Live Load Testing of Historic Covered Timber Bridges

ICTB 2013

Las Vegas

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Notables

- Improved Analytical Techniques for Historic Covered Bridges

- Acknowledgements:
  - ISU: Doug Wood, Dr. Brent Phares, Dr. Terry Wipf, Dr. Dr. Junwon Seo, Dr. Fouad Fanous, Allison Machtemes, Owen Stephes, Justin Dahlberg, Venkata Kollipara
  - FPL: Jim Wacker, Doug Rammer
  - Numerous City, County, and State employees from Indiana and Vermont who assisted with load testing, provided vehicles and traffic control

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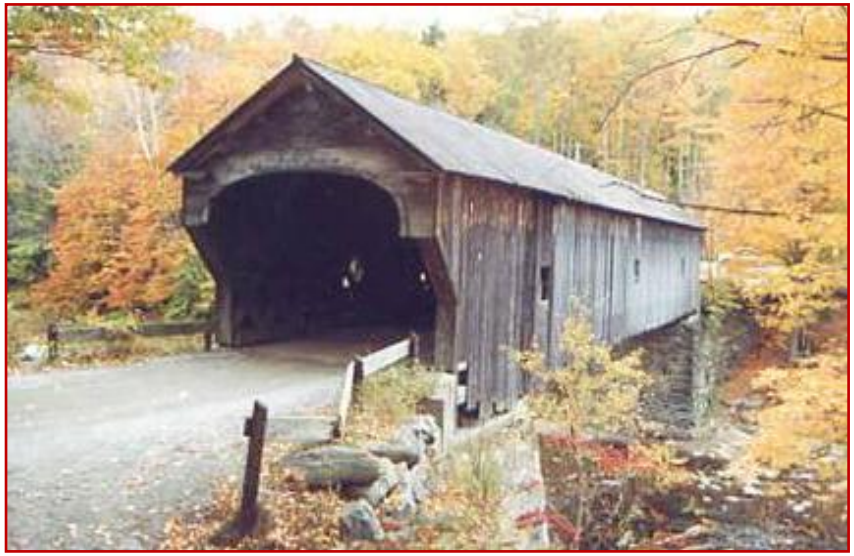
Outline

- 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
- Currently no established testing or rating procedures for covered timber bridges
- Tests repeatedly show: Load tested bridges often perform better than currently assigned ratings

Methodology

- Live load test selected bridges
  - 3 – Burr Arch (IN), 4 – Queenpost (VT), 4 – Howe (IN)
    - ❖Collected the following information:
      - ✓ Member dimensions
      - ✓ Member strains
      - ✓ Global/local displacements
      - ✓ Material properties (FPL)
- 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**

Selected Bridges

- 3 – Burr Arch (IN)
- 4 – Queenpost (VT)
- 4 – Howe (IN)
  - Collected the following information:
    - ✓ Member dimensions
    - ✓ Member strains
    - ✓ Global/local displacements
    - ✓ Material properties (FPL)

Cox Ford Covered Bridge

- Burr Arch, 1913 (rehab 1975 and 1991)
- Parke County, Indiana
- Single, simply supported 192 ft (58.5m) span
- Posted 5 ton

Field Testing

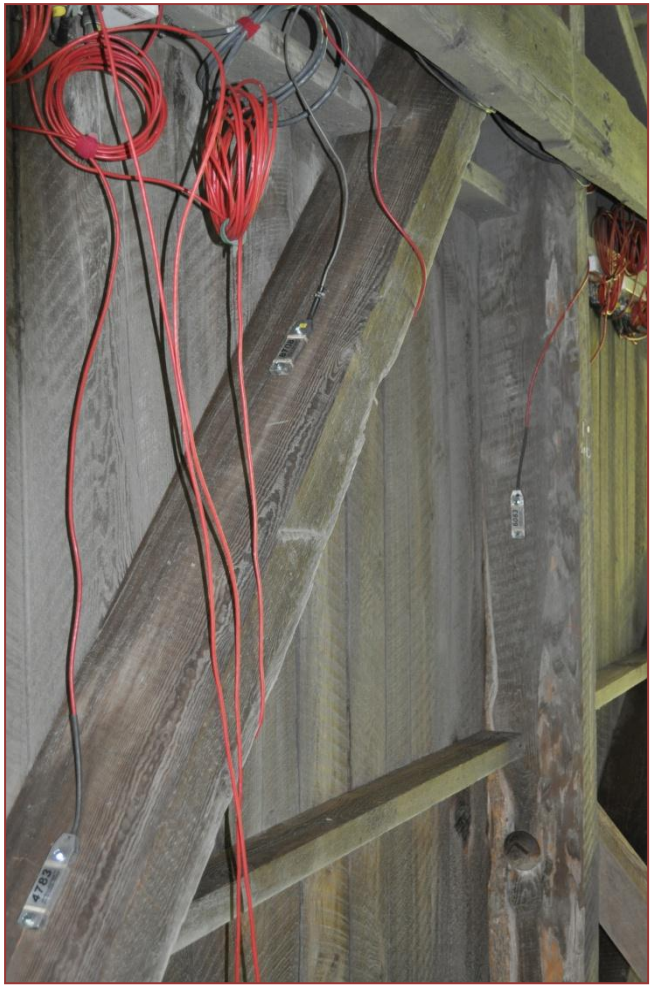
- Static Load
  - Truck 1 (~10,500lb), Truck 2 (~19,000lb)
- Displacement
  - Global
- Strain
  - Member strains (verticals, diagonals, TC, BC, etc)

Truck 1

Truck 2

Field Testing Cont.

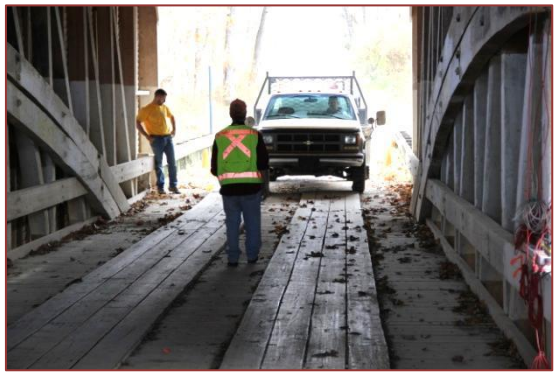
- Typical sensor setup: Deflection and Strain

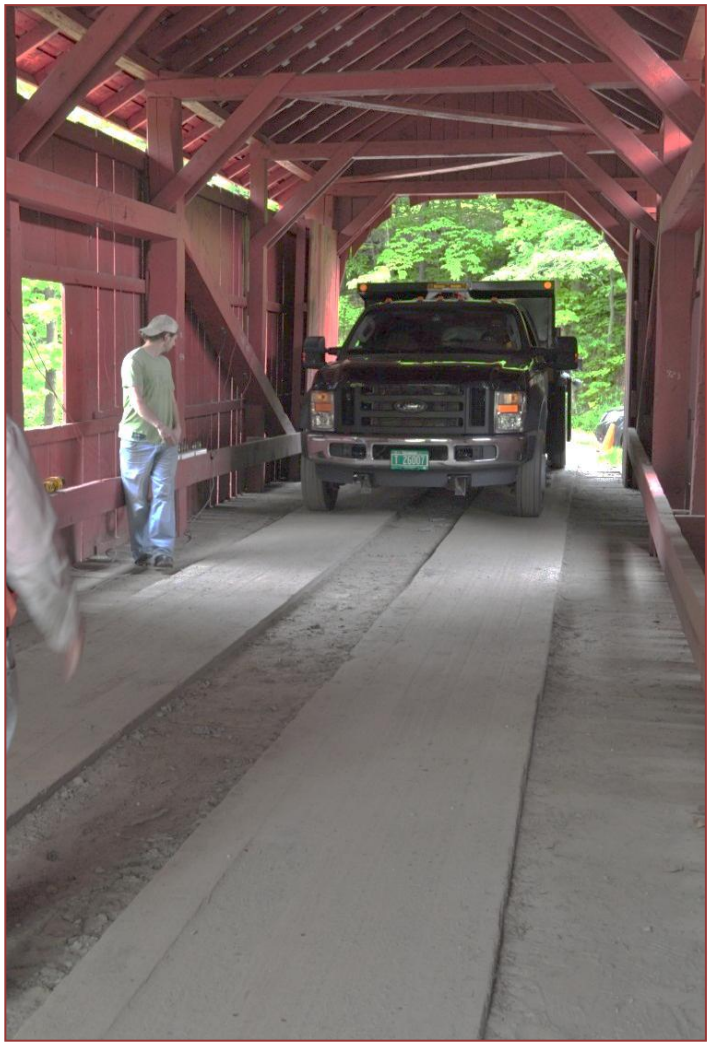


Field Testing Cont.

Field Testing Cont.

- Static Loading To Collect Deflection & Strain Envelope Data





Field Testing Cont.

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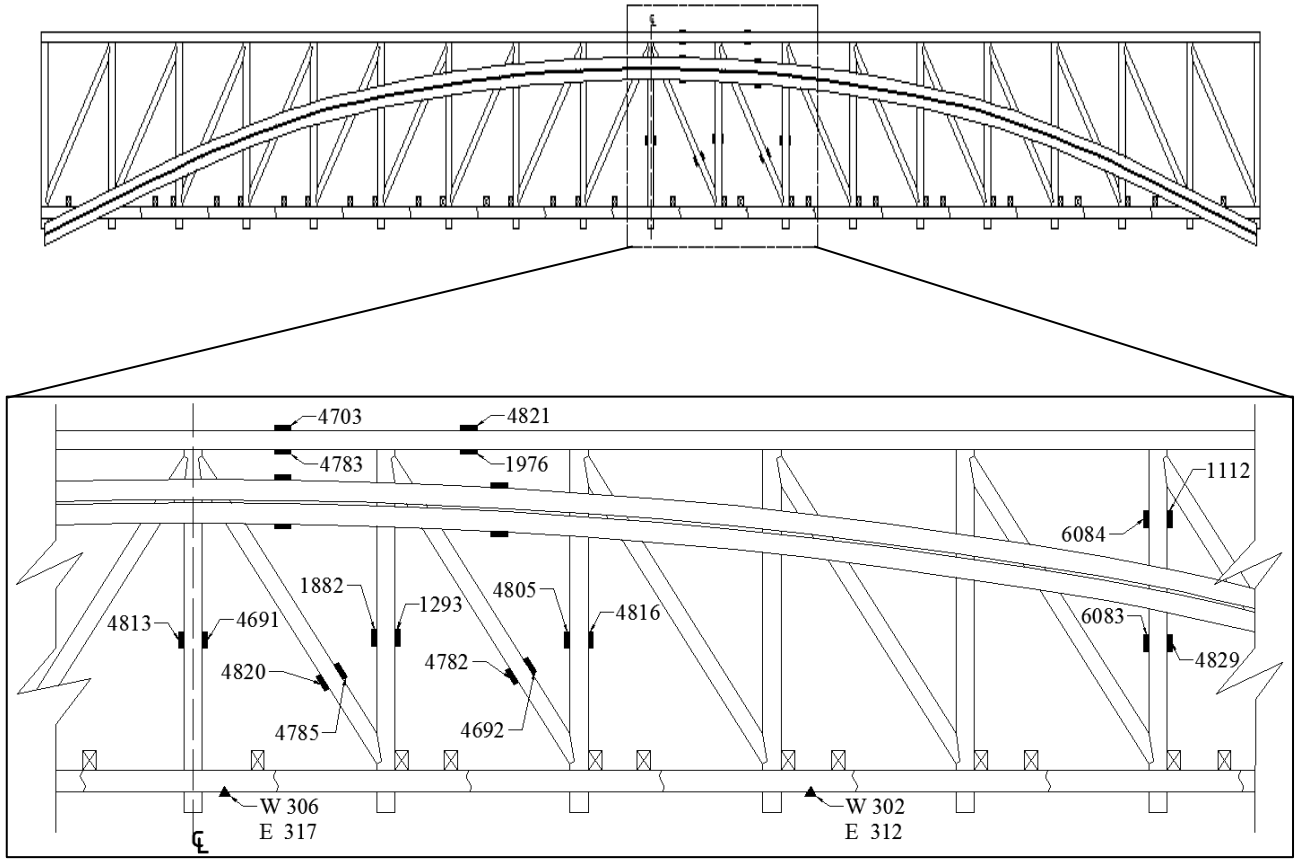
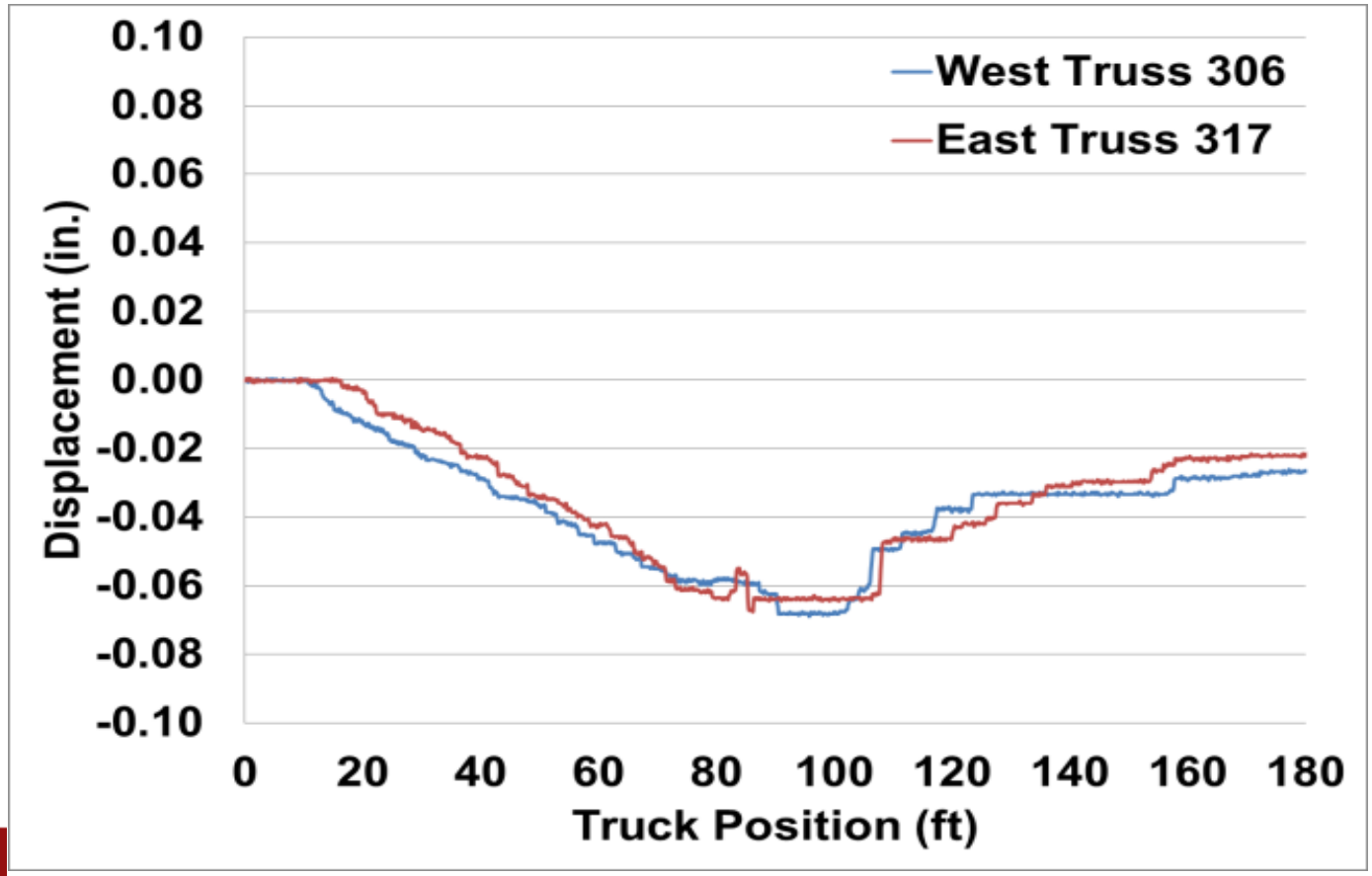


Field Test Results

- 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

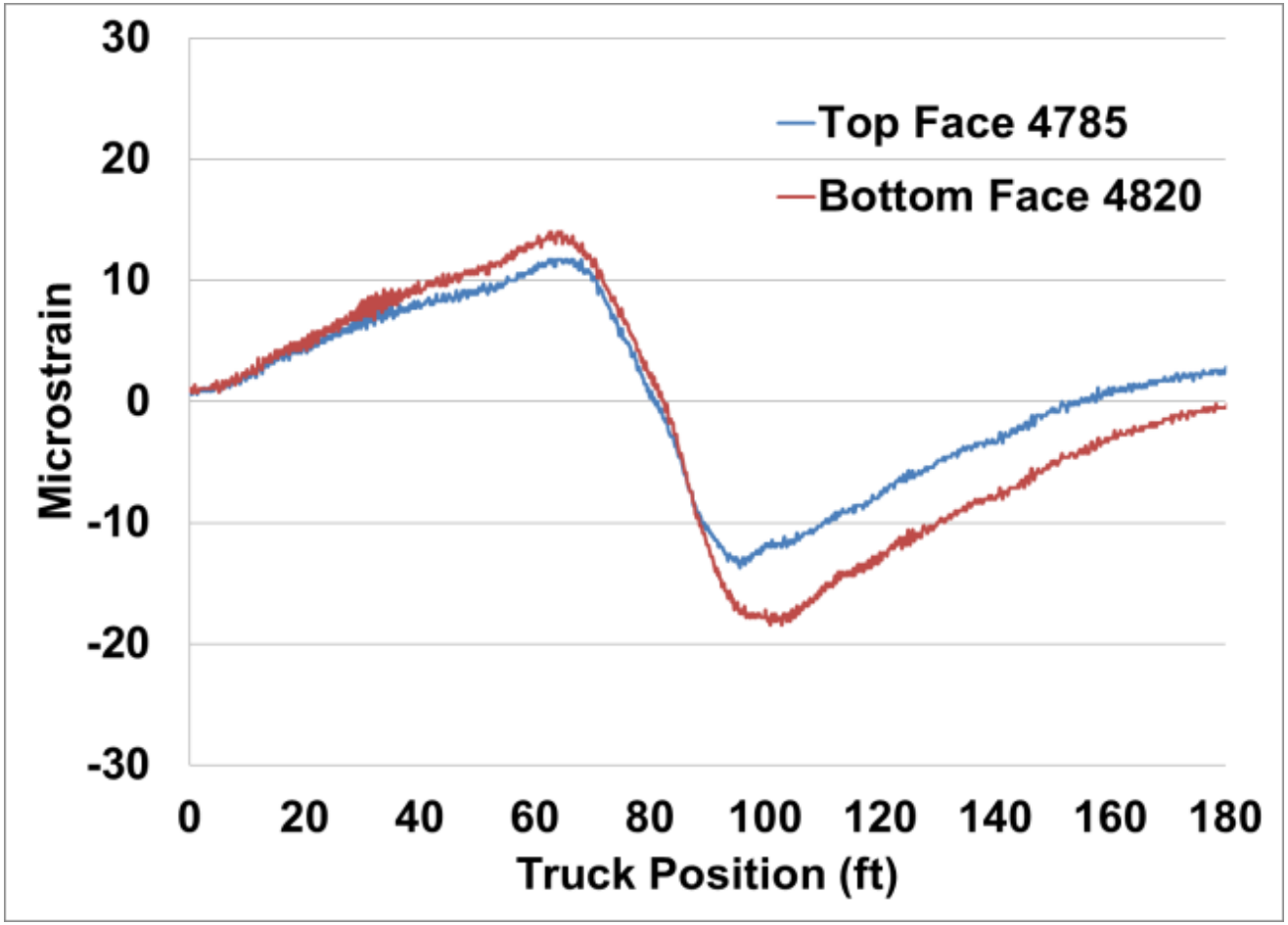
Field Test Results

- Midspan Global Displacements



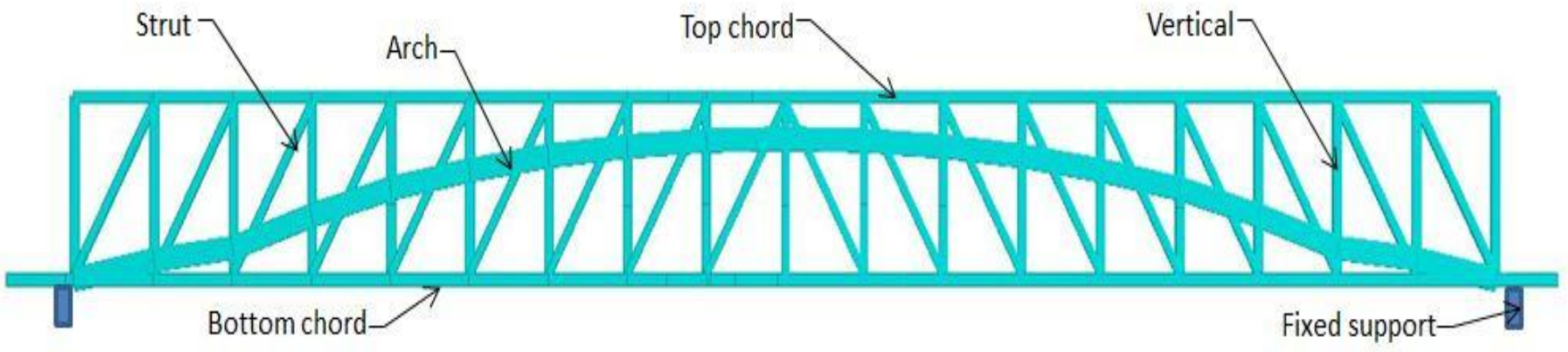
Field Test Results

- 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)
- $\text{Percent deviation} = \frac{(F.S - A.S)^2}{(F.S)^2}$
- Modify model parameters (dimensions, E, etc.)
- Re-evaluate percent deviation until model response correlates with field response

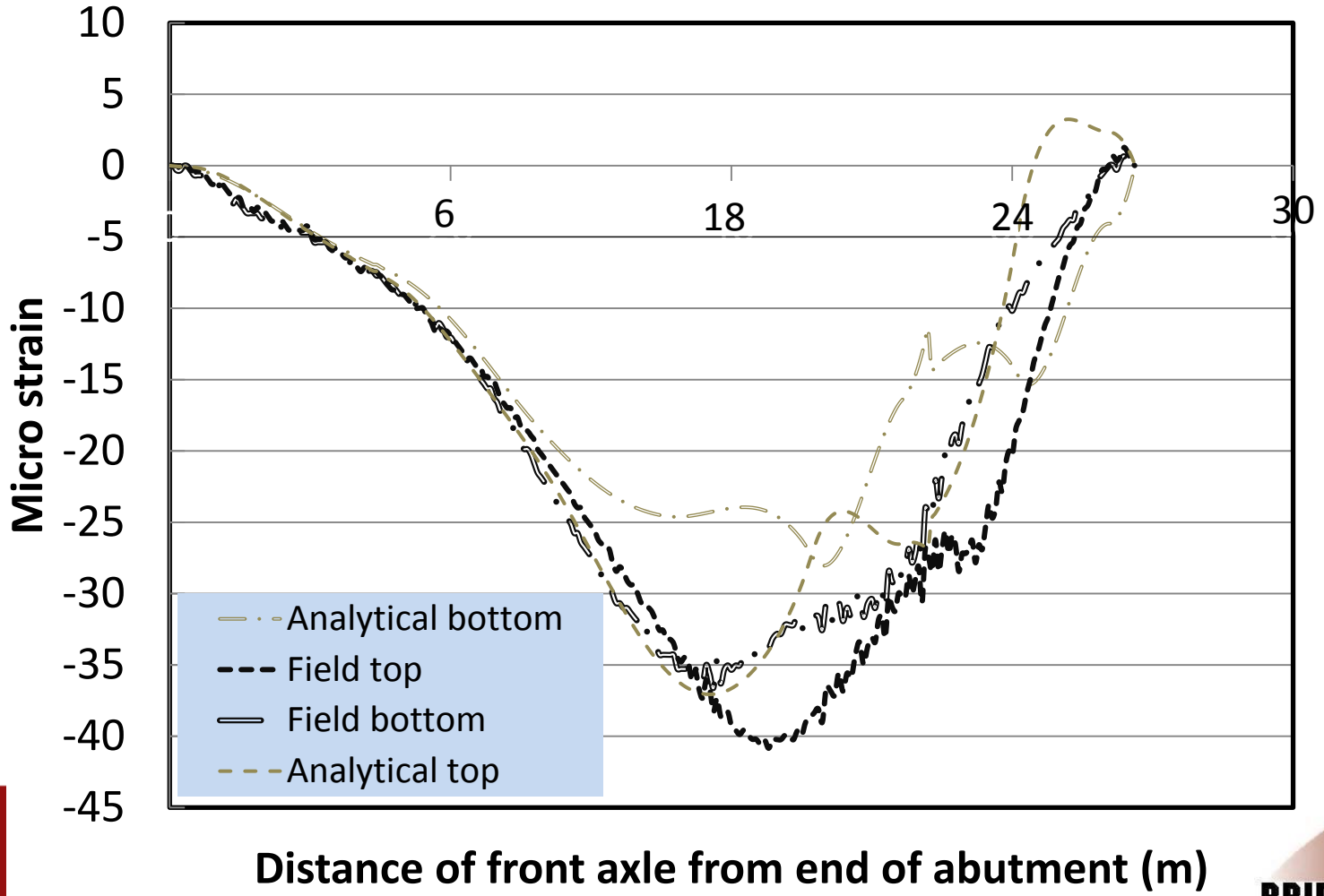
Result = Calibrated model for load rating

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%

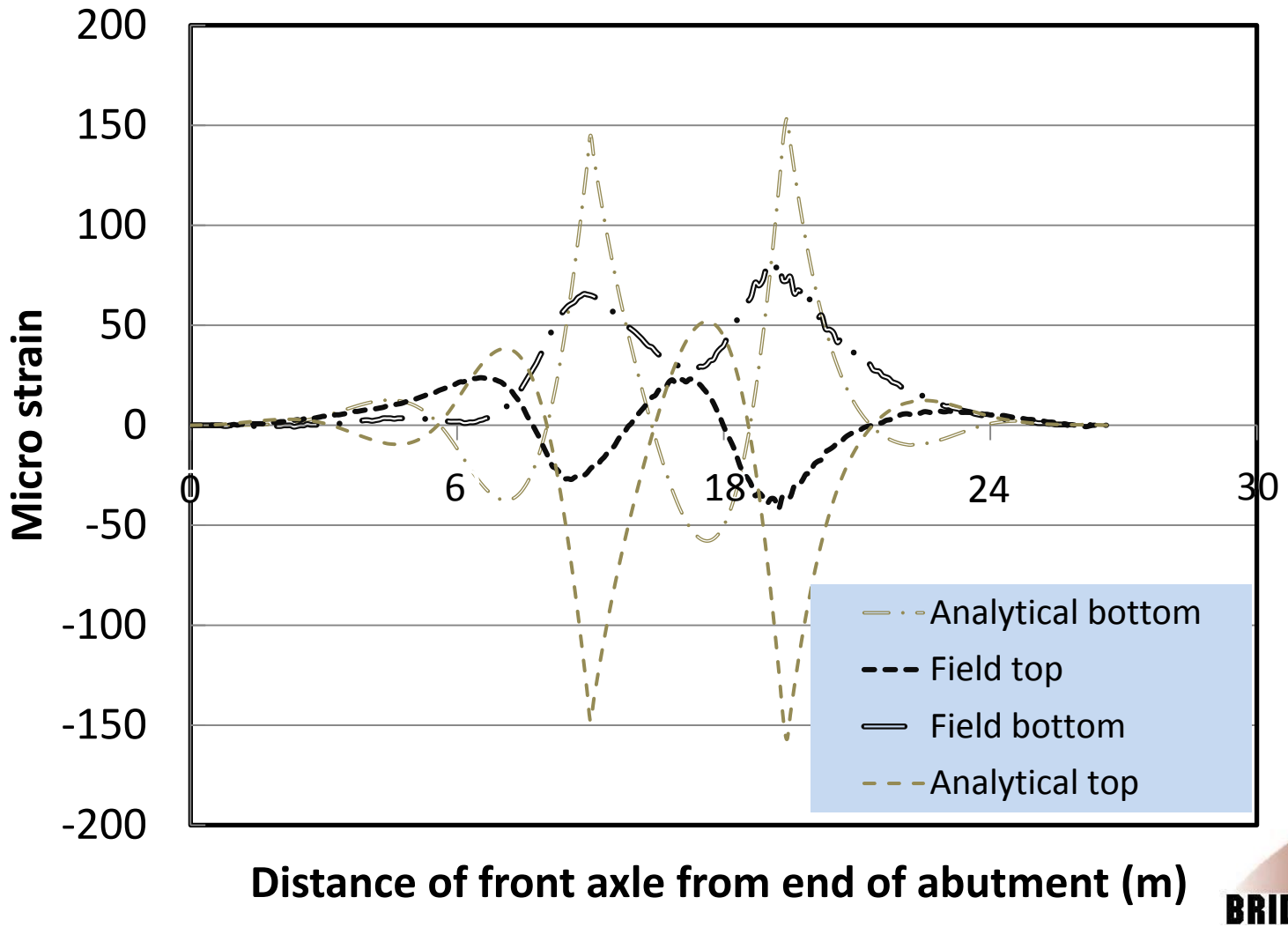
Graphical Calibration:

Top Chords



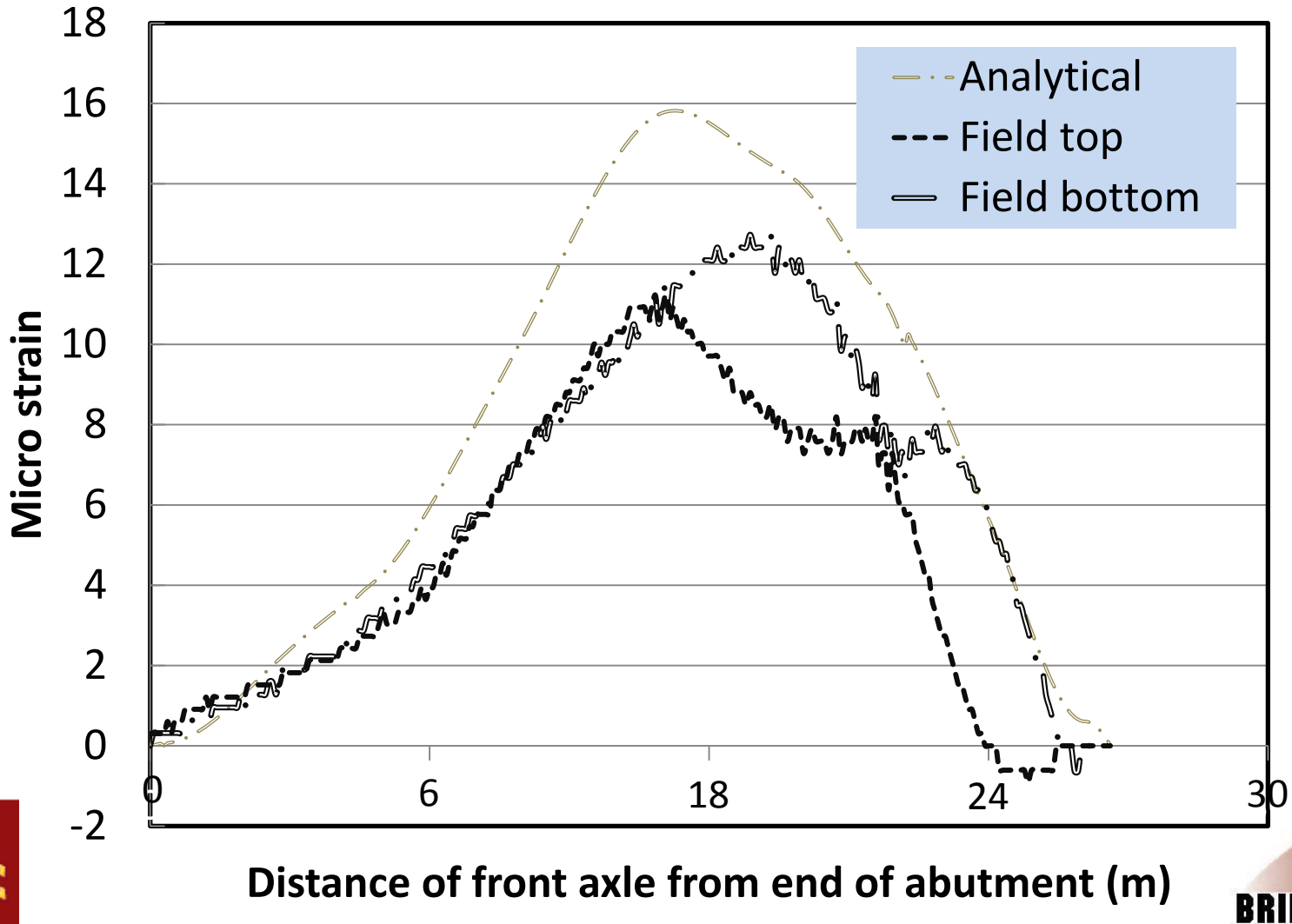
Graphical Calibration:

Bottom Chords



Graphical Calibration:

Verticals



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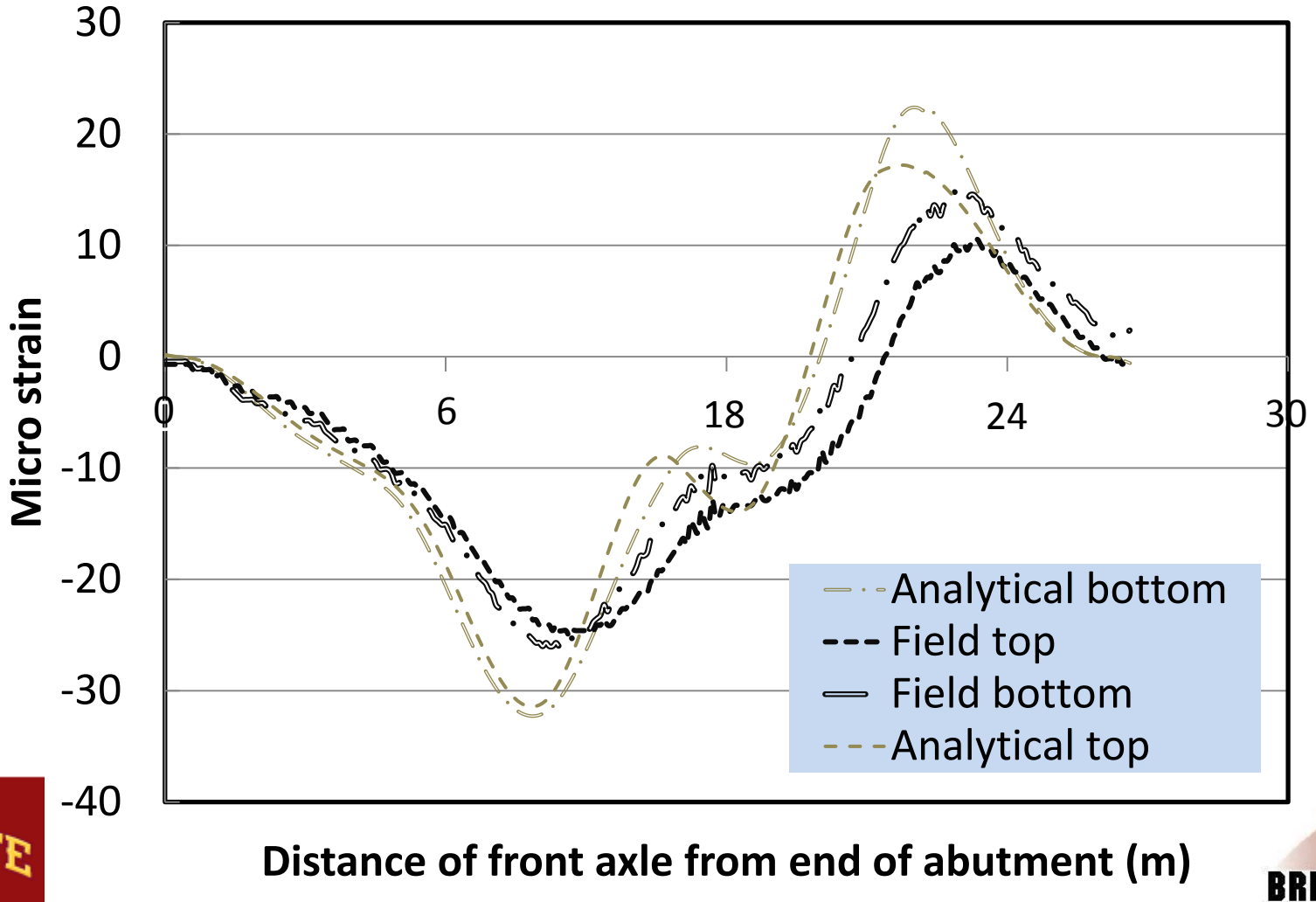
Graphical Calibration:

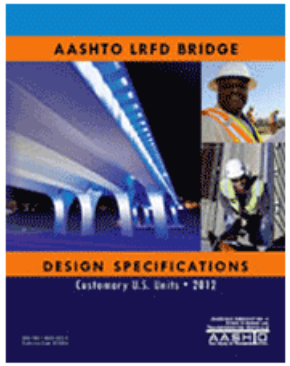
Diagonals



Load Rating

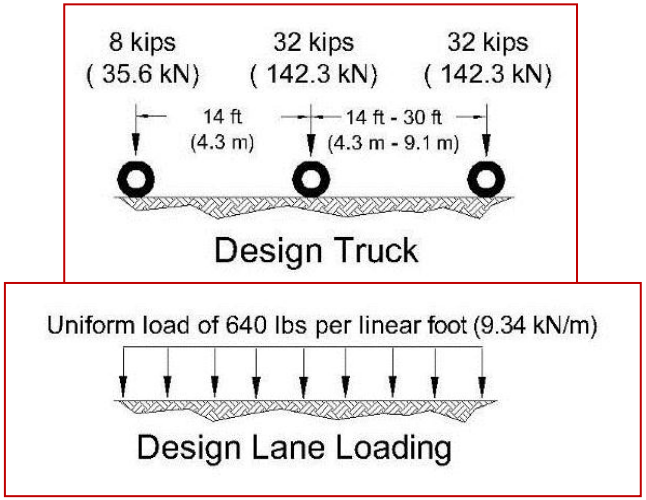
- Create calibrated analytical model
- Dead loads
- Live loads (AASHTO LRFR Manual)
- Impact factor
- Calculate member capacities
- Perform load rating – input live load vehicle data into model to run simulated rating load on calibrated analytical model

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:

- Two approaches to Rating
  1. Single Force Component
     - Axial
     - Bending
  2. Combined Forces
     - Axial PLUS Bending

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
  - $\left(\frac{Mu}{Mr}\right) + \left(\frac{Pu}{Pr}\right)^{x} \leq 1 \quad x = 1 \text{ in tension}, 2 \text{ in compression}$
    - 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 bridges completed
- Analytical models calibrated for all 11 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

Publications

- New Zealand Proceedings Paper and Presentation to World Conference on Timber Engineering (completed)
- 2nd National Conference on Covered Timber Bridges
- Final Report and Load Rating Manual (this quarter)
- ICTB 2013

Future Work

- Live load test additional covered bridge types
  - 2 more bridge clusters (PA, VT, IN)
    - King Post
    - Town Lattice
- Truss joint detail investigation
  - Bottom chord

Thanks for your Attention.

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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.