U.S. Department of Transportation
Federal Highway Administration

Intelligent Compaction for Pavement Foundation

By
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The Transtec Group

WERIS

THE TRANSTEC GROUP
The World's Pavement Engineering Specialists

Project Overview

- FHWA Contract No. HIF190100PR
- Title: **Feasibility of Utilizing Intelligent Compaction Equipment to Ensure Uniformity and Quality of Pavement Foundation**
- Project Period: Oct. 2019 to June. 2024
- FHWA COTR: Dr. Tom Yu
- Objectives

  Develop a procedure for ensuring uniformity and adequacy of pavement foundation using IC and demonstrating feasibility.

https://www.intelligentconstruction.com/projects/fhwa-ic-for-foundation-project/

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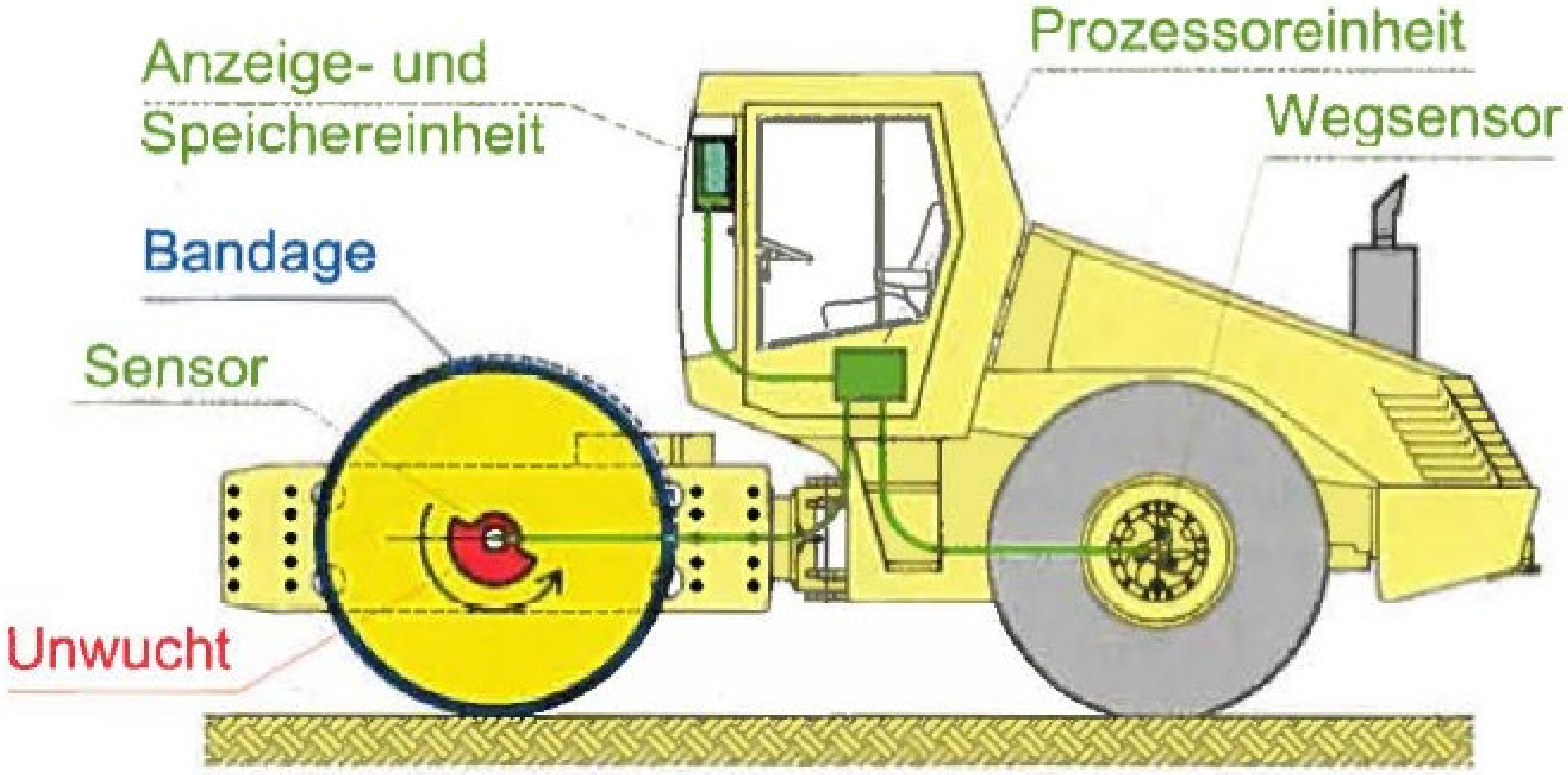
Outlines

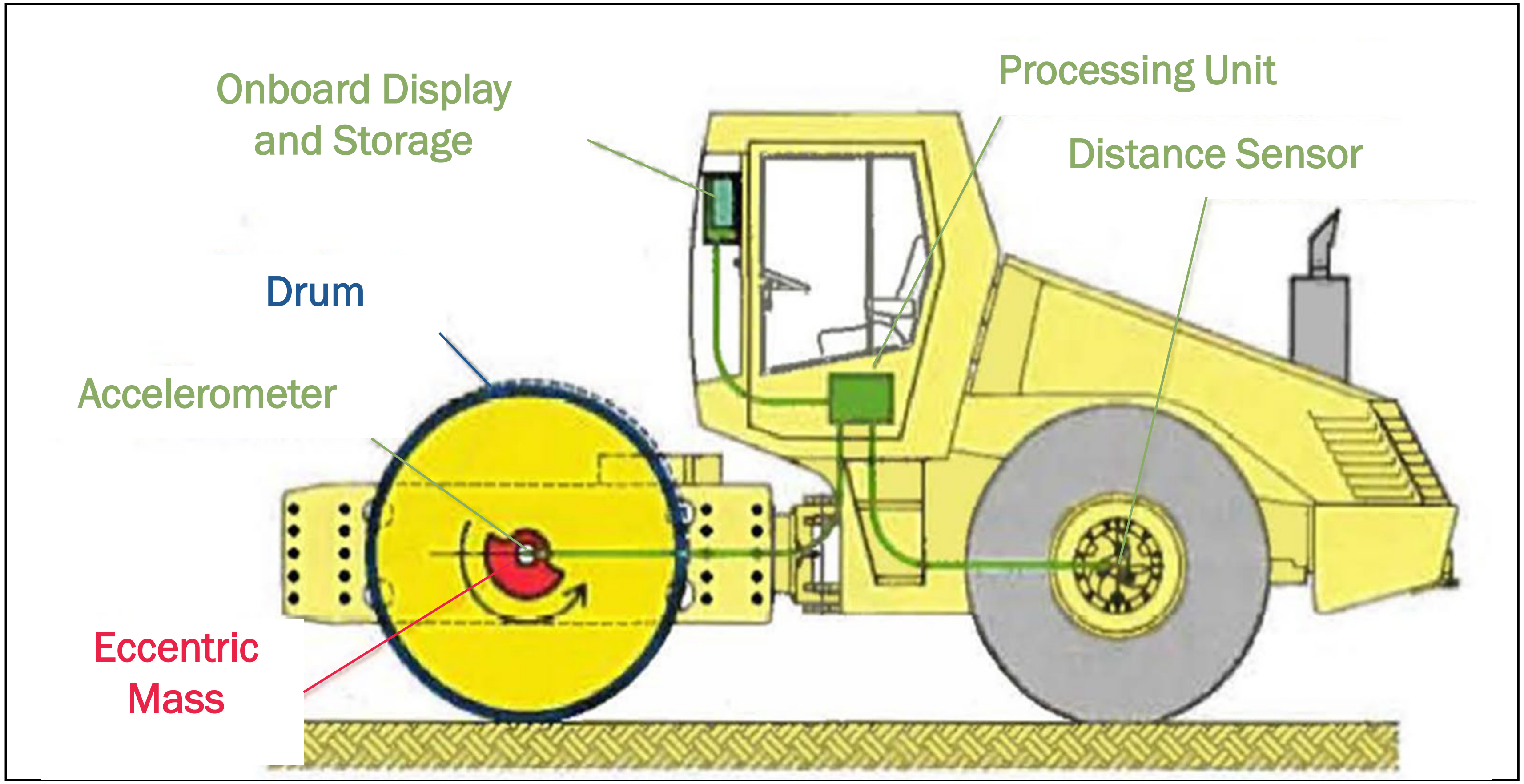
- IC for Foundation
- Benefits and Challenges
- FHWA IC Field Demo
- Summary of Findings

IC for Foundation

First Generation of CCC



First Generation of CCC

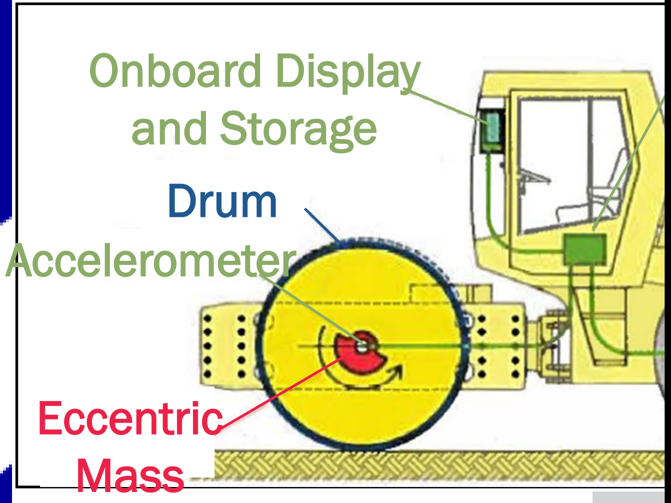


Source: Geodynamic (Modified)

Source: 40 years of CCC (2018)

CCC to IC

CCC




FHWA

INTELLIGENT COMPACTION

STRATEGIC PLAN

April, 2005

Prepared by:

Bob Horan, Ted Ferragut
Salut, Inc.

Prepared for:

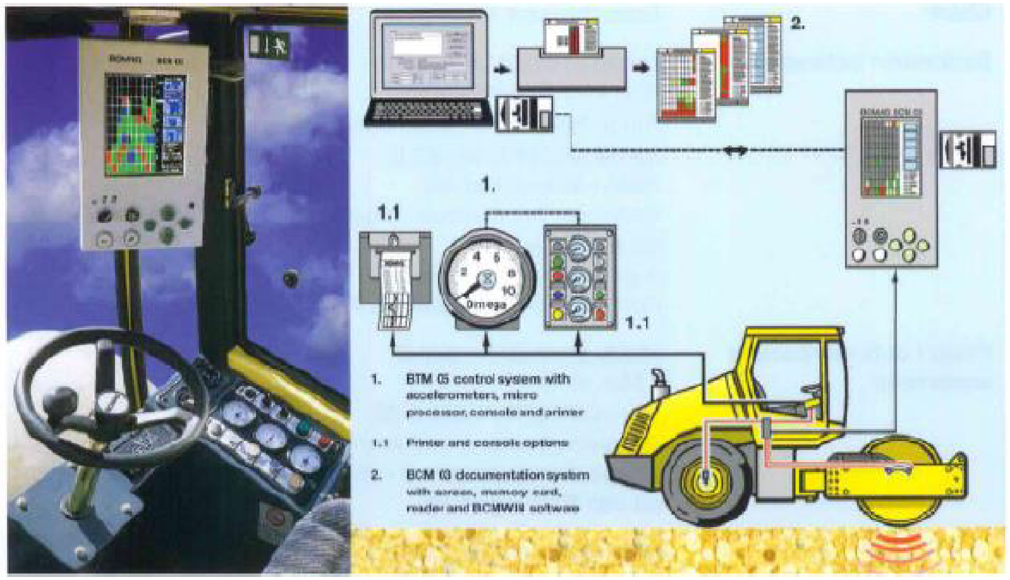
Tom Harman, John D'Angelo
Federal Highway Administration

=

IC

Source: HAMM

Continuous Compaction Control Demonstration
MnROAD Research Facility
September 27, 28, and 29, 2004
10 am to noon each day



Compaction equipment is becoming available that can measure the stiffness of grading materials during compaction at the construction site. Some of these compactors also adjust their compactive energy on the fly during compaction. This optimizes resources by allowing the specified stiffness to be achieved without over compaction. This equipment is available in Europe, but only a few compactors are believed to be present in the United States. The FHWA and several DOTs are currently working to organize demonstrations of this equipment.

A demonstration of continuous compaction control (CCC), also referred to as intelligent compaction, will occur on a road embankment at the MnROAD facility during the week of September 27-29, and will also be included as part of the MnROAD tour during the 2nd International Accelerated Pavement Testing Conference. Bomag equipment will be used for compaction, field testing will be completed during the demonstration, and an engineering report will be produced. In situ testing devices will include the nuclear density gauge and sand cone. In addition, alternative measures of compaction will include the following devices: Dynamic Cone Penetrometer (DCP), Light weight deflectometer (LWD), and GeoGauge. The State will facilitate all arrangements required to accommodate those attending the demonstration, which is open to anyone interested in continuous compaction control and intelligent compaction. All contractors and public/private sector engineers and technicians are welcome. For directions and a map to the MnROAD facility please see:

http://mnroad.dot.state.mn.us/research/mnroad_project/directionstomnroad.pdf

Please contact John Siekmeier, at john.siekmeier@dot.state.mn.us for further details or if you plan to attend. Thanks for your interest.

Modern OEM Soils IC Systems

Ammann-Case

Caterpillar

HAMM-Wirtgen

BOMAG

Dynapac

Sakai

Modern Soils IC Retrofit System

Courtesy Trimble

Modern IC Retrofit System

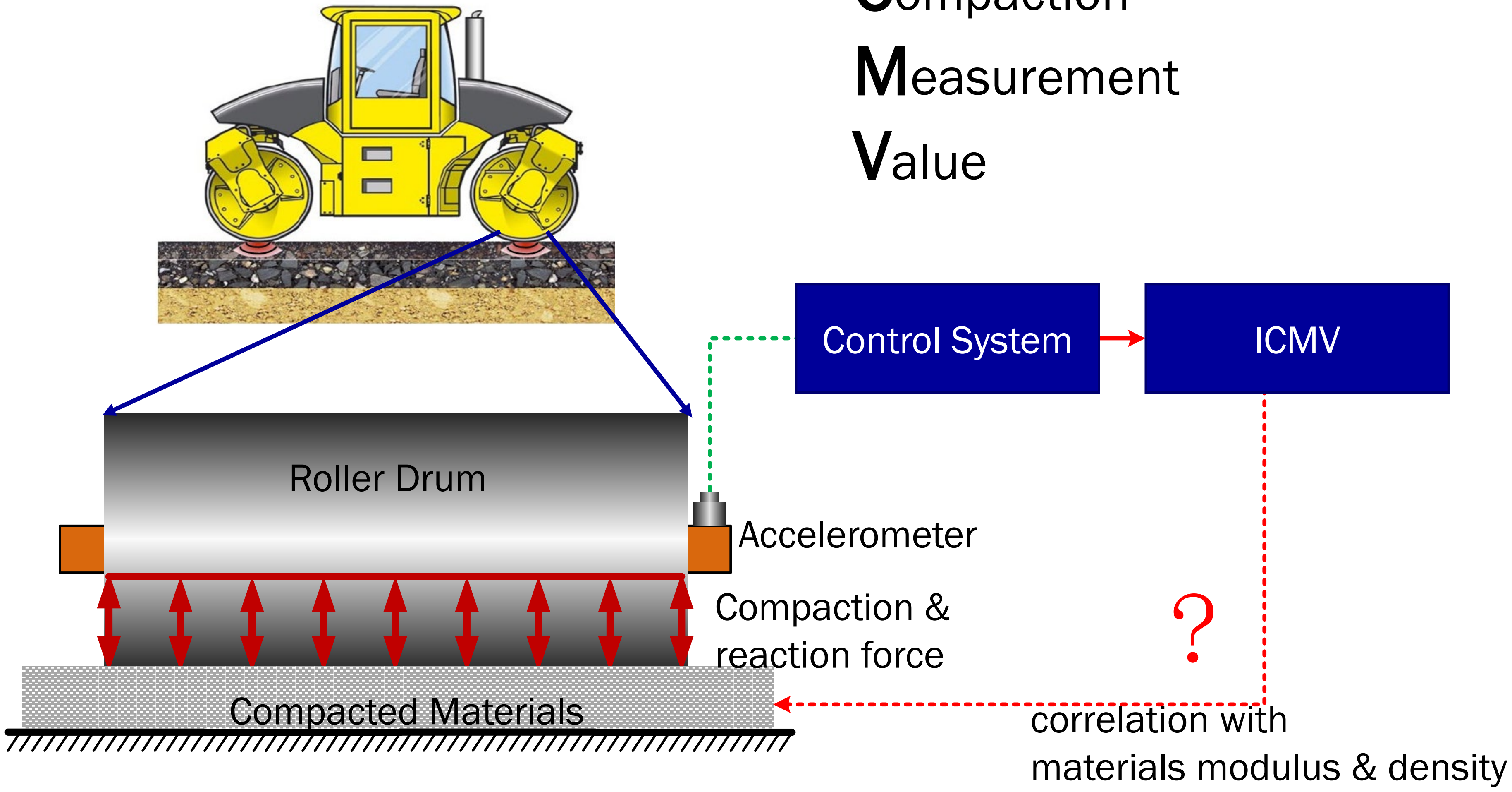
Source: MOBA

IC Application for Pavement Foundation

TPF IC project at TxDOT

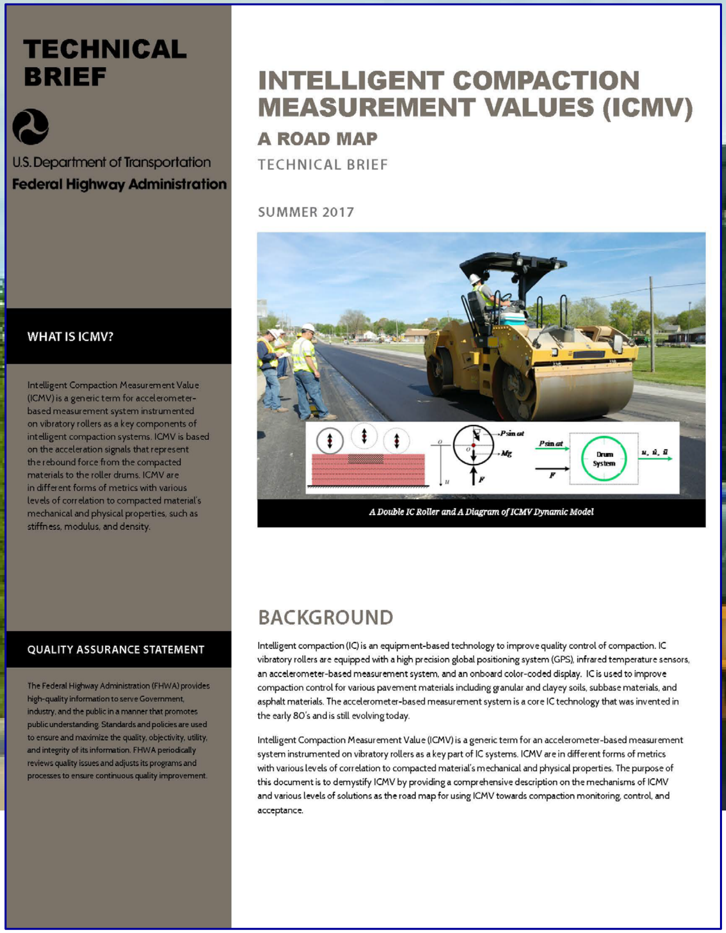
ICMV Mechanism

Intelligent
Compaction
Measurement
Value



Tech Brief - ICMV Road Map

FHWA-HIF-17-046



TECHNICAL BRIEF

U.S. Department of Transportation
Federal Highway Administration

INTELLIGENT COMPACTION MEASUREMENT VALUES (ICMV)

A ROAD MAP

TECHNICAL BRIEF

SUMMER 2017

A Double IC Roller and A Diagram of ICMV Dynamic Model

WHAT IS ICMV?

Intelligent Compaction Measurement Value (ICMV) is a generic term for accelerometer-based measurement system instrumented on vibratory rollers as a key components of intelligent compaction systems. ICMV is based on the acceleration signals that represent the rebound force from the compacted materials to the roller drums. ICMV are in different forms of metrics with various levels of correlation to compacted material's mechanical and physical properties, such as stiffness, modulus, and density.

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The Federal Highway Administration (FHWA) provides high-quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

BACKGROUND

Intelligent compaction (IC) is an equipment-based technology to improve quality control of compaction. IC vibratory rollers are equipped with a high precision global positioning system (GPS), infrared temperature sensors, an accelerometer-based measurement system, and an onboard color-coded display. IC is used to improve compaction control for various pavement materials including granular and clayey soils, subbase materials, and asphalt materials. The accelerometer-based measurement system is a core IC technology that was invented in the early 80's and is still evolving today.

Intelligent Compaction Measurement Value (ICMV) is a generic term for an accelerometer-based measurement system instrumented on vibratory rollers as a key part of IC systems. ICMV are in different forms of metrics with various levels of correlation to compacted material's mechanical and physical properties. The purpose of this document is to demystify ICMV by providing a comprehensive description on the mechanisms of ICMV and various levels of solutions as the road map for using ICMV towards compaction monitoring, control, and acceptance.

5 Levels of ICMV

Level	Model	Measurement Values	Correlation[1]	Decouple[2]	Layer Specific[3]	Advanced IC[4]
1	Empirical	Harmonic ratio	O	×	×	×
2	Energy	Energy index	?	×	×	×
3	Discrete vibration	Stiffness Coefficient	✓	×	×	O
	Steel drum movement	Resistance force	✓	✓	O	O
	Continuous static	Modulus	✓	×	✓	✓
4	Hybrid	Resistance force, Modulus	✓	✓	✓	✓
5	Continuous dynamic	Density, Modulus	✓	✓	✓	✓

Detailed Models of 5-Level ICMVs

DEPARTMENT OF TRANSPORTATION

Evaluation of Level 3-4 Intelligent Compaction Measurement Values (ICMV) for Soils Subgrade and Aggregate Subbase Compaction

George Chang, Principal Investigator
The Transtec Group

MARCH 2023

Final Report NRRA202304

NRRA National Road Research Alliance

Office of Research & Innovation • mndot.gov/research

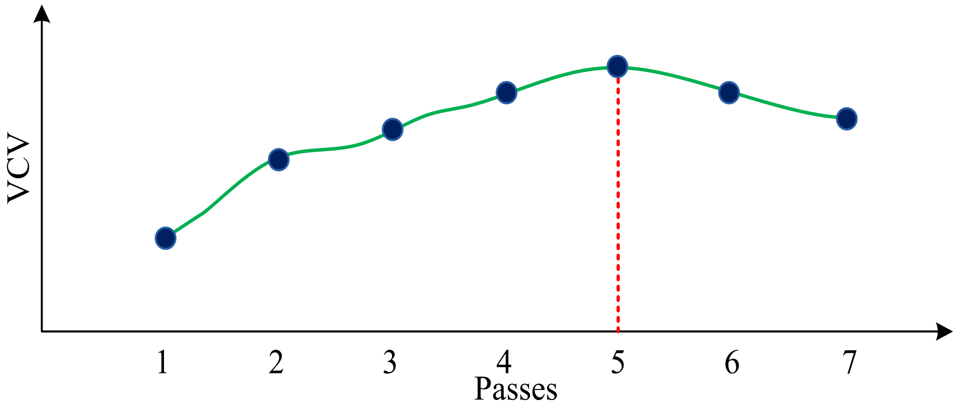
Appendix A

Background of Level 1 to Level 5 Intelligent Compaction Measurement Values (ICMVs)

https://mdl.mndot.gov/items/NRRA202304

Benefits and Challenges

Optimize Roller Passes



7 Passes √

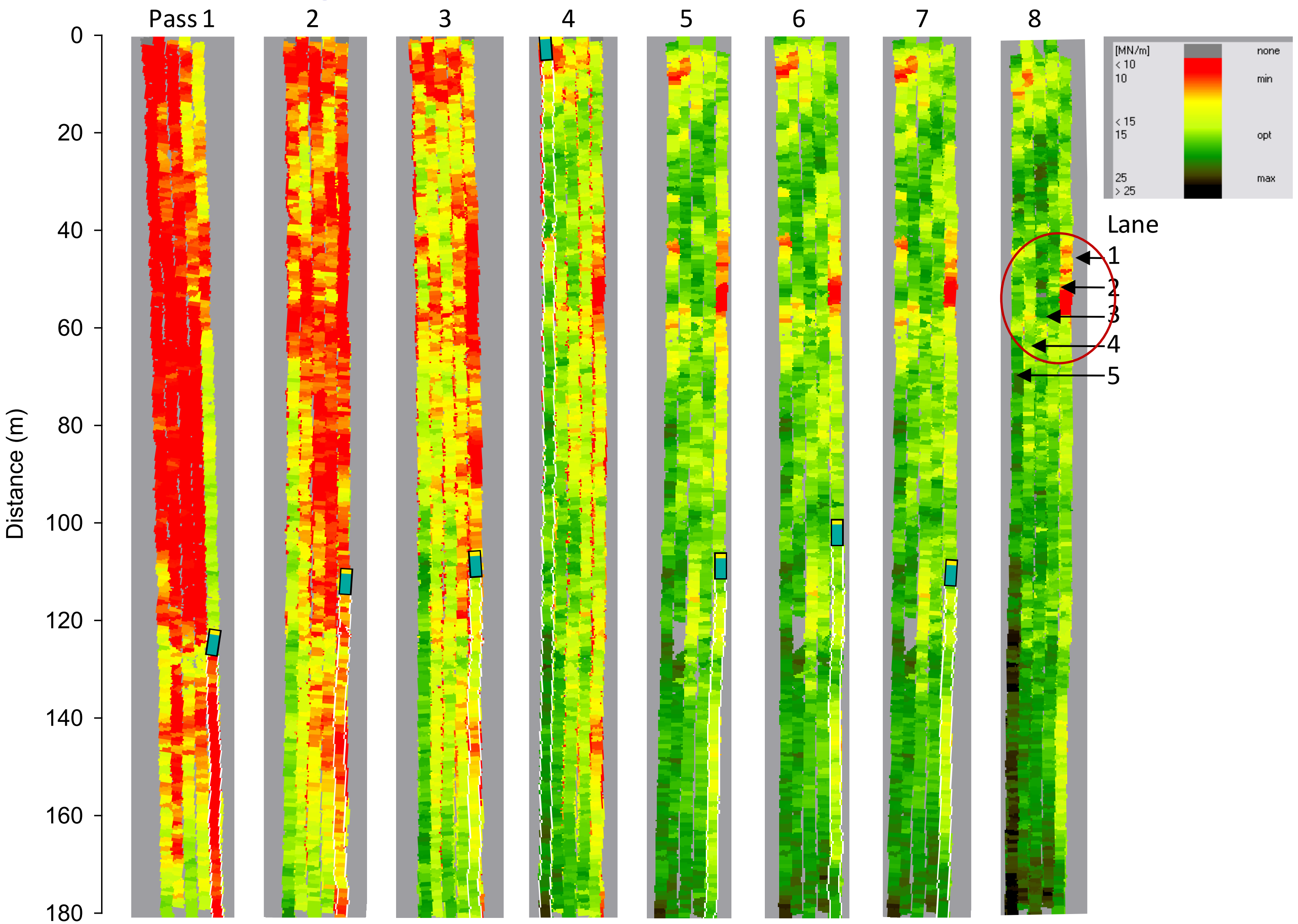
Test section

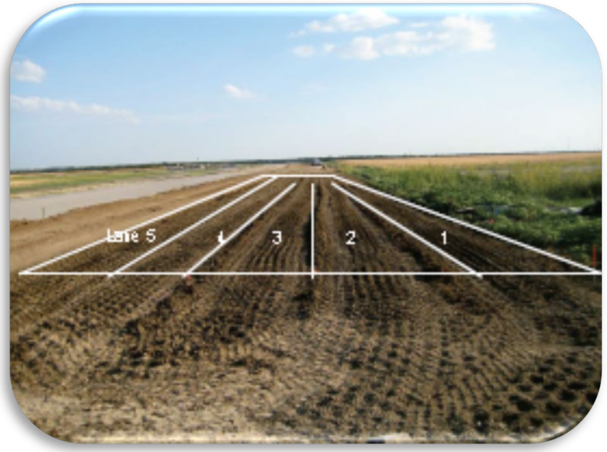
5 Passes √

Construction section

Courtesy Prof. G Xu

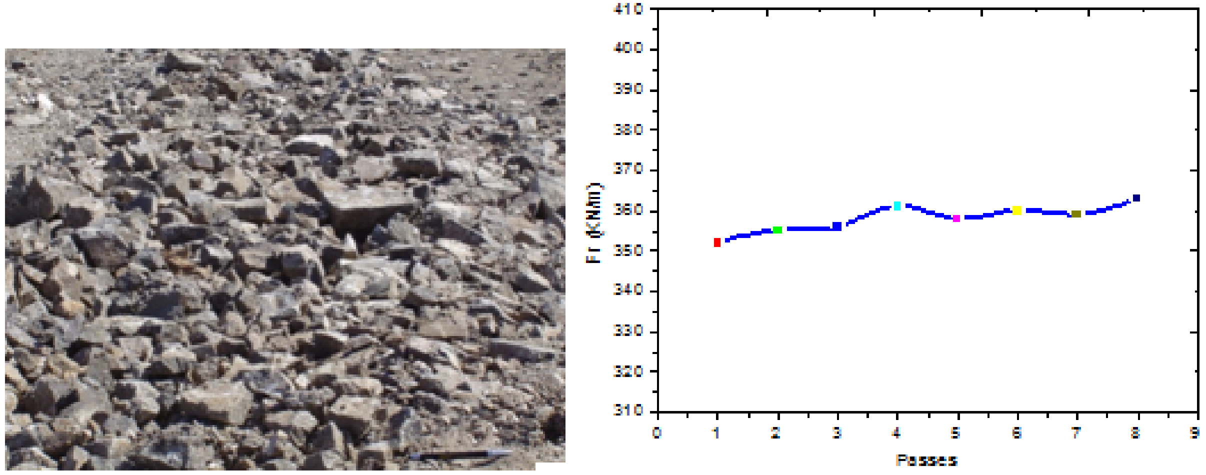
Identify Weak Areas



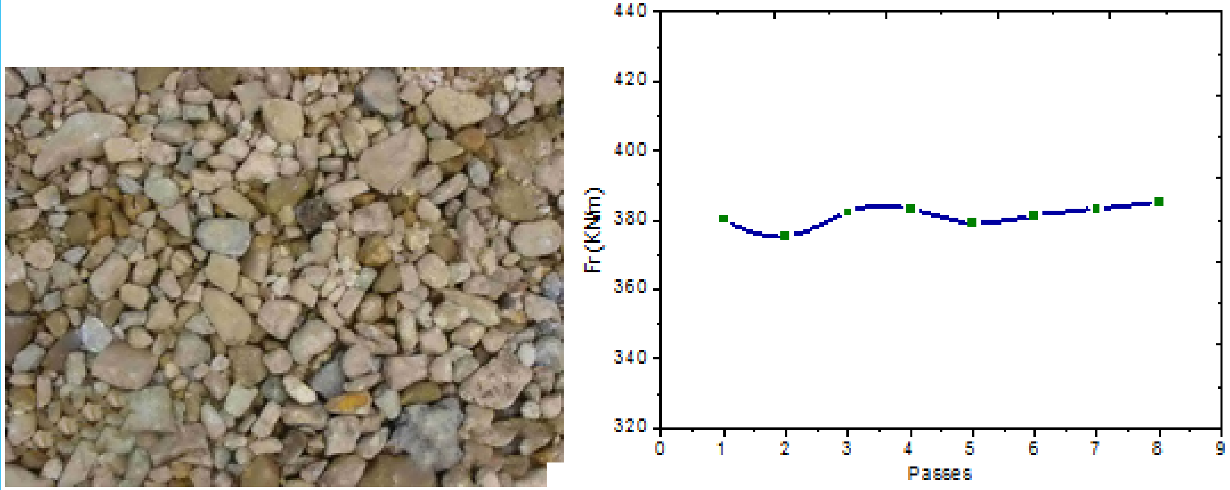


TPF IC project at TxDOT

Identify Poor Aggregate & Gradation

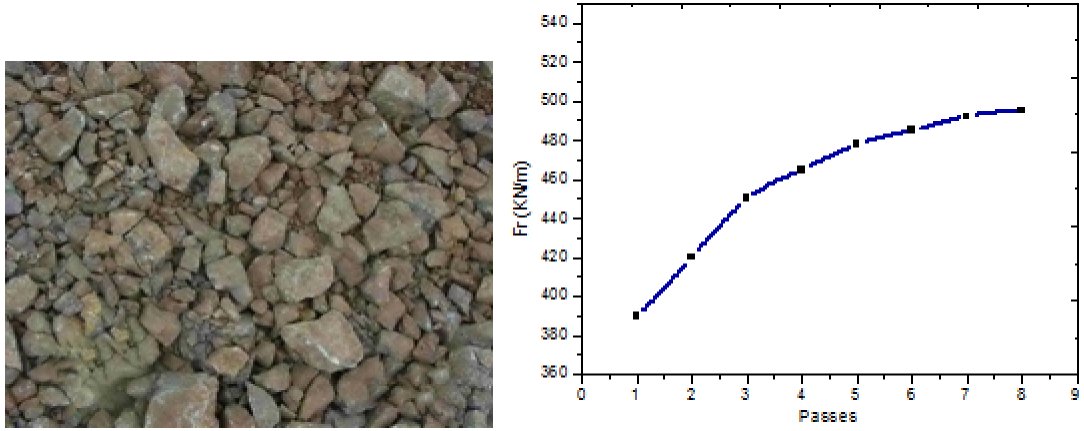


（a） poor-graded



（b） rounded gravel

Sinecore
Level 3 ICMV - VCV

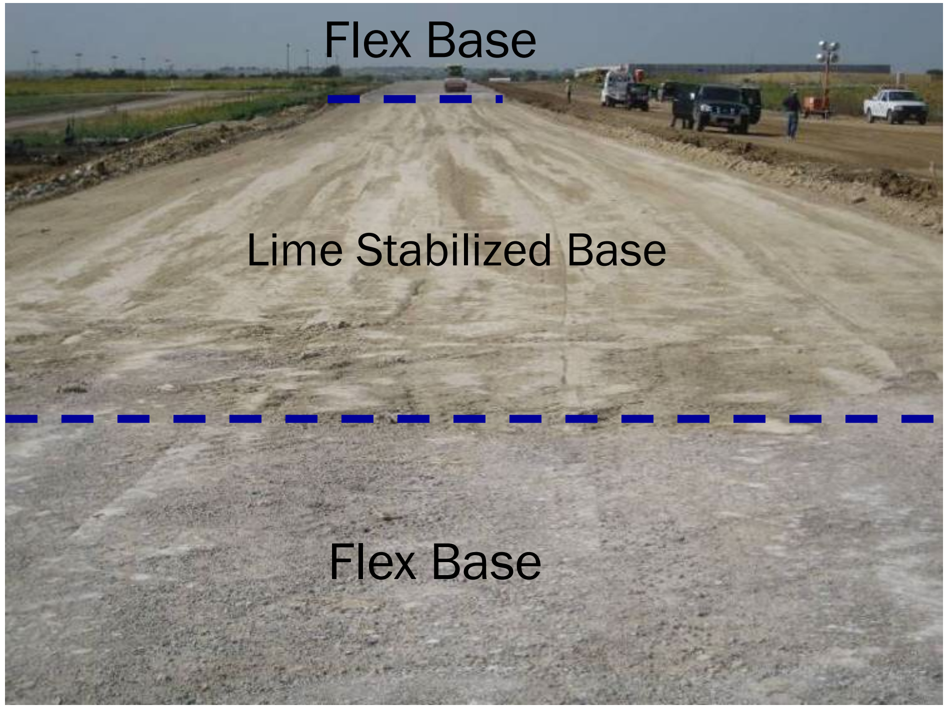


（c） well-graded

Xu, GH (2017)

Differentiate Materials

Flex Base ← Lime Stabilized Base → Flex Base

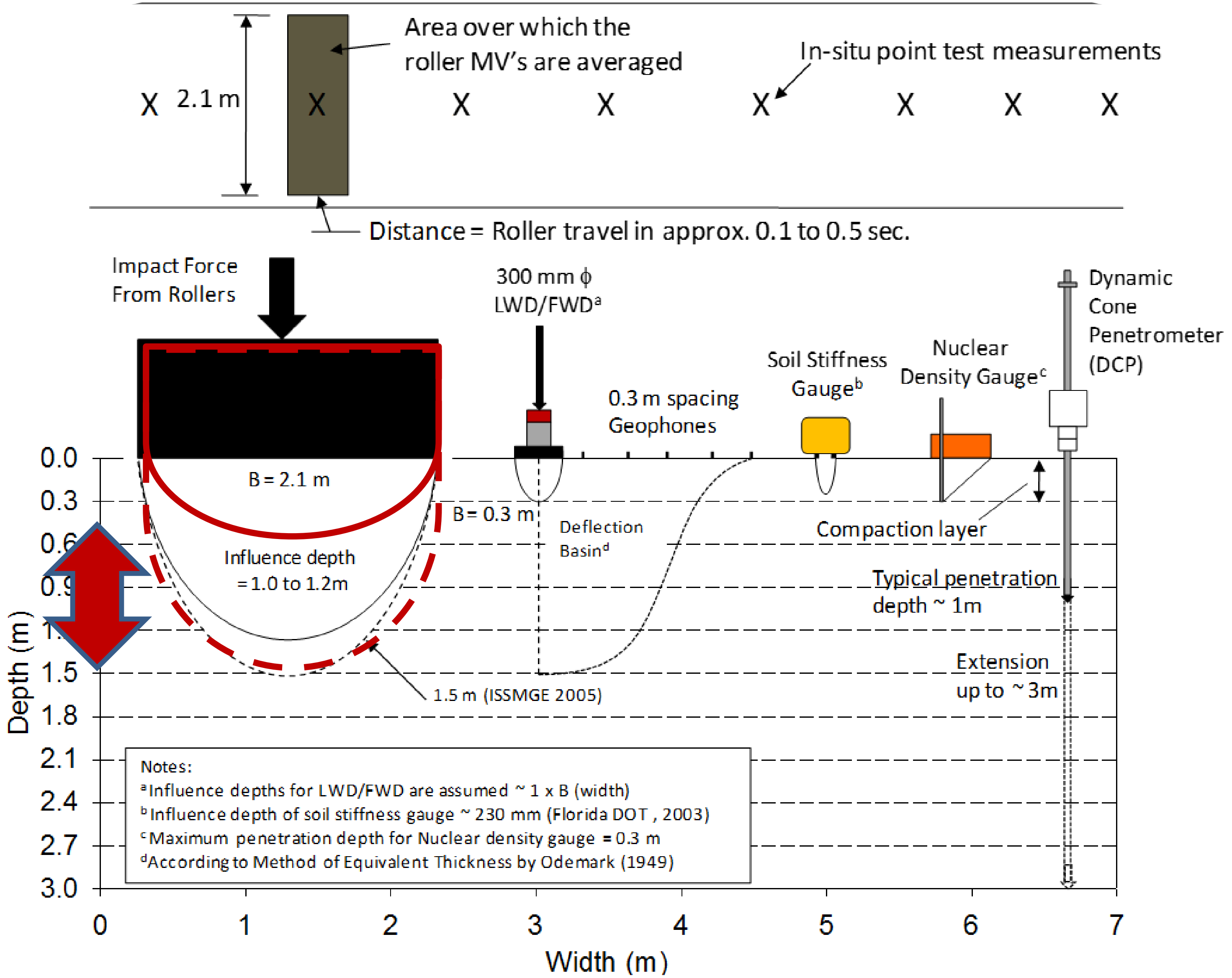


TPF IC project at TxDOT

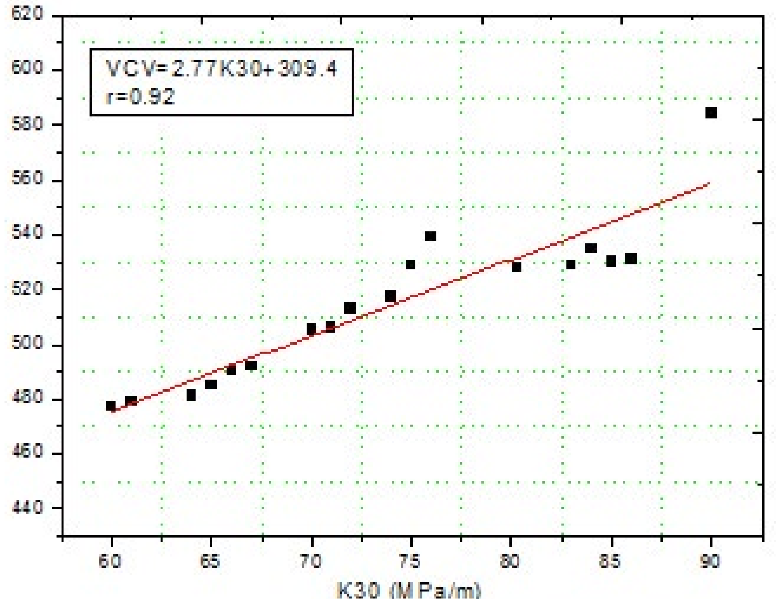
Challenges on Correlation

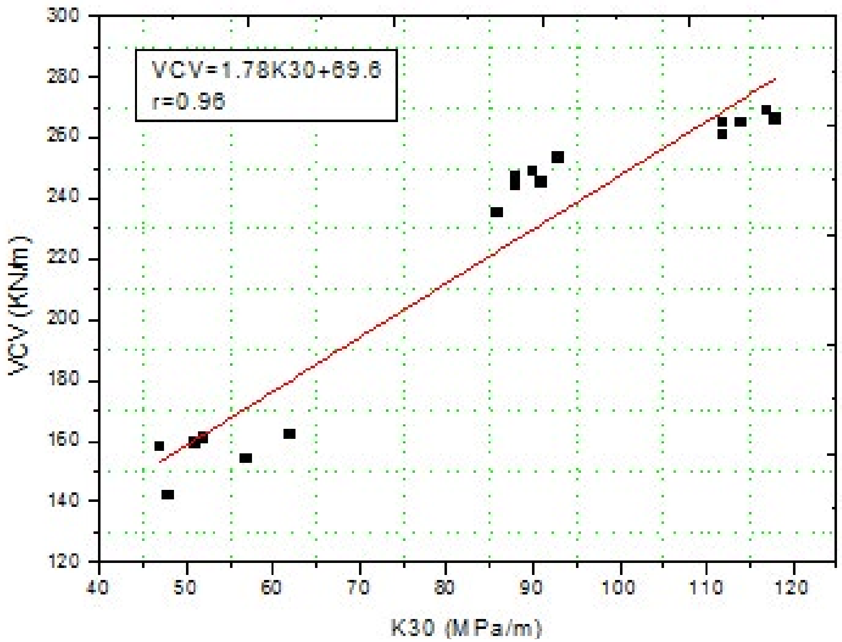
0.5 m **20 in.**

1.2 m **5 ft**



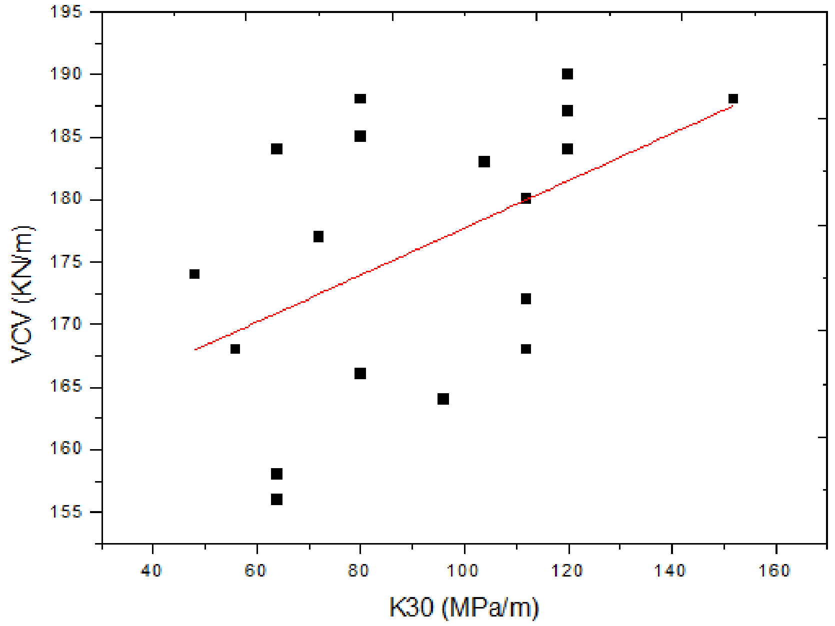
Correlation Cases





Courtesy Prof. G Xu

Correlation Cases



Courtesy Prof. G Xu

FHWA IC Field Demo

Field Work Plan

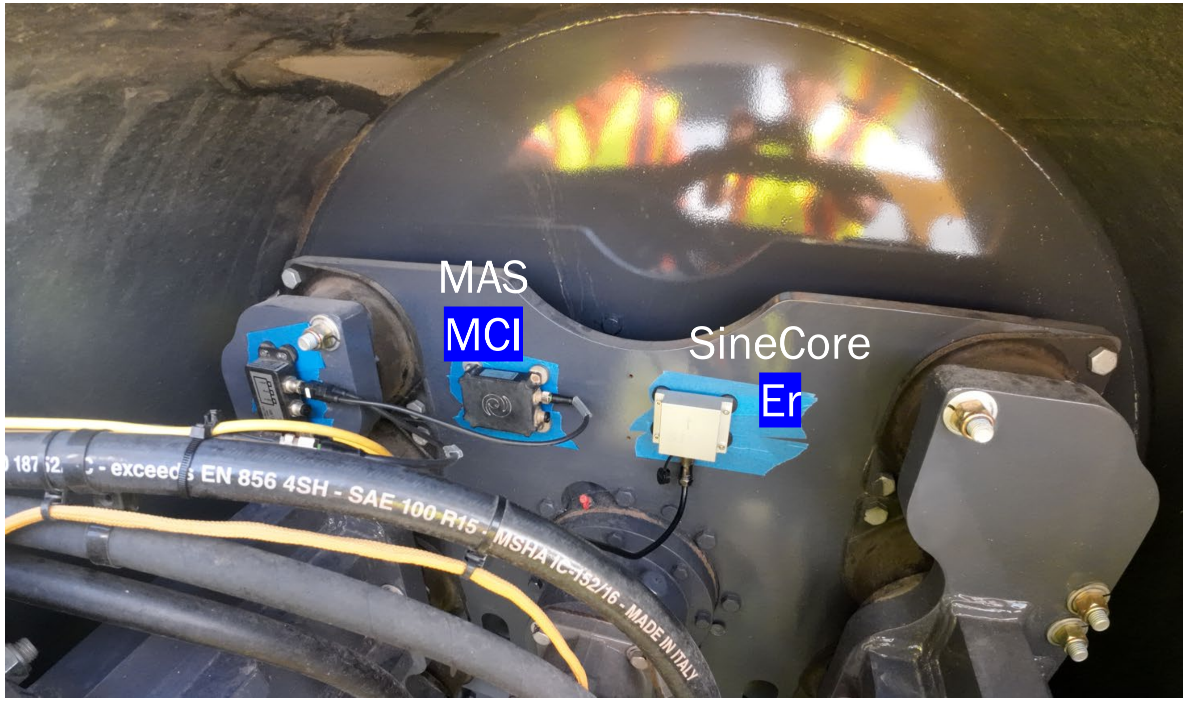
- Test Site Selection
- 3+ Days of field tests
  - Day 1 – Roller instrumentation and Mapping test section’s subgrade
  - Day 2 – Mapping test section’s subbase
  - Day 3 – Mapping near-by subbase sections

XCMG Single Drum Roller

XCMG XS165 Smooth Drum Roller

MOBA IC Retrofit System

- MOBA MCA-3000 IC Retrofit with MAS (MCI) and SineCore (Er)



IC Demo # 1 - MnDOT TH 34 Site

MnDOT District 2, Becker Co., SP0303-68, TH34

Tuesday, Aug. 22 to Thursday, Aug. 24, 2023

IC Demo # 2 - MnDOT TH 15 Site

MnDOT District 8, Meeker Co. and Stearns Co. SP4707-26, TH15

Tuesday, Aug. 29 to Thursday, Aug. 31, 2023

IC Demo # 3 - MoDOT I-44 Site

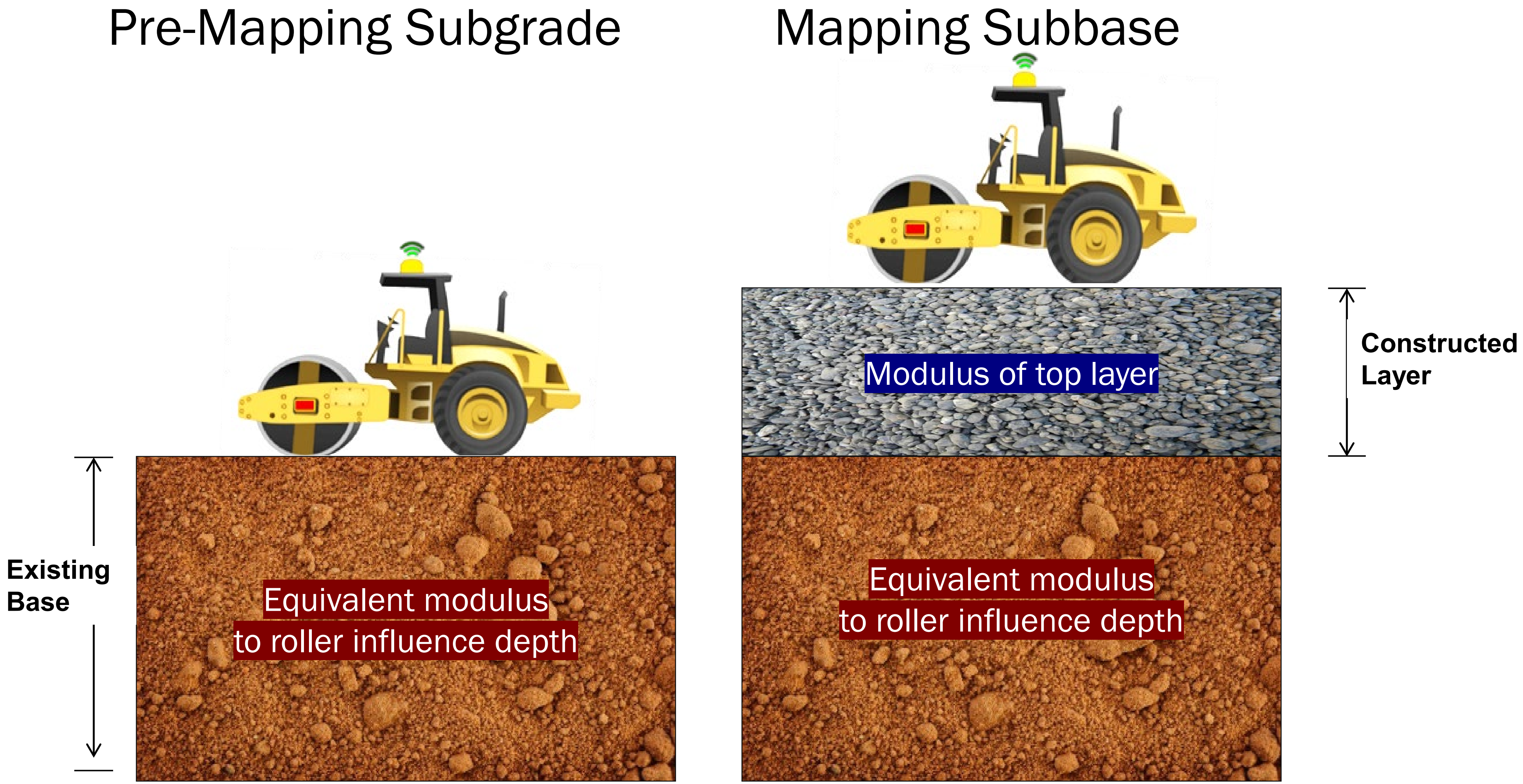
MoDOT Central District, I-44 (East of Rolla, MO)

Oct.9 to Oct. 10, 2023

Initial Set Up and Trial Runs

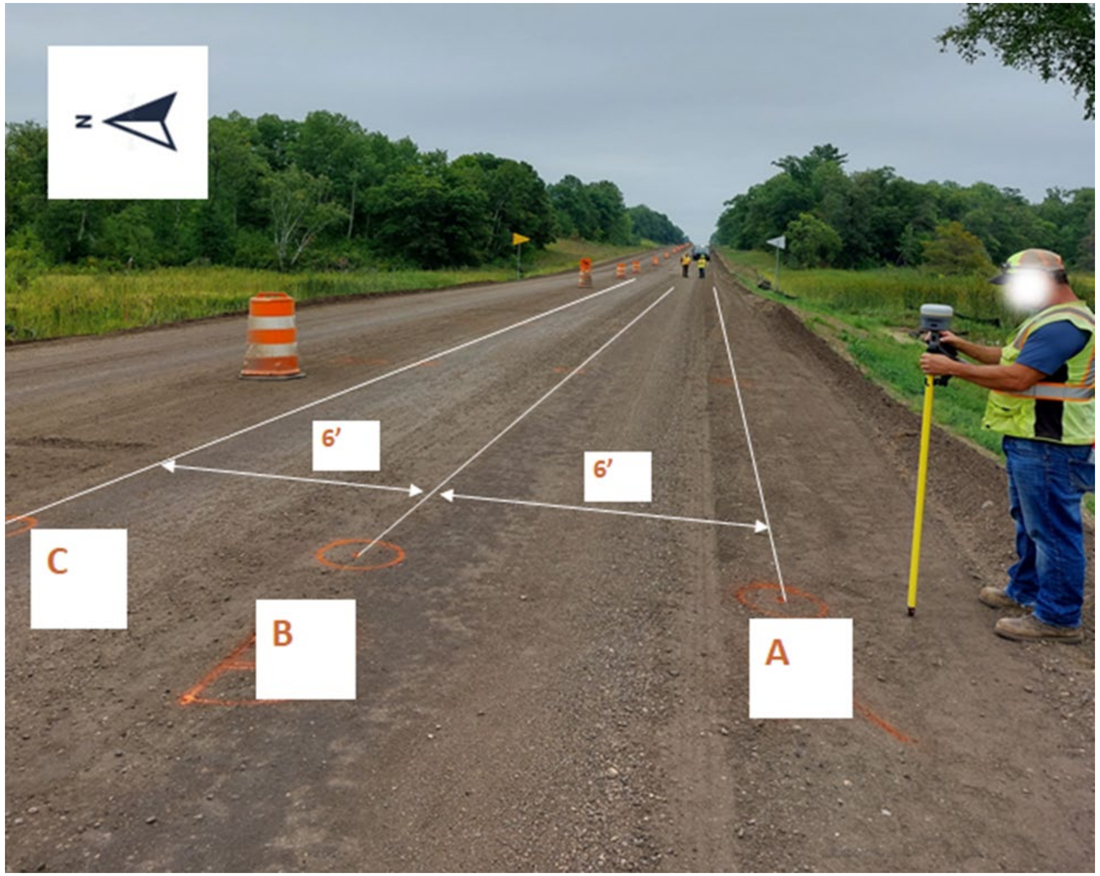
Initial Set Up and Trial Runs

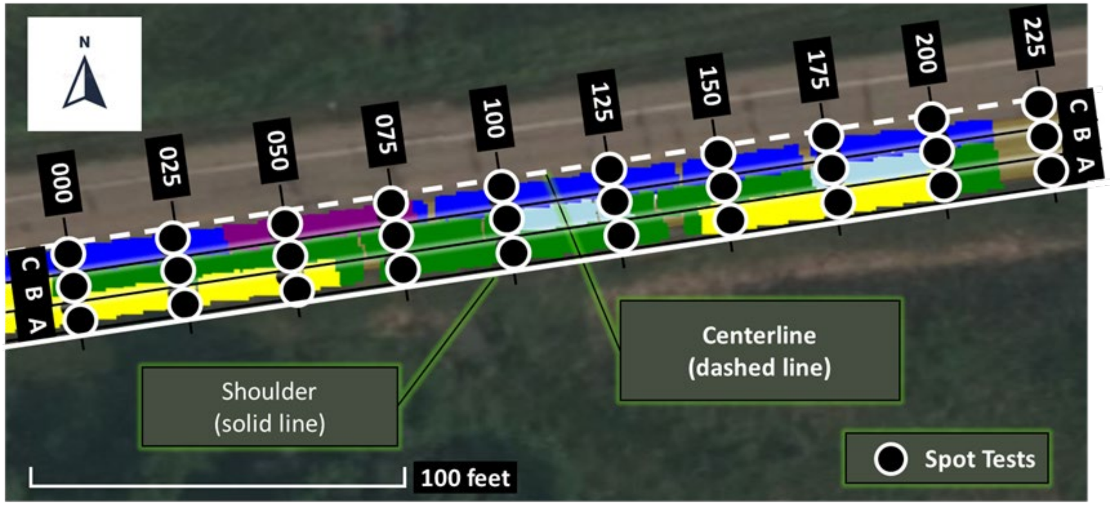
IC Mapping – Two Stages



Gridded section

- 250 ft X 24 ft
- Three test lines
- Grid spacing 25 ft





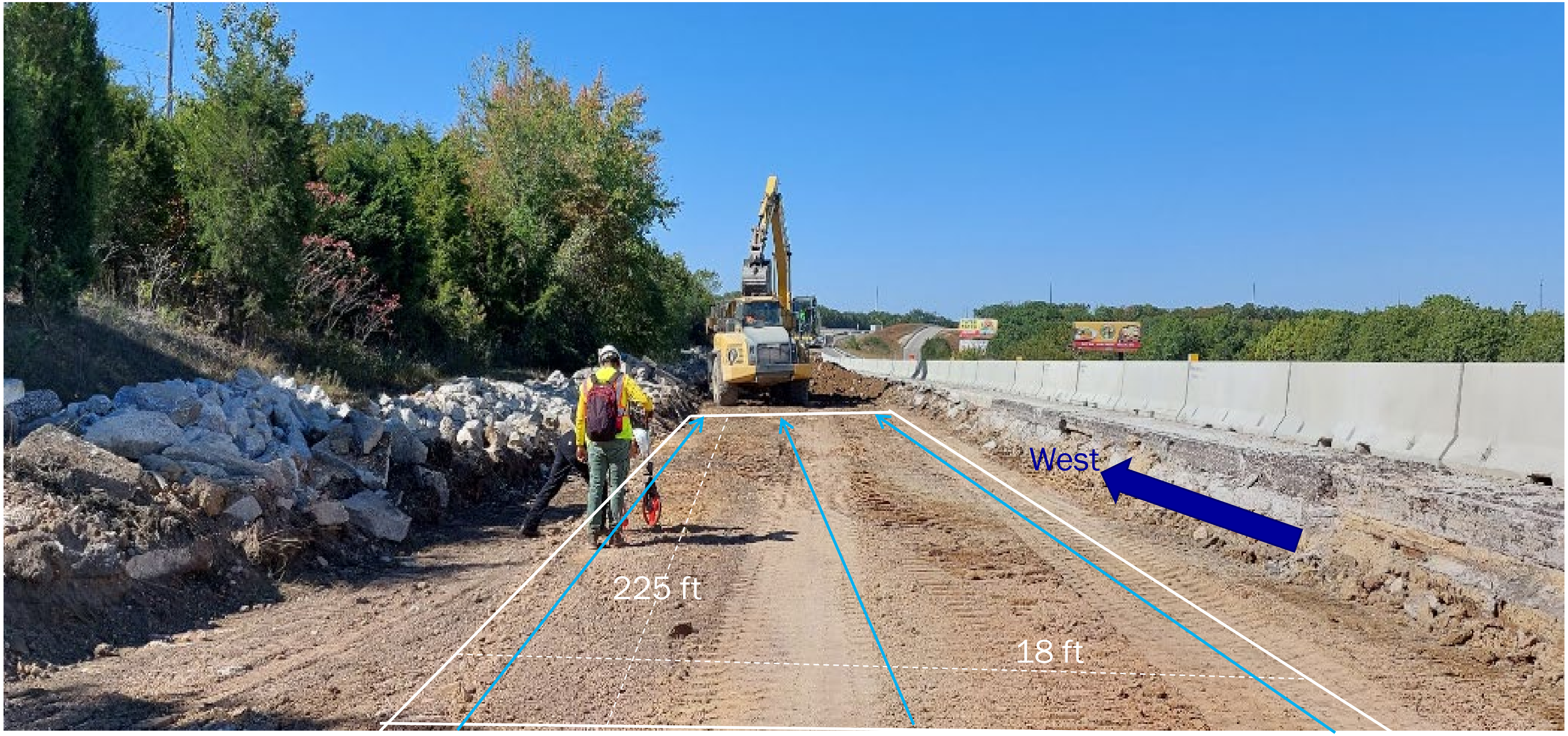
Soft/Medium/Hard Sections

Test Sections

- Demo No.1
  - Gridded Section: Subbase Mapping only (SG not available)
  - L/M/H sections mapping
- Demo No.2
  - Gridded Section: Subbase mapping only (SG not available)
  - L/M/H sections mapping
- Demo No.3
  - Gridded Section: Subgrade mapping and Subbase mapping
  - No L/M/H sections mapping (near-by mapping not available)

Subgrade Mapping

Test section:
225 ft X 18 ft
Three test lines
Spot tests 25 ft apart



IC Mapping on the Subgrade

A Weak Subgrade Area

Subbase Testing

Test section:

- 250 ft X 18 ft
- Three test lines
- Spot tests 25 ft apart

IC Mapping on Subbase

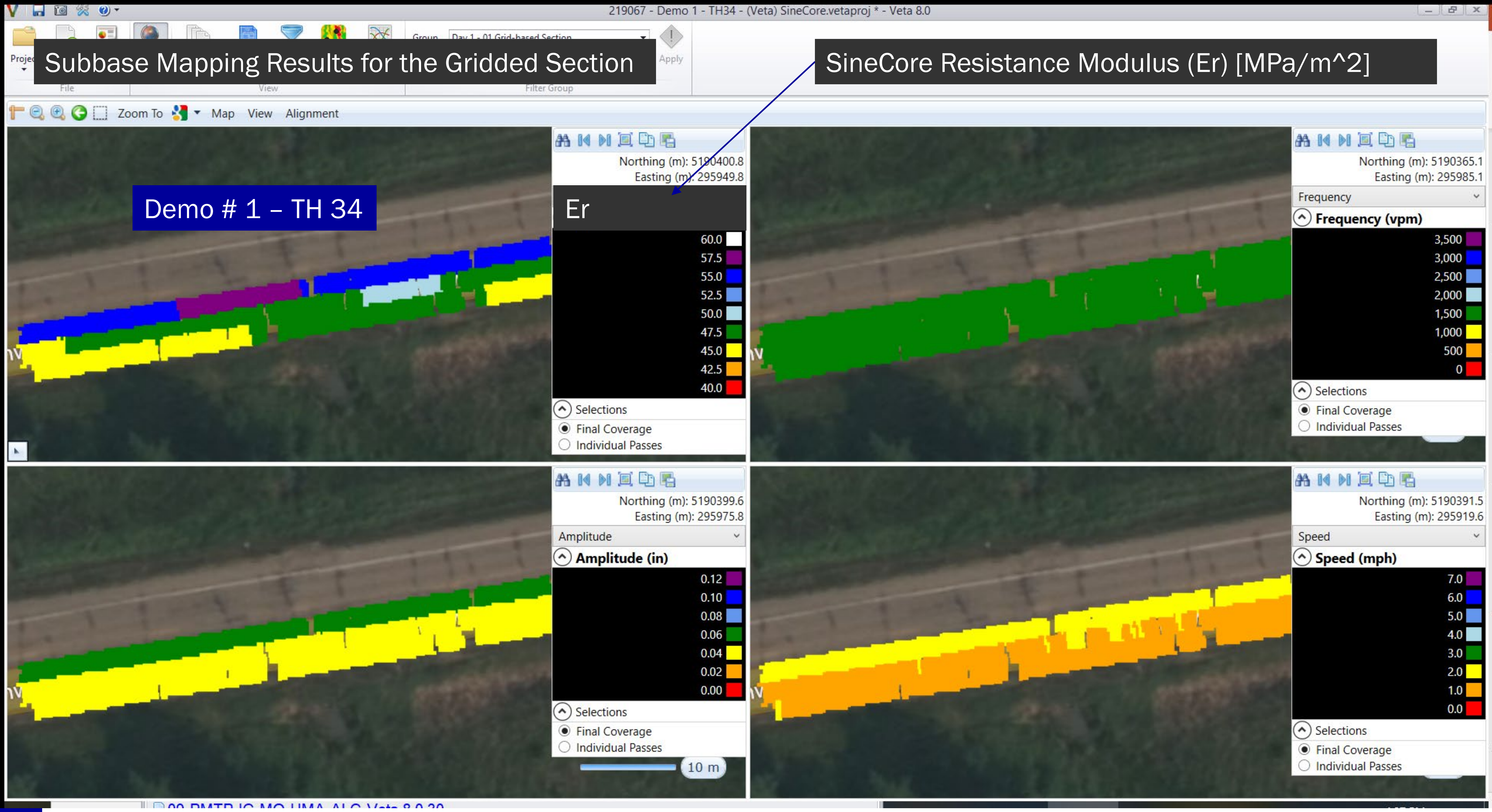
LWD and NDG Spot Tests

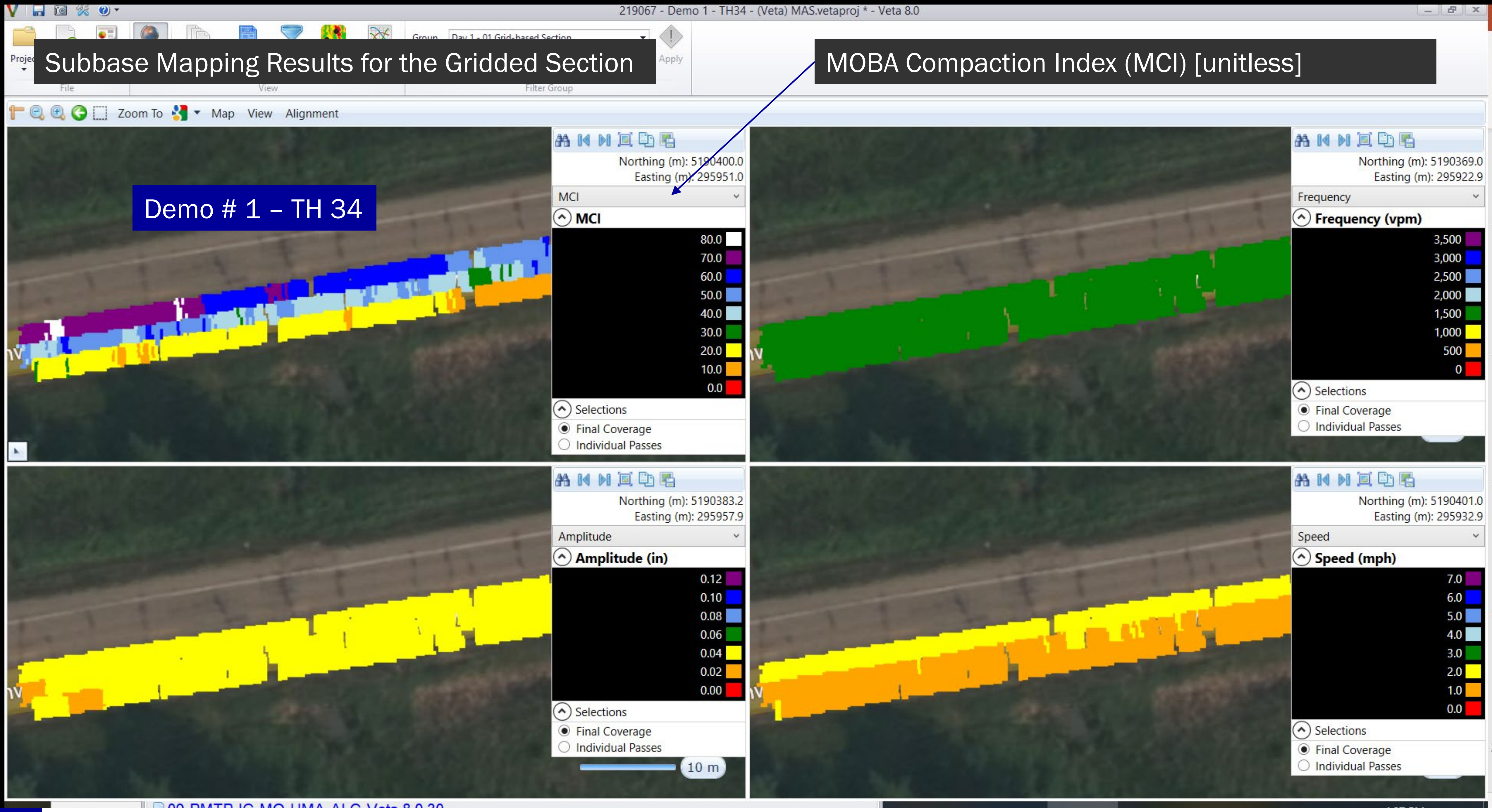
LWD and GPS Tests

Example Results

Subbase Mapping Results for the Gridded Section

SineCore Resistance Modulus (Er) [MPa/m^2]



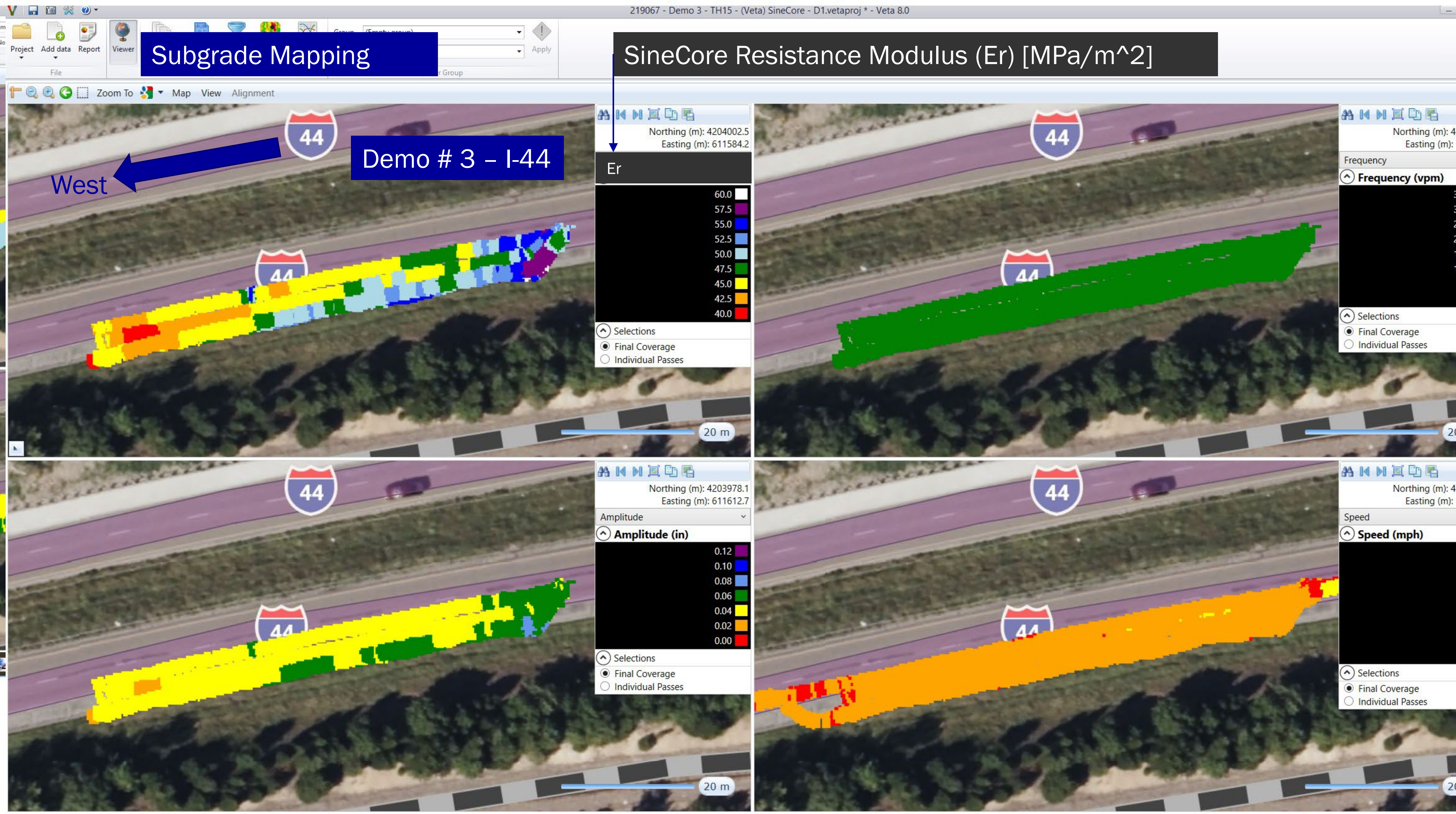


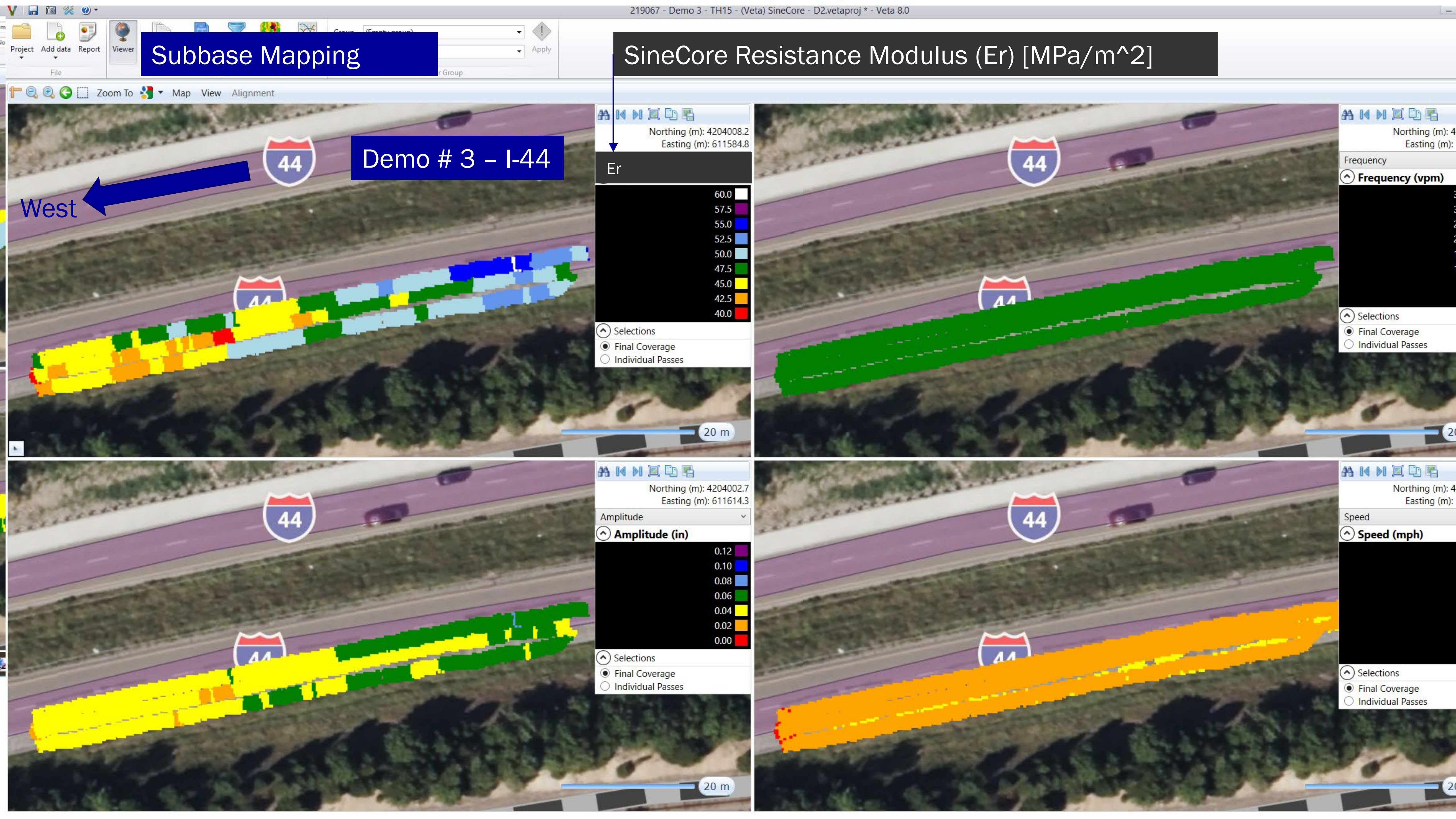
219067 - Demo 1 - TH34 - (Veta) MAS.vetaproj * - Veta 8.0
Subbase Mapping Results for the Gridded Section
MOBA Compaction Index (MCI) [unitless]
Demo # 1 – TH 34
Apply
Filter Group
Zoom To
Map
View
Alignment
Northing (m): 5190400.0
Easting (m): 295951.0
MCI
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Selections
Final Coverage
Individual Passes
Northing (m): 5190369.0
Easting (m): 295922.9
Frequency
Frequency (vpm)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Selections
Final Coverage
Individual Passes
Northing (m): 5190383.2
Easting (m): 295957.9
Amplitude
Amplitude (in)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Selections
Final Coverage
Individual Passes
10 m
Northing (m): 5190401.0
Easting (m): 295932.9
Speed
Speed (mph)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Selections
Final Coverage
Individual Passes

Subgrade Mapping

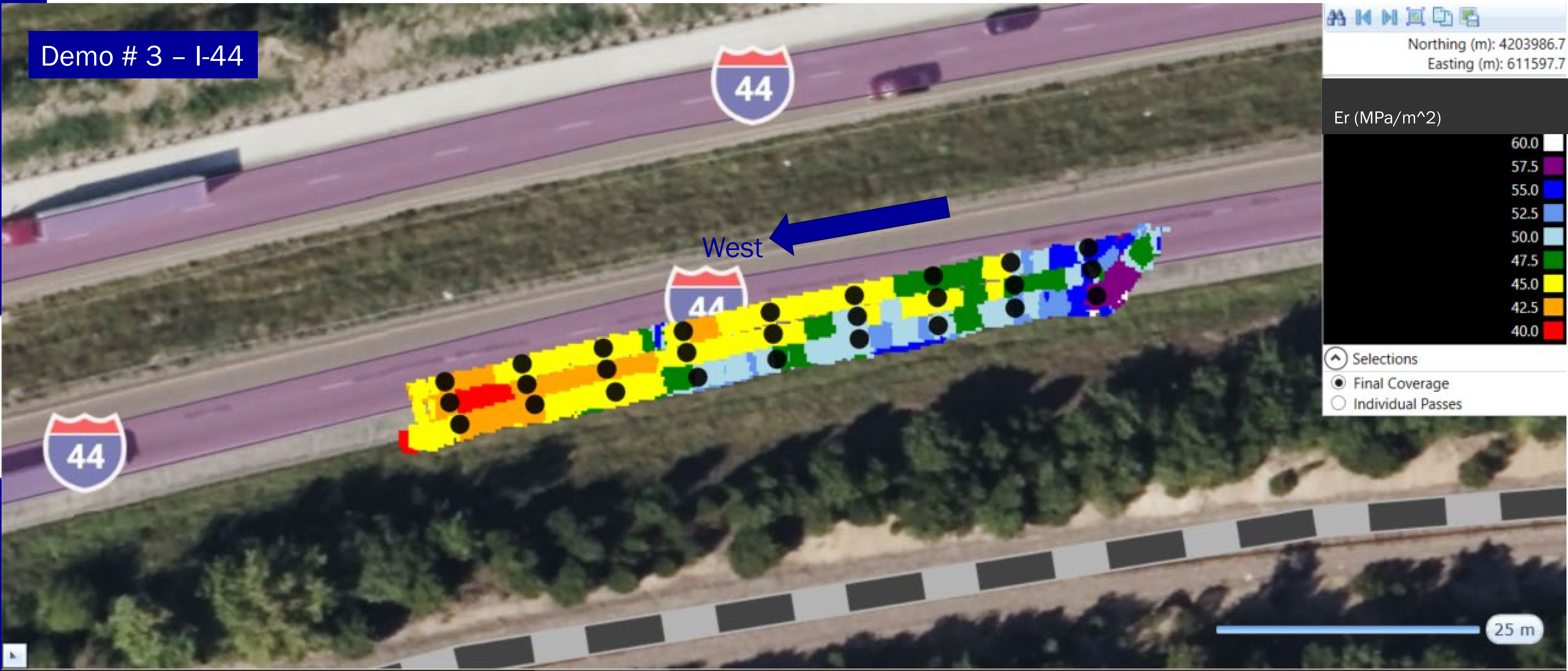
SineCore Resistance Modulus (Er) [MPa/m^2]

Demo # 3 – I-44



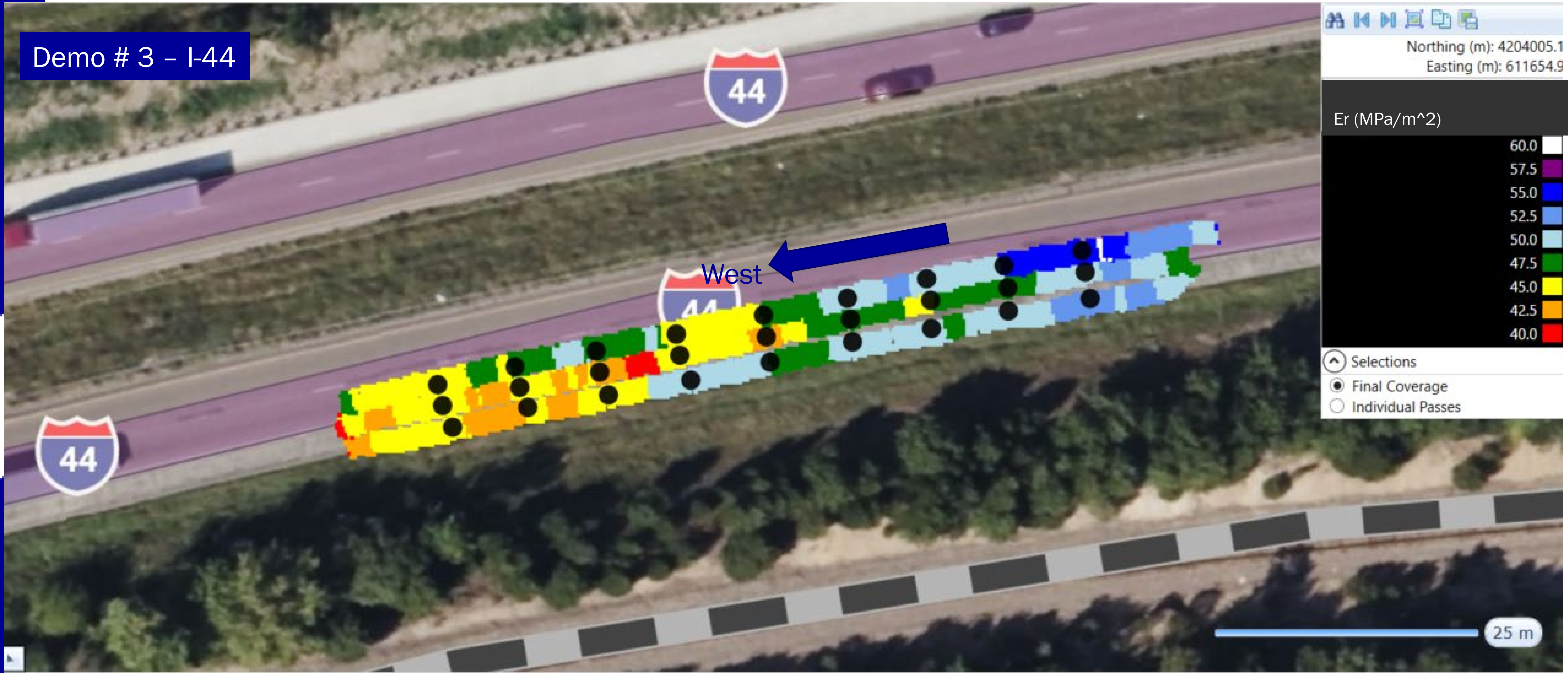

219067 - Demo 3 - TH15 - (Veta) SineCore - D2.vetaproj * - Veta 8.0
Project
Add data
Report
Viewer
File
Apply
Subbase Mapping
SineCore Resistance Modulus (Er) [MPa/m^2]
Zoom To
Map
View
Alignment
Demo # 3 – I-44
West
44
Northing (m): 4204008.2
Easting (m): 611584.8
Er
60.0
57.5
55.0
52.5
50.0
47.5
45.0
42.5
40.0
Selections
Final Coverage
Individual Passes
20 m
Frequency
Frequency (vpm)
Northing (m): 4204002.7
Easting (m): 611614.3
Amplitude
Amplitude (in)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Speed
Speed (mph)

Subgrade Mapping ICMV Results (Er)



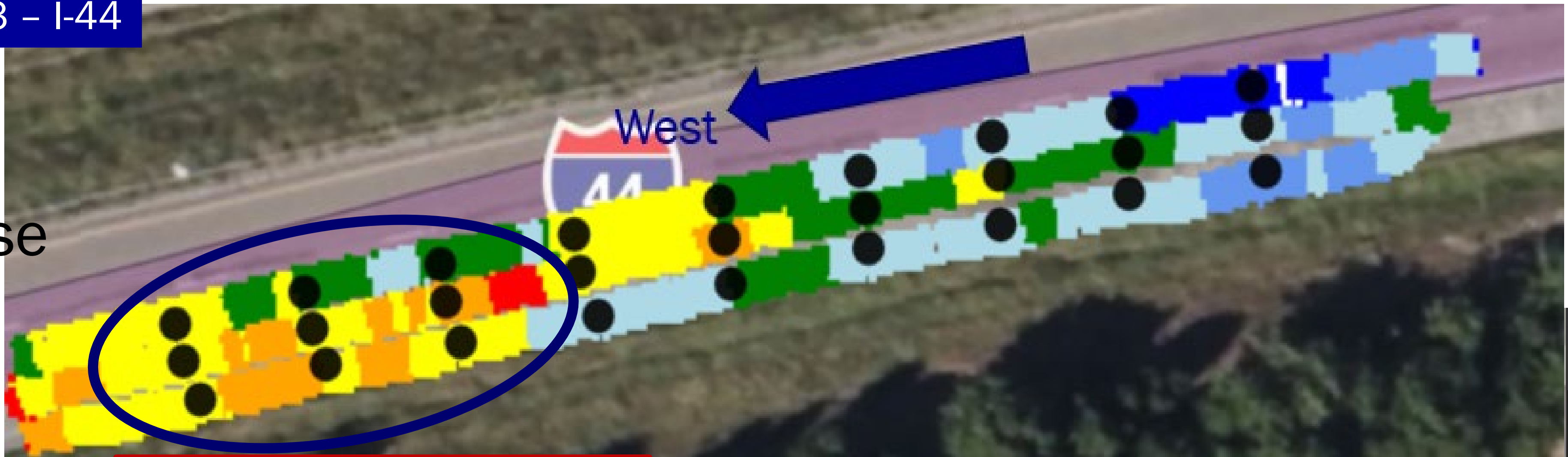

Demo # 3 – I-44
Subbase
West
44
Northing (m): 4203989.8
Easting (m): 611611.6
MCI
MCI
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Selections
Final Coverage
Individual Passes
20 m
Subgrade
West
44
Northing (m): 4203984.9
Easting (m): 611557.7
MCI
MCI
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Selections
Final Coverage
Individual Passes

Subbase Mapping ICMV Results (Er)

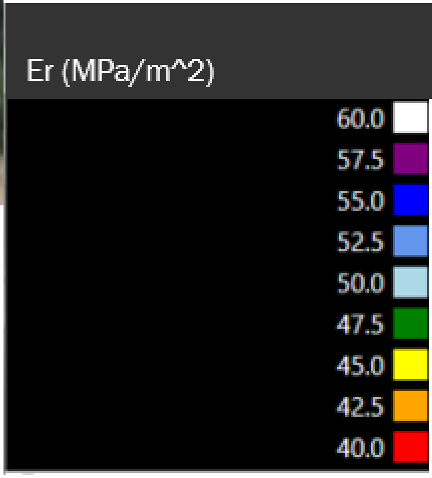


Demo # 3 – I-44

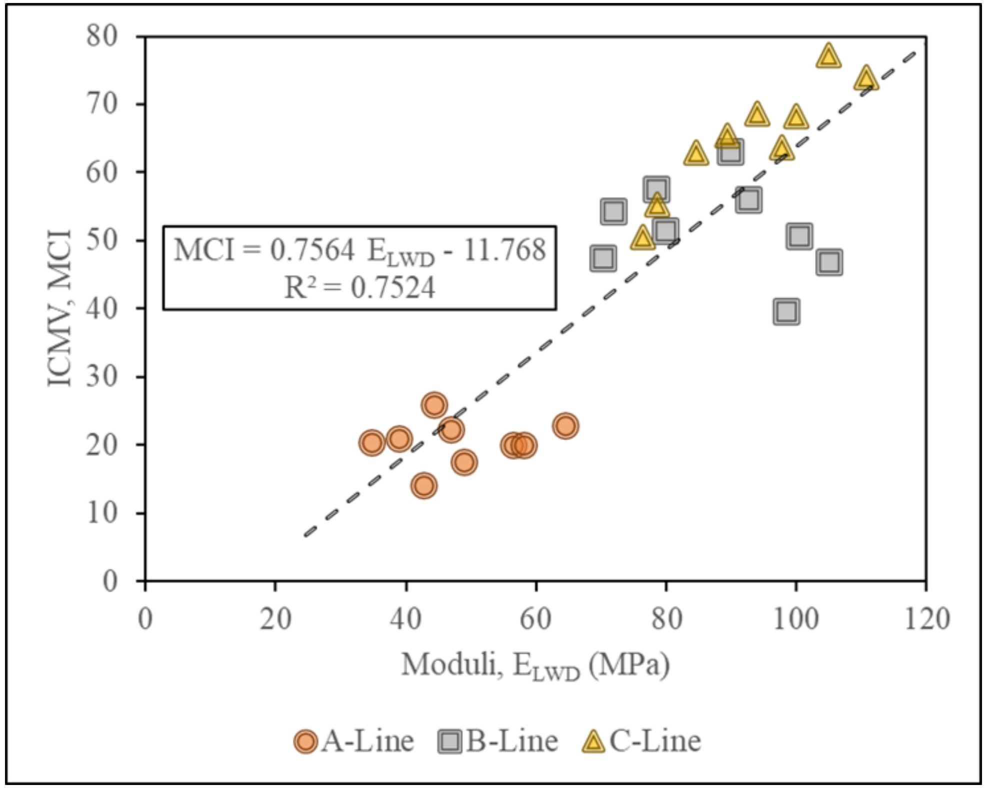
Subbase

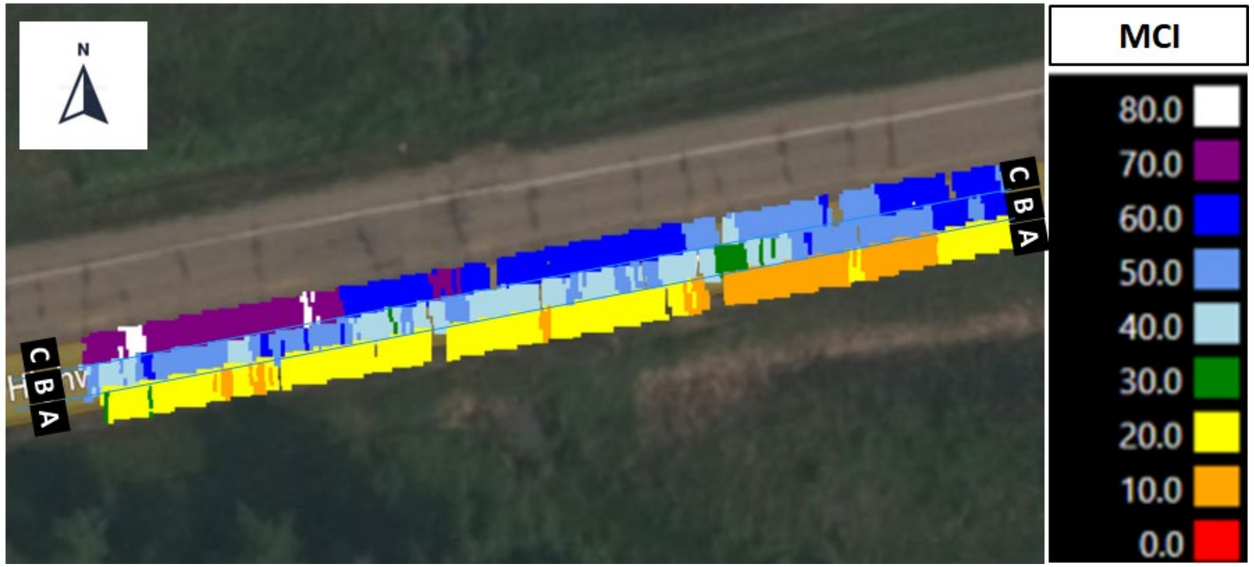


Subgrade



Demo no. 1 - Example Correlation (gridded Section)

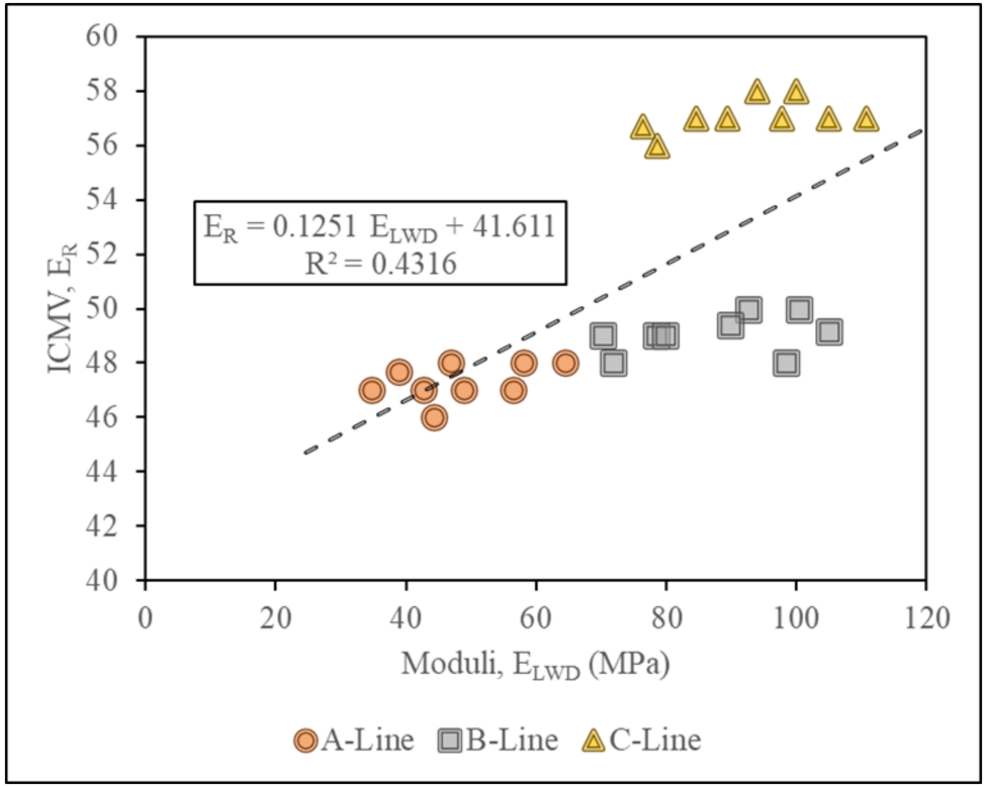


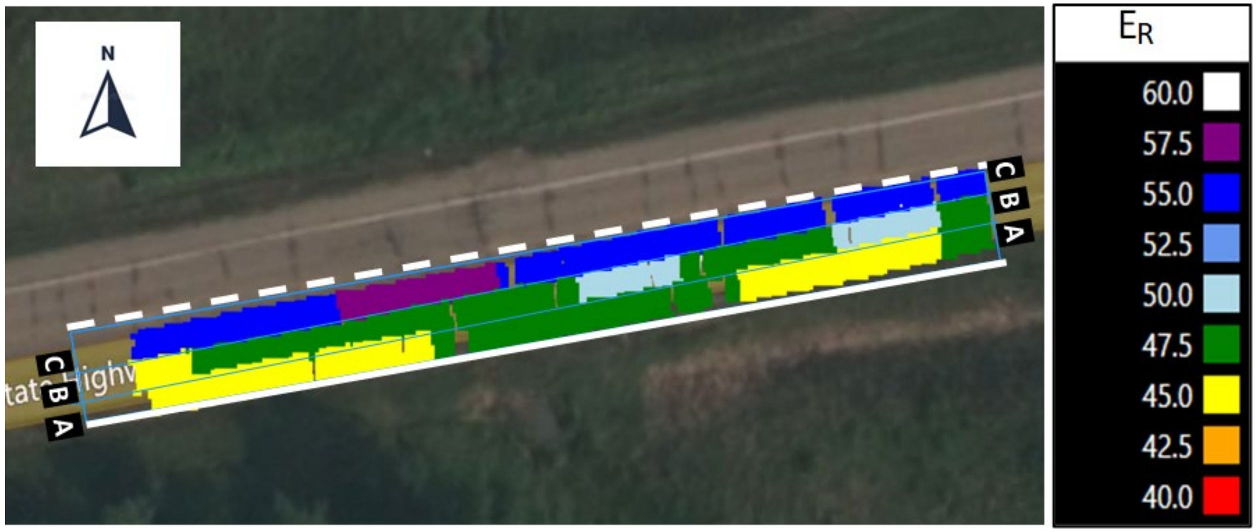


MCI vs. LWD

Relatively Uniform Support
Wide Range of Stiffnesses

Demo no. 1 - Example Correlation (gridded Section)

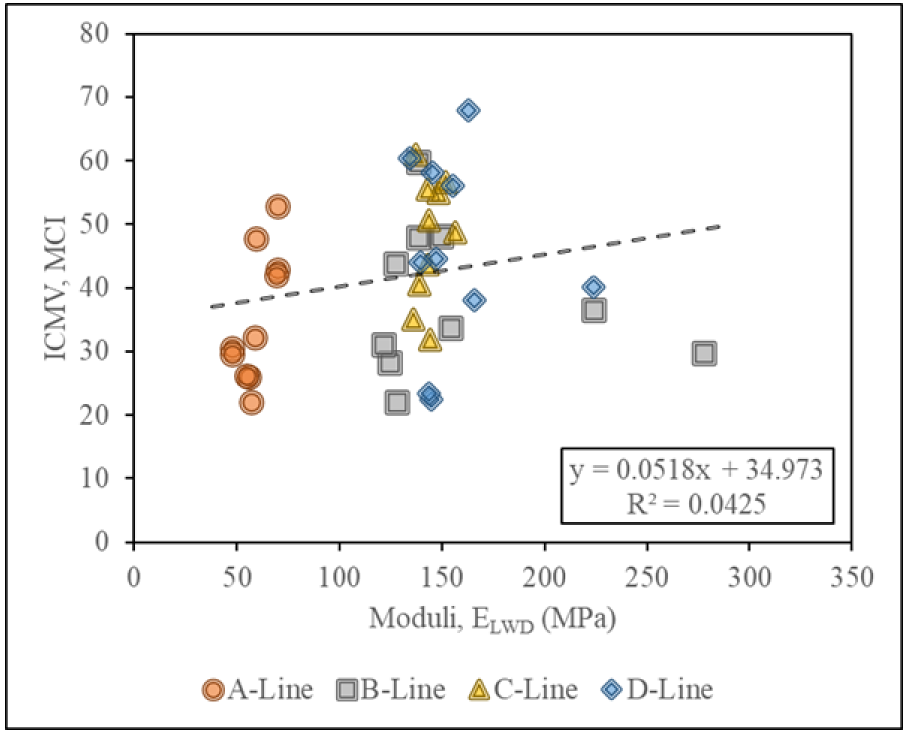


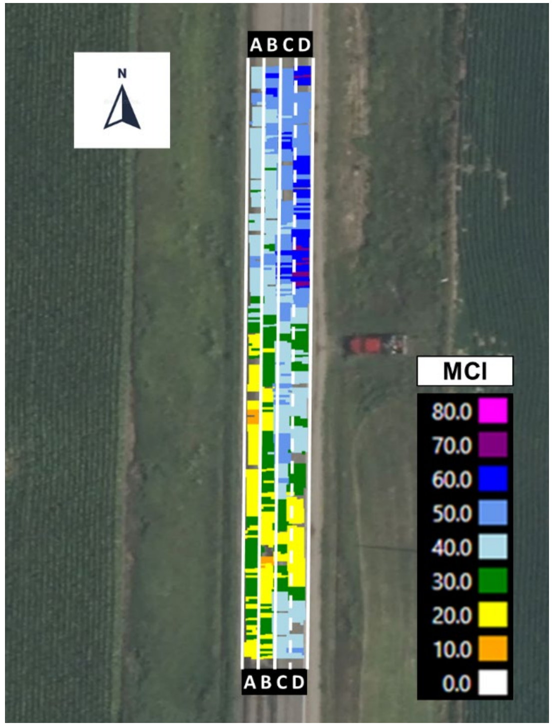


Er vs. LWD

Relatively Uniform Support
Wide Range of Stiffnesses

Demo no. 2 - Example Correlation (gridded Section – Day 1)

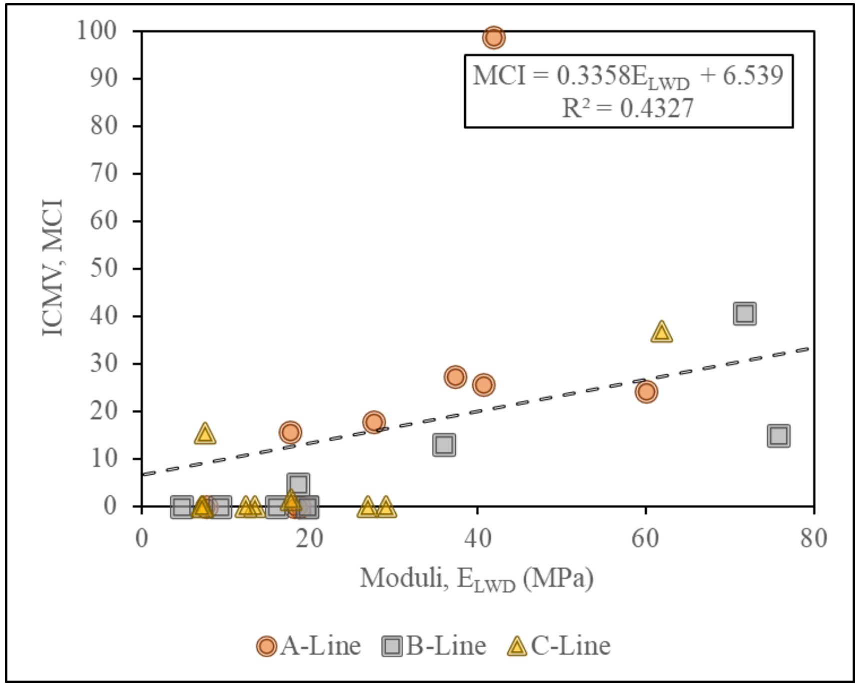


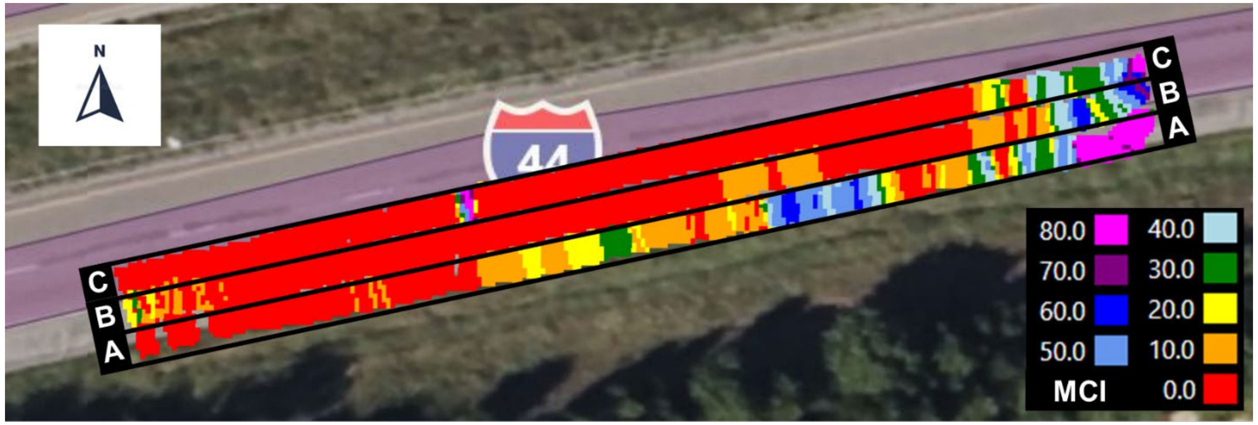


MCI vs. LWD

SB Extremely Stiff

Demo no. 3 - Example Correlation (gridded section - SG)

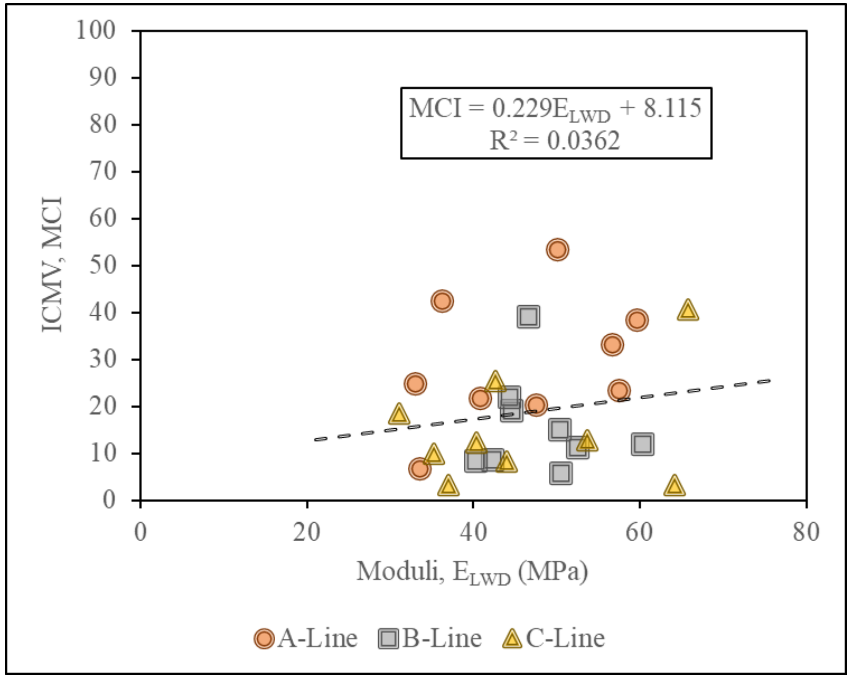


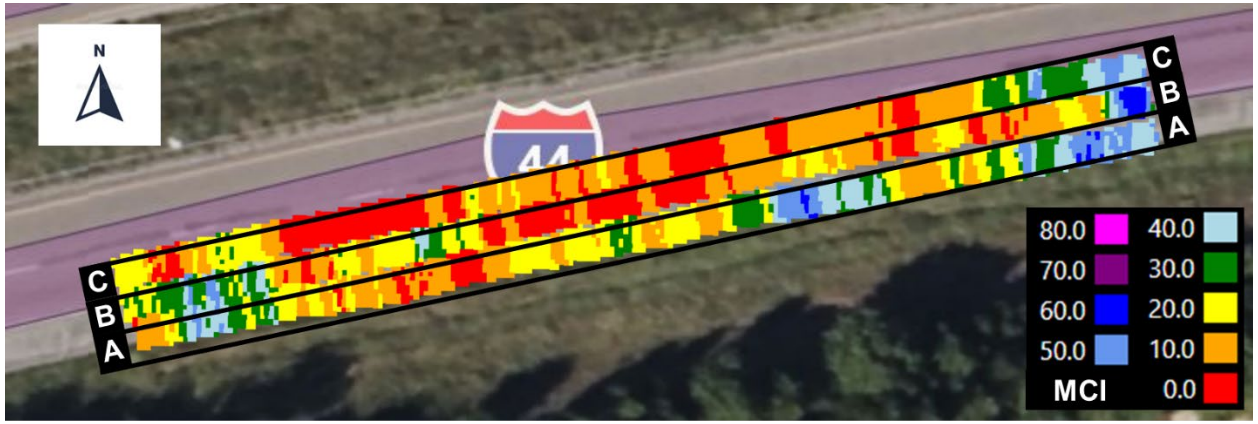


MCI vs. LWD

ICMV bottoms at soft areas

Demo no. 3 - Example Correlation (gridded section - SB)





MCI vs. LWD

18” of Rock Base

LWD Measures 12”

Comparison of Test Efficiency

Gridded Test Sections

LWD
2 Hours
Spot Tests

NDG
6 Hours
Spot Tests

IC Mapping
10 Min.
100% Coverage

Summary of Findings

(Draft) Summary of Findings

- IC mapping in gridded sections is efficient (20X and 50X faster than LWD and NDG) and has 100% full coverage.
- Subgrade mapping is not always available due to the construction pace.
- If subgrade mapping is available, it'd help to interpret subbase mapping and correlation results.
- Correlation results are affected by different footprints and influence the depths of testing and field uniformity.
- Even relative ICMVs from mapping (proofing) the entire constructed surface are great values to identify quality issues and potential weak spots.
- IC procedures need to be SIMPLIFIED for the industry to adopt.
- Higher Levels of ICMVs would help.

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