NATIONAL ACADEMIES *Sciences Engineering Medicine*

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Protocols for Macrotexture Measurement to Prevent Wet Weather Crashes

October 27, 2022

2:30 – 4:00 PM

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Beth Ewoldsen at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

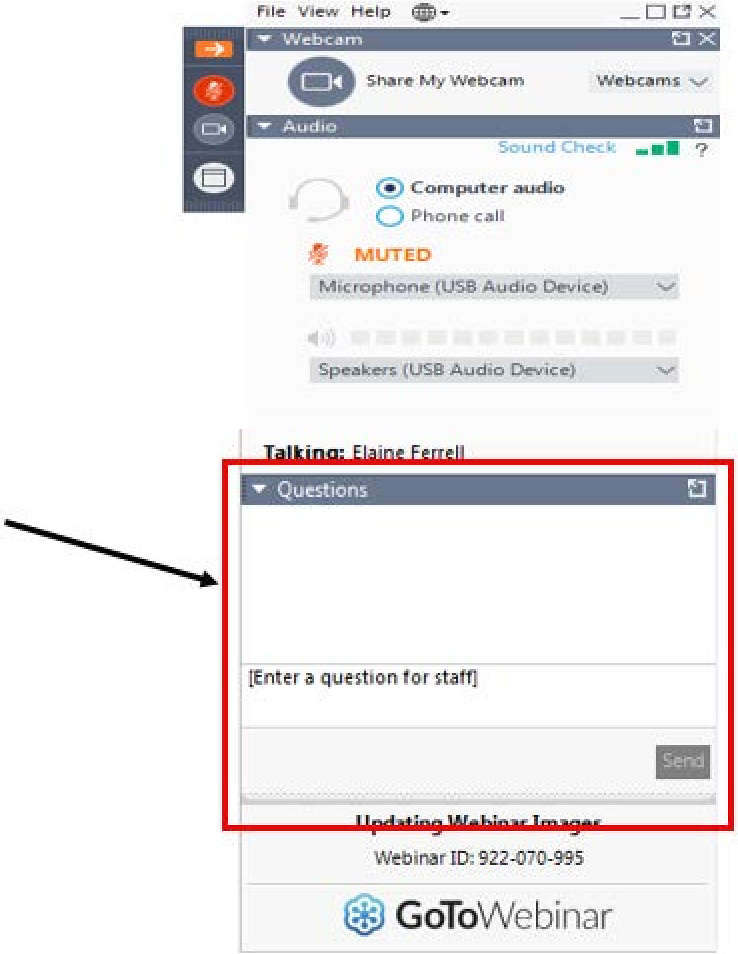
RCEP
REGISTERED CONTINUING EDUCATION PROGRAM

Learning Objectives

- Collect accurate and repeatable macrotexture data

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today’s presenters

Gerardo Flintsch
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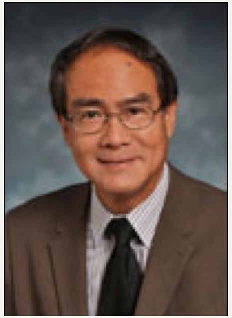
Virginia Polytechnic Institute and State University



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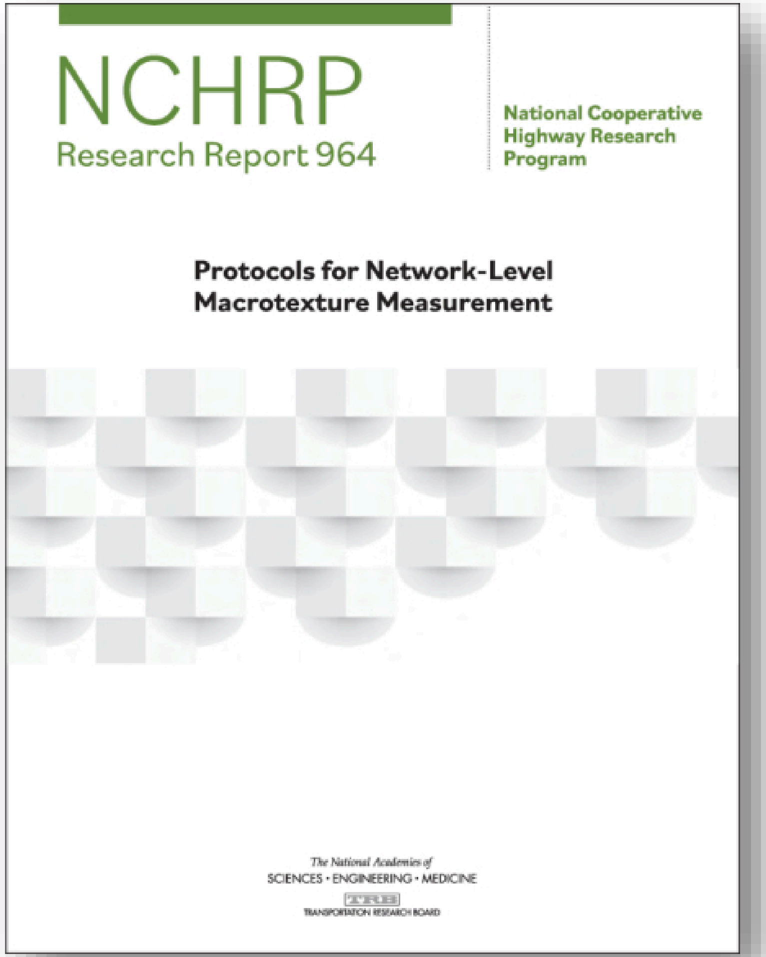
NCHRP Project 10-98: Protocols for Network-Level Macrotexture Measurement

Background

NCHRP Report 964 Protocols for Network-Level Macrotexture Measurement (2021)

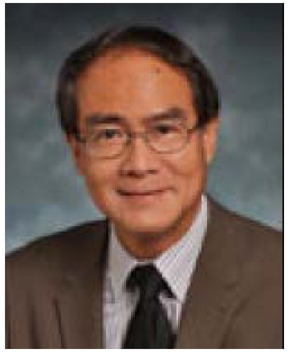


Gerardo Flintsch

Edgar de Leon

Vincent Bongioanni

Kyle Maeger



Emanuel Fernando

Rohan Perera

Kevin McGhee

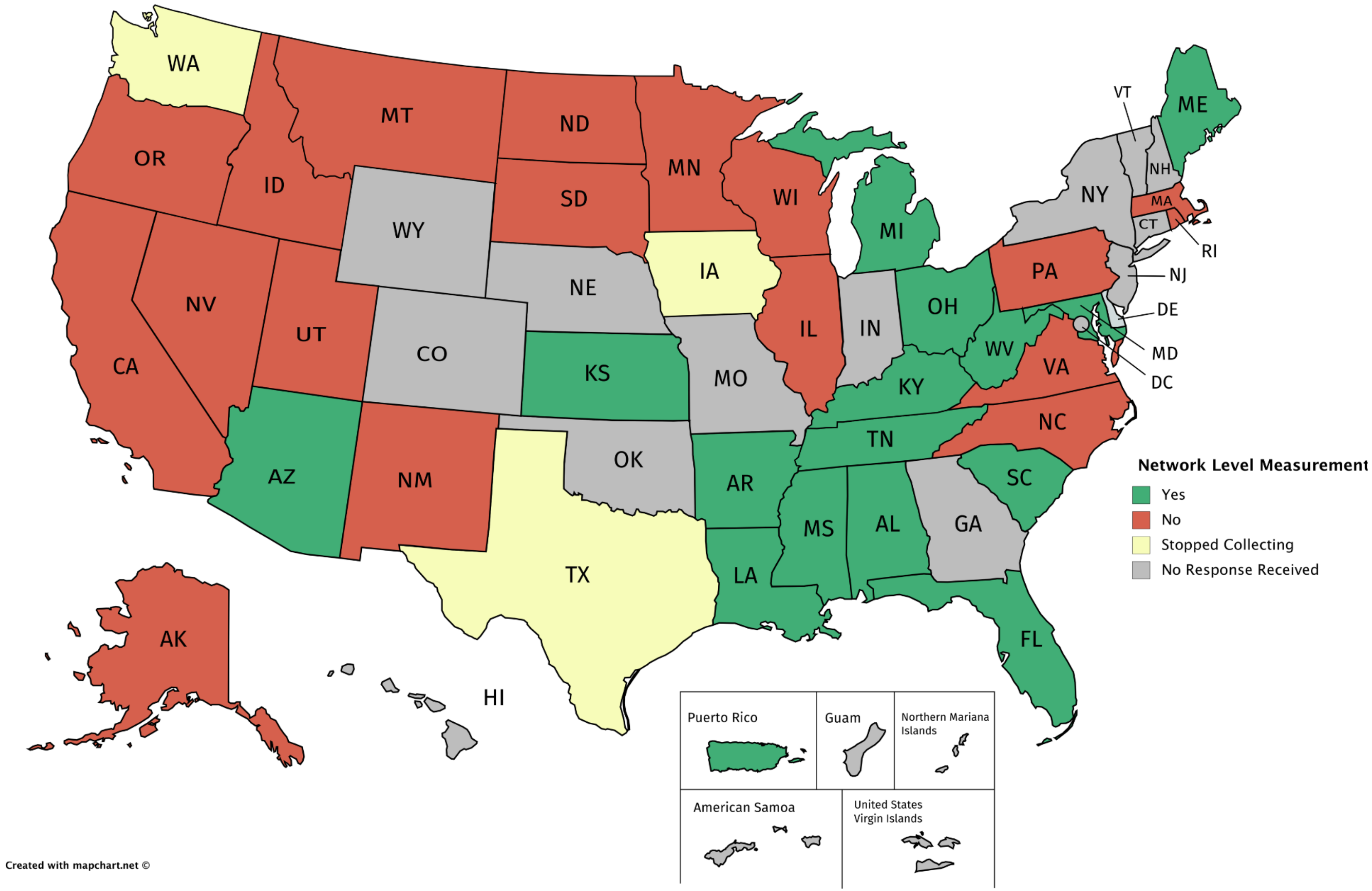
https://www.nap.edu/catalog/26225/protocols-for-network-level-macrotexture-measurement

Objective

- ✓ To develop recommended protocols for test methods, equipment specifications, and data quality assurance practice for network-level macrotexture measurement

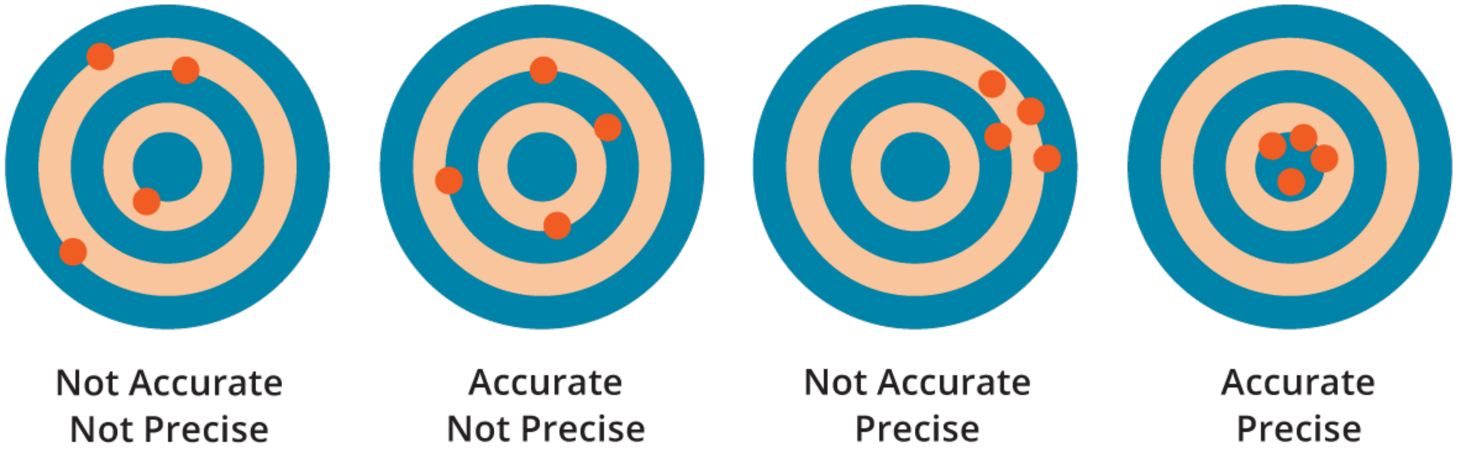
1. Identify the equipment, environmental, and operational factors that influence macrotexture measurement and the macrotexture characterization parameters used for representing the macrotexture,
2. Develop improved methods for network-level macrotexture measurement that address these factors and parameters, and
3. Prepare recommended test procedures, equipment specifications, data quality assurance practices, and implementation guidelines to facilitate use of these methods.

States Collecting Network Level Macrotexture



Criteria for Evaluating Measurement Technologies

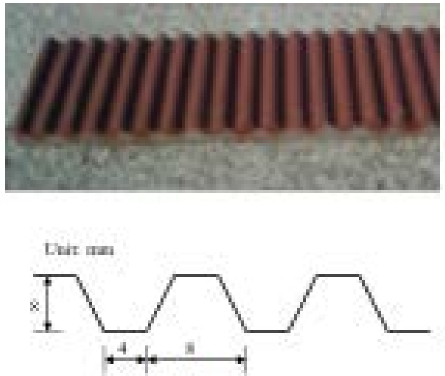
- ✓ Precision and Accuracy
  - – Sub-millimeter under harsh conditions (debris, spray, truck bounce)
  - – Precise: repeatable results under identical experimental conditions
  - – Accurate: unaffected by variations not within control of operator



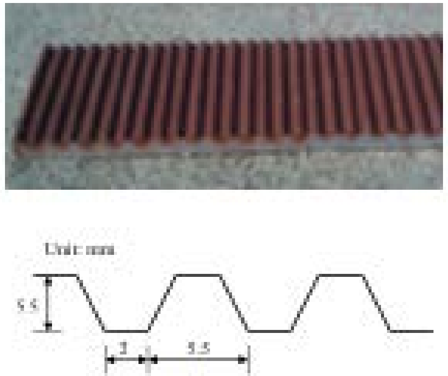
- ✓ Bias
  - – Minimize the difference between the measured and **actual profiles**

Reference Surfaces

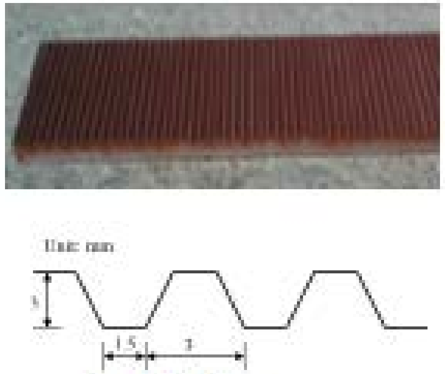
Machined Plates



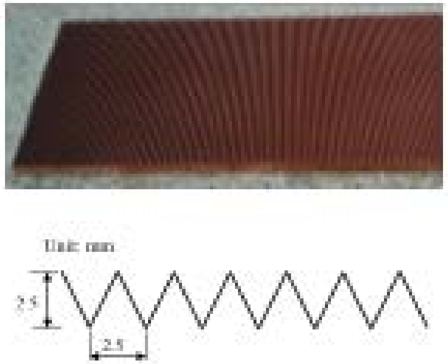
8 mm block



5.5 mm block

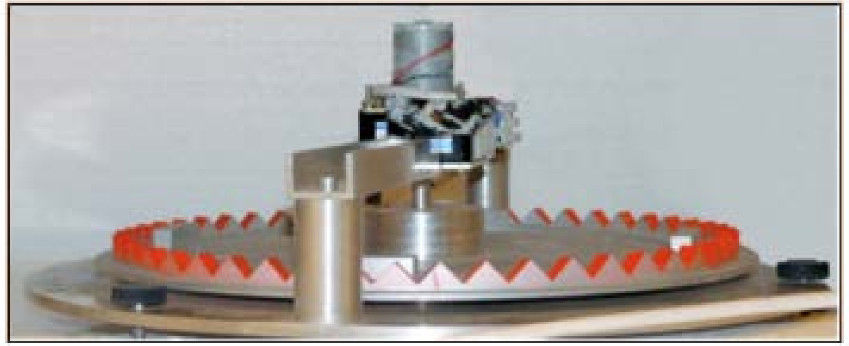


3 mm block



2.5 block

ISO “Calibrator”



ARRB “Texture Jig”

Ames Engineering

Experiments

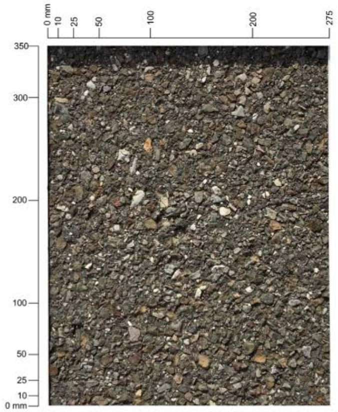
Experiment 1 - Equipment Comparison

- ✓ The Virginia Smart Road

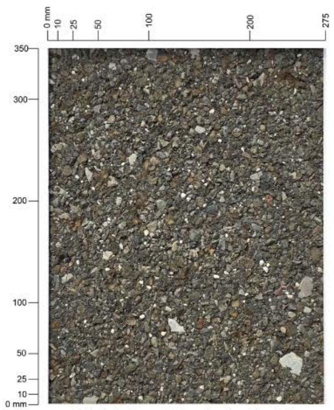
- ✓ Single-spot vs. lane lasers
- ✓ Variable speed and acceleration
- ✓ Repeatability and reproducibility
- ✓ Emerging macrotexture parameters

- ✓ Reference measurements: CT Meter, Ames Laser Texture Scanner, etc.
- ✓ "Waking" devices
- ✓ High-speed

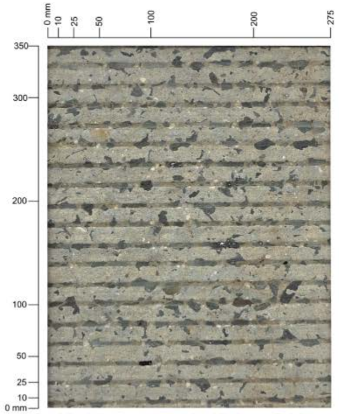
Surfaces Studied



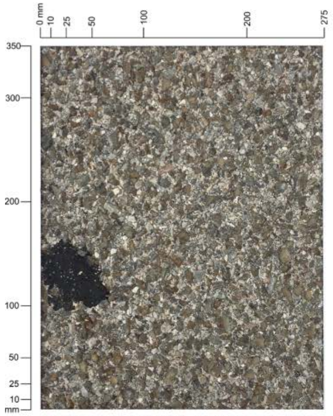
Virginia Smart Road - Section C



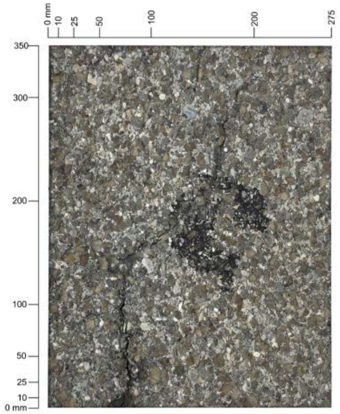
Virginia Smart Road - Section D1



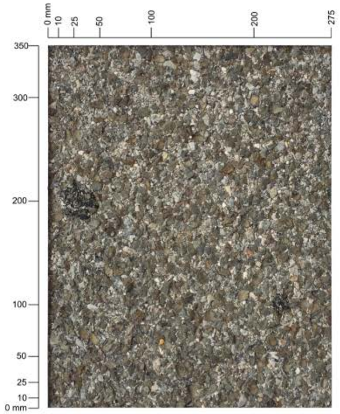
Virginia Smart Road – Highway Bridge



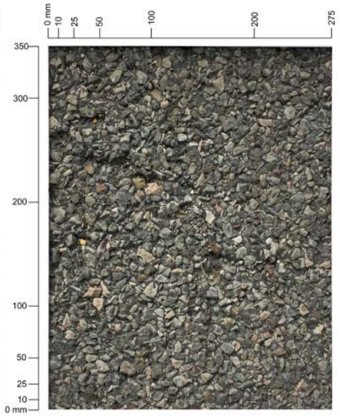
Virginia Smart Road - Sections E2, F, G,



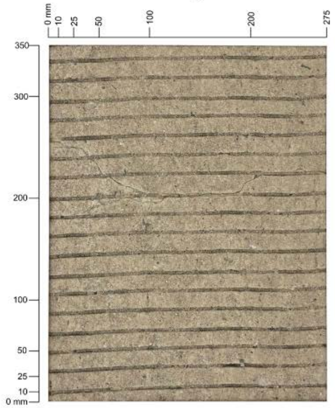
Virginia Smart Road - Section I



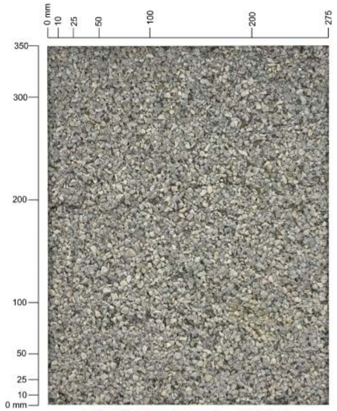
Virginia Smart Road - Section J



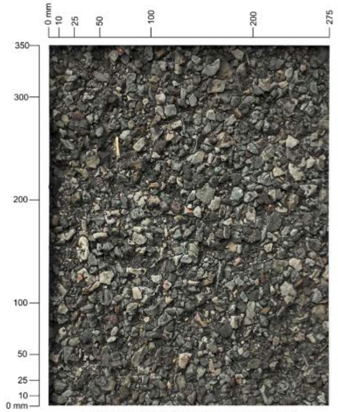
Virginia Smart Road - Section L1



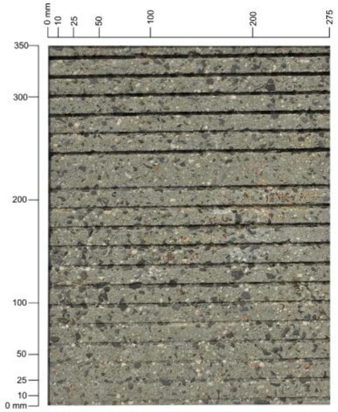
Virginia Smart Road – PCC 1a, c, e, g



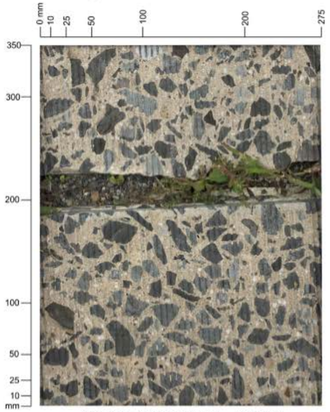
Virginia Smart Road – PCC 1d



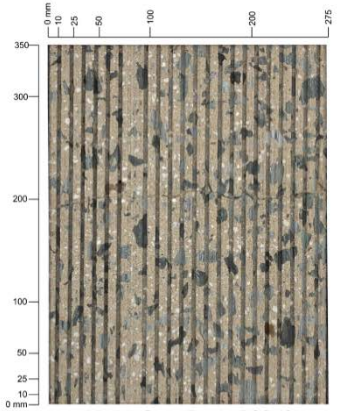
Virginia Smart Road - Section K



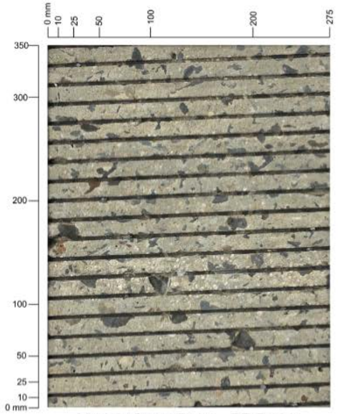
Virginia Smart Road – Smart Road Bridge



Virginia Smart Road – PCC 2



Virginia Smart Road – PCC 1f



Virginia Smart Road – RR Bridge

High Speed Devices Tested at the SR

Device ID	Laser Type	Sampling Frequency	Raw Data Spatial Interval	Vertical Resolution
1*	Single Spot	100 kHz	0.25 mm	0.020 mm
2	Single Spot	32 kHz	1 mm	0.010 mm
3	Single Spot	32 kHz	0.9 mm	0.049 mm
4	Single Spot	100 kHz	0.5 mm	0.020 mm
5	Line Laser	5 kHz	0.3 mm (transverse) 25mm (longitudinal)	0.015 to 0.040 mm
15*	Single Spot	64kHz	0.25 mm	0.045 mm

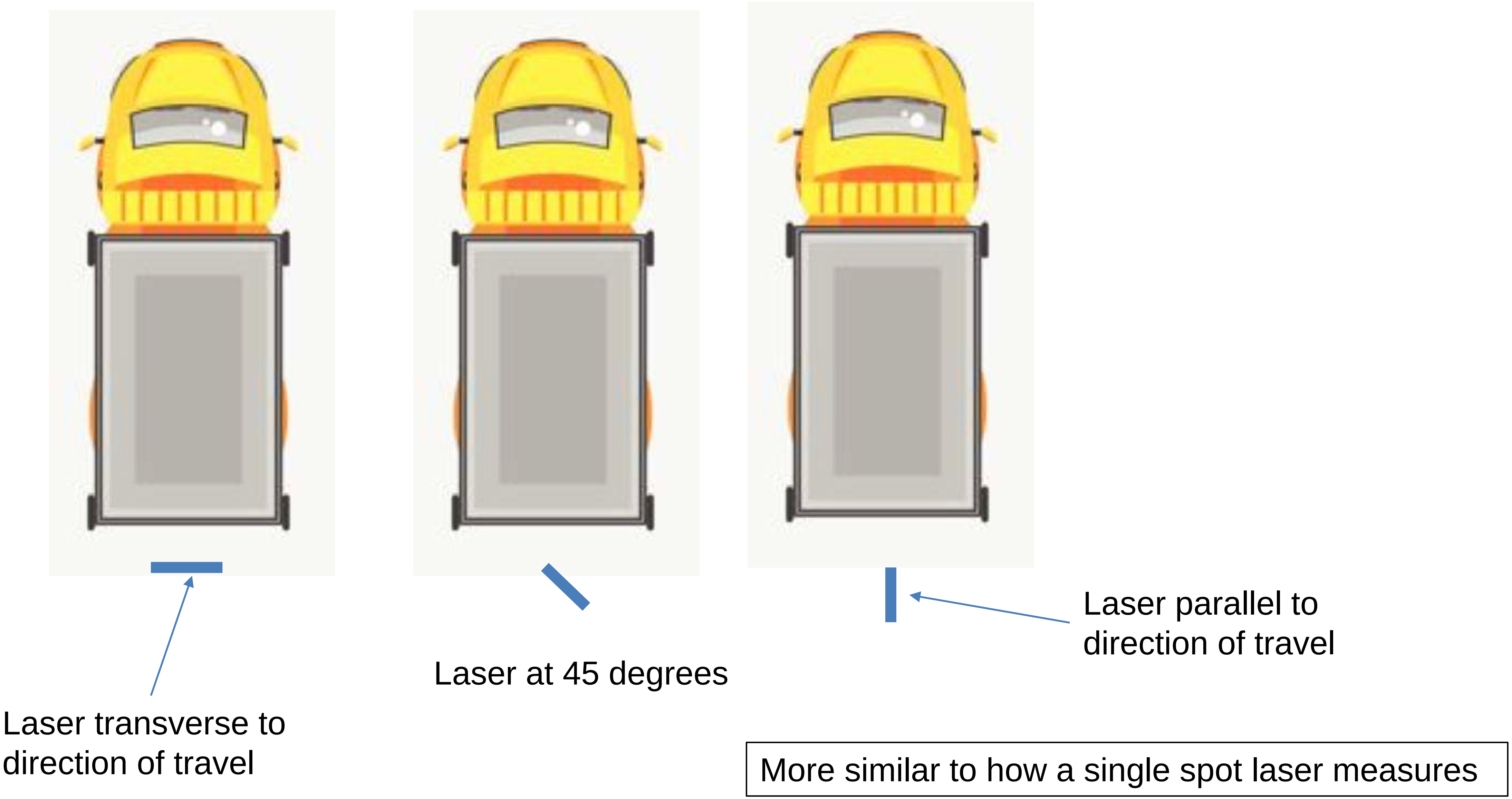
* Sensors 1 and 15 mounted to the same vehicle

Experiment 2 - Verification

MnROAD facility

- ✓ To refine the data collection approaches and finalize the proposed macrotexture characterization parameter(s)

- ✓ Few invited participants
- ✓ “Walking” system as reference
- ✓ Line lasers at different angles
- ✓ Different exposure times


Laser transverse to direction of travel
Laser at 45 degrees
Laser parallel to direction of travel
More similar to how a single spot laser measures

Devices Tested at MnRoad

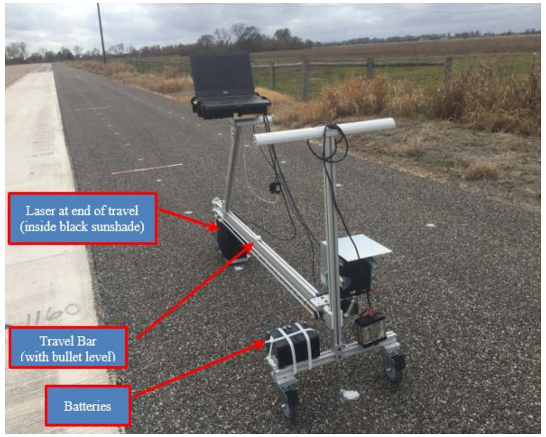
Device ID	Device	Measurement Speed	Sampling Frequency	Raw Data Interval
1	Line	Walking	1kHz	1mm trans 1mm long
2	SSL	50 mph	32 kHz	TBD
3	SSL	50 mph	100 kHz	0.5mm
4	SSL	50 mph	100 kHz	0.25mm
5	SSL	50 mph	62.5 kHz	0.5mm
6	Line	50 mph	5 kHz	0.5 mm trans 25.4 mm long
7	SSL	50 mph	62.5 kHz	0.25mm
8	FTM	Static	NA	NA
9	Line	50 mph	5 kHz	TBD

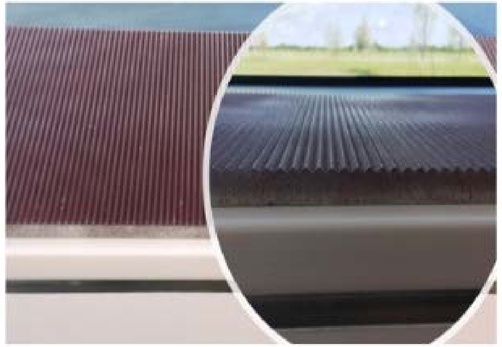
Experiment 3 - Validation

Texas A&M RELLIS Campus

- ✓ To validate the recommended method for network-level macrotexture data collection and processing

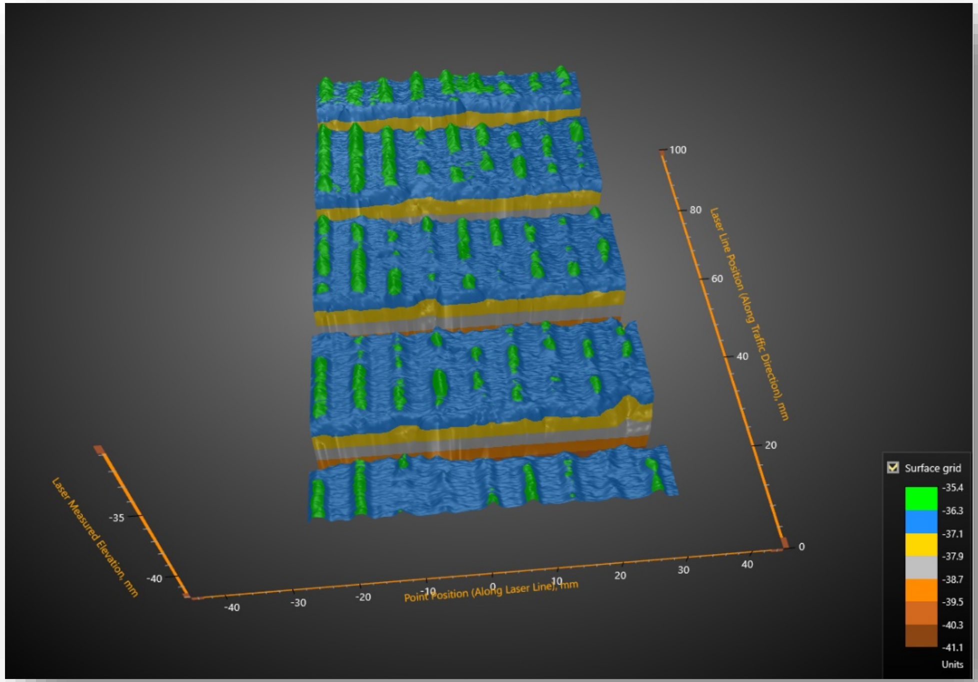
- ✓ New reference device.
- ✓ Manufactured surfaces





TxDOT Plate #1

Examples of Results



Device Repeatability @ 1 m MPD

✓ $c_r = 1.96 * \sqrt{2} * SD$

High-Speed

	Device 1	Device 2	Device 3	Device 4	Device 5	Device 15
MSE (mm)	7.3 E-4	6.7 E-4	10.07 E-4	5.27 E-4	5.2 E-4	9.38 E-4
c_r (mm)	0.075	0.072	0.088	0.064	0.063	0.085

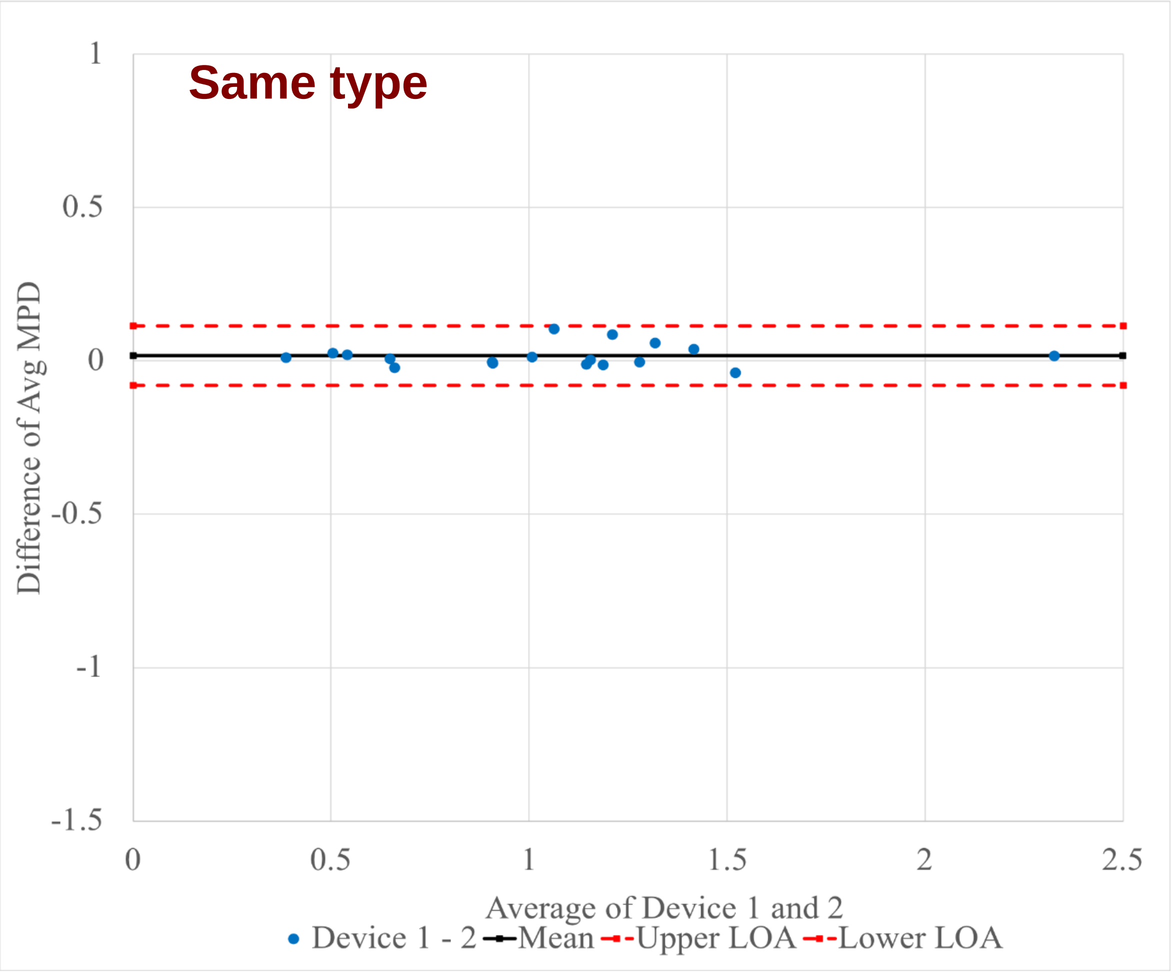
– C_r for all devices tested was in a similar range: 0.06 to 0.09

Walking devices

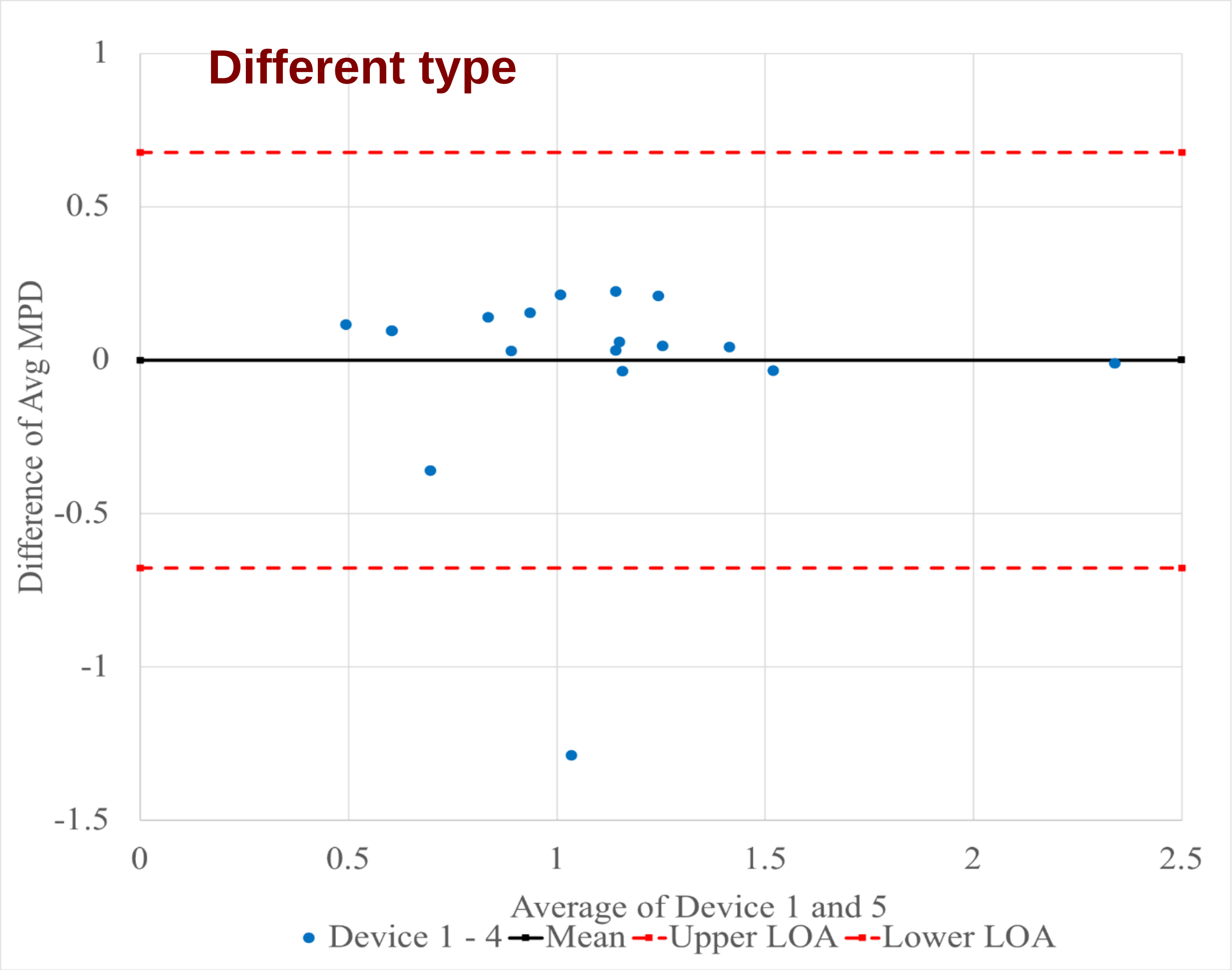
	Device 7	Device 9	Device 11
MSE (mm)	8.5 E-5	9.4 E-5	3.8 E-4
c_r (mm)	0.025	0.027	0.054

Reproducibility - Example Limits of Agreement

Device 1 and 2



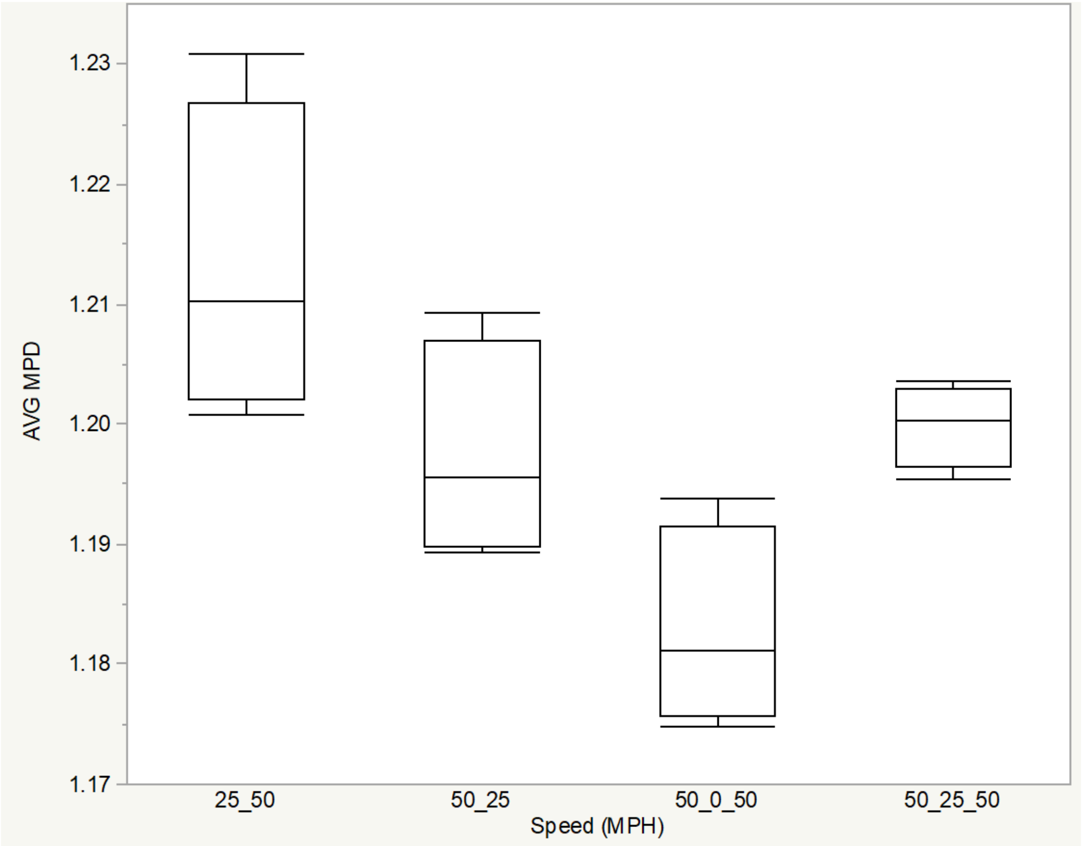
Device 1 and 5



Acceleration / Deceleration Effect

- ✓ Braking and acceleration scenarios treated as nominal variable model inputs and MPD as the response
- ✓ ANOVA with significance level of $\alpha = 0.05$
- ✓ Failure to reject the null hypothesis demonstrates no effect of speed or acceleration

Device	P-Value
1	0.4653
2	0.6184
3	0.4306
4	0.8423
5	**0.0051**



Data range: 1.17 to 1.23mm
Spread of 0.06mm
C_r = 0.06mm

Alternative Macrotexture Parameters

Var #	Parameter
1	Mean Profile Depth (MPD)
2	Root Mean Square (RMS)
3	Mean Difference of Elevation (MDE)
4 – 7 22-25	Enveloping Profiles - Empirical - Physical - Effective Area of Water Evacuation (EAWE)
8 – 9	Geometric Statistical Methods - Skewness (R_{sk}) - Kurtosis (R_{ku})
10	Maximum Height (Max H)
11 – 13	Percentile MPD (MPD_{95}, MPD_{97}, MPD_{99})

Var #	Parameter
14 - 21	Tire Contact Length (TCL)
26 – 55	Wavelet Transformations ($w_{d\ x}$) - Various statistical measures of Haar details
56 – 60	Enveloped Profile MPD (MPD_e)
61	Profile Length Ratio (PLR)
62 – 79	Peak Data Parameters - Mean Peak height above Zero (MPGZ) - Mean peak above zero Separation (MSEPGZ) - Mean Prominence Separation Ratio (MPMSR) - Mean Prominence above zero (MPROMGZ) - Mean width of peaks above zero (MWGZ) - Mean Prominence to Width Ratio (MPWR) - Mean peak Width Mean peak Separation Ratio (MWMSR) - Number of Peaks above zero (NPGZ)

Single Variable Pearson Correlation Coefficients - Random Texture

SCRIM 		GT 		OBSI 	
EAWE (filt, d*=1E-2)	**-0.64**	**PLR (no filt)**	**-0.69**	**$W_{d,,\ RMS}$ (lvl 7, no filt)**	**0.34**
PLR (no filt)	**-0.61**	**EAWE (filt, d*=1E-2)**	**-0.69**	**$W_{d,,\ RMS}$ (lvl 9, no filt)**	**0.34**
TCL (filt, tol = 0.1, d*=1E-2)	0.61	$W_{d,,\ RMS}$ (lvl 1, no filt)	-0.68	$W_{d,,\ RMS}$ (lvl 10, no filt)	0.34
…	-0.56	…		…	
MPD	**-0.42**	**MPD**	**-0.57**	**MPD**	**0.31**
RMS	**-0.49**	**RMS**	**-0.61**	**RMS**	**0.33**
SCRIM	1	SCRIM	0.80	SCRIM	0.07
GT	0.80	GT	1	GT	0.02
OBSI	0.07	OBSI	0.02	OBSI	1

Main Findings

NCHRP 10-98 Main Conclusions

- ✓ Single-spot and line-laser Mean Profile Depth results should not be used interchangeably
- ✓ Commercially available walking equipment with a line-laser to collect reference profiles
- ✓ Engineered surfaces can be used to test for accuracy of reference walking devices.
- ✓ Use of line-laser oriented at 45 degree angle to the travel direction appear to be the most practical solution
- ✓ Macrotexture parameters that account for the enveloped shape of the tire on the pavement's surface show promise but more testing was needed before switching.

Main Outcomes - Proposed Standards

Standard Specification for Equipment for Collecting Macrotexture Data on Pavements at Highway Speeds

- ✓ *Defines the required attributes of equipment that can measure pavement macrotexture at highway speeds*
- ✓ Equipment
  - – Single function or component of a multifunctional system
  - – Network or project level data level data.
  - – Single-spot, line-lased, 3D system
- ✓ Software to compute macrotexture indices
  - – Particularly the Mean Profile Depth (MPD)
  - – Reports dropouts, spikes and total invalid

Standard Practice for Operating Equipment for Collecting Macrotexture Data on Pavements at Highway Speeds

- ✓ *Procedure for operating and verifying the calibration of equipment to measure macrotexture at highway speeds*
  - – Network and project level data collection
  - – Does not purport to address all the safety
- ✓ Verification
  - – Calibration of the DMI
  - – Height sensors
- ✓ Quality control and assurance
  - – Step by step procedure for QC

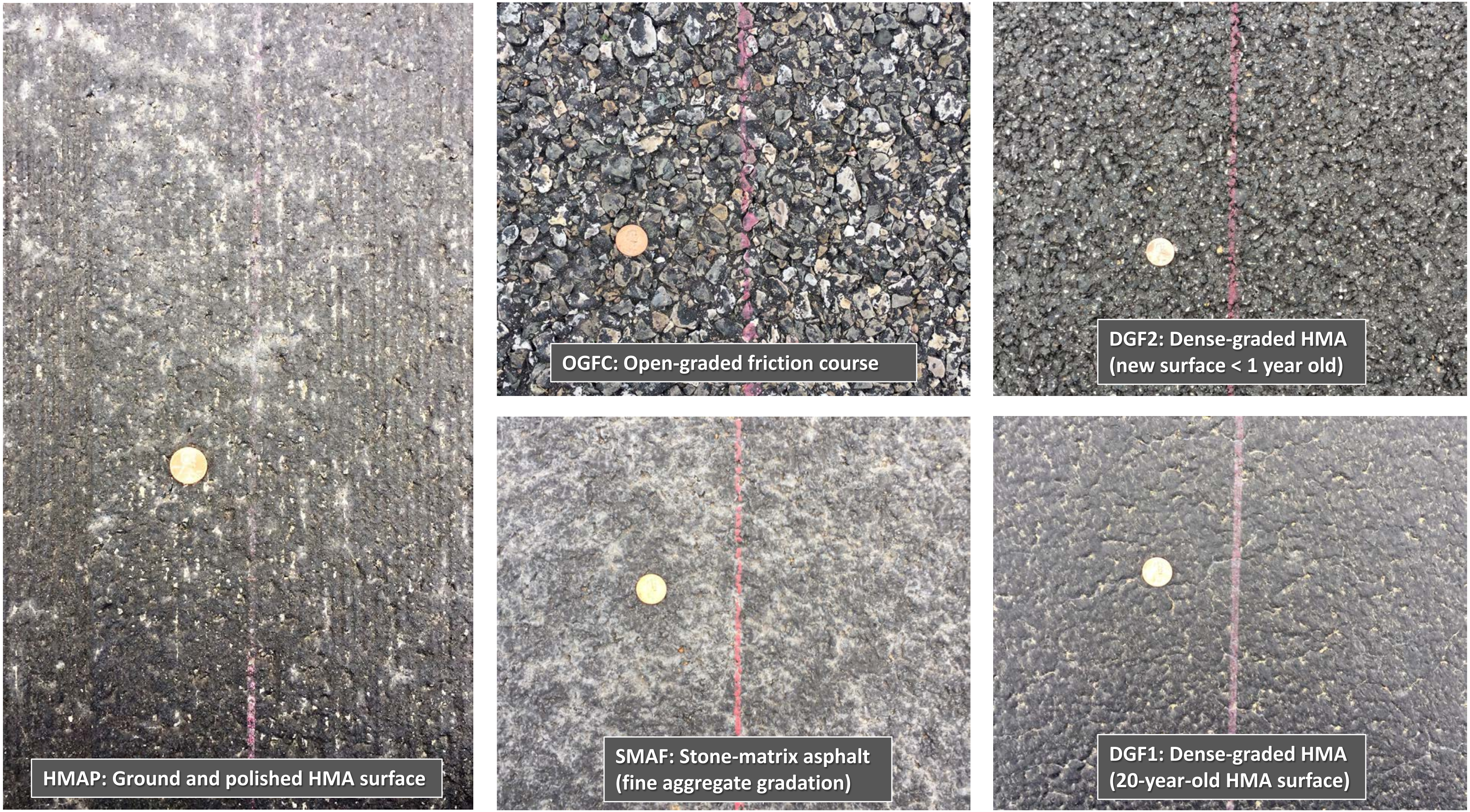
Standard Practice for Certification of High-Speed Macrotexture Measurement Equipment

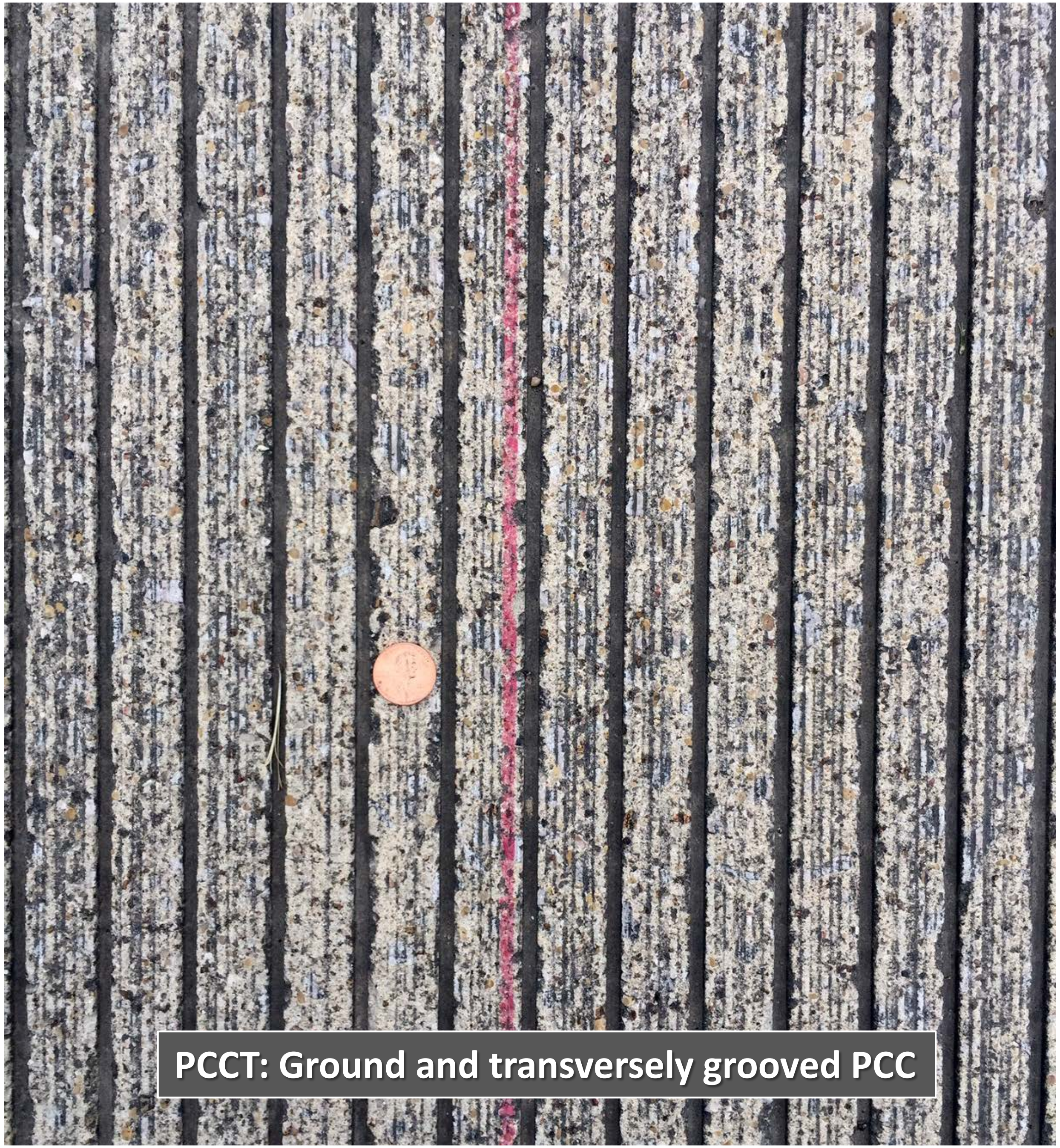
- ✓ *Certification procedure for equipment used to measure macrotexture of pavements at highway speeds*
  - –Minimum requirements to collect repeatable and accurate data
- ✓ Frequency of certification
- ✓ Testing (type of sections, etc.)
- ✓ Repeatability and accuracy
- ✓ Reference data with a walk along device
- ✓ Optional tests

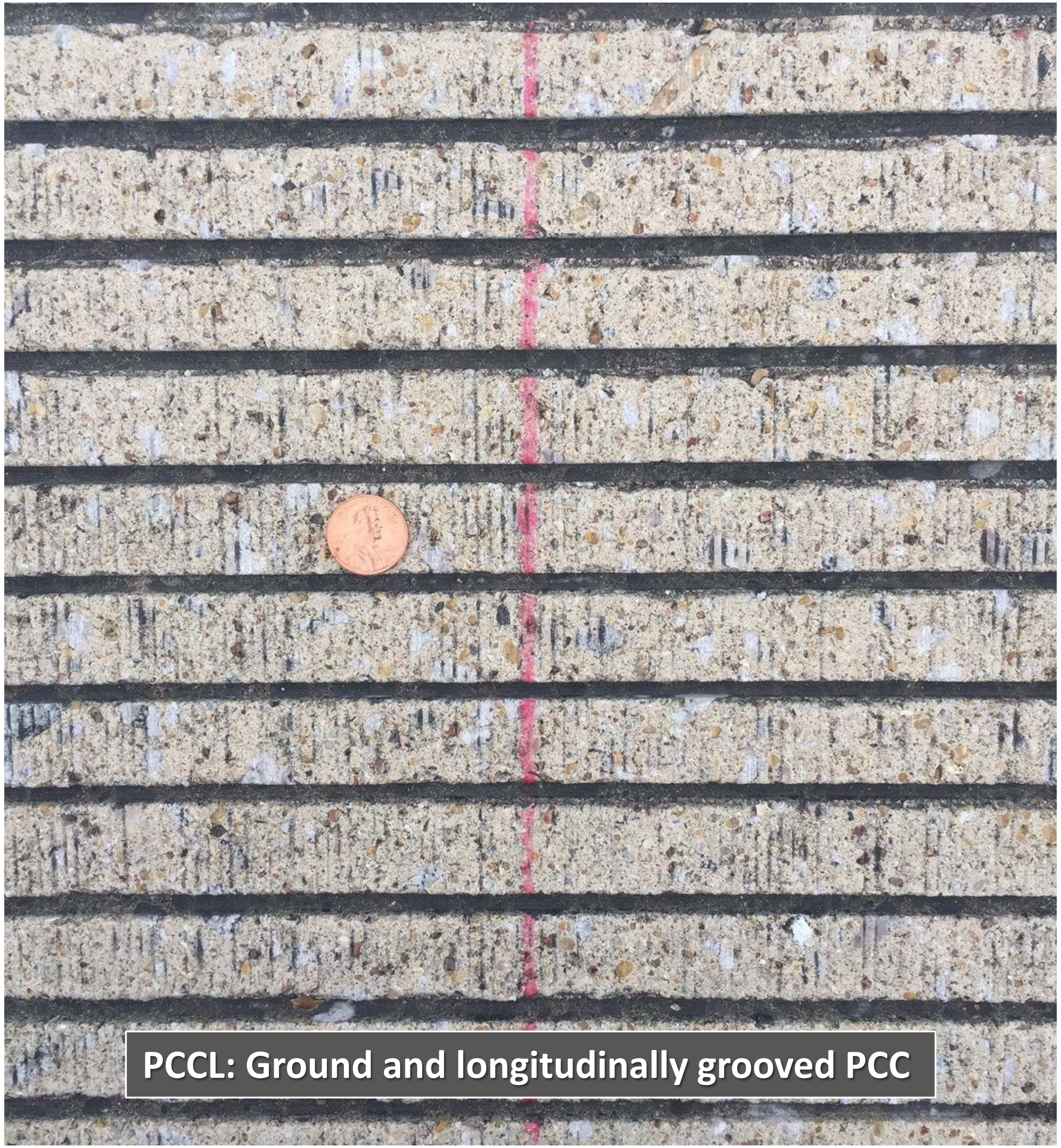
Questions?

RELLIS Field Experiment

Emmanuel Fernando
Texas A&M Transportation Institute
Texas A&M University System


HMAP: Ground and polished HMA surface
OGFC: Open-graded friction course
DGF2: Dense-graded HMA (new surface < 1 year old)
SMAF: Stone-matrix asphalt (fine aggregate gradation)
DGF1: Dense-graded HMA (20-year-old HMA surface)

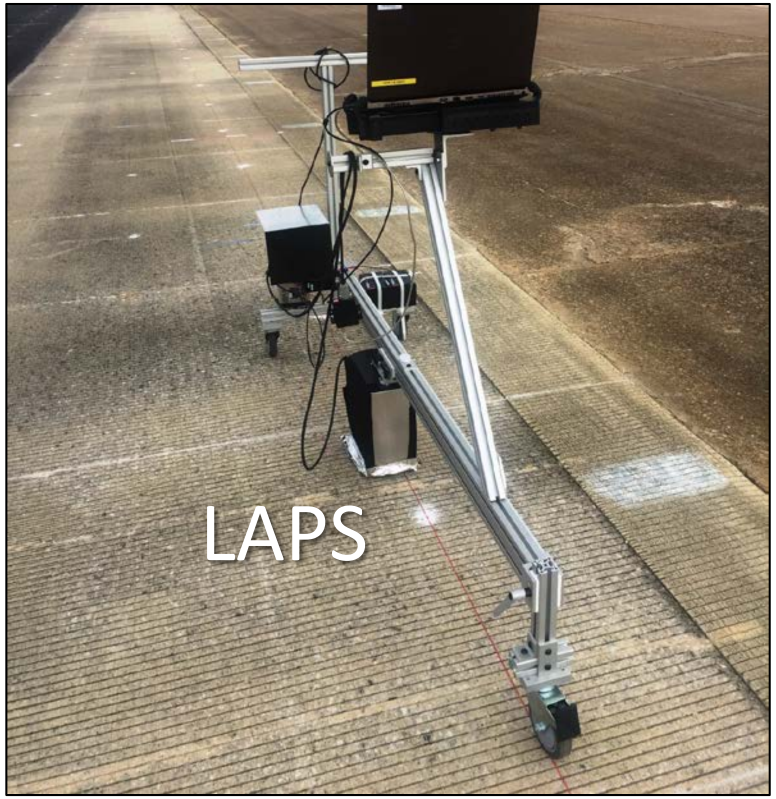

PCCT: Ground and transversely grooved PCC


PCCL: Ground and longitudinally grooved PCC

High-Speed Texture Measurements

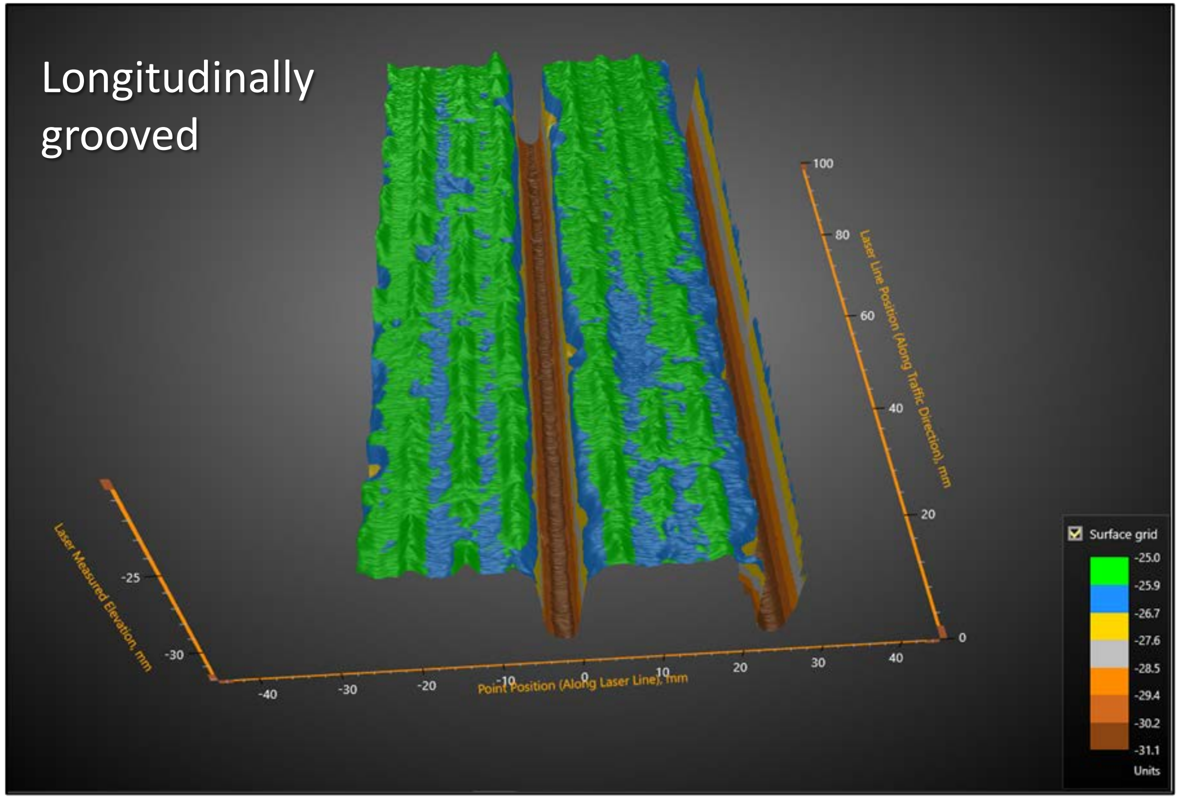
Test Speed (mph)	Test Vehicle A Single-Point: Acuity 100 KHz and LMI Optocator (62.5 KHz)			Test Vehicle B Gocator Line Laser (LLT/LLA)			
	Exposure Time			Exposure Time			
	Normal (5 – 12 µs)	Medium (10 – 12 µs)	Long (30 – 40 µs)	Auto (30 – 300 µs)	Short (40 µs)	Medium (80 µs)	Long (160 µs)
25	X	X	X	X	X	X	X
40	X	X	X	X	X	X	X
55	X	X	X	X	X	X	X

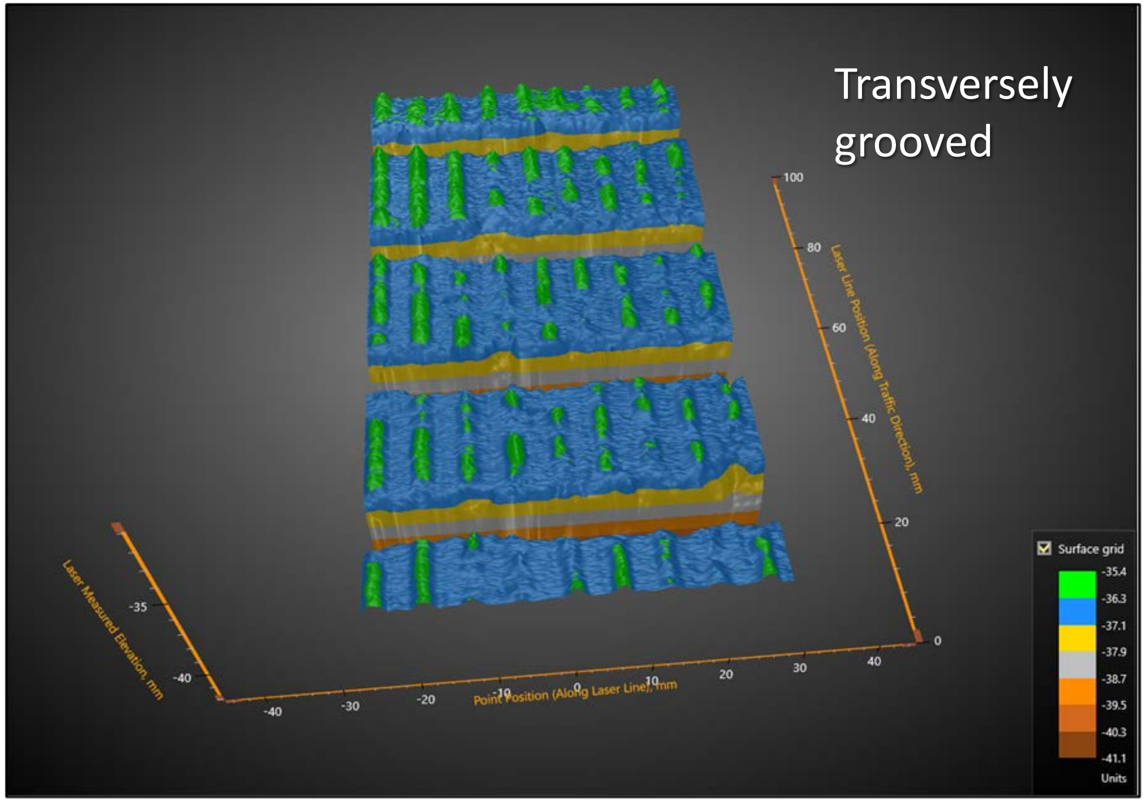
*3 repeat runs



Reference Texture Measurements

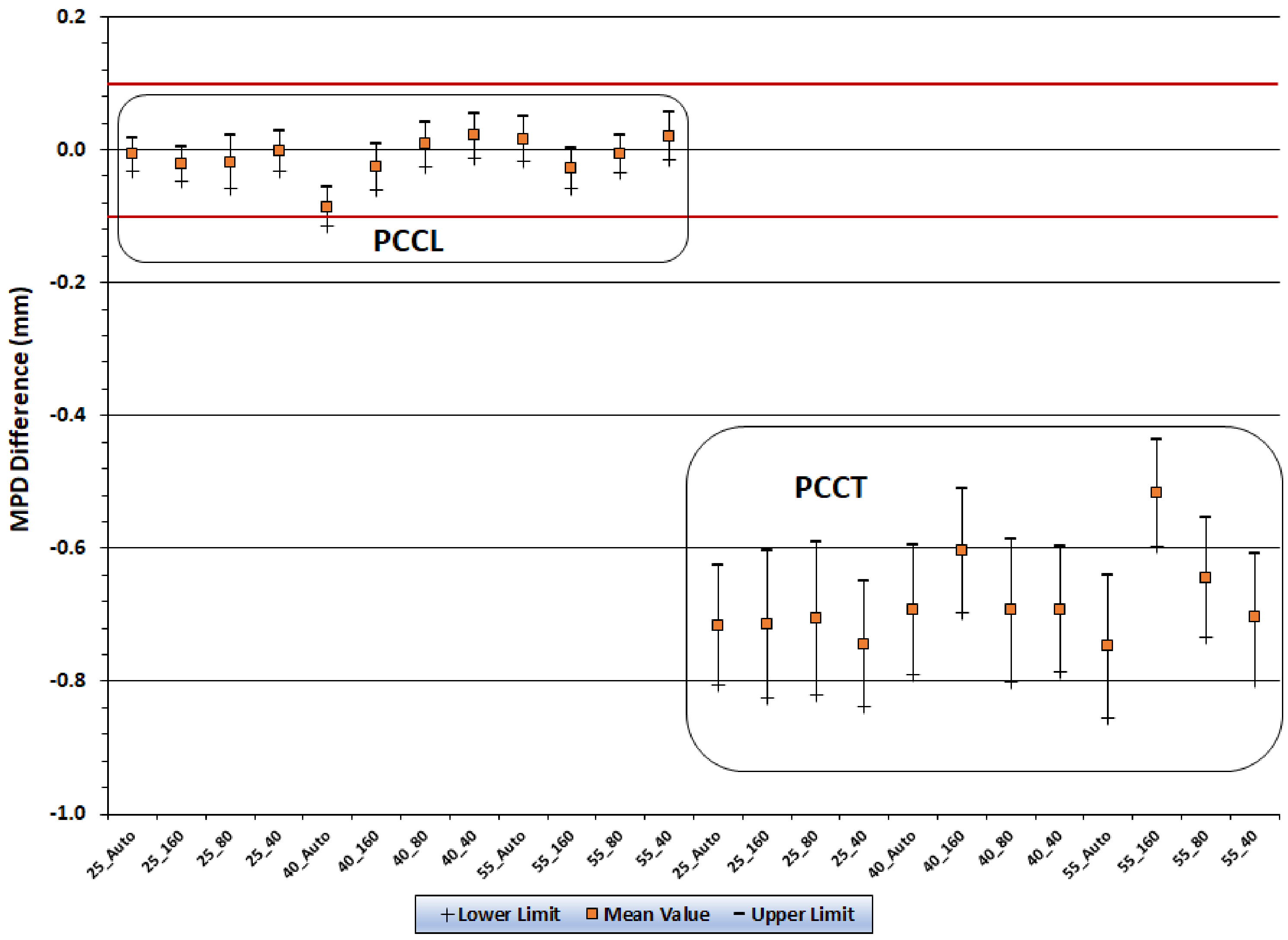
Test Results

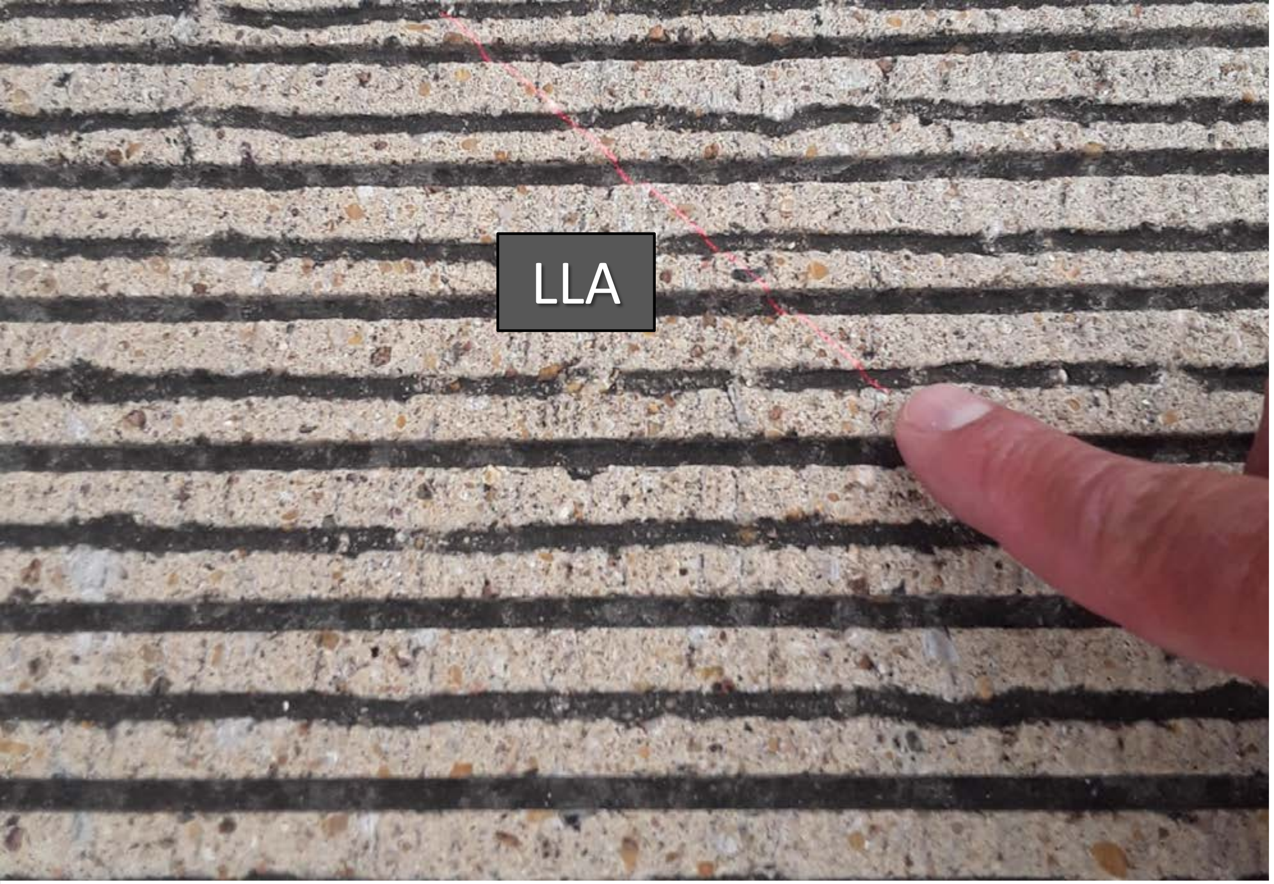




3D Plots of LAPS Measurements

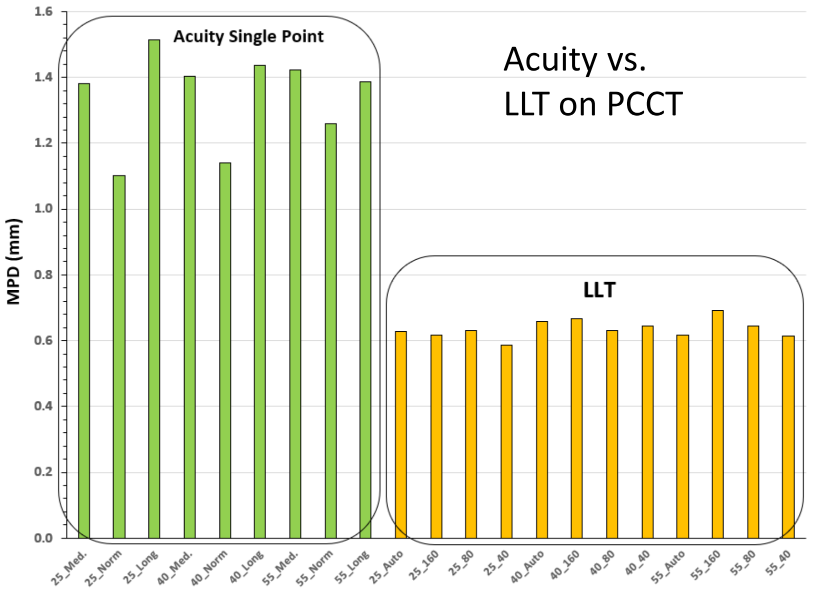
Comparison of MPDs between Line Lasers: LLA vs. LLT

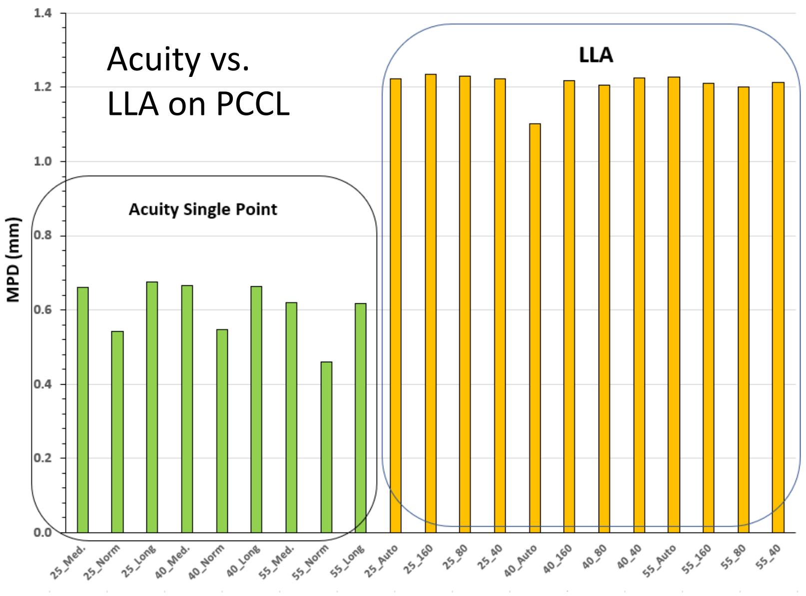


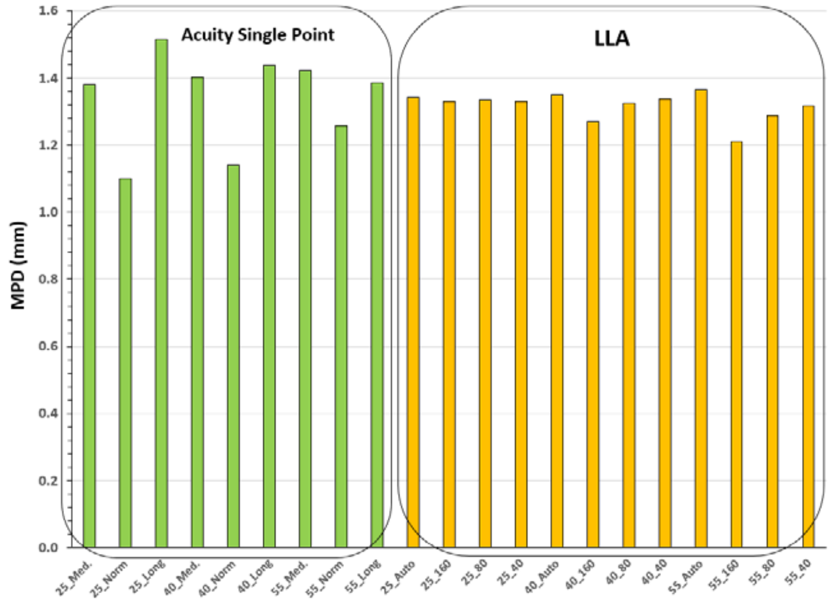


LLA vs. LLT: Line Laser Footprint Orientation

Single-Point vs. Line Laser MPDs

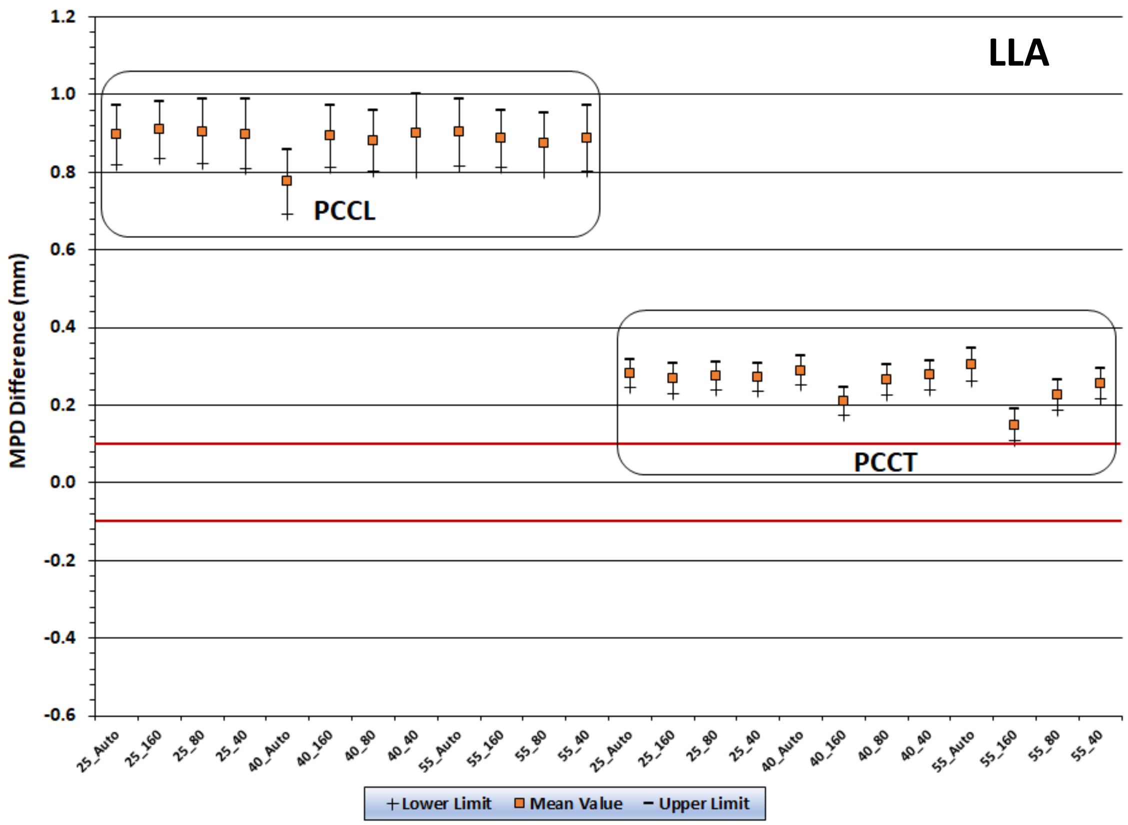


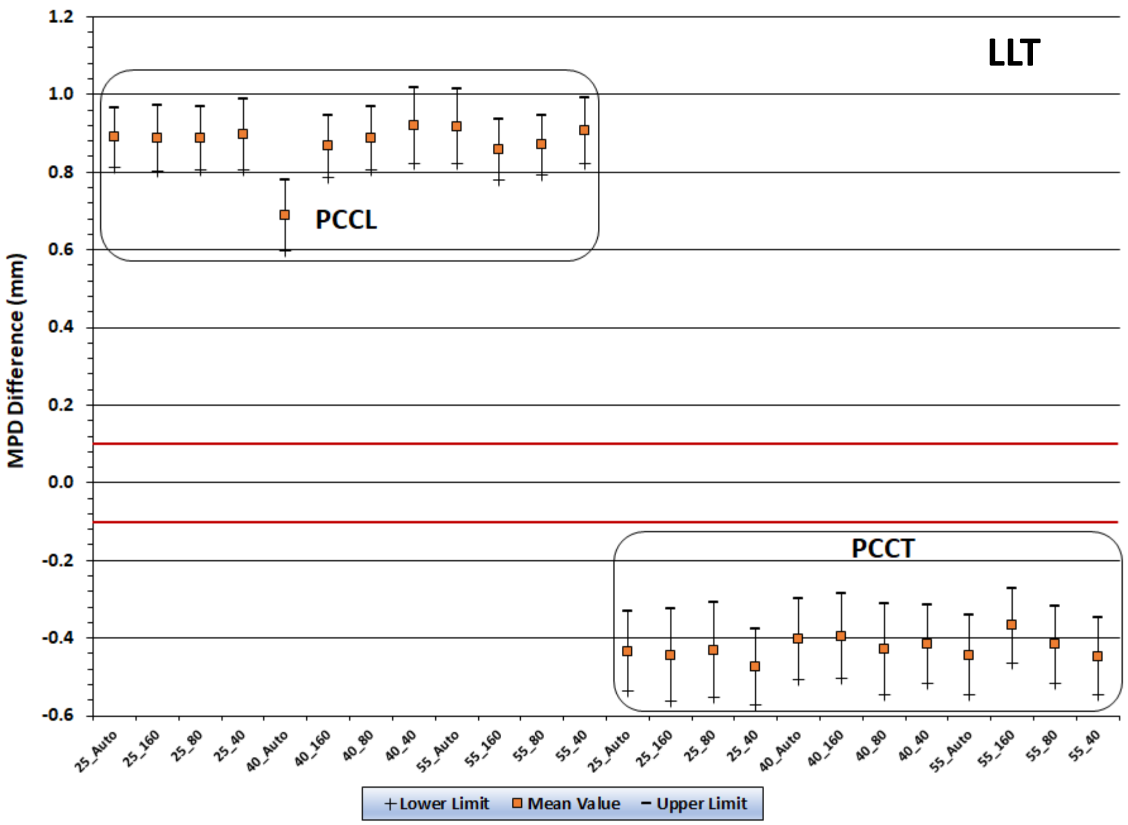




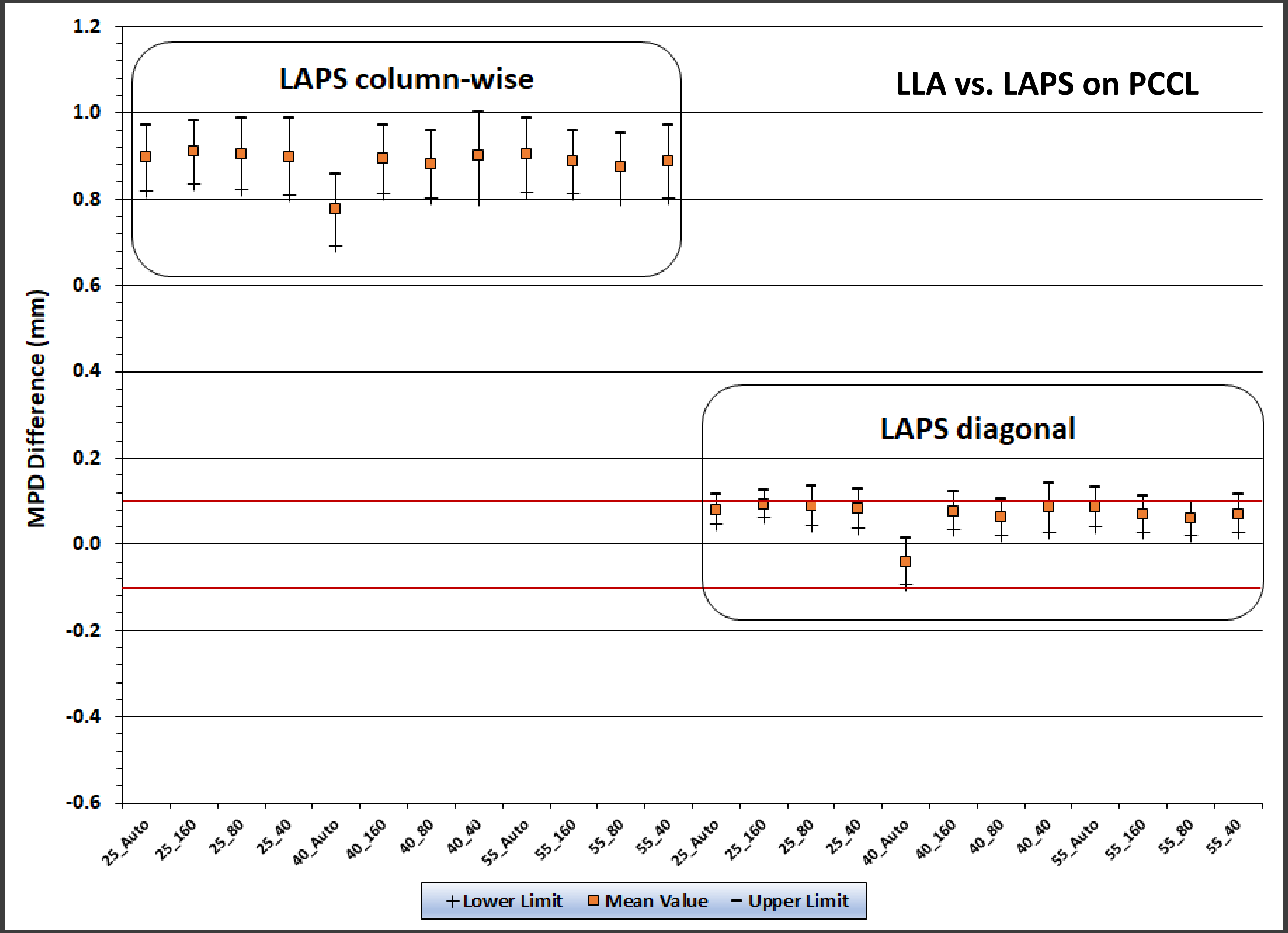
Acuity vs. LLA PCCT

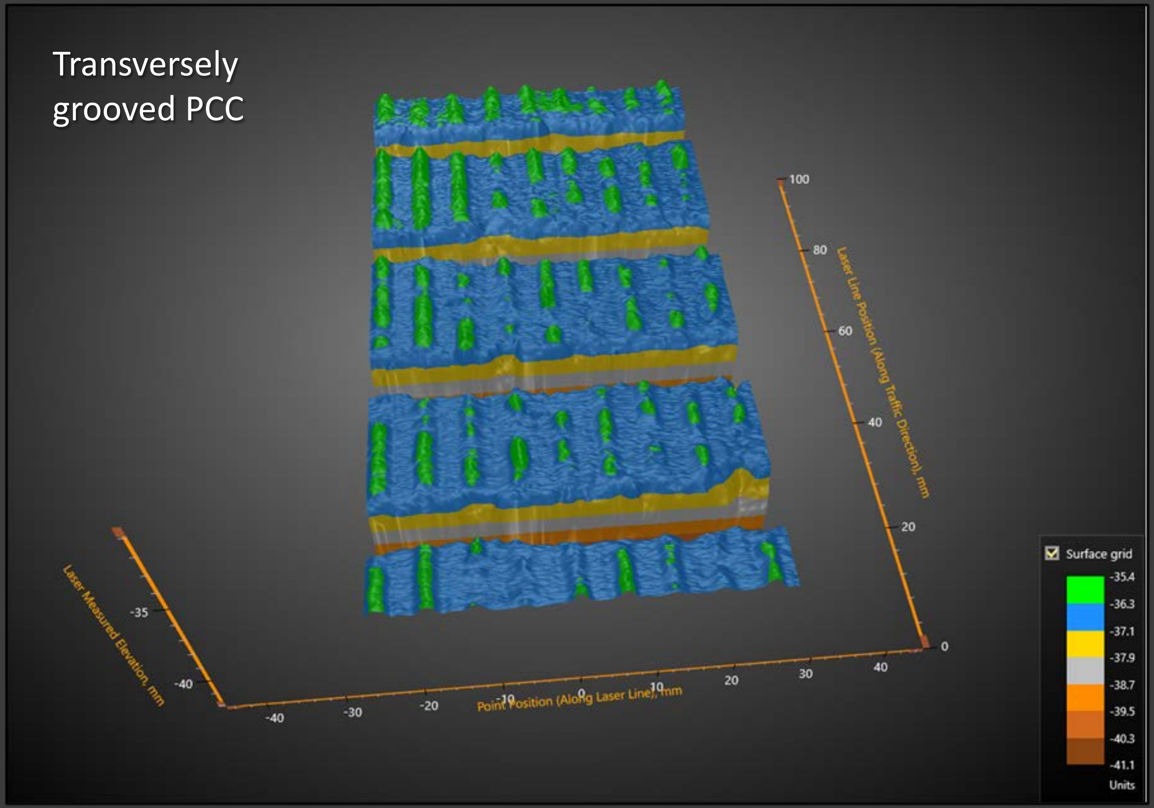
Comparison of Line Laser and LAPS MPDs

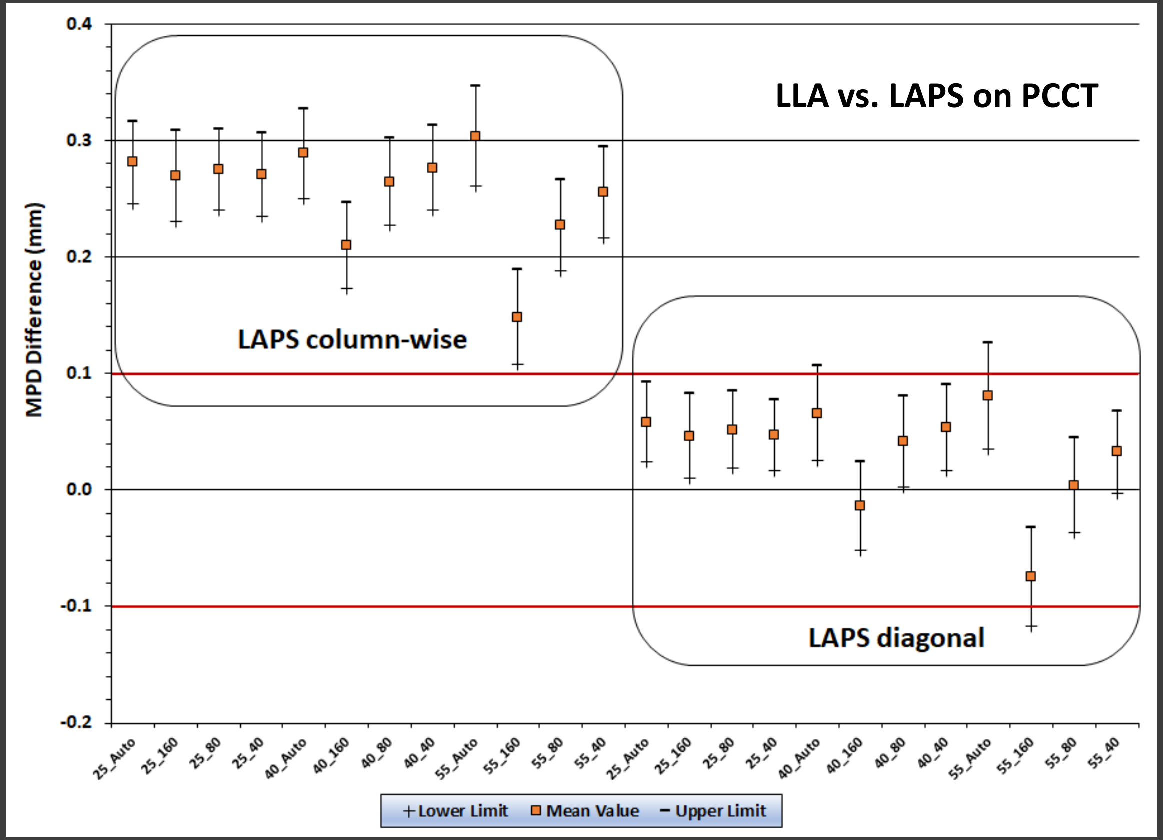




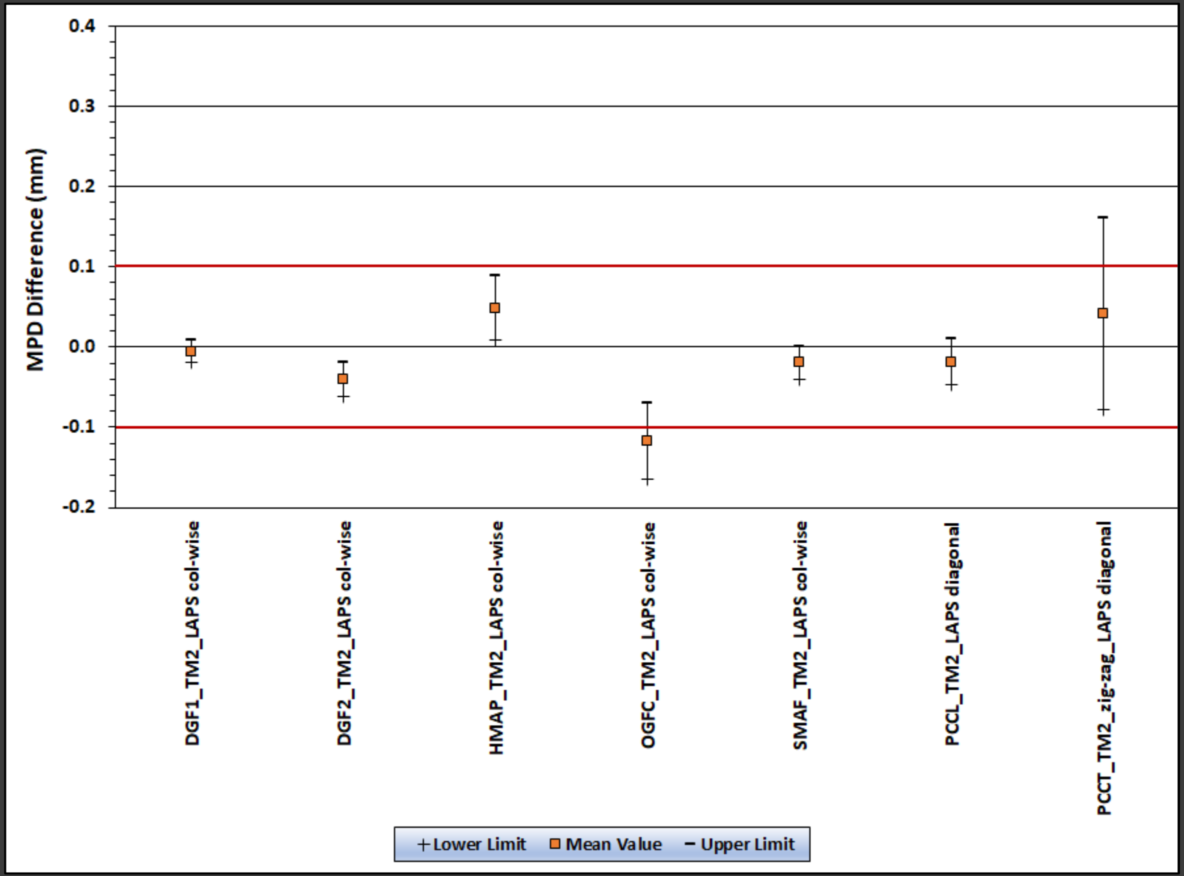
Effect of Directional Surface Features







Effect of Directional Surface Features



Rolling Texture Meter (TM2) vs. LAPS

Summary and Conclusions

- Higher frequency (100 KHz) Acuity laser showed better agreement with LAPS compared to 62.4 KHz optocator.
- Test findings indicate using Acuity laser under normal exposure to measure macrotexture.
- Need to account for directional nature of PCC surfaces when measuring macrotexture.
- Between LLT and LLA, test findings favor LLA (45°) laser footprint orientation.
- Acuity and LLA gave comparable MPDs on transversely grooved surface but not on longitudinally grooved surface.
- Line laser better suited for macrotexture measurements on longitudinally grooved concrete surfaces.
- In general, TM2 and LAPS showed favorable agreement.
- Modifying TM2 to permit adjustment of line laser angle would help account for directional features along the test wheel path.
- Using line lasers to measure macrotexture can be implemented through modifications of existing inertial profiling systems that use the same lasers.

Thank you for your attention! Questions?

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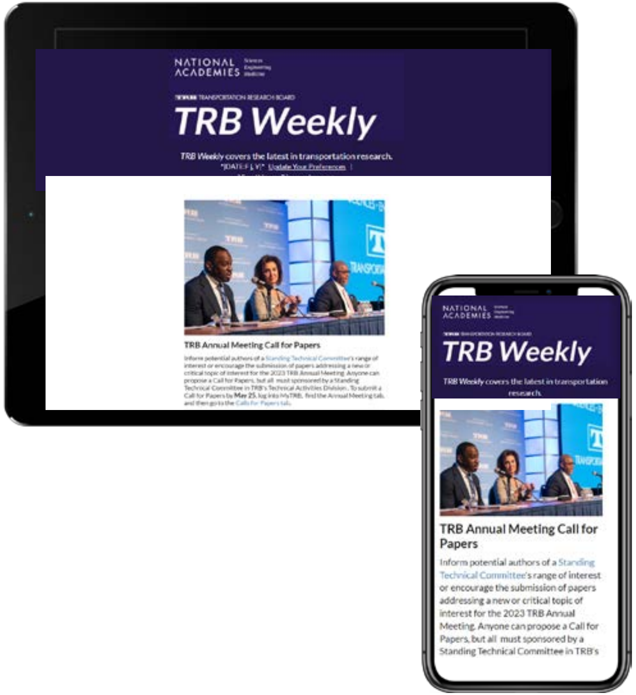

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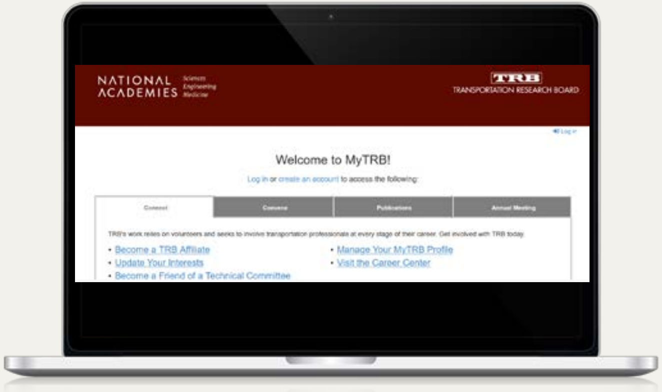

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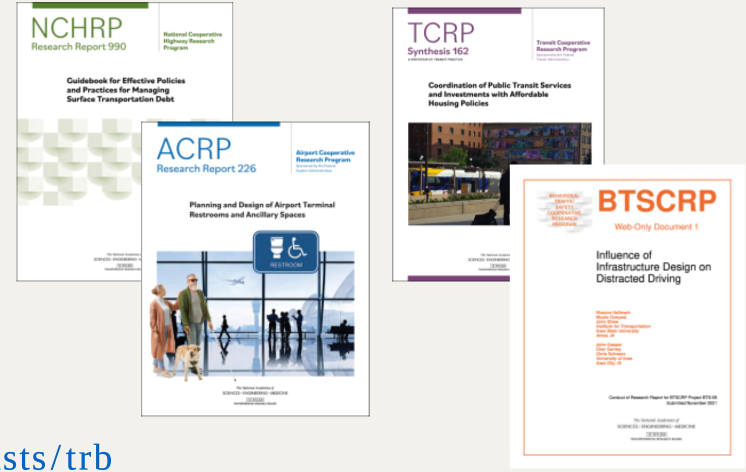

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