Field Monitoring and Numerical Simulation for Performance Assessment of Integral Abutment Bridges

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Transportation & Highway Engineering (T.H.E.) Conference
February 27th, 2018

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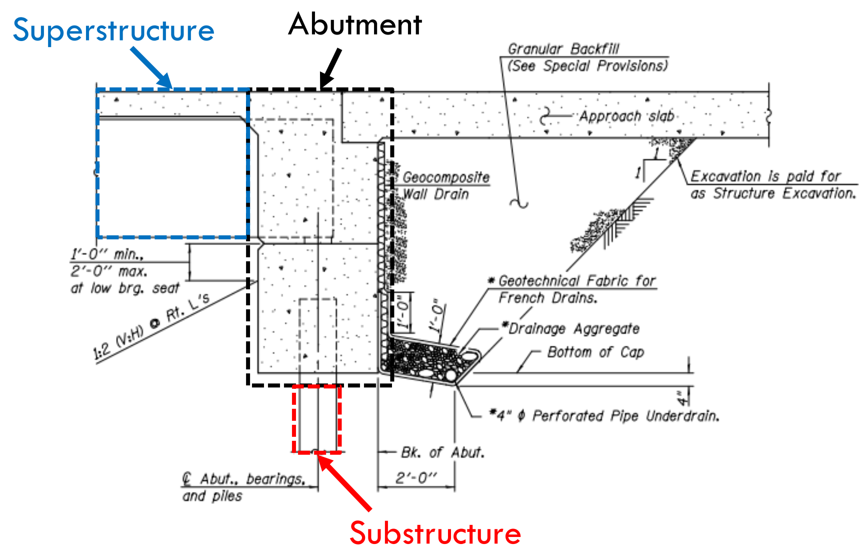
Outline

- Introduction – Integral Abutment Bridges (IABs)
- IAB Parametric Study – Numerical Simulations
  - Overview of modeling methodology
  - Summary of analytical modeling results
- IAB Field Monitoring of Two Highway Bridges
  - Implementation of field monitoring systems
  - Summary of field data
- Ongoing Work

Integral Abutment Bridges (IABs)

- IABs can provide benefits in terms of decreased construction and maintenance costs
- The superstructure & substructure acts as one continuous unit under thermal & other post-construction loading
- Most previous IAB research has focused on substructure behavior & demand



Typical Integral Abutment Detail (IDOT Bridge Manual, 2012)

IABs in Illinois

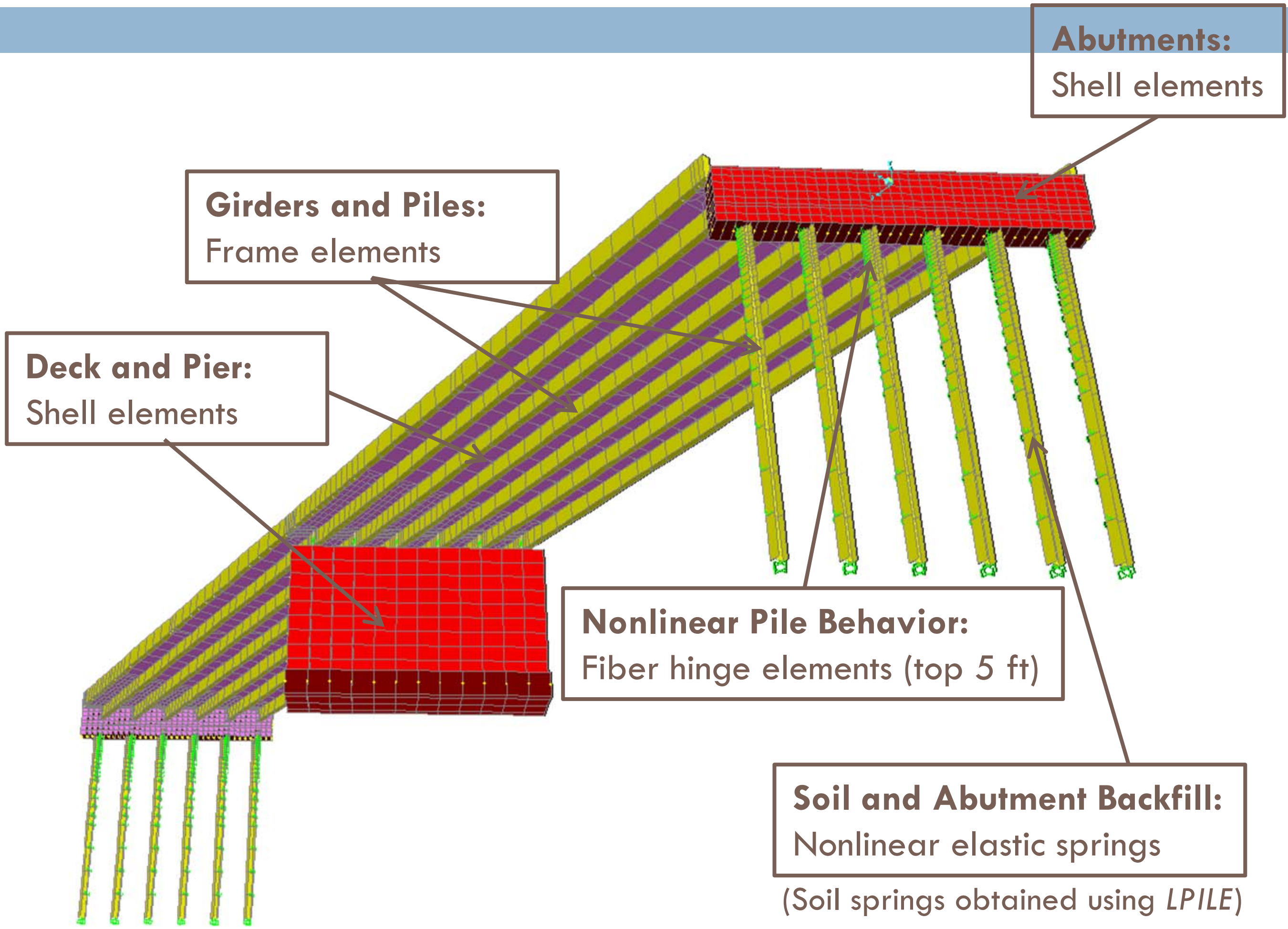
- IDOT IAB design & construction limits have been placed on highway bridge length & skew configurations
  - Mainly a function of pile type, based on substructure considerations
- Previous research in Illinois has investigated soil-pile interaction at IAB foundations

UIUC CEE IAB Research

- Research Goals:
  - Gain a better understanding of IAB behavior (particularly under thermal loads and for superstructures)
  - Improve the design and construction provisions for IDOT IABs
- Two-Part Research Project:
  - Detailed parametric study employing finite element models of IABs
  - Instrumentation & field monitoring of two (2) IABs in northern Illinois

IAB Parametric Study – Numerical Simulations

Typical IAB SAP Analytical Model



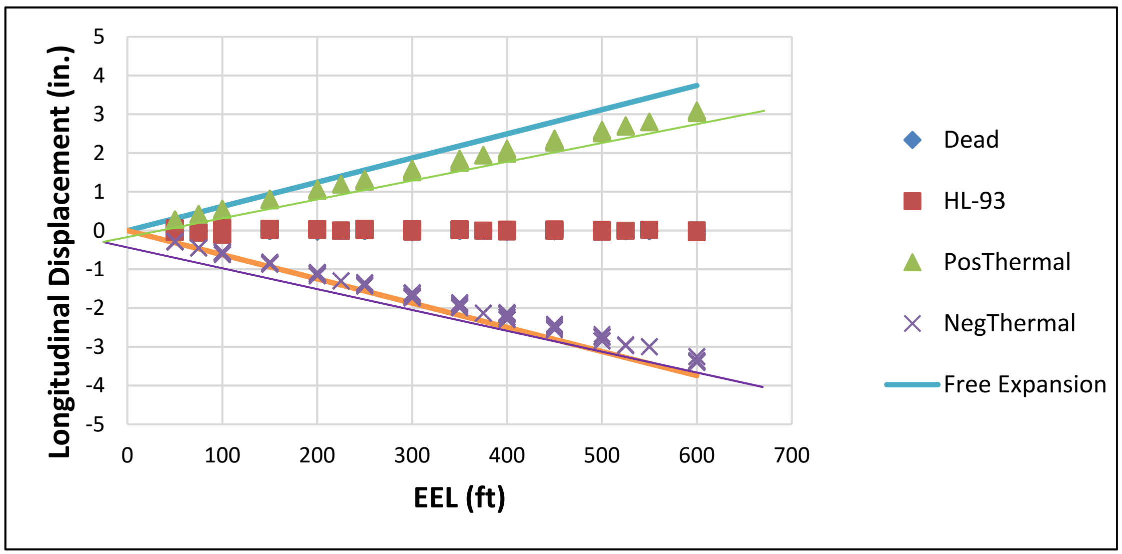
(Soil springs obtained using *LPILE*)

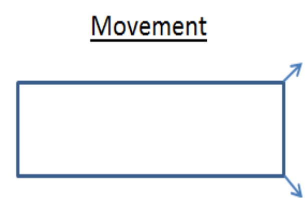
IAB Modeling – Primary Parameters

- Primary Parameters Are Largely Based Around Bridge Geometry:
  - Number of spans (1 to 20)
  - Individual span lengths (50, 100, 150 & 200 ft) & end-span ratio
  - Overall length (up to 1200 ft)
  - Skew (0, 15, 30, 45 & 60 degrees)
  - Width (36, 60 & 96 ft)
  - Piles (HP8 → HP18)

Global Movement vs. Effective Expansion Length

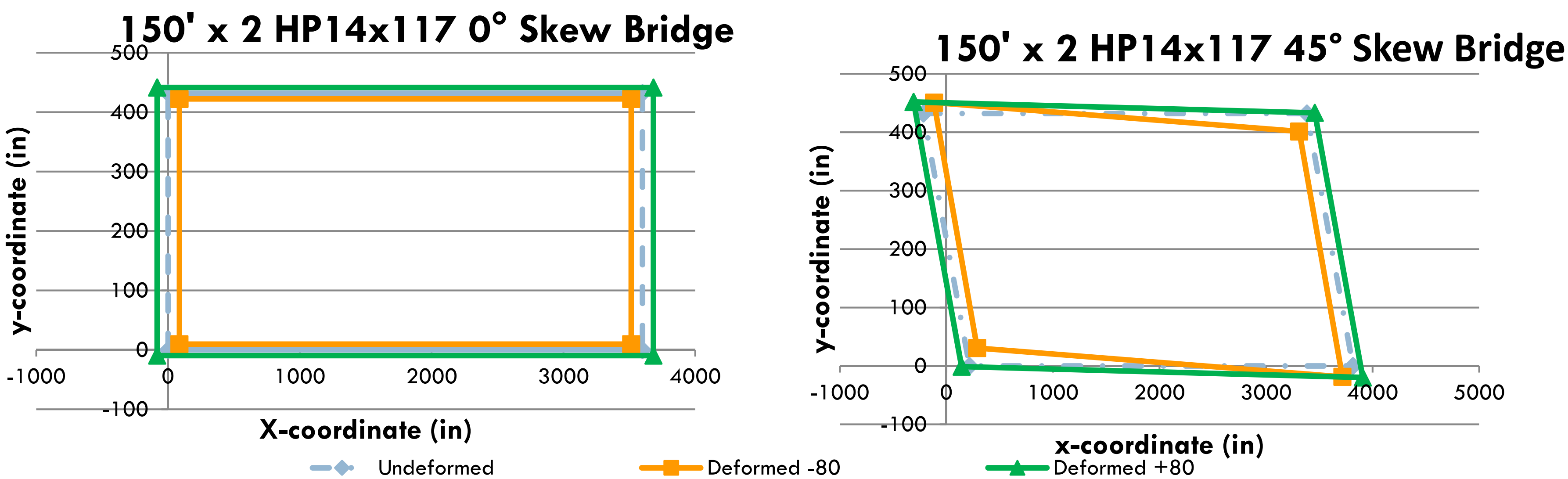
- Increasing EEL results in an increase in global longitudinal movement
- The resulting model displacements are typically more than 90% of those corresponding to free expansion / contraction



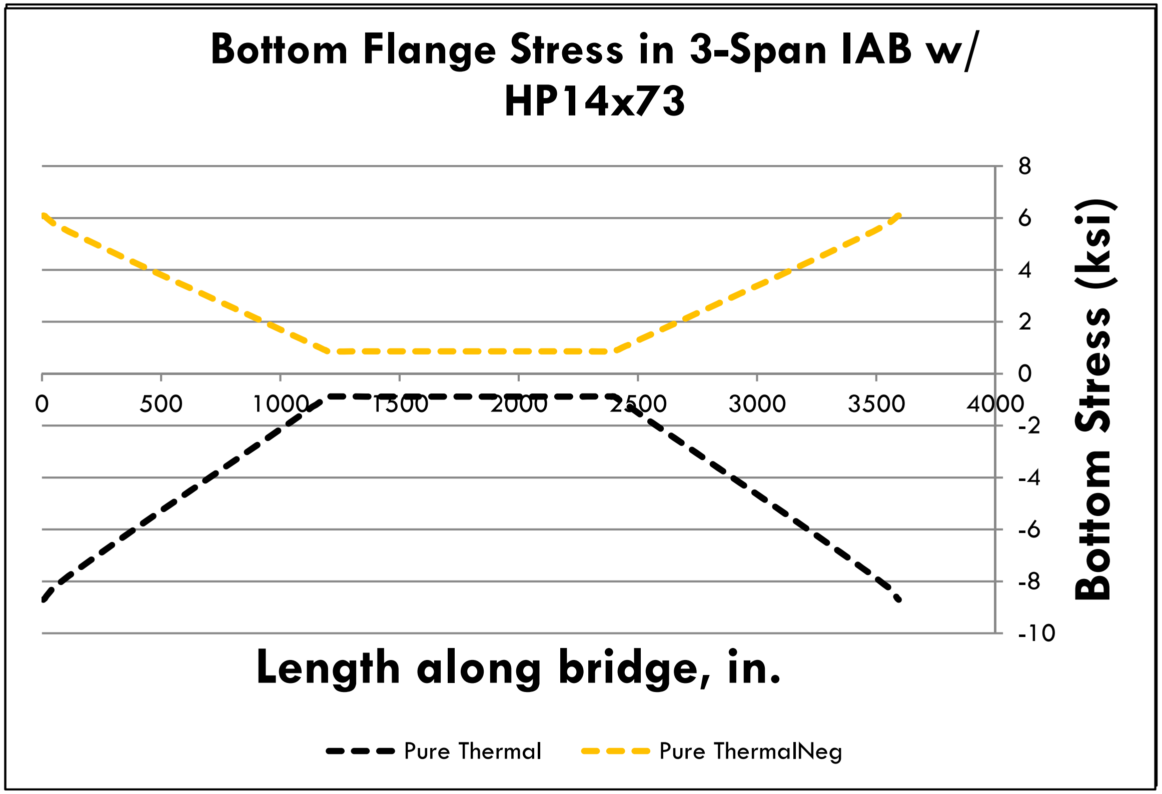


Global Movement with Skew

- Increased bridge skew results in non-symmetric movement of the acute and obtuse corners
  - Bridges with skew between 0° and 30° exhibit more symmetric movement
  - For skews above 30°, movement is toward the acute corner



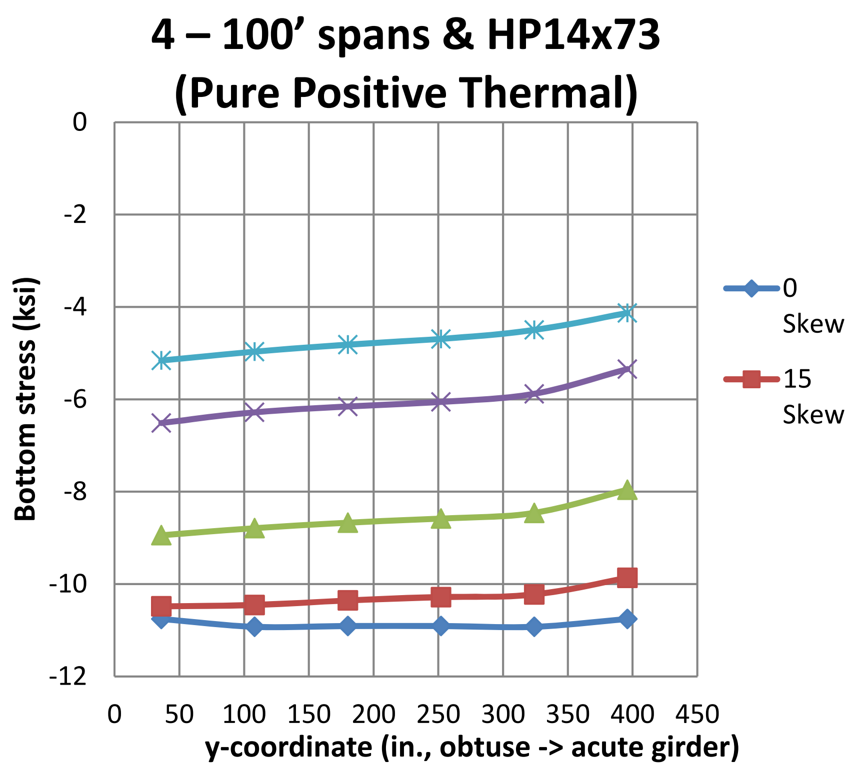
Thermally-Induced Girder Stresses

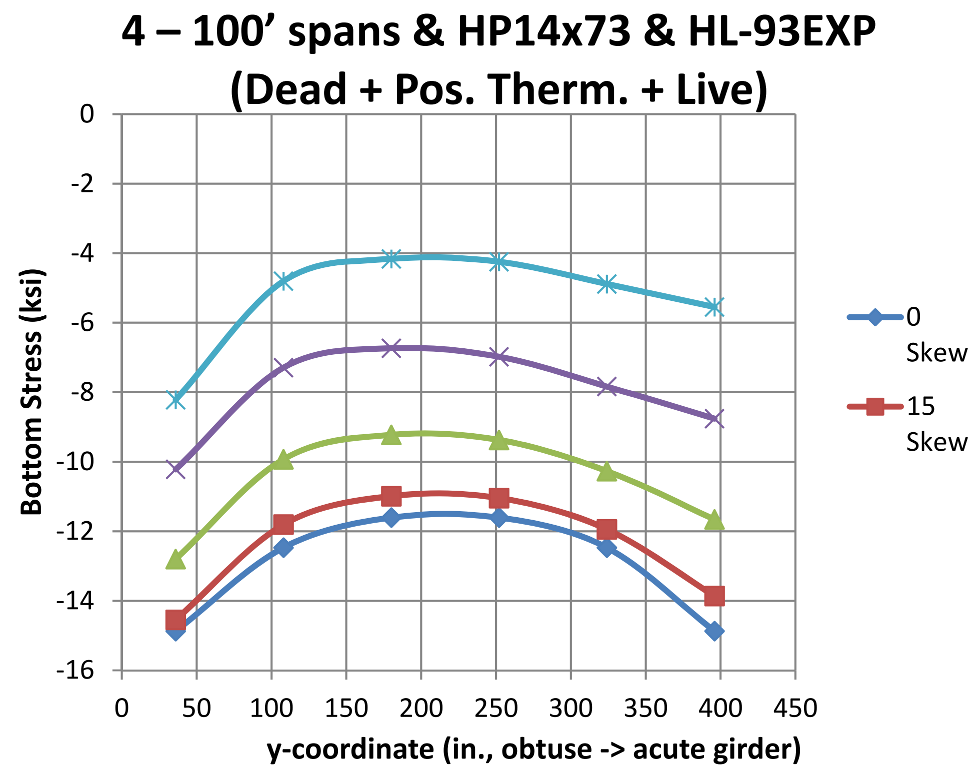


Girder Section: W36x194

- Girder bottom stress values control for composite sections
- Maximum stresses due only to thermal load are located at the abutments

Girder Bottom Stress with Skew

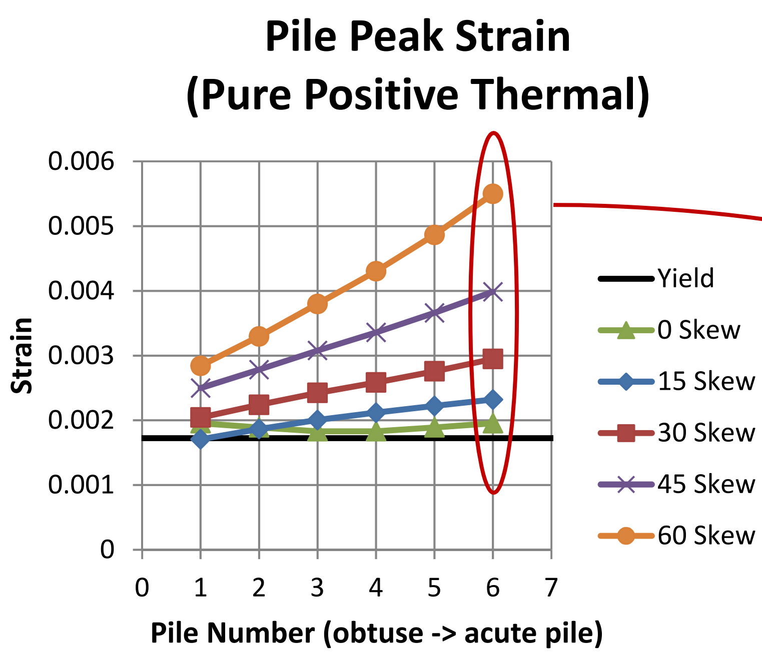


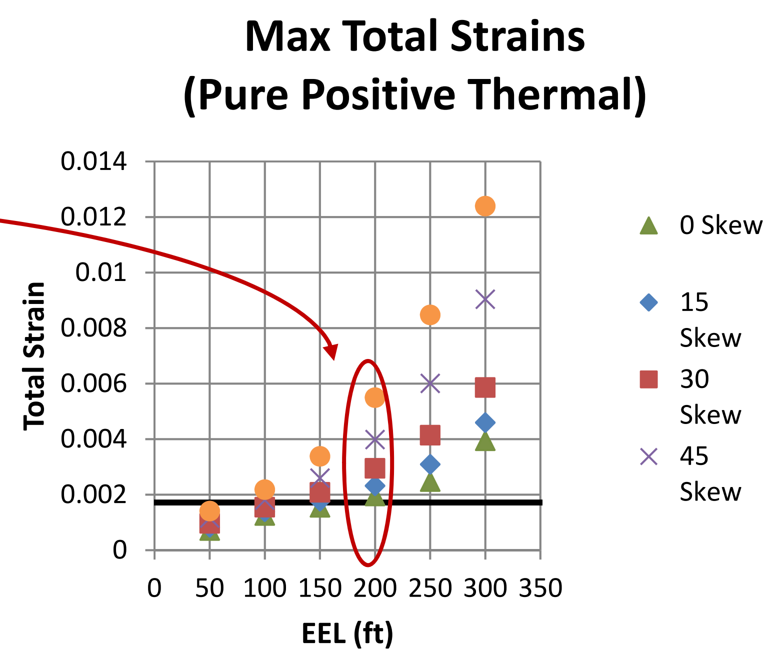


Pile Strains vs. Skew and EEL

4x100 ft, HP14x73, EEL = 200 ft

100 ft Spans, HP14x73





General Effects of IAB Parameters

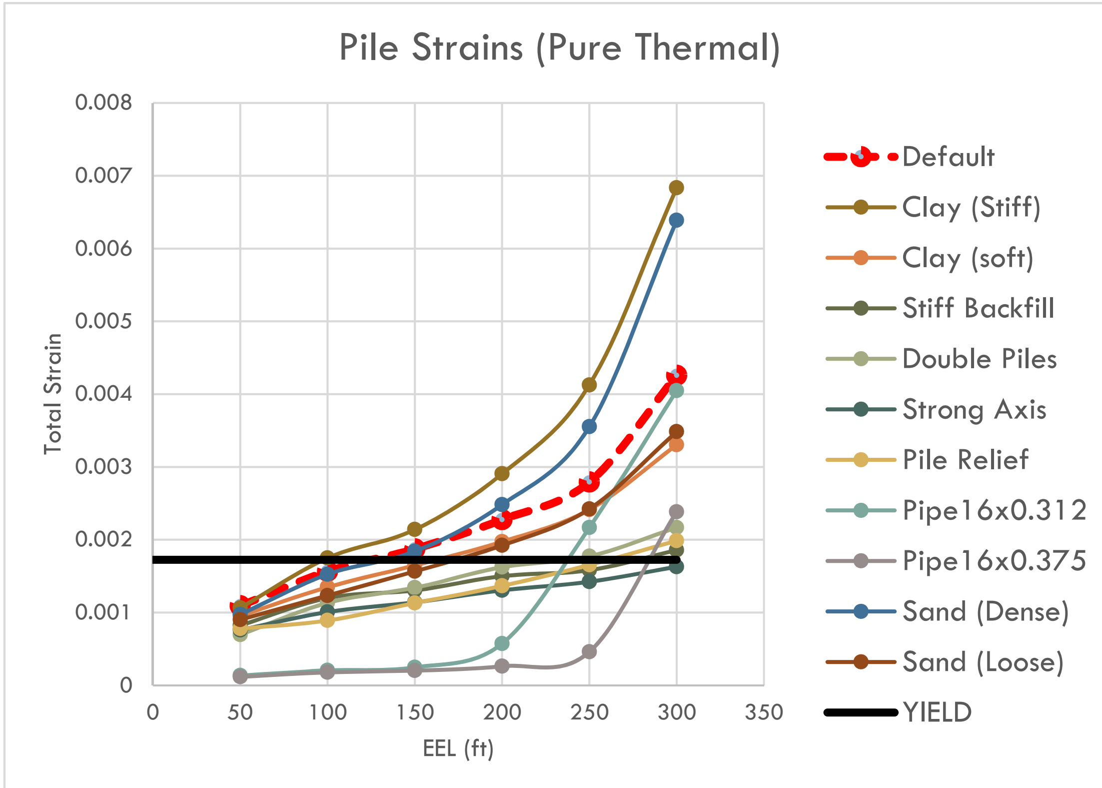
Increase in:	Effect:
EEL	Increase in pile & girder demands
Pile size	Decrease in pile demands, increase in girder demands
Bridge skew	Increase in pile demands, decrease in girder demands
Bridge width	Small increase in pile demands
End-span ratio	Decrease in pile & girder demands

IAB Modeling – Secondary Parameters

- Soil Foundation Stiffness
  - Default: medium clay
  - Variations: stiff and soft clay, dense and loose sand
- Backfill Stiffness
  - Default: uncompacted sand
  - Variations: stiff backfill
- Pile Conditions
  - Default: H-piles, weak-axis orientation
  - Variations: pipe piles, H-pile w/ strong-axis orientation, double H-piles
- Pile-Top Relief

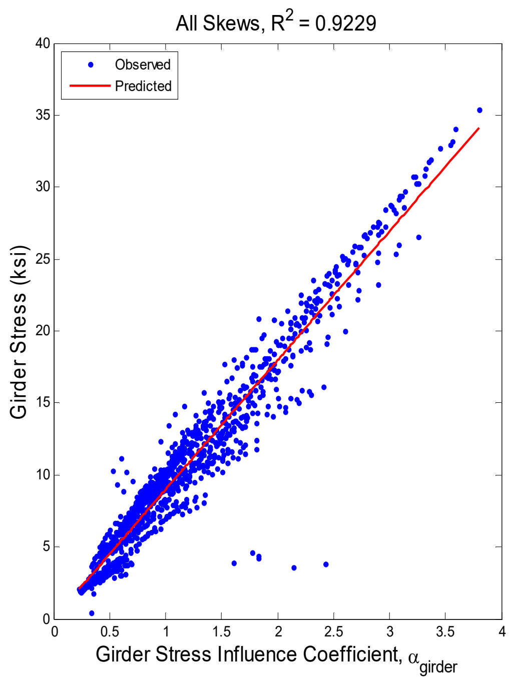
Secondary Parameters

- Pile strains increase with:
  - Dense Sand
  - Stiff Clay
- Pile strains decrease with:
  - Pipe Piles
  - Pile Relief
  - Loose Sand
  - Soft Clay
  - Stiff Backfill
  - Double Piles
  - Strong-Axis

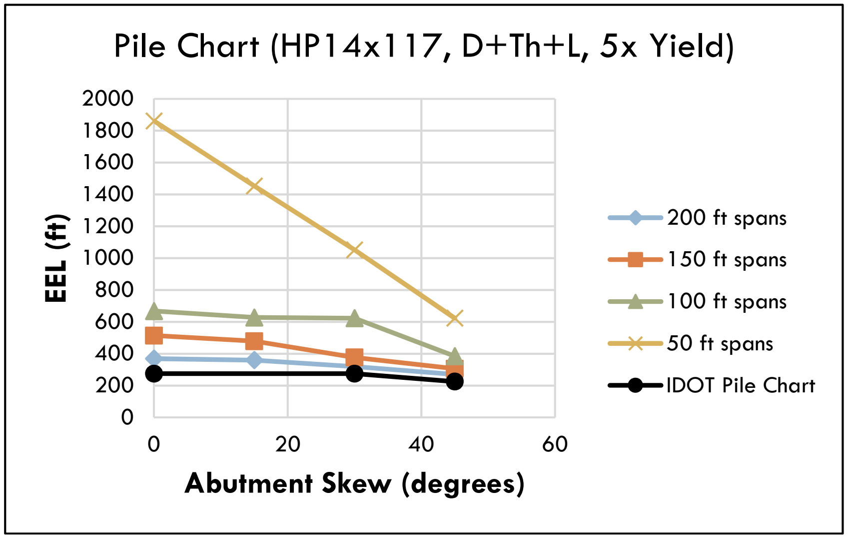


Outcomes for Design

- Pile strain and girder stress nonlinear regressions:



- Proposed updated pile charts:



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CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 16-015
UILU-ENG-2016-2015
ISSN: 0197-9191

INTEGRAL ABUTMENT BRIDGES UNDER THERMAL LOADING: NUMERICAL SIMULATIONS AND PARAMETRIC STUDY

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Research Report No. FHWA-ICT-16-014

A report of the findings of

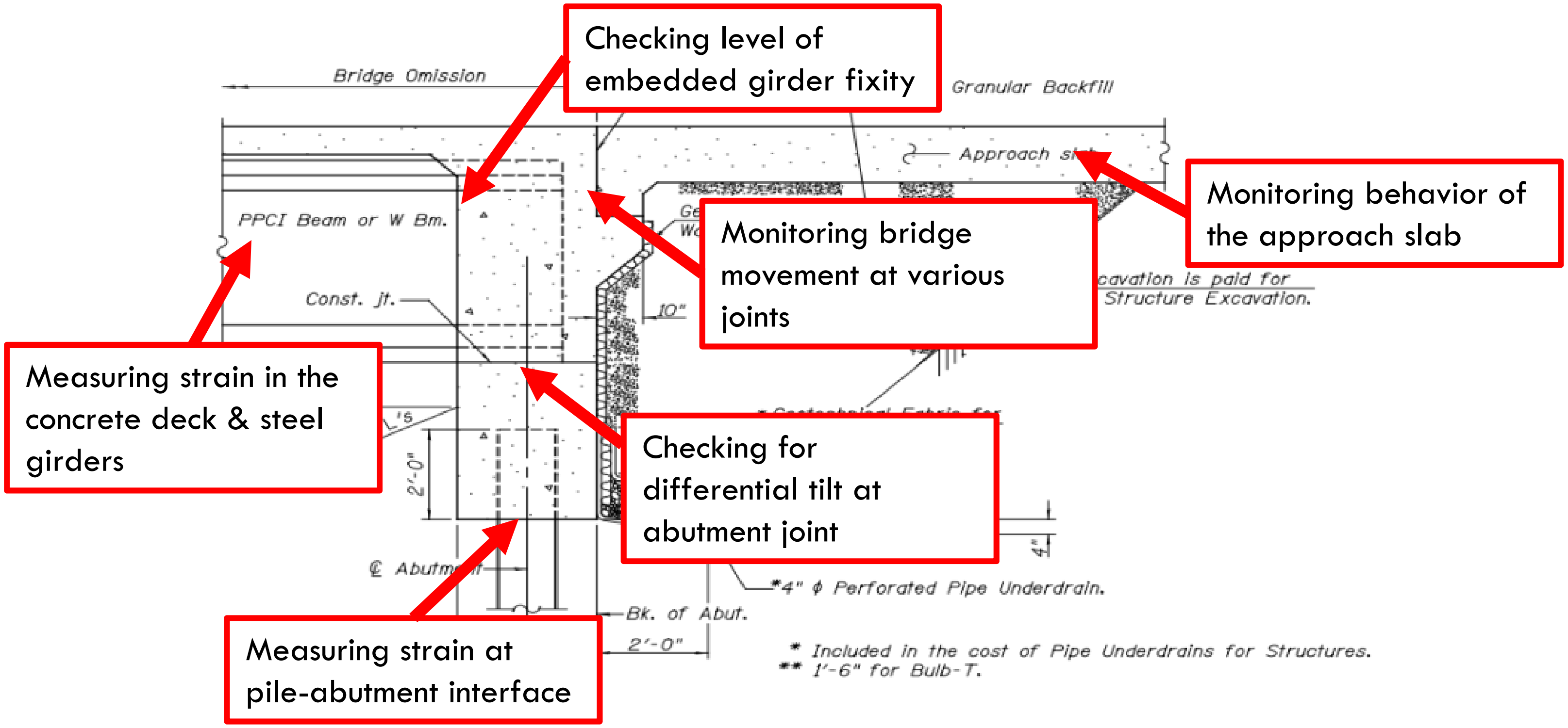
ICT PROJECT R27-115
Analysis of Superstructures of Integral Abutment Bridges

Illinois Center for Transportation

June 2016

IAB Field Monitoring of Two Highway Bridges

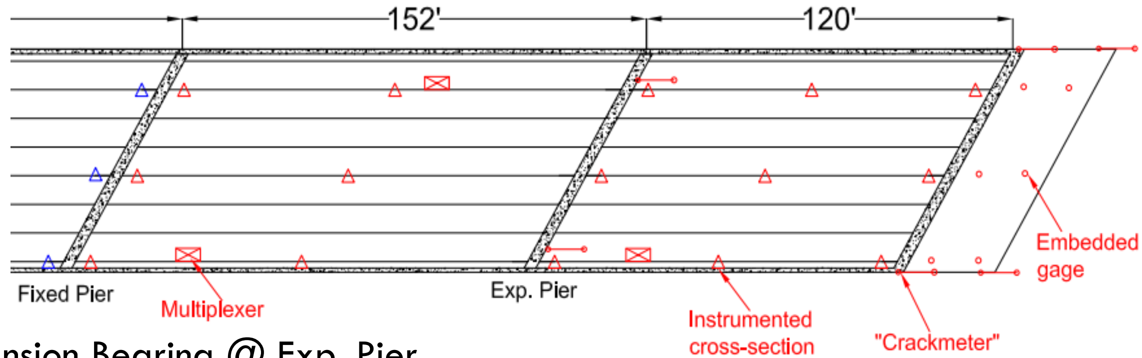
IAB Instrumentation Goals



Bridge Instrumentation Schematics

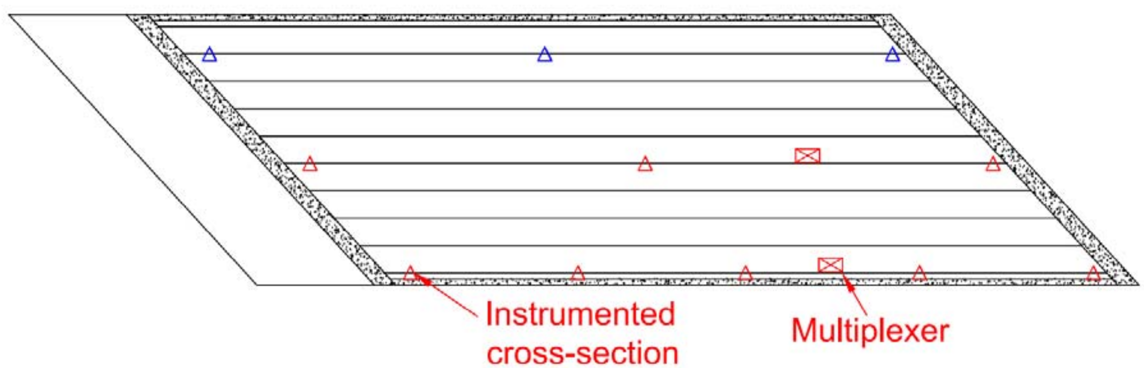
EB I-90
Kishwaukee River
Bridge

- 4-Span
- 549 ft
- 30° Skew
- HLMR Guided Expansion Bearing @ Exp. Pier

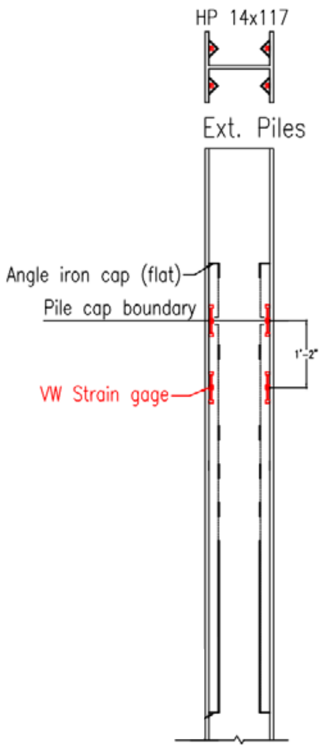


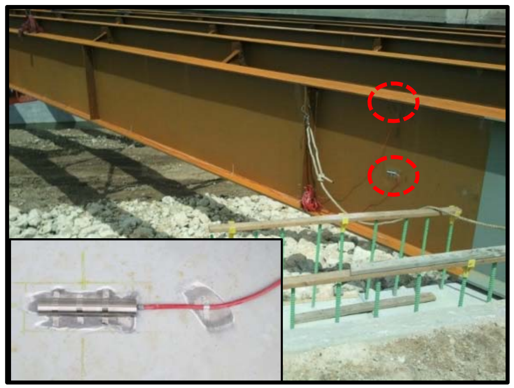
EB I-90 Union
Pacific Railroad
(UPRR) Bridge

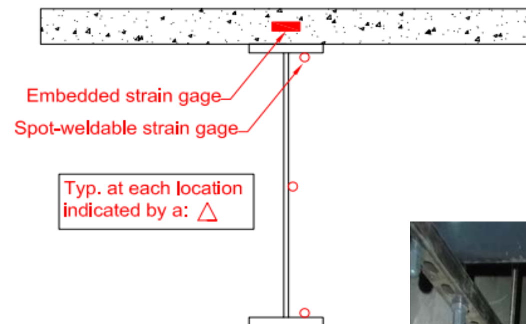
- Single-Span
- 184.5 ft
- 42.5° Skew

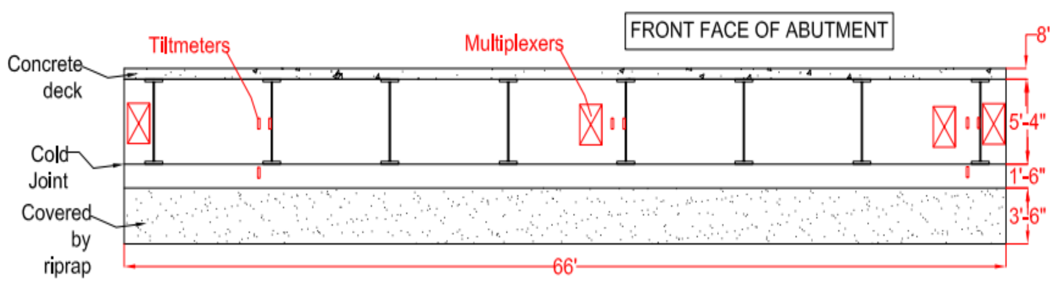


Kishwaukee Bridge Instrumentation Details (similar scheme for UPRR)



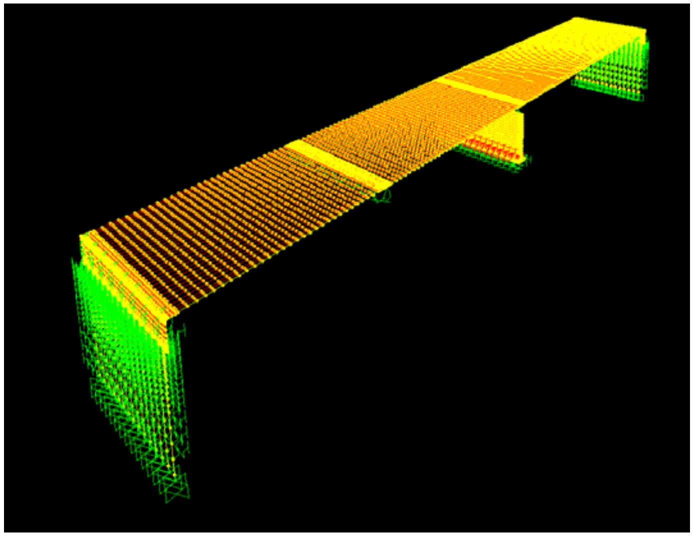




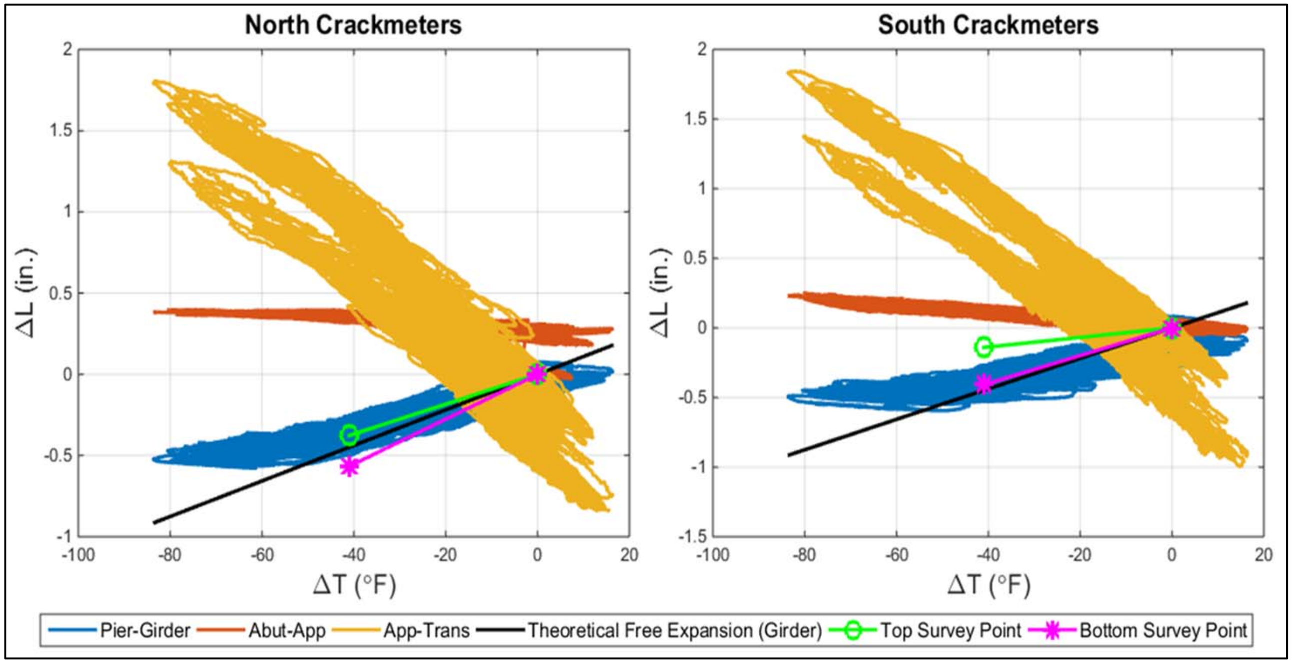


Modeling of Site Bridges

- SAP2000 was also used to model each instrumented bridge
- Boring logs were utilized to determine backfill and foundation soil properties at each site
- Soil softening was included to represent pile-top relief:
  - Kishwaukee → Bentonite slurry
  - UPRR → MSE wall effects

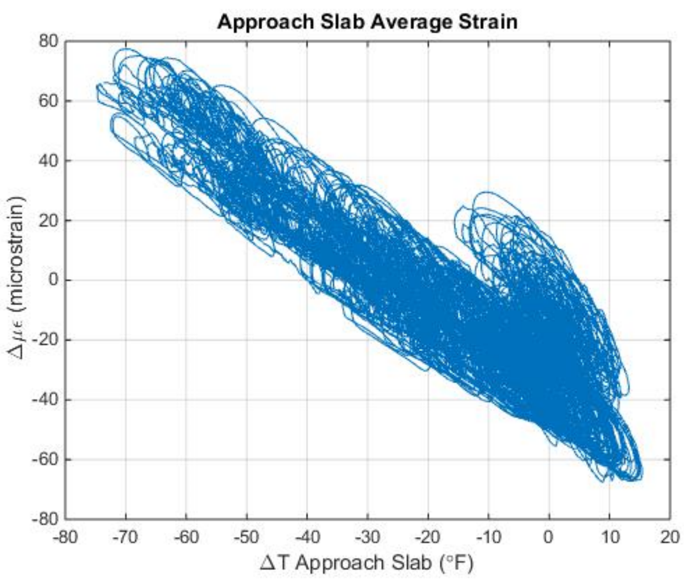


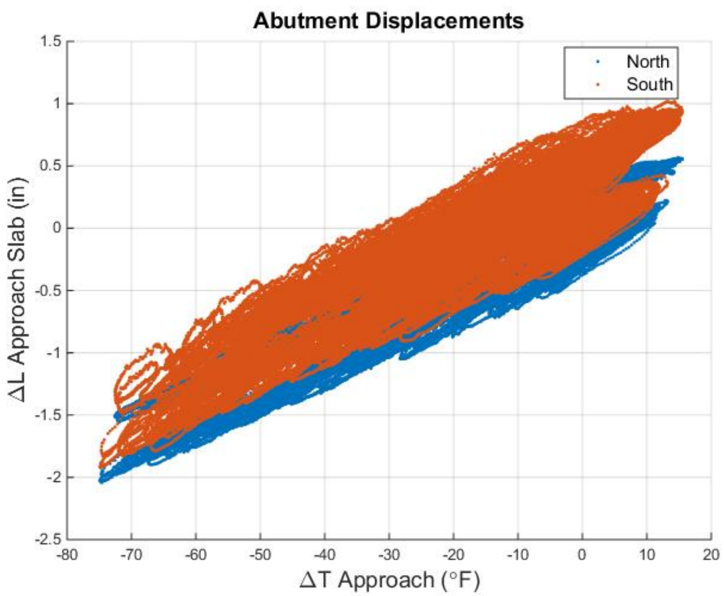
Displacements – Kishwaukee



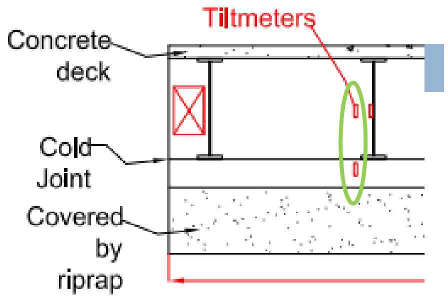
Approach Slab Behavior

- Strains are not uniform throughout the approach slab
- Average strain indicates a clear trend with change in temperature

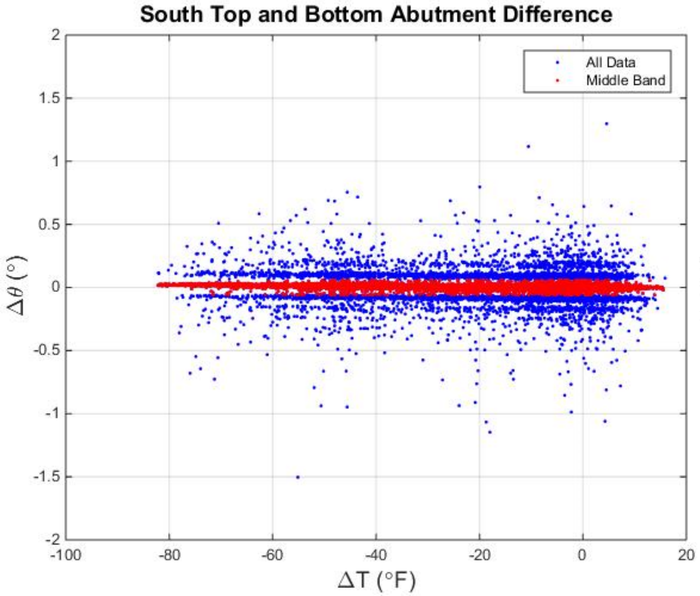




Abutment Cold Joint Rotations

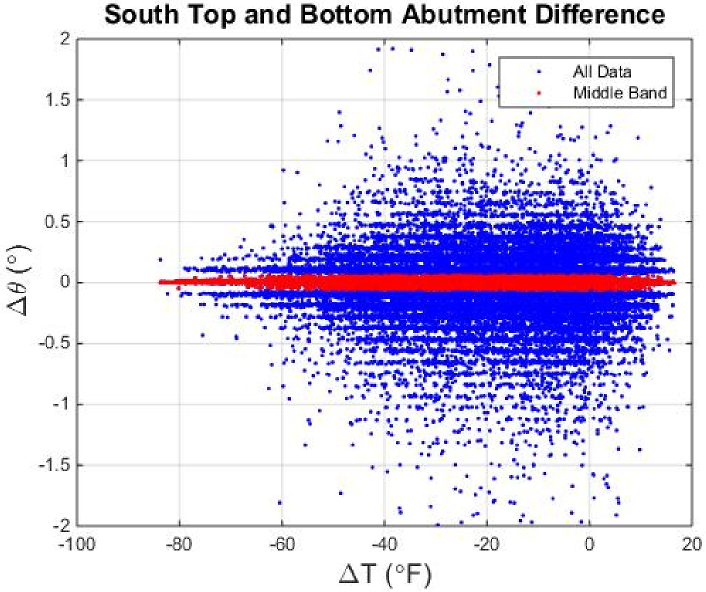


UPRR



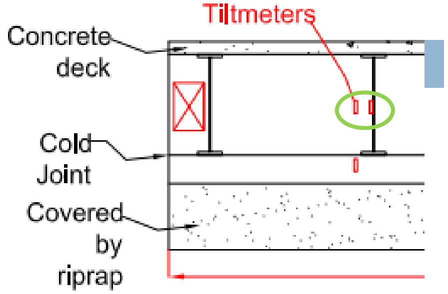
Middle band = 86% of data

Kishwaukee

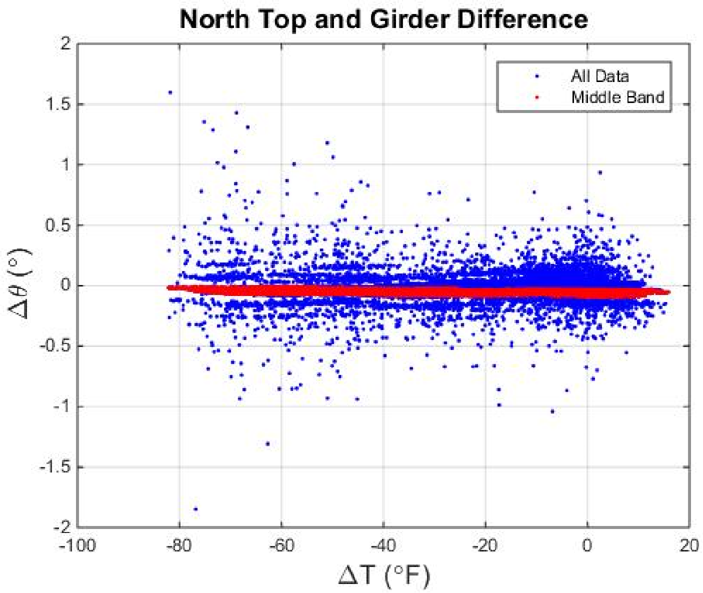


Middle band = 74% of data

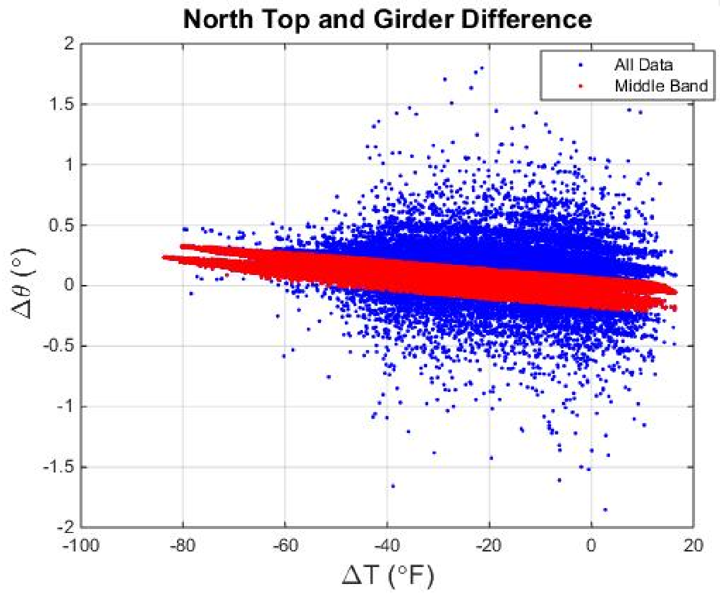
Girder Differential Rotations



UPRR



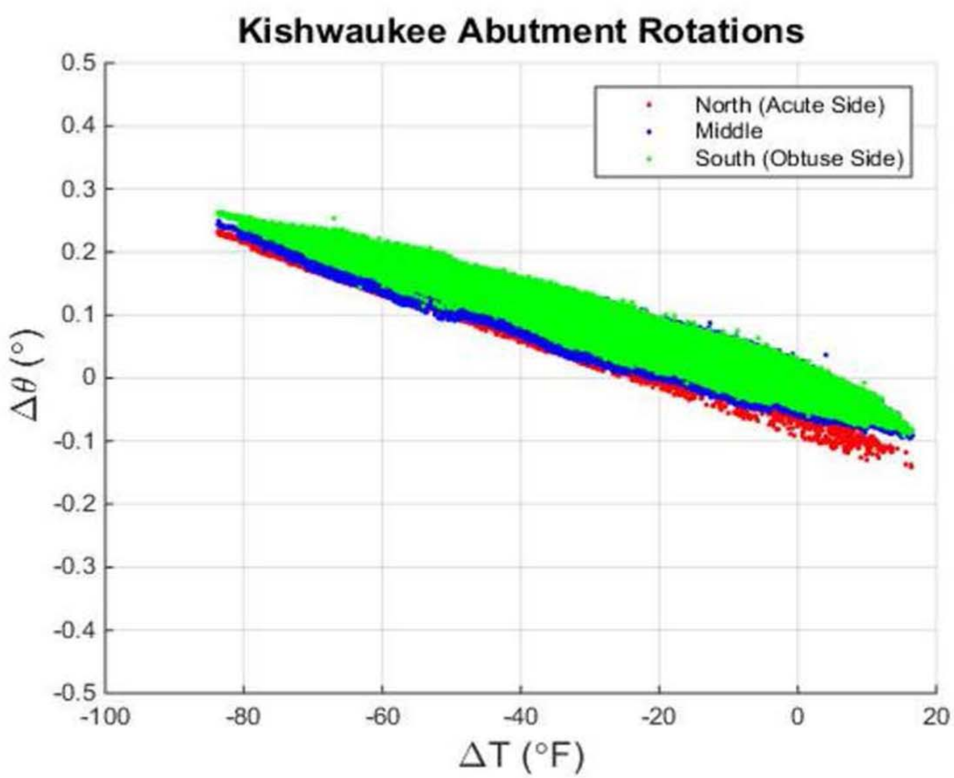
Kishwaukee

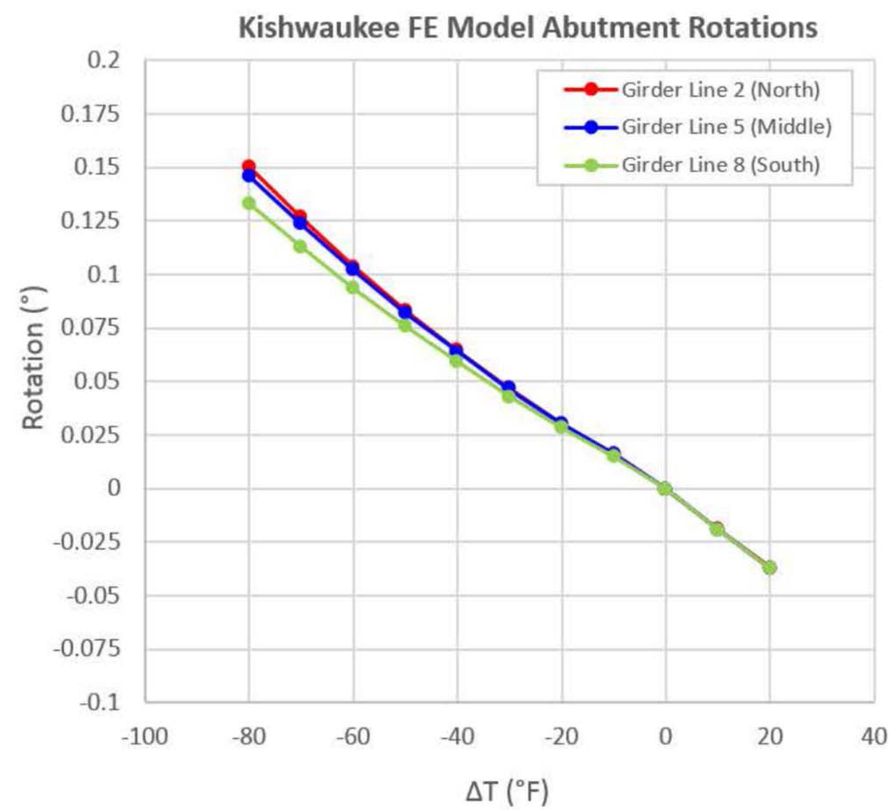


Middle band = 49% of data
Max rotation: 0.1°

Middle band = 68% of data
Max rotation: 0.33°

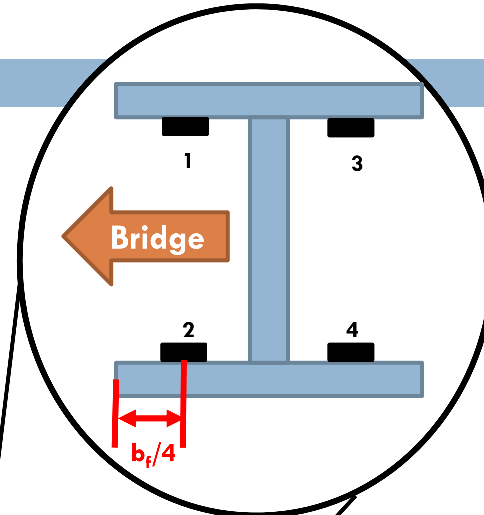
Kishwaukee Field vs. Model Abutment Rotations

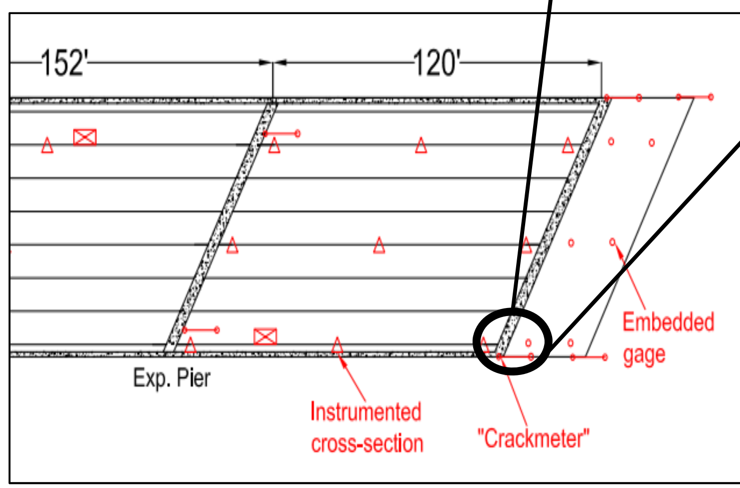




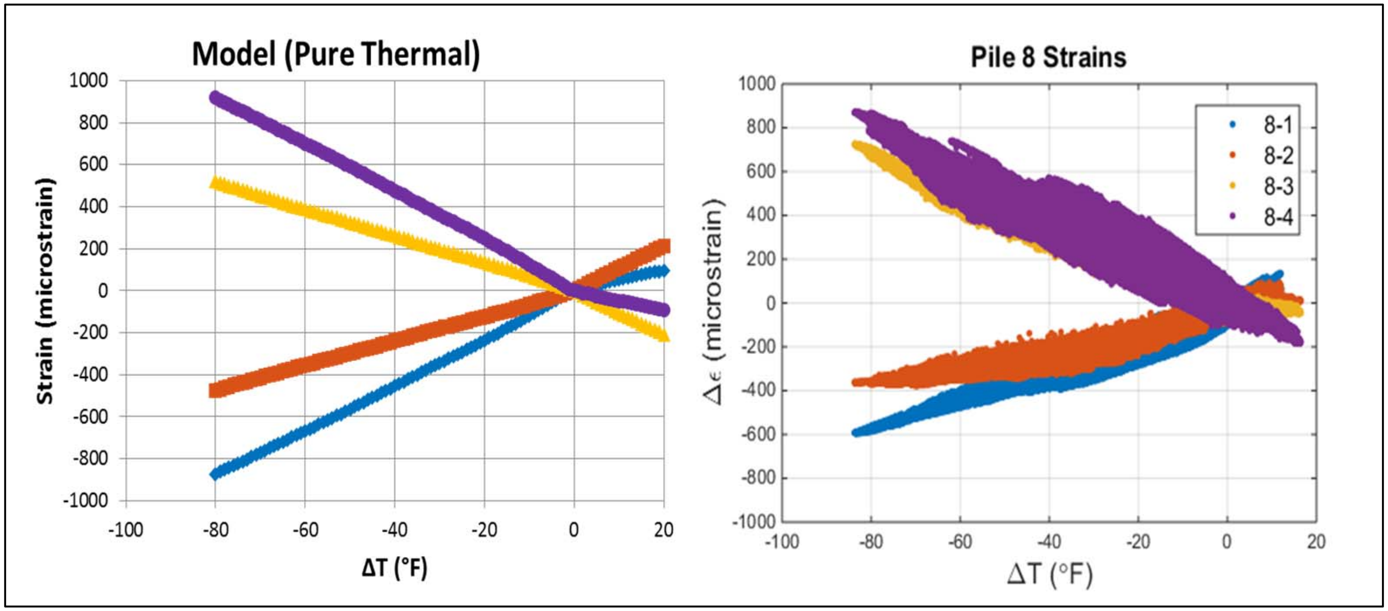
Pile Strains

- Pile top strains from the field data are closer to pure weak-axis flexure than combined flexure
- Strong-axis bending causes a separation in magnitude between strain gage pairs
- Axial force causes a shift in the magnitude of tensile vs. compressive strain





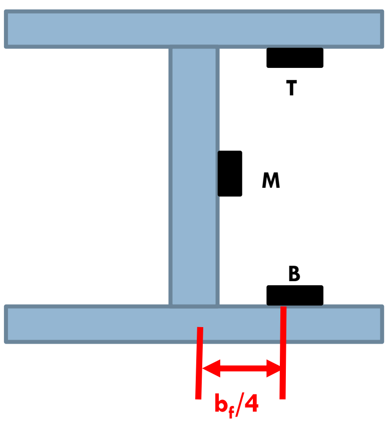
Kishwaukee – Obtuse Pile Top Strains

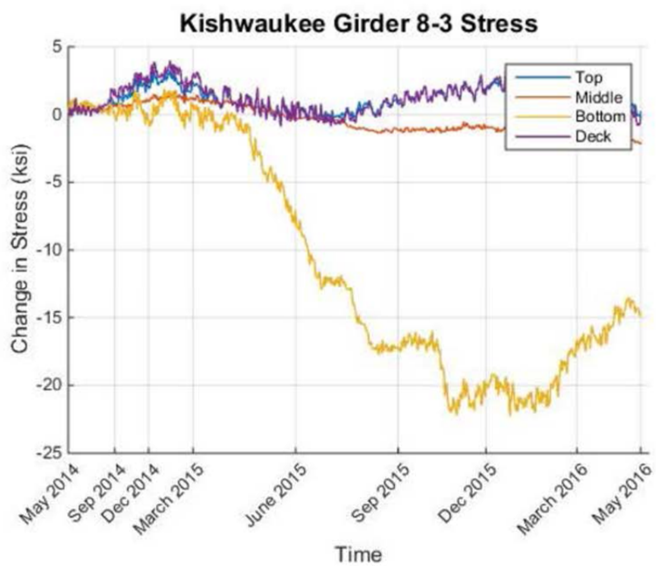


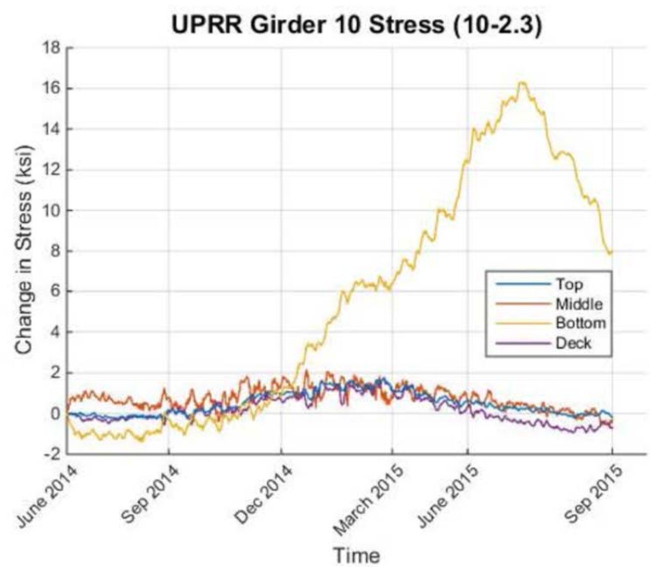
Axial contribution causes upward shift in magnitude; strong-axis bending causes a separation between gage pairs

Girder Demands

- Top-flange and web gages trend well over time and with temperature
- Bottom-flange measurements typically deviate from expected trends over time, after the first fall/winter/spring

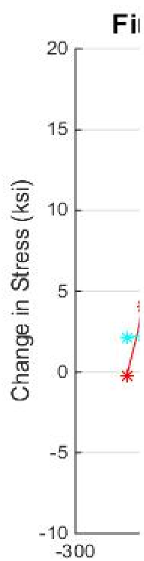


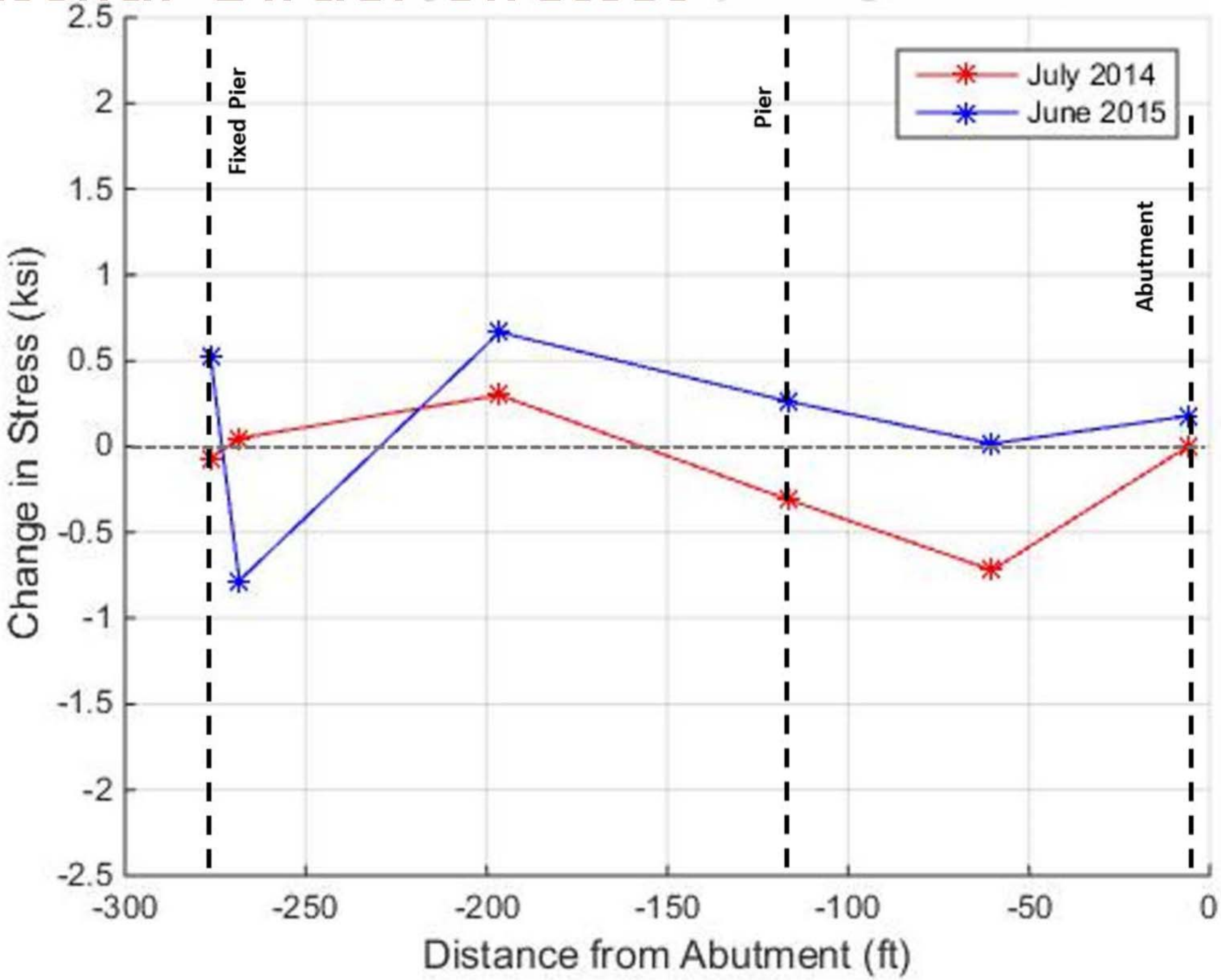


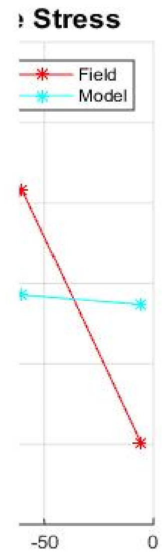


Seasonal Girder Stresses

- After t… te from m… fore
- The hig…







CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 17-022
UILU-ENG-2017-2022
ISSN: 0197-9191

Integral Abutment Bridges under Thermal Loading: Field Monitoring and Analysis

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Research Report No. FHWA-ICT-17-017

A report of the findings of

ICT PROJECT R27-115
Analysis of Superstructures of Integral Abutment Bridges

Illinois Center for Transportation

August 2017

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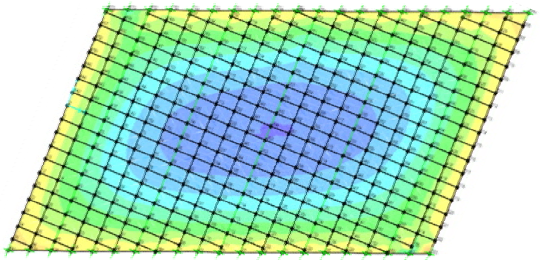
Overall Conclusions for IABs

- IAB Analysis (Parametric Study)
  - Bridge expansion & contraction are about 90% of the magnitude of free expansion & contraction
  - Thermally-induced stresses in the superstructure should be considered when proportioning girders (especially in end-spans)
  - An allowance for moderate inelastic deformation in pile foundations may broaden the range of acceptable bridge layouts
- IAB Instrumentation (Field Monitoring)
  - Field results were used to validate parametric study analytical models and to better understand IAB & approach slab performance
  - Pile strains in the field closely follow predicted analytical trends
  - Girder bottom flanges exhibit the highest thermal stress ranges

Ongoing Work – IAB Approach Slab Research

- Research Goals:
  - Identify the fundamental cause of cracking issues in IAB approach slabs
  - Develop improved design criteria and procedures to mitigate cracking
- Three Main Components:
  - Investigation of existing IAB approach slabs
  - Numerical modeling parametric study
  - Field instrumentation & monitoring of two Illinois Tollway IAB approach slabs

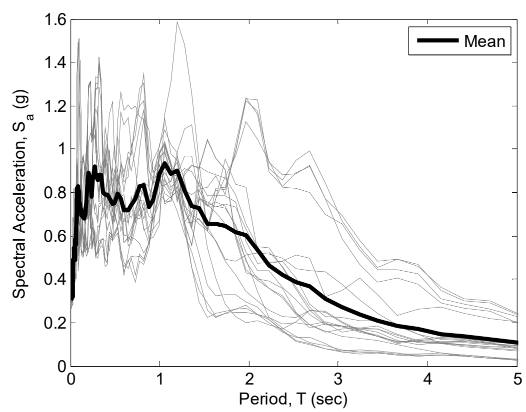
Approach slab embedded strain gage instrumentation



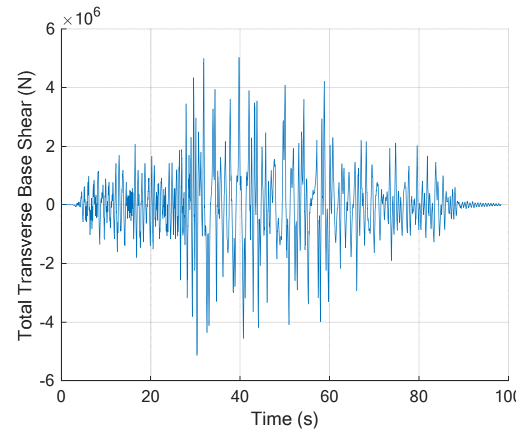
Initial Approach Slab Model

IAB Seismic Research

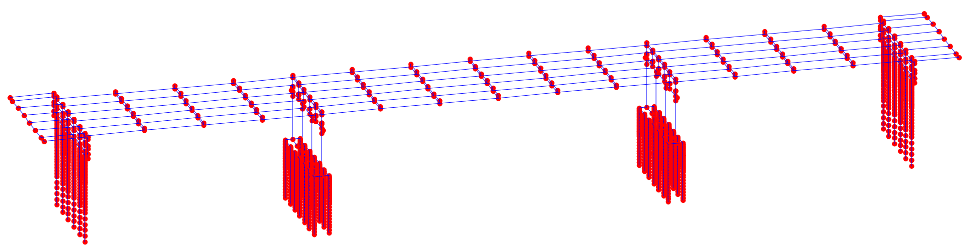
- Research Goals:
  - Assess the behavior of IABs to a 1000-year return period seismic event
  - Form recommendations to improve seismic design & construction of IABs, with a focus on southern Illinois
- Two Main Components:
  - Develop 1000-year return period hazard ground motions for southern Illinois
  - Model IABs in OpenSees and assess their seismic behavior



Ground motions developed for Cairo, IL



Total base shear in a three-span steel IAB during a ground motion



Schematic of the three-span IAB used for modeling in OpenSees

Acknowledgements

- Illinois Department of Transportation (IDOT)
- Illinois Tollway
- Illinois Center for Transportation (ICT)
- ICT R27-115 Technical Review Panel – Chair: Mark Shaffer (IDOT)
- Co-PI & UIUC CEE Professor Larry Fahnestock
- Gabriela Brambila, Joseph Riddle, Matthew Jarrett, Jeffrey Svatora, Beth Wright & Huayu An (former UIUC CEE Graduate Student Researchers)