27 -30 June 2022 in Trondheim, Norway

Usage of TSDDs at network level – what do we have, what is missing

TPF 5-385 *Pooled Funded Study Update*

Gerardo Flintsch, Samer Katicha & Brian Diefenderfer

June 27, 2022

TRANSPORTATION INSTITUTE VIRGINIA TECH
Center for Sustainable and Resilient Infrastructure (CSRI)

Outline

1. Introduction
2. Main Issues Being Investigated
3. Examples of Practical Applications
4. Examples of Research Efforts
5. Final Remarks

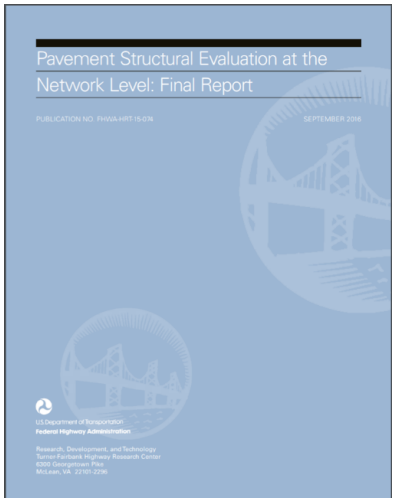
1. Introducción

TSDD Use in the US

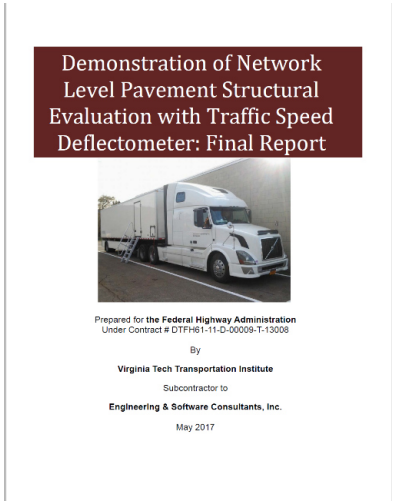
Development

2011 Rada and Nazarian

Assessment



Evaluation

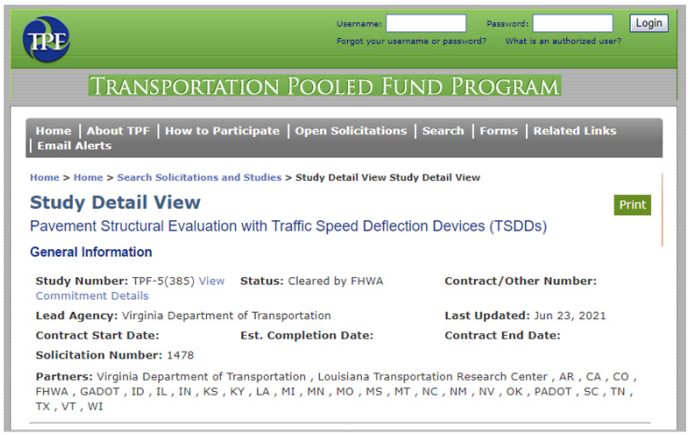


Demonstration

Implementation

Several State Efforts

- ✓ Virginia
- ✓ Louisiana
- ✓ Nationwide



https://www.pooledfund.org/Details/Study/637

Verification

NCHRP 10-105

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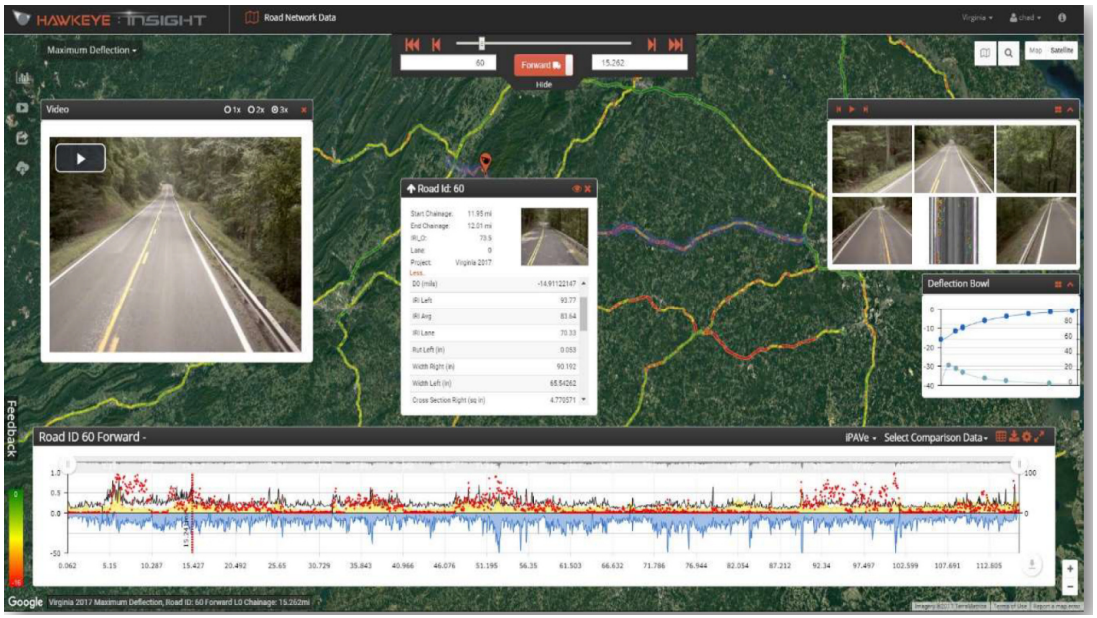
Demonstration of Network Level Pavement Structural Evaluation with Traffic Speed Deflectometer

Transportation Pooled Fund Study TPF-5(385)

Objective: Providing participating agencies guidelines on how to specify collection and use data collected with TSDDs for network- and project-level (if feasible) pavement management applications.



http://www.pooledfund.org/Details/Study/637

Partners: AR, CA, CO, FHWA, GA, ID, IL, IN, KS, KY, LA, MI, MN, MO, MS, MT, NC, NM, NV, OK, PA, SC, TN, TX, VA, VT, WI

Research Team:

VT TRANSPORTATION INSTITUTE VIRGINIA TECH.

VTRC Virginia Transportation Research Council

rrb

INFRASENSE

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TPF 5(385) Activities

- ✓ “Demonstrations”
- ✓ Data analysis support
- ✓ **Webinars**
- ✓ **State of the Art Reports**
- ✓ Case studies
- ✓ **Research**
- ✓ User group (under development)

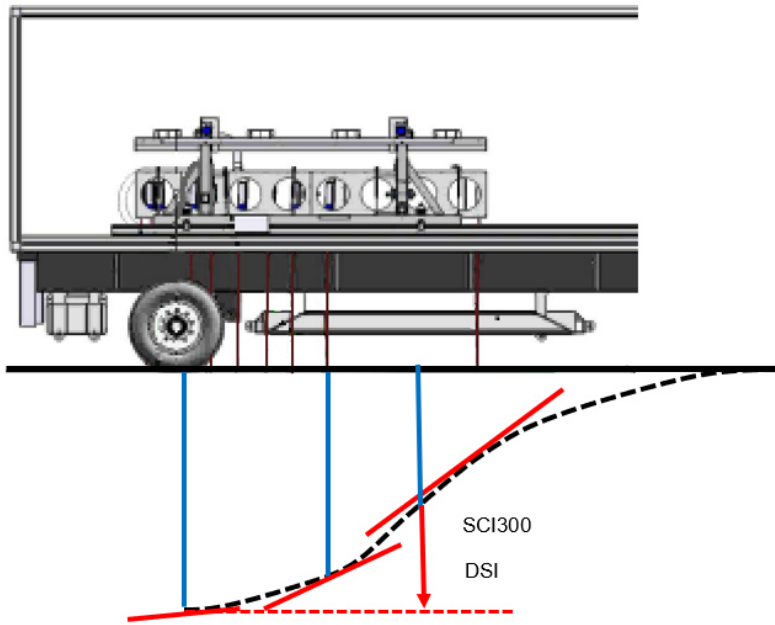
2. Main Issues Being Investigated

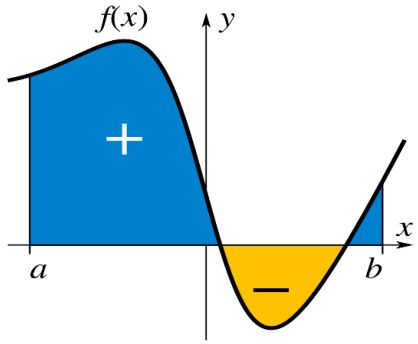
Data Analysis Methods and Issues

- ✓ Data processing
  - Averaging
  - Calculation of deflections
- ✓ Evaluation of TSD
  - Variance (precision), bias (accuracy), repeatability
  - FWD comparison
- ✓ Calculation of structural parameters
  - Deflection bowl indices (e.g. SCI_{300})
  - Effective structural number (SN_{eff})

Calculate Deflections

- ✓ Measured slopes are integrated
  - Numerical, (e.g. trapezoidal rule)
  - AUTC (Hermite interpolation)
  - Greenwood approach
  - Weibull curve fit
  - 3D-MOVE
- ✓ Not different for network level
  - Except constant of integration



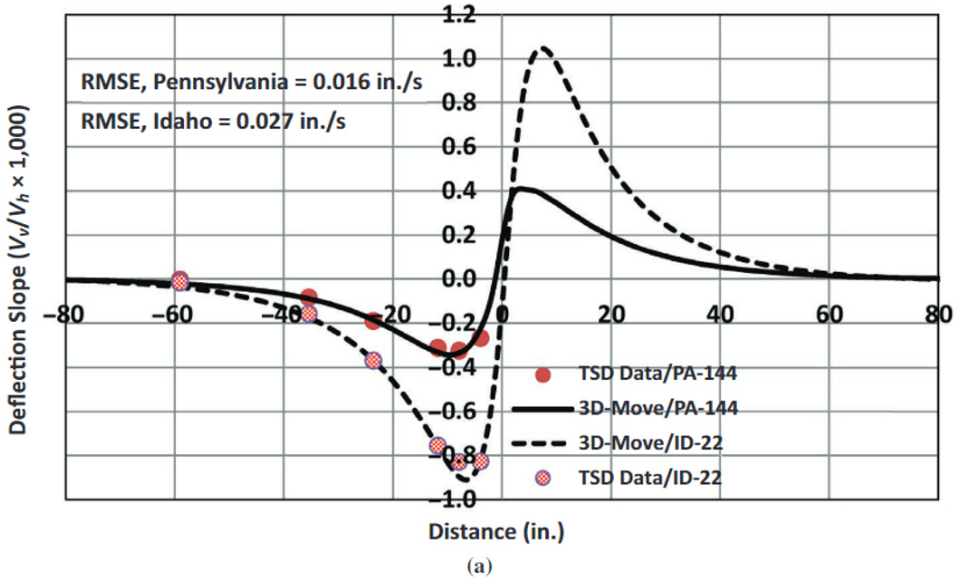


Deflection Bowl Indices

- ✓ $SCI_{b-a} = D_b - D_a$, or $\int_a^b S(x)dx$
- ✓ Many exist, few categories (~3)
  - See Rada et al. (2016); 77 different indices
- ✓ Correlate to strains of interest
  - Tensile strain (fatigue cracking): b and a smaller
  - Compressive strain (subgrade): b and a larger
- ✓ Effective Structural Number

Other Data Analysis Issues

- ✓ Temperature correction
  - Pavement temperature: Bells3 equation
  - D0 correction: AASHTO chart
  - SCI300 correction: for TSD (Rada et al. 2016)
- ✓ Backcalculation
  - Elastic
  - Viscoelastic
  - At least same issues as FWD



(a)

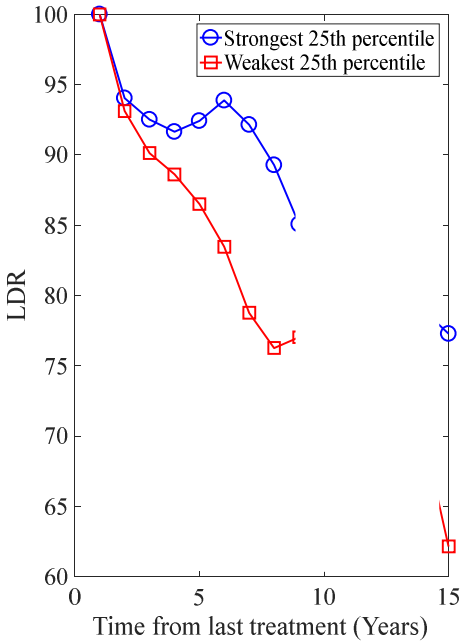
Applications of the TSD

- ✓ Mostly network-level
  - – Delineation of weak-strong sections
  - – PMS implementation (starting)
- ✓ Some “select” project level ventures
  - – Backcalculation
  - – Comparing TSD data with surface data
- ✓ Mostly flexible pavements but promising for concrete and composite pavements

Example of Network Level Pavement Structural Testing with the TSD

Proposed Project Scoping Enhanced Approach

SCI300 and Deterioration



Alligator Cracking			
Frequency	R	O	F
Severity			
NS	DN	DN	PM
S	DN	PM	CM
VS	CM	CM	RM

Pavement Surface Distresses

- Alligator Cracking
- Transverse Cracking
- Rutting
- Potholes

Decision Matrix

Condition Index

Treatments	Interstate	Primary
DN	>89	>89
DN, PM	>84	>79
CM, RM, RC	<60	<60
RM, RC	<49	<41
RC	<37	<26

SURFACE CONDITION

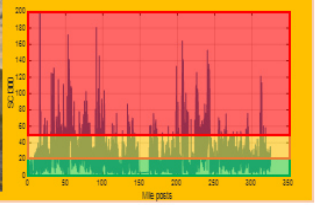
Initial Treatment Category	Modified Treatment Category with Structural Condition		
	Strong	Fair	Weak
DN	DN	DN	DN
PM	PM	PM	DN
CM	PM	CM	RM
RM	CM	RM	RC
RC	RM	RC	RC

Preliminary Treatment Selection

Final Treatment Selection

Structural Condition from TSD

Good | Fair | Poor



STRUCTURAL CONDITION

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3. Examples of Practical Applications - Reports, Webinars & Case Studies

Available and Planned Reports

- ✓ Guide for Network Level Flexible Pavement Structural Evaluation and Management (completed)
- ✓ Guidelines for Data Collection (internal draft)
- ✓ Case Studies
  - Idaho
  - Eastern Federal Lands
  - Virginia
  - Wisconsin

Guide for Network Level Flexible Pavement Structural Evaluation and Management

- ✓ Agency strategic goals and federal mandates
  - – Strategic-, Network-, and Project-level pavement management
  - – Importance of structural evaluation
- ✓ Data collection
  - – Data quality management plan
  - – Collected data: structural data and supporting data
- ✓ Structural condition assessment
  - – Temperature correction
  - – Selecting structural index(es)
  - – Defining thresholds
- ✓ PMS implementation
  - – Approaches
  - – Examples

Demonstration of TSD Data Extraction and Collection Tool

Senthil Thyagarajan

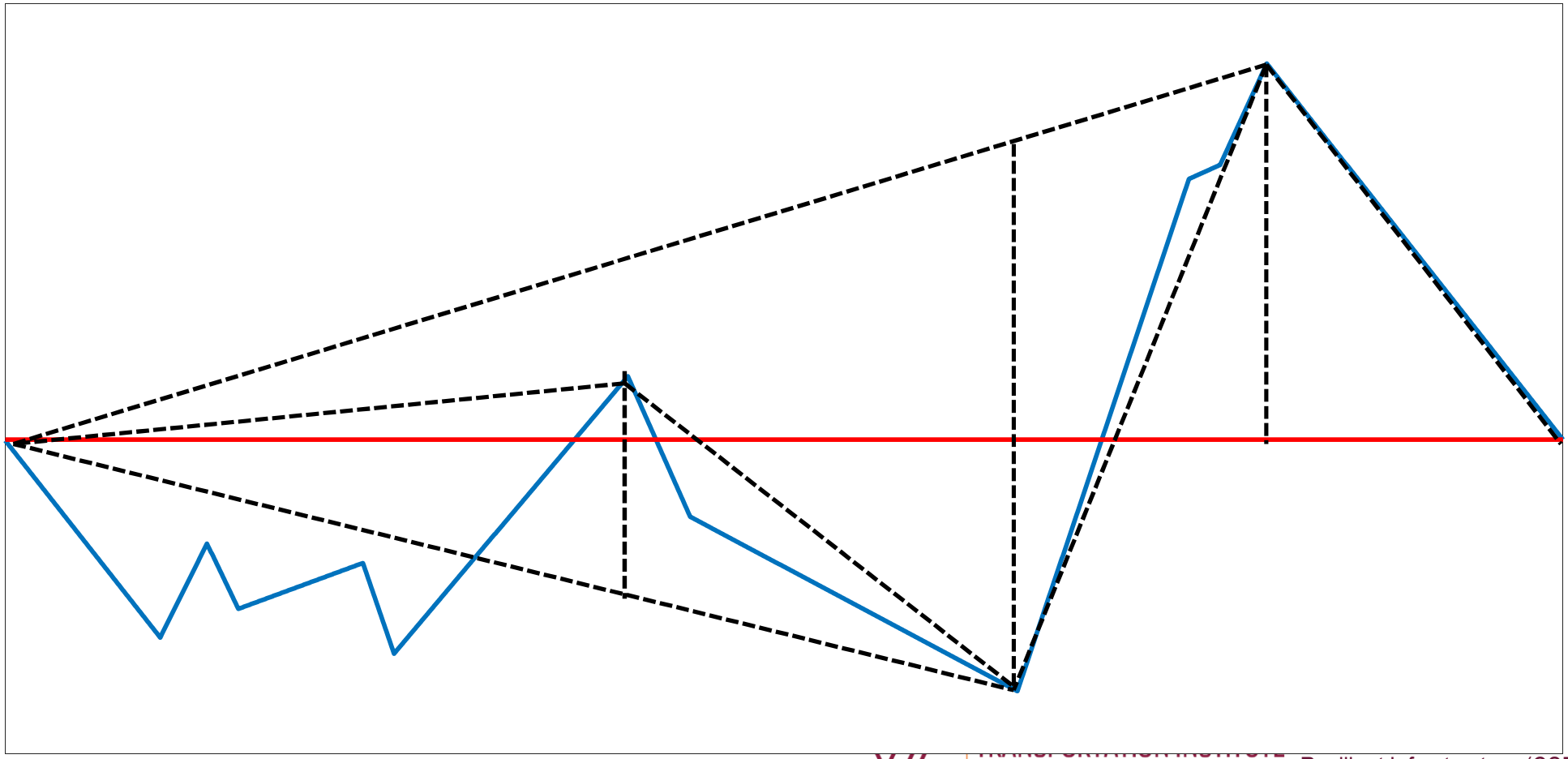
- ✓ Excel tool (available):
  - Combine TSD data and GPR data
  - Performs temperature correction
  - Calculate structural indices
    - SCI300
    - SNeff
  - Performs backcalculation

Pavement Data Segmentation

Samer Katicha

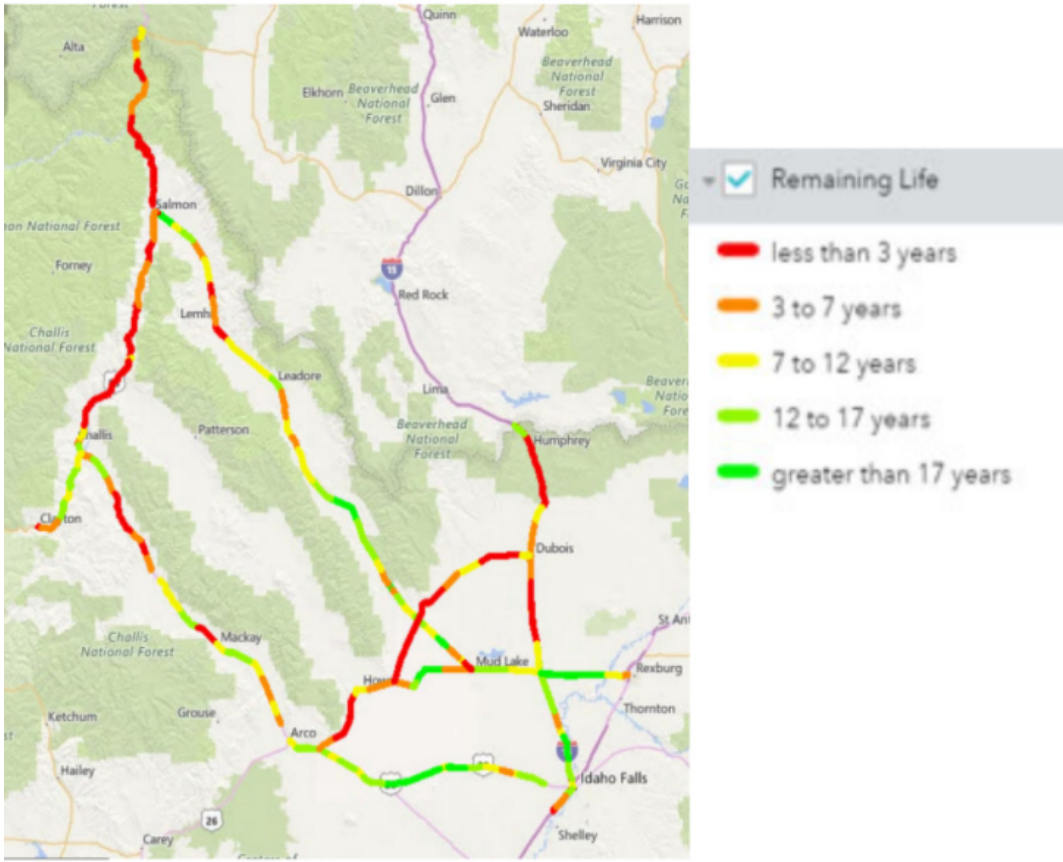
- ✓ Based on the AASHTO cumulative sum of differences
  - – Automated approach
  - – Peak finding instead of change in slope (too sensitive to small variations)
- ✓ Specify minimum segment length
- ✓ Specify minimum difference between segments
- ✓ Tool available

Pavement Data Segmentation (cont.)



Implementation of TSD in Idaho
Ken Maser

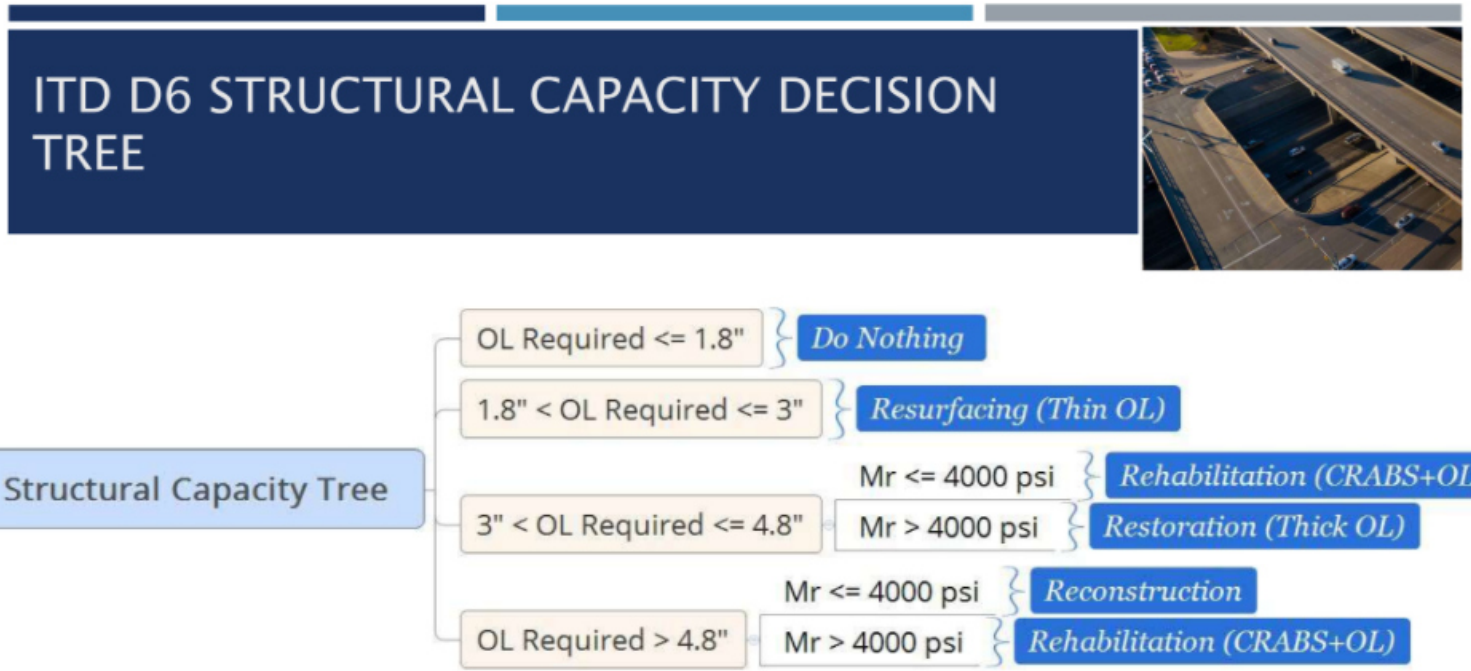
- ✓ Objectives
  - Add GPR data in the analysis
  - Develop more effective strategies for project selection
  - Publish data in geospatial database
  - Demonstrate the use of the data
- ✓ Methodology
  - Calculate Mr
  - Calculate SNeff
  - Traffic data: remaining life, overlay thickness
  - Homogeneous section segmentation



Implementation of TSD in Idaho – Including the TSDD Data in Pavement Management Systems

The Kercher Group

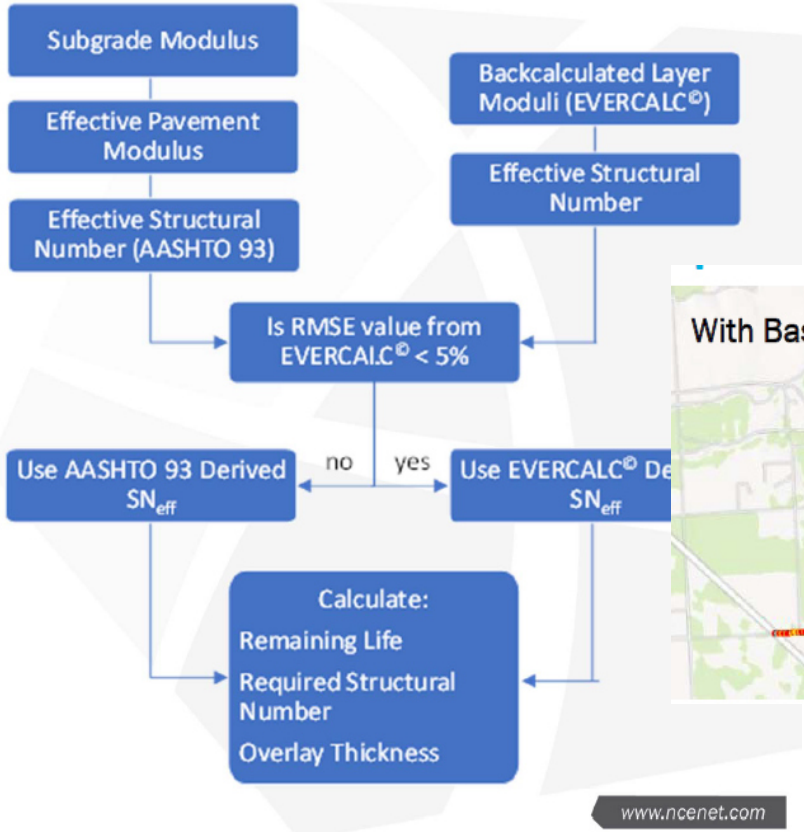
- ✓ Idaho example
  - – ROI = 4.2 (50 years analysis)

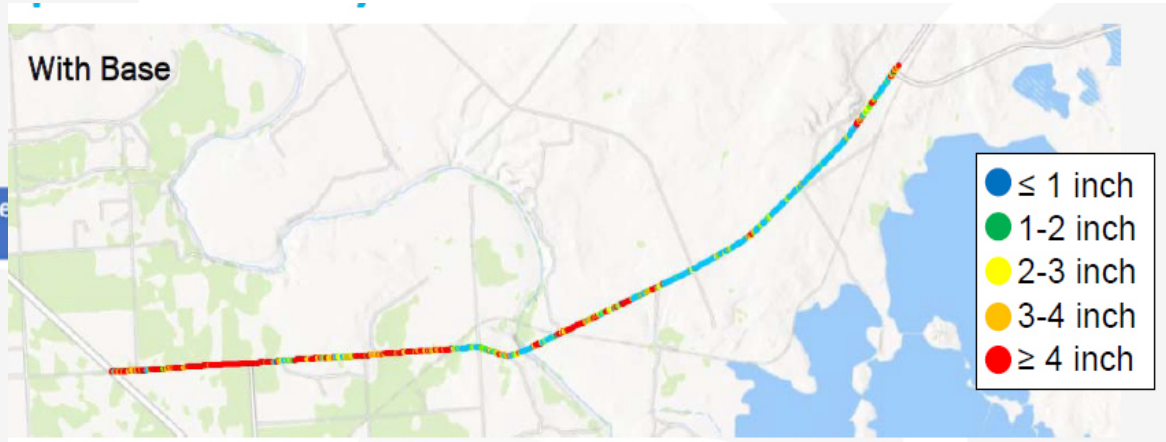


New Mexico TSD Data Analysis Results
Linda Pierce

NCE

TSD Analysis Flowchart

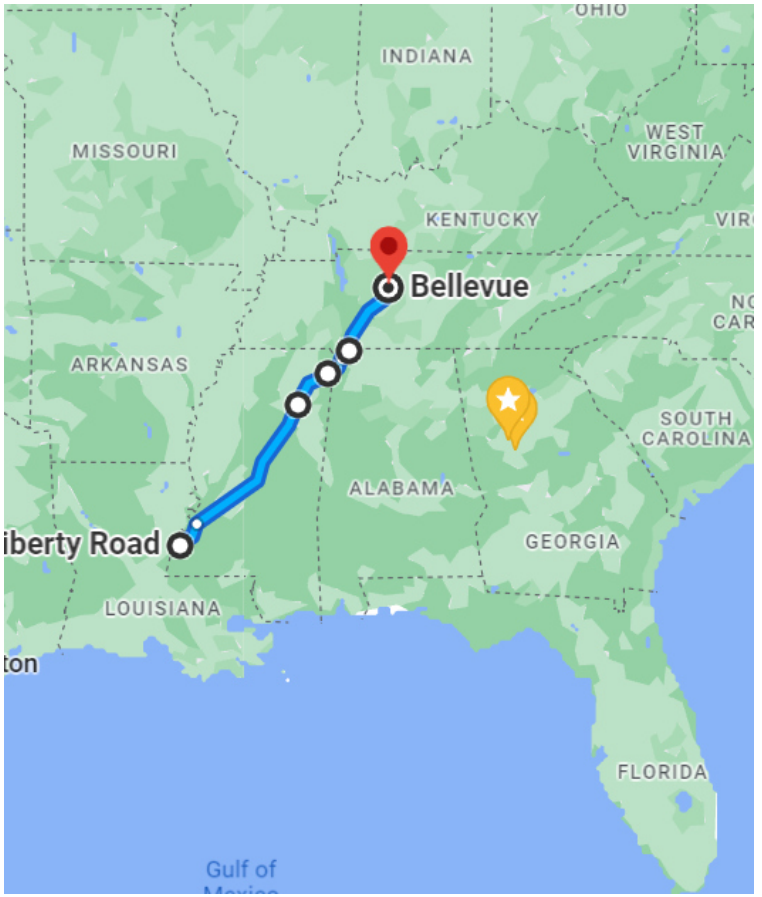




Data Analysis for the Eastern Federal Lands

Samer Katicha

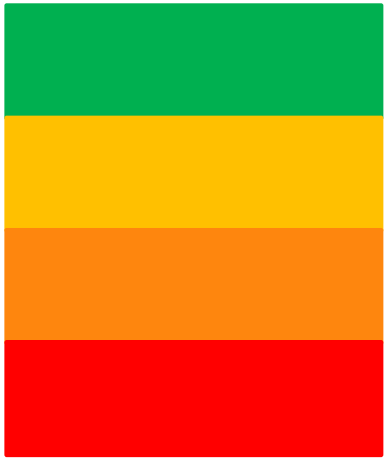
- ✓ Natchez Trace and Blue Ridge Parkway
- ✓ Collected data:
  - TSD deflection data
  - Layer thicknesses from GPR
  - Mile Post
  - Traffic
  - Distress data
- ✓ Structural analysis:
  - SN_{eff}: AASHTO and Rohde
  - SN_{req}: traffic data
  - SN_{design}: layer thickness and coefficient
  - Subgrade modulus (M_r)



Data Analysis for the Eastern Federal Lands (cont.)

Overlay Thickness

- ✓ Input
  - SN_{eff}
  - SN_{req}
    [need truck traffic]
- ✓ Output:
  - $H = \frac{SN_{req} - SN_{eff}}{Layer\ Coefficient}$



Strong < 1”

Fair < 2”

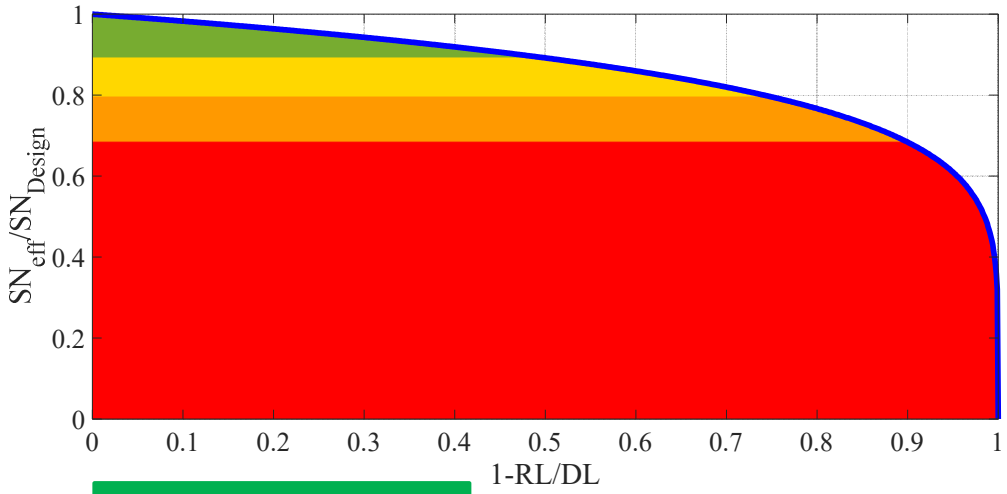
Weak < 3”

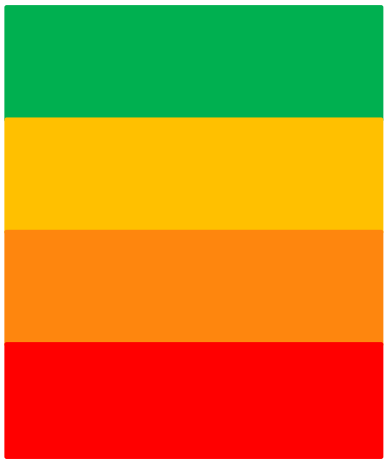
Very Weak > 3”

Data Analysis for the Eastern Federal Lands (cont.)

Remaining Life

- ✓ Input
  - SN_{eff}
  - SN^{design}
- ✓ Output:
  - $\frac{SN_{eff}}{SN_{design}} = \left(\frac{RL}{DL}\right)^{0.165}$
  - $\frac{RL}{DL} = \left(\frac{SN_{eff}}{SN_{design}}\right)^{6.06}$





Strong RL/DL > 0.5

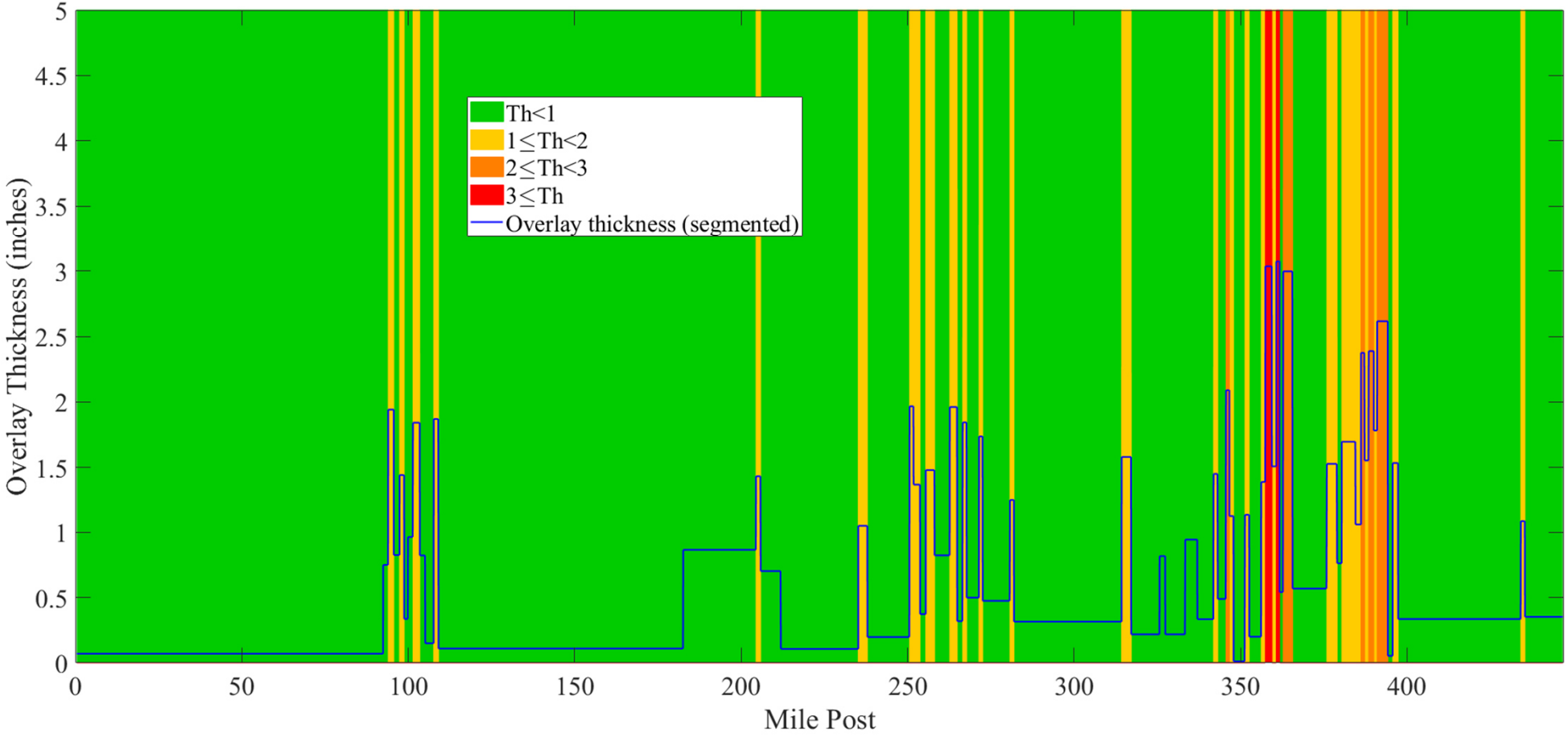
Fair 0.25 < RL/DL < 0.5

Weak 0.1 < RL/DL < 0.25

Very Weak RL/DL < 0.1

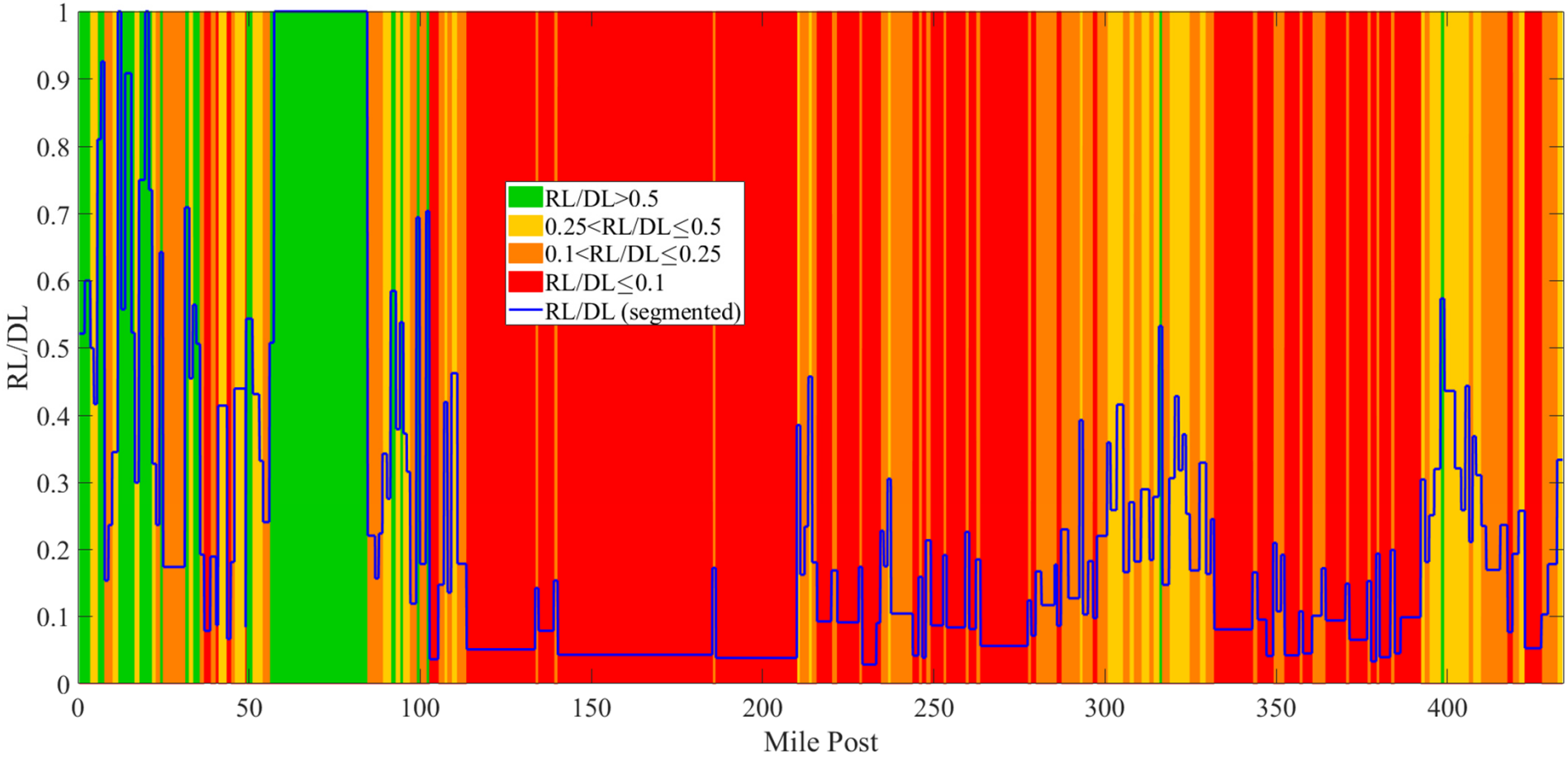
Data Analysis for the Eastern Federal Lands (cont.)

Condition - Overlay Thickness



Data Analysis for the Eastern Federal Lands (cont.)

Condition - RL/DL



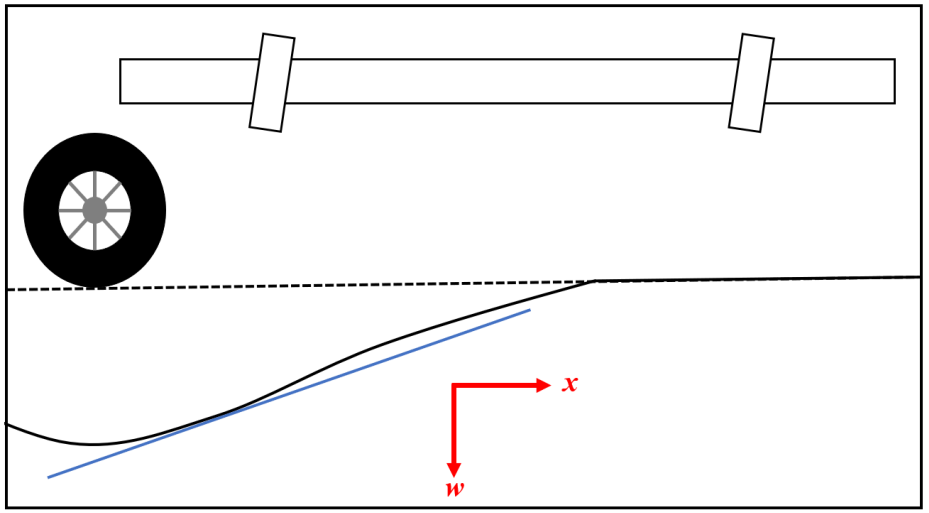
4. Examples of Research Efforts

Example 1: **Analysis of TSD Measurements on Jointed Concrete**

- ✓ Why rethink TSD measurements?
  - – TSD data collected at 5 cm intervals on MnRoad
  - – Modeled deflection slope not matching measured TSD deflection slope
- ✓ Deflection velocity and deflection slope
- ✓ Modeling of jointed PCC
- ✓ Comparing TSD measurements with model prediction

Deflection Velocity and Deflection Slope

- ✓ What is velocity?
- ✓ How can we get slope from velocity?
- ✓ Definition of velocity
  - Velocity: change of deflection over time
  - Deflection depends on:
    - x: the location
    - M: material properties (E, cracks, thickness, composition)
  - x depends on time t because of moving truck
  - M depends on x and hence also time t
- ✓ $w = w\left(x(t), M\left(x(t)\right)\right)$



Deflection Velocity and Deflection Slope (cont.)

- ✓ $w = w\left(x(t), M\left(x(t)\right)\right) = w(x(t), t)$

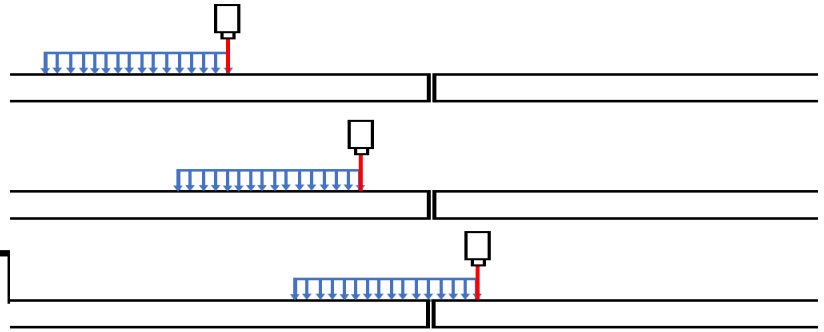
Chain Rule from calculus

- ✓ $v_w = \frac{dw}{dt} = \frac{\partial w}{\partial x}\frac{\partial x}{\partial t} + \frac{\partial w}{\partial M}\frac{\partial M}{\partial x}\frac{\partial x}{\partial t} = \frac{\partial w}{\partial x}\frac{\partial x}{\partial t} + \frac{\partial w}{\partial t}$

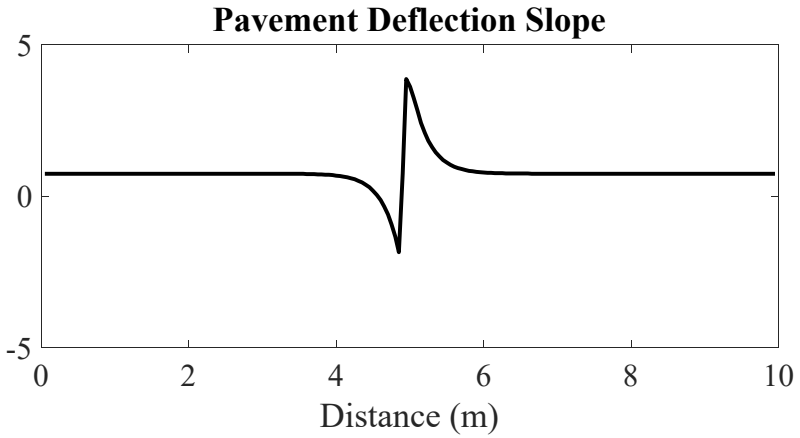
$$v_w = S v_x + \frac{\partial w}{\partial t}$$

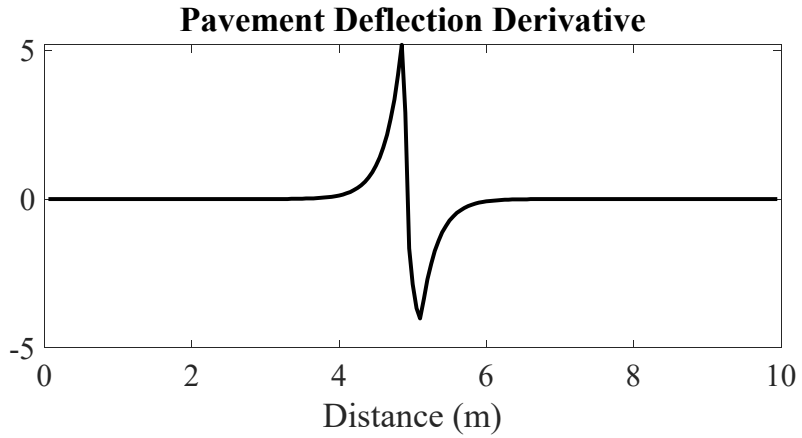
$$\frac{v_w}{v_x} = S + \frac{1}{v_x}\frac{\partial w}{\partial t}$$

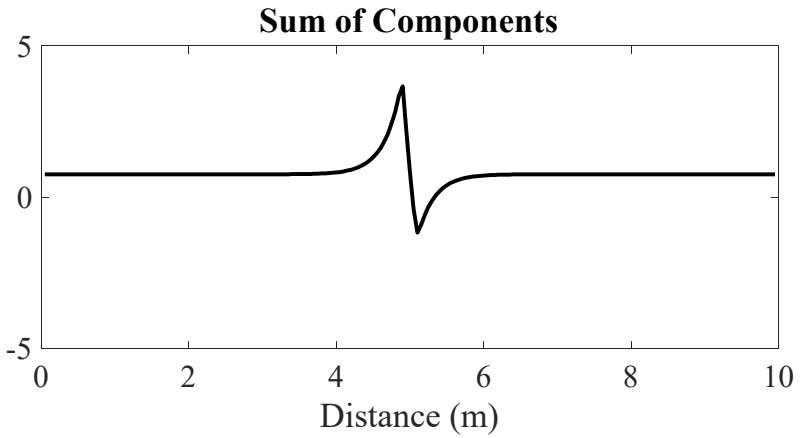
MODELING THE JOINT

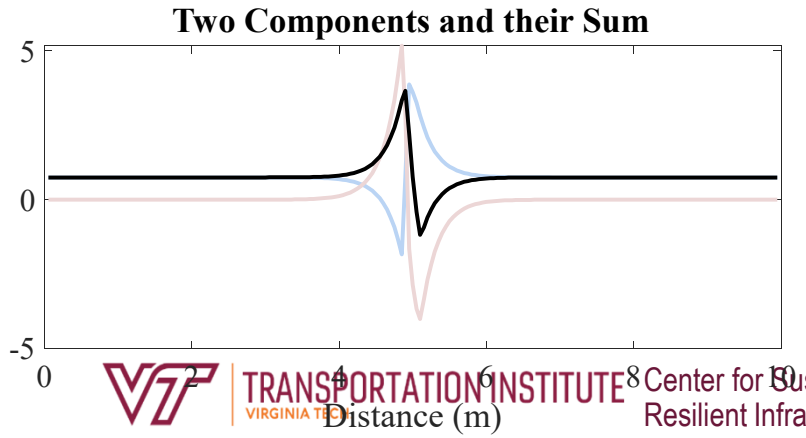


- ✓ Beam on Pasternak Foundation LT

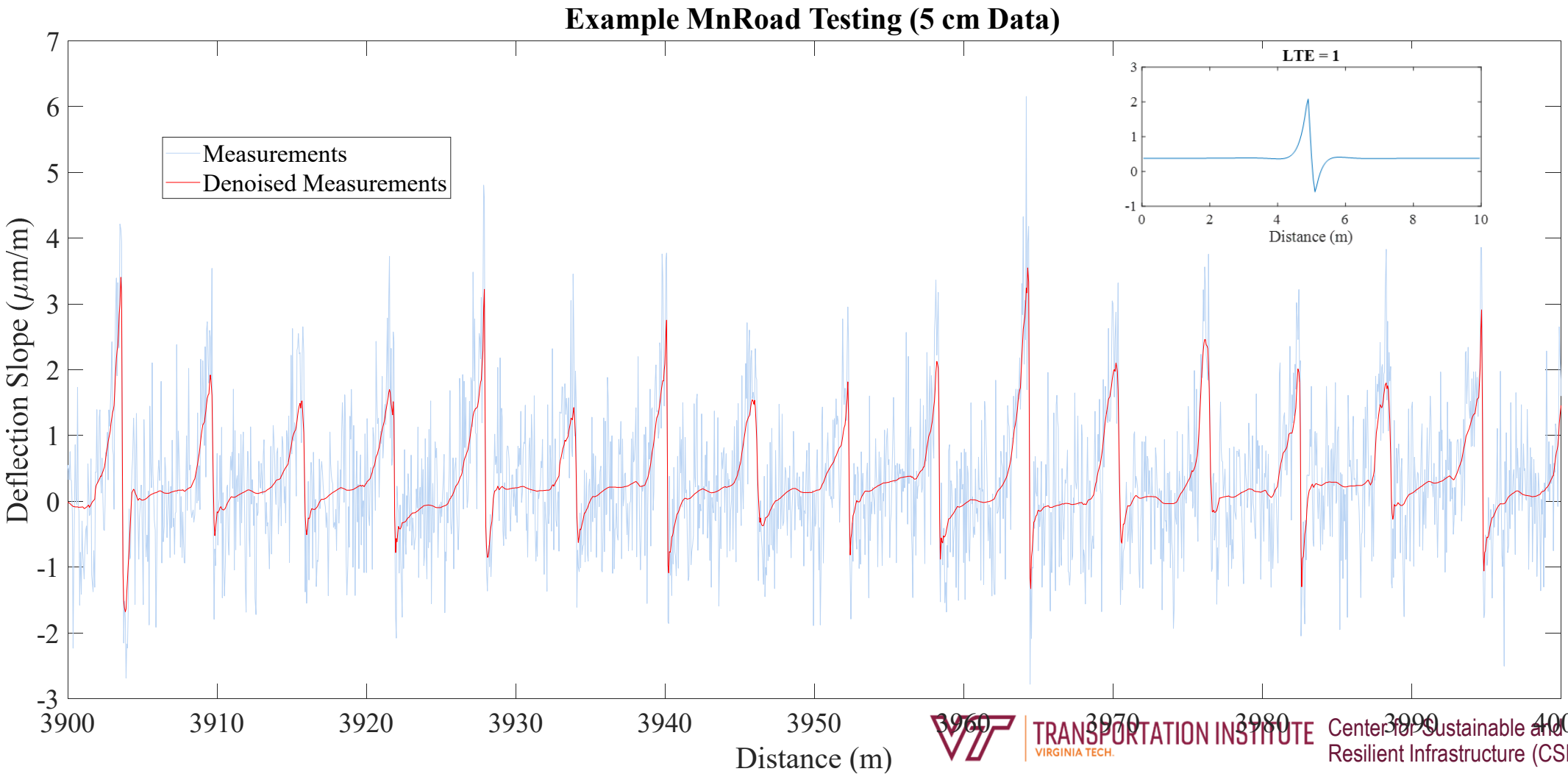




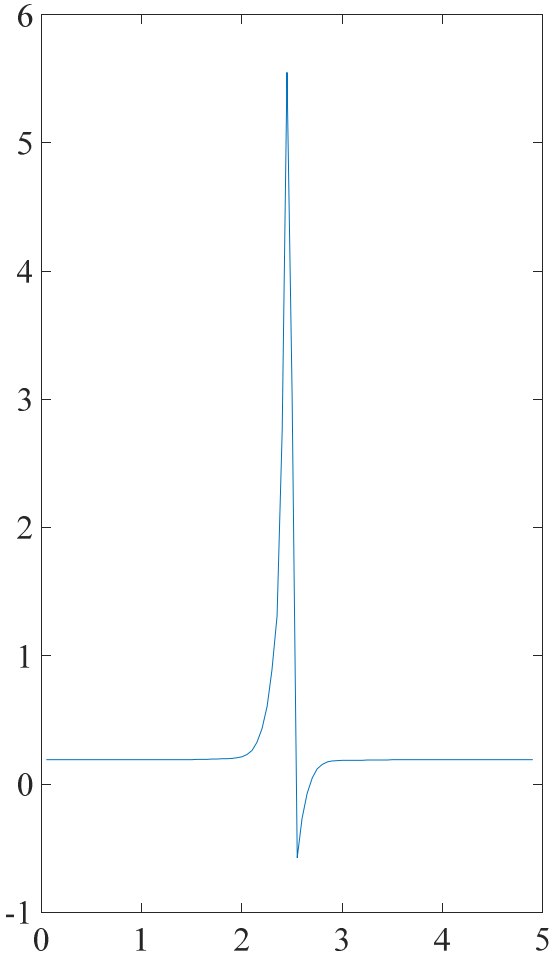


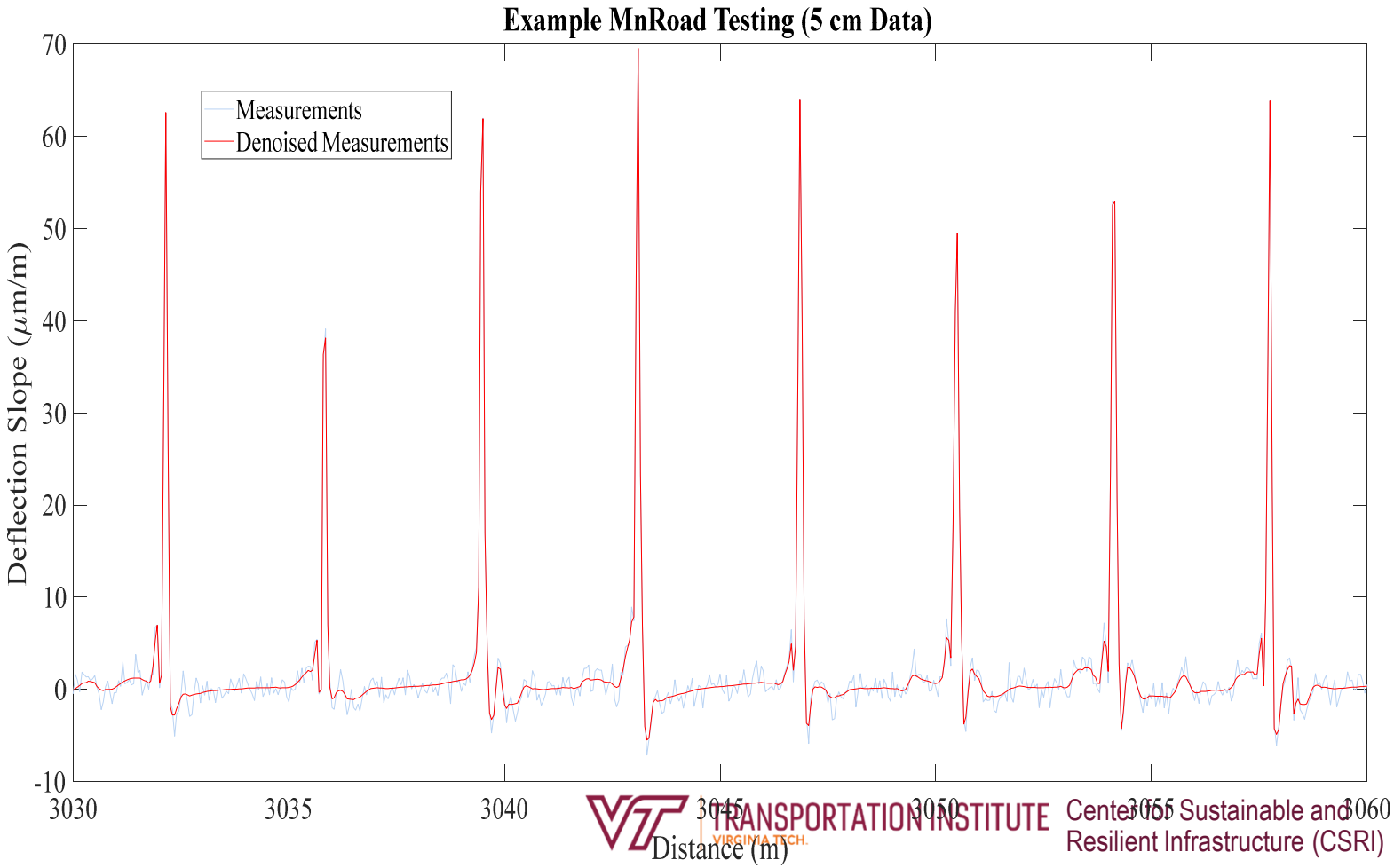


TSD MEASUREMENTS

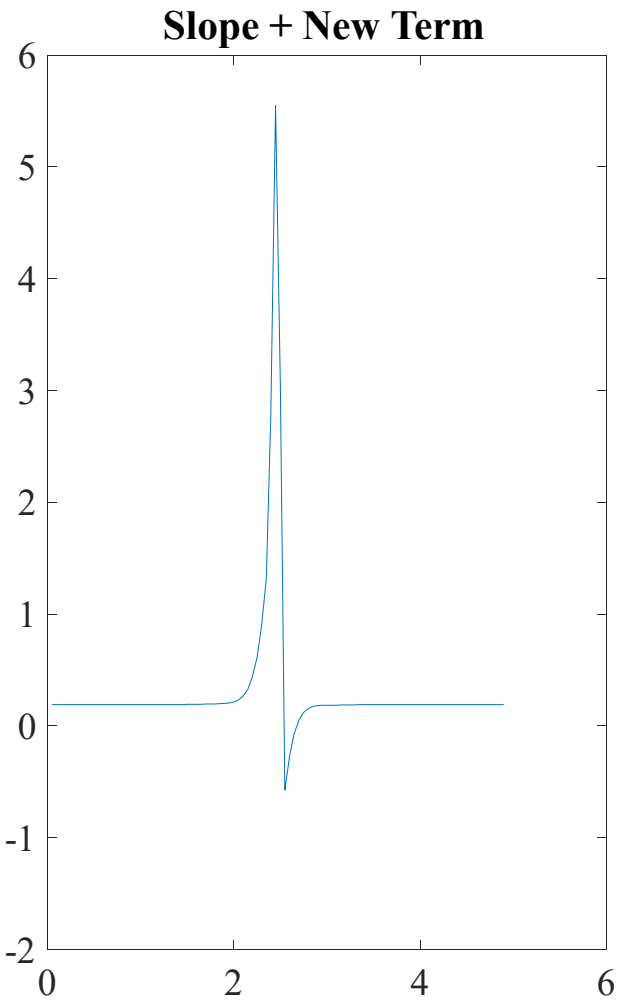


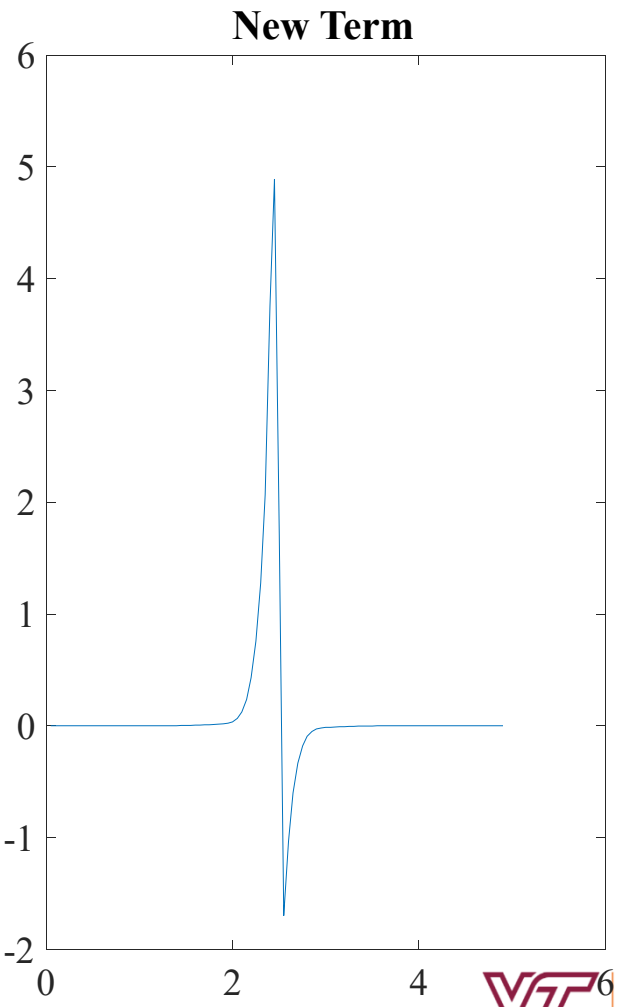
TSD MEASUREMENTS AND MODEL LTE = 0

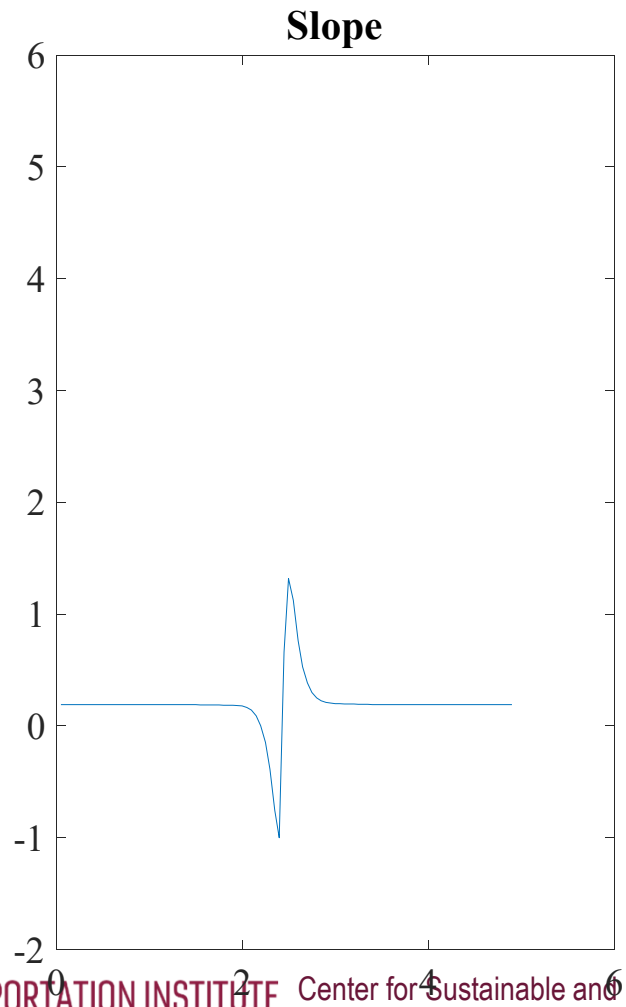




NEW TERM DOMINATES JOINTS RESPONSE







Some Preliminary Findings

- ✓ Two component of pavement deflection velocity
  - – Component 1: related to pavement deflection slope
  - – Component 2: related to changes in pavement properties
- ✓ Analysis of joints of JCP
  - – Deflection slope component much smaller than component 2
  - – Deflection slope is not very sensitive to joint LTE
- ✓ The second component also affects asphalt pavement measurements (may need to be considered for project level)

Example 2: **Development of Pavement Structural Metrics/Indices from Continuous Measurement for Pavement Management and Pavement Design Applications**

- ✓ To develop structural metrics/indices to characterize pavement structural deflections based on continuous structural response measurements, as measured by the TSDD, for pavement management and pavement design applications.

Preliminary Work Plan

Task 1: Conduct a literature review

Task 2: Identify or develop methodologies and guidance for effectively generating the structural metrics/indices.

- Identify critical structural items
- Develop the metrics/indices based on continuous deflection measurements
- Evaluate the new metrics/indices on different pavement types having different structural condition (using both modeling and available field data).

Preliminary Work Plan (cont.)

Task 3: Provide recommendations for implementation and application of the metrics/indices proposed.

- Identify metrics/indices thresholds as a function of key indicators, such as annual ESALs or annual average daily truck traffic (AADTT), pavement type, etc., that provide unique performance distinctions.
- Demonstrate value through application for pavement management.

Task 4: Identify Future Research Needs

5. Final Remarks

Final Remarks

- ✓ TSD is ready for network-level implementation
  - Accuracy and precision adequate
  - Information compatible with FWD
- ✓ Some important issues still need to be addressed
  - Protocols for data collection, calibration, verification
  - Device specific analysis methods (not just FWD adopted)
  - Adoption and implementation feedback
- ✓ We are also very close to be able to used it for project level applications

27 -30 June 2022 in Trondheim, Norway

Usage of TSDDs at network level – what do we have, what is missing

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