Overview of UIUC's Concrete Cross-tie and Fastening System Laboratory Study




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Sihang Wei, Daniel A. Kuchma, J. Riley Edwards, Marcus S. Dersch

U.S. Department of Transportation
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RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Outline

- Introduction
- Instrumentation plan overview
- Preliminary laboratory test
  - Built up load cell feasibility study
  - Partial instrumentation plan feasibility study
- Rail displacement laboratory study
- Conclusion

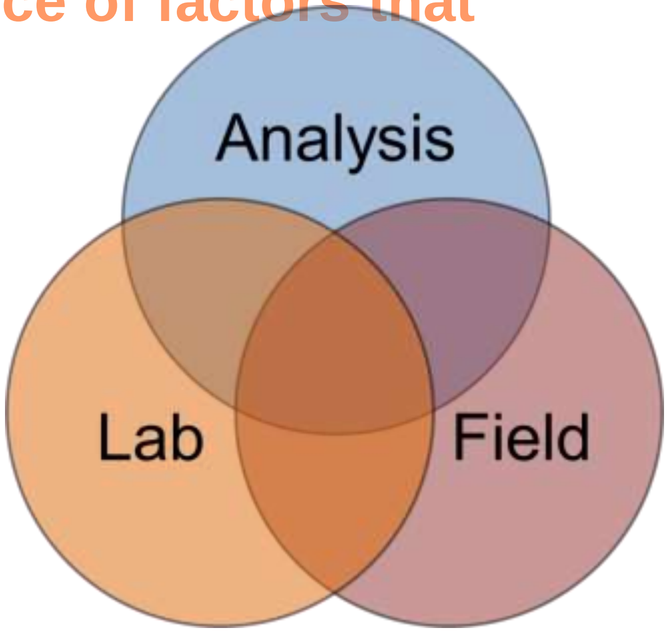
Introduction

- Overall laboratory instrumentation objectives:
  - Develop instrumentation plan to measure forces at critical interfaces (pad-tie, insulator-clip, insulator-rail, etc.) prior to field testing
  - Guide field instrumentation
  - Provide model validation

Role of Lab Instrumentation

Lab

- Validate model assumptions
- Understand and quantify the influence of factors that affect the flow of forces



Lab-Field

- Develop field instrumentation plan
- Develop test load conditions

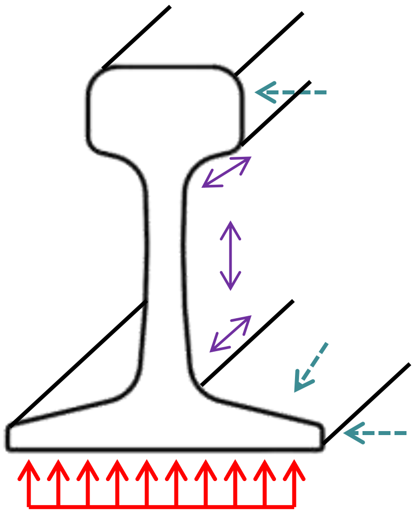
Lab-Analysis

- Confirm assumptions in FEM analysis
- Supply insight on undocumented behaviors

Areas of Investigation

Rail

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

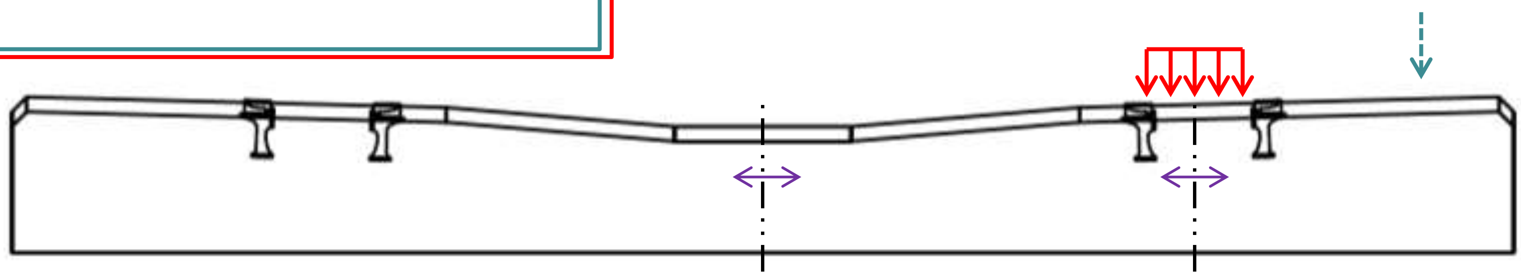


Fasteners/ Insulator

- Strain of fasteners
- Stresses on insulator

Concrete Crossties

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

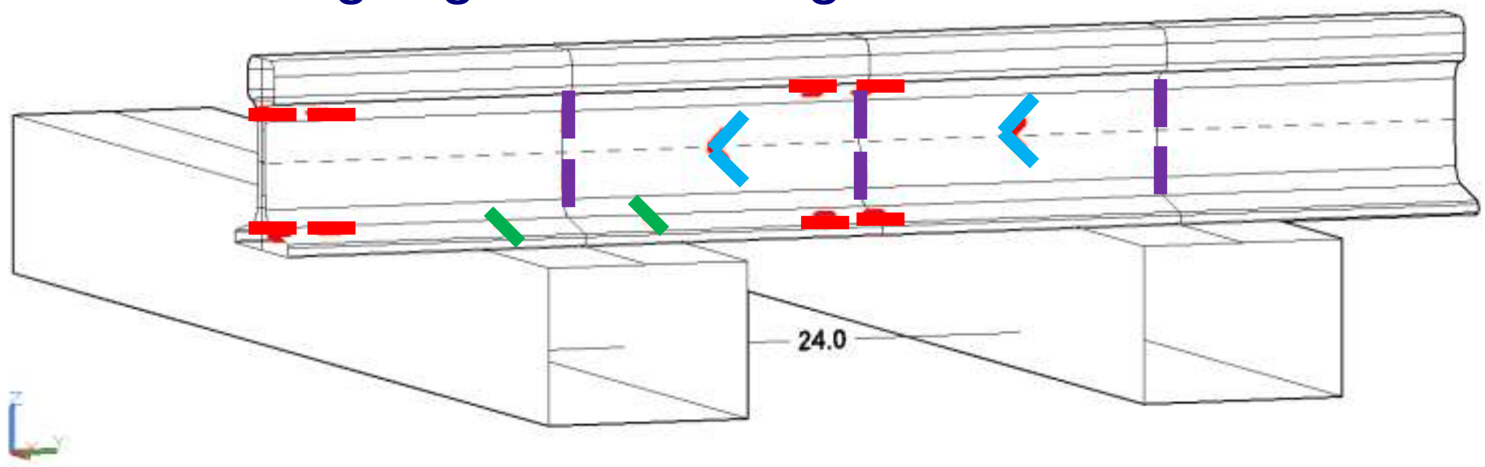


Instrumentation Plan

- Rail deformation measurement (strain gauges)
- Deflection measurement (LVDT/potentiometers)
- Load transfer measurement (load cells & concrete embedment strain gauges)

Rail Deformation Measurement

- Strain gauge locations:
  - Lateral built-up load cell – moment & shear force
  - Vertical gauges – lateral wheel load
  - Chevron pattern – vertical wheel load
  - Transverse gauges – bending at rail base



Built-up Load Cell

Curvature:

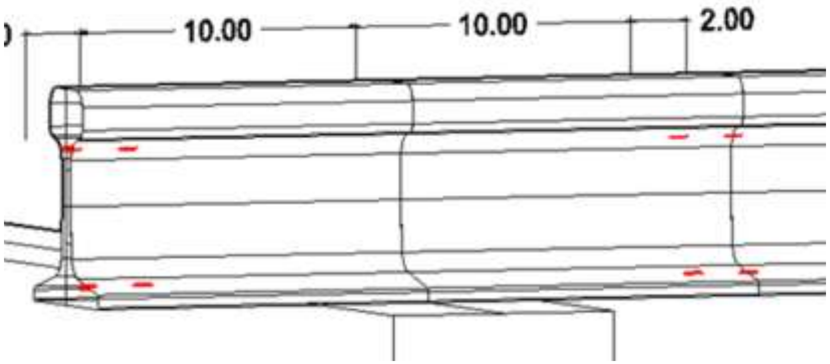
$\phi = \varepsilon / d$

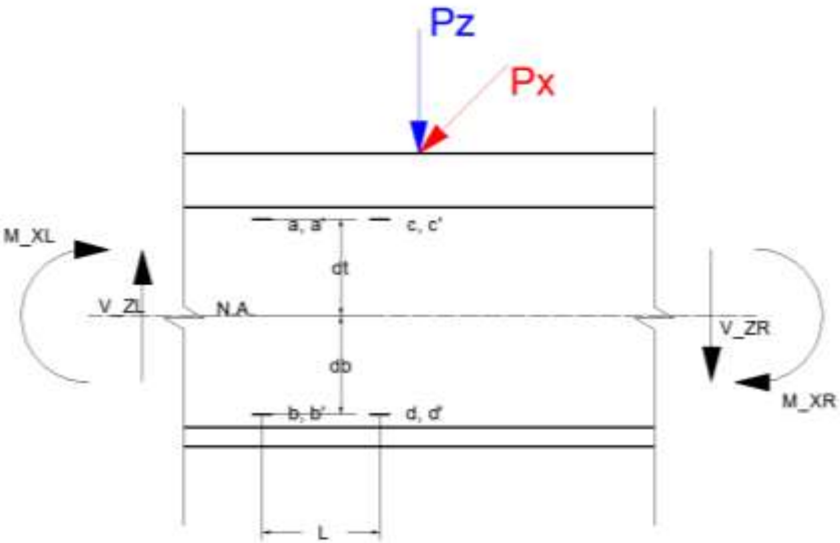
Moments:

$$M_{XL} = EI\rho_{XL} = EI\left(\frac{\varepsilon_a + \varepsilon_{a'}}{2}\right) \cdot \frac{1}{d_t} = EI\left(\frac{\varepsilon_b + \varepsilon_{b'}}{2}\right) \cdot \frac{1}{d_b}$$

Shear force:

$$\Delta V_Z = V_{ZL} - V_{ZR} = (M_{XL} - M_{XR}) \cdot \frac{1}{L}$$





Vertical Gages

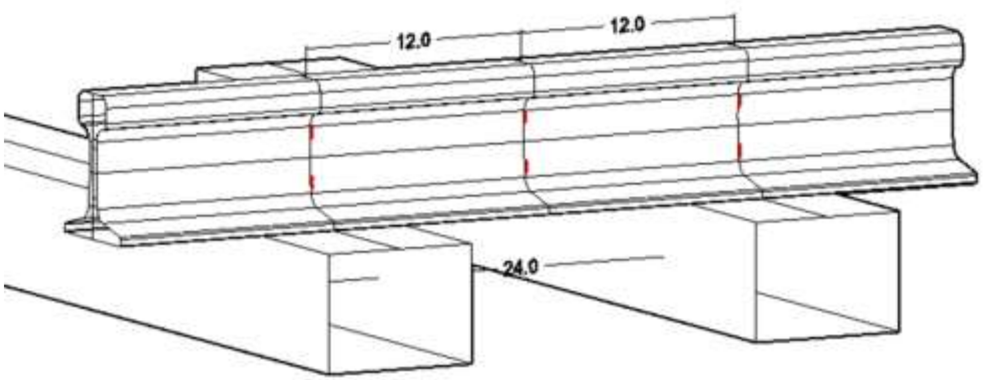
$$P_X \propto V\ (shear\ force)$$

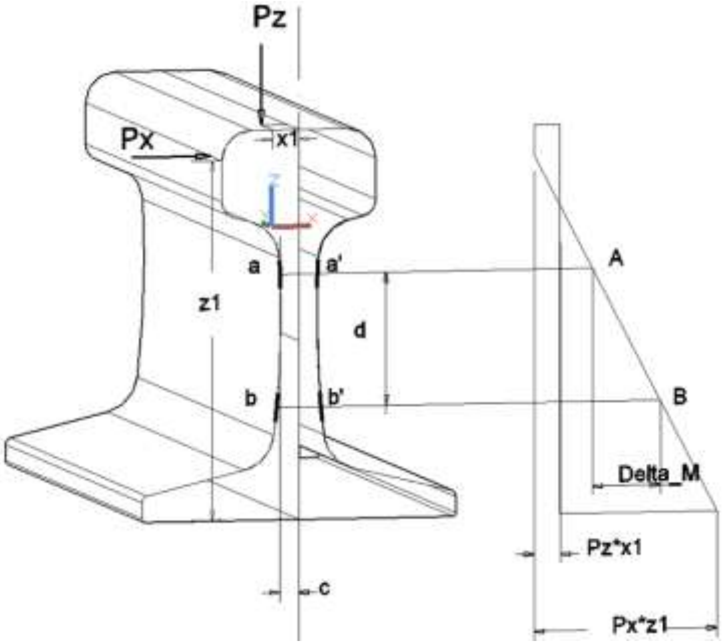
$$V = \frac{\partial M}{\partial x} = \frac{M_B - M_A}{d} \quad (independent\ of\ P_Z, x_1, y_1)$$

$$M_A = \left(\frac{EI}{c}\right)\varepsilon_A\,, \quad M_B = \left(\frac{EI}{c}\right)\varepsilon_B$$

$$P_X = V = \frac{M_B - M_A}{d} = \left(\frac{EI}{cd}\right)(\varepsilon_B - \varepsilon_A)$$

$$P_X \propto (\varepsilon_B - \varepsilon_A), \quad where \begin{cases} \varepsilon_A = (\varepsilon_a - \varepsilon_{a'})/2 \\ \varepsilon_B = (\varepsilon_b - \varepsilon_{b'})/2 \end{cases}$$





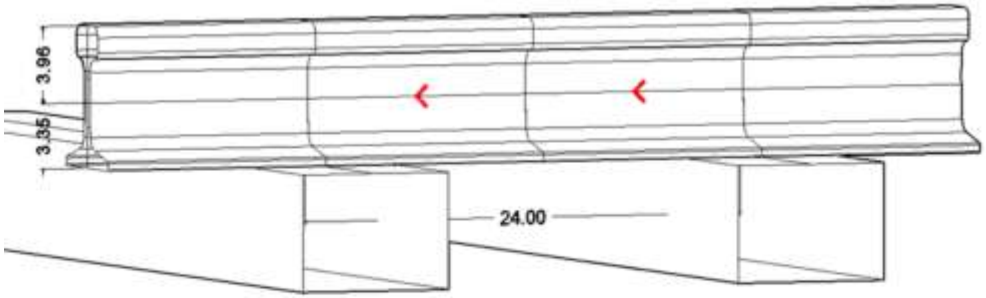
Chevron Gages

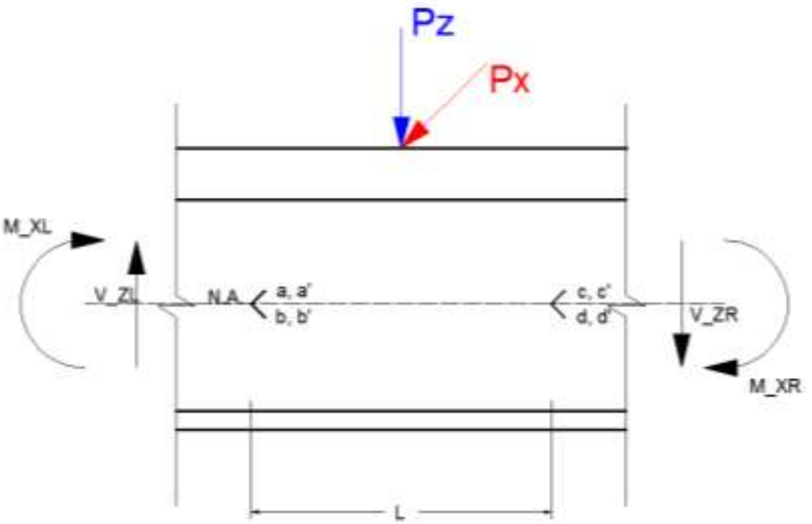
$$P_Z = V_{ZL} - V_{ZR}$$

$$V_{ZL} = \frac{EI}{(1+\nu)Q}\varepsilon_1, V_{ZR} = \frac{EI}{(1+\nu)Q}\varepsilon_2$$

$$\varepsilon_1 = \varepsilon_a - \varepsilon_b + \varepsilon_{a'} - \varepsilon_{b'}, \varepsilon_2$$
$$= \varepsilon_c - \varepsilon_d + \varepsilon_{c'} - \varepsilon_{d'}$$

$$P_Z = \frac{EI}{(1+\nu)Q}(\varepsilon_1 - \varepsilon_2)$$





Transverse Gauges

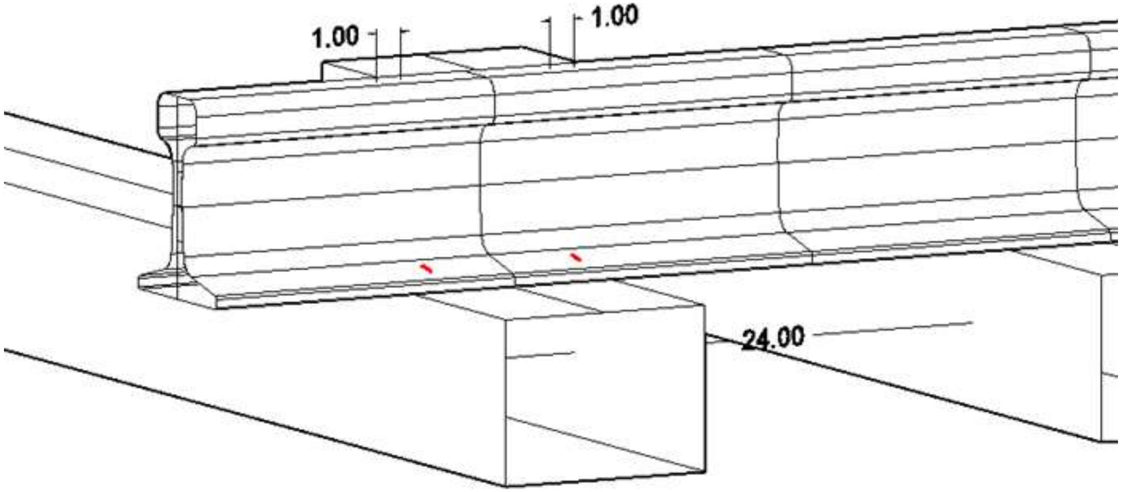
Curvature:

$$\phi = \varepsilon / (\frac{t}{2})$$

t – thickness of rail base

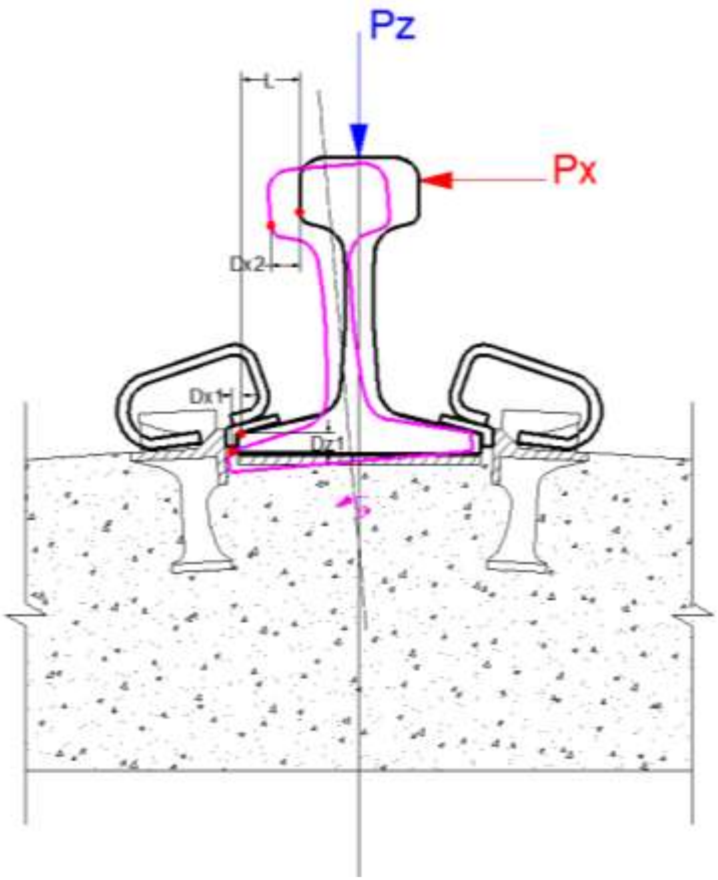
Moments:

$$M_{XL} = EI\phi = EI\varepsilon / (\frac{t}{2})$$



Displacement Measurement

- Lateral disp. of the rail head (Dx_2)
- Lateral disp. of the rail base (Dx_1)
- Vertical disp. of the rail base (Dz_1)



Rigid Body Displacements

Total vertical displacement:

Dz1

Vertical displacement of the rail (due to Pz) :

$$DPz = \frac{Pz}{E}$$

Rotating angle:

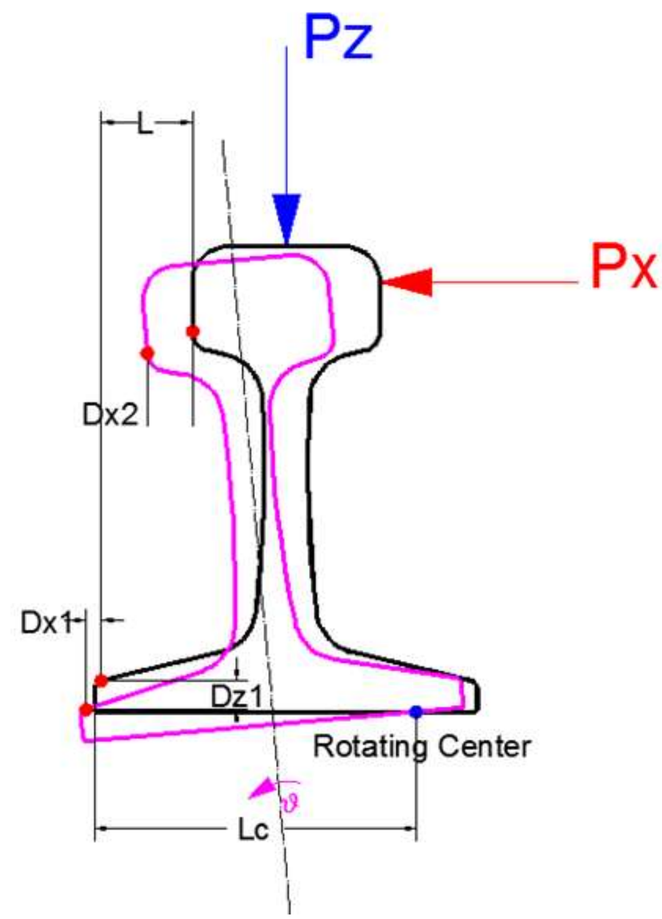
$$\theta = arctan\frac{y2'-y1'}{x2'-x1'} - arctan\frac{y2-y1}{x2-x1}$$

Old: *(x1, y1) (x2, y2)*

New: *(x1', y1') (x2', y2')*

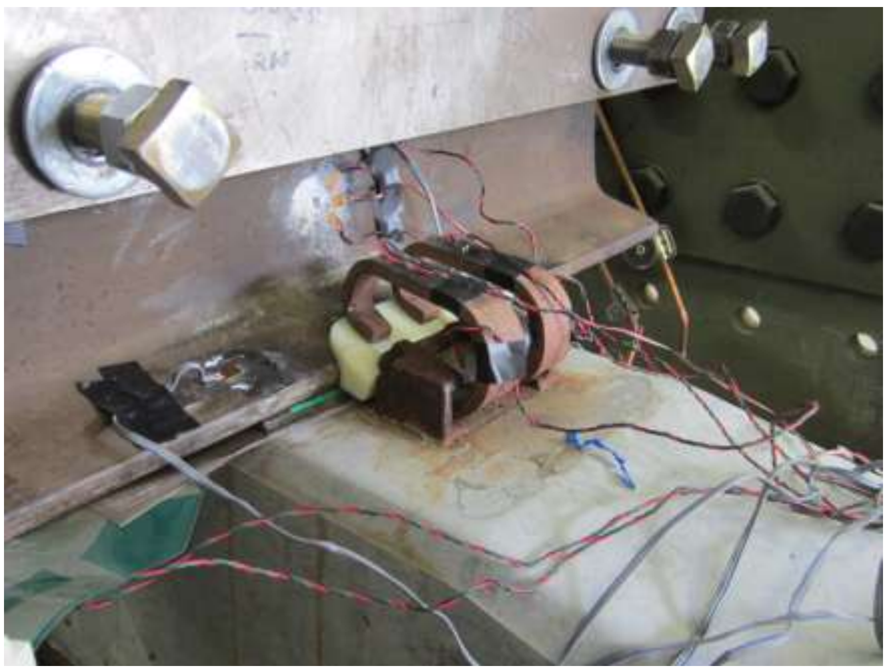
Rotating center:

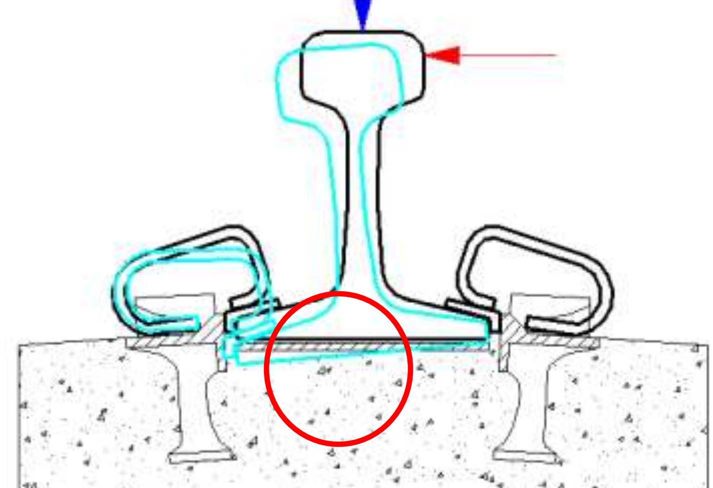
$$Lc = \frac{Dz1}{\theta}$$

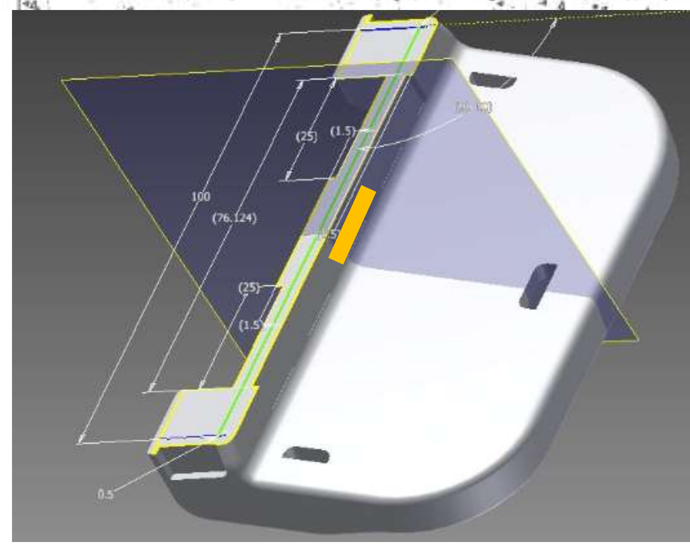


Lateral Load Transfer

- To measure the load transfer between the rail base and the cast-in shoulder







Vertical Rail Seat Load Transfer

- Plan: Install concrete embedment strain gauges in rail seat area to measure the load transfer from rail base to concrete tie
- 3x3 or 2x2 strain gauge patterns are planed to use to measure the uneven stress distribution

Built up Load Cell Feasibility Study

(Aug. 2011)

- **Objective**: Test feasibility of built up load cell
- **Strategy**: Utilize eight strategically located strain gauges on the rail
- **Test**: Simple 3-point bending test with loads ranging from 0 to 32,500 pounds
- **Results**:
  - Strains remained linear
  - In elastic range

Test setup at Newmark Lab, UIUC

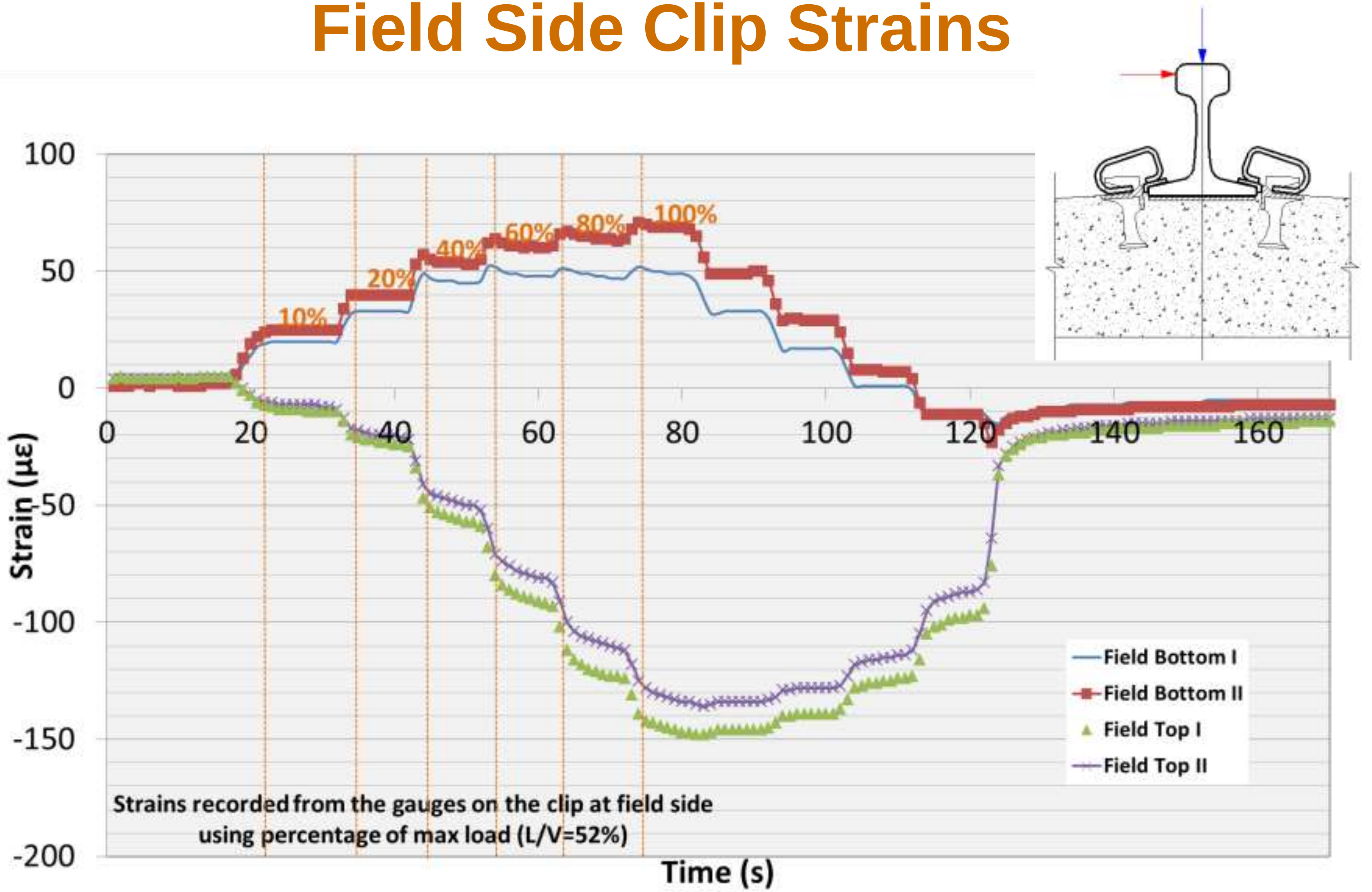
Preliminary Partial Instrumentation Plan Feasibility Study

(Sep. 2011)

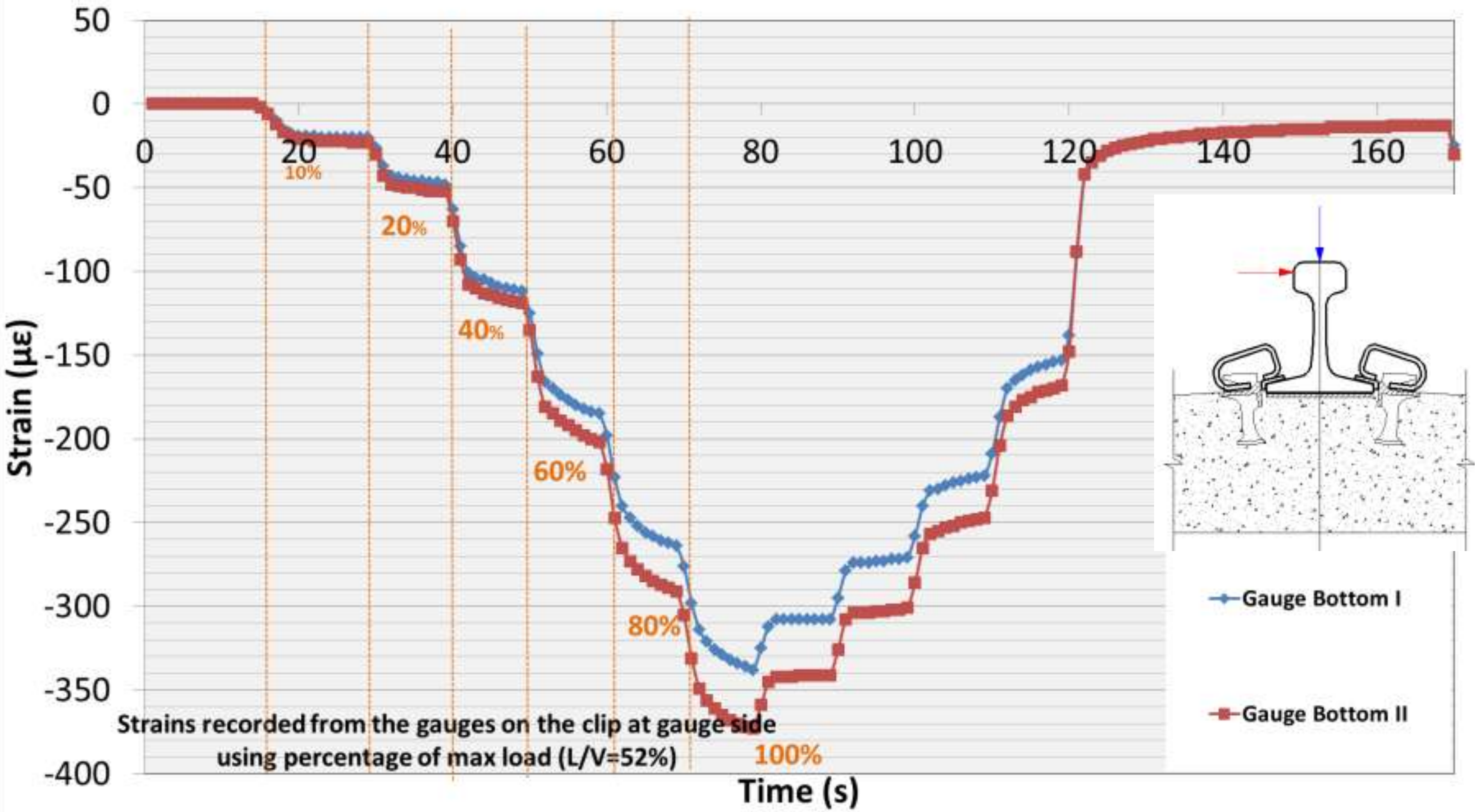
- **Objective**: Test feasibility of built up load cell & strain gauged clips while fully assembled
- **Strategy**: Utilize 20 strategically located strain gauges on rail & clips
- **Test**: Applied load to single rail seat on a fully supported tie at an L/V of 0.25 & 0.52 with static & dynamic loads ranging from 0 to 32,500 pounds
- **Results**:
  - Strains behaved non-linear at clips
  - Residual strains in system
  - Strains in gauge clip greater than field clip

PLTM test setup at ATREL, UIUC)

Field Side Clip Strains

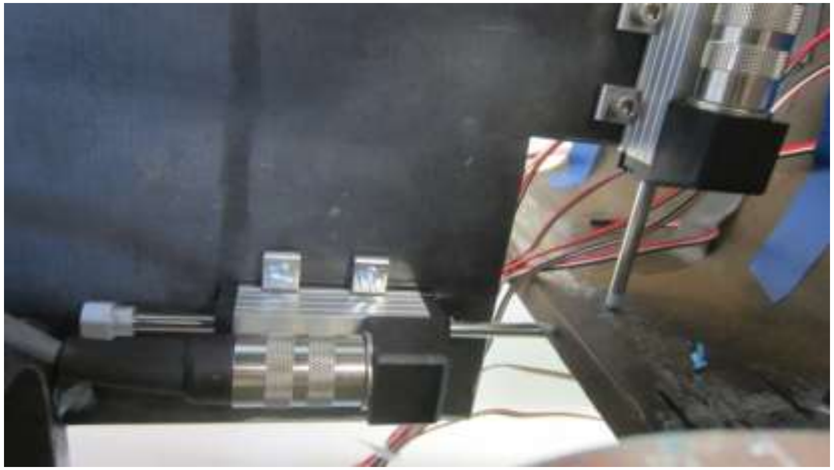


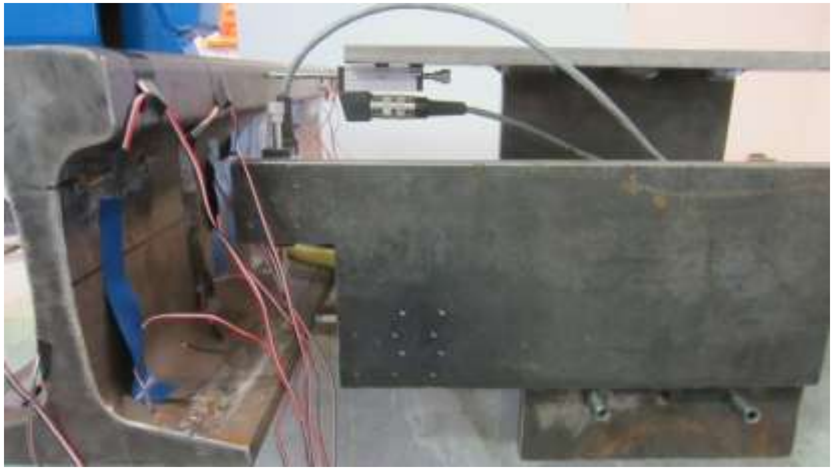
Gauge Side Clip Strains



Rail Displacements Laboratory Study

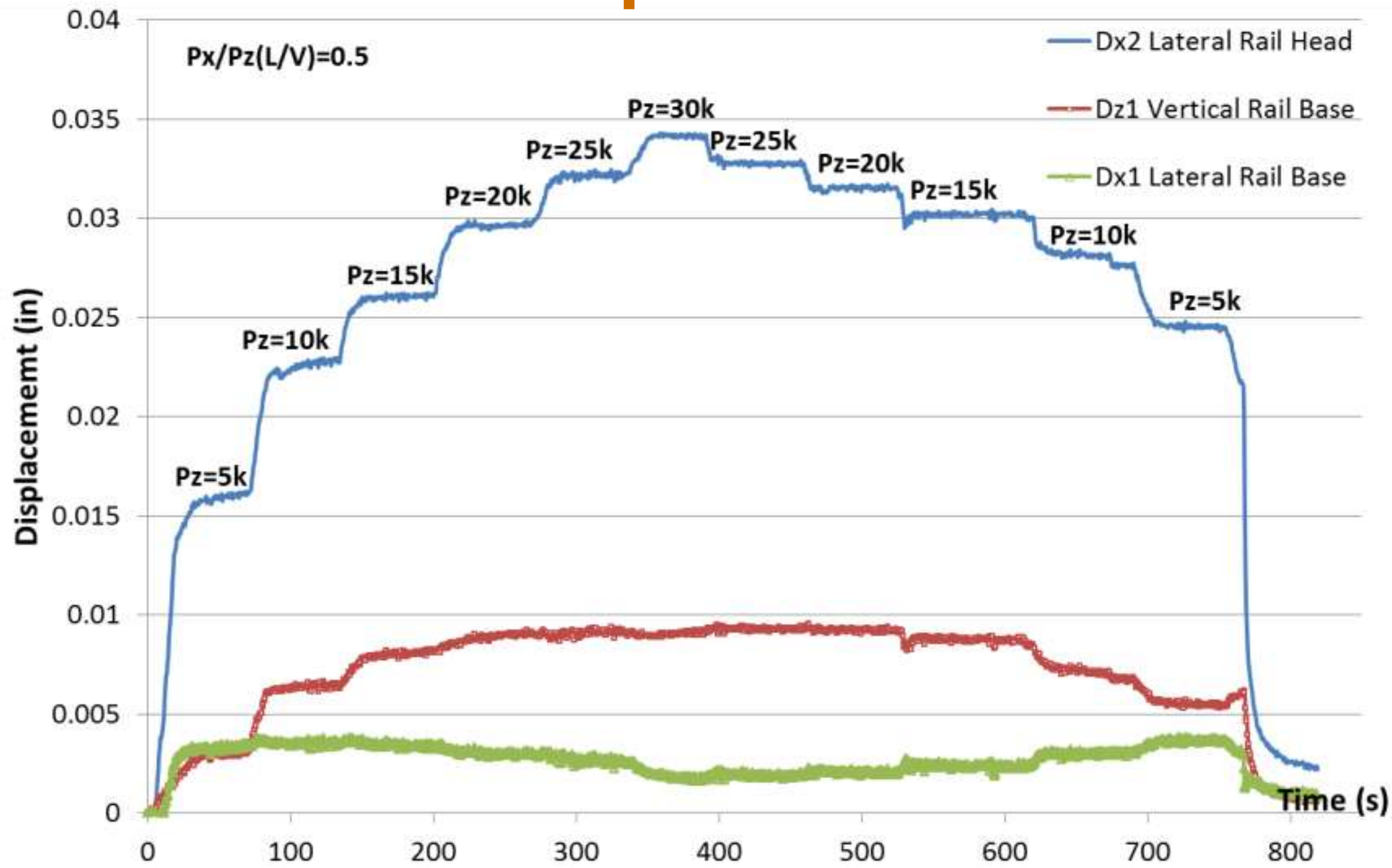
(spring 2012)



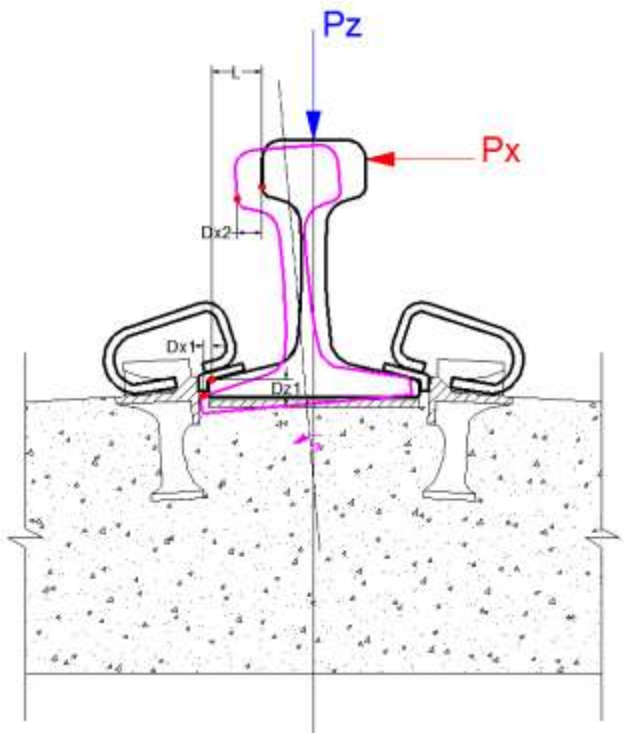


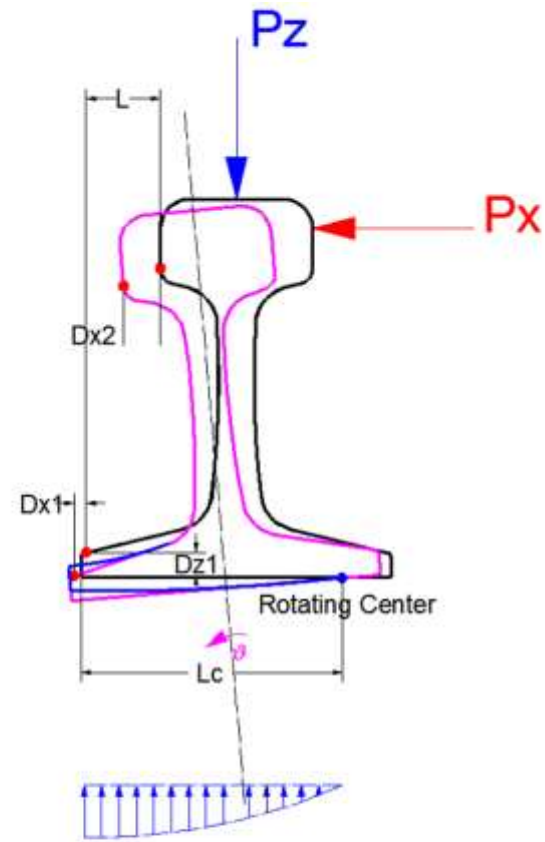
SLTM test set up at ATREL, UIUC

Rail Displacements



Rail Displacements





Rail Displacements Dx1, Dz1, Dx2 - SLTM 120315													
Pz (kips)	0	5	10	15	20	25	30	25	20	15	10	5	0
Dx1	0	0.003255	0.003534	0.003255	0.002976	0.002697	0.00186	0.00186	0.001953	0.002418	0.00279	0.00372	0.000837
Dz1	0	0.002883	0.006324	0.007905	0.008928	0.0093	0.009114	0.009393	0.009207	0.008649	0.007161	0.005394	0.000651
Dx2	0	0.016089	0.022506	0.025947	0.029574	0.032271	0.034224	0.032736	0.031341	0.030039	0.028458	0.024459	0.002604

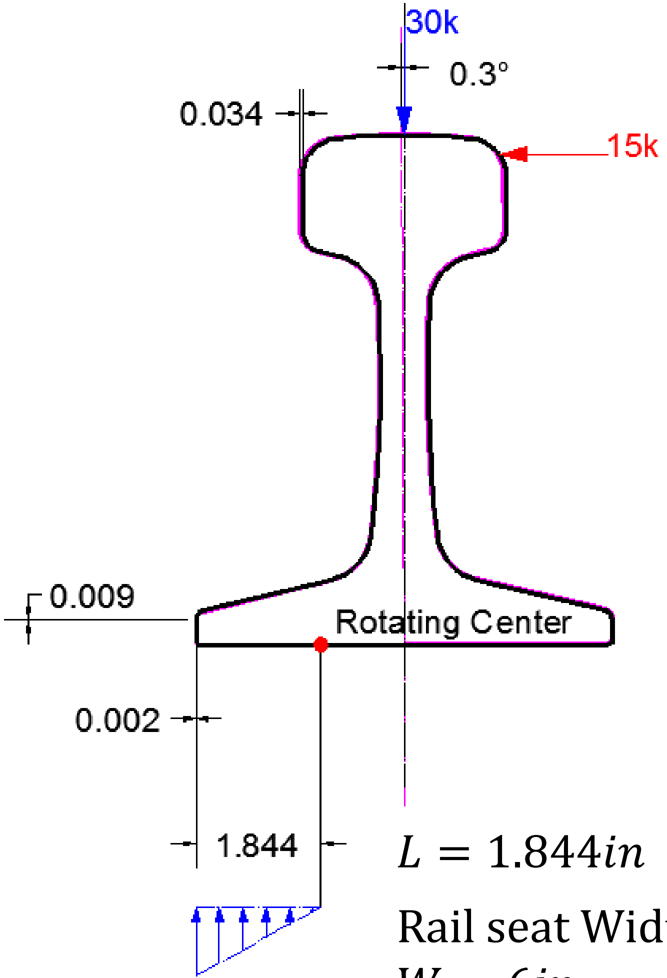
Rail Displacements & Stress distribution

Assumption:
Rigid body motion

Limitations:
Neglected bending action of rail web & base

Check Results:
Rail pad deflection (tip): $\Delta T = 0.009in$
Rail pad thickness: $T = 0.3in$
Strain: $\varepsilon = \Delta T/T = 0.009/0.3 = 0.03$
Total vertical reaction:

$$
\begin{aligned}
Rv &= \varepsilon \times E \times W \times L/2 \\
&= 0.03 \times 345 \times 6 \times 1.844/2 \\
&= 57.2kips \approx 1.9 \times (30kips) \\
&= 1.9Pz
\end{aligned}
$$



$L = 1.844in$

Rail seat Width
$W = 6in$

Learning:
Need to consider bending behavior of rail web/base in future work

Summary

- Three laboratory studies have been performed thus far
  1) Built up load cell feasibility
  2) Preliminary partial instrumentation plan feasibility
  3) Rail displacement laboratory study
- Each study has guided this project's instrumentation plan
- Laboratory setup variability between field conditions
  – Support conditions
  – No "lateral" constraint from short rail piece
  – Loading conditions

Summary (cont.)

- Laboratory studies allow us to:
  - Refine instrumentation plan
  - Develop detailed studies within controlled variables
  - Validate laboratory finite element model
  - Study pressure distribution under different L/V ratio & different support conditions
  - Study the effect of dynamic load
  - Compare results to field investigation
  - Make recommendations to refine lab tests in future

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FRA Tie and Fastener BAA Industry Partners:

Questions?

Sihang Wei
Graduate Research Assistant
Email: wei22@illinois.edu