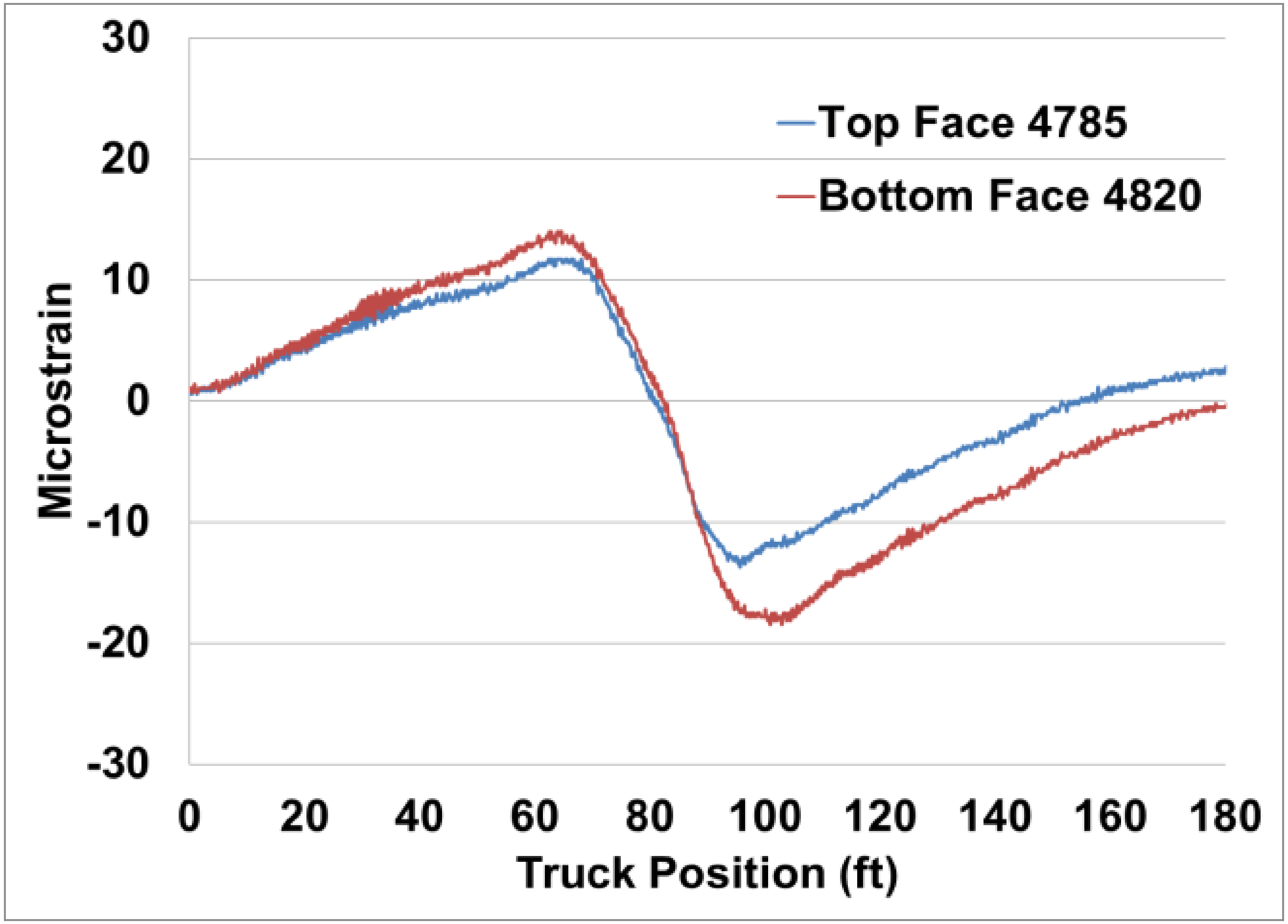
Field Test Results

- Midspan Global Displacements



Field Test Results

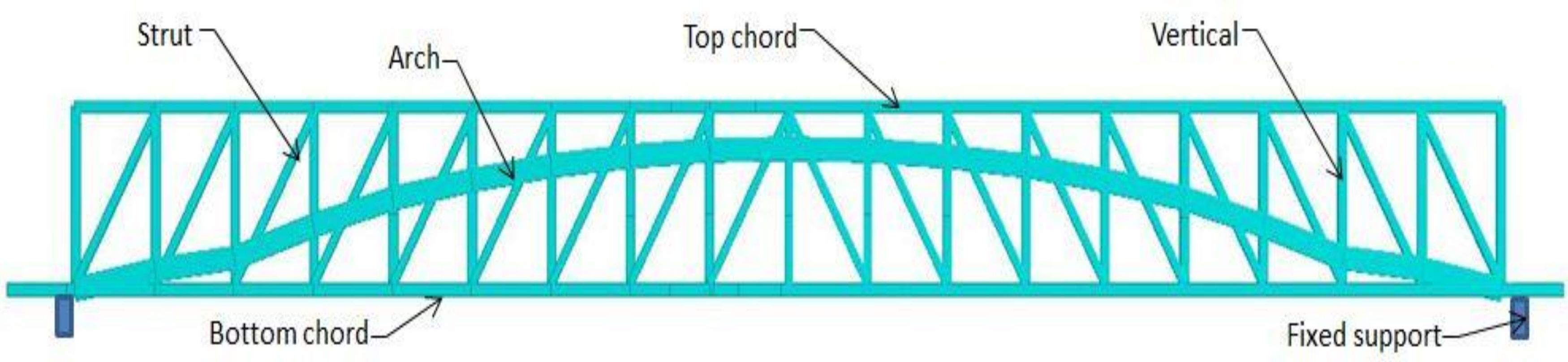
- Strain, Diagonal Truss Member



Analytical Modeling

➢ Model Generation

- STAAD
- Linear elastic approach
- 2-D (one truss)



Analytical Modeling

- Initially Pinned-Pinned
- Bottom Chord = continuous, beam elements
- Top Chord = continuous, beam elements
- Diagonal/Verticals = beam elements
- Arch = compression elements

Model Calibration

- Response Parameter – Strain
- Compare: F_S vs $A.S_S$
  - F_S - Field strain (measured during live load test)
  - $A.S_S$ - model strain (strain computed from analytical model)
- Percent deviation $= \frac{(F.S-A.S)^2}{(F.S)^2}$
- Modify model parameters (dimensions, E, etc.)
- Re-evaluate percent deviation until model response correlates with field response

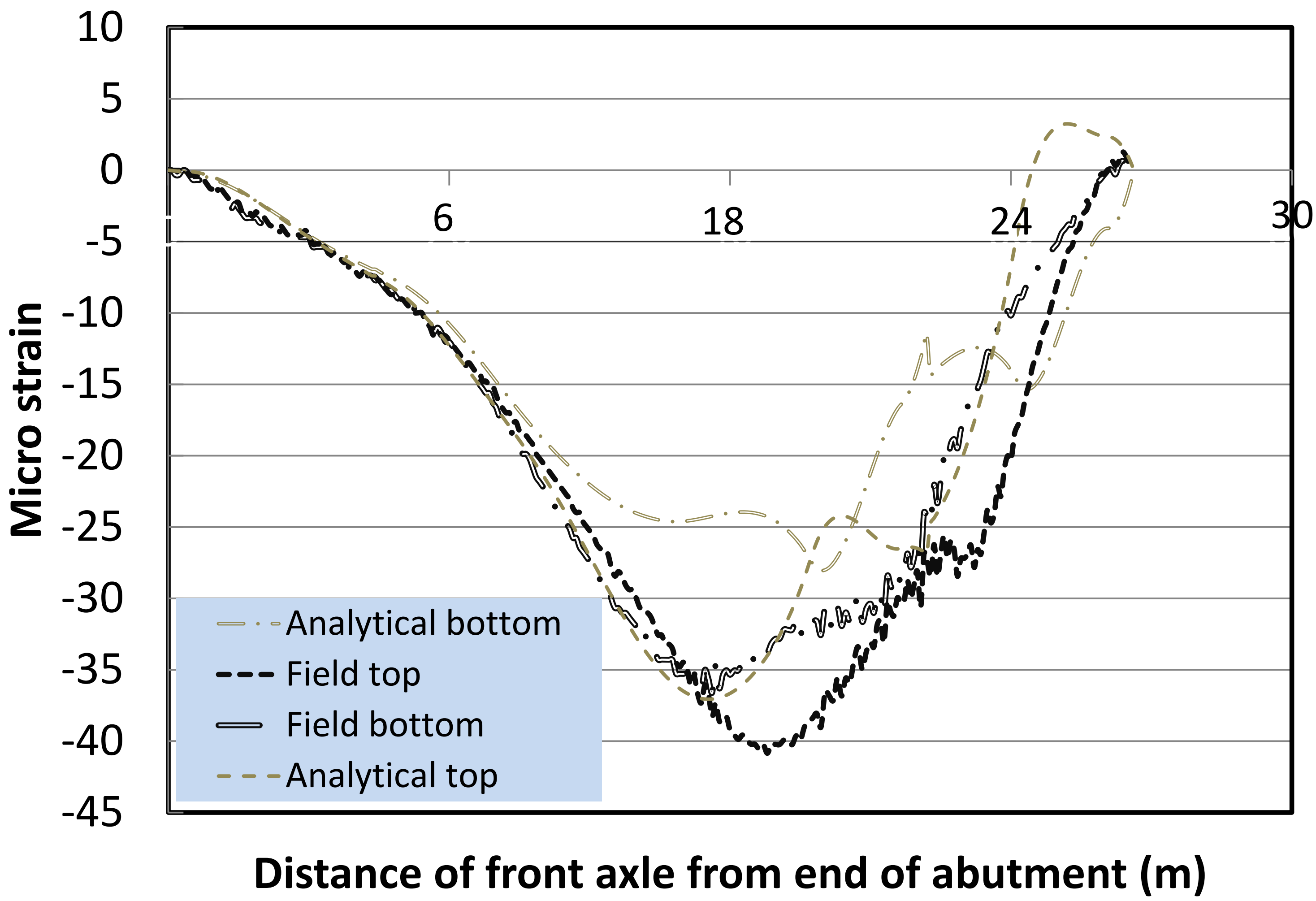
<u>*Result = Calibrated model for load rating*</u>

Model Calibration Cont.

- Pinned-Pinned revised to Fixed-Fixed
- Response bounded by P-P, F-F…as expected
  - HOWEVER, rather than modifying end restraint with complex joint fixity parameters (springs), a simpler, more straight forward approach was developed to obtain an accurate model:
    - Fixed supports, pinned member connections, truss elements for verticals/diagonals/TC, beam element for BC
  - Model correlation with field data improved from 40-50% to 75-85%

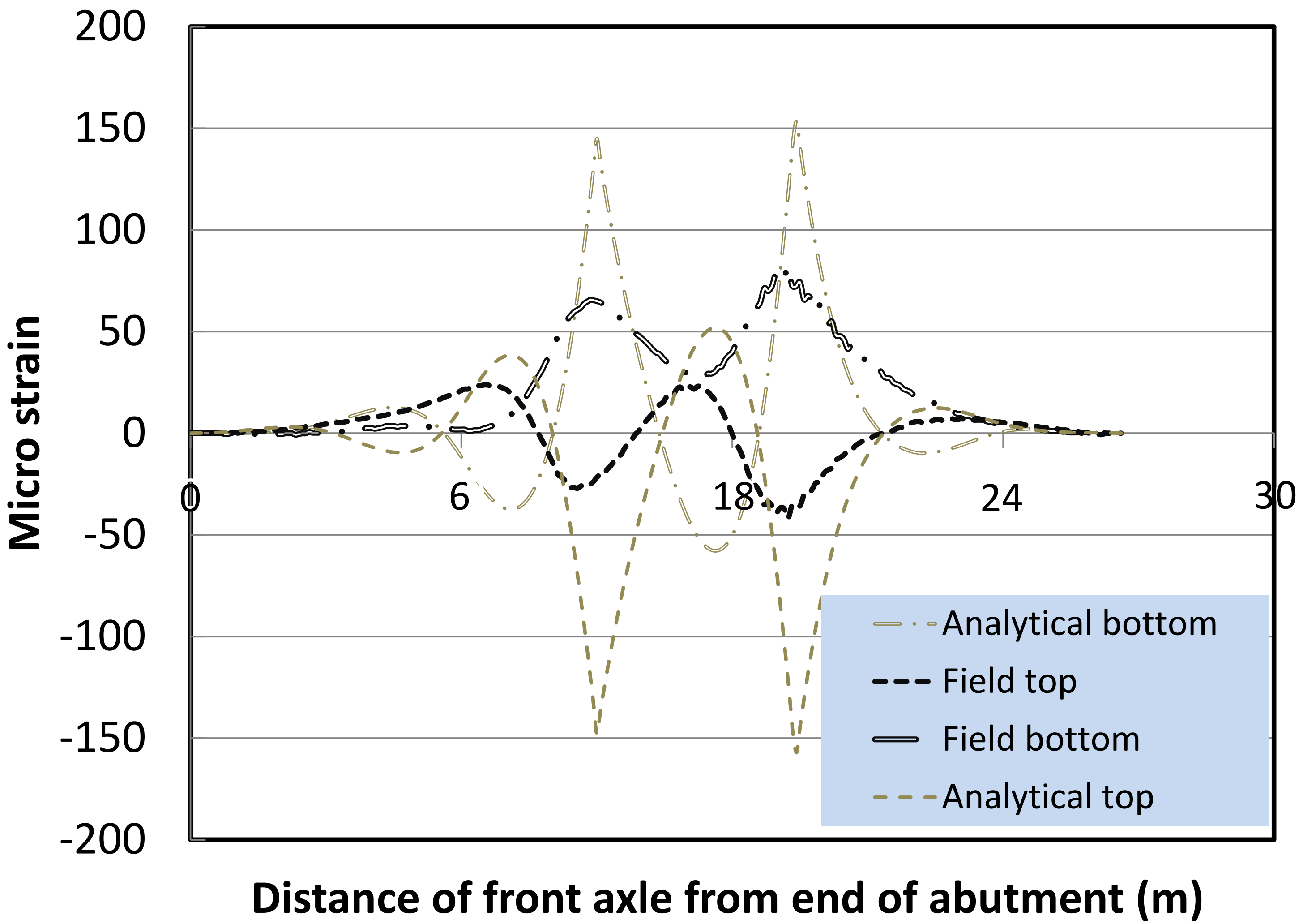
Graphical Calibration:

Top Chords



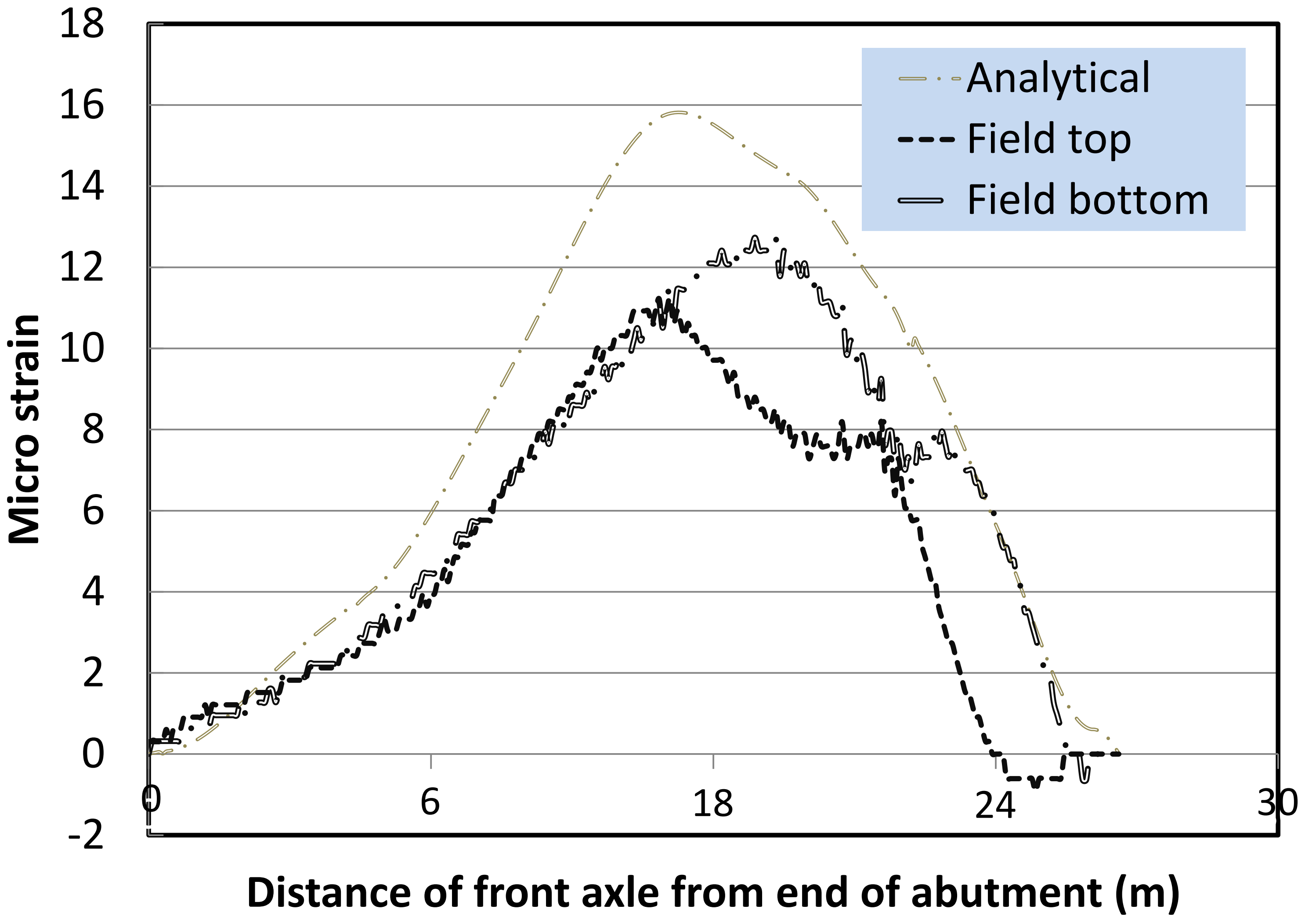
Graphical Calibration:

Bottom Chords



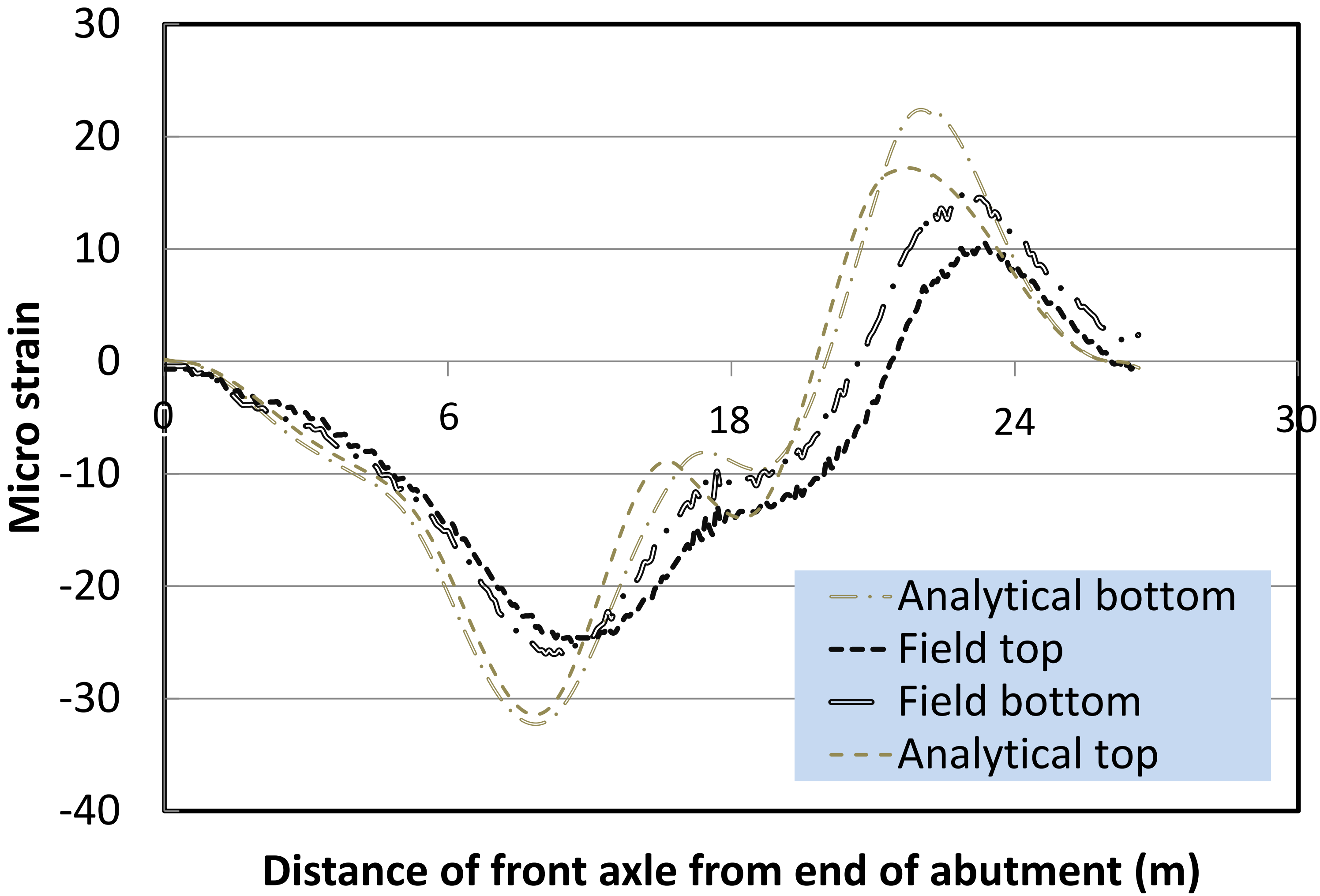
Graphical Calibration:

Verticals



Graphical Calibration:

Diagonals



Load Rating

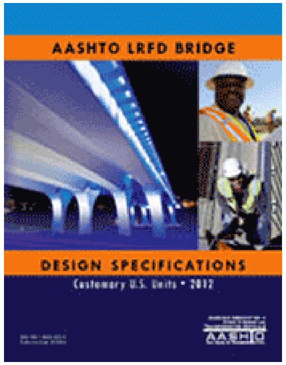
- Create calibrated analytical model
- Dead loads
- Live loads (AASHTO LRFR Manual)
- Impact factor
- Calculate member capacities
- Perform load rating – input live load vehicle data into model to run simulated rating load on calibrated analytical model

Load Rating Computations:

➢ AASHTO LRFD approach to Load Rating

- HL-93 (320kN) = HS20 truck plus superimposed lane load

- $RF = \frac{C-(\gamma_{DC})(DC)}{(\gamma_L)(LL+IM)}$



where: C = Capacity;

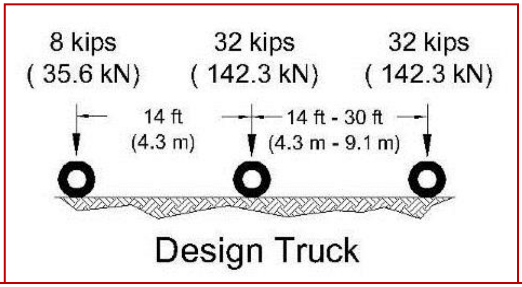
γ_{DC} = dead-load factor;

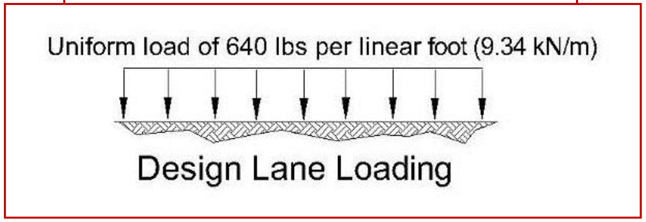
DC = dead load;

γ_L = live-load factor;

LL = live load;

IM = dynamic load factor





Load Rating Computations:

Single Force Component: Axial or Bending

Axial

- Calculate member capacity, C
- Check lateral buckling (compression)
- Calculate unfactored member response to loading, DC & LL
- $RF = \frac{C-(\gamma_{DC})(DC)-(\gamma_{DW})(DW)\pm(\gamma p)(P)}{\gamma_L(LL+IM)}$

Bending

- Calculate member moment capacity, C
- Calculate unfactored member response to loading, DC & LL
- $RF = \frac{C-(\gamma_{DC})(DC)-(\gamma_{DW})(DW)\pm(\gamma p)(P)}{\gamma_L(LL+IM)}$

Load Rating Computations:

Combined Forces: Axial PLUS Bending

Bottom Chord

- M_r - Flexural Bending Capacity
- P_r - Axial (tension or compression) Capacity
- M_u - Factored Bending Response
- P_u - Factored Axial Response
- Evaluate Interaction Eq. (IE) for Combined Loading => Load Rating
  - $\left(\frac{\mathrm{Mu}}{\mathrm{Mr}}\right) + \left(\frac{\mathrm{Pu}}{\mathrm{Pr}}\right)^{\mathrm{x}} \leq 1 \quad \mathrm{x} = 1 \text{ in tension}, 2 \text{ in compression}$
    - If IE $\leq$ 1, member capacity ok
    - If IE > 1, member capacity insufficient

Load Rating Computations:

- If IE > 1, we need to calculate the live load reduction factor (load rating) that makes IE = 1
- $\left(\frac{Mu}{Mr}\right) + \left(\frac{Pu}{Pr}\right)^{x} \leq 1$ => $\{(a_1 * z)+c_1\}+\{(a_2 * z)+c_2\}=1$
  - Where,
    - a_1 = live load response to flexure
    - c_1 = dead load response to flexure
      - (M_u/M_r)
    - a_2 = live load response to axial
    - c_2 = dead load response to axial
      - (P_u/P_r)
    - z = live load reduction factor = load rating

Summary

- Field testing of Burr Arch, Howe and Queen Post –
  Total of 11 bridges completed
- Analytical models calibrated for all bridges
- Developed new recommended practices for live load testing, modeling and load rating of historic covered bridges
- New engineer’s guide for live load testing, modeling and load rating of historic covered bridges in draft form

Future Work

- Phase II - Test remaining truss types
  - bridge clusters (PA, VT, IN)
    - King Post
    - Town Lattice
    - Burr Arch

- Field work to focus more closely
  - Truss joint load-slip behavior
  - Bottom chord behavior

Thanks for your Attention.

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U.S. Department of Transportation
Federal Highway Administration

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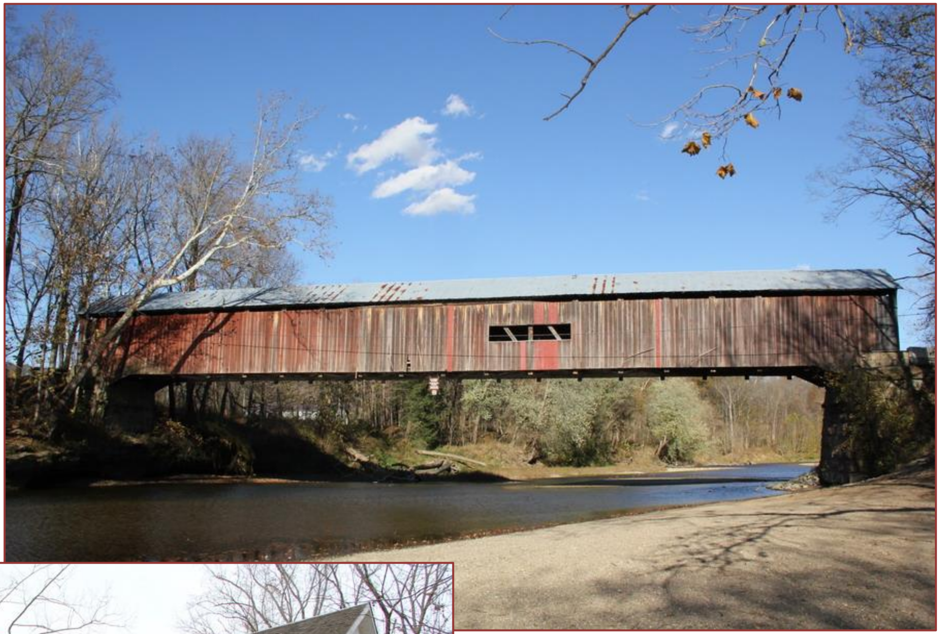
This study is part of the Research, Technology and Education portion of the **National Historic Covered Bridge Preservation** (NHCBP) Program administered by the Federal Highway Administration. The NHCBP program includes preservation, rehabilitation and restoration of covered bridges that are listed or are eligible for listing on the National Register of Historic Places; research for better means of restoring, and protecting these bridges; development of educational aids; and technology transfer to disseminate information on covered bridges in order to preserve the Nation's cultural heritage.

Burr-Arch Truss Bridges



Queen Post Truss Bridges

Howe Truss Bridges