Dynamic Responses of Bridge Approach Concrete Ties after the Applications of Polyurethane Injection, Stone Blowing and Under-Tie Pad Remedial Measures

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Presentation Outline

- Brief Project Background
- Instrumented Bridge Approach Performance Summaries
- Near Bridge Approach Tie Lifting and Oscillations
- Applications of Remedial Measures
  - **Under-Tie Pad (UTP) Installation**
  - **Chemical Polyurethane Grouting**
  - **Stone Blowing**
- Transient Responses of Concrete Ties
- Summary and Conclusions

Federal Railroad Administration High Speed Rail Broad Agency Announcement (BAA) Project

Mitigation of Differential Movement at Railway Transitions for US High Speed Passenger Rail and Joint Passenger/Freight Corridors

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2016 International Crosstie & Fastening System Symposium

14-16 June 2016

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  - Gary Carr, Cam Stuart, Hugh Thompson, Ted Sussmann (Volpe)
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  - Steve Chrismer (Now with LTK)
  - Dave Staplin, Mike Trosino, Mike Tomas, Marty Perkins, Carl Walker
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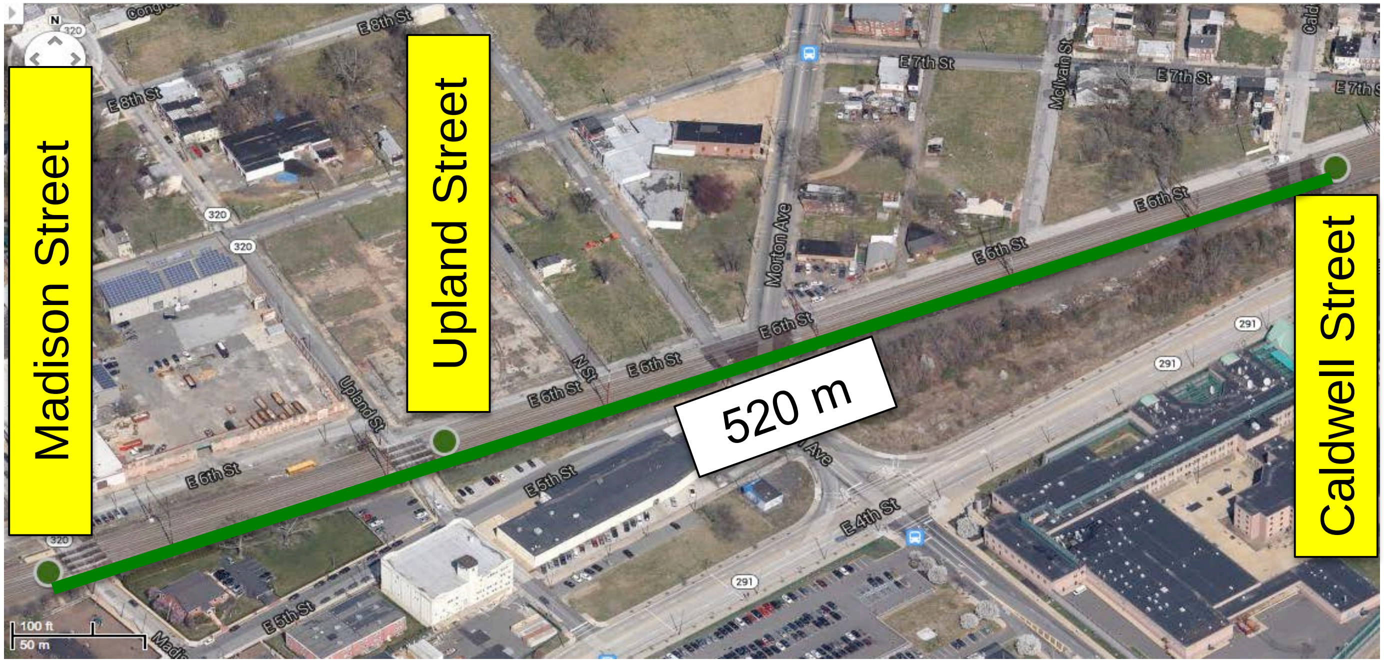
  - Tom Planert (Now with Substrate Testing, Inc.)
- Pandrol CDM Track
  - Jeff Marty and Bill Moorhead
- University of Illinois
  - James Pforr, Jim Meister, Aaron Coenen, Liang Chern Chow, Marcelo Suarez, Wenting Hou, Steve Wilk

Three Bridge Approaches at Chester, PA Site



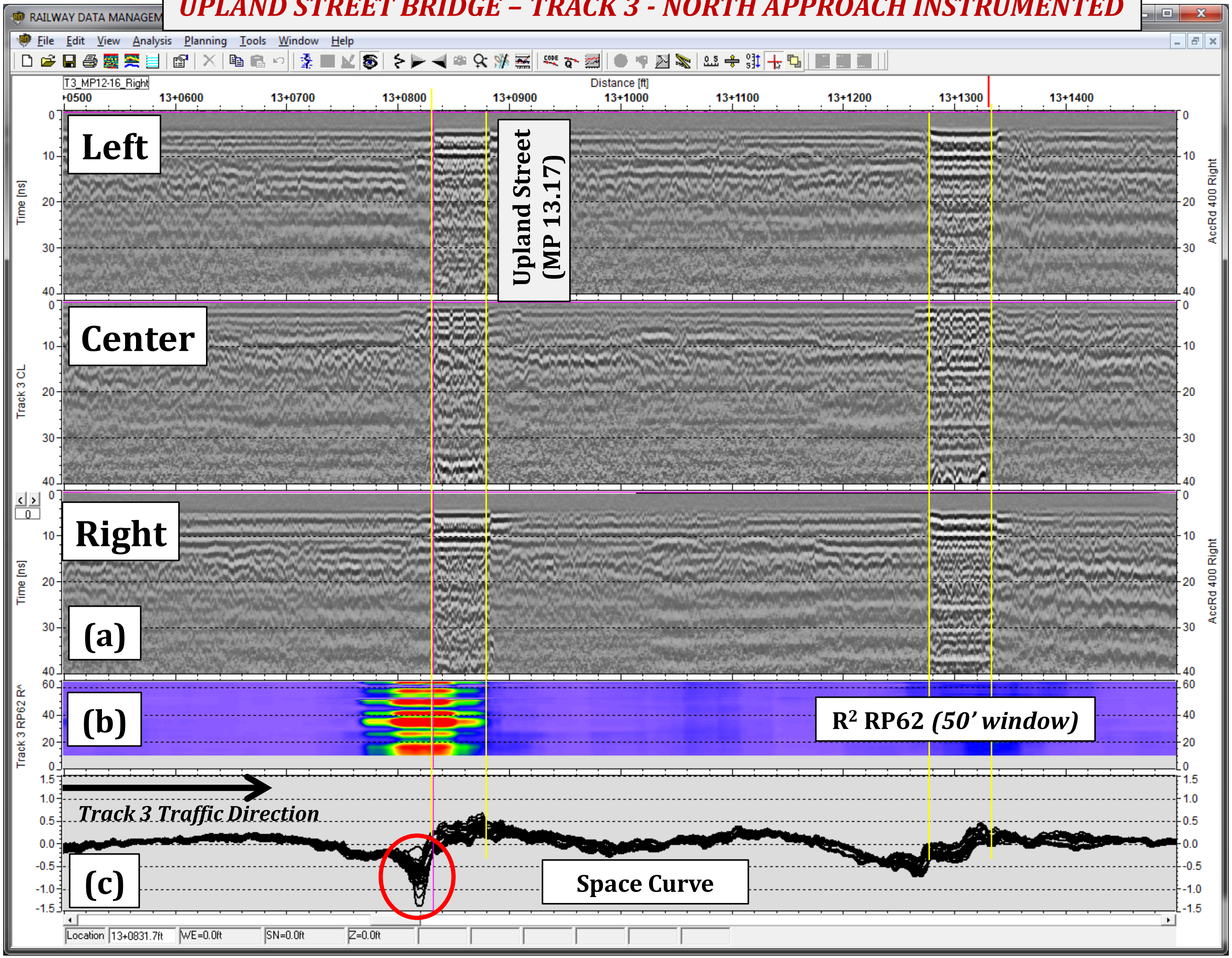
AMTRAK NEC

ACELA Passenger Trains 110 mph (177 km/h)

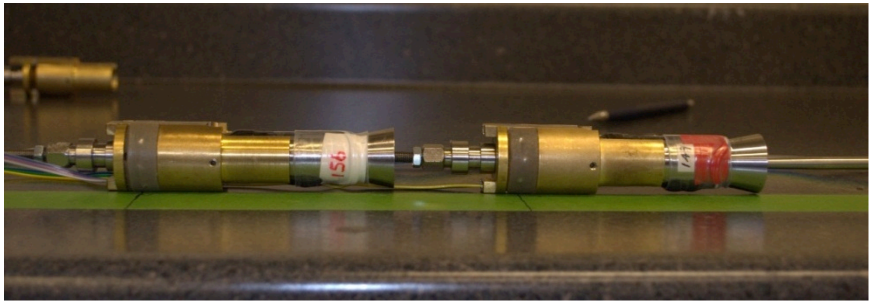
Recurring bridge approach settlement and geometry problems

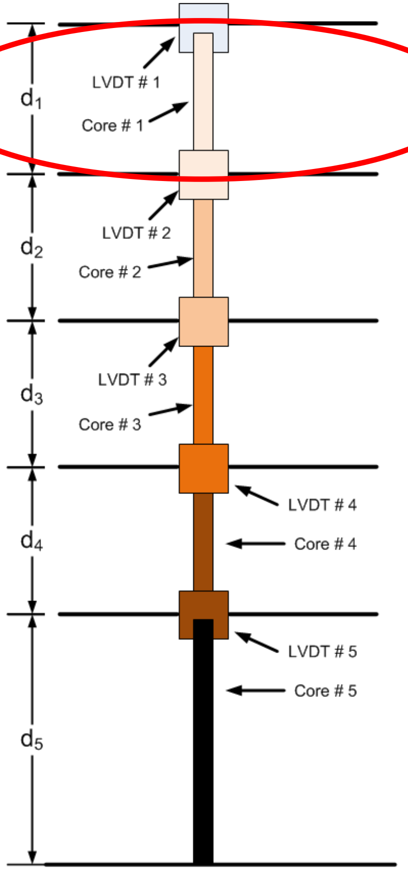
Chester Amtrak Station Bridge Approach (January 2012)

UPLAND STREET BRIDGE – TRACK 3 - NORTH APPROACH INSTRUMENTED

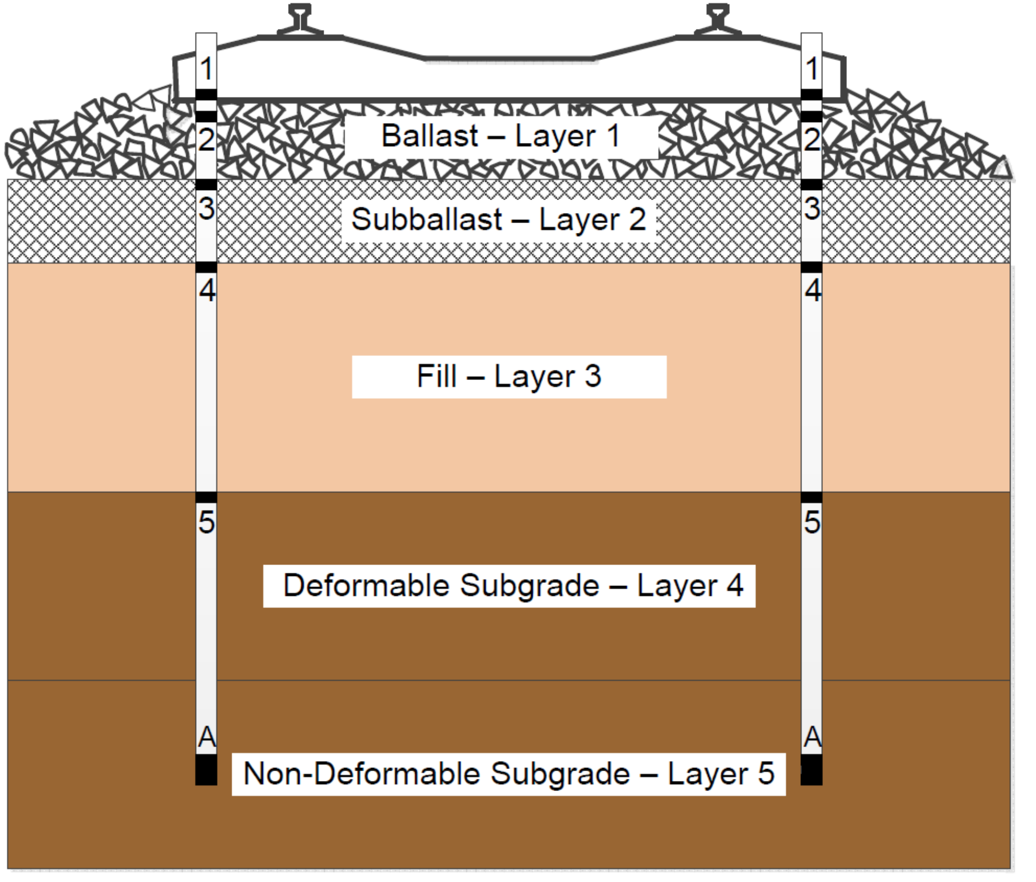


Installed **Multidepth Deflectometers (MDDs)** at 3 Bridge Approaches



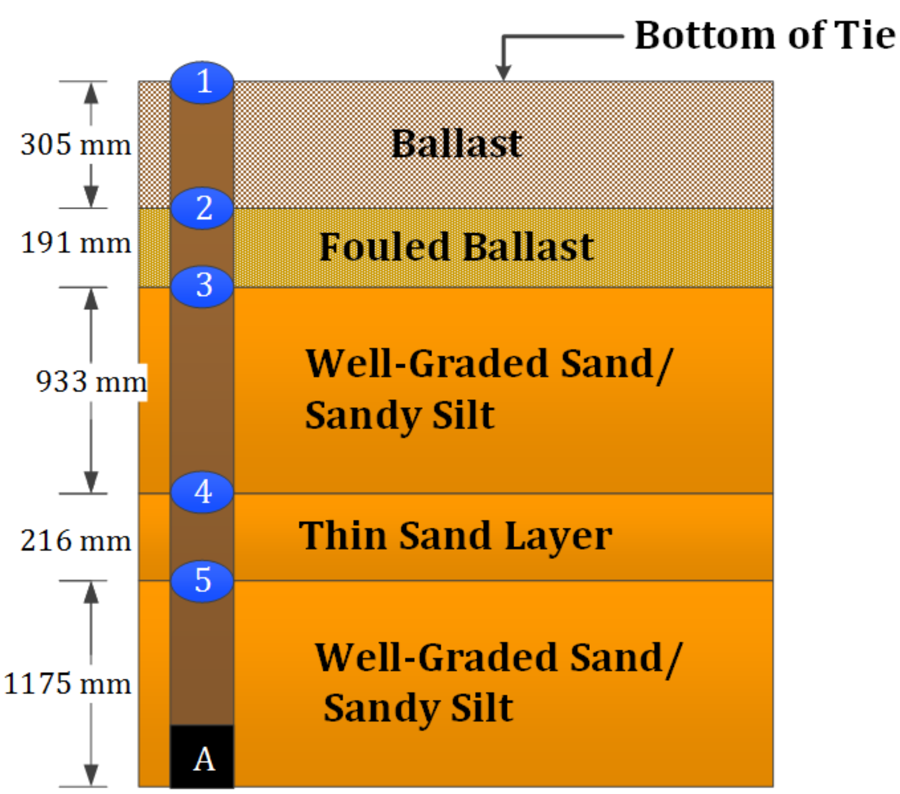


Layer 1 or LVDT 1 displacement is the crosstie deformation

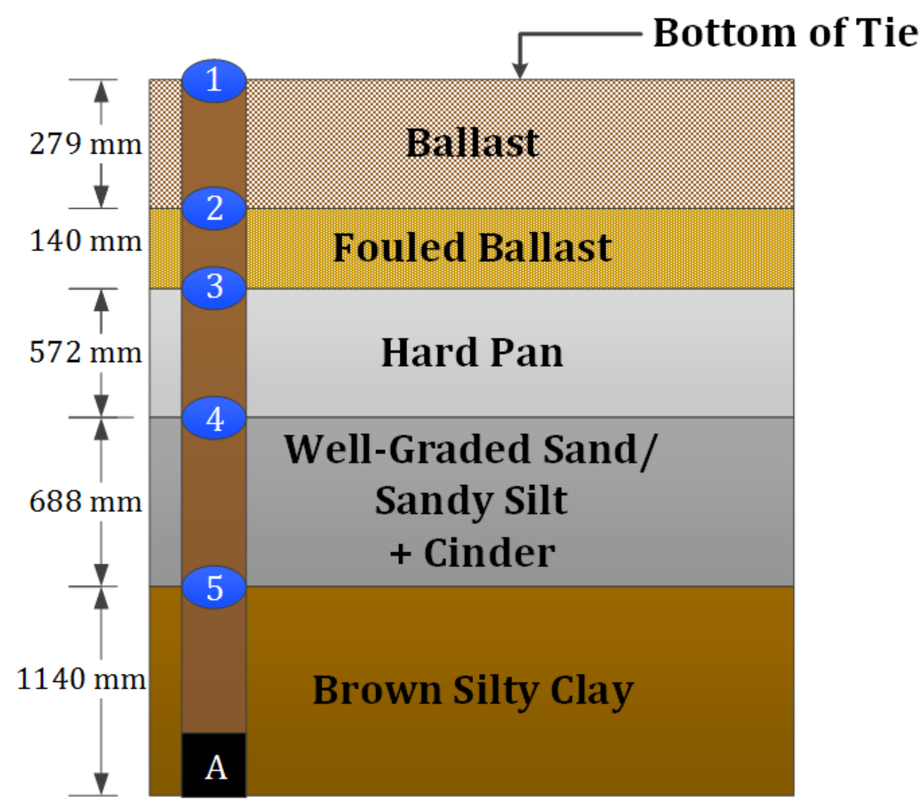


The Independent Anchoring MDD System

Substructure Layer Profiles for Upland and Madison Street Bridge Approaches

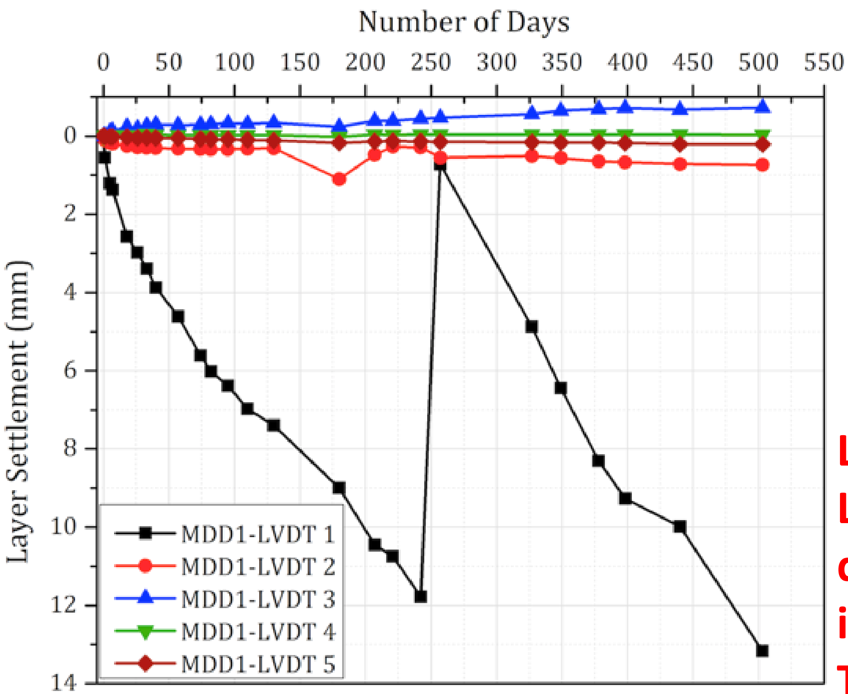


Upland Street
15 ft. from North Abutment



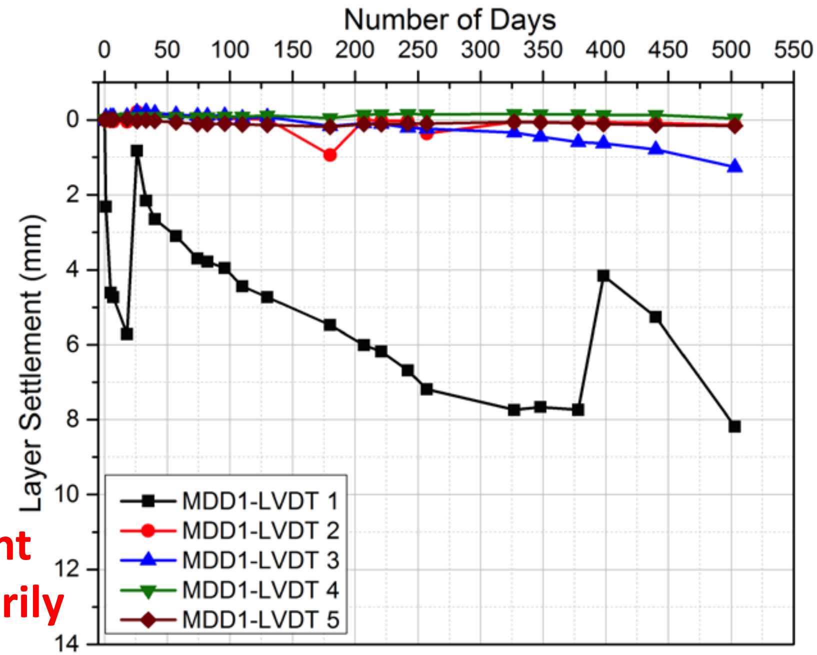
Madison Street
12 ft. from South Abutment

Layer Settlement Trends for Upland and Madison Street Bridge Approaches



Upland Street
15 ft. from North Abutment

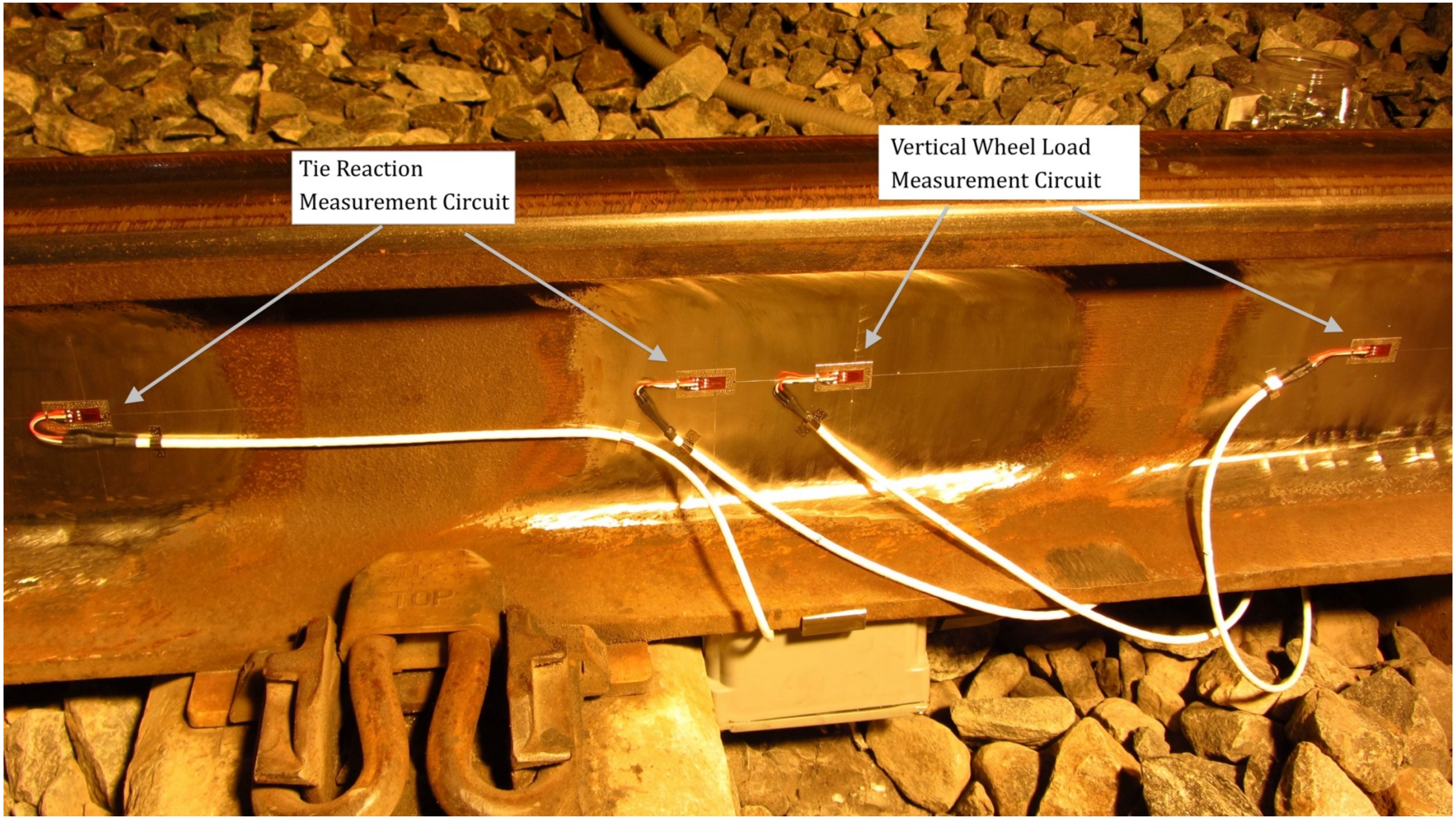
Layer 1 or LVDT 1 displacement is the primarily The crosstie deformation



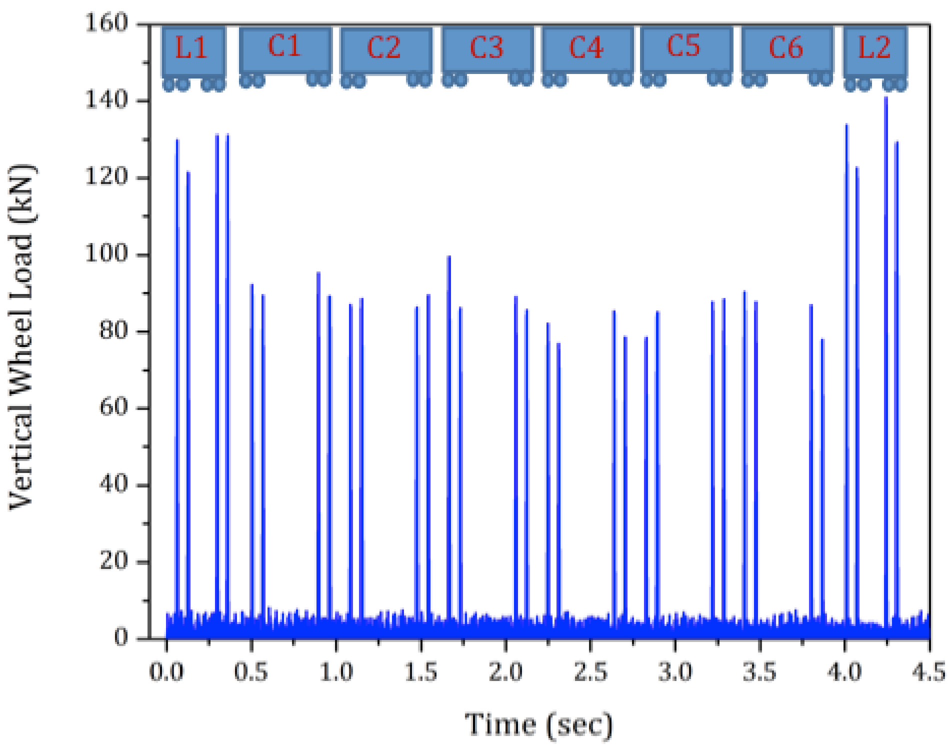
Madison Street
12 ft. from South Abutment

- Ballast movement at both approaches – Major factor contributing to track settlement
- Remedial measures targeted at reducing ballast settlement would likely lead to favorable performance

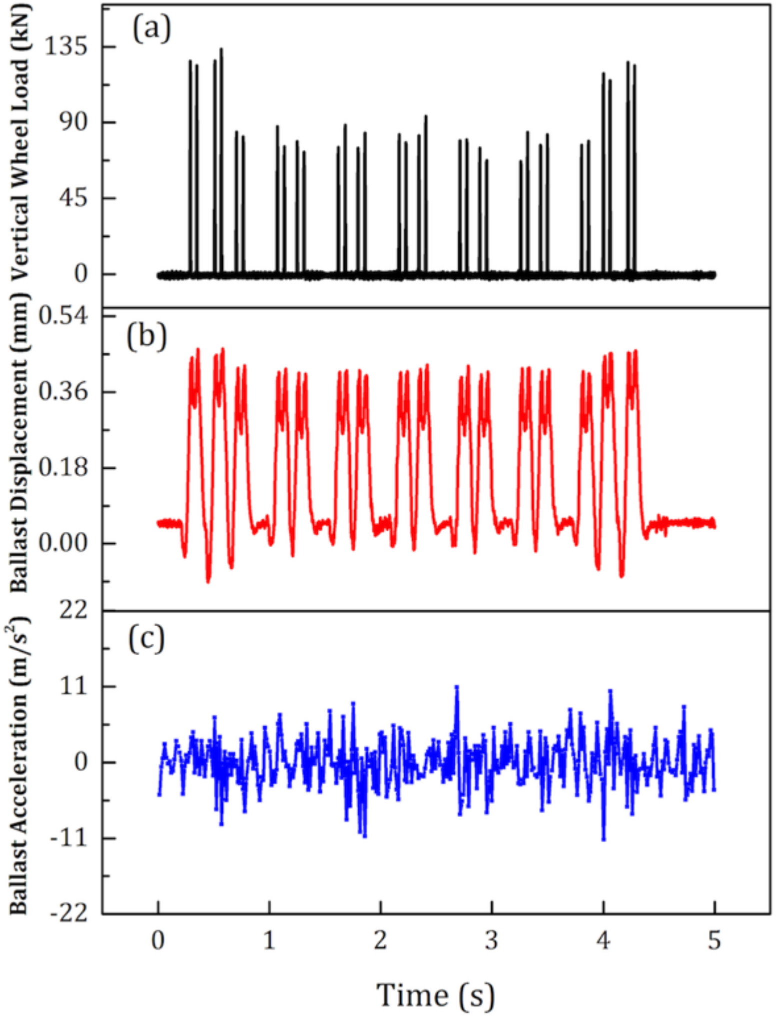
Strain Gauge Layout – Wheel Loads



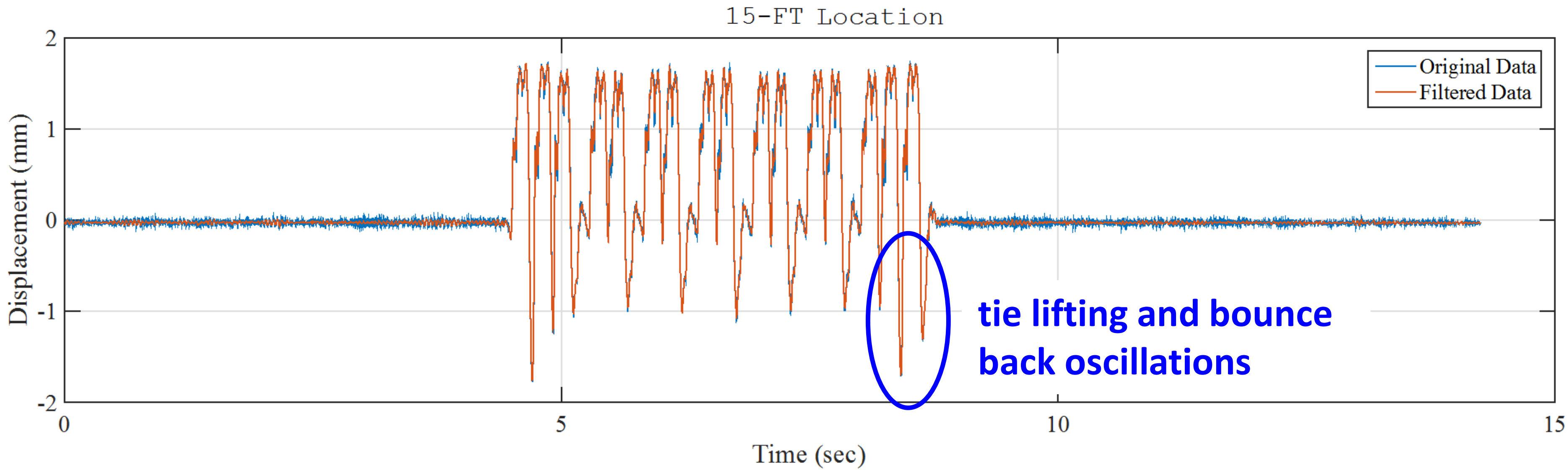
Measured (a) Wheel Loads; (b) Ballast Layer Displacements; and (c) Ballast Accelerations

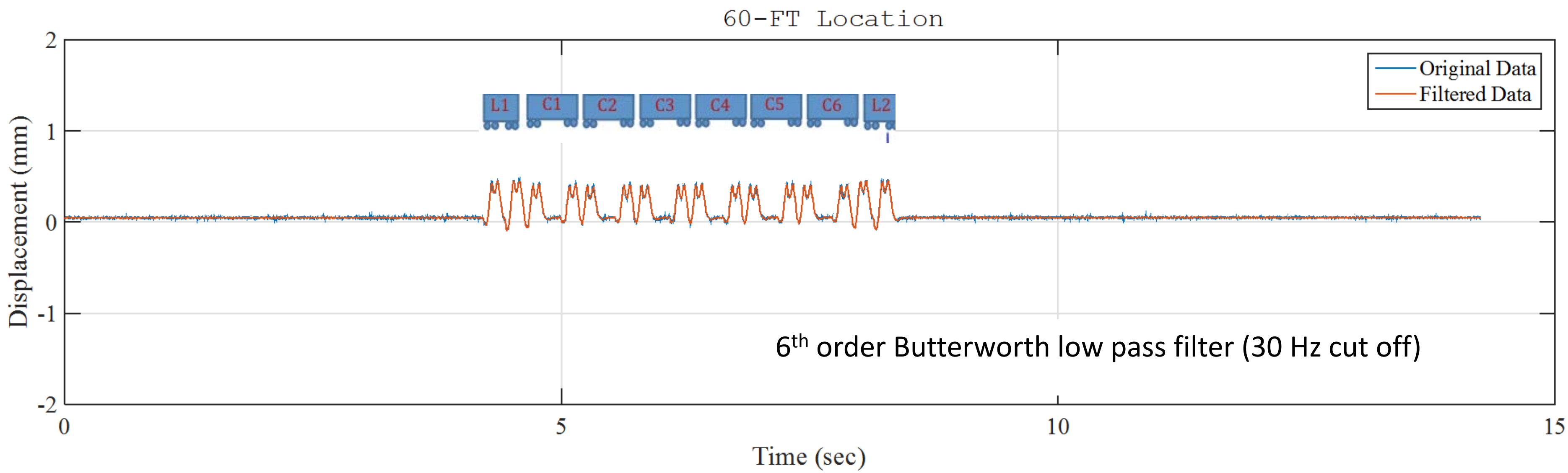


Acela Express Wheel Loads

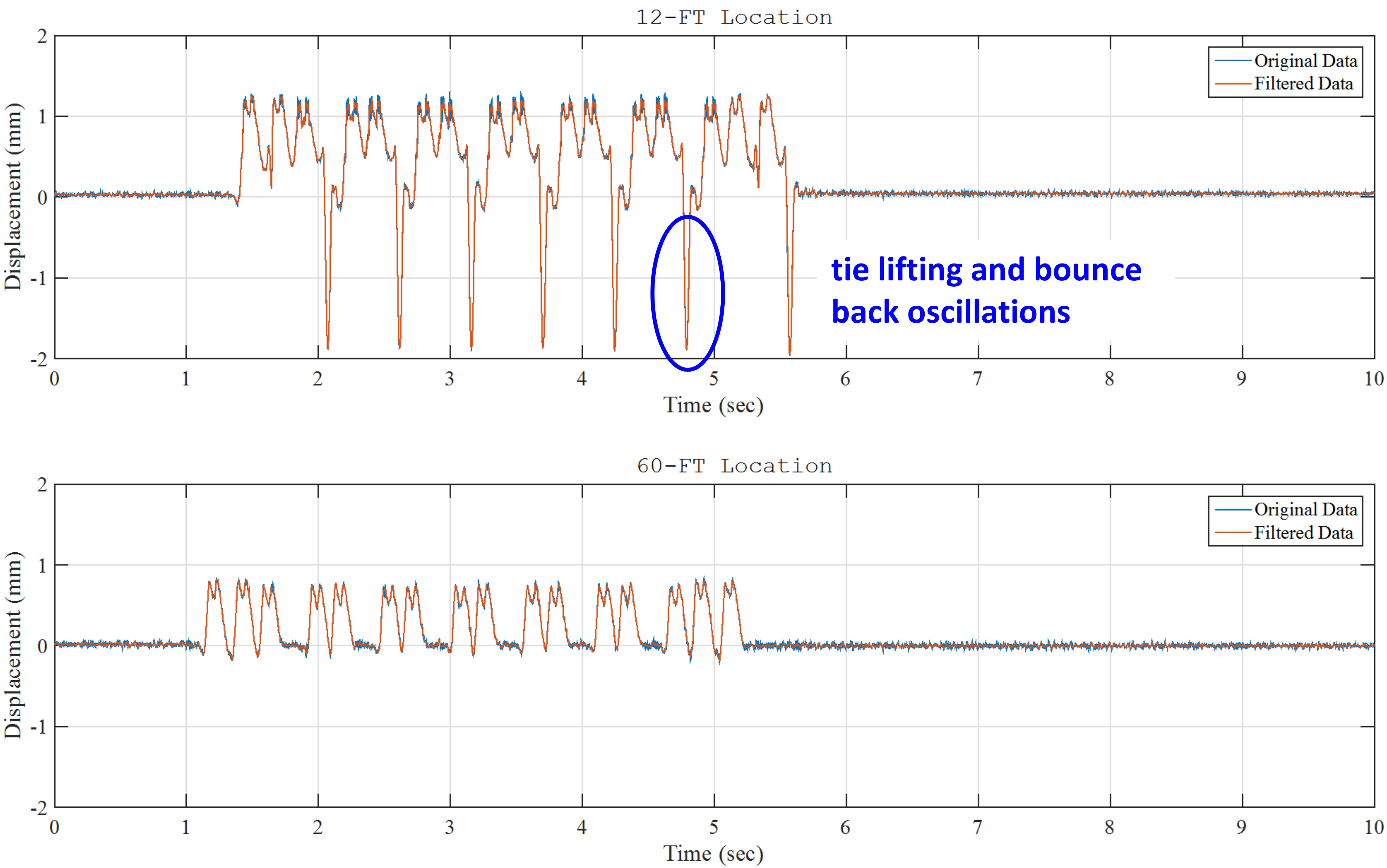


August 2012 – LVDT 1 (**Layer 1 – Ballast**) Data
Upland St. Track 3 – ACELA Train

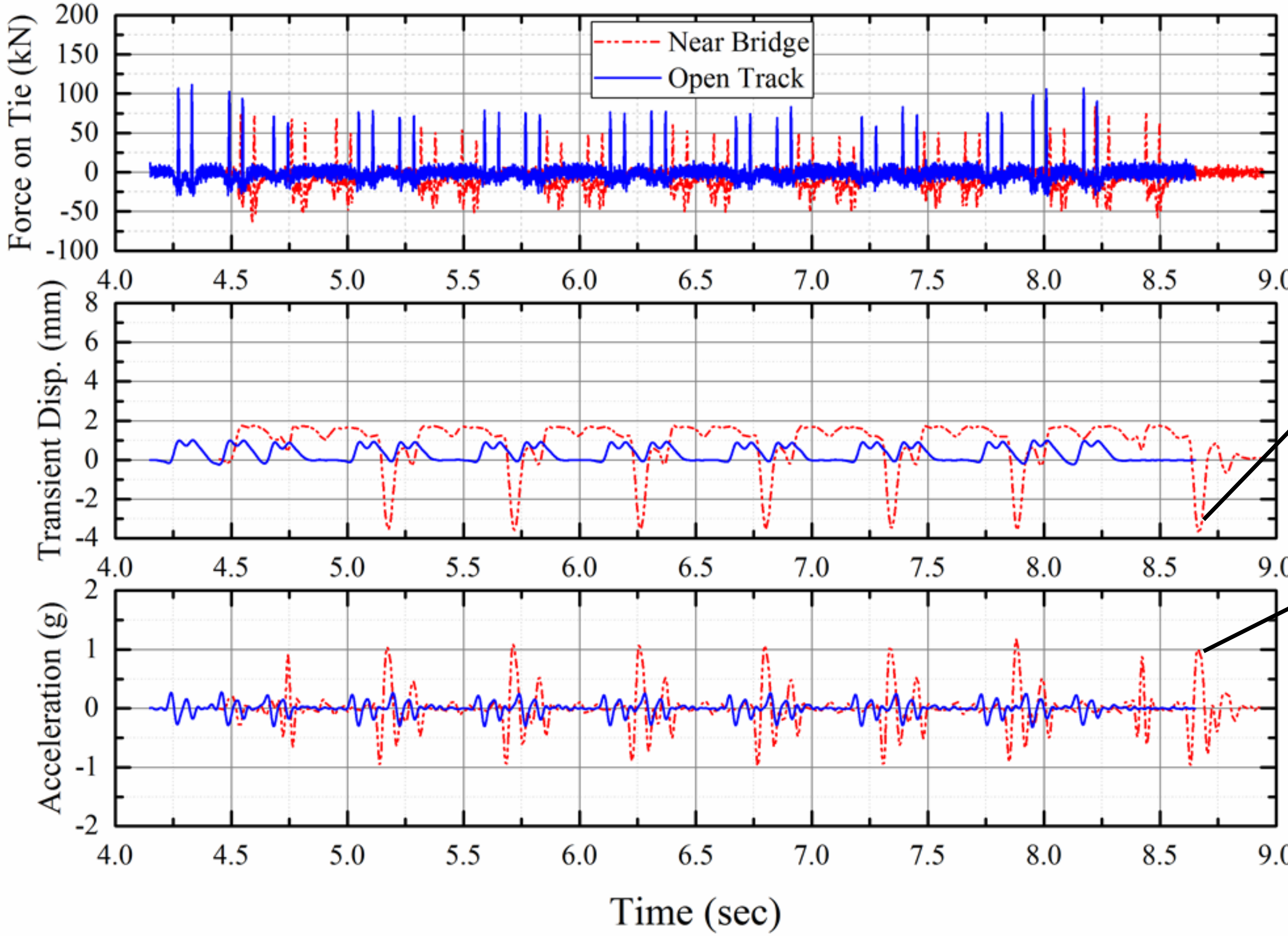




November 2012 – LVDT 1 (**Layer 1 – Ballast**) Data
Madison St. Track 2 – ACELA Train



June 2013 – LVDT 1 (**Layer 1 – Ballast**) Data
Madison St. Track 2 – ACELA Train



Negative displacements on near bridge locations due to tie lifting

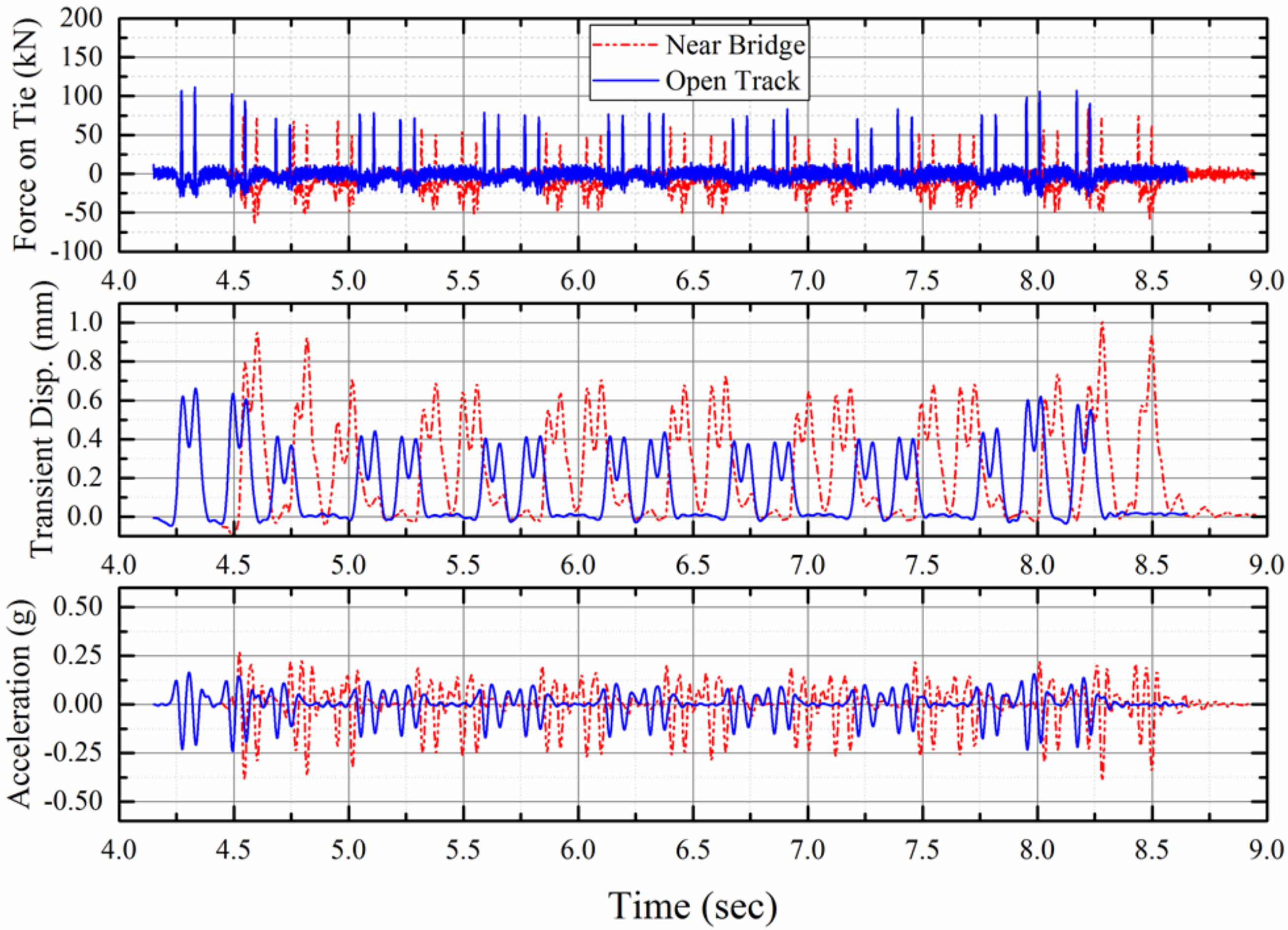
Acceleration peaks correspond to tie lifting

Sixth Order Finite Difference Equation

u_{i-3} Δt u_{i-2} Δt u_{i-1} Δt u_i Δt u_{i+1} Δt u_{i+2} Δt u_{i+3}

$$\ddot{u}_i = \frac{2u_{i-3} - 27u_{i-2} + 270u_{i-1} - 490u_i + 270u_{i+1} - 27u_{i+2} + 2u_{i+3}}{180\Delta t^2}$$

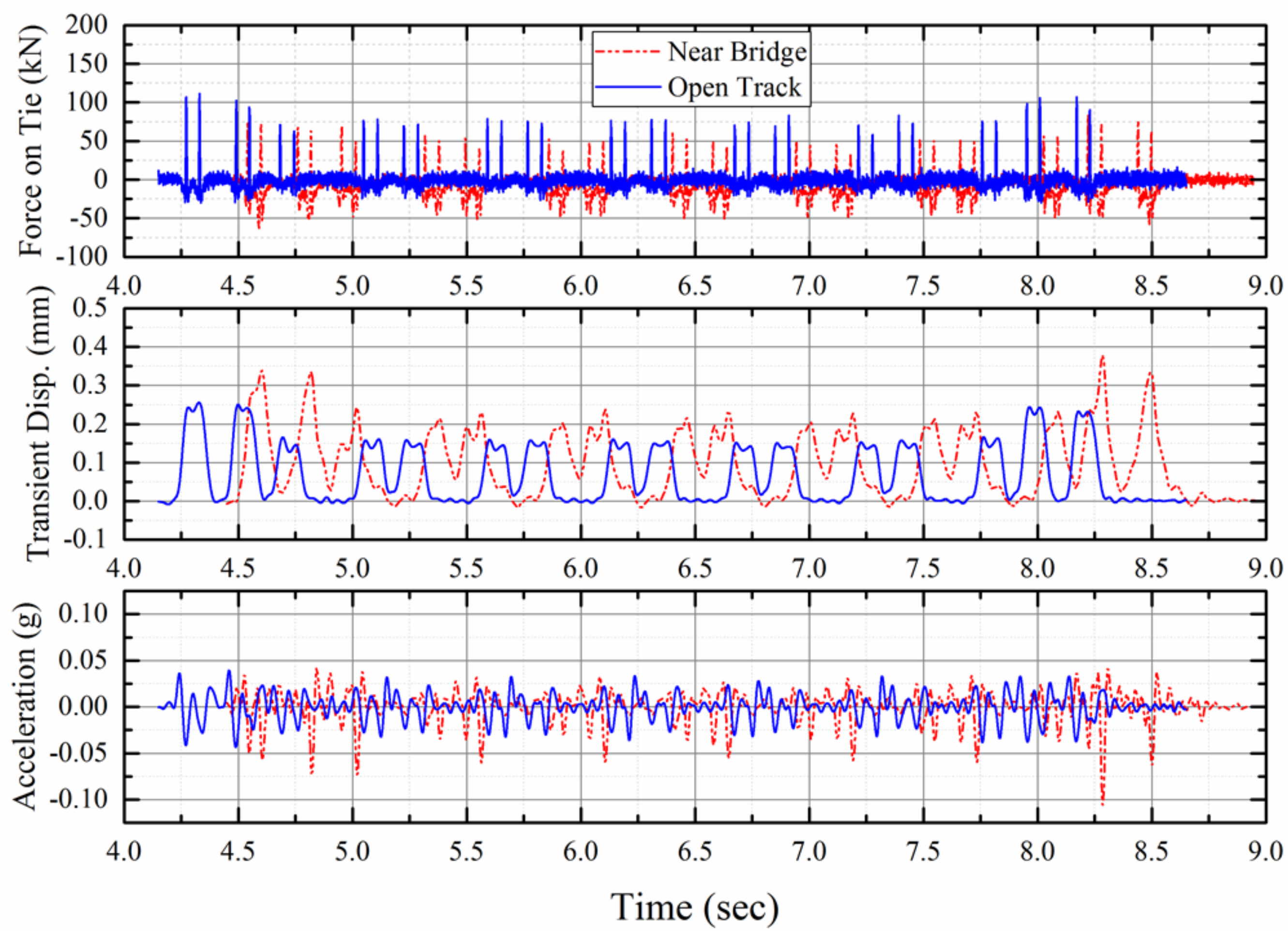
June 2013 – **Layers 2+3+4** Data
Madison St. Track 2 – ACELA Train



Smaller transient displacements at bridge approach

No negative displacements

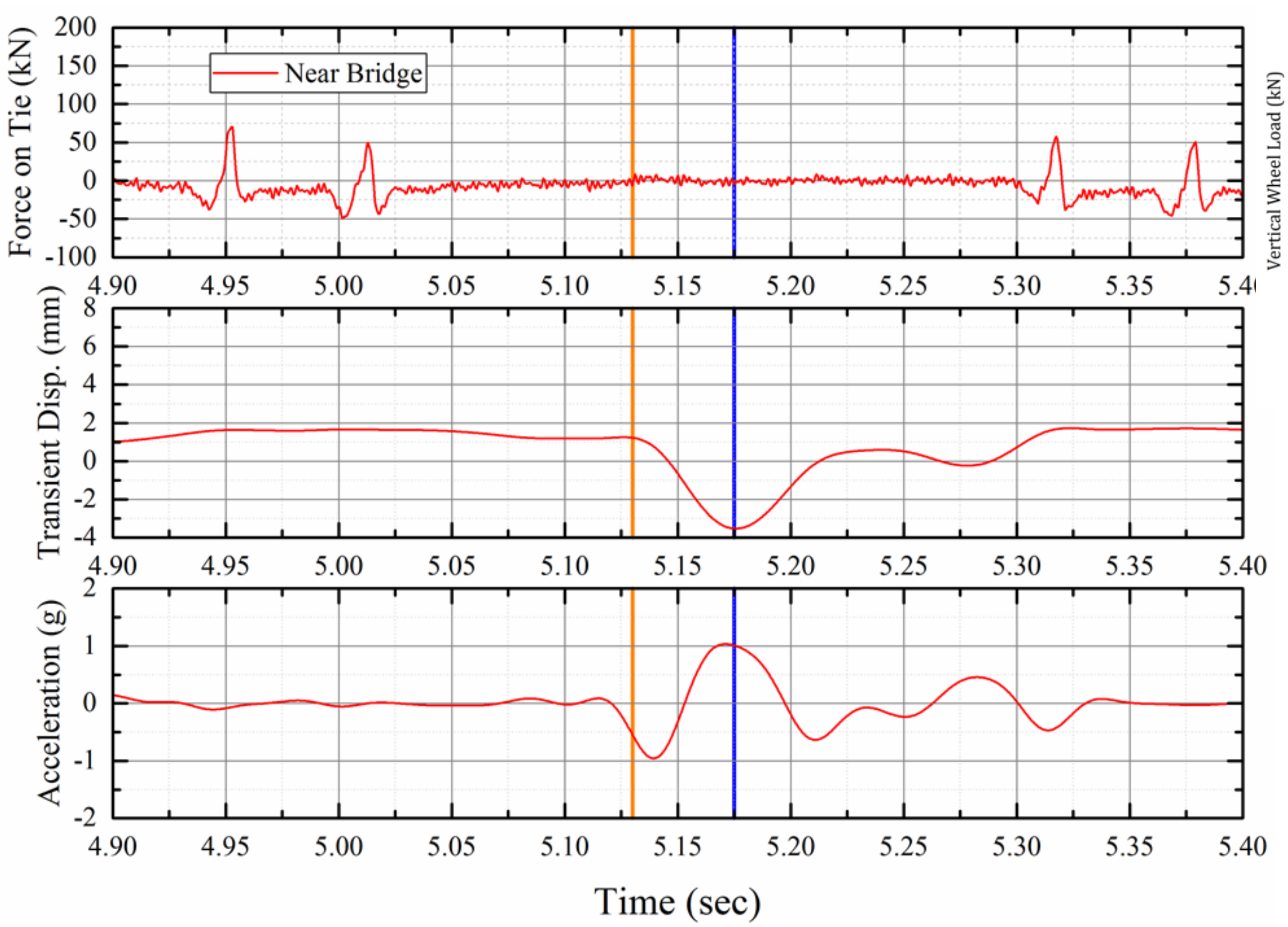
June 2013 – **Layer 5** Data
Madison St. Track 2 – ACELA Train

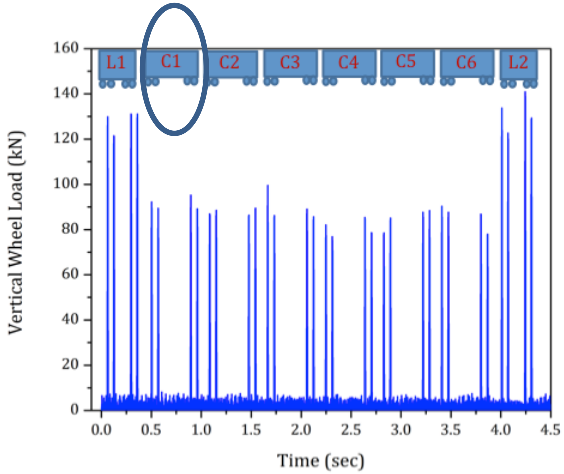


Similar to the intermediate layers, smaller transient displacements at bridge approach

No negative displacements

June 2013 – Madison St. Track 2
Zoom in to Second Car Passage **(Tie Lifting)**

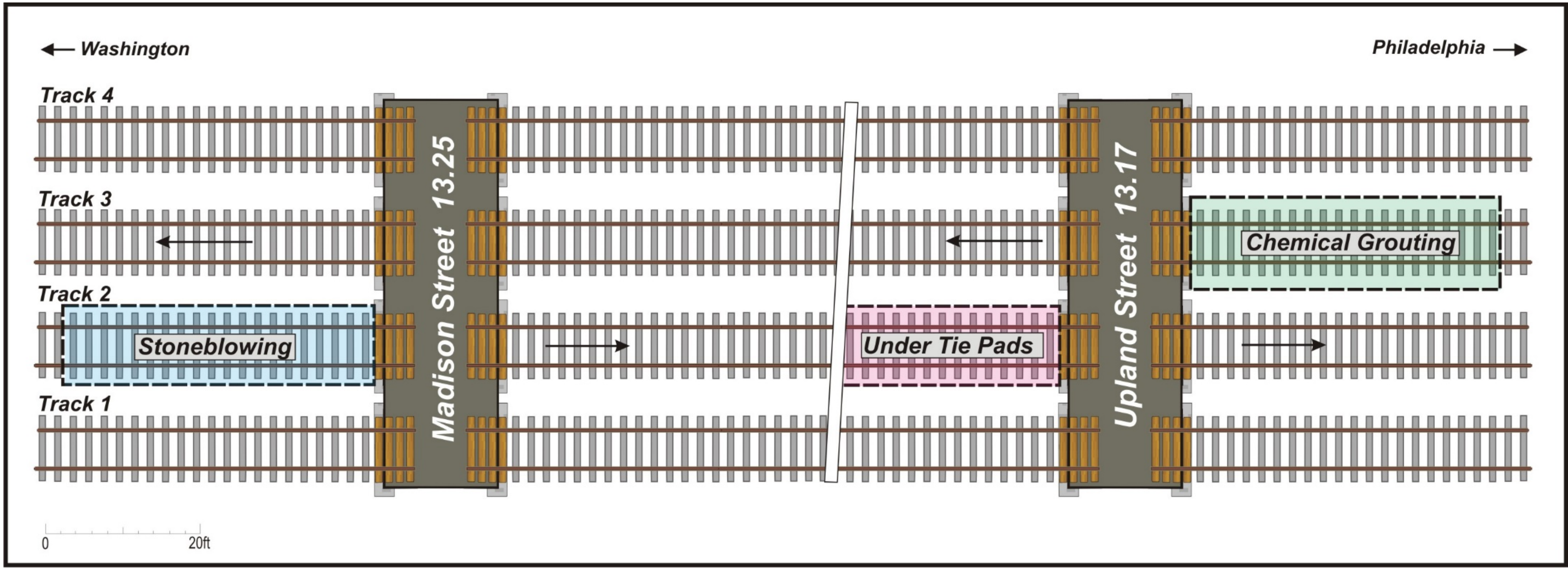




Zoom in to first car after locomotive time domain to investigate tie lifting phenomenon.

Train travels around 5.8 meters from the moment wheel hits the instrumented tie to time tie starts lifting.

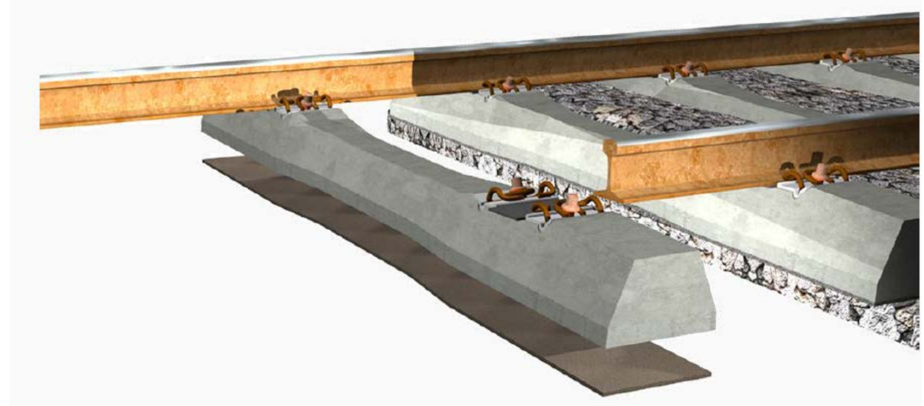
Selection and Implementation of Remedial Measures

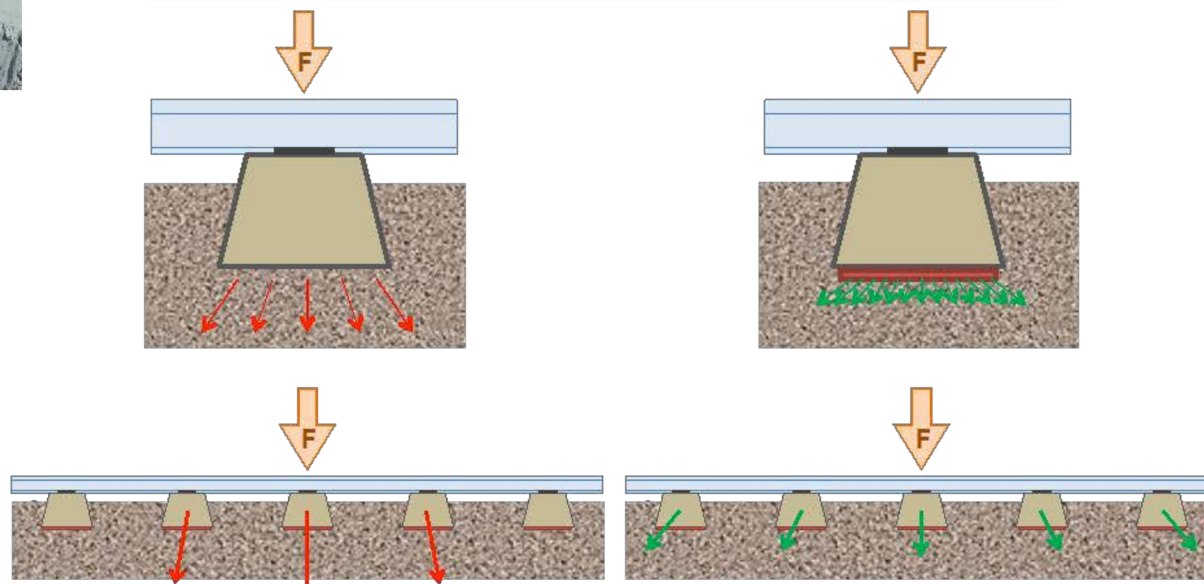


Under-Tie Pad (UTP) Installation Effort

- UTP Manufacturer: Pandrol-CDM Track/Novitec
- A block of 30 ties were installed on the Upland Street bridge south approach (Track 2)
  - Approach represents train entering the bridge from the embankment
- Work was performed with a pre-approved 36-hour outage
  - Start: 10:00 PM on Friday, 29 August 2014
  - End: 12:00 AM on Saturday, 30 August 2014
- A pre-constructed concrete tie track panel was placed in the track

UTP Installation Effort



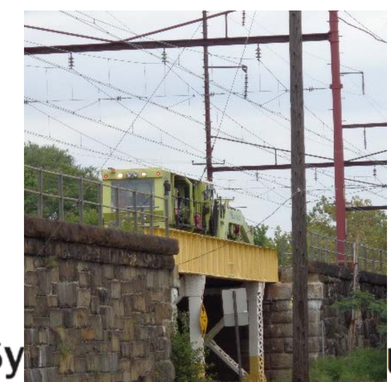


Without Under-Tie Pads **With Under-Tie Pads**

Under Tie Pad Track Panel Installation: Aug. 28-29, 2014

30 Tie Track Panel with Installed UTPs under New Ties

Track 2 – Upland St. Bridge



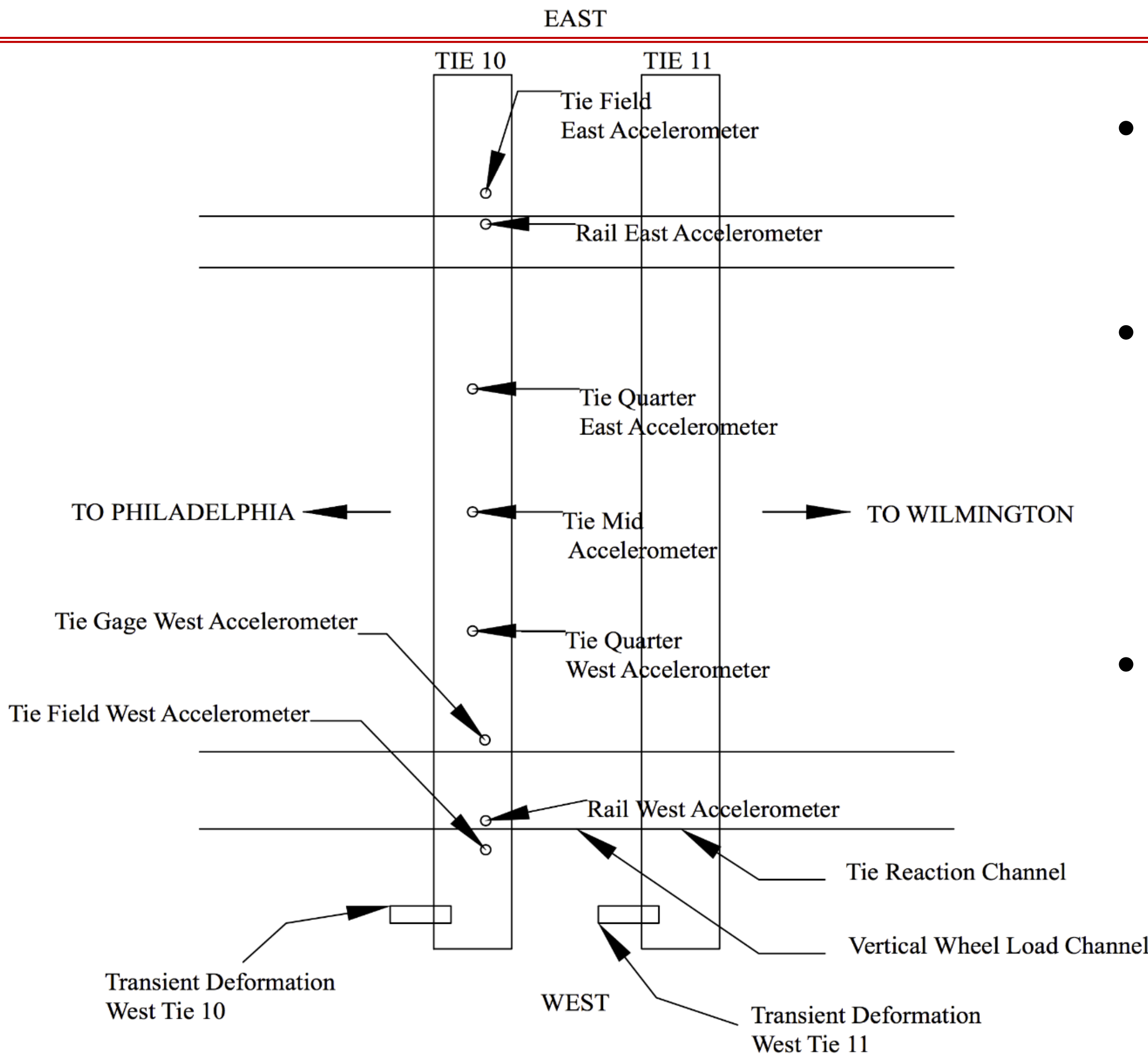
Effect UTP Installation – Inferences based on Transient Response Data

- Note that the south approach (Track 2) of the Upland Street bridge was not instrumented with MDDs and strain gauges during the original instrumentation effort (July 2012)

- A separate instrumentation effort was carried out in August 2015 to measure the transient response of the track panel under train loading (Courtesy: Michael Tomas, Amtrak)

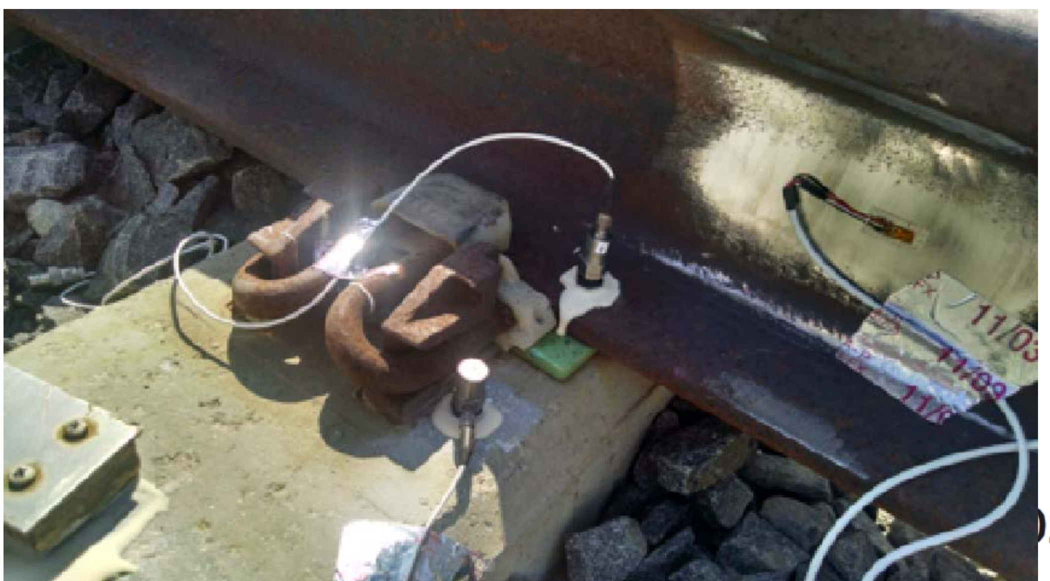
- Instrumentation effort was carried out 11 months after the UTP installation – Hence, the data can be used as an indicator of long-term performance of the UTPs as a remedial measure

Instrumentation Effort - Details



- Instrumentation mounted on the 10th and the 11th tie from the abutment
- Accelerations and displacement time histories of ties were recorded under the passage of Acela Express trains
- Accelerations were measured with accelerometers; Displacements were measured with a calibrated cantilevered metal strip mounted with strain gauges

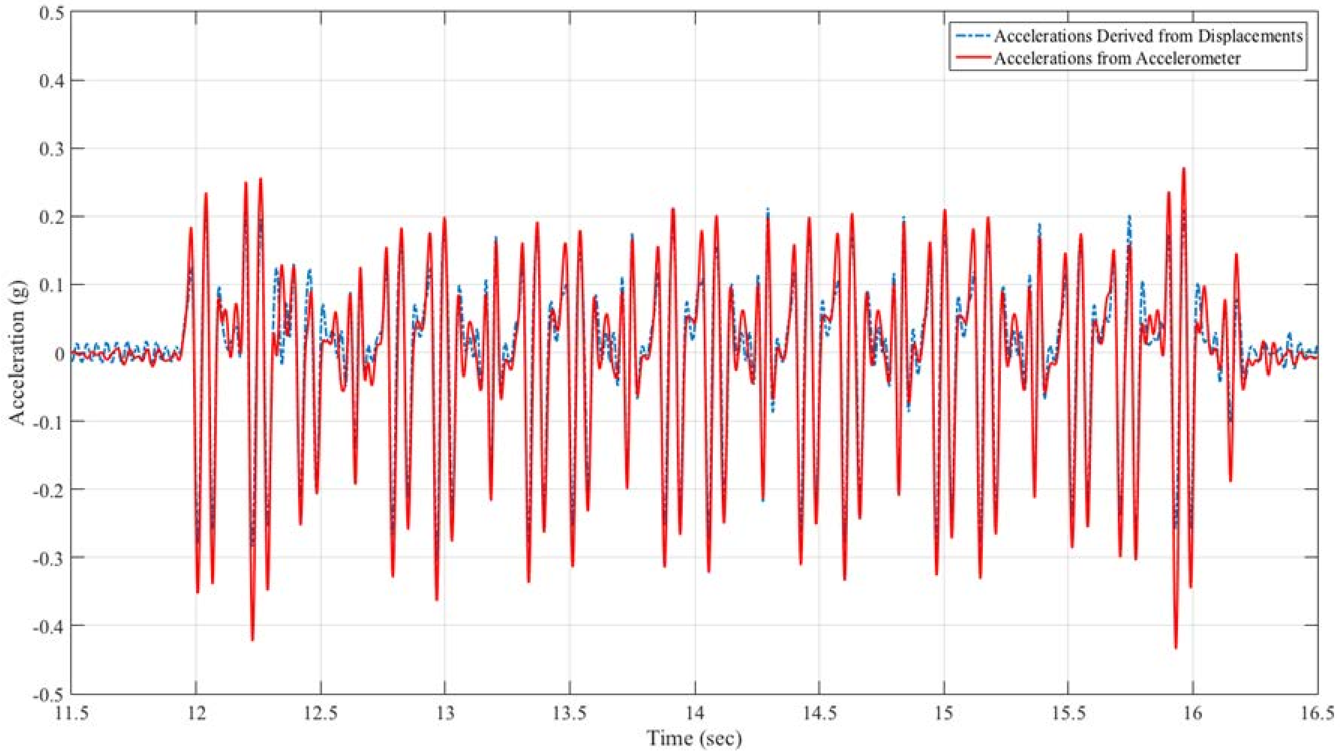
Instrumentation Effort - Details



- Note that unlike the MDDs, this set-up for displacement measurement can measure transient displacements of the ballast layer only!

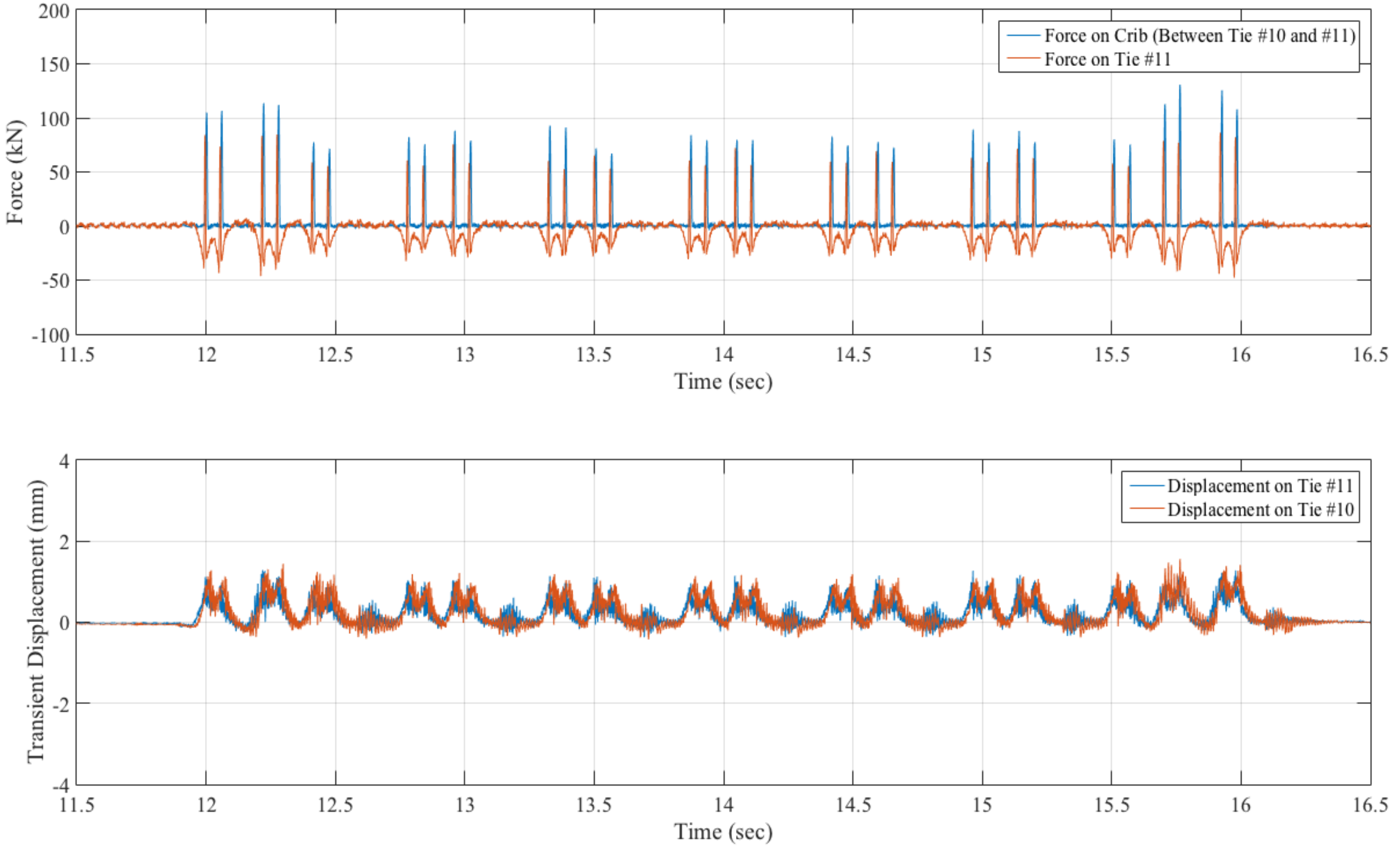
- This is acceptable as analysis of the MDD data has shown the ballast layer to be the primary contributor to the total transient (as well as permanent) deformations

Checking the Accuracy of the Displacement and Acceleration Data through Numerical Differentiation



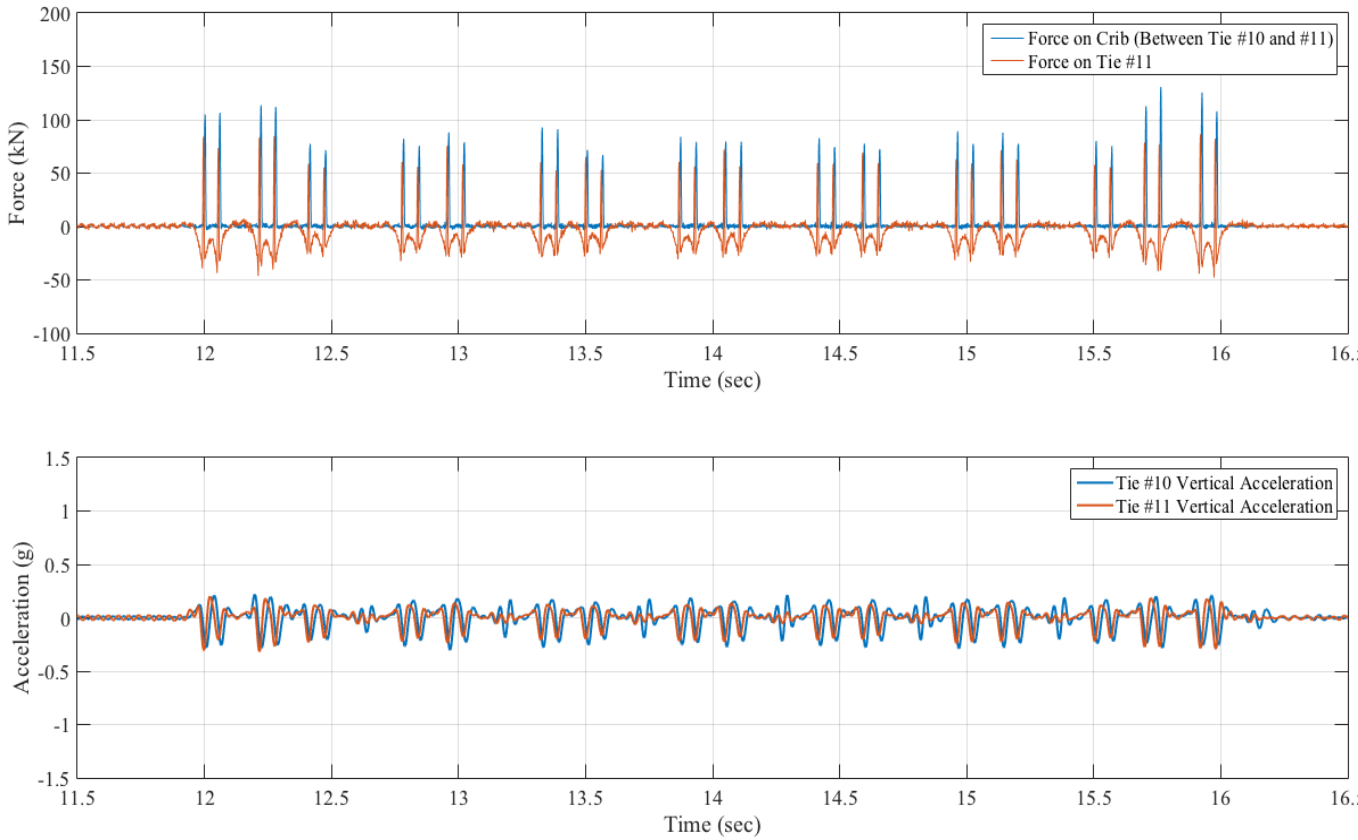
- Close match between tie accelerations obtained from the acceleration as well as displacement time histories establishes the *consistency of the instrumentation effort!*

Effect of UTPs: Force and Displacement Time Histories



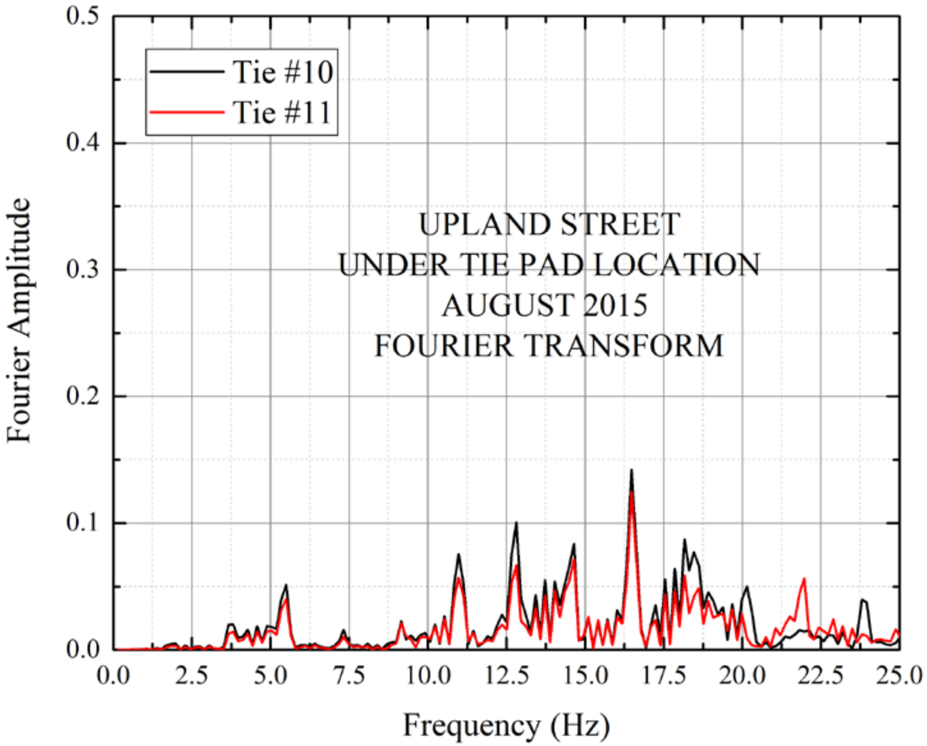
- Peak transient displacements ~ 1.5 mm
- Indicates adequate performance 11 months after installation!

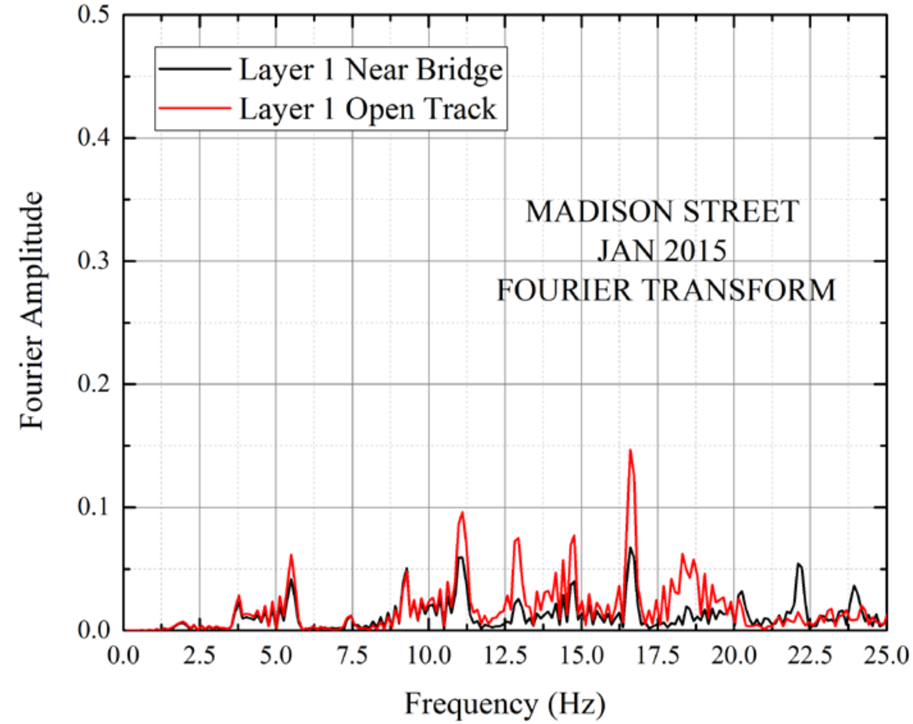
Effect of UTPs: Force and Acceleration Time Histories

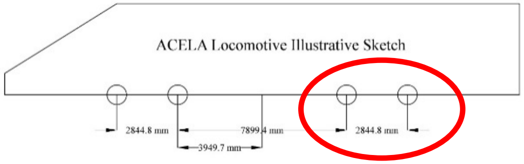


- Peak acceleration levels of < 0.25g
- Clearly indicates adequate support conditions underneath the ties

Effect of UTPs: Frequency Domain Analysis of Tie Acceleration







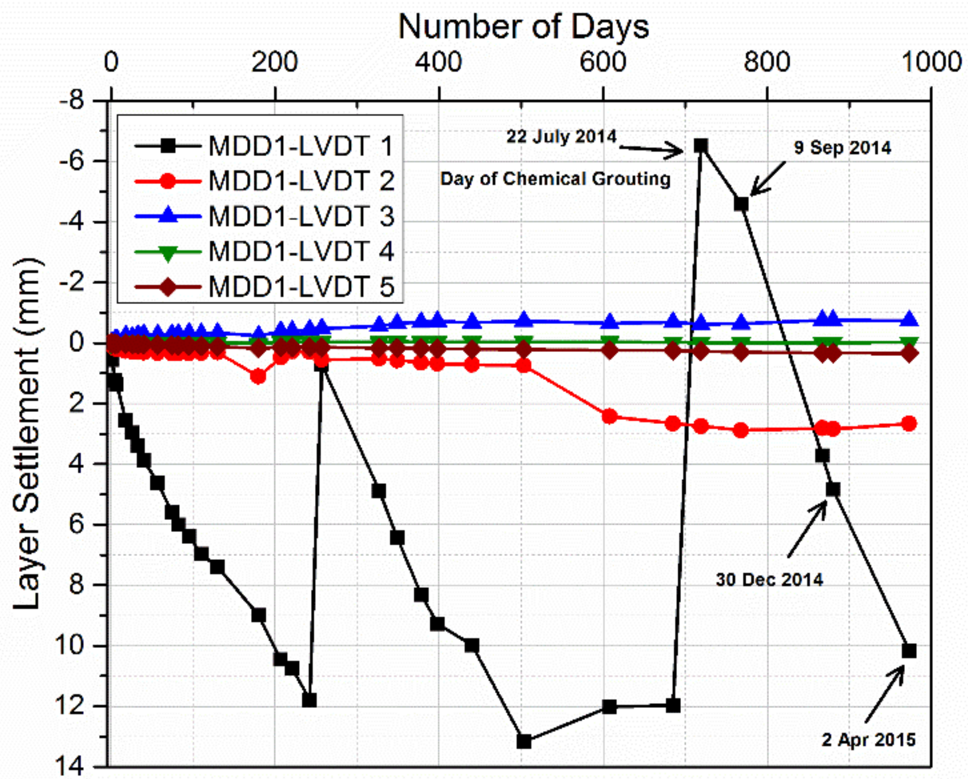
- Dominant frequencies observed at **11** Hz, **12.5** Hz, & **16.5** Hz
- Interestingly, these frequency peaks are identical to those observed for the Madison Street bridge approach after stone blowing (indicative of improved support)

Chemical Grouting (Polyurethane Injection)

- Chemical grouting at Upland Street bridge approach was carried out on July 17, 2014
- Grout Properties
  - Density: 240 kg/m^3 (15 pcf)
  - Compressive Strength:
    - 5516 kPa (800 psi) @ 0% strain
    - 1380 kPa (2000 psi) @ 10% Strain
  - Tensile Strength: 1,034 kPa (150 psi)

Photographs Showing Grout Injection and Expansion through Injection Ports

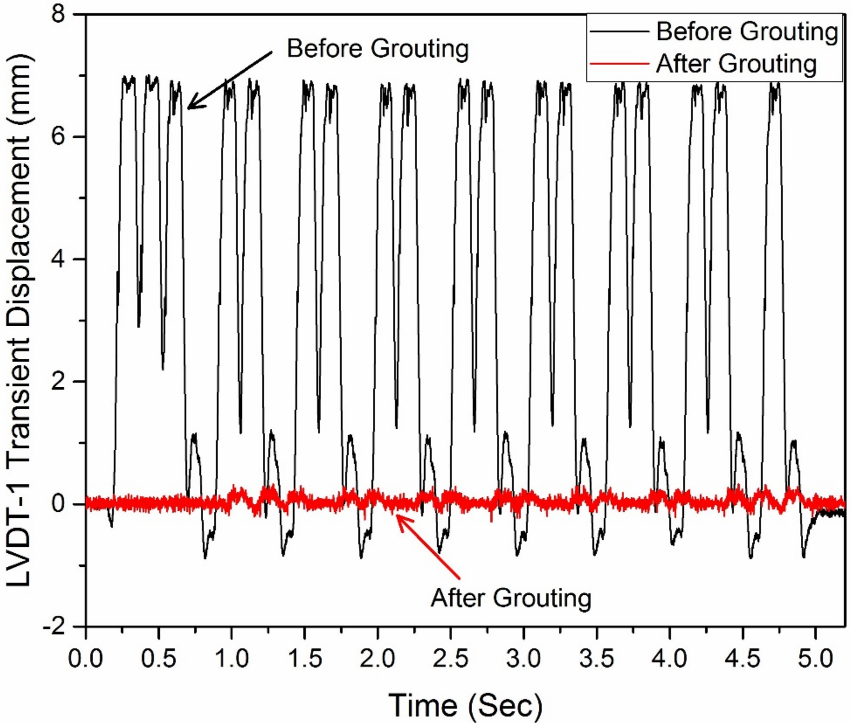
Layer Settlement Trends – Upland Street Bridge Approach



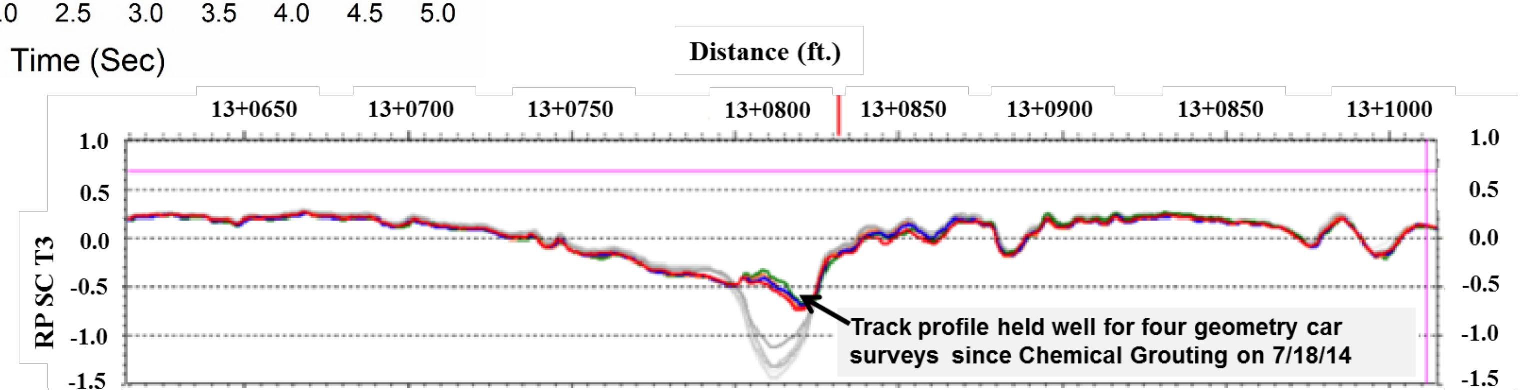
- Ballast layer is clearly the most significant contributor to track settlement
- Slope of the settlement line reduced initially after the grout application
  - Between 22 July 2014 and 9 September 2014
- However, the slope increased significantly leading to a total layer settlement value of more than 10 mm

The effect of chemical grouting as a remedial measure to mitigate the problem of differential movement was "short-lived"

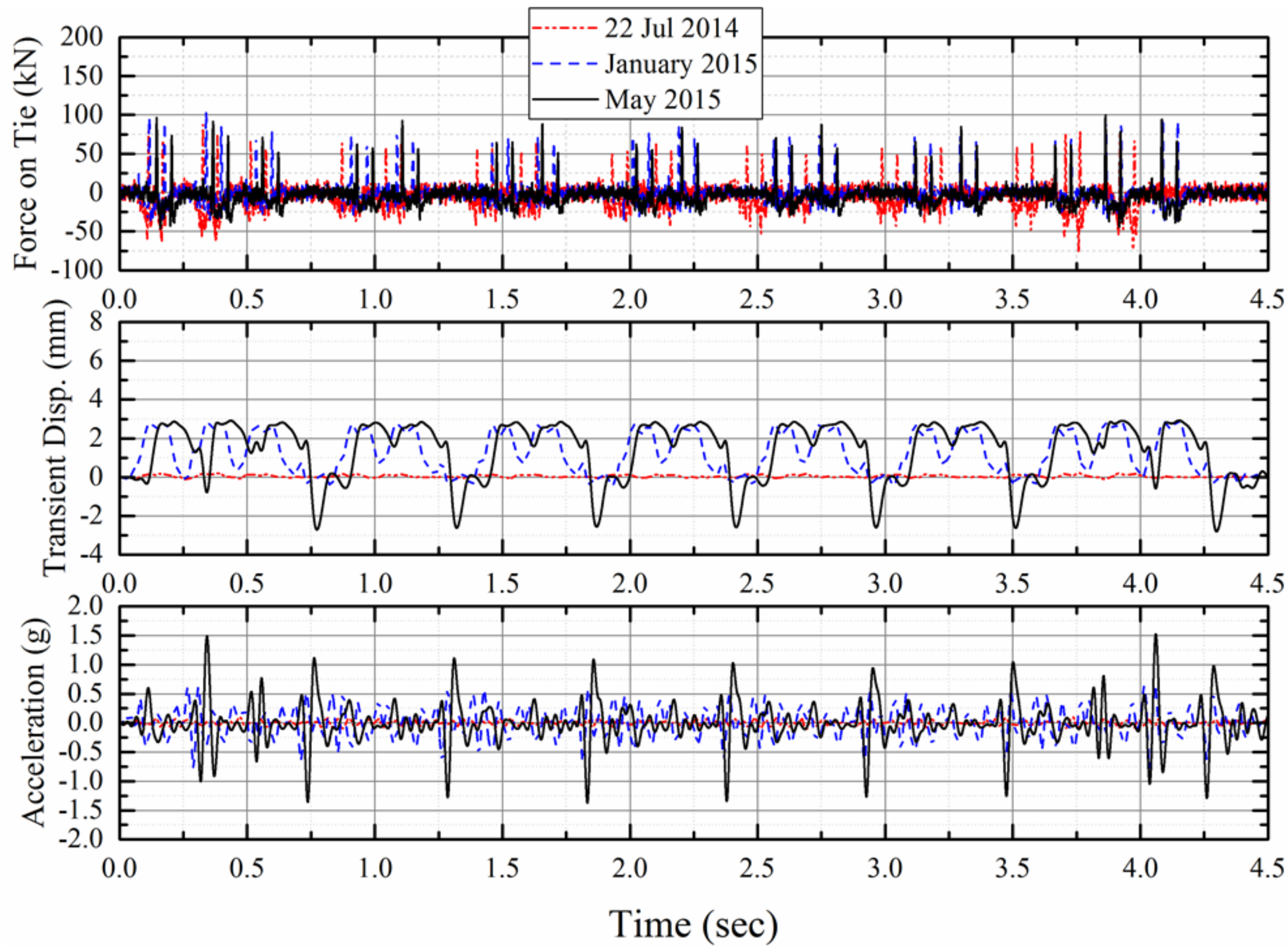
Effect of Chemical Grouting on Transient Response and Track Geometry Data



- *Significantly reduced transient deformations for the top layer were recorded shortly after grouting*
- *Peak transient response reduced from 7 mm (before grouting) to 0.25 mm (after grouting)*
- *The space curve profiles indicated that the corrected profile was maintained for at least two months*

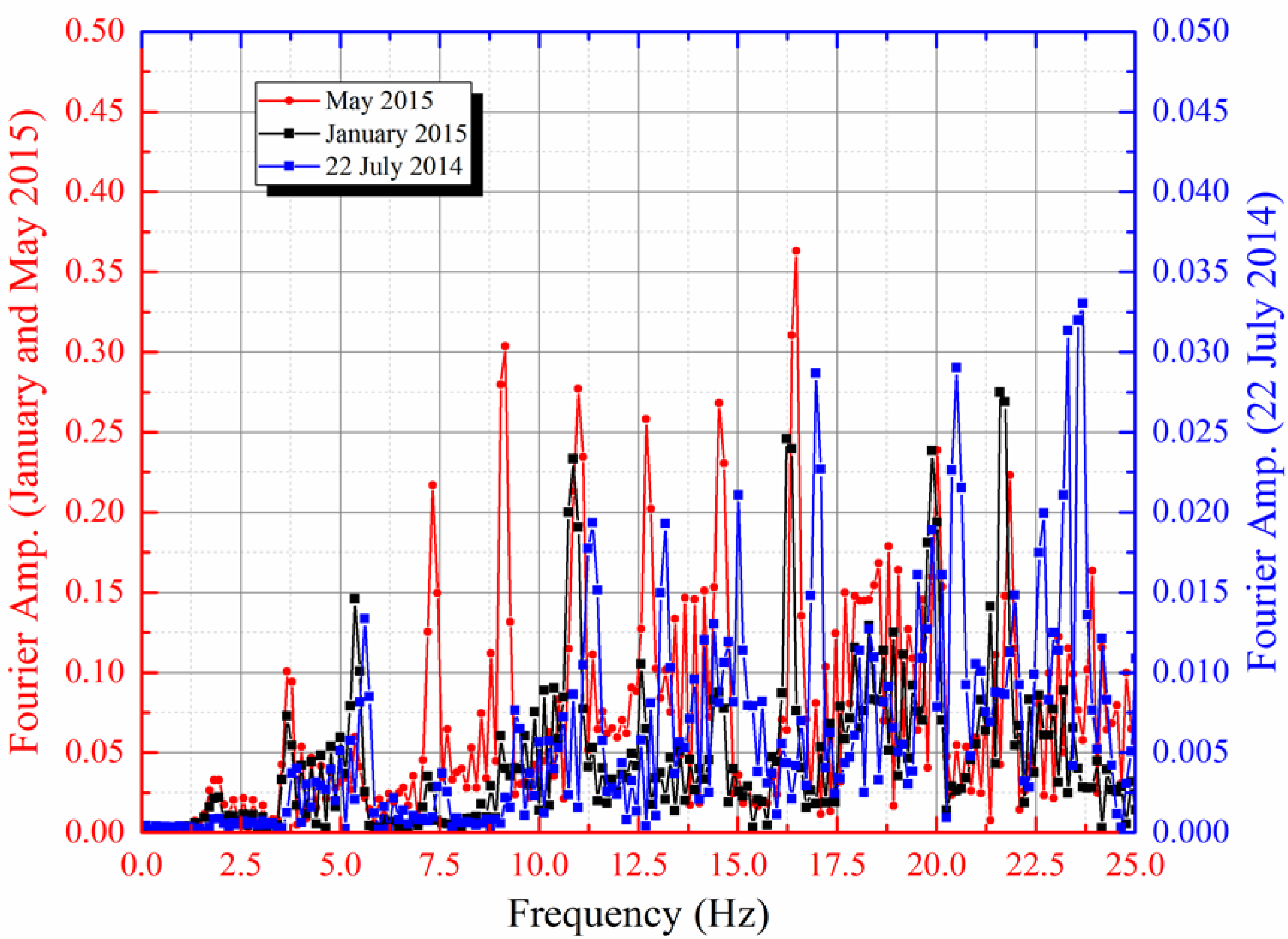


Upland Street
Layer 1 Time Domain After Polyurethane

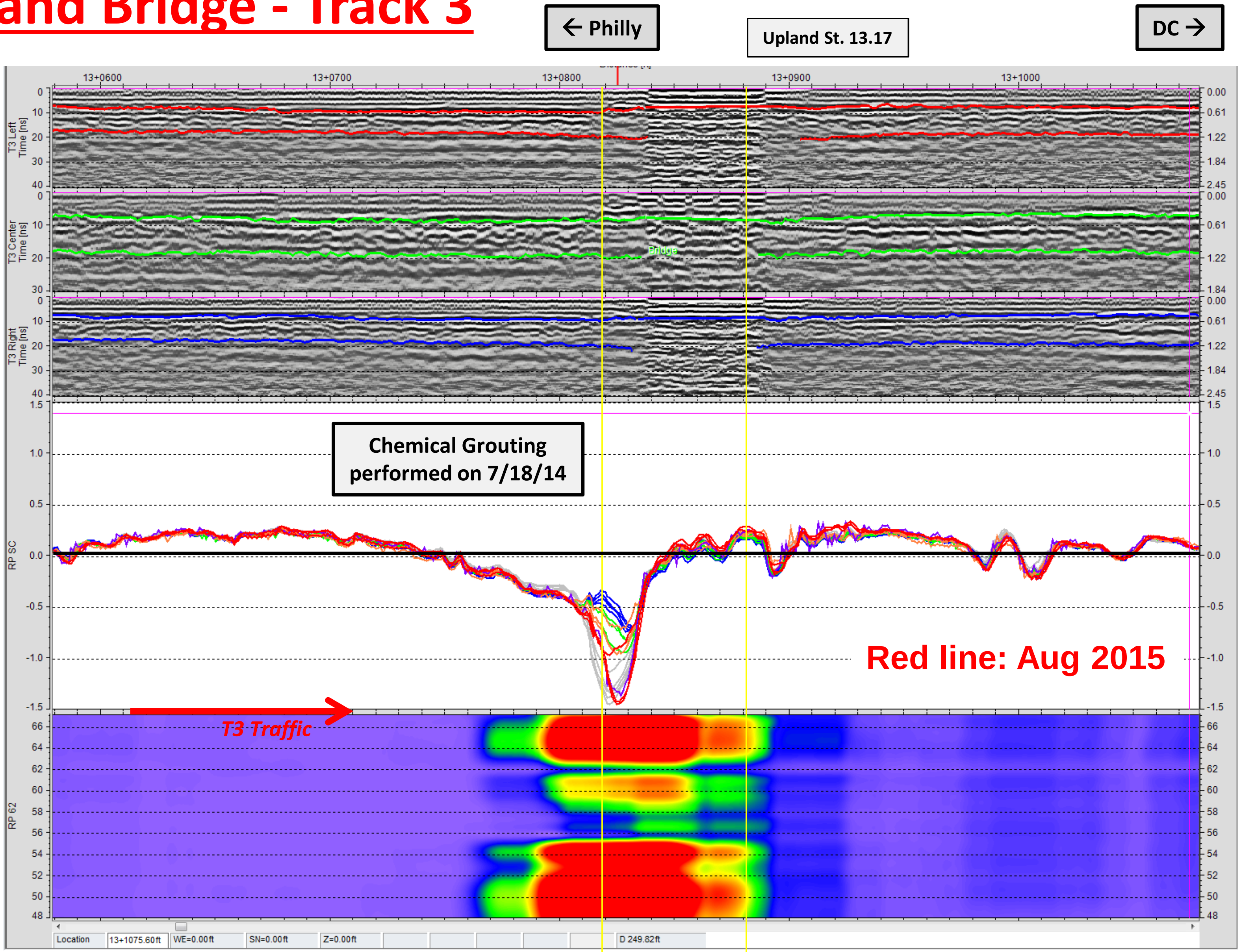


Negative displacements were observed in May 2015's measurement where peak accelerations were observed.

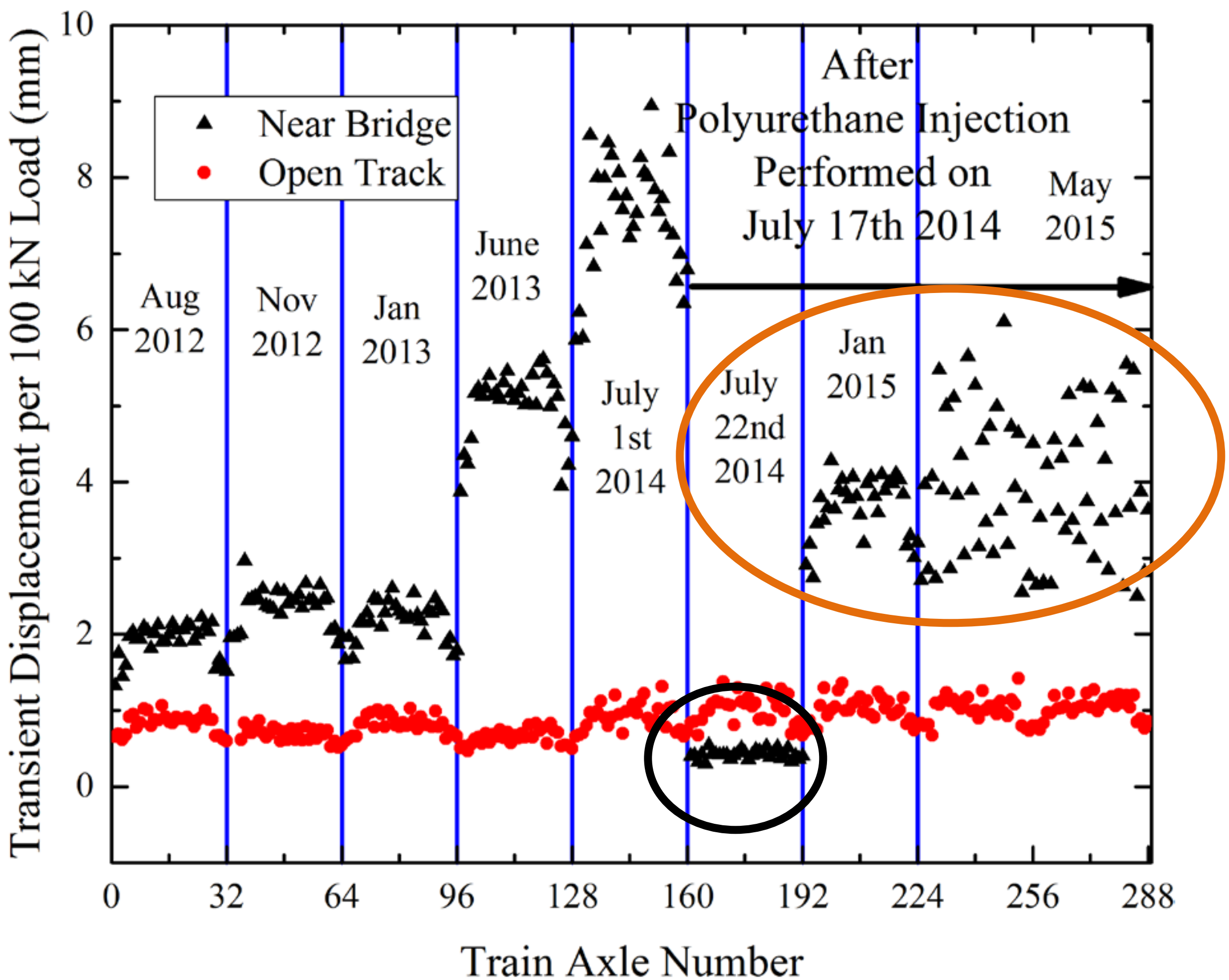
Upland Street
Layer 1 Frequency Domain After Polyurethane Injection



Upland Bridge - Track 3



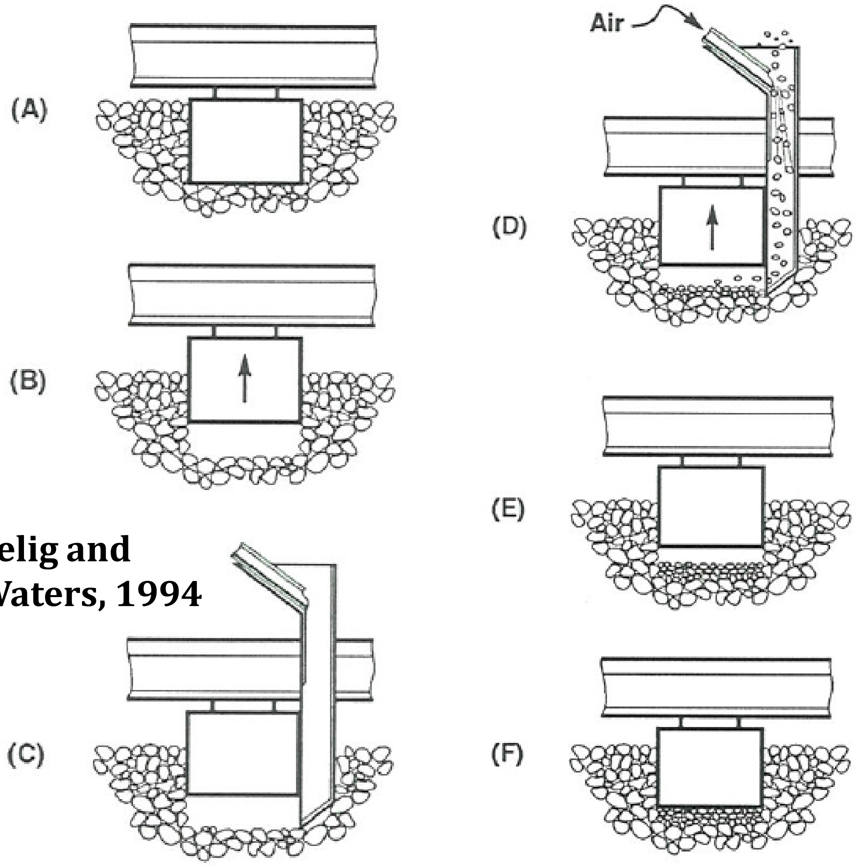
Peak Transient Displacement of the Tie (Normalized to a Load Level of 100 kN)



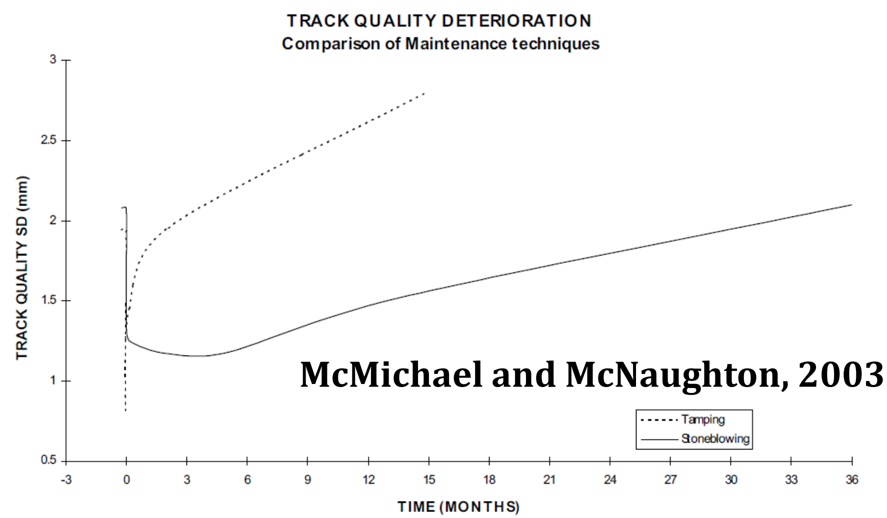
Notice the drastic improvement immediately after the grout application

Benefit of the grout application diminishes with time

Stone Blowing



Selig and Waters, 1994



McMichael and McNaughton, 2003

A	Initial condition
B	Ties raised
C	Stoneblowing tubes driven next to tie
D	Compressed air used to blow stones
E	Stoneblowing tubes withdrawn
F	Ties lowered to rest on freshly inserted stone

Photographs of Different Steps Involved in the Stone Blowing Process

Surveying of Track to
Establish Top-of-Rail Profile

Jacking of Track
to Pre-Determined Level

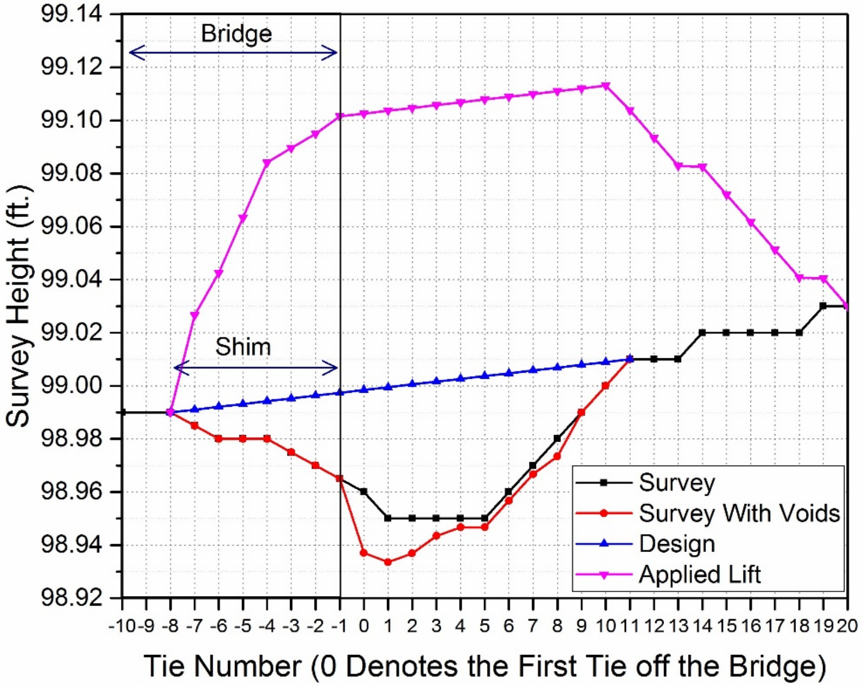
Driving Injector Tube
Adjacent to Tie

Injector Tube Driven Into Ballast Adjacent to Tie

Injection Chute with Air Connection
Mounted on Top of the Injector Tube

Measuring Voids under Ties and Establishing Target Track Elevation

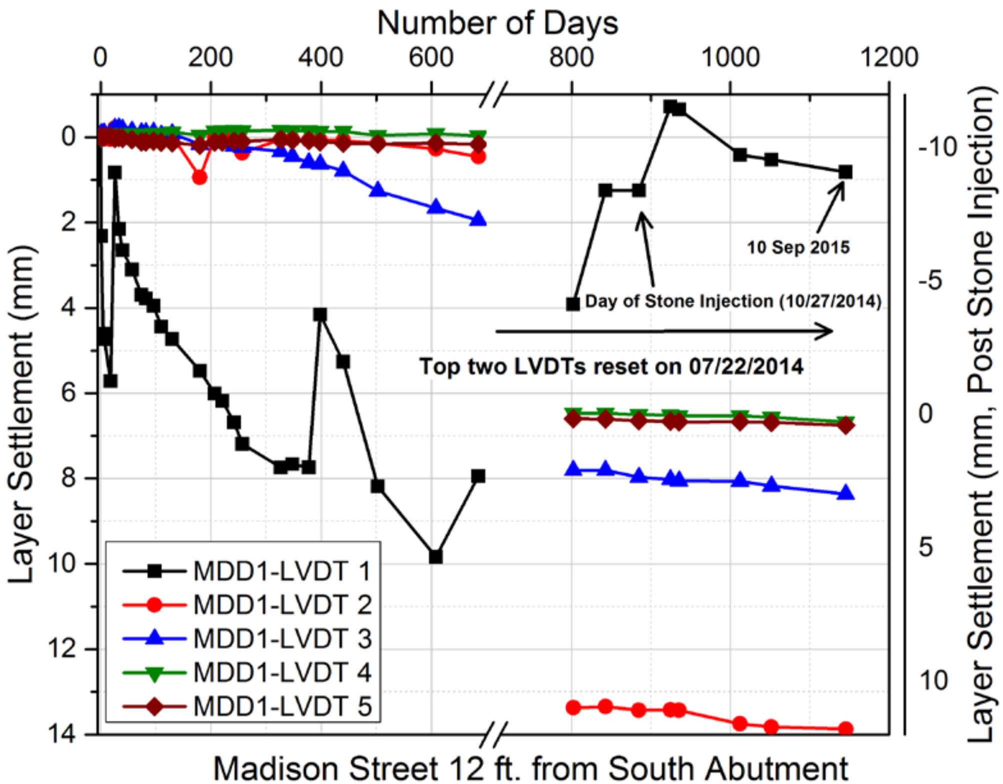
Measurement of Voids Underneath Ties Using Void Meters



Design of Target Track Elevation Using Stone Injection at the Madison Street Bridge Approach

Special Thanks: Kevin Hansen (Harsco), Steve Chrismer (Formerly Amtrak; Now at LTK Engineering)

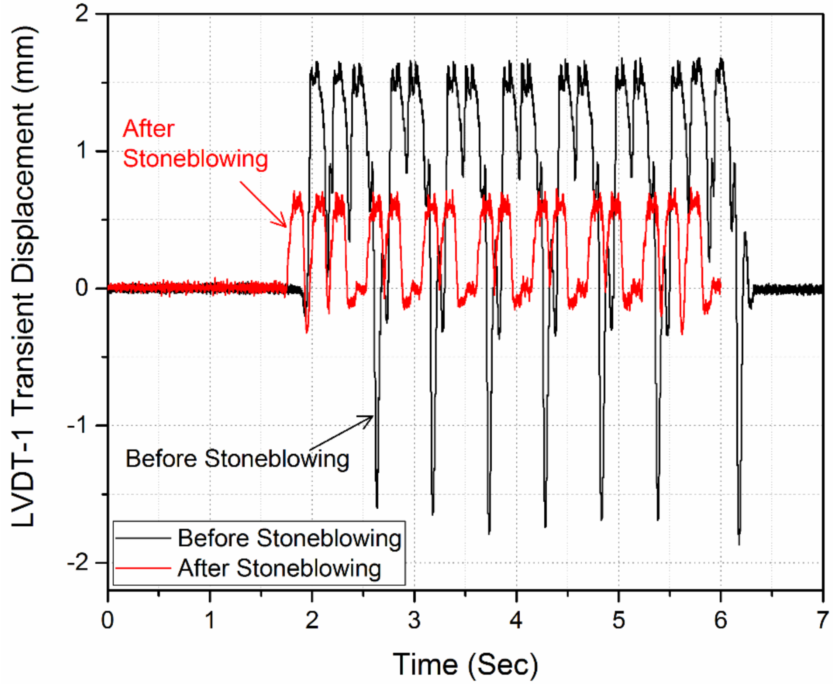
Layer Settlement Trends – Madison St. Bridge Approach



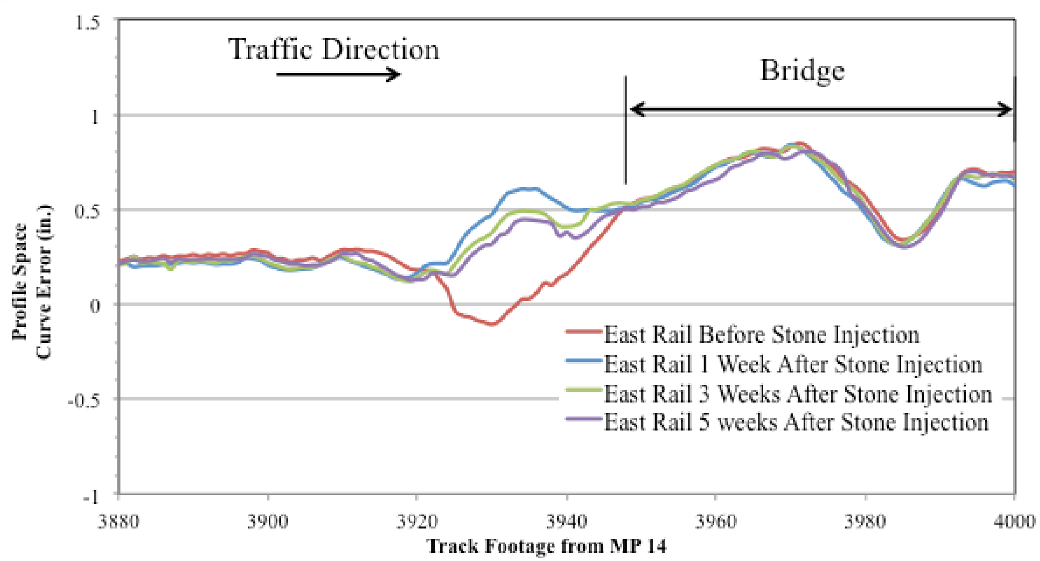
Note that all data after 22 July 2014 have been plotted on the secondary vertical axis

- Ballast layer was observed to be the primary contributor to track settlement
- Crest in the LVDT 1 trace after stone injection indicates an "upward bump" in the track profile intentionally introduced during this process
  - Design Over-lift
- This artificially introduced bump gradually dissipates to attain a stable configuration

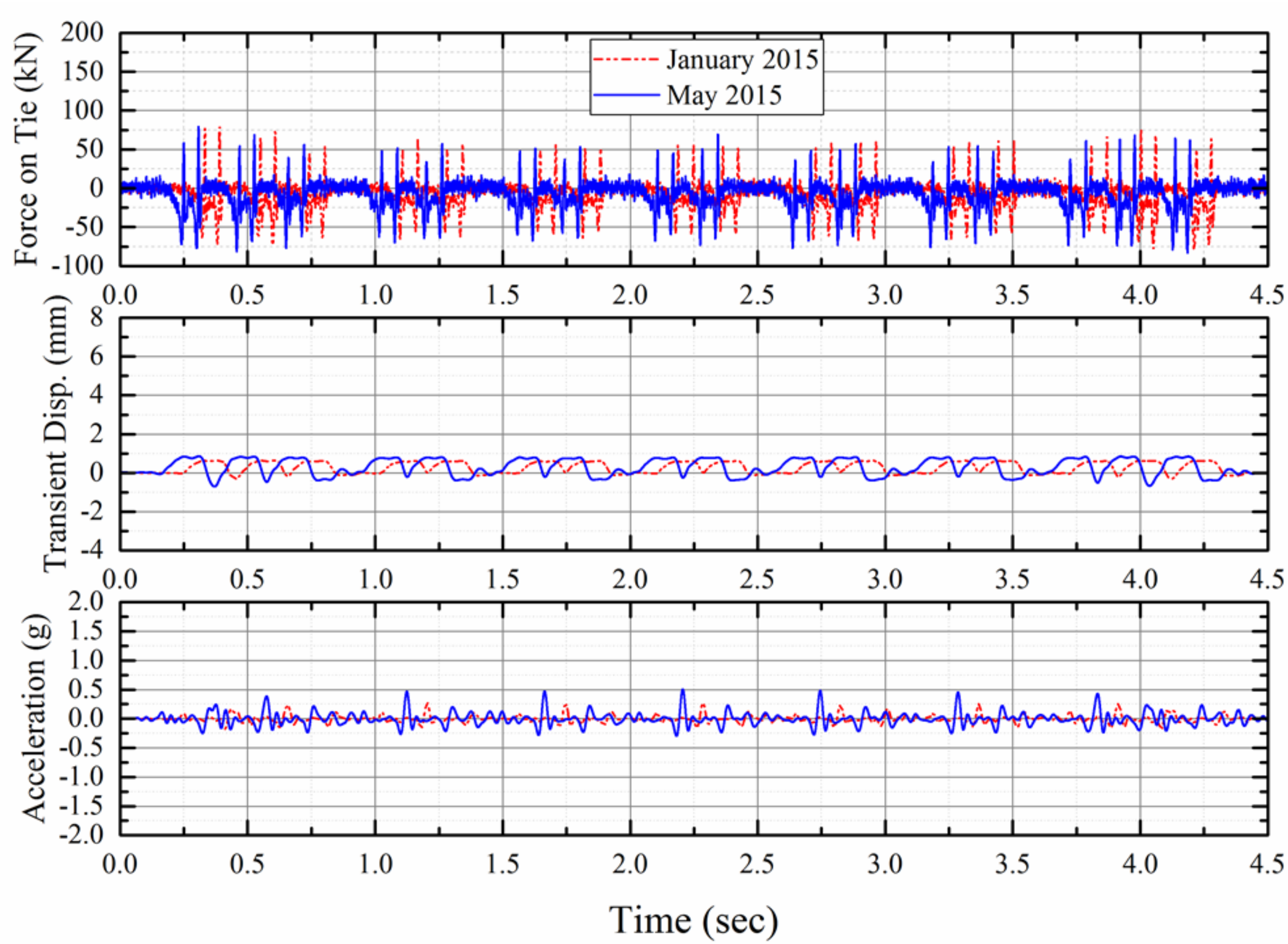
Effect of Stoneblowing on Transient Response and Track Geometry Data



- *Significantly reduced transient deformations for the top layer were recorded shortly after stoneblowing*
- *Track space curve shows elimination of the downward dip through the stone injection*

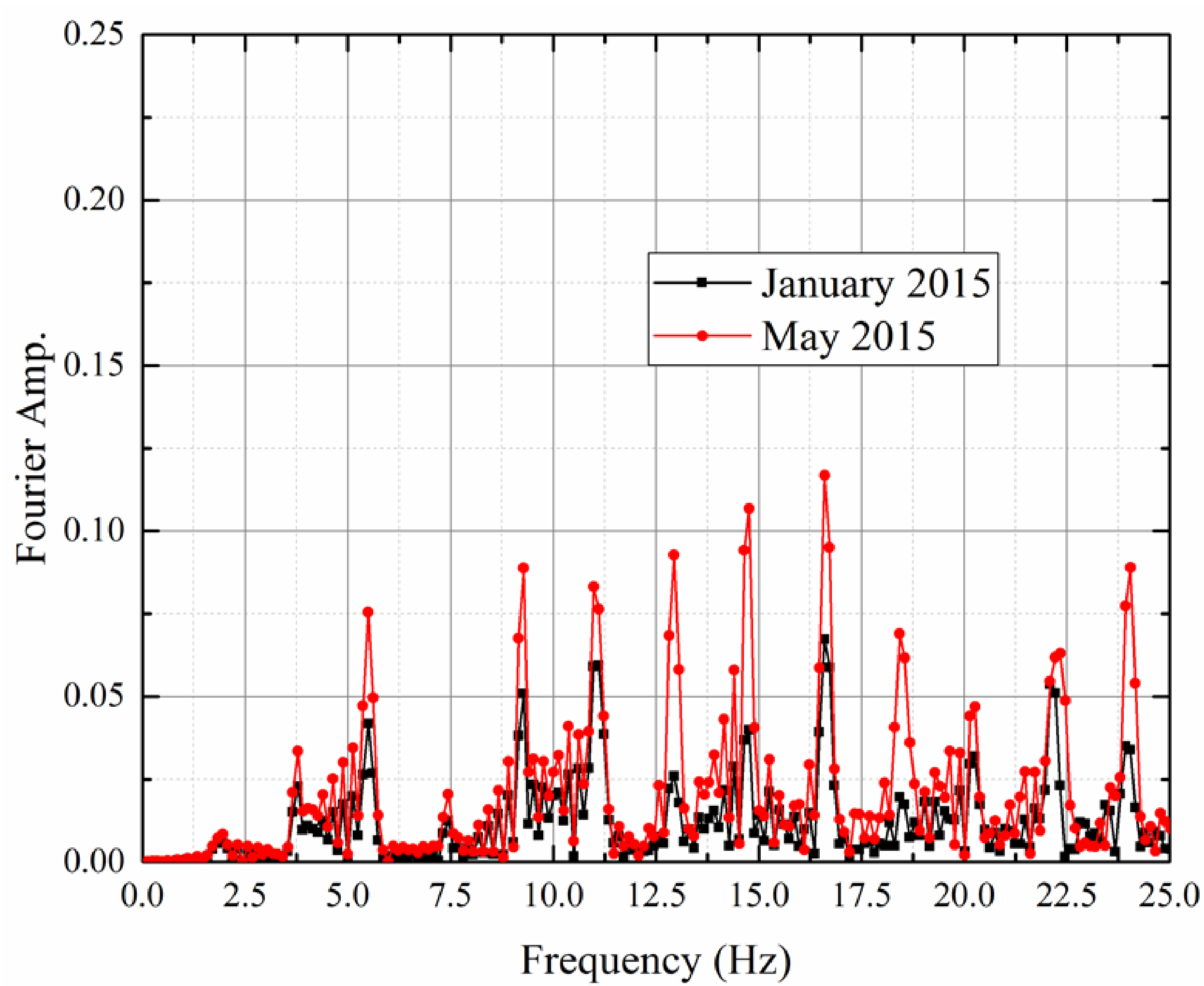


Madison St. Layer 1 Time Domain after Stone Blowing



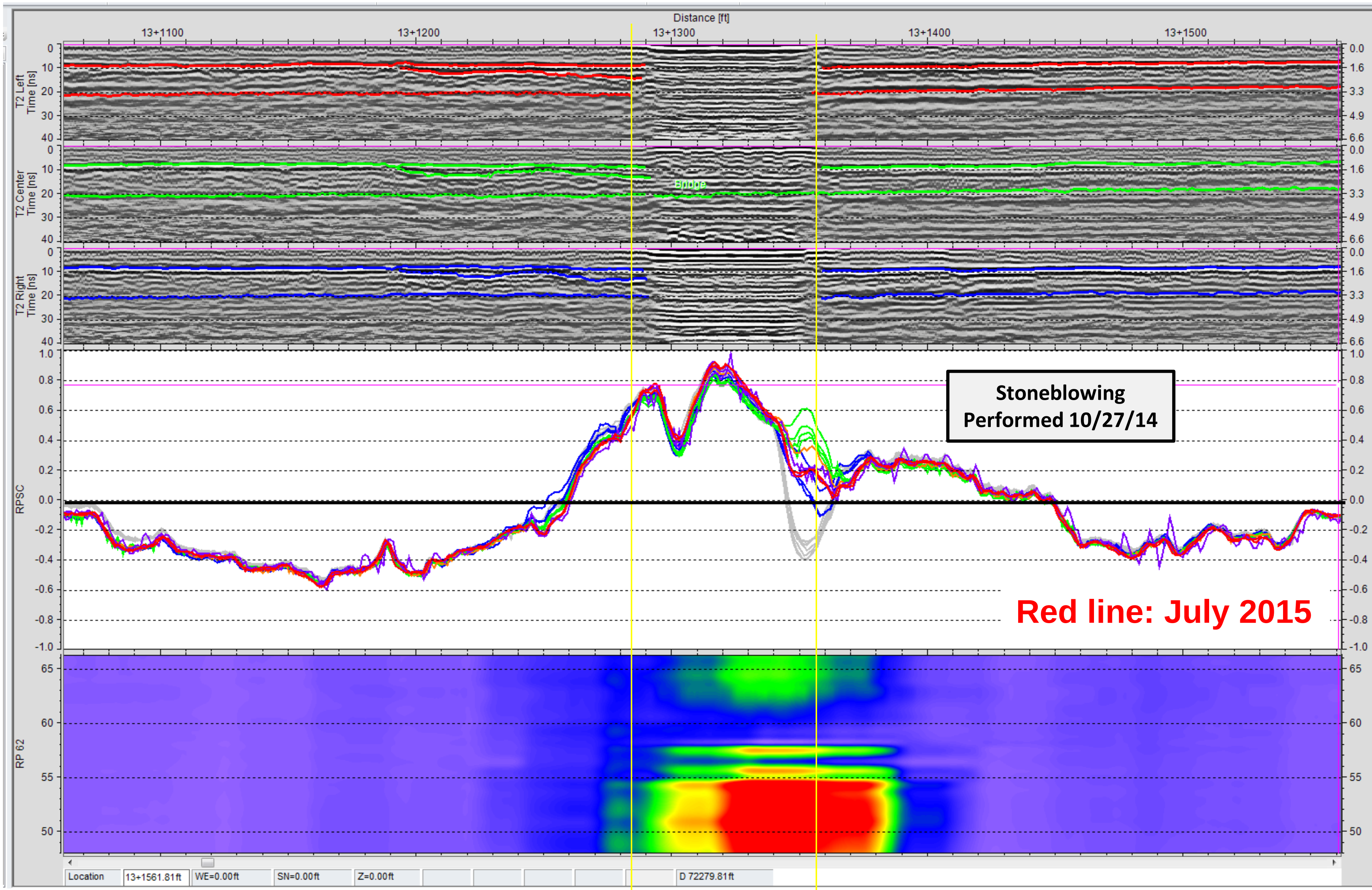
Negative displacements were **NOT** observed until May 2015 when the last data set was collected. No excessive accelerations were observed.

Madison Street – Layer 1 Near Bridge Frequency Domain after Stone Blowing

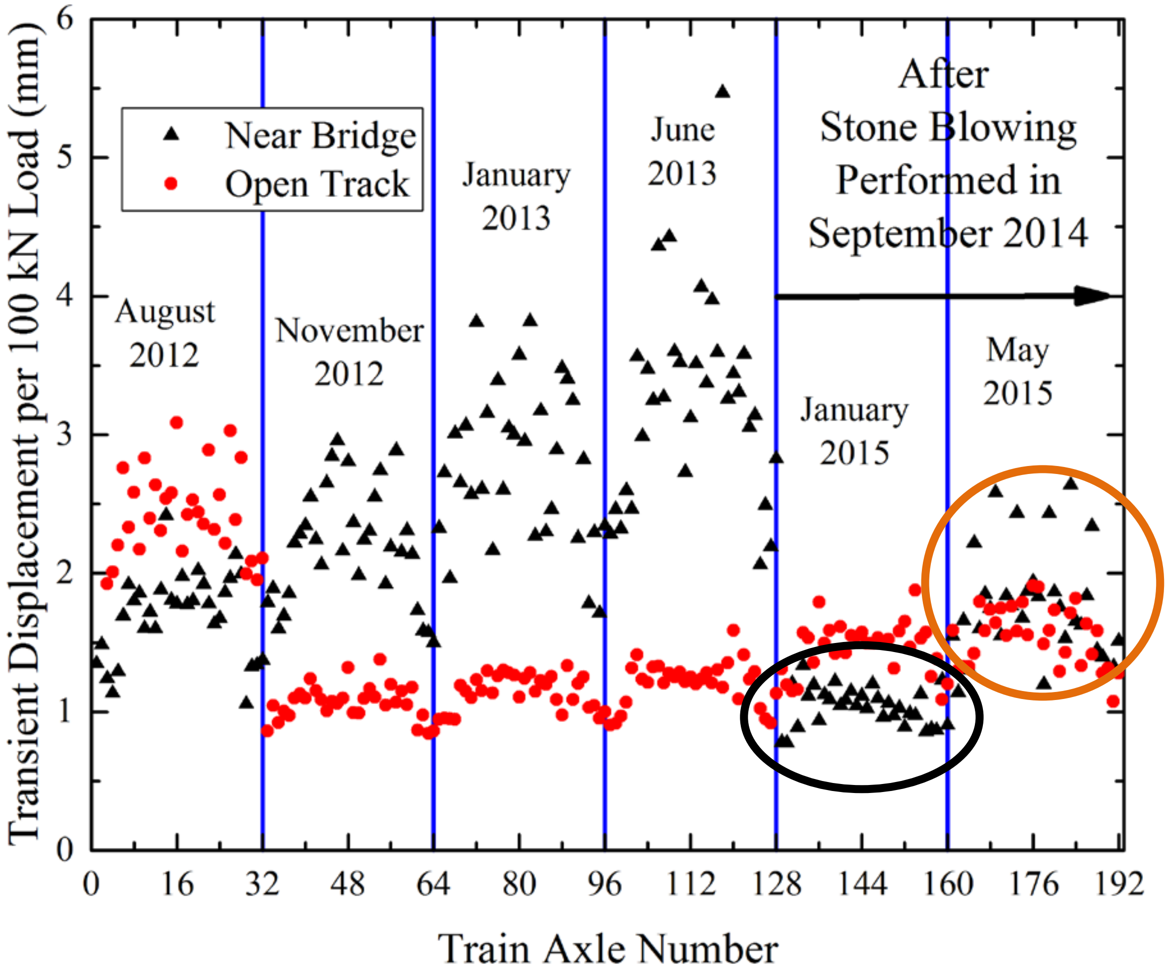


Madison St. Bridge - Track 2

T2 Traffic



Peak Transient Displacement of the Tie (Normalized to a Load Level of 100 kN)



Notice the drastic improvement immediately after the stone injection

Stoneblowing appears to be effective as a remedial measure even several months after the injection

Summary and Conclusions

- From advanced transient data analyses, **certain high acceleration magnitudes and higher frequency vibration** modes were only measured at the near-bridge locations installed along Amtrak's Northeast Corridor near Chester, PA

- Significant amounts of **peak negative transient displacements and tie lifting** were observed only in these near-bridge locations

- A **30-tie track panel comprising concrete ties mounted with UTPs** maintained stable geometry after 11 months of service

- Transient response of the ties measured under the passage of Acela Express trains showed significantly low peak displacement and acceleration numbers. Frequency domain analyses of the tie accelerations indicated **significantly improved support conditions** underneath ties

Summary and Conclusions (2)

- **Chemical grouting** of the ballast proved to be **effective in the short-term**, but its effectiveness as a remedial measure **diminished rapidly after a few months**

- Excessive fouling of the ballast layer may have led to inadequate bonding between the grout and individual ballast particles *(**grout application at another bridge approach comprising a clean ballast layer indicated better performance**)*

- **Stone blowing** proved to be an *effective remedial measure* as far as sustained improvement in mitigating differential movement at the track transitions and maintaining low peak transient displacement and acceleration trends of the tie

Final Report

U.S. Department of Transportation

Federal Railroad

MITIGATION OF DIFFERENTIAL MOVEMENT AT RAILWAY TRANSITIONS FOR US HIGH SPEED RAIL AND JOINT PASSENGER/FREIGHT CORRIDORS

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Thank You !

Questions?

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HYGROUND

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