JRC2013
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Instrumentation and Performance Monitoring of Railroad Track Transitions using Multidepth Deflectometers

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Presentation Outline

- ✓ Amtrak Northeast Corridor (NEC) Instrumentation
- ✓ Data Acquisition and Monitoring
- ✓ Analysis of Acquired Data
- ✓ Future Monitoring
- ✓ Discussions

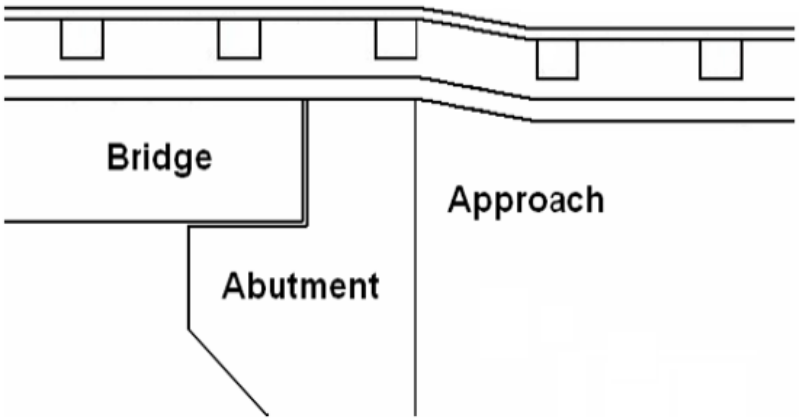
Problem Statement

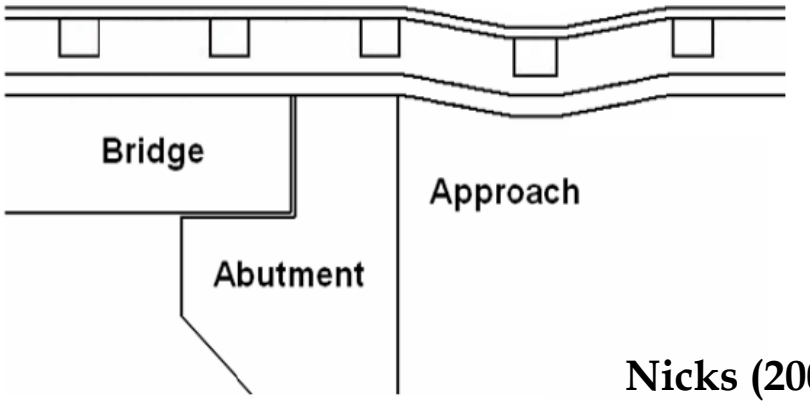
- ✓ Differential settlement between the bridge deck and approach pavement often leads to "bump" development at bridge ends

- ✓ Briaud (1997) reported $100 million/year spent in the US towards mitigating highway bridge approach problems

Problem Statement (2)

- ✓ Similar problems at railroad transitions may lead to:
  - ➢ Bridge damage
  - ➢ Passenger discomfort
  - ➢ Damage to rail and car components





Nicks (2009)

Bump **Dip**

- ✓ Approximately $200 million is spent annually on track transition maintenance (Sasaoka et al., 2005)
- ✓ $110 million/year is spent on transition zones in Europe (ERRI, 1999)

Potential Mechanisms

- ✓ Settlement/particle reorientation within the ballast layer
- ✓ Settlement/permanent deformation of the approach embankment subgrade
- ✓ Settlement/permanent deformation of native subgrade
- ✓ Stiffness differential across track transition

Instrumentation Objectives

- ✓ Measure elastic (recoverable) deformation of ballast layer
- ✓ Measure plastic (permanent) deformation of embankment fill and native subgrade
- ✓ Measure vertical wheel loads on rail and tie seats
- ✓ Monitor changes in substructure layer profile with time

Research Objective

Development of design and repair techniques to minimize and mitigate, respectively, differential movement at railway transitions to ensure safe high speed operation.

Railroad Industry Partners

AMTRAK®

UNION PACIFIC BUILDING AMERICA®

NS NORFOLK SOUTHERN

Industry Research Partners

NICHOLSON

GEOPIER FOUNDATION COMPANY

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Track Transitions Instrumented

- ✓ Amtrak Northeast Corridor (NEC)
  - ✓ Recurrent differential movement at several bridge approaches along the Northeast Corridor (NEC)
  - ✓ Two bridges originally identified by Amtrak for detailed investigation
  - ✓ Frequency of "bump appearance" requires repeated track surfacing

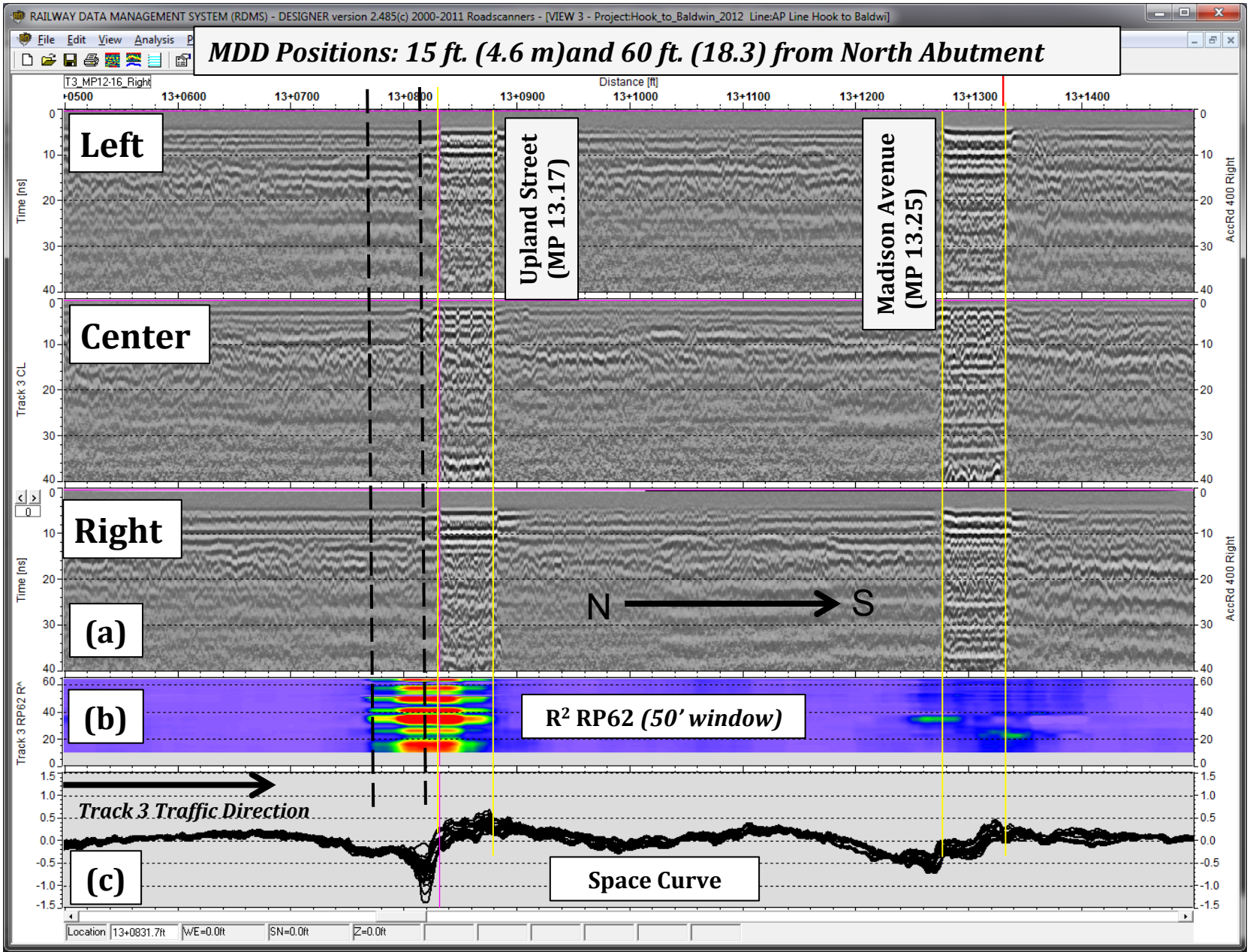
Amtrak NEC – Chester, PA
Site Characteristics

- ✓ Four Tracks
- ✓ Track 1 & 4: Primarily Commuter and Local Freight
- ✓ Tracks 2 and 3: Acela and Regional Passenger Trains
- ✓ Predominant Traffic Directions:
  - ➢ Track 2: North Bound
  - ➢ Track 3: South Bound
- ✓ Speed of Operation: 110 mph (177 km/h)

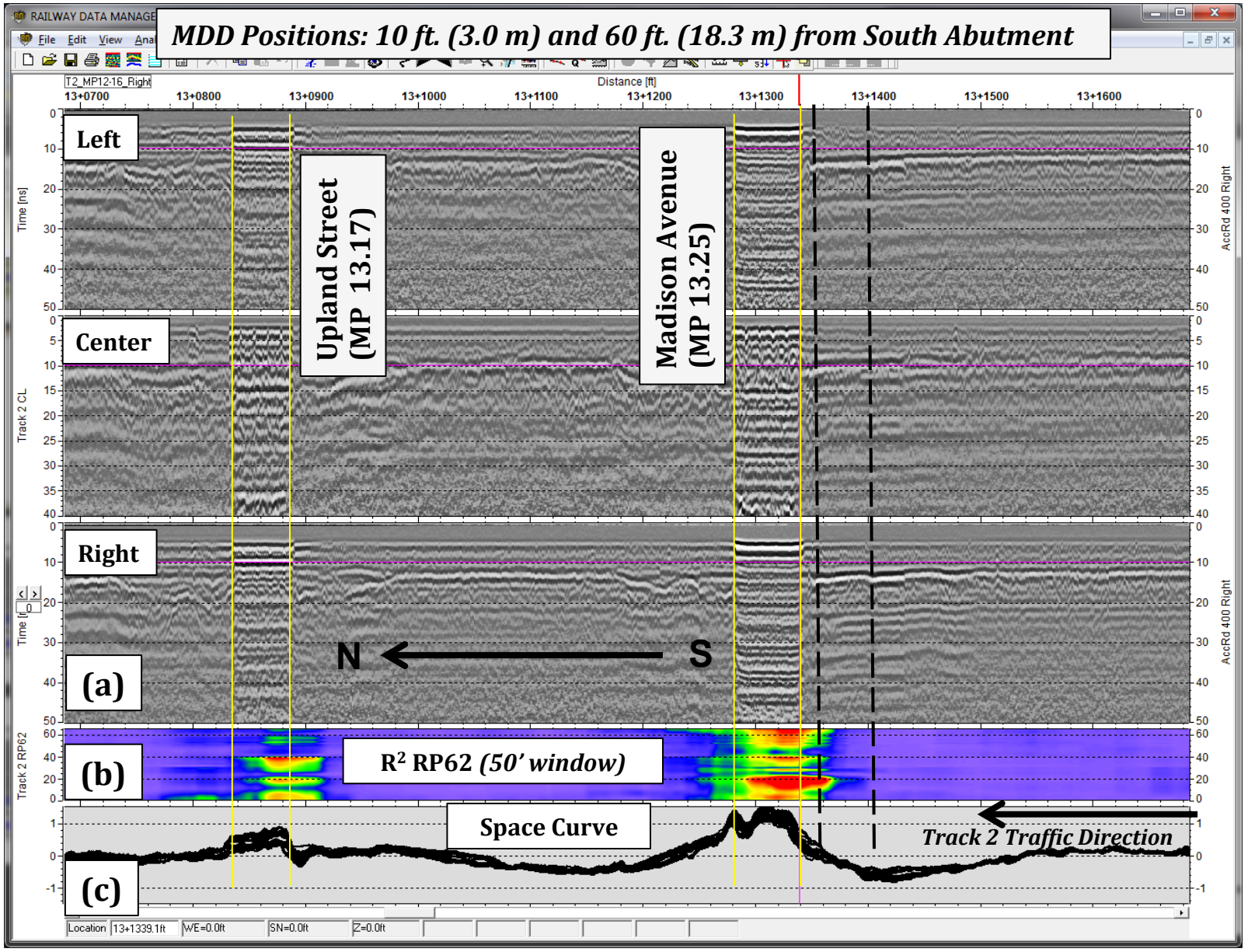
Amtrak NEC – Chester, PA Site Characteristics (2)

- ✓ Analysis of track geometry data focused on both Tracks 2 and 3
- ✓ GPR scanning of bridge approaches (Tracks 2 & 3) conducted in June-2012
- ✓ Three bridge approaches selected for instrumentation

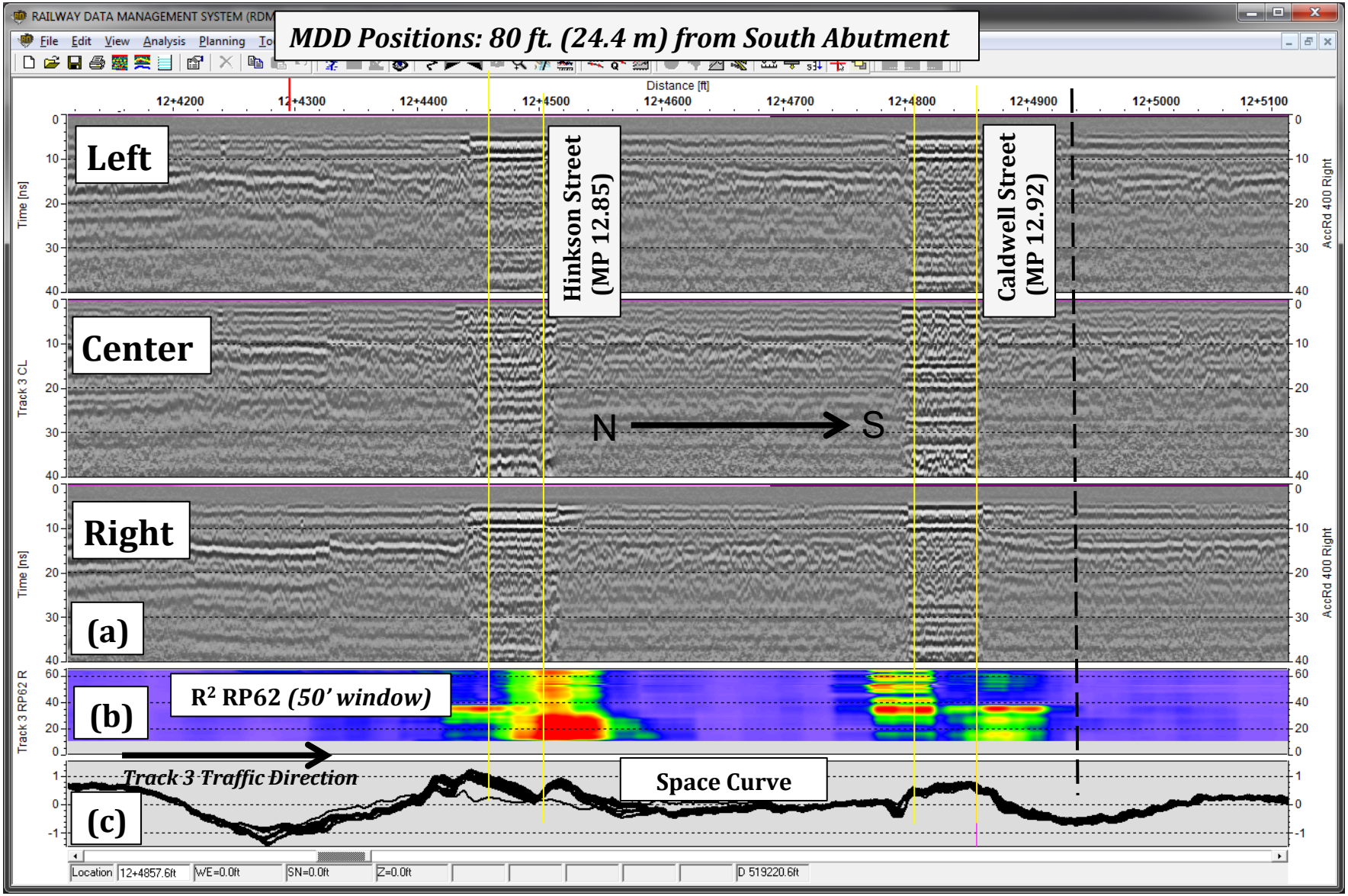
Upland Street Bridge - Track 3



Madison Street Bridge - Track 2



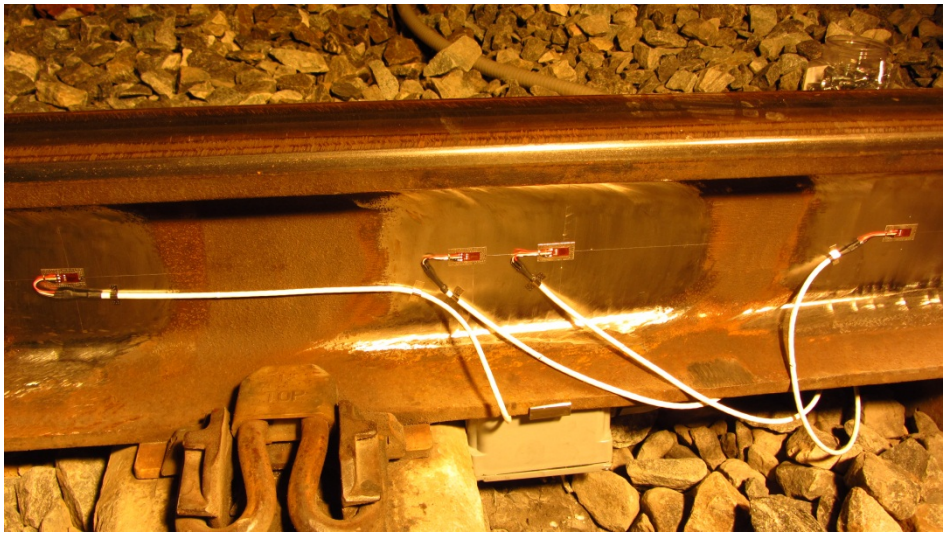
Caldwell Street Bridge - Track 3



Instrumentation Layout

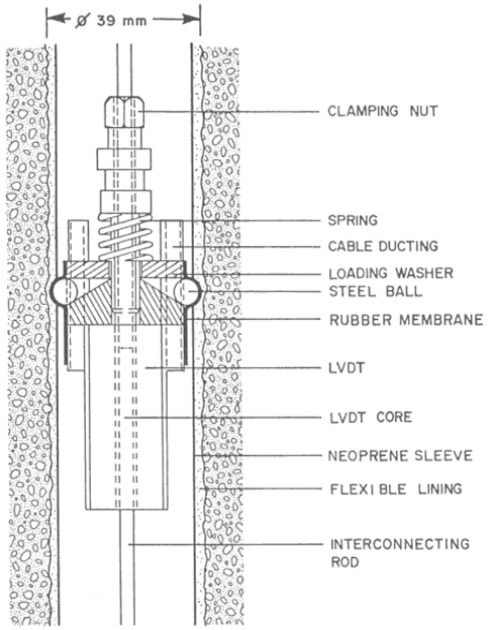
- ✓ Each approach was instrumented with
  - Two Multi-Depth Deflectometers (MDDs)
  - Sixteen (16) Strain Gages on Rail
- ✓ Instrumentation carried out between 1 AM and 4:30 AM
  - Start Date: 10-July 2012
  - End Date: 3-August 2012

Assembled MDD Module

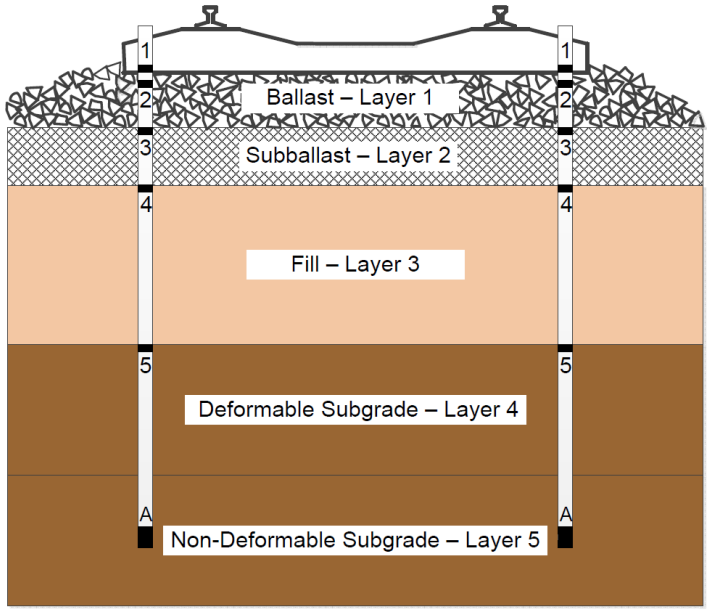


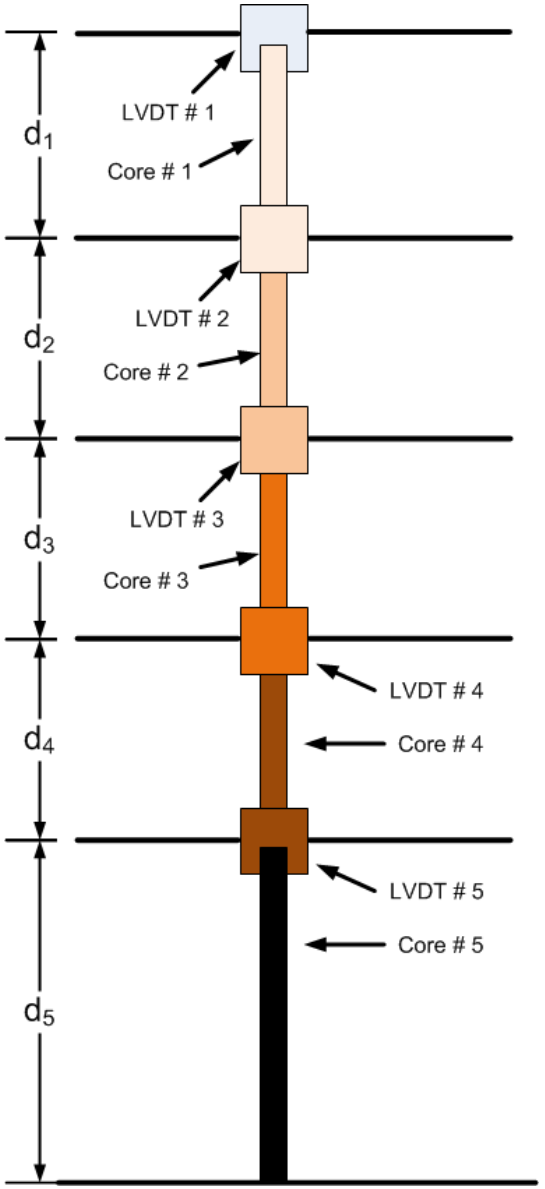
Rail Section Instrumented with Strain Gauges

Figure Source: DeBeer, 1989



MDD Layout



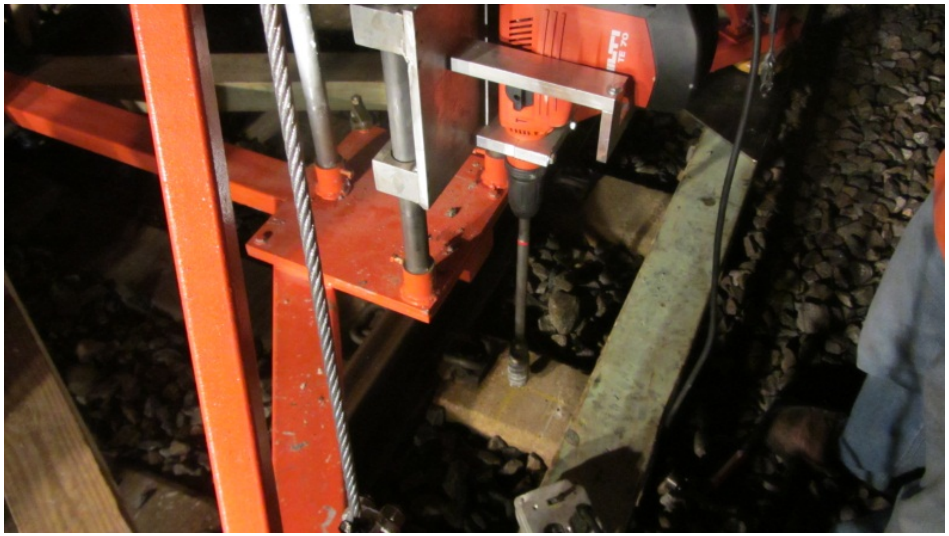


Independent Anchoring MDD System

Drilling and Layer Profile Determination

Tripod Base for Drill Rig

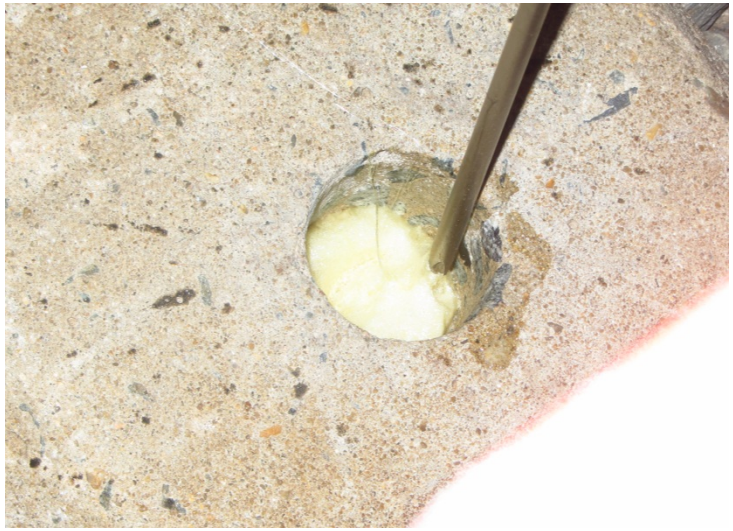
Custom-Designed Drill Rig being Mounted on Tripod Base



Hammer Drill Mounted on Drill Rig

Drilling through Concrete Tie for MDD Installation

45-mm Diameter Hole for MDD Installation



Drilled Hole with Foam used for Ballast Stabilization

Soil Removed from the Hole using the Spiral Drill Bit

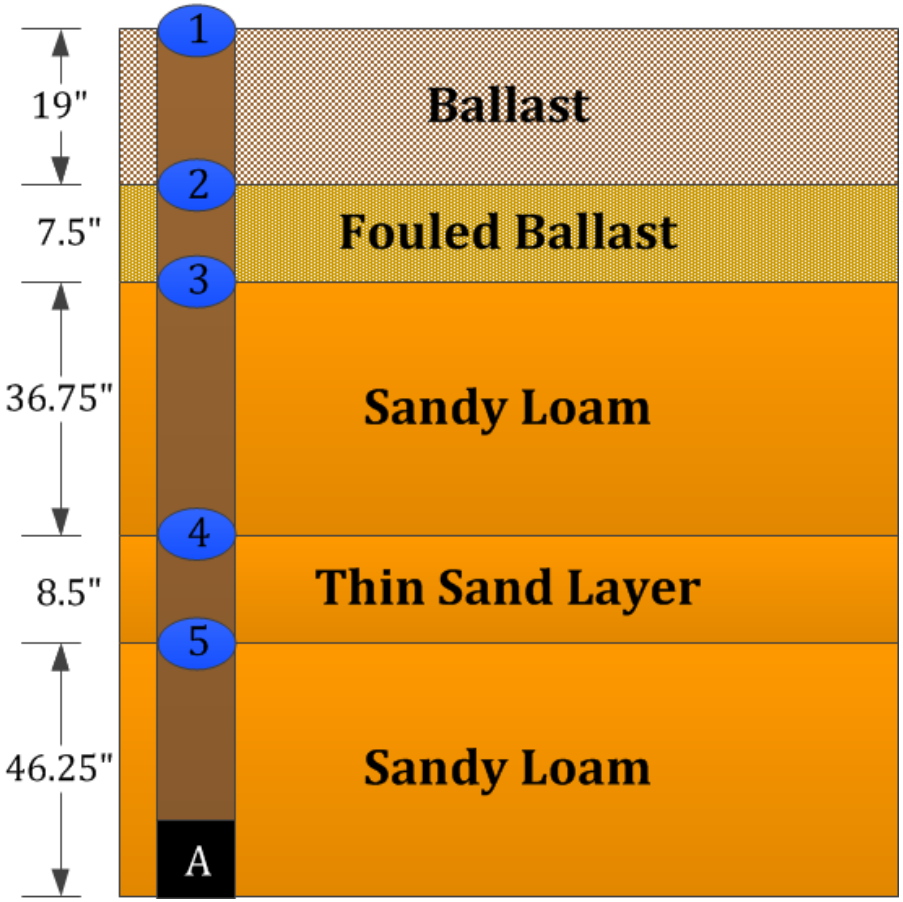
2-Part Epoxy Grout used to "Bind" the Lining Tube

Lining Tube with Anchor

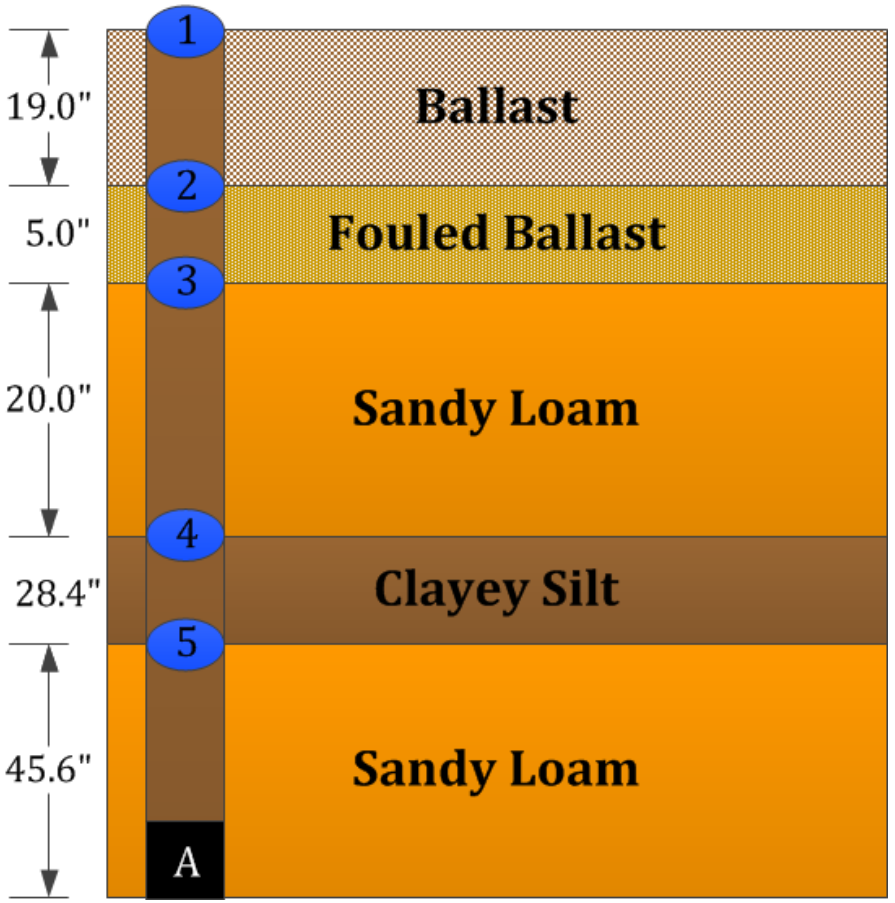
Lining Tube Installation

Drilled Hole with Installed Lining Tube

Substructure Layer Profiles



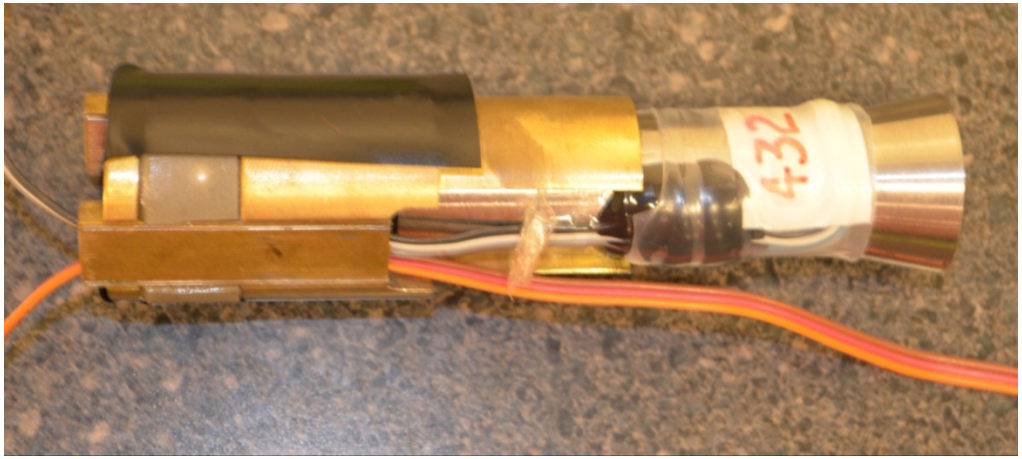
15-ft. from North Abutment



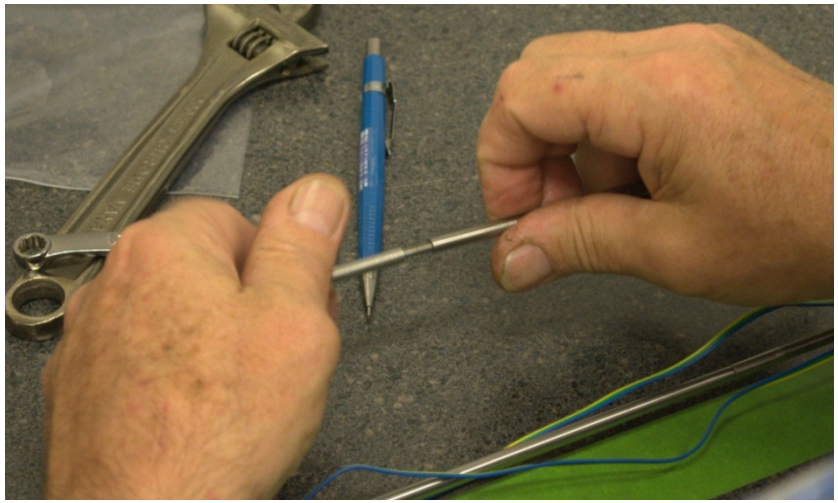
60-ft. from North Abutment

Upland Street Bridge Approach

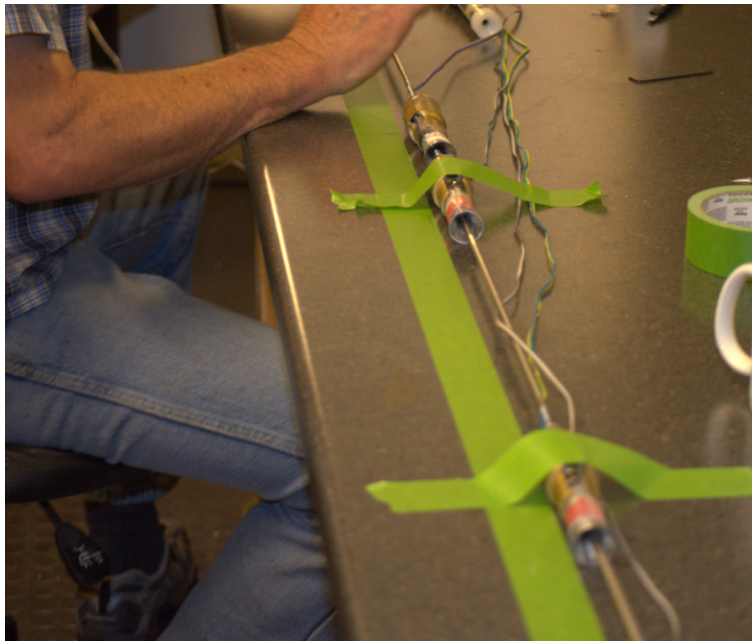
Figures Not to Scale



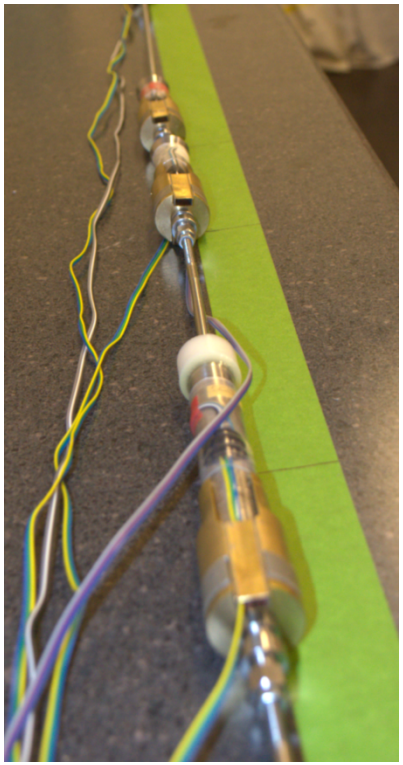
Assembled MDD Module



Joining of Cores to Achieve Required Depths



Preparation of MDD String



Assembled MDD String Ready for Installation into the Drilled Hole

Core for Lowest MDD Ready for Installation on Top of the Anchor

MDD Module Mounted on Custom-Designed Installation Tool

MDD Installation into the Drilled Hole

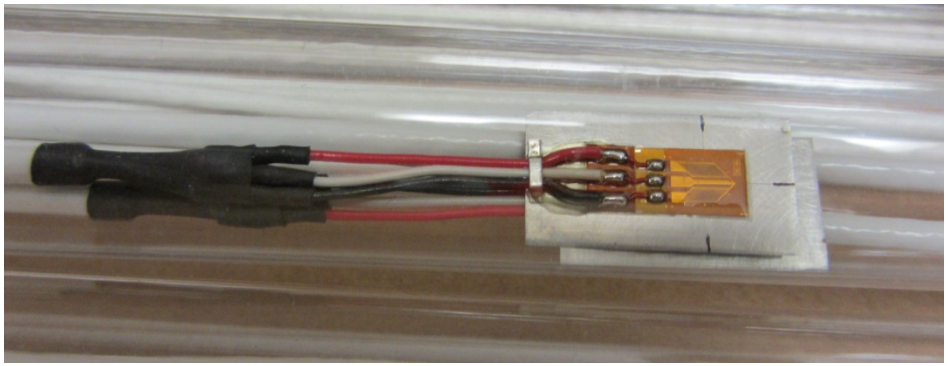
Positioning of MDD at Layer Interface Corresponding to "Zero" Output Voltage

Tamping Protectors were installed to prevent collapse of the holes

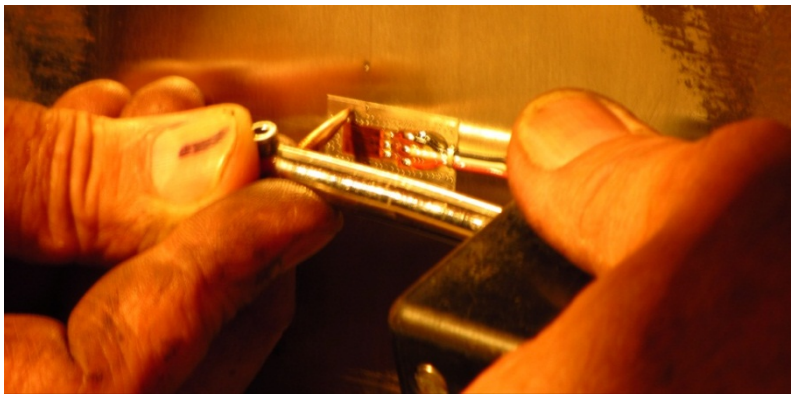
Each approach was tamped after installation of the bottom three modules

Rail Marking for Strain Gage Installation

Rail Grinding



Weldable Strain Gages
(Dual Element-Shear)



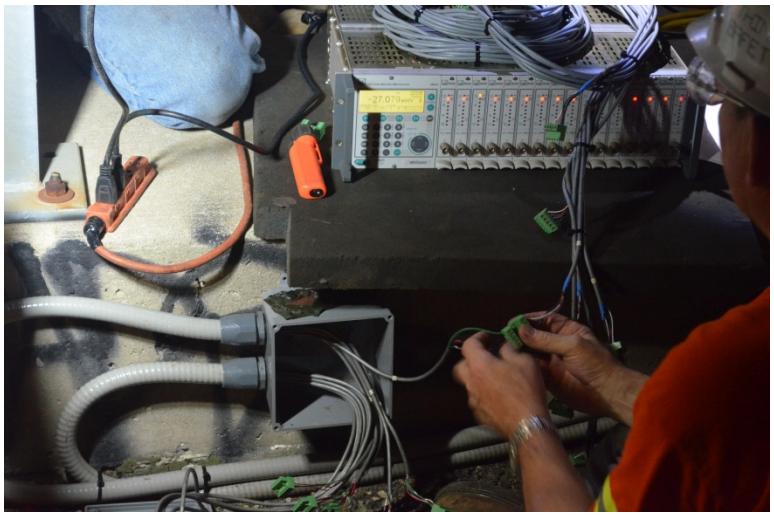
Spot Welding of Strain Gages

Strain Gages for Wheel Load and Tie Reaction Measurements

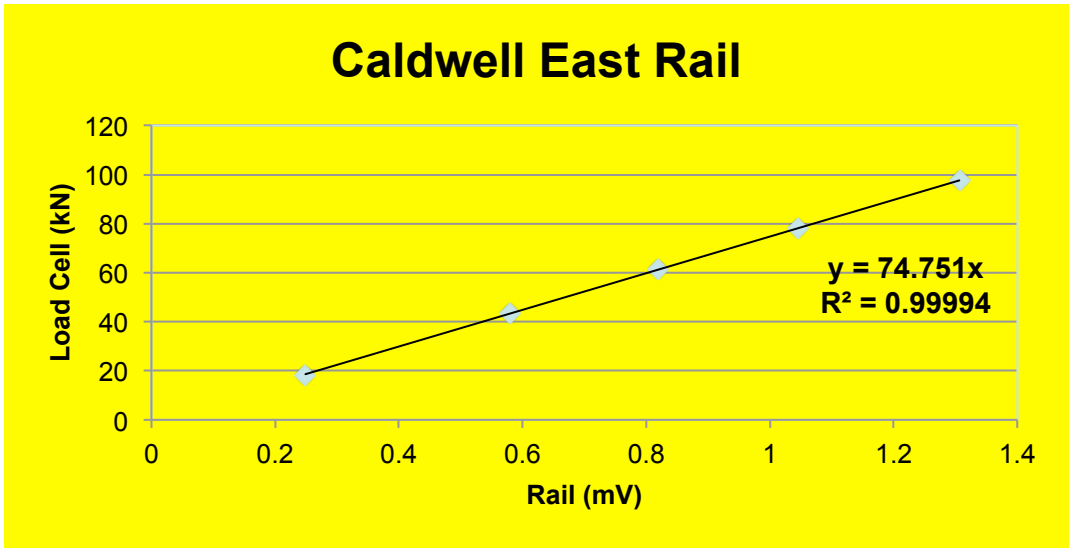
Protecting Strain Gages using Silicone

Calibration Frame

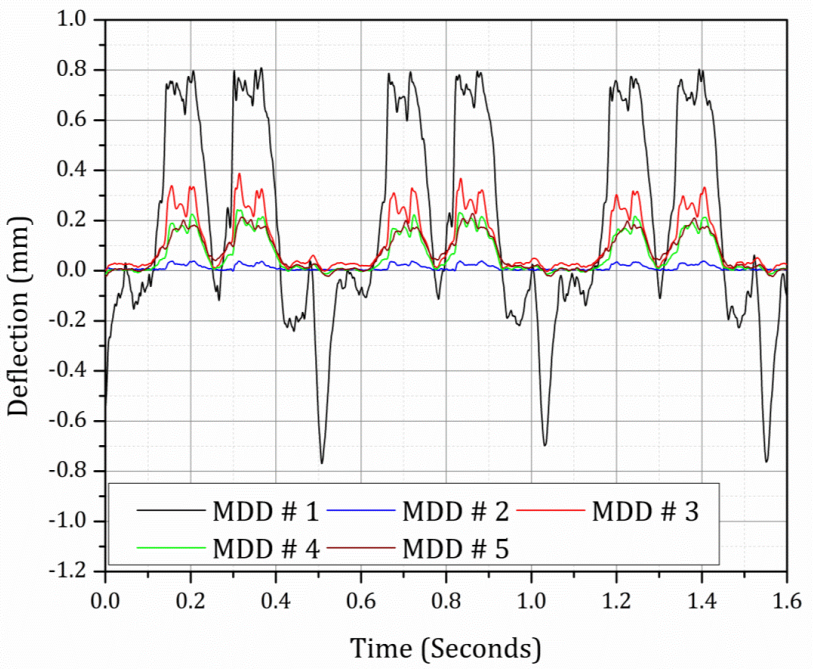
Calibration Frame Mounted on Rail



HBM Amplifier used for Data Acquisition

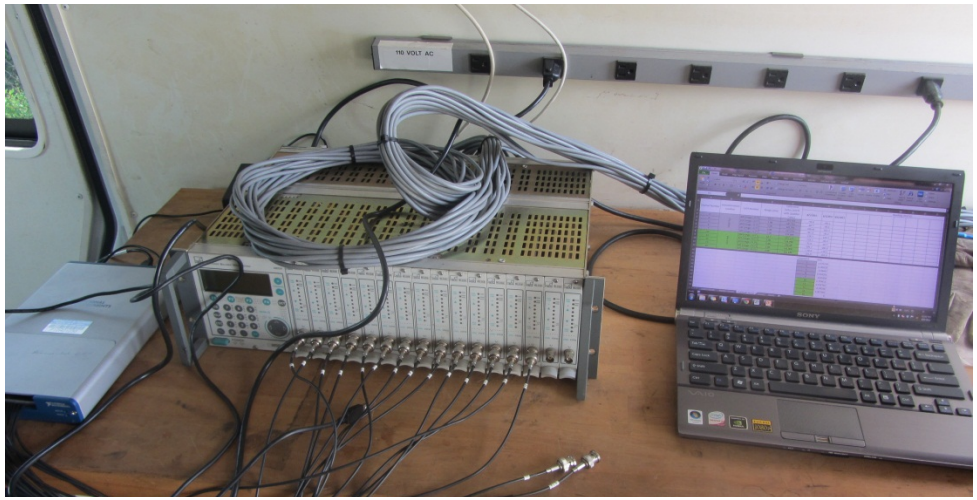


Example Dynamic Response



Way-Side Cable Connections

Cable Connections from Way-Side Box to DAQ System



Signal Conditioner and DAQ System

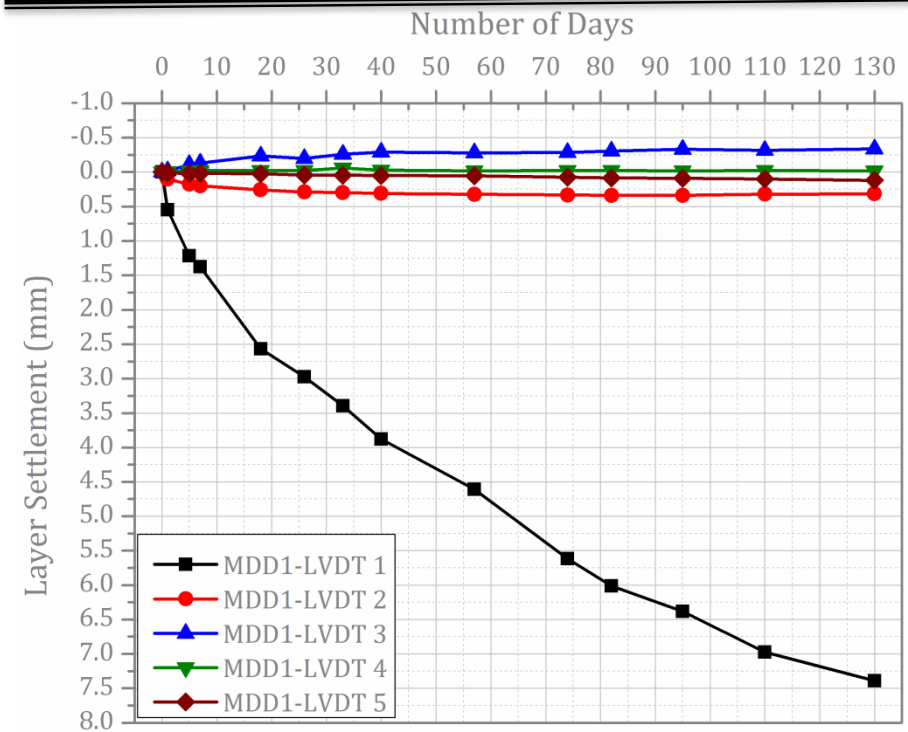
Analysis of Acquired Data

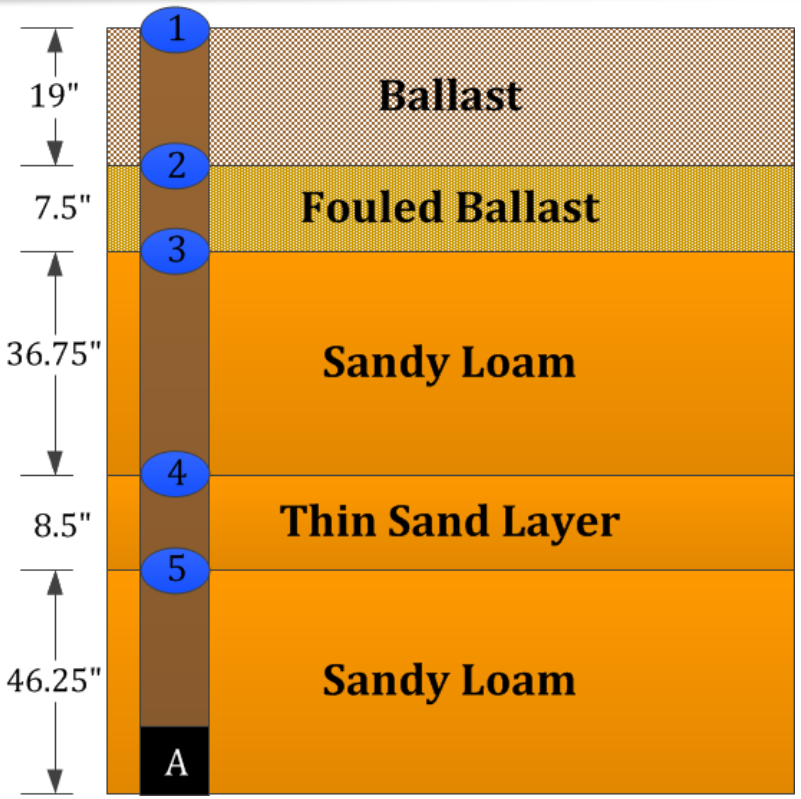
Duration of Performance Monitoring

- ✓ MDD offsets acquired at (approximate) 1-2 week intervals
- ✓ Offsets collected on:
  - ✓ 2-Aug, 3-Aug, 7-Aug, 9-Aug, 20-Aug, 28-Aug, 4-Sep, 11-Sep, 28-Sep, 15-Oct, 23-Oct, 5-Nov, 20-Nov, 10-Dec, 29-Jan, 25-Feb, 11-Mar, 1-April
- ✓ Significant rainfall for 4-5 days immediately following the installation of sensors
- ✓ This was followed by 2-3 weeks of dry period, and subsequent heavy rainfall

Permanent Deformation Accumulation

Upland Street Bridge

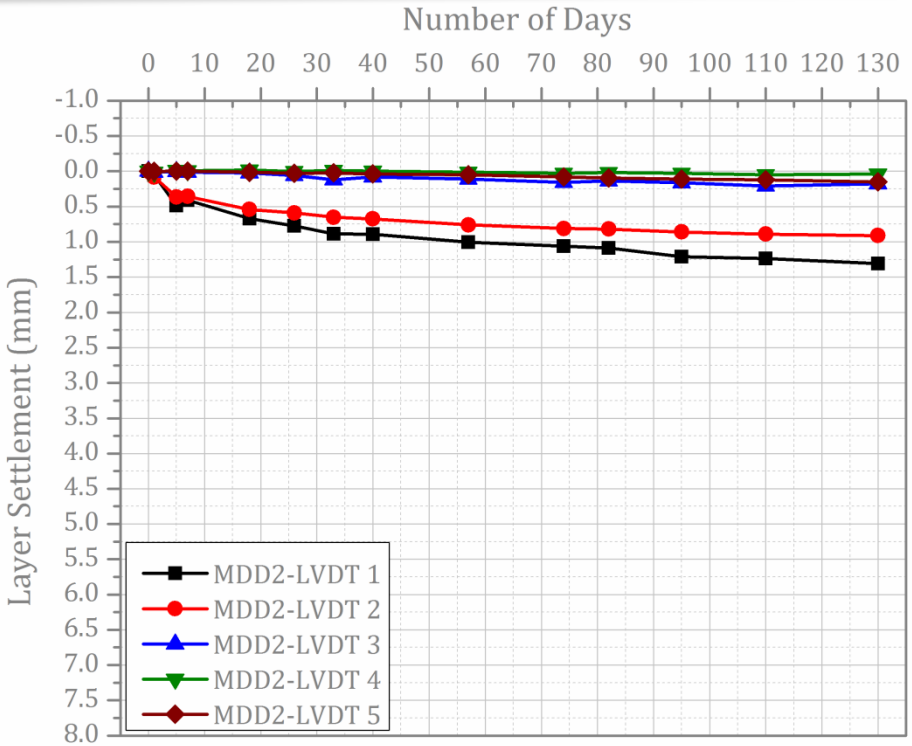


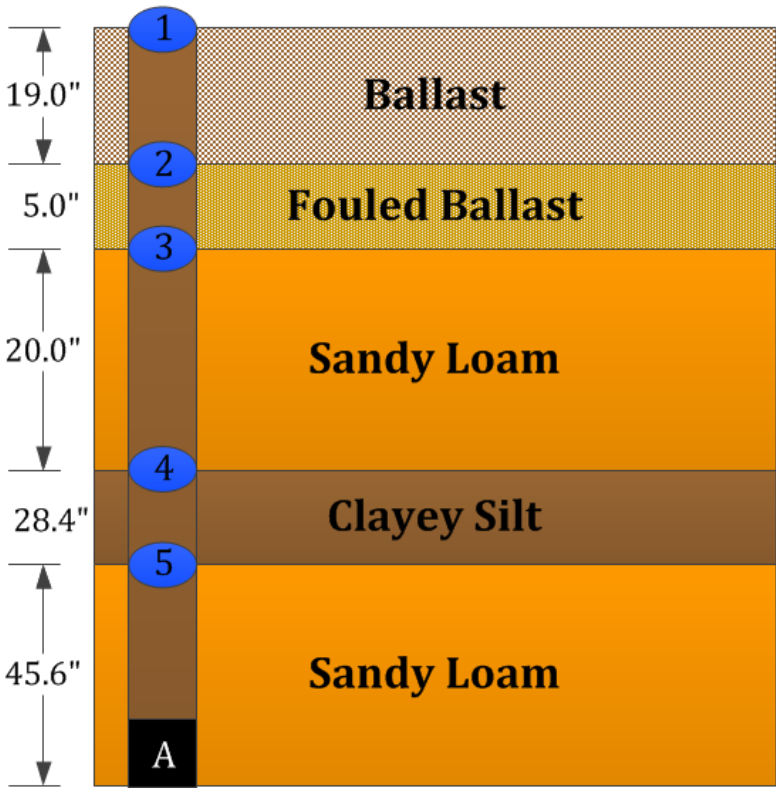


- **LVDT-1 includes deformation of ballast layer as well as "hanging tie" effect**

15-ft. from North Abutment

Upland Street Bridge (2)

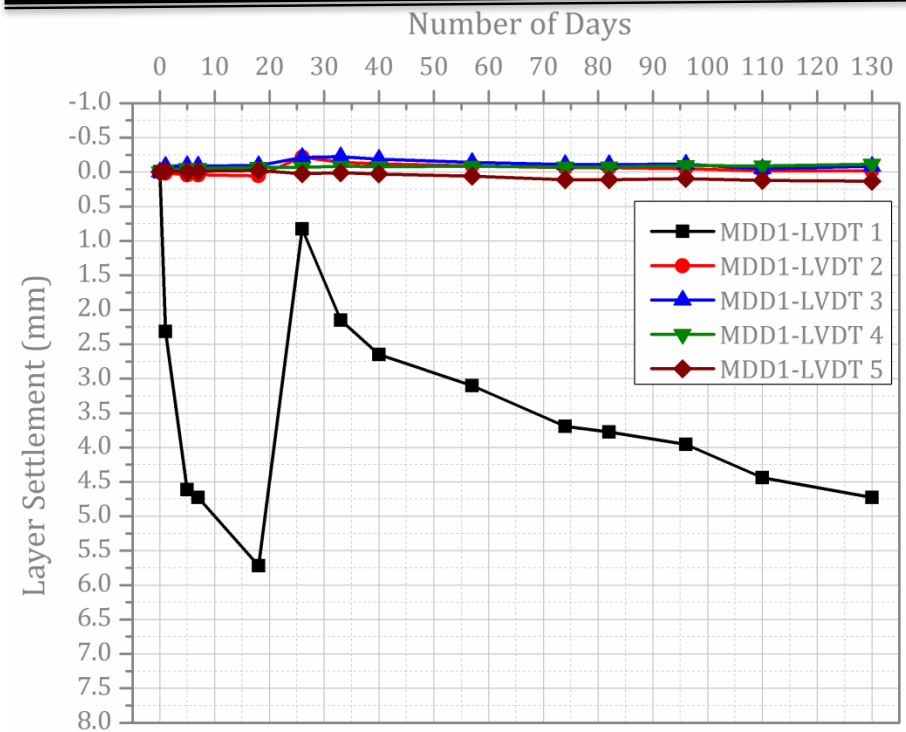


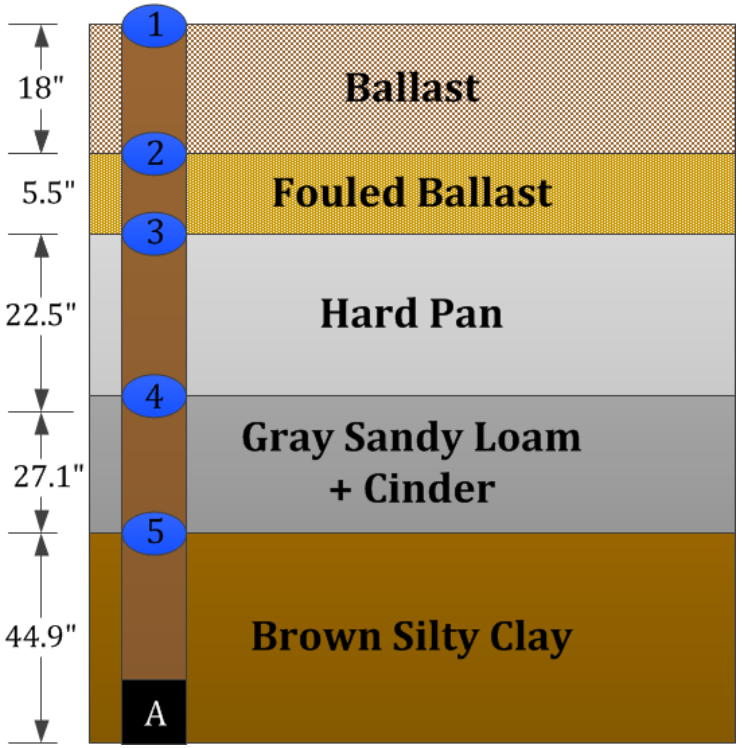


- **Significantly less deformation compared to the 15-ft. location**

60-ft. from North Abutment

Madison Street Bridge

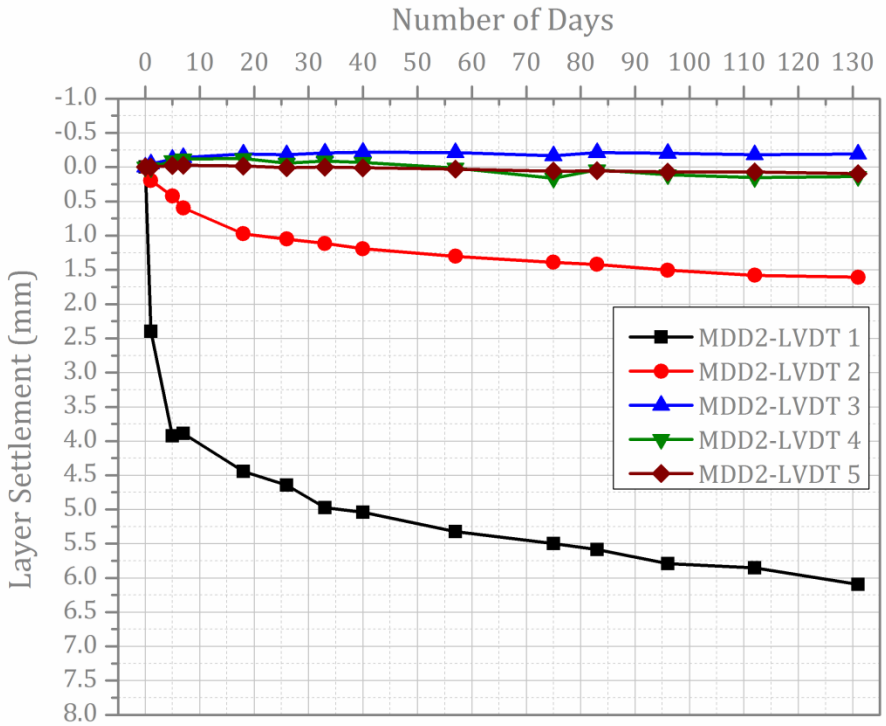


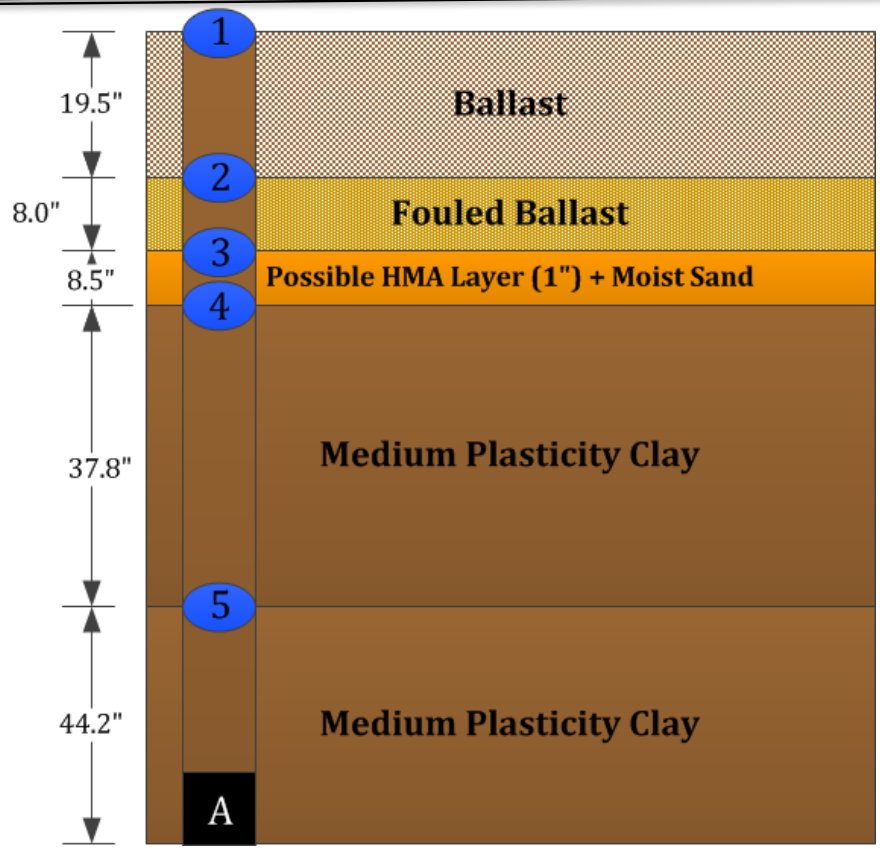


- This location was tamped approximately 20 days after instrumentation
- Tamping was conducted before permanent deformation in the ballast layer had "stabilized"

12-ft. from South Abutment

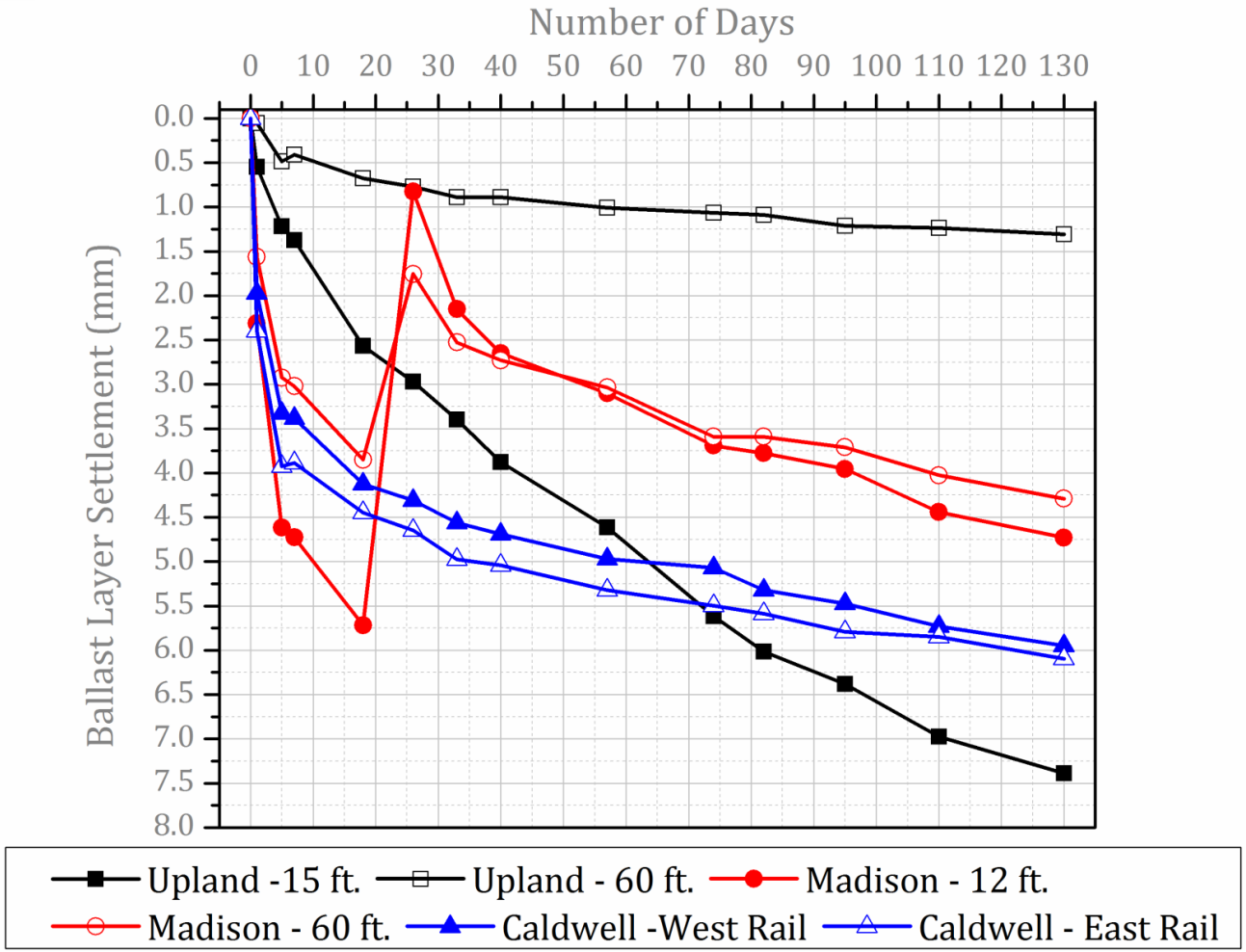
Caldwell Street Bridge





80-ft. from South Abutment (East Rail)

Comparing Top-Most LVDT Results for the Three Sites

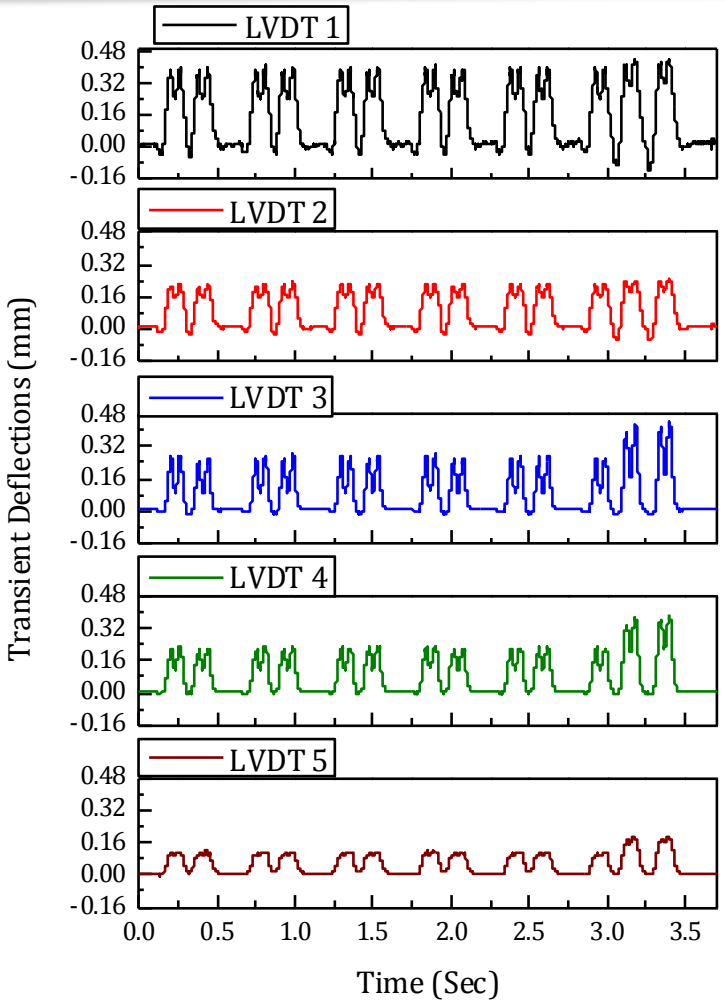


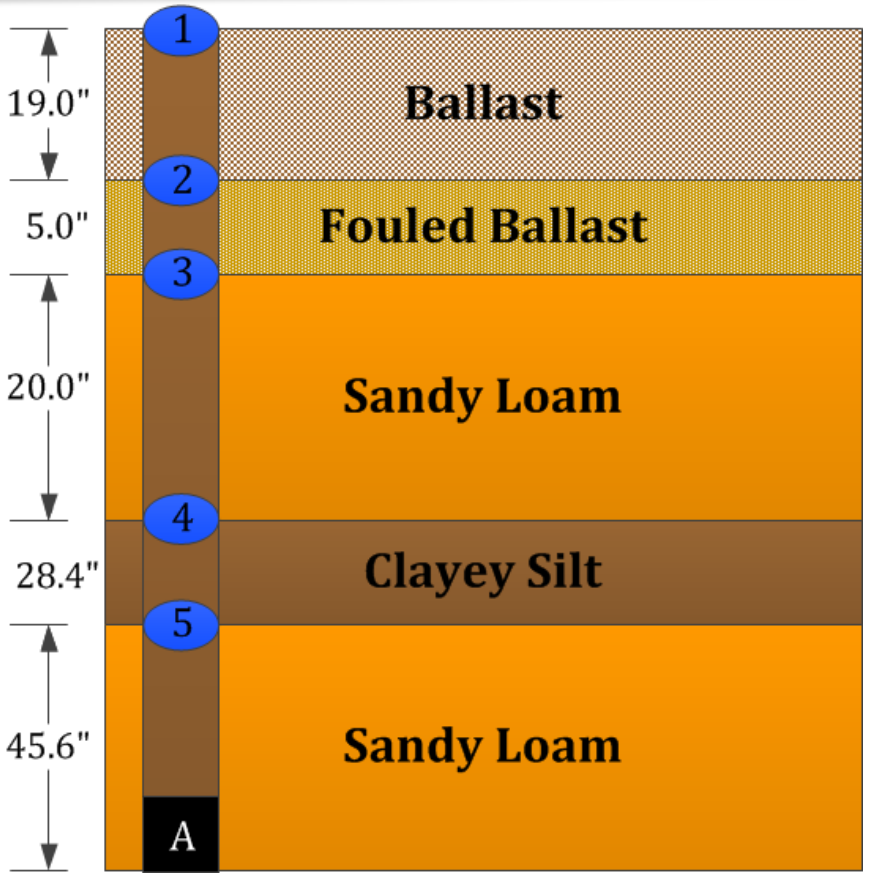
Transient Deformations Under Train Loading

Data Collection Frequency

- ✓ Dynamic deflection data collected for each approach at 3-month intervals
- ✓ Two trains each (per approach) captured in
  - ✓ August 2012
  - ✓ November 2012
  - ✓ January 2013
- ✓ Dynamic deflection data can be used to "estimate" individual layer modulus values

Dynamic Data Acquisition Under Train Loading

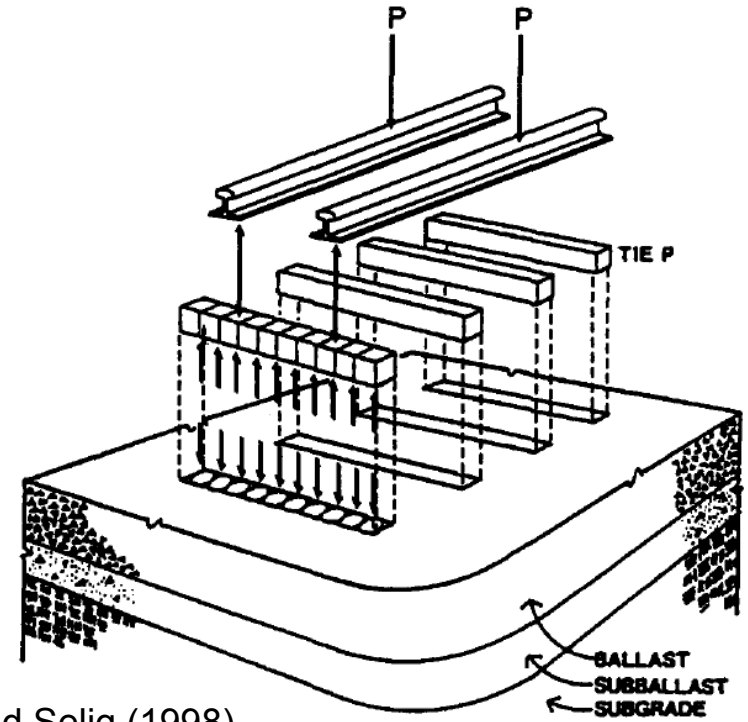




Upland Street Bridge Approach (Train 1)

60-ft. from North Abutment

Using Geotrack to Estimate Layer Moduli



Li and Selig (1998)

- ✓ 3-Dimensional, Multilayer
- ✓ Up to 5 layers
- ✓ Infinite horizontal extent
- ✓ No slip at layer interfaces
- ✓ Only vertical loading considered

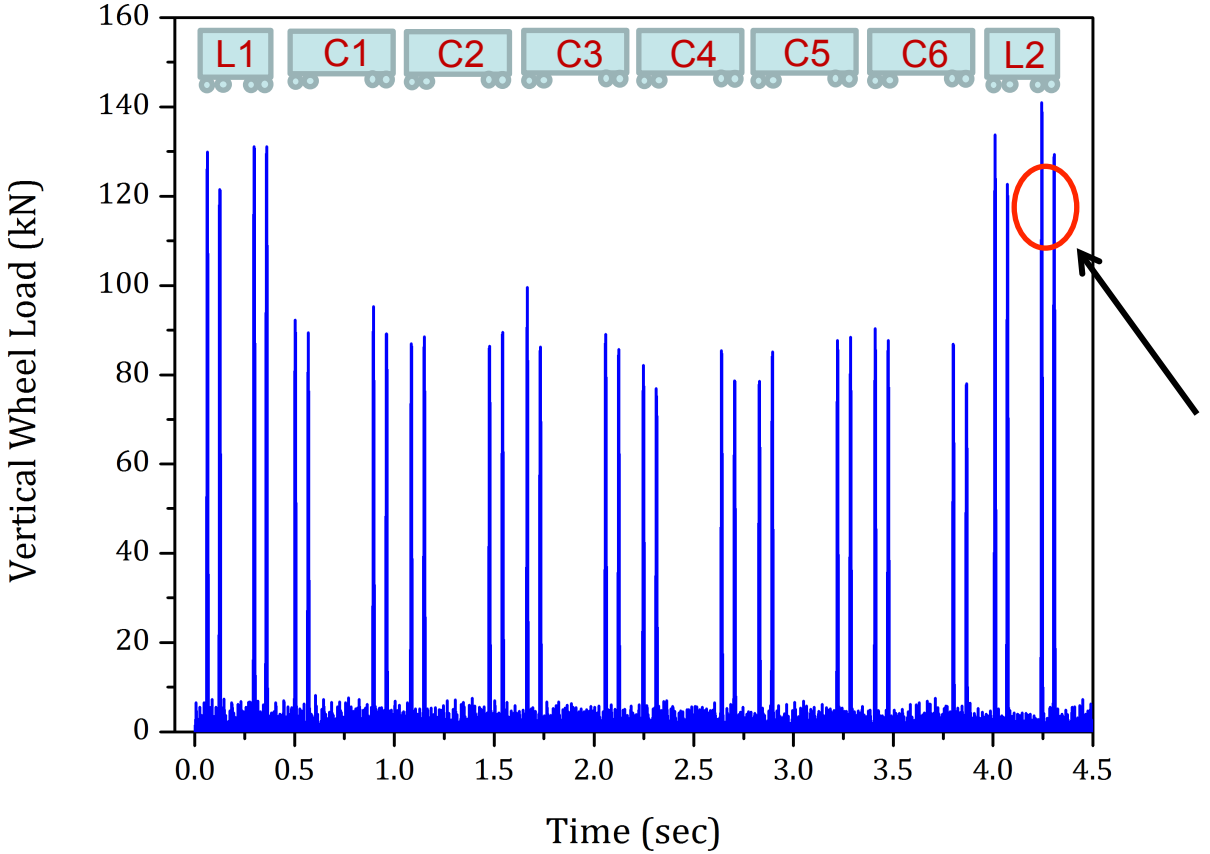
- ✓ **Rails**
  - Linear elastic beams
  - Span eleven ties
  - Free to rotate and ends and at each tie
  - Linear spring between rail and tie
- ✓ **Ties**
  - Linear elastic beams
  - Supported at 10-equally spaced circular locations by the underlying ballast

Geotrack: Assumptions and Limitations

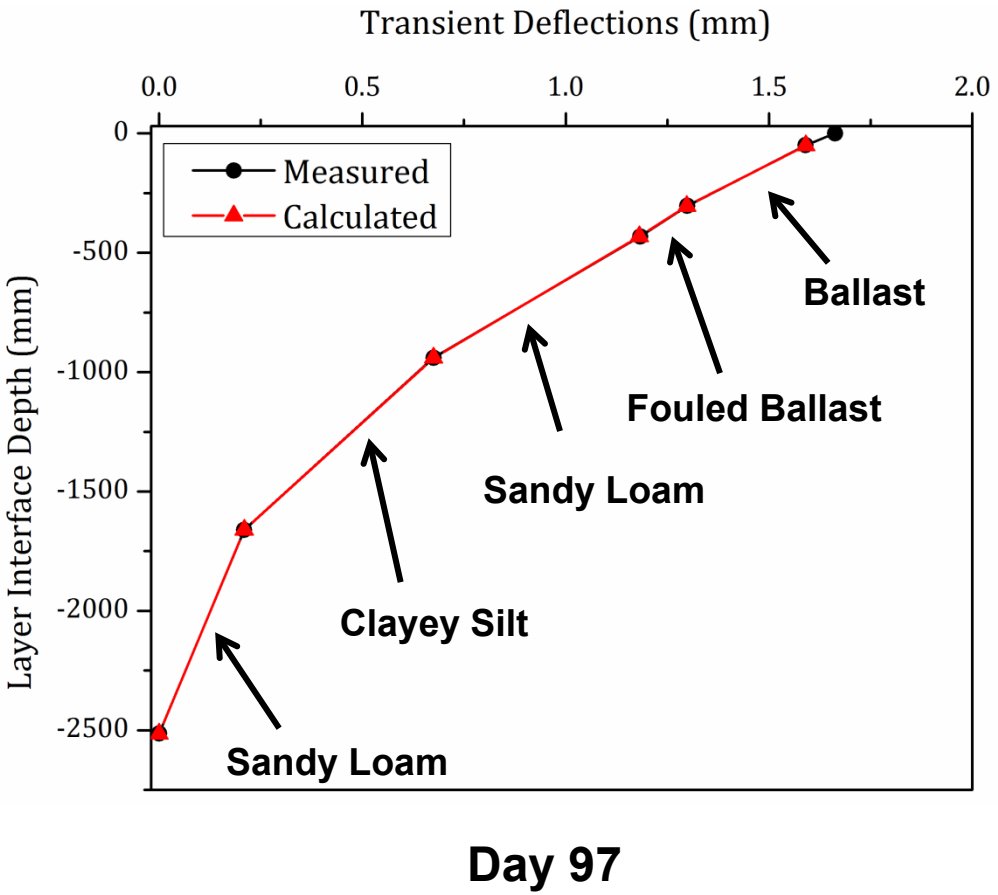
- ✓ Measured load value applied for static analysis
- ✓ Constant modulus values assumed for track substructure layers (Geotrack has the capability to consider stress-dependent behavior)
- ✓ Not a Finite Element program.
  - ✓ Only one modulus value assigned to each layer (stresses calculated at mid-depth in this case)

Using Geotrack to Estimate Layer Moduli (2)

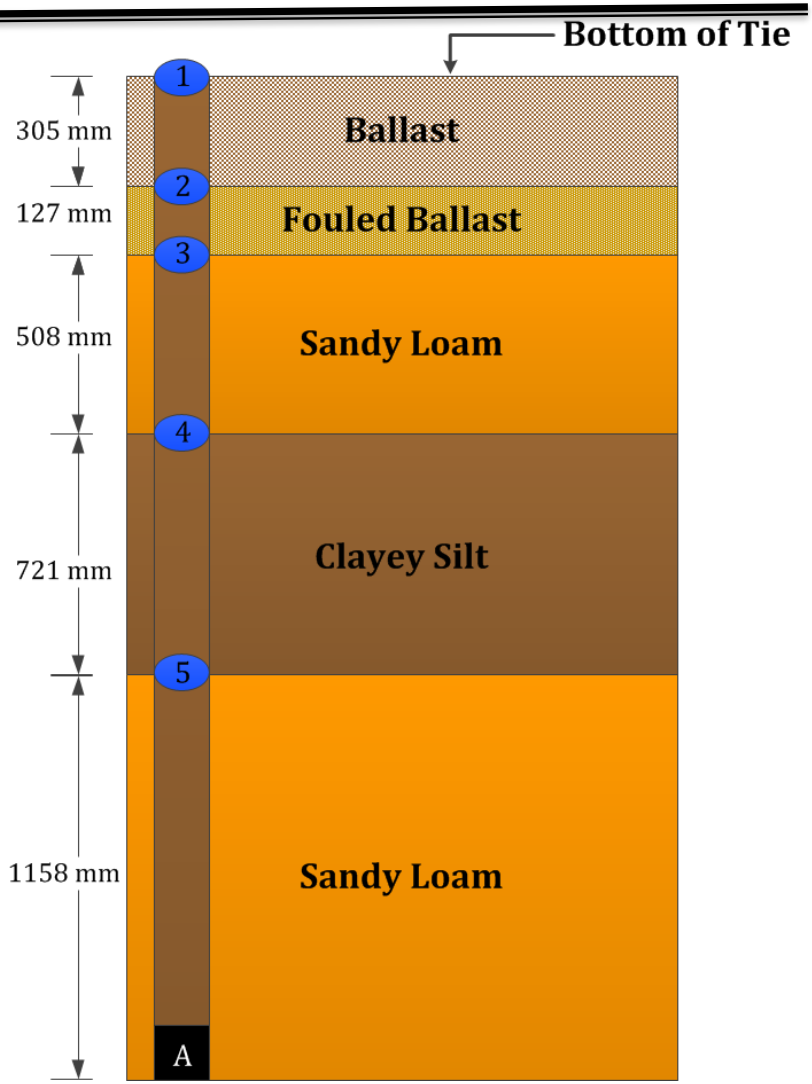
✓ Acela Express Axle Layout



Measured Vs. Calculated Deflections



Day 97



Not to Scale

Layer Modulus Trends

- ✓ Layer modulus values calculated from matching deflection values at MDD positions

Layer	Modulus (MPa)	
	Day 0	Day 97
Ballast	45	69
Fouled Ballast	17	55
Sandy Loam	32	31.5
Clayey Silt	34	32
Sandy Loam	66	69

- ✓ Overall Track Modulus:
  - ✓ **Day 0: 3.310 kips/in./in. = 22.818 N/mm/mm**
  - ✓ **Day 97: 3.838 kips/in./in. = 26.460 N/mm/mm**

Typical Track Modulus Values

- ✓ Stable Tracks: 17 - 69 N/mm/mm (Nicks, 2009)
- ✓ Typical Track Modulus with Concrete Ties: 41 N/mm/mm (Hay, 1982; AREMA, 2008)
- ✓ Typical Values for Bridge Approaches: 14 - 41 N/mm/mm (Plotkin et al., 2006)
- ✓ Upland Street Bridge Approach:
  - ➢ Day 0: 3.310 kips/in./in. = 22.818 N/mm/mm
  - ➢ Day 97: 3.838 kips/in./in. = 26.460 N/mm/mm

Future Amtrak Site Monitoring and Data Analysis

- ✓ Instrumented approaches will be monitored for at least one more year, or until major rehabilitation work requires removal
- ✓ Permanent deformation measurements will be taken at 1-2 week intervals
- ✓ Dynamic data under train loading will be collected at 3-4 month intervals to monitor changes in layer modulus
- ✓ Estimated substructure moduli will be used as initial inputs for FLAC modeling

Planned Instrumentation of UP and NS Bridge Approaches

- ✓ The research team is currently working with UP and NS to plan the instrumentation of selected bridge approaches
  - ✓ Selection of bridge approaches was primarily based trying to capture different mechanisms contributing to the bump development

- ✓ UPRR: HSIPR Track 2A Proect - Dwight, IL to Saint Loius, MO
- ✓ NS: East Megasite (West Virginia)

Acknowledgements

✓ FRA

- Cam Stuart
- Ted Sussmann
- Hugh Thompson
- Gary Carr

✓ Amtrak

- Mike Tomas
- Marty Perkins
- Carl Walker
- Steve Chrismer
- Dave Staplin
- Mike Trosino

✓ Union Pacific Railroad

- Dwight Clark
- John Jerome

✓ University of Illinois (ICT)

- James Pforr
- Hasan Kazmee
- Mike Wnek

✓ HyGround Engineering

- Mike LaValley

Thank You!

Questions ?