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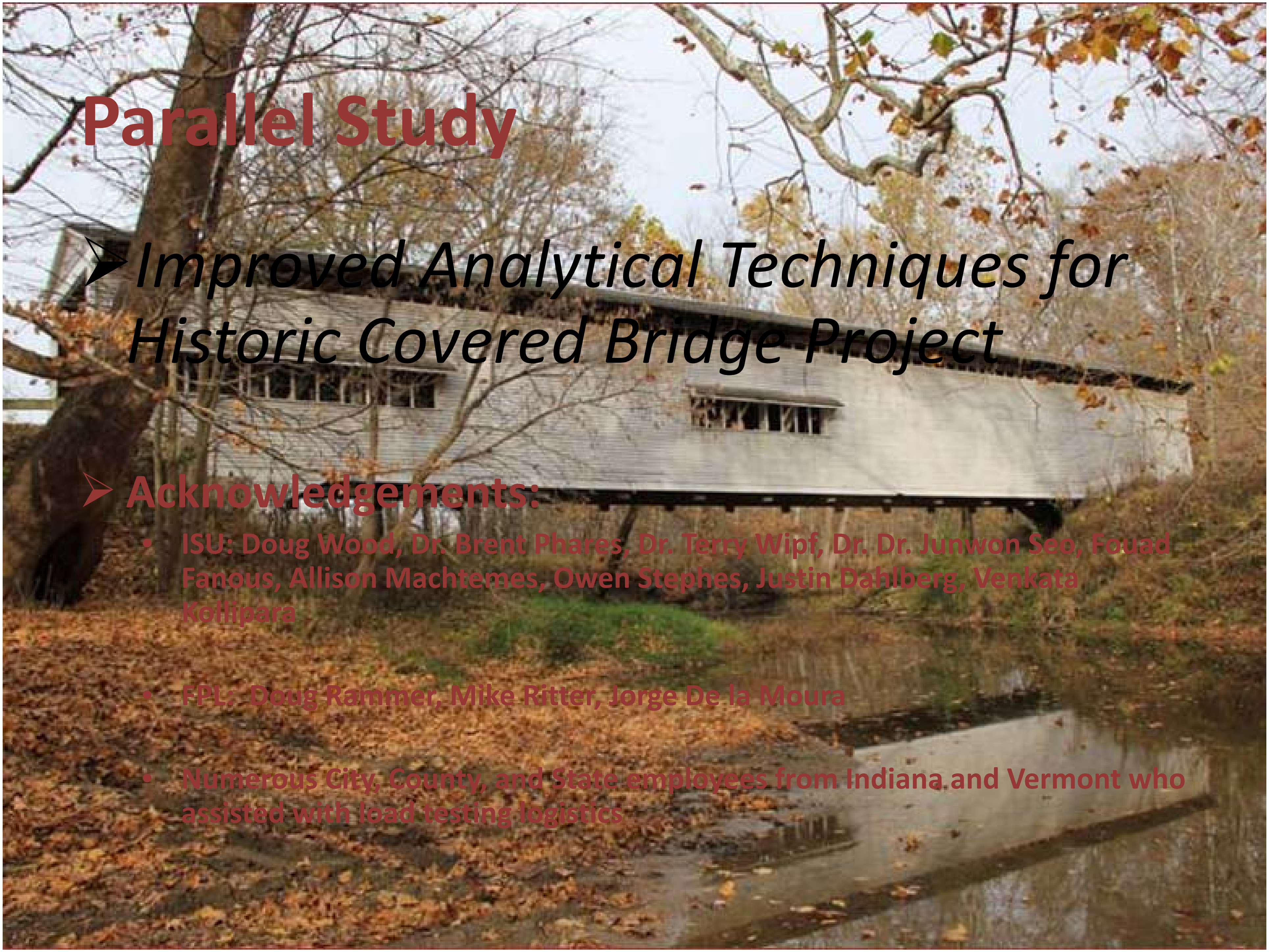
Load Rating Historic Covered Bridges Through Physical Load Testing

James Wacker
Forest Products Laboratory
USDA Forest Service

Travis Hosteng & Brent Phares
Bridge Engineering Center
Iowa State University



Parallel Study

- *Improved Analytical Techniques for Historic Covered Bridge Project*

- **Acknowledgements:**
  - ISU: Doug Wood, Dr. Brent Phares, Dr. Terry Wipf, Dr. Dr. Junwon Seo, Fouad Fanous, Allison Machtemes, Owen Stephes, Justin Dahlberg, Venkata Kollipara
  - FPL: Doug Rammer, Mike Ritter, Jorge De la Moura
  - Numerous City, County, and State employees from Indiana and Vermont who assisted with load testing logistics

Outline

- ➢Introduction
- ➢Objective
- ➢Work Plan
- ➢Bridges Evaluated
- ➢Load Testing Methods
- ➢Load Rating Example

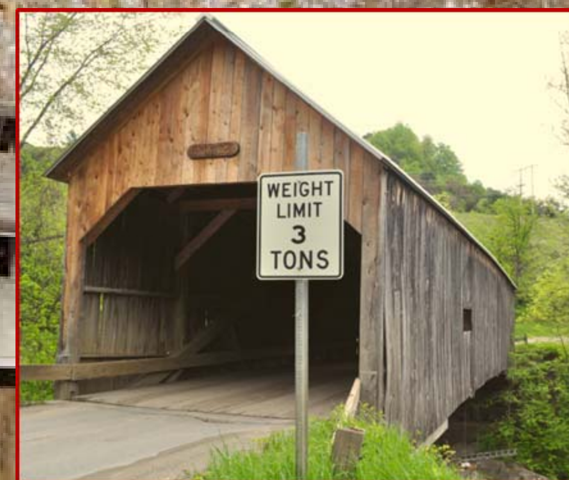
Over 800 Historic Covered Bridges still exist in the United States, most of them constructed between years 1830--1890. (*Source: FHWA Covered Bridge Manual*)

Introduction

- All bridges, including historic covered bridges, open to vehicular traffic are required to be load rated periodically
- Currently no established testing or rating procedures exist for covered timber bridges
- Load tested bridges often found to perform better than currently assigned ratings

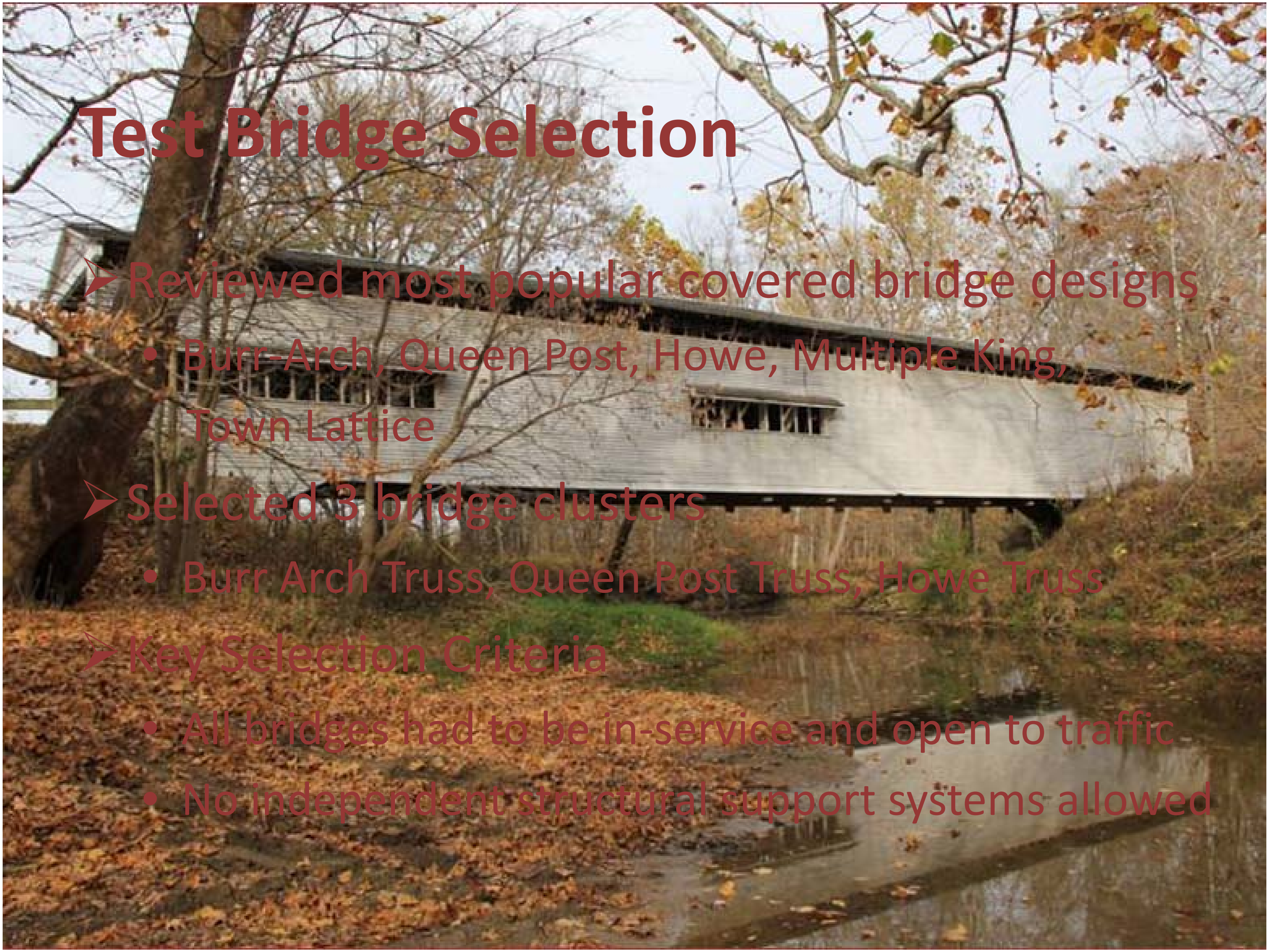
Objective

- The objective of this research is to develop and establish new recommended procedures for safely and reliably load-rating historic covered bridges through live load testing. The test results will also be useful for validating analytical bridge models that may be used for accurately evaluating bridges.



Work Plan

- 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
- 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**

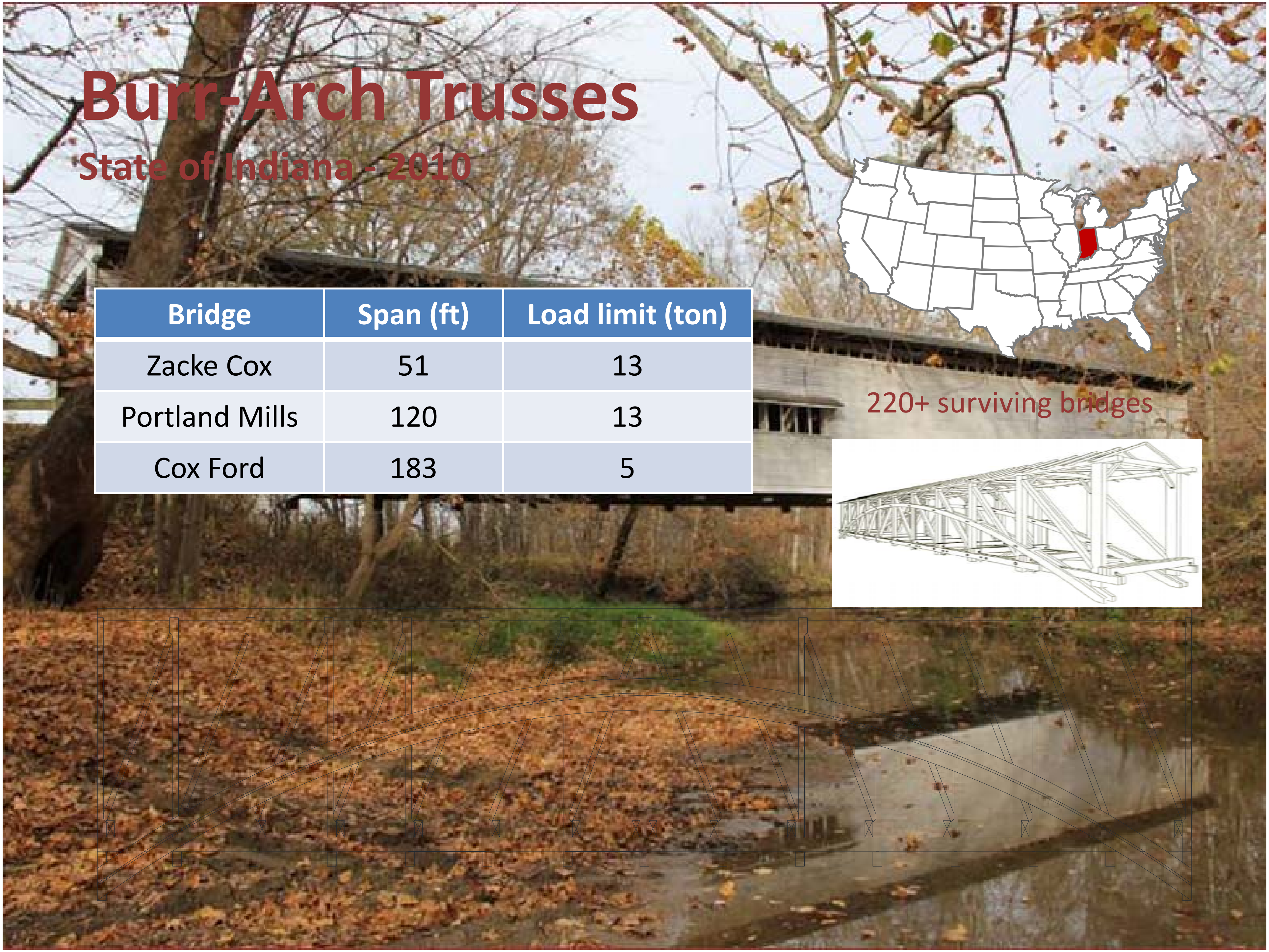


Test Bridge Selection

- Reviewed most popular covered bridge designs
  - Burr-Arch, Queen Post, Howe, Multiple King, Town Lattice
- Selected 3 bridge clusters
  - Burr Arch Truss, Queen Post Truss, Howe Truss
- Key Selection Criteria
  - All bridges had to be in-service and open to traffic
  - No independent structural support systems allowed

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

Burr-Arch Truss 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

Queen Post Truss Bridges

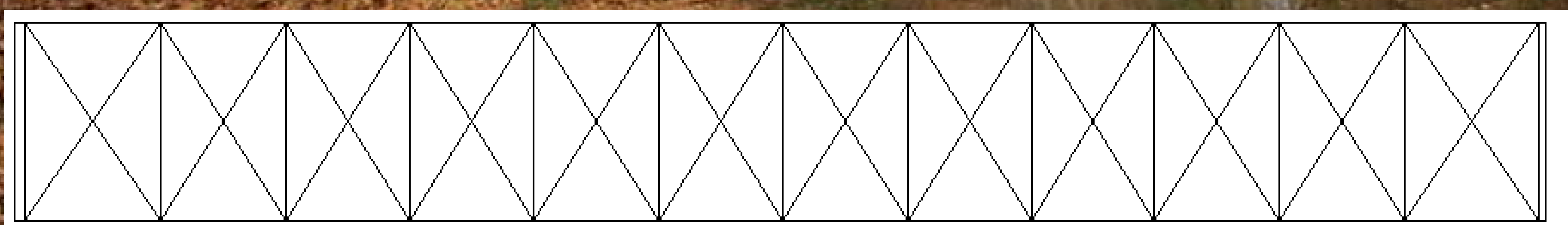
Howe Truss Bridges

State of Indiana - 2012

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

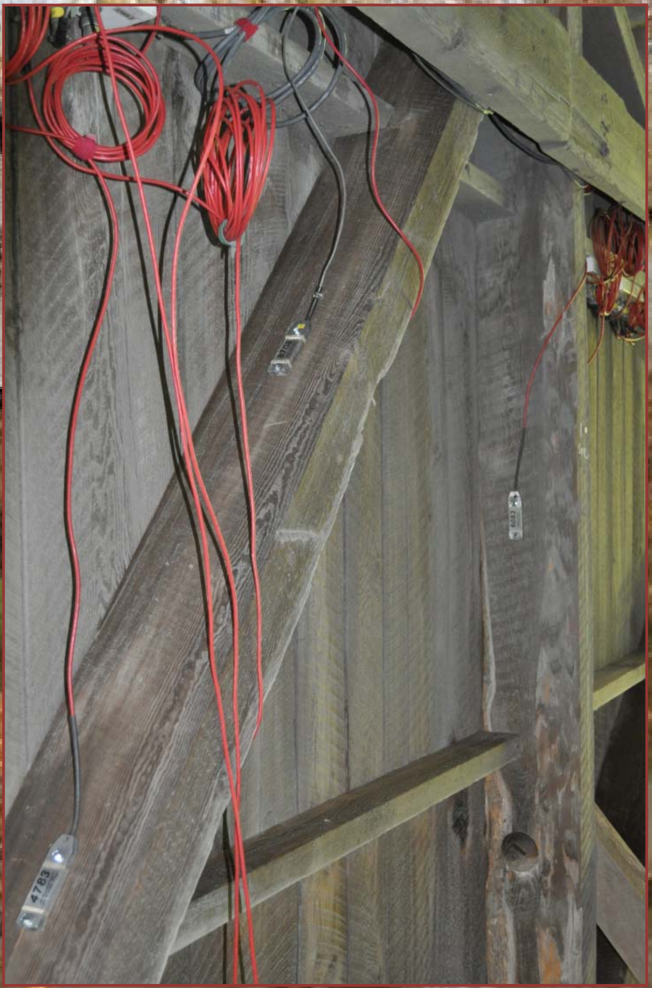
140+ surviving bridges



Howe Truss Bridges

Instrumentation

- Typical sensor setup: Deflection and Strain



Instrumentation

Live Load Testing

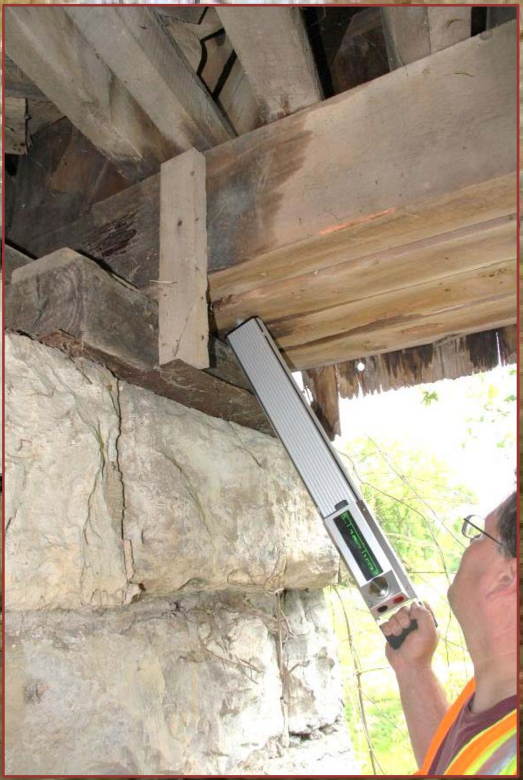
- Static Loading To Collect Deflection & Strain Envelope Data

Material Property and Conditions

Nondestructive Evaluation (NDE) Techniques

- Estimate Elastic Modulus
  - Stress wave velocity (C), parallel-to-grain
- Core Samples
  - Species identification
  - Oven dry density
- MC Surveys
- Resistance Micro-drilling

Moisture content readings

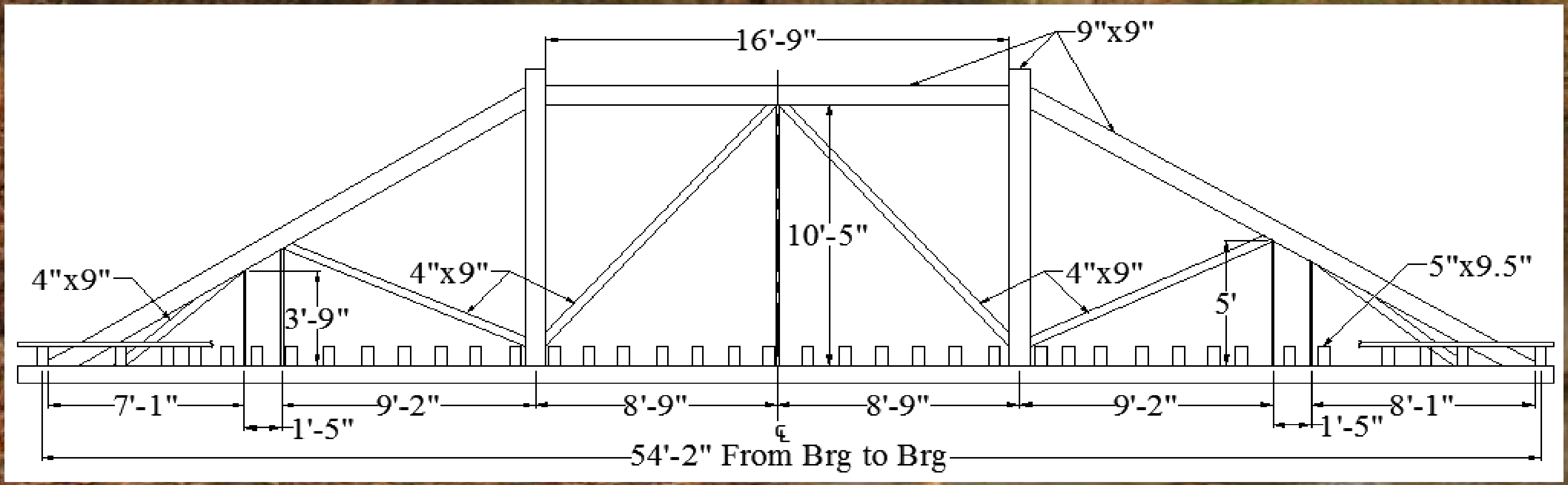


Resistance micro-drilling

Load Rating Example - Vermont

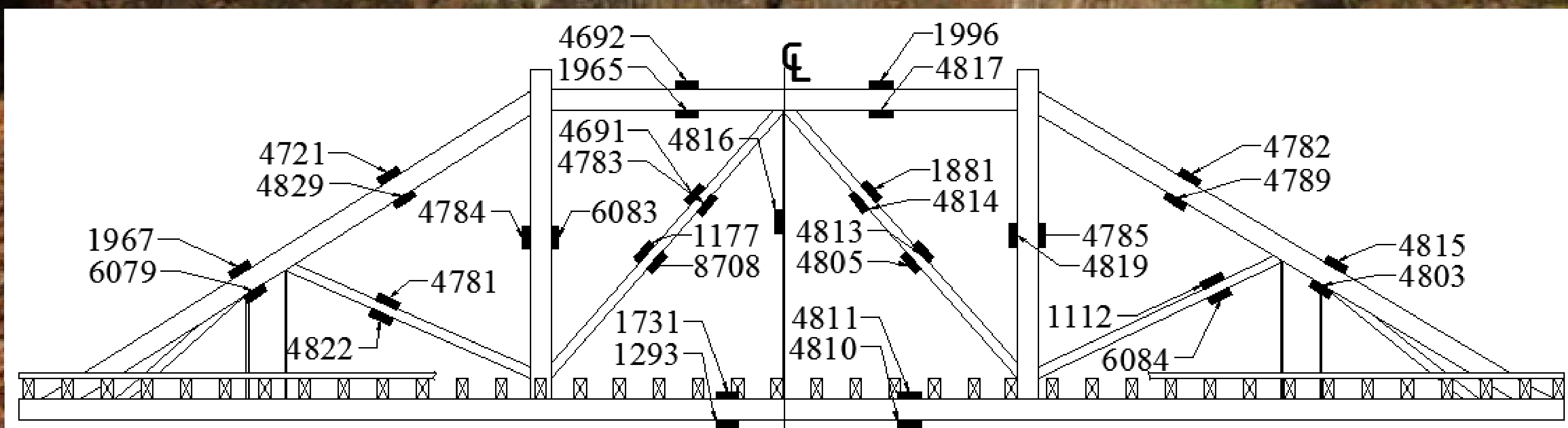
Moxley Bridge

- Queen post truss
- Constructed 1886
- Single span, 55 ft long
- Posted @ 4 tons

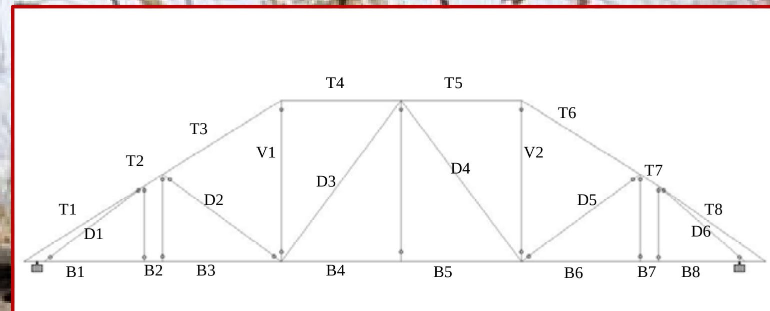


Field Strain Sensor Layout

33 total locations

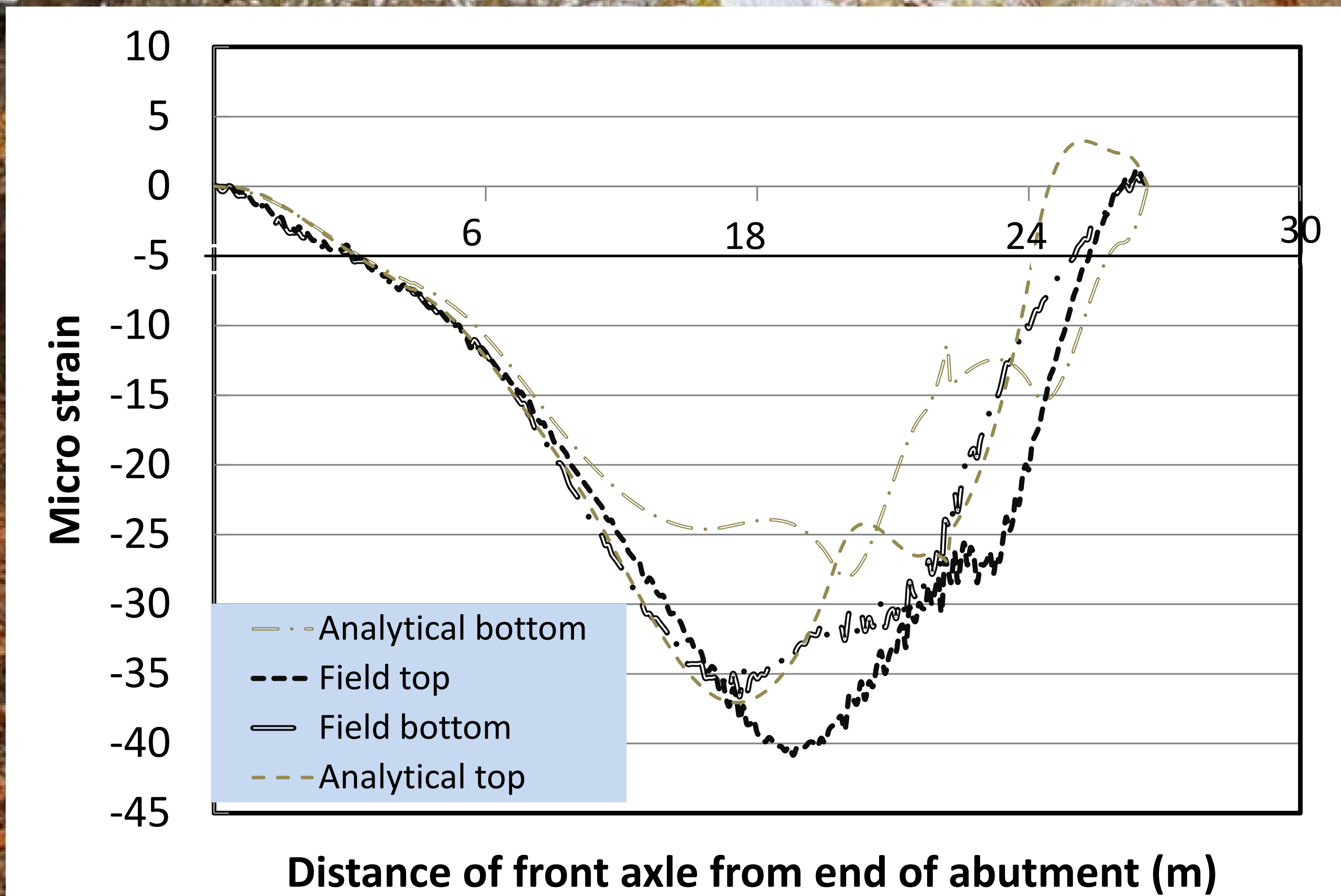


Model Calibration

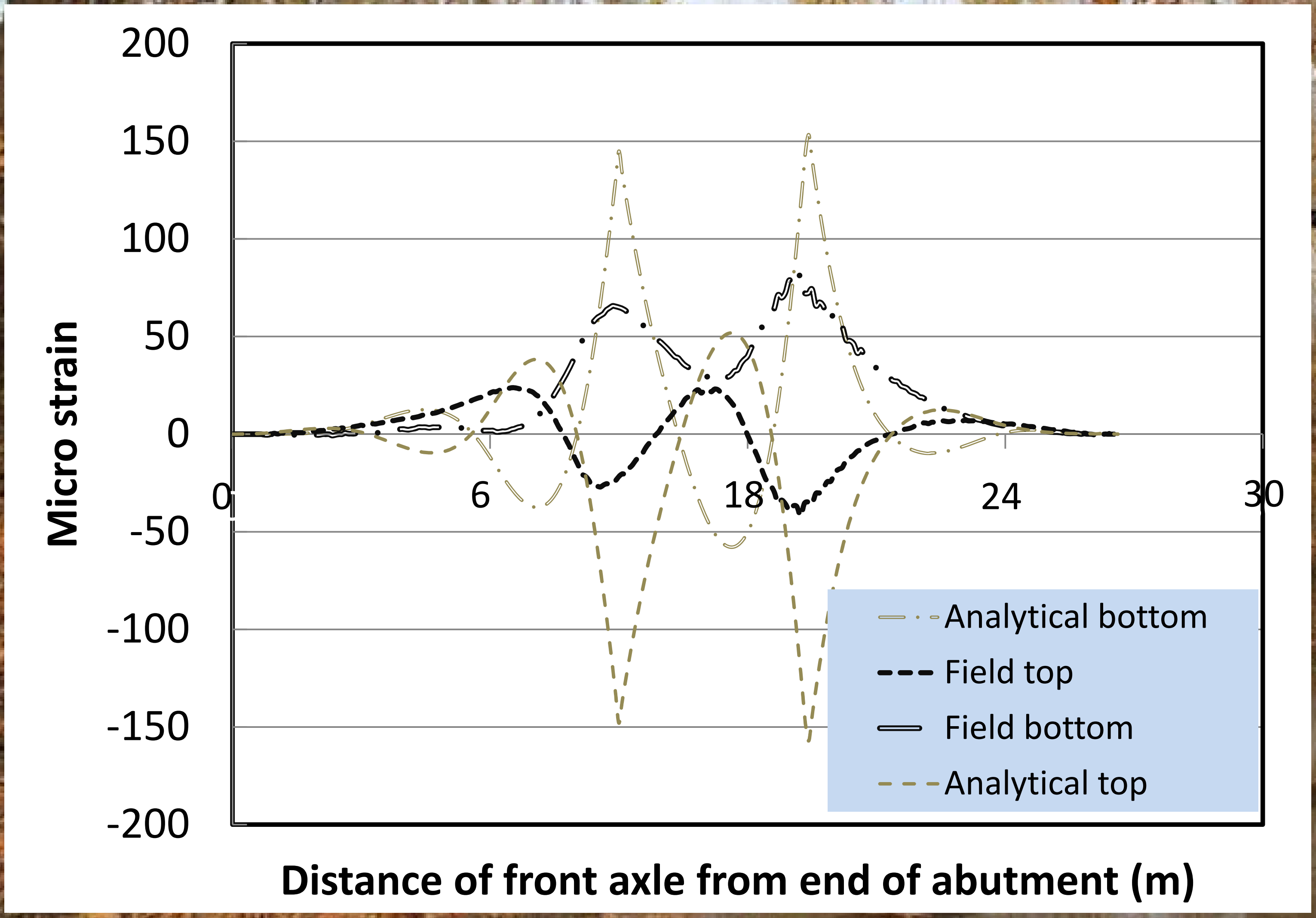


- Response Parameter – Strain
- Compare: F_S vs $A.S_S$
  - F_S - Field strain (measured during live load test)
  - $A.S_S$ - model strain (strain computed from analytical model)
- Percent deviation $= \frac{(F.S - A.S)^2}{(F.S)^2}$
- Modify model parameters (dimensions, E, etc.)
- Re-evaluate percent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

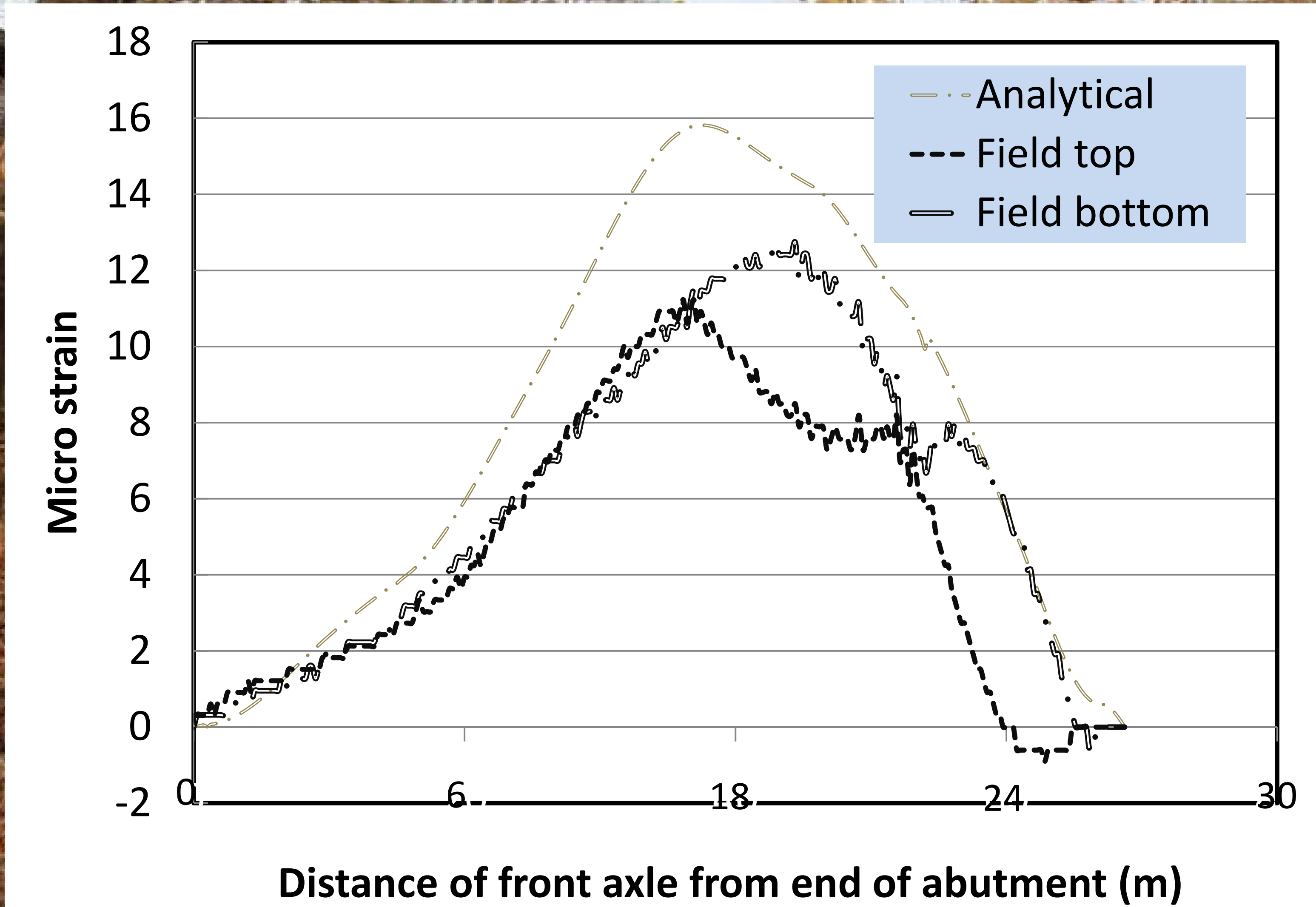
Graphical Calibration:
Top Chords



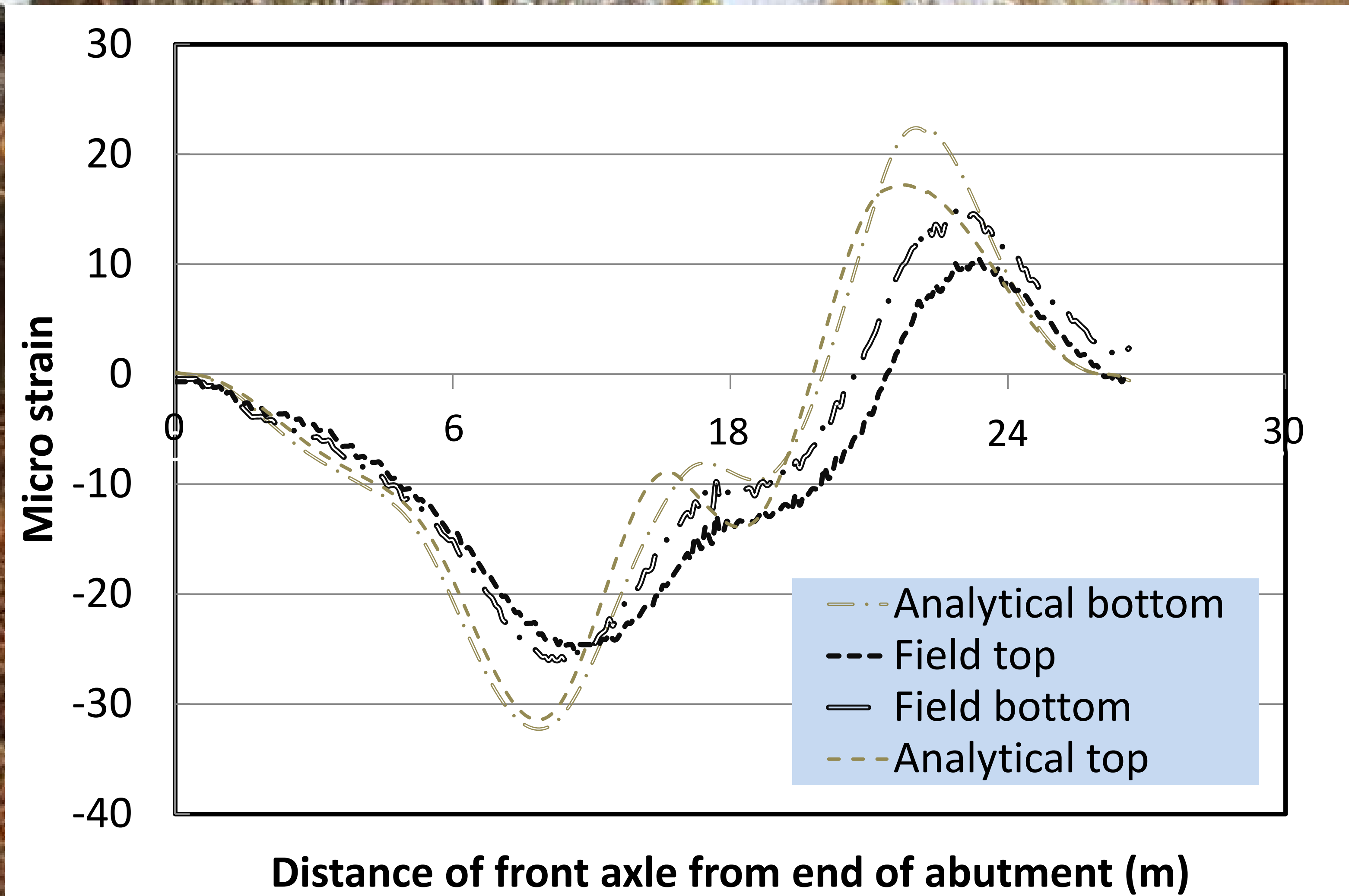
Graphical Calibration:
Bottom Chords



Graphical Calibration:
Verticals



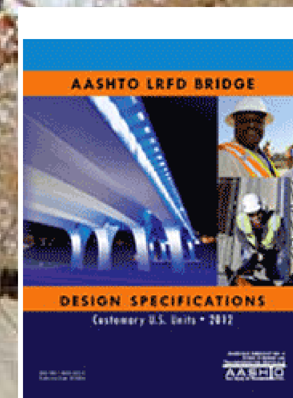
Graphical Calibration:
Diagonals

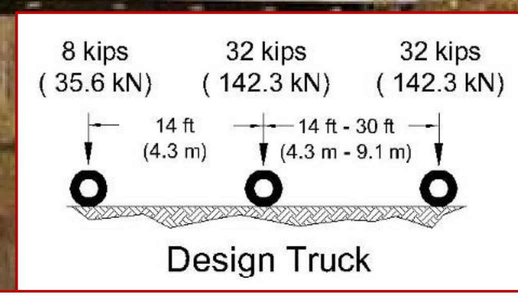


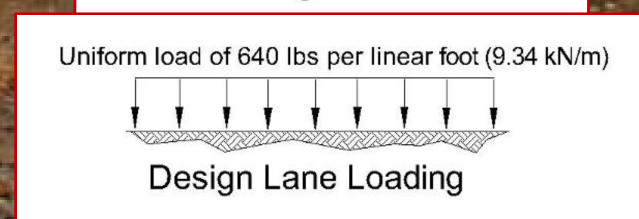
Load Rating Computations:
Generic Members

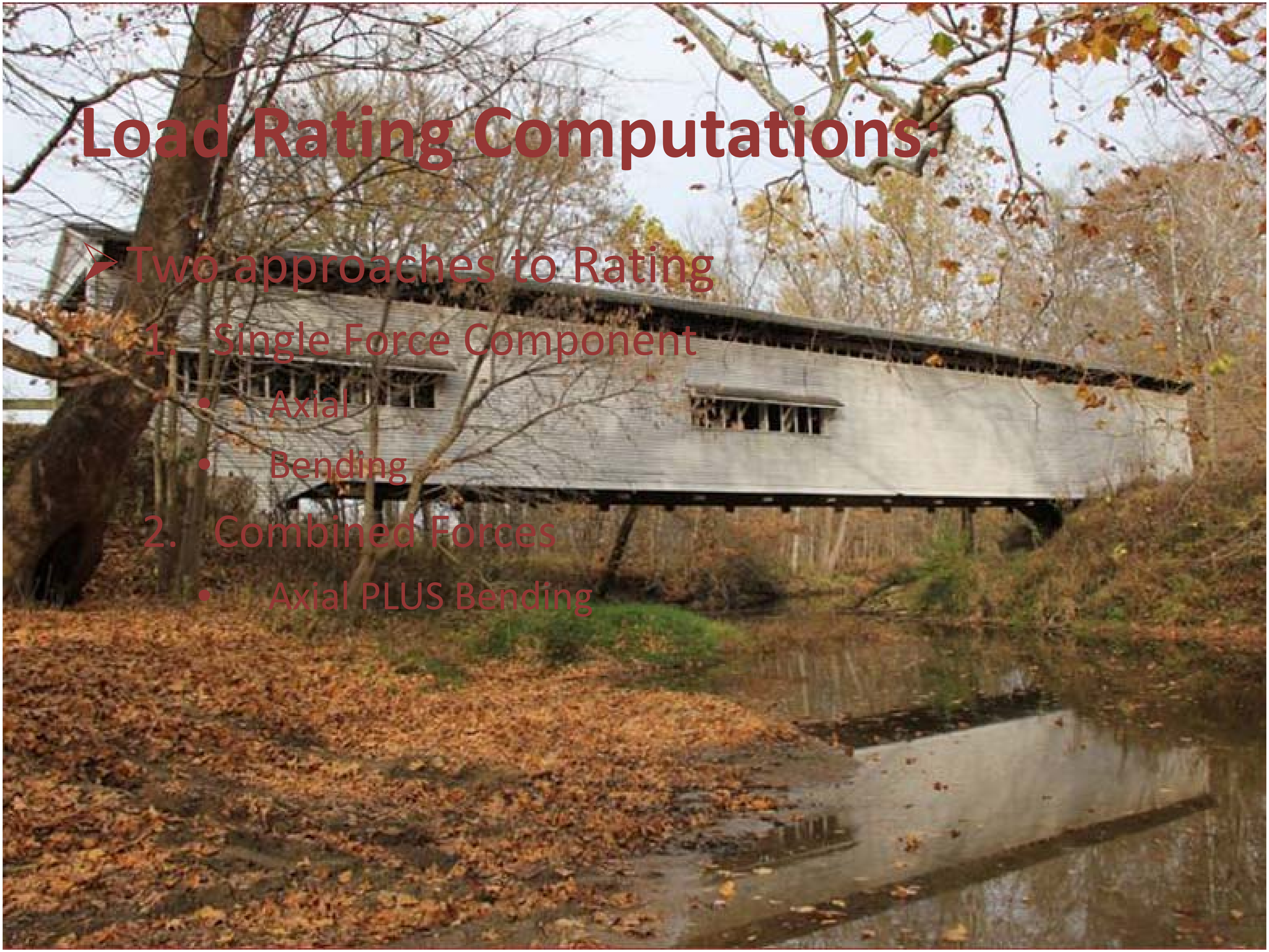
- AASHTO LRFD approach to Load Rating
  - HL-93 (320kN) = HS20 truck plus superimposed lane load
  - $RF = \frac{C-(\gamma_{DC})(DC)}{(\gamma_L)(LL+IM)}$

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

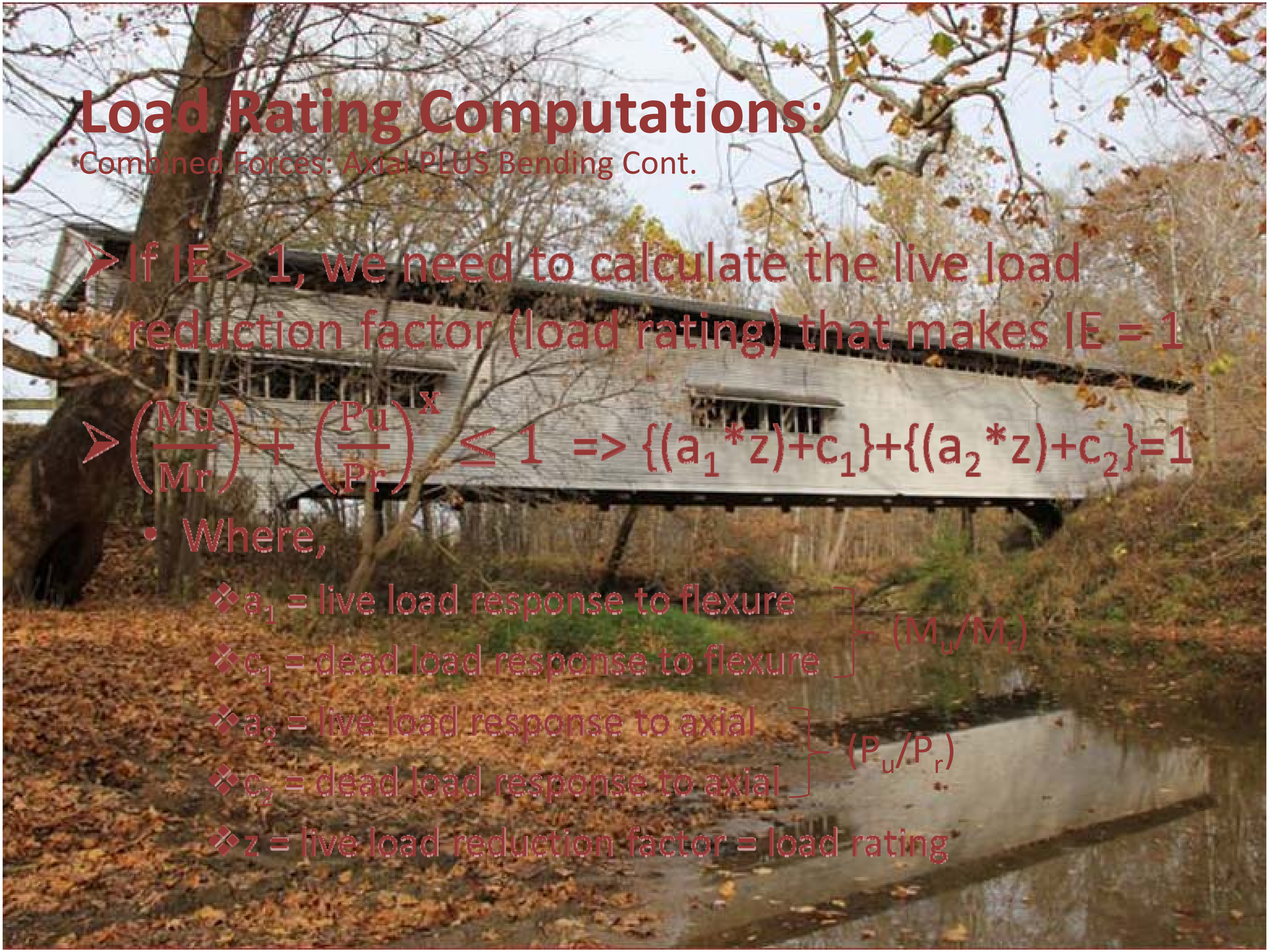
- Calculate member moment capacity, C
- Calculate unfactored member response to loading, DC & LL
- $RF = \frac{C-(\gamma_{DC})(DC)-(\gamma_{DW})(DW)\pm(\gamma p)(P}{\gamma_L(LL+IM)}$

Load Rating Computations:

Combined Forces: Axial PLUS Bending

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
  - $\left(\frac{Mu}{Mr}\right) + \left(\frac{Pu}{Pr}\right)^x \leq 1$, x = 1 in tension , 2 in compression
    - If IE $\leq$ 1, member capacity ok
    - If IE > 1, member capacity insufficient



Load Rating Computations:

Combined Forces: Axial PLUS Bending Cont.

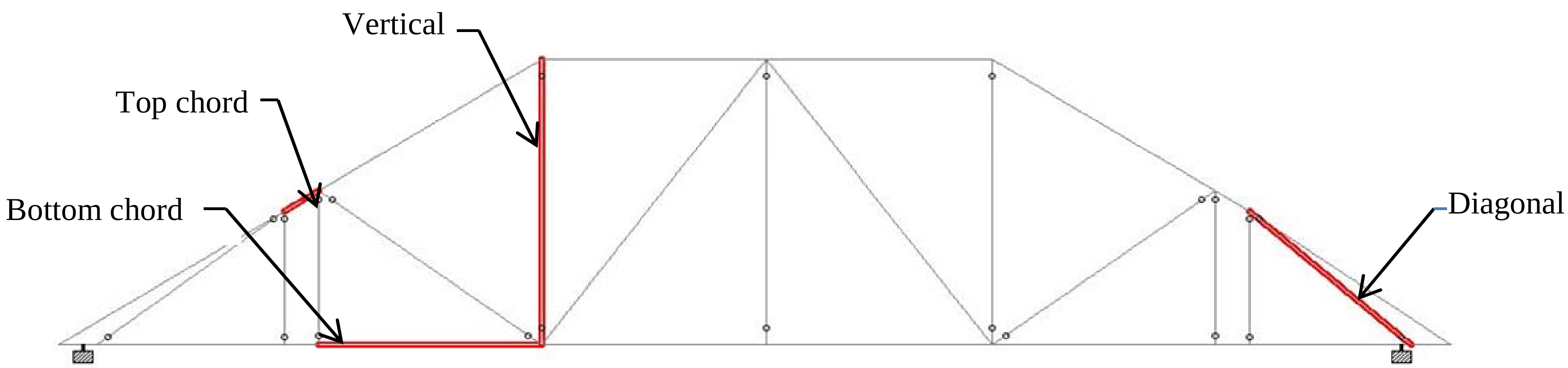
- If IE > 1, we need to calculate the live load reduction factor (load rating) that makes IE = 1
- $\left(\frac{Mu}{Mr}\right) + \left(\frac{Pu}{Pr}\right)^x \leq 1 \Rightarrow \{(a_1 * z) + c_1\} + \{(a_2 * z) + c_2\} = 1$
  - Where,
    - a_1 = live load response to flexure
    - c_1 = dead load response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

Moxley Br. Critical Members

Based on Calculated Rating Factors



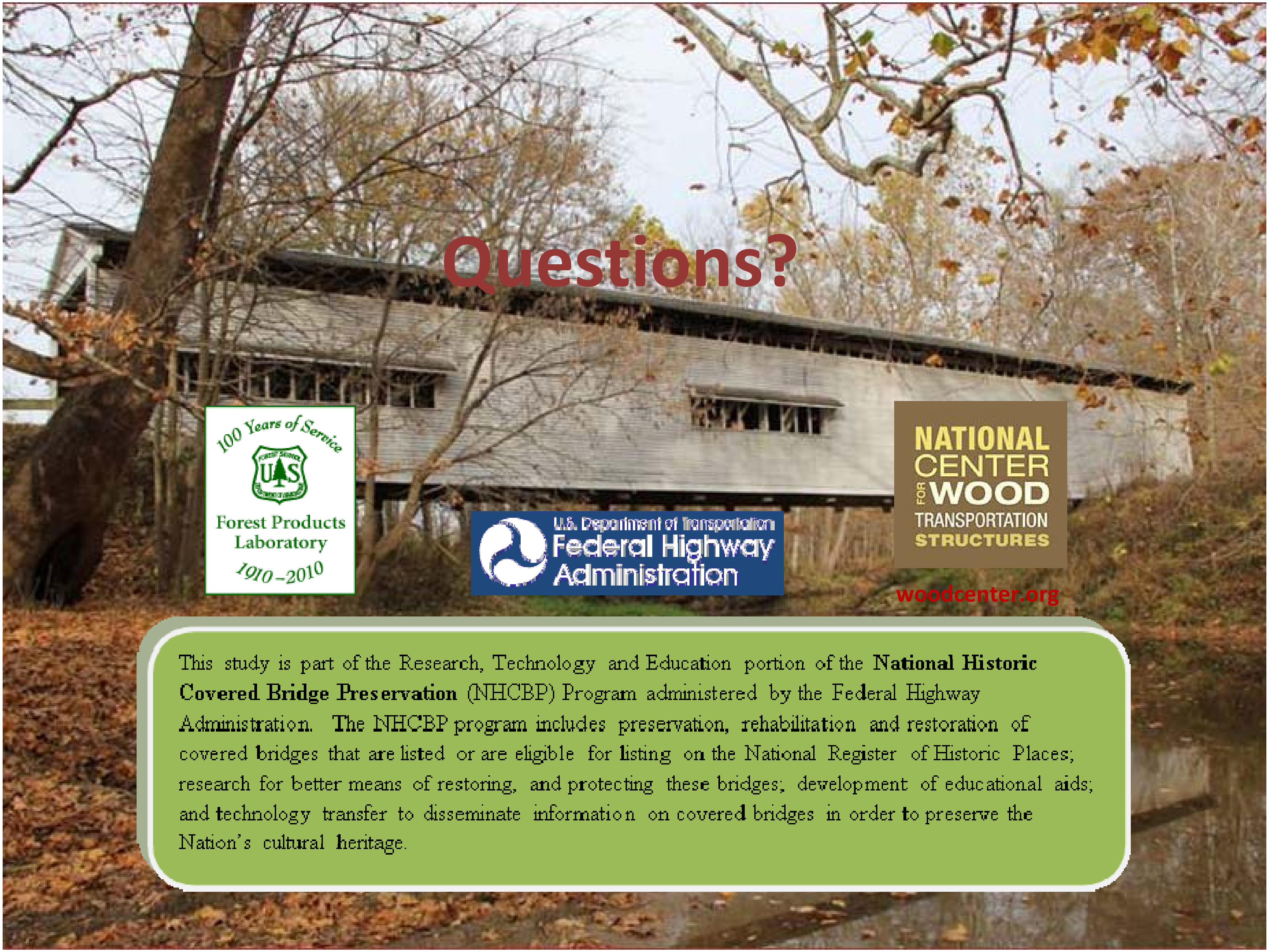
Summary

- Field testing completed at 11 covered bridge sites.
- Analytical models were developed & calibrated with field strain data.
- Developed new recommended practices for live load testing, modeling and load rating of historic covered bridges.
- New engineering guidance manual available soon. (**Currently under review**)


Field Testing and Load Rating Manual
Introduction
Chapter 1
Literature Review
Chapter 2
Field Testing
Analytical Modeling
Rating Process
MODEL CALIBRATION
LOAD RATING CALCULATIONS

Future Work

- Disseminate Results – TRR, HAER, AASHTO
- Phase II -- Live Load Testing
  - Focus on other historic bridge truss types (Town lattice, multiple kingpost)
- Possible Lab Investigations
  - Truss joint details
  - Bottom chord behavior



Questions?

Forest Products Laboratory
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1910–2010

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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.


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