OFFICE OF RESEARCH & DEVELOPMENT

2012 R&D REVIEW

Improved Concrete Crossties and Fastening Systems for High Speed Rail and Joint Passenger/Freight Corridors
FRA BAA 2010-1

U.S. Department of Transportation
Federal Railroad Administration

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Presentation Outline

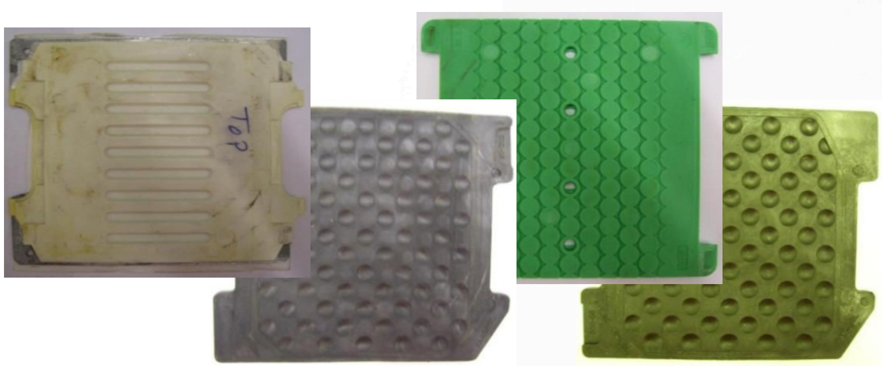
- Concrete Crosstie and Fastening System Background
- FRA Concrete Crosstie and Fastening System BAA
  - Overview and Objectives
  - Industry Involvement
  - Preliminary Results
  - Future Work
- Mechanistic Design
  - Introduction
  - Path Forward
- Acknowledgements

Concrete Crosstie and Fastening System Components

Concrete Crossties

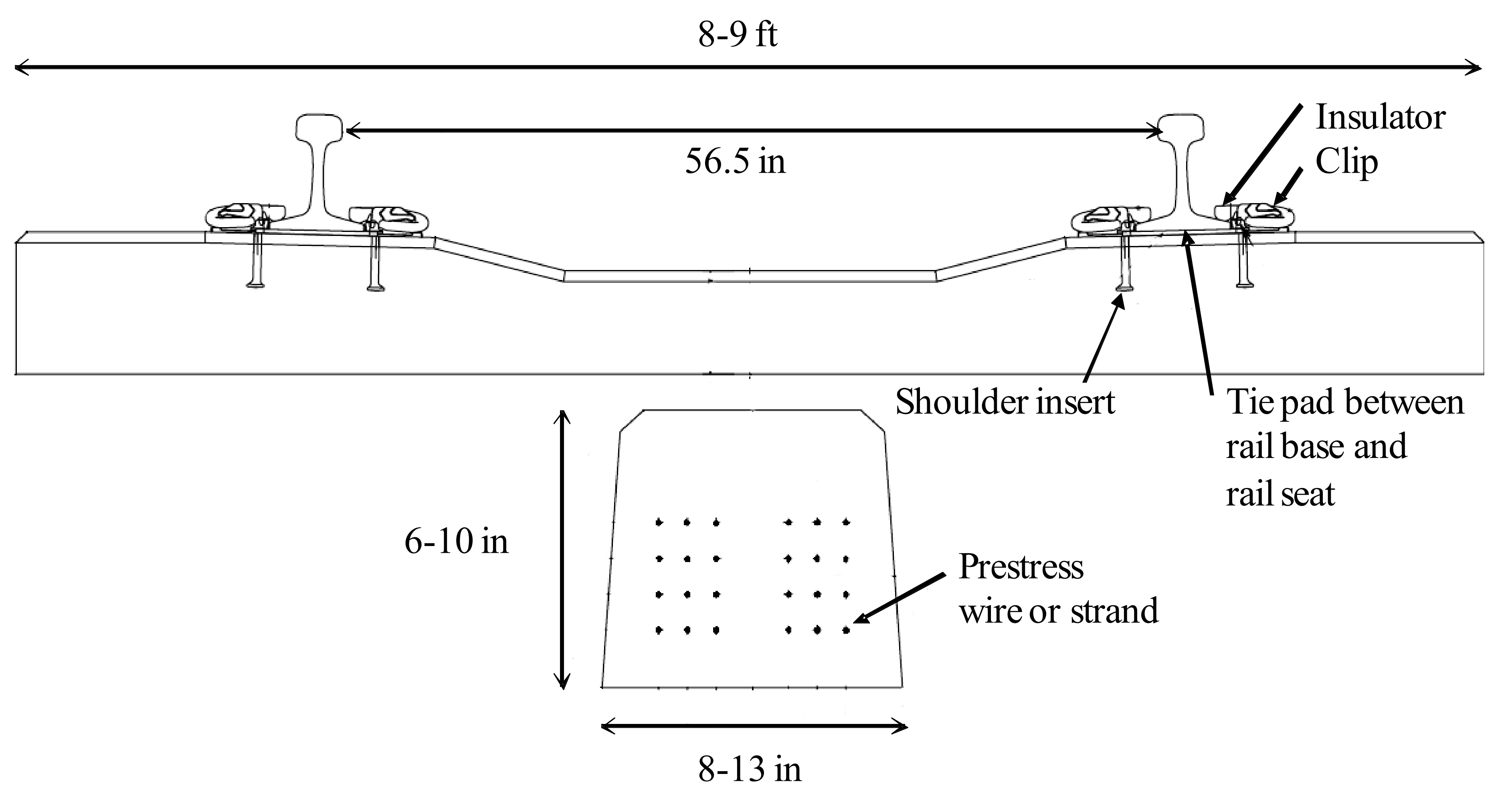
Clips

Rail Pads



Fastening Insulators

Complete System



FRA Concrete Crosstie and Fastening System BAA

- **Program Objectives**
  - Conduct comprehensive literature review and state-of-the-art assessment for design and performance
  - Conduct experimental laboratory and field testing, leading to improved recommended practices for design
  - Provide mechanistic design recommendations for US concrete crossties and fastening system design

- **Industry Partner Involvement**
  - Industry partner meetings (Fall 2011 and Spring 2012)
  - Examples of industry involvement:
    - Obtaining approval for crosstie and fastening system types to be tested and modeled
    - Provision of drawings, instrumented crossties, etc.
  - Strong support from AREMA Committee 30 (Ties)

U.S. Department of Transportation
Federal Railroad Administration

FRA Tie and Fastener BAA Industry Partners:

UNION PACIFIC BUILDING AMERICA®

BNSF RAILWAY

AMTRAK®

Amsted RPS

Amsted Rail

GIC INGENIERÍA Y CONSTRUCCIÓN S.A. DE C.V.

HANSON

LBFoster CXT Concrete Ties

FRA Tie and Fastener Program Structure

Inputs

Comprehensive Literature Review

International Tie and Fastening System Survey

Loading Regime (Input) Study

Rail Seat Load Calculation Methodologies

Involvement of Industry Experts

Modeling

Laboratory Study

Field Study

Outputs/Deliverables

Data Collection

Document Depository

Groundwork for Mechanistic Design

International Survey Report

Load Path Map

Parametric Analysis

State of Practice Report

Validated Tie and Fastening System Model

Improved Recommended Practices

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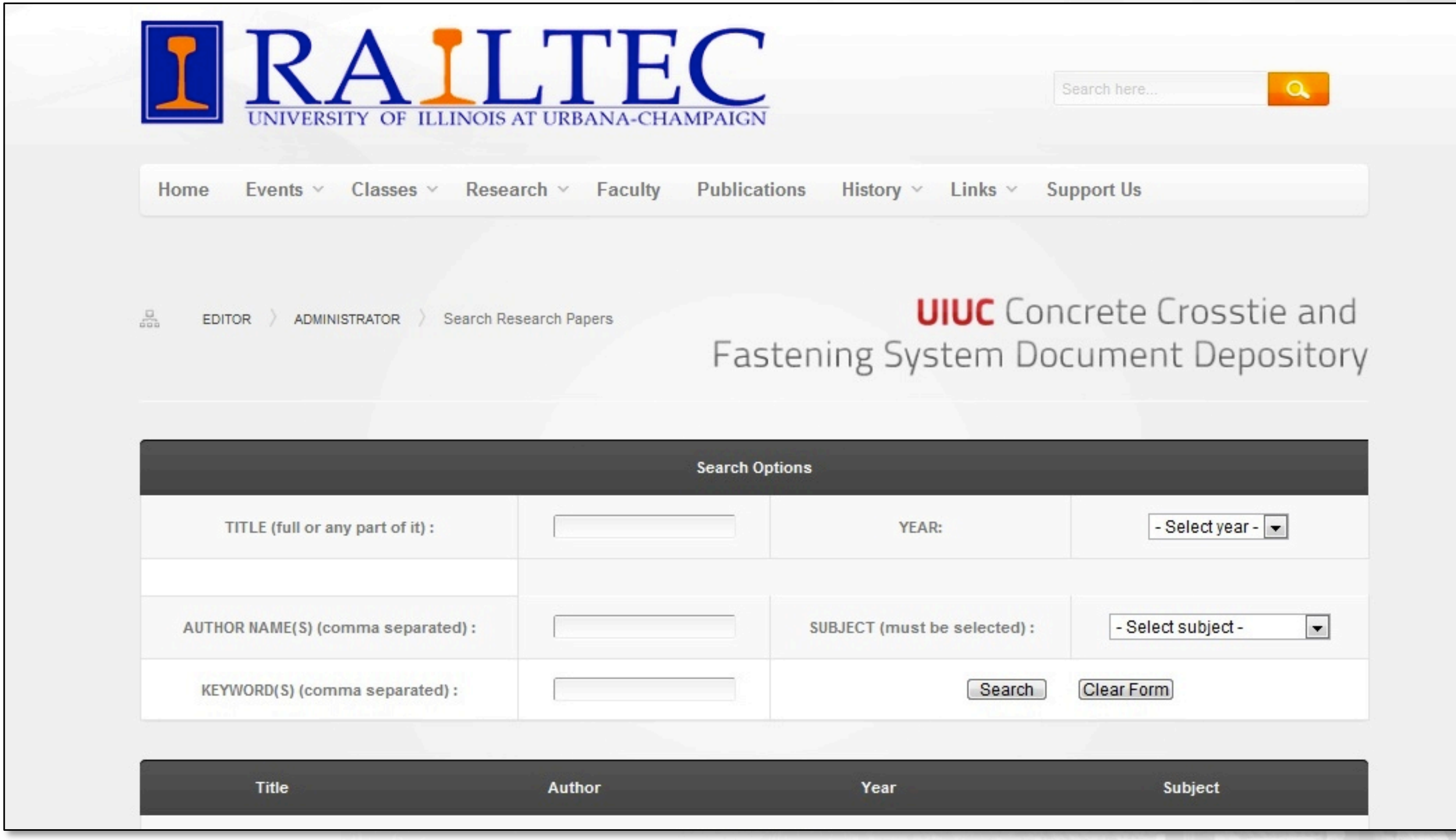
UIUC Concrete Crosstie and Fastening System Document Depository



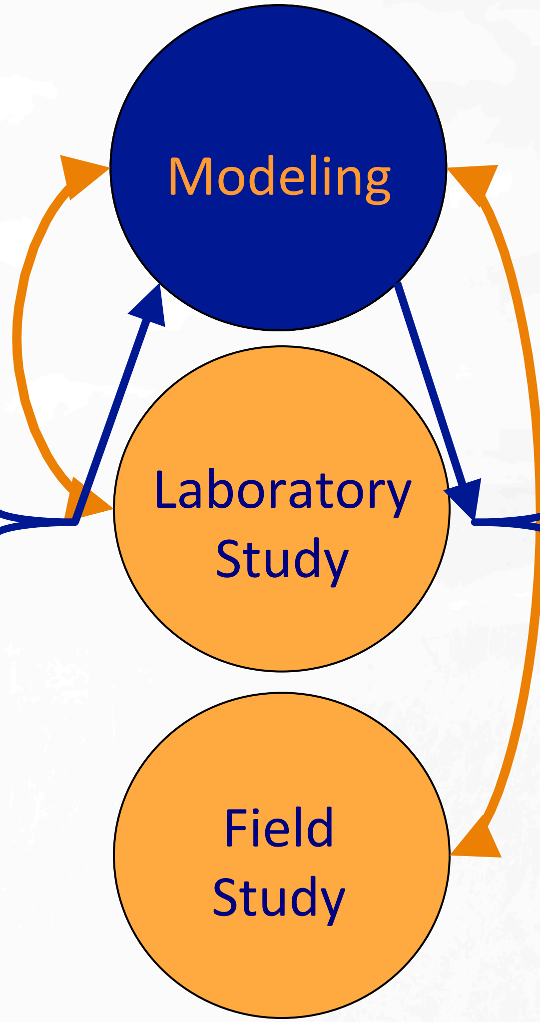
2012 International Survey Results – Research Needs

Research topic (higher ranking is more important)	Average Rank
International Responses	
Track system design	4.08
Optimize crosstie design	3.93
Fastening system design	3.50
Materials design	2.23
Prevention or repair of rail seat deterioration	1.58
North American Responses	
Prevention or repair of rail seat deterioration	3.60
Fastening system design	3.60
Materials design	3.00
Optimize crosstie design	2.80
Track system design	2.00

FRA Tie and Fastener Program Structure

Inputs

- Comprehensive Literature Review
- International Tie and Fastening System Survey
- Loading Regime (Input) Study
- Rail Seat Load Calculation Methodologies
- Involvement of Industry Experts



Outputs/Deliverables

- Data Collection
- Document Depository
- Groundwork for Mechanistic Design
- International Survey Report
- Load Path Map
- Parametric Analysis
- State of Practice Report
- Validated Tie and Fastening System Model

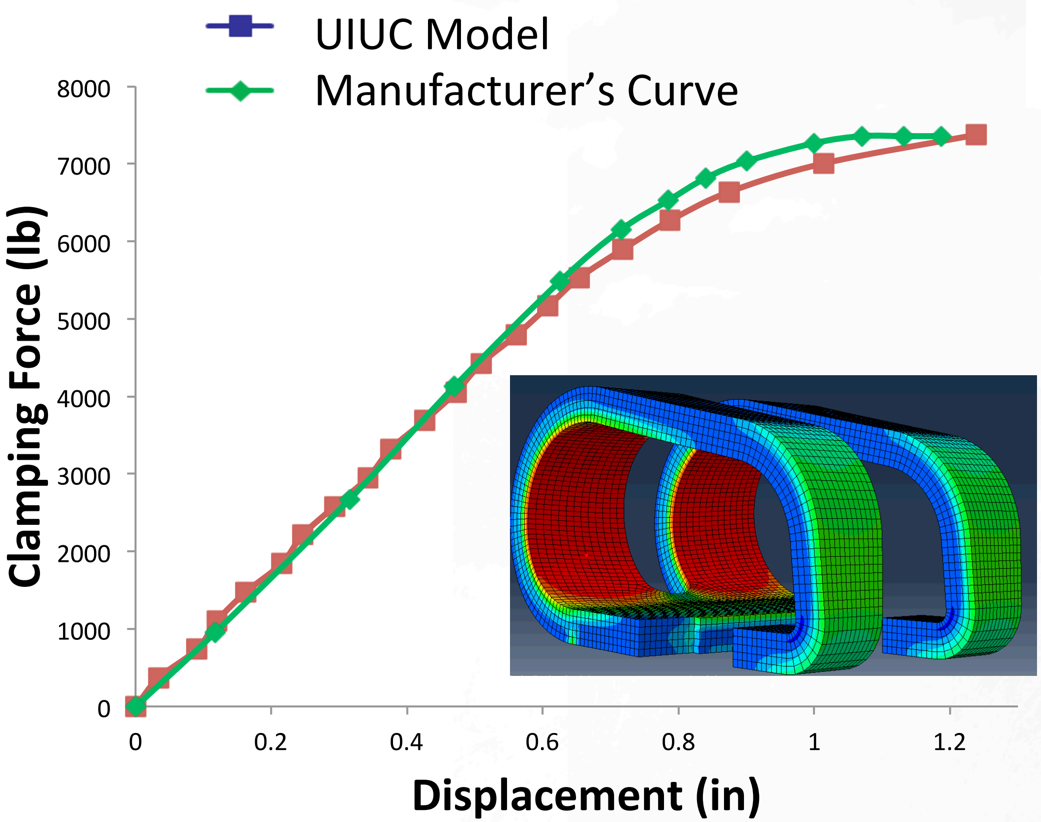
Improved Recommended Practices

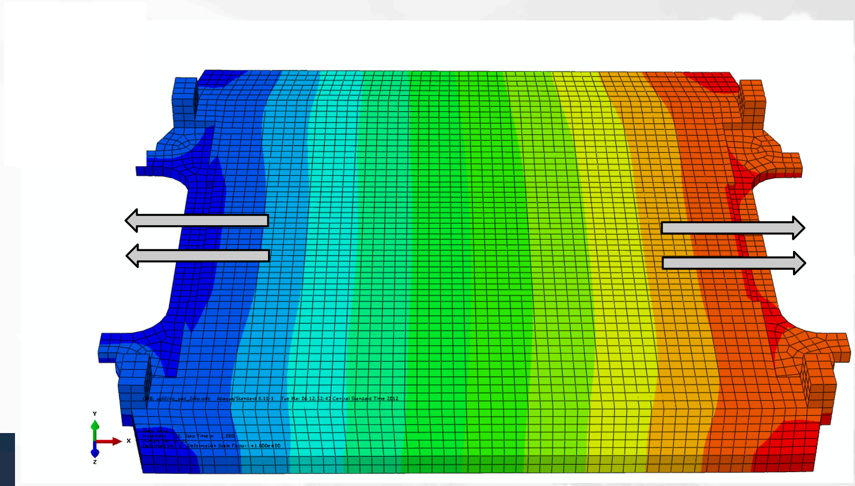
Finite Element Modeling Overview

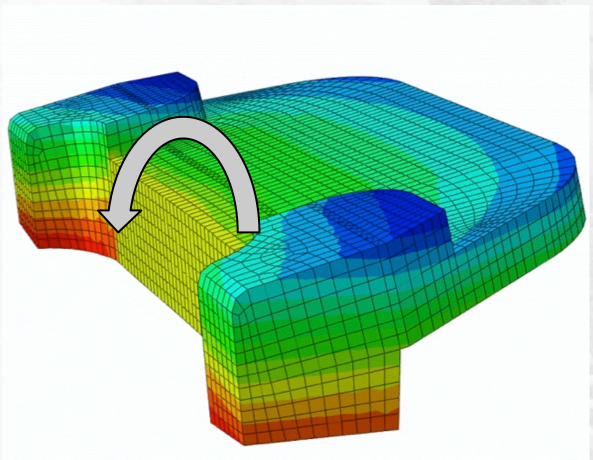
- **Work thus far has included**
  - 2D and 3D component modeling
  - 2D and 3D system modeling
    - rail, clips, insulator, rail pad assembly, and crosstie
    - rail, rail pad assembly, crosstie, and ballast

- **Future work**
  - Assemble all components to complete system model
    - rail, clips, insulator, rail pad assembly, cast-in shoulder, crosstie, ballast, sub-ballast, subgrade
  - Validate model
  - Introduce additional loading types and forms
    - Lateral and longitudinal as well as dynamic
  - Perform parametric study to investigate effects of changing:
    - rail pad geometry and material, clip toe load, etc.

Component Modeling: Clamping Force Response



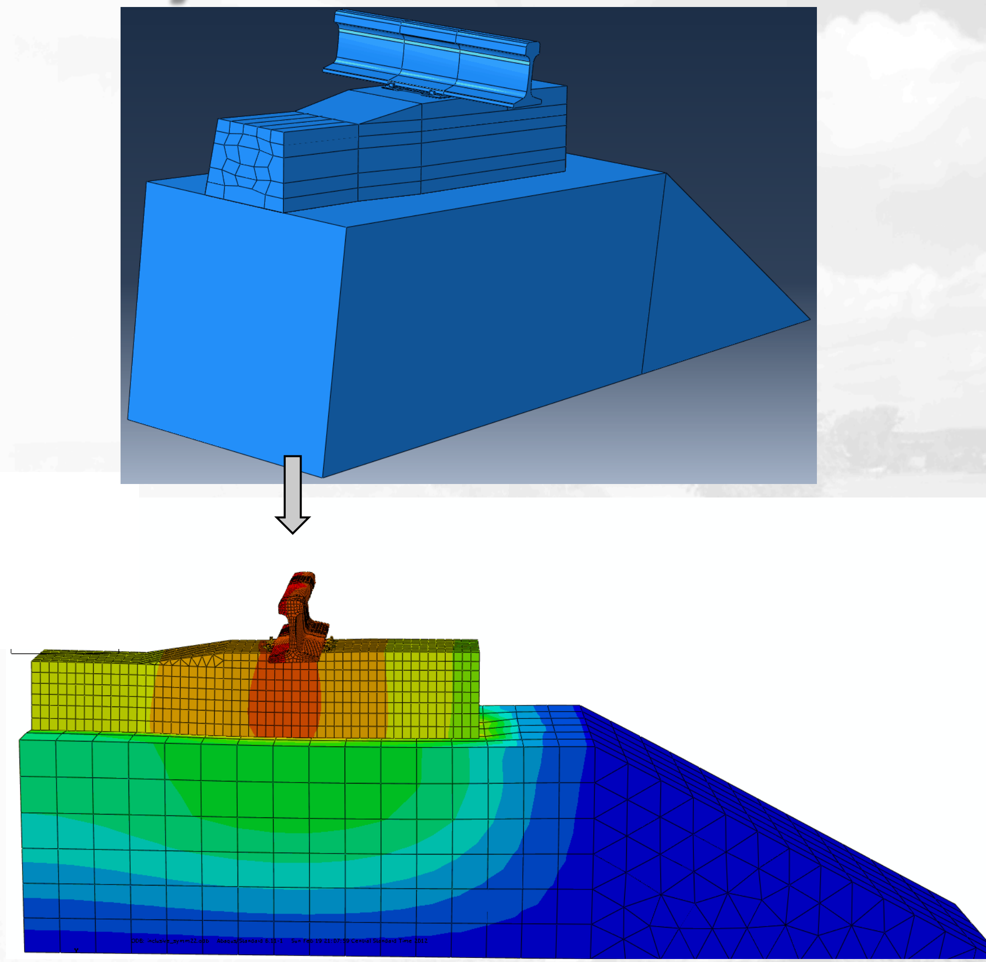




Current Model: System Modeling Rail and Pad Assembly

Model Features:

- Concrete material property follows damage plasticity model
- Connector element is used to simulate the bond relationship between concrete and strand
- Geometry and material properties of rail and rail pad assembly are based on manufacturer data
- Confining pressure effect on material property is considered in ballast modeling
- Vertical static loading applied
- Friction is assumed for interfaces



Vertical Loading Model

FRA Tie and Fastener Program Structure

Inputs

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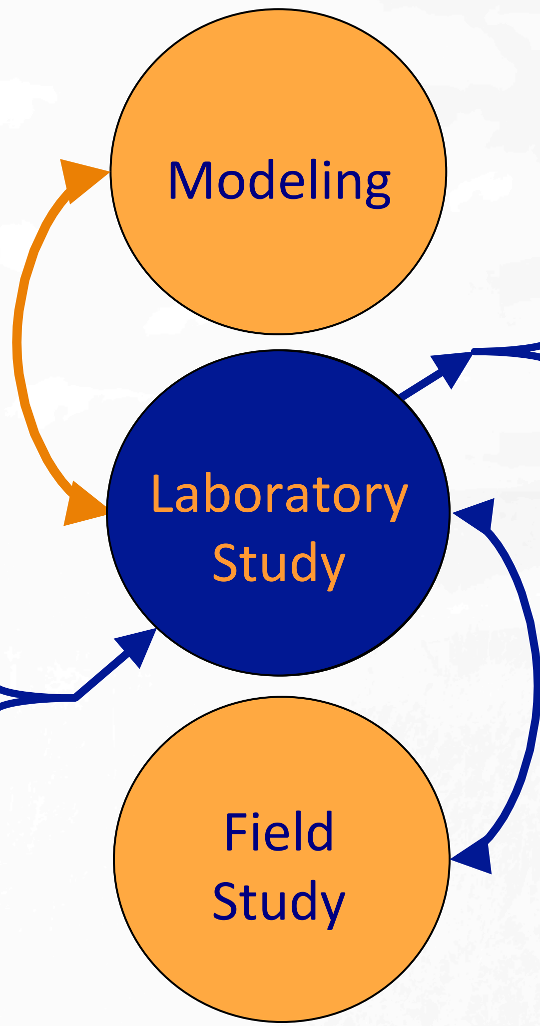
Rail Seat Load Calculation Methodologies

Involvement of Industry Experts



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Validated Tie and Fastening System Model

Improved Recommended Practices

Laboratory Investigation Overview

- Laboratory studies allow:
  - Development and refinement of project instrumentation plan
  - Research with controlled variables to investigate
    - displacement of rail and fastening system components
    - pressure distribution under different L/V ratios, support conditions, and fastening system components
    - the effect of dynamic load
  - Make recommendations to refine lab tests in future
- Three laboratory studies have been completed (one in progress)
  1) Built up load cell feasibility
  2) Instrumentation plan feasibility
  3) Rail seat pressure distribution with varying L/V and rail pad
  4) Rail displacement study (In progress)

FRA Tie and Fastener Project Structure

Inputs

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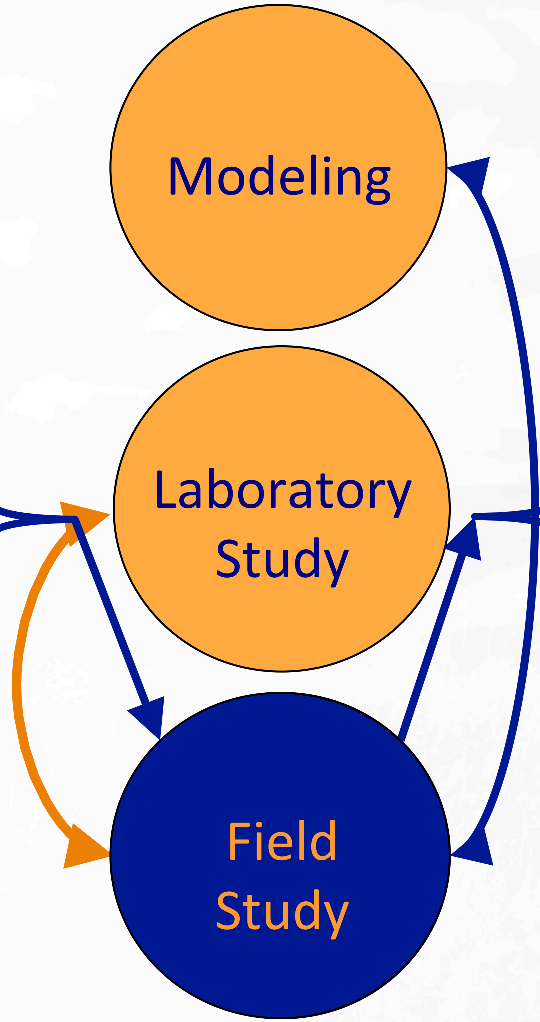
International Tie and Fastening System Survey

Loading Regime (Input) Study

Rail Seat Load Calculation Methodologies

Involvement of Industry Experts



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Improved Recommended Practices

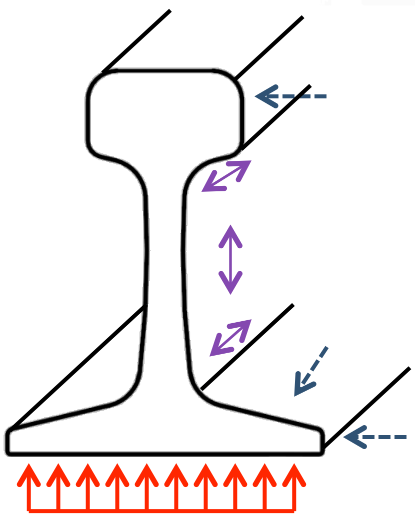
Field Study Overview

- Instrumentation plan will provide synchronized measurements of:
  - Loading conditions
  - Rail and component movement
  - Component stresses
  - Rail seat pressures
- Results will feed into comprehensive FE model
- Strategy will be implemented in variable track conditions (e.g. fastening systems, curvature) for parametric analysis

Areas of Investigation

Rail

- Stresses at rail seat
- Strains in the web
- Displacements of head/base

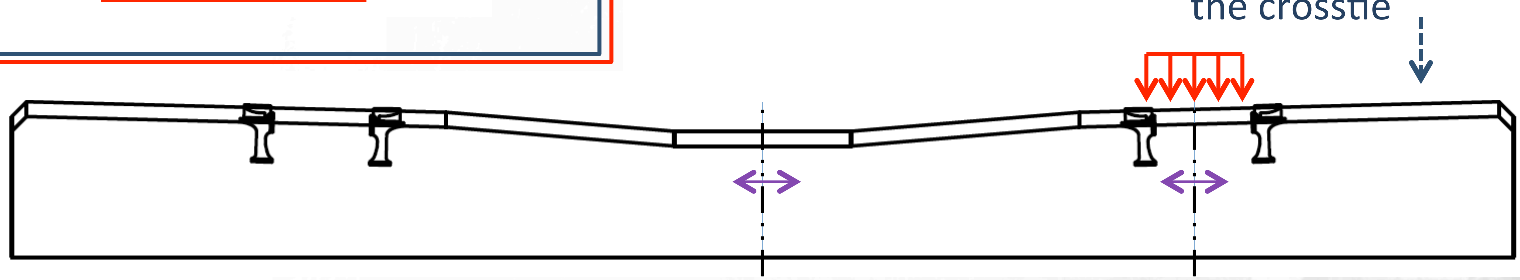


Fasteners/ Insulator

- Strain of fasteners
- Stresses on insulator

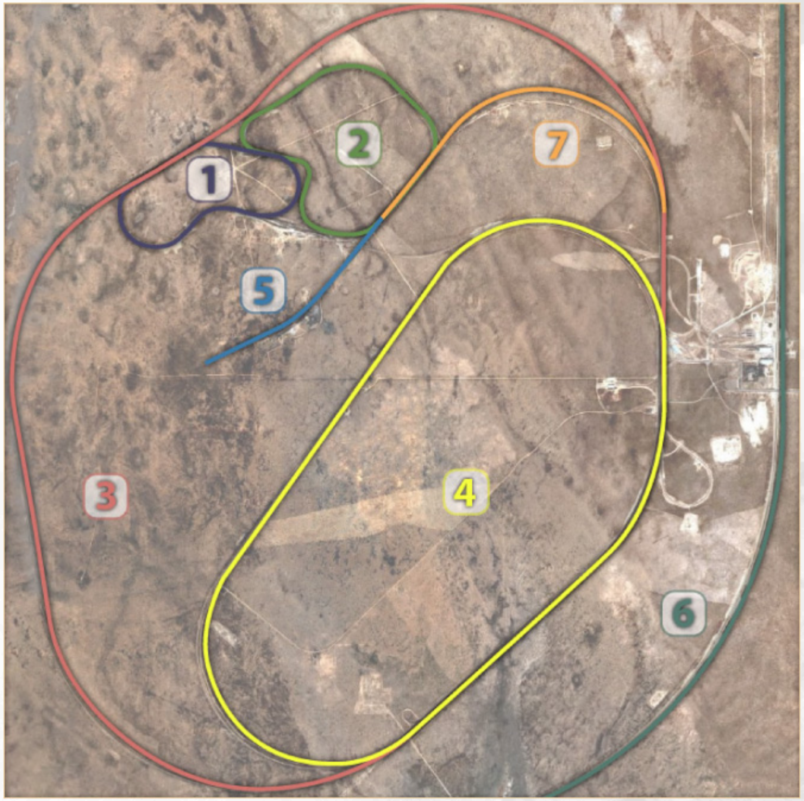
Concrete Crossties

- Internal strains
  - Midspan
  - Rail Seat
- Stresses at rail seat
- Global displacement of the crosstie



Planned Locations for Field Testing

- Monticello Railway Museum
- Transportation Technology Center (TTC)
  - July 2012
  - November 2012
  - Spring 2013
- Class I Railroads
  - Amtrak
  - BNSF
  - Union Pacific



Transportation Technology Center (TTC)

Transportation Technology Center, Inc.

AMTRAK®

BNSF RAILWAY

UNION PACIFIC BUILDING AMERICA®

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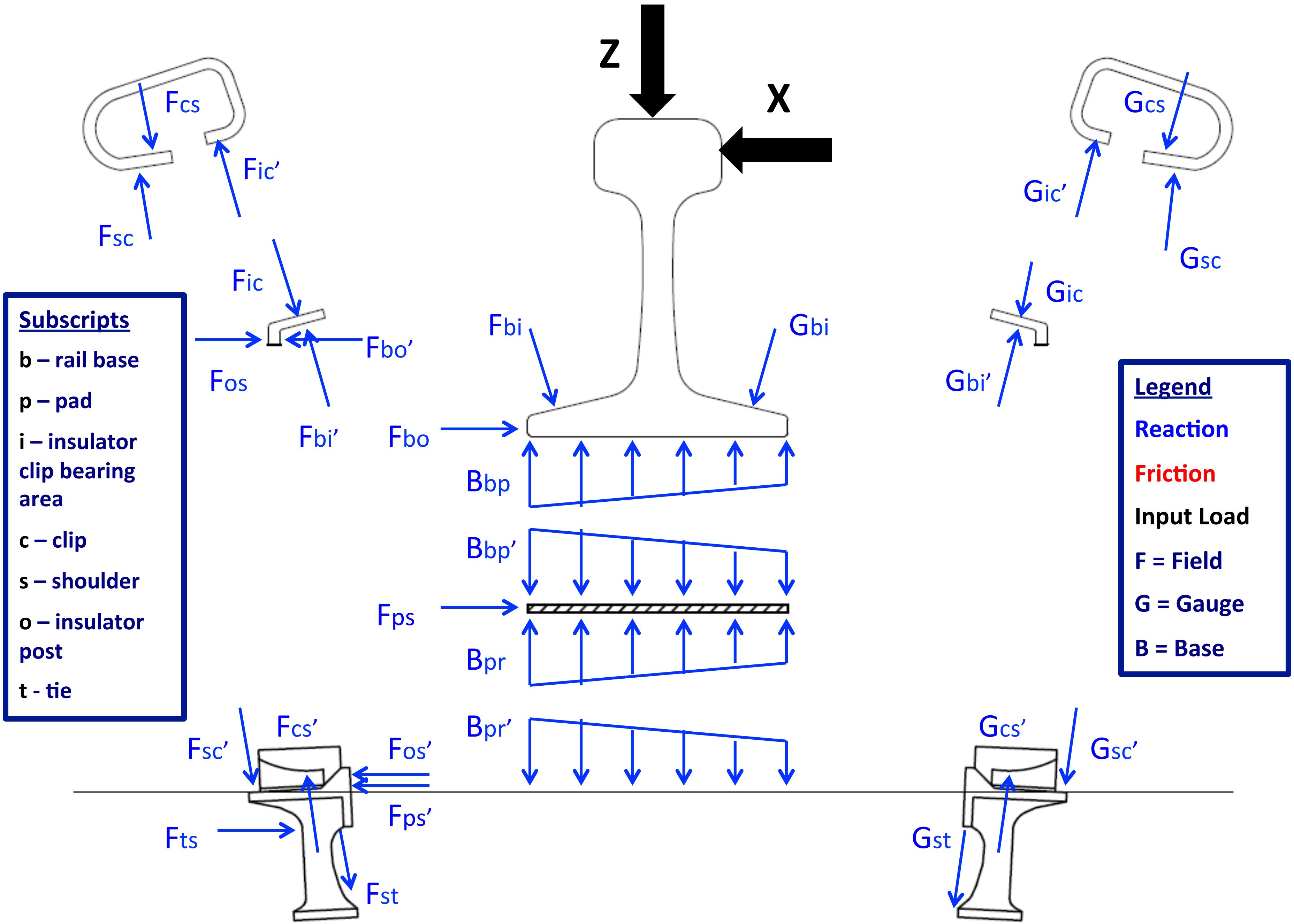
Improved Recommended Practices

What Is Mechanistic Design?

- Analytical approach → not an iterative design process
- Uses loading data to develop a design that functions under expected loading conditions
- Requires design for specific *failures modes* or *performance indicators*
  - e.g. RSD, center cracking, post insulator wear, etc.
- **Inputs** – Fastening system component geometry, traffic (axle load and tonnage), climate, materials
- **Outputs** – Tie and fastening system responses (stresses/strains) to loads, performance characteristics, wear rates?



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Fcs’
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Fts
Fst
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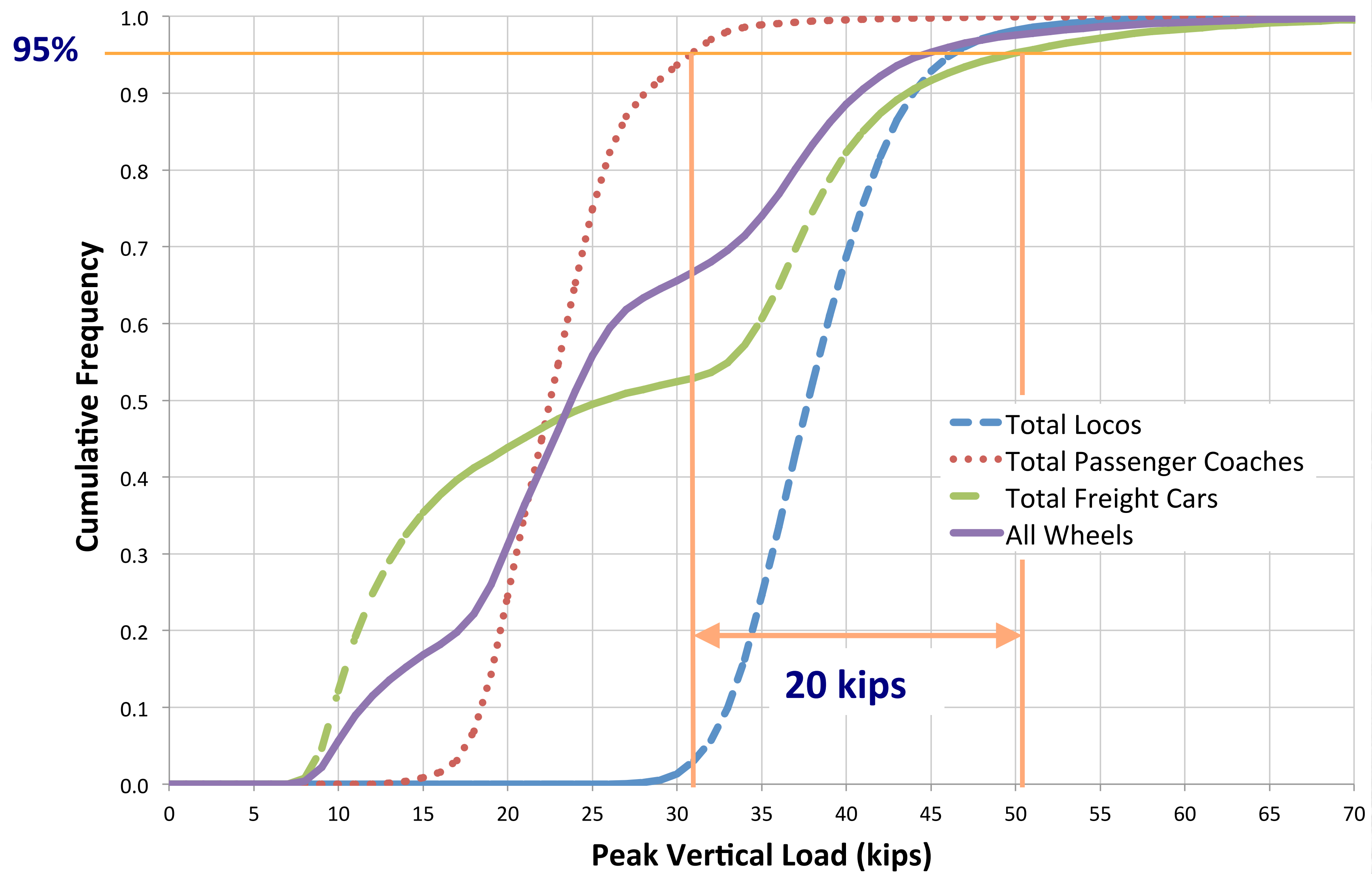
Gsc’
Gst
Subscripts
b – rail base
p – pad
i – insulator clip bearing area
c – clip
s – shoulder
o – insulator post
t - tie
Legend
Reaction
Friction
Input Load
F = Field
G = Gauge
B = Base

Distribution of Vertical Wheel Loads



Source: Amtrak, Edgewood, MD, November 2010

Future Work

- Development of System Level Tie and Fastener Model
- Field and Laboratory Testing of Components and Systems
- Materials Research and Improvements (all components)
- Understand how deterioration methods are related to differing axle loadings (important on shared corridors)
- Development of mechanistic design procedures → Adoption into AREMA Recommended Practices
- **Ultimate objective → increase safety and lower life cycle costs of the crosstie and fastening system**

June 6-8, 2012 – International Crosstie and Fastening System Symposium

Held in Conjunction with AREMA Committee 30 (Ties) Meeting
Website: http://ict.illinois.edu/railroad/crossties.asp

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Acknowledgements

Industry Partnership and support has been provided by

- Union Pacific Railroad
- BNSF Railway
- National Railway Passenger Corporation (Amtrak)
- Amsted RPS / Amsted Rail, Inc.
- GIC Ingeniería y Construcción
- Hanson Professional Services, Inc.
- CXT Concrete Ties, Inc., LB Foster Company

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Amsted RPS

Amsted Rail

GIC INGENIERÍA Y CONSTRUCCIÓN S.A. DE C.V.

HANSON

LBFoster CXT Concrete Ties

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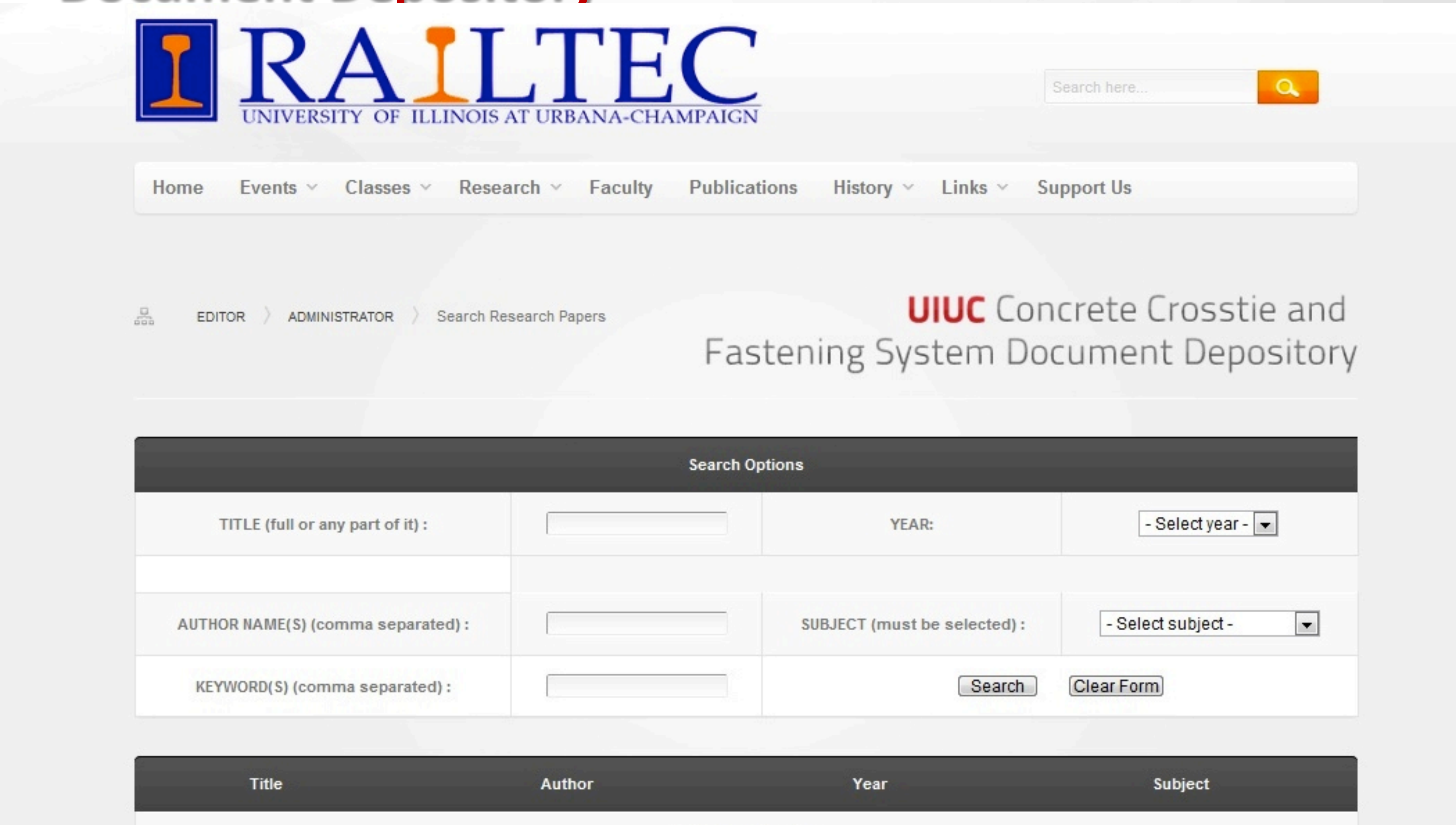
Rail Transportation and Engineering Center – RailTEC
University of Illinois at Urbana-Champaign - UIUC

Appendices

UIUC Concrete Crosstie and Fastening System Document Depository

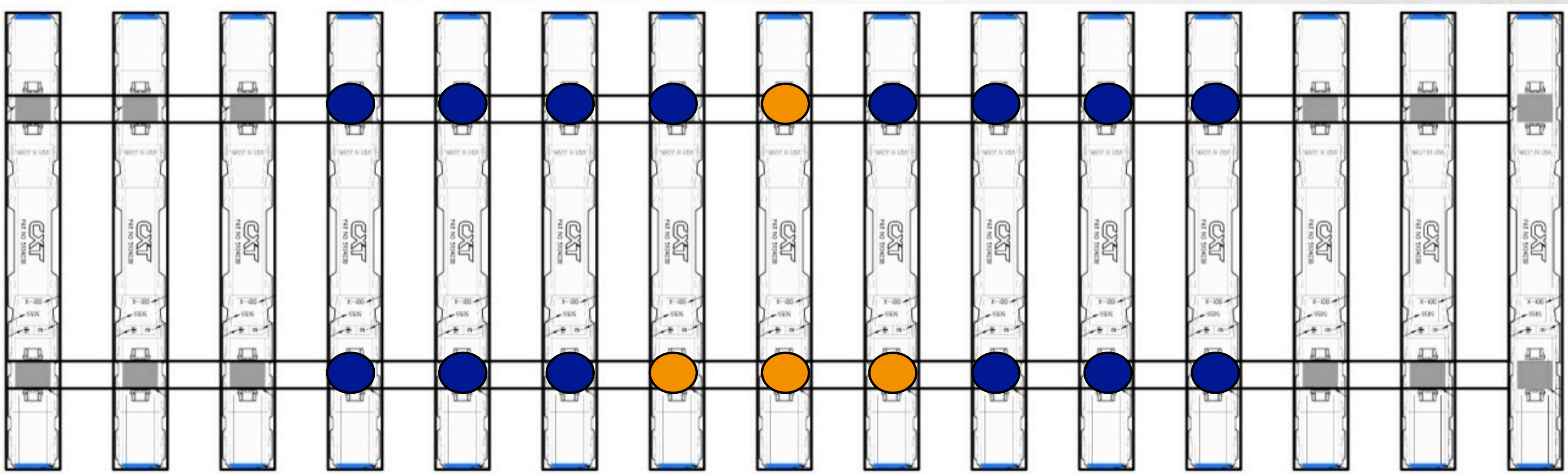


International Crosstie and Fastening System Survey Objectives

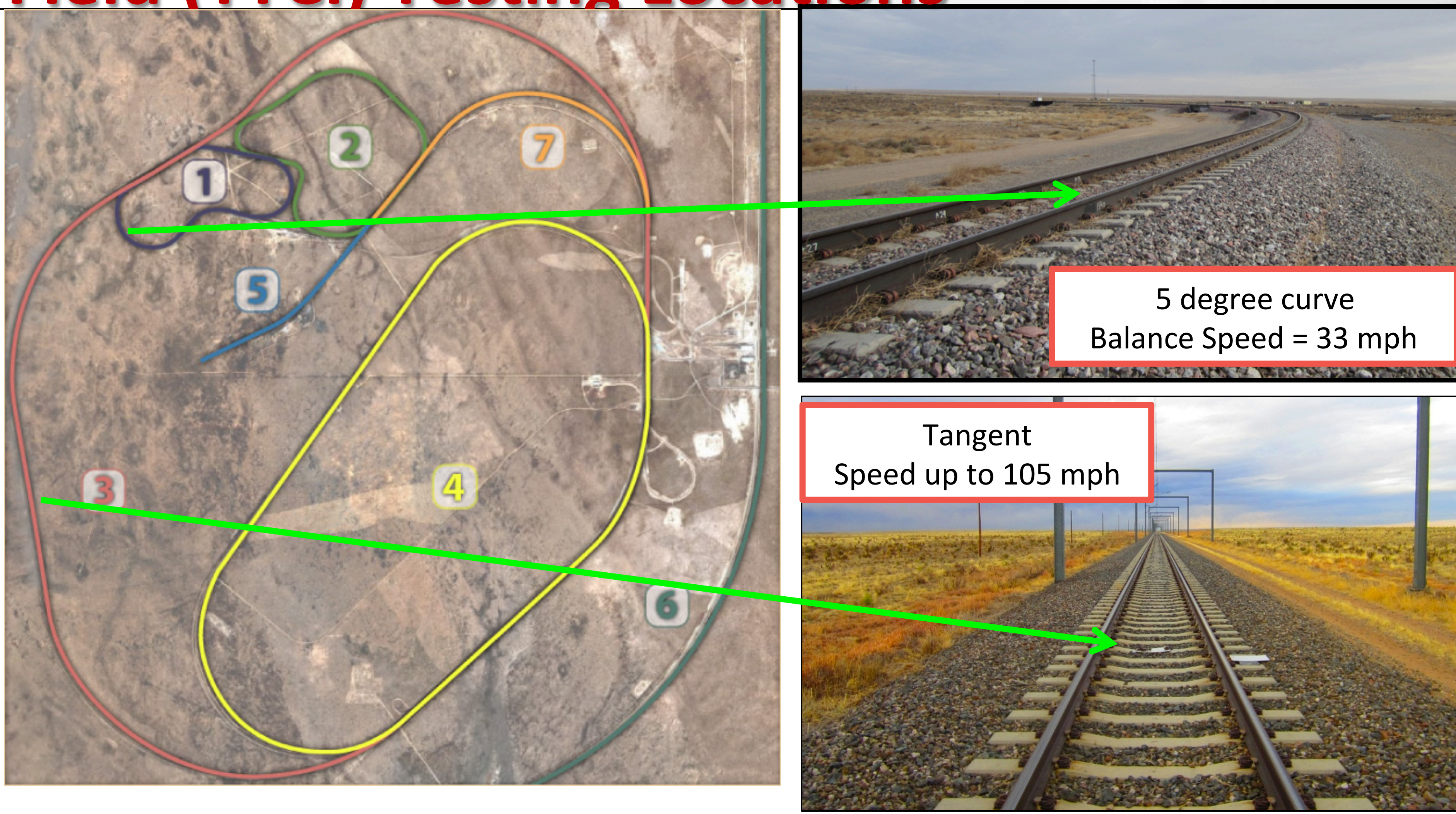
- Understand the current state-of-practice regarding the use of concrete crossties and fastening systems
- Develop an understanding of the most common types of crosstie and fastening system failures
- Continue establishing relationships and encouraging collaboration with railways, researchers, and manufacturers around the world

Field Instrumentation Strategy

- Full Instrumentation
  - Lateral, vertical, and chevron strain gauges on rail
  - Embedment and external concrete strain gauges on crosstie
  - Matrix based tactile surface sensors at rail seat
  - Linear potentiometers on rail and crosstie
- Partial Instrumentation
  - Vertical strain gauges on rail



Transportation Technology Center, Inc. Field (TTCI) Testing Locations



Design and Performance Trends

	International Responses	North American Responses
Average minimum allowable concrete strength at transfer	6,500 psi	4,700 psi
Average 28-day concrete compressive strength	8,700 psi	8,250 psi
Prominent concrete crosstie manufacturing process	Carousel	Long line
Abrasion plate or frame	No	Yes
Commonly failed components	Screw, clip	Pad, rail seat
Rail seat deterioration	No	Yes
Focus of research	Loading, testing, design	Life cycle cost reduction

Survey Results – Criticality of Problems

Problem (higher ranking is more critical)	Average Rank
International Responses	
Tamping damage	6.14
Shoulder/fastening system wear or fatigue	5.50
Cracking from center binding	5.36
Cracking from dynamic loads	5.21
Cracking from environmental or chemical degradation	4.67
Derailment damage	4.57
Other (e.g. manufactured defect)	4.09
Deterioration of concrete material beneath the rail	3.15
North American Responses	
Deterioration of concrete material beneath the rail	6.43
Shoulder/fastening system wear or fatigue	6.38
Cracking from dynamic loads	4.83
Derailment damage	4.57
Cracking from center binding	4.50
Tamping damage	4.14
Other (e.g. manufactured defect)	3.57
Cracking from environmental or chemical degradation	3.50

- Technical Tours
  - UPRR IL High Speed Rail
  - UIUC Research Laboratories
- Technical Sessions
  - Failure Modes
  - Loading Environment and Field Performance
  - Materials and Testing/Validation
  - Modeling
  - Design
  - Research Needs
- Keynote Speakers
  - Dr. Alex Remennikov of Wollongong University
  - Dr. Stephan Freudenstein of Technical University Munich

International Concrete Crosstie & Fastening System Symposium

Hosted by the Rail Transportation and Engineering Center

RAILTEC

6-8 June 2012

Preliminary Agenda

WEDNESDAY 6 JUNE

11:00 AM - 6:00 PM	Technical Tour:

- Union Pacific Railroad Illinois High Speed Rail Project
- Advanced Transportation Research and Engineering Lab (ATREL) at the University of Illinois at Urbana-Champaign

THURSDAY 7 JUNE

7:45 - 8:00 AM	Continental Breakfast
8:00 – 8:30 AM	Opening Session: Welcome and Objectives
8:30 – 10:00 AM	Session 1: Failure Modes
10:30 AM–12:30 PM	Session 2: Loading Environment and Field Performance
12:30 – 2:00 PM	Lunch
	Keynote Address: Dr. Alex Remennikov
2:00 – 4:00 PM	Session 3: Materials and Testing/Validation
4:30 – 5:30 PM	Newmark Civil Engineering Lab Tours
6:30 PM	Dinner at UIUC Memorial Stadium
	Keynote Address: Dr. Stephan Freudenstein

FRIDAY 8 JUNE

7:45 – 8:00 AM	Continental Breakfast
8:00 – 10:00 AM	Session 4: Modeling
10:30 AM–12:30 PM	Session 5: Design
12:30 – 1:30 PM	Lunch
1:30 – 2:30 PM	Session 6: Research Needs
2:30 – 3:00 PM	Recap, Look Ahead & Closing Remarks
3:00 PM	Adjourn

Additional Information

Symposium Registration

Registration is open!
ict.uiuc.edu/railroad/crossties.php
$290 per person (includes most meals, bus transportation for the technical tour, and electronic copies of all of the presentations)

Submit an Abstract

Call for Presentations due by April 24th:
ict.uiuc.edu/railroad/callforpapers.php

Venue

The Symposium will be held at the University of Illinois at Urbana-Champaign Department of Civil and Environmental Engineering in the Yeh Student Center classrooms.

Hotels

Hampton Inn (217.337.1100) and Illini Union (217.333.1241)

U.S. Department of Transportation
Federal Railroad Administration

At the University of Illinois at Urbana-Champaign

http://ict.illinois.edu/railroad/crossties.php

Pulsating Load Testing Machine (PLTM)

- Owned by Amsted RPS
- Used for Full Scale Concrete Tie and Fastening System Testing
- Following AREMA Test 6 – Wear and Abrasion recommended practice
- Housed at Advanced Transportation and Research Engineering Laboratory (ATREL)
- Three 35,000 lb. actuators: two vertical and one horizontal
  - Ability to simulate various L/V ratios by varying loads

Pressure (PSI)
0
500
1000
1500
2000
2500
3000

GAUGE — FIELD

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0	0	0	0	0	0	0	36	135	351	568	712	838	766	1000	1072	1162	1072	1289	1162	1361	1541	1325	1415	1289	234
0	0	0	0	0	0	0	0	45	90	207	252	297	676	712	451	496	676	487	676	766	631	757	1036	982	36
0	0	0	0	0	0	0	0	0	72	36	45	81	0	63	270	243	550	604	541	108	126	153	234	0	0

0.22”

0.22”

162

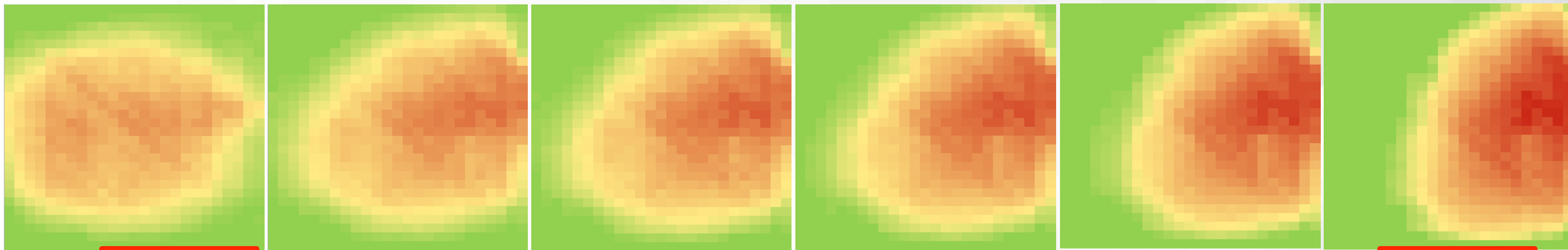
Area = 0.0484 in^2

Rail Pad Test Results

← GAUGE FIELD →

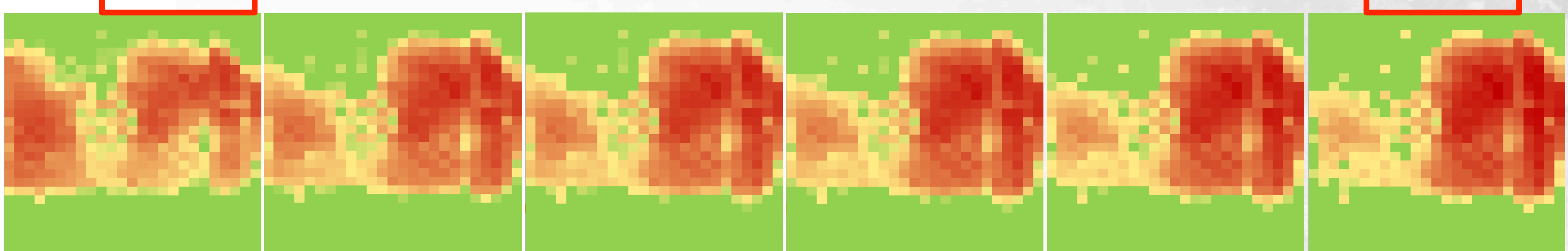
L/V Ratio	0.25	0.44	0.48	0.52	0.56	0.60

Santoprene™



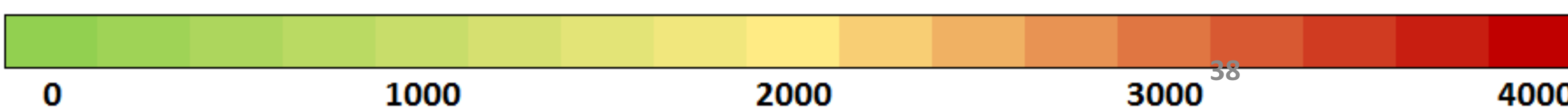
Contact Area (in²)	28.8	27.9	27.3	25.8	24.0	21.3
% of Rail Seat	85	82	80	76	71	63
Peak Pressure (psi)	2,139	2,573	2,800	2,925	3,162	3,400

HDPE



Contact Area (in²)	20.1	19.3	19.1	19.0	18.6	17.8
% of Rail Seat	59	57	56	56	55	52
Peak Pressure (psi)	3,213	3,469	3,546	3,721	3,838	4,096

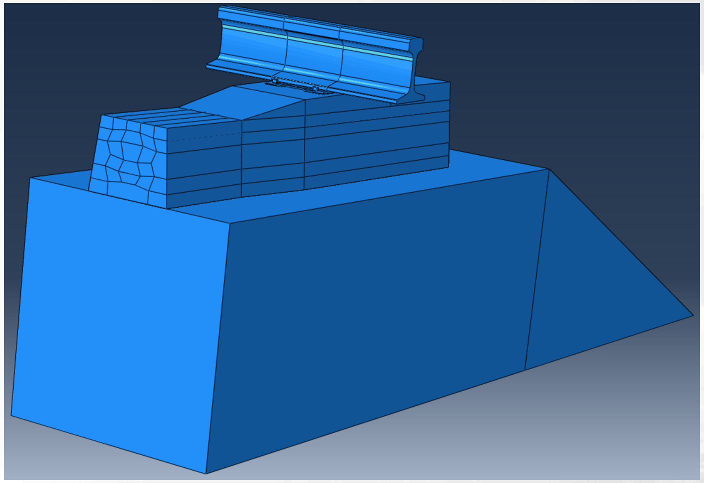
Pressure (psi)

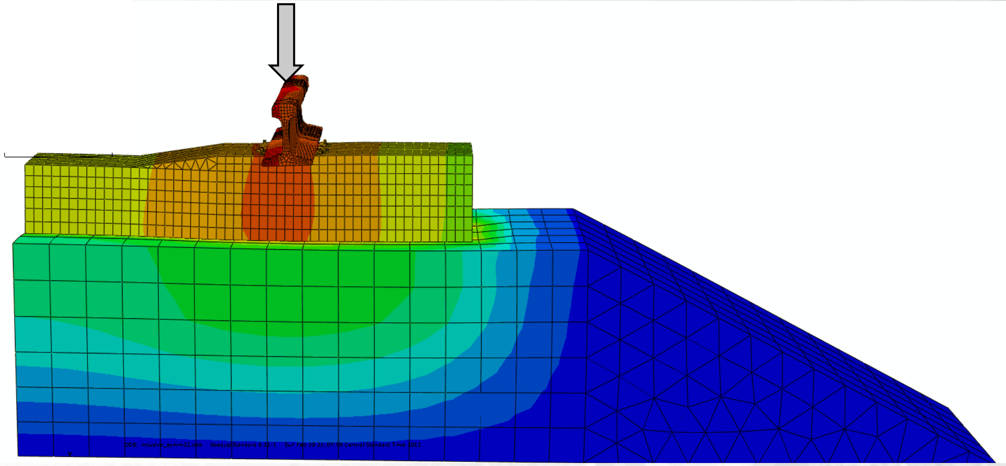


Current Model: System Modeling
Rail and Pad Assembly

Model Features:

- Concrete material property follows damage plasticity model
- Connector element is used to simulate the bond relationship between concrete and strand
- Geometry and material properties of rail and rail pad assembly are based on manufacturer data
- Confining pressure effect on material property is considered in ballast modeling
- Vertical static loading applied
- Friction is assumed for interfaces





Vertical Loading Model

Conclusions (old)

- North American loads are, on average, substantially higher than those throughout the rest of the world
- The most critical failure concerns in **North America** are related to wear or fatigue on the rail seat, rail pad, or shoulder
- The most critical failure concerns **internationally** are cracking from dynamic loads, shoulder wear, and tamping damage
- Greater emphasis placed on system design and optimization internationally

Conclusions (new)

- Manufacturing process differences may be the cause of significantly different trends in requirements and performance
- The most critical failure concerns in North America are related to wear or fatigue on the rail seat, rail pad, or shoulder
- The most critical failure concerns internationally are tamping damage, cracking from dynamic loads, and shoulder wear
- Greater emphasis placed on system design and optimization internationally
- Component and system interaction, which is considered in the design process of the fastening systems, should also be considered in the mechanistic design of concrete crossties

Survey Results – Loading Environment

	International Responses	North American Responses
Average maximum freight axle load*	29.5 tons (26.8 tonnes)	39.1 tons (35.4 tonnes)
Average maximum passenger axle load*	21.6 tons (19.6 tonnes)	29.1 tons (26.4 tonnes)
Average concrete crosstie design axle load	27.6 tons (25.0 tonnes)	37.4 tons (33.9 tonnes)
Average tangent crosstie spacing	24.2 inches (61.4 centimeters)	24.0 inches (61.0 centimeters)
Average annual tonnage (per track)	38.7 million gross tons (35.1 million gross tonnes)	100.0 million gross tons (90.7 million gross tonnes)

*Interpreted from responses due to discrepancies in wheel or axle loads

U.S. Department of Transportation
Federal Railroad Administration
Office of Research & Development
2012 R&D Review

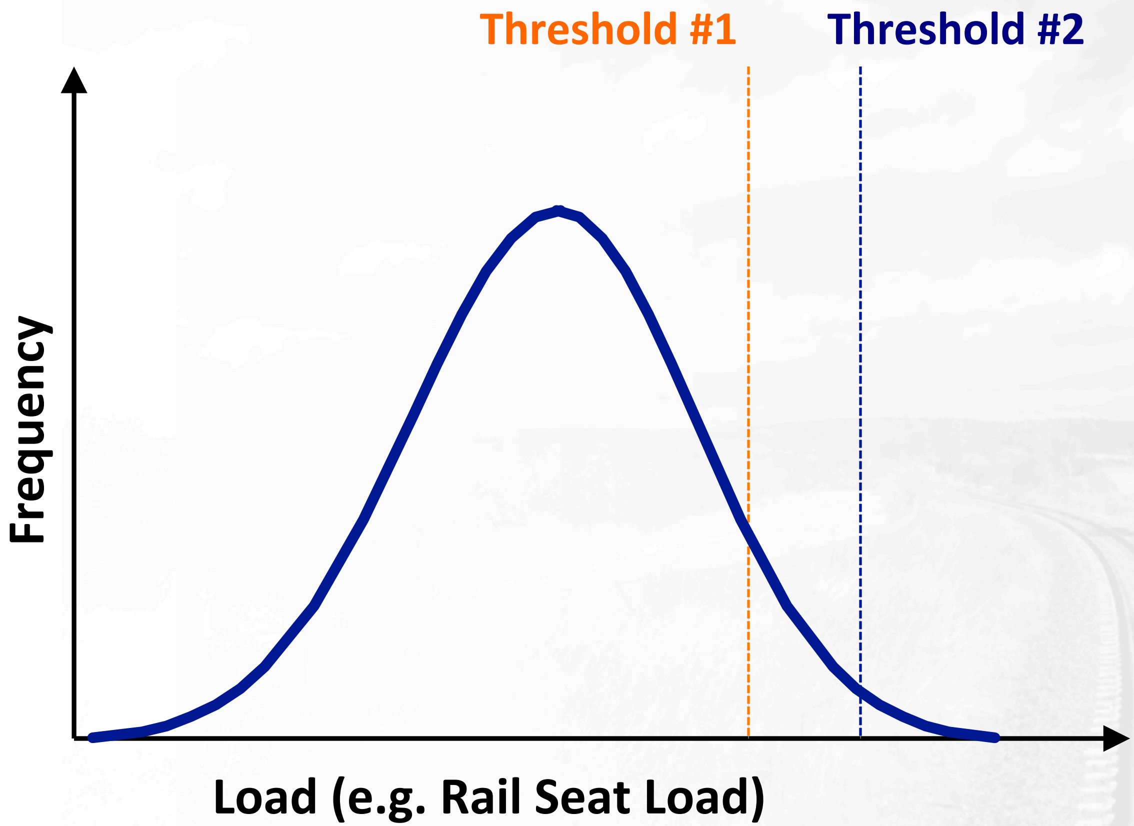
Survey Content

- Usage
- Crosstie Characteristics and Manufacturing Techniques
  - Concrete
  - Prestress
- Fastening System Performance and Characteristics
  - Prevalence
  - Materials
- Effectiveness and Failure
  - Design Life
  - Maintenance
  - Failure Modes
- Industry Recommended Practices and Tests
- Research

Current Design Practices

- Governed by AREMA Chapter 30 Ties (Section 4)
  - Room for improvement
- Current Limitations → Research Needs
  - Example – Tie Flexural design does not consider impact factors, wheel/axle load, type of track (curves, grades), or design life
  - Other (non-structural) design recommendations
    - Lateral resistance
- **Option for Improvement → Mechanistic Design**

So What is Our Design Threshold?



*Need curves for each component / interface and failure mode