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# Pavement Macrotexture

## *State of the Art and of the Practice*

Vincent Bongioanni

# Overview

- ✓ Introduction to macrotexture
- ✓ Macrotexture parameters
- ✓ Operationalizing macrotexture data collection
- ✓ Who’s collecting macrotexture data?
- ✓ Upcoming equipment comparison

# Introduction to macrotexture

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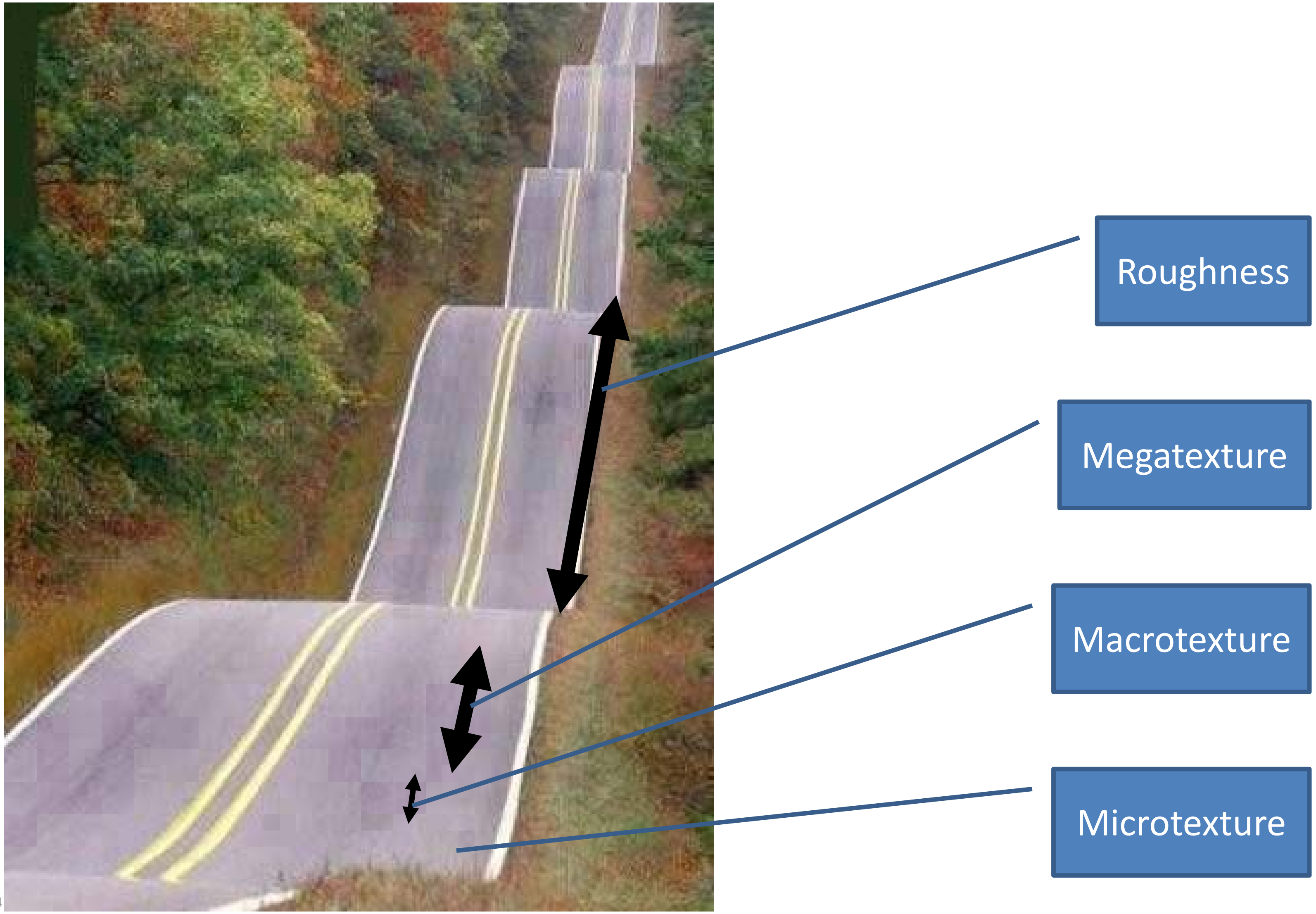
# What the Wavelength ???!!!?




https://i.pinimg.com/474x/5b/0c/49/5b0c4990d1aa44e7ad36c0b5e162d2e5--tulsa-oklahoma-roller-coasters.jpg

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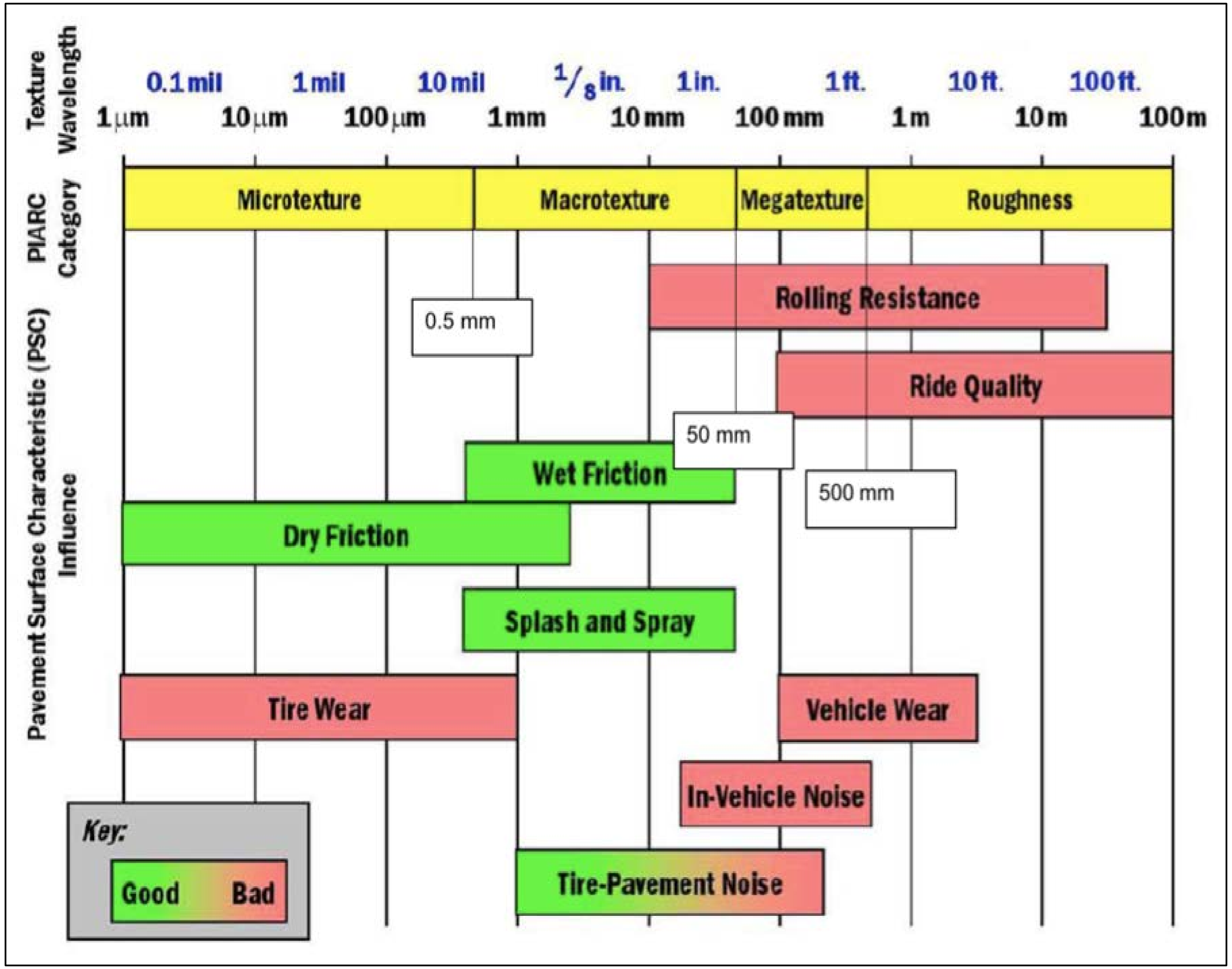
# Pavement Texture Characteristics




Source: Adapted from PIARC

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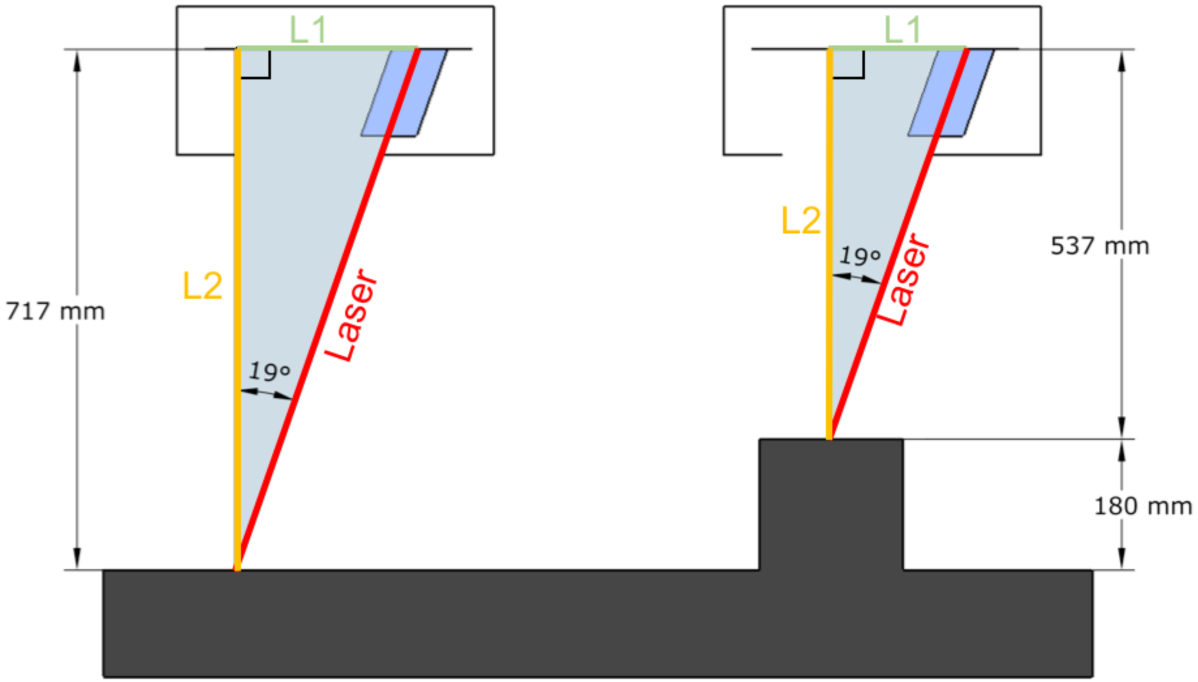
# Macrotexture Measurement Equipment

| Texture Method | Spec. | Type | Speed | Texture Parameter [1] | Technology | Referen |
|---|---|---|---|---|---|---|
| **Volumetric** | | | | | | |
| Sand patch | E-965 | Volumetric | N/A | MTD | Manual | Current |
| Grease patch | NASA | Volumetric | N/A | MTD | Manual | |
| HydroTimer | E-2380 | Volumetric | N/A | MTD | Mechanical | HydroT |
| **Manual** | | | | | | |
| Profile recorder | | 2-D profile | N/A | Average peak height | Mechanical | Ashkar El Genc |
| Manual depth gauge | - | 1-D depth | N/A | Depth | Tine and groove depth | |
| **Stationary Laser Systems** | | | | | | |
| C.T. Meter | E-2157 | 2-D profile | N/A | MPD | Laser | Current |
| ELAtextur | E-1845 | 2-D profile | N/A | MPD/ ETD | Laser | (IWSm |
| Laser Texture Scanner | E-1845 | 2-D profile | N/A | MPD/ ETD RMS | Laser | (Ames : |
| DSRM | - | 2-D profile | N/A | MPD | Laser & optics | |
| **Stationary Optical imaging systems** | | | | | | |
| Stereo Vision System | - | 3-D area measurement | N/A | MPD/ MTD | Digital stereovision | Flintsch |
| Photometric stereo | - | 3-D area measurement | N/A | MPD/ RMS | Surface normal vector maps: 4-point photo stereo & integration | El-Genc |
| Pavement Surface Imager[2] Mark ½ | - | Surface Normal Vectors for 2-D analysis | N/A | MTD/ others | Surface normal vectors - polynomial texture mapping | Goodm |
| **Walking Speed Laser System** | | | | | | |
| ARRB Walking Profiler TM2 Texture Meter, | ISO 13473 | 2-D profile | < 5 mph | MPD | Laser (line) | ARRB ( |
| ROBOTEX | - | 2-D profiles (from 3-D scan) | < 5 mph | MPD | Laser (line) | TRANS |
| **High Speed Laser Equipment (HSLE)** | | | | | | |
| HSLE (Single spot laser) | E-1845 | 2-D profile | 0-60 mph | MPD | Laser | Various |
| HSLE (Line laser) | E-1845 | 2-D profile | 0-60 mph | MPD | Laser (line) | Various |
| 3-D Laser/ camera | - | 3-D area | <60 mph | MPD/ ETD | Laser and line scan camera | Various |

# Principle of Laser Triangulation




L2 tan($\theta$) = L1

If L1 measured by sensor = 246.9mm,
246.9mm * tan(19) = 717mm

If L1 measured by sensor = 184.9mm,
184.9mm * tan(19) = 537mm

Setting first distance measurement (717mm) = 0,
Height of object in second measurement = 537mm – 717mm = -180mm

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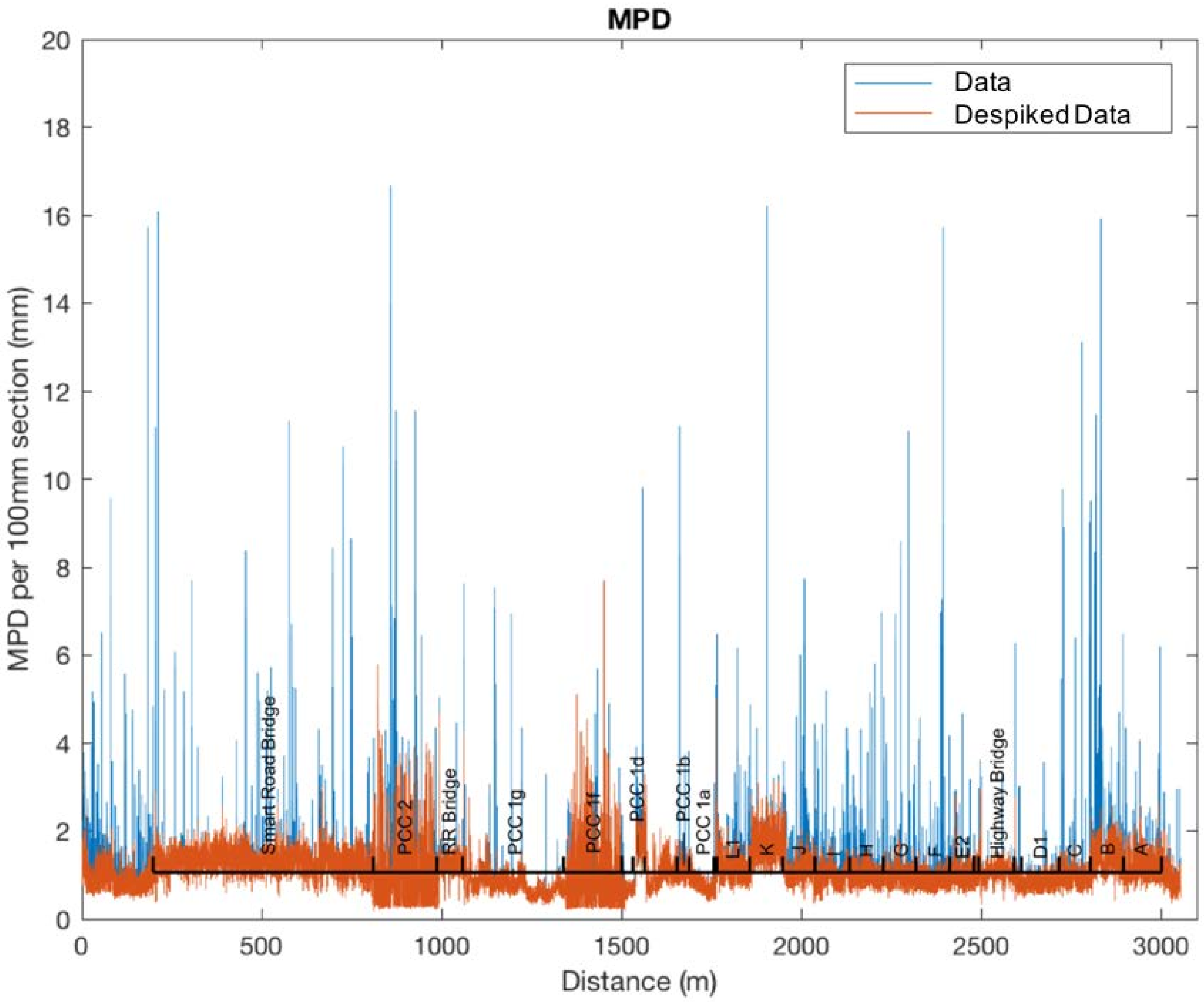
# Data Processing: Removal of Outliers




Robustness: MPD before and after spike removal
Source: Katicha et al. (2015)

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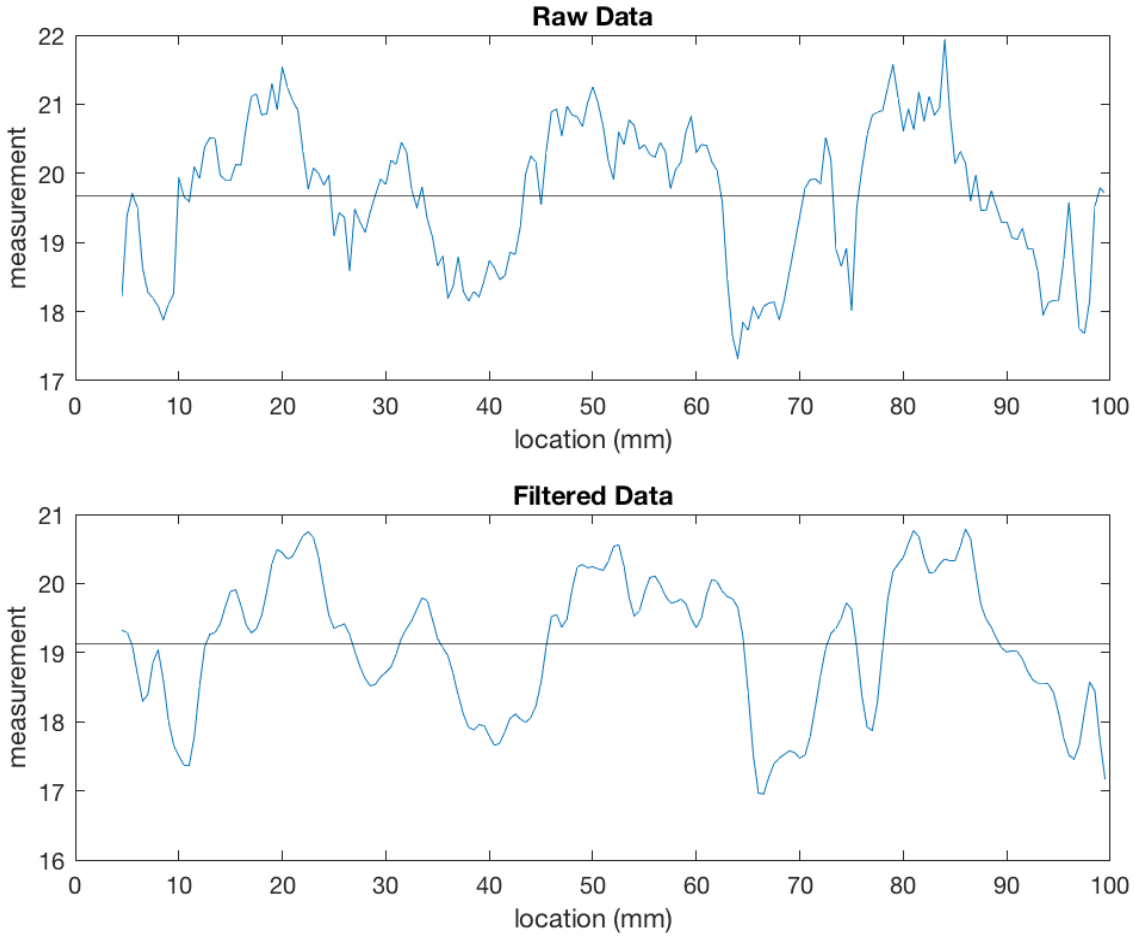
# Data Processing: Filtering




Raw data mean = 19.7
Filtered data mean = 19.1

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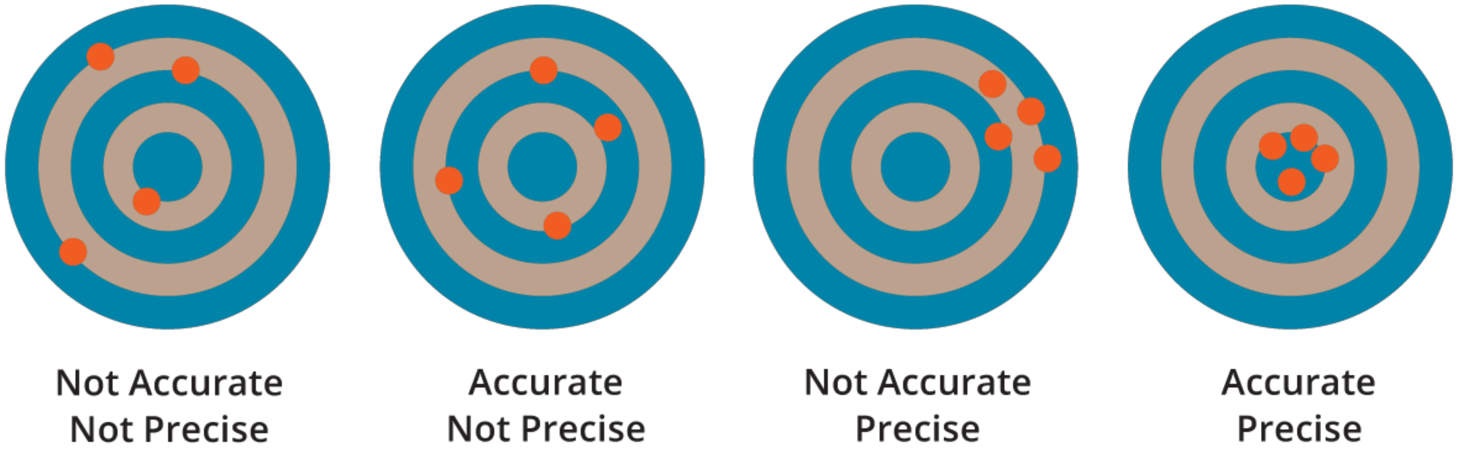
# Criteria for Evaluating Measurement Technologies

- ✓ 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

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# Macrotexture parameters

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# Available Macrotexture Parameters

| | Parameter | Reference | Strengths | Limitations |
|---|---|---|---|---|
| 1. | MTD - Mean Texture Depth | ASTM E965 (2015) | Time-tested | Operator error |
| 2. | MPD – Mean Profile Depth | ASTM E1845 (2015); ISO 13473-1 (1997) | Time-tested, widely used | Typically, limited sampling of roadway |
| 3. | ETD - Estimated Texture Depth | ASTM E1845 (2015); ISO 13473-1 (1997) | Relation to MTD Collected by MPD equipment | Correlation-based parameter |
| 4. | SMTD - Sensor Measured Texture Depth | Roe et al. (1998) | Uses statistical measure (vs. MPD's 2 peaks) | Typically limited sampling of roadway |
| 5. | PD – Profile Depth | ASTM E1845 (2015) | Basic measure, information can be further processed | Uses single peak height as reference |
| 6. | TD - Texture Depth | ISO 13473-1 (1997) | Basic measure, information can be further processed | Uses average of three highest peaks in 3-D profile |
| 7. | RMS - Root Mean Square | Wennink and Gerritsen (2000) | Stronger statistical basis, describes variation | Not widely used in US |
| 8. | Texture Spectra<br>PSD – Power Spectral Density<br>Texture Power Spectra<br>TL – Texture Level | Goubert (2007),<br>Anfosso-Lédée and Do (2002),<br>Leandri and Losa (2015) | Relation to road noise, some operations computationally simpler | Not widely used in US, can require additional analysis |

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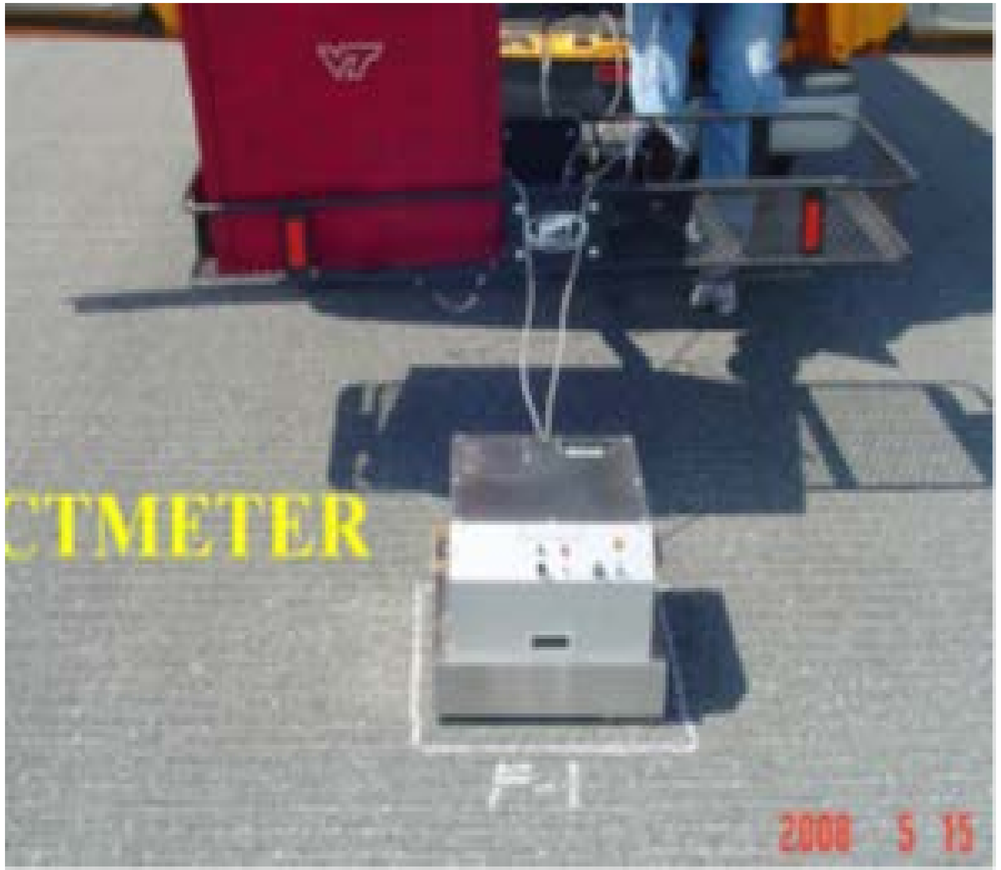
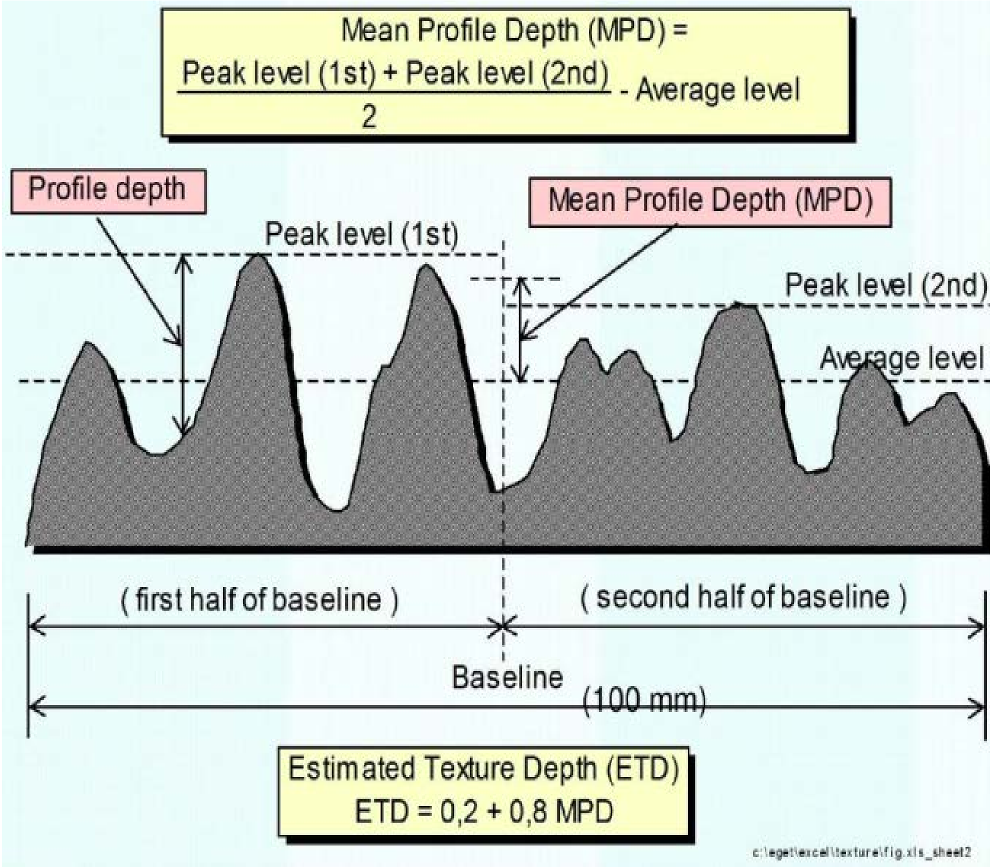
# Static Macrotexture Measurement




Example CT Meter and MPD Calculation
MPD Figure Source: ISO 13473-1 (1997)

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# Emerging Macrotexture Parameters

| Parameter | Reference | Strength | Limitation |
|---|---|---|---|
| MTD3 - Digitally Simulated 3-D Mean Texture Depth | Liu et al. (2016) | High Resolution; correlation to established parameters | Most often gathered by stationary dev |
| RMSD3 – 3D Root Mean Square Deviation | Liu et al. (2016) | High Resolution; correlation to established parameters | Most often gathered by stationary dev |
| MPDi - Mean Profile Depth from 3-D image measurements | El Gendy and Shalaby (2007) | High Resolution; correlation to established parameters | Typically gathered by stationary dev |
| Enveloping Profiles (Goubert 2007)<br>- Empirical<br>- Physical<br>- Spectral<br>- Effective Area of Water Evacuation | Von Meier et al. (1992), Klein et al. (2004), Clapp (1983), Mogrovejo et al. (2016) | Accounts for more realistic area for water evacuation. Improved correlations to friction and noise | Not implemen in existing software or measurement schemes |
| Wavelet Transformations | Leandri and Losa (2015) Zelelew et al. (2013) | Greater granularity on measured profile waveform | Processing intensive |

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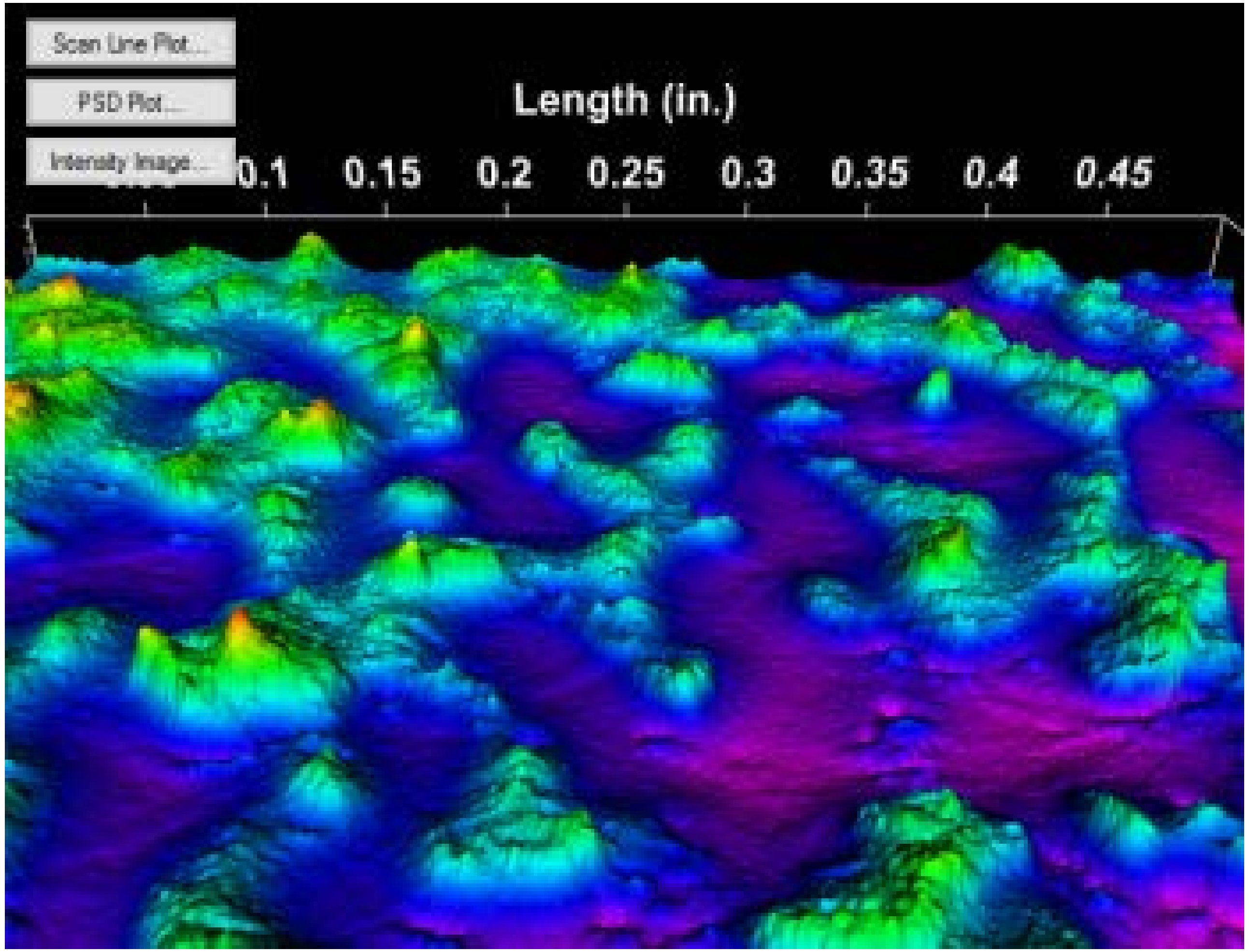
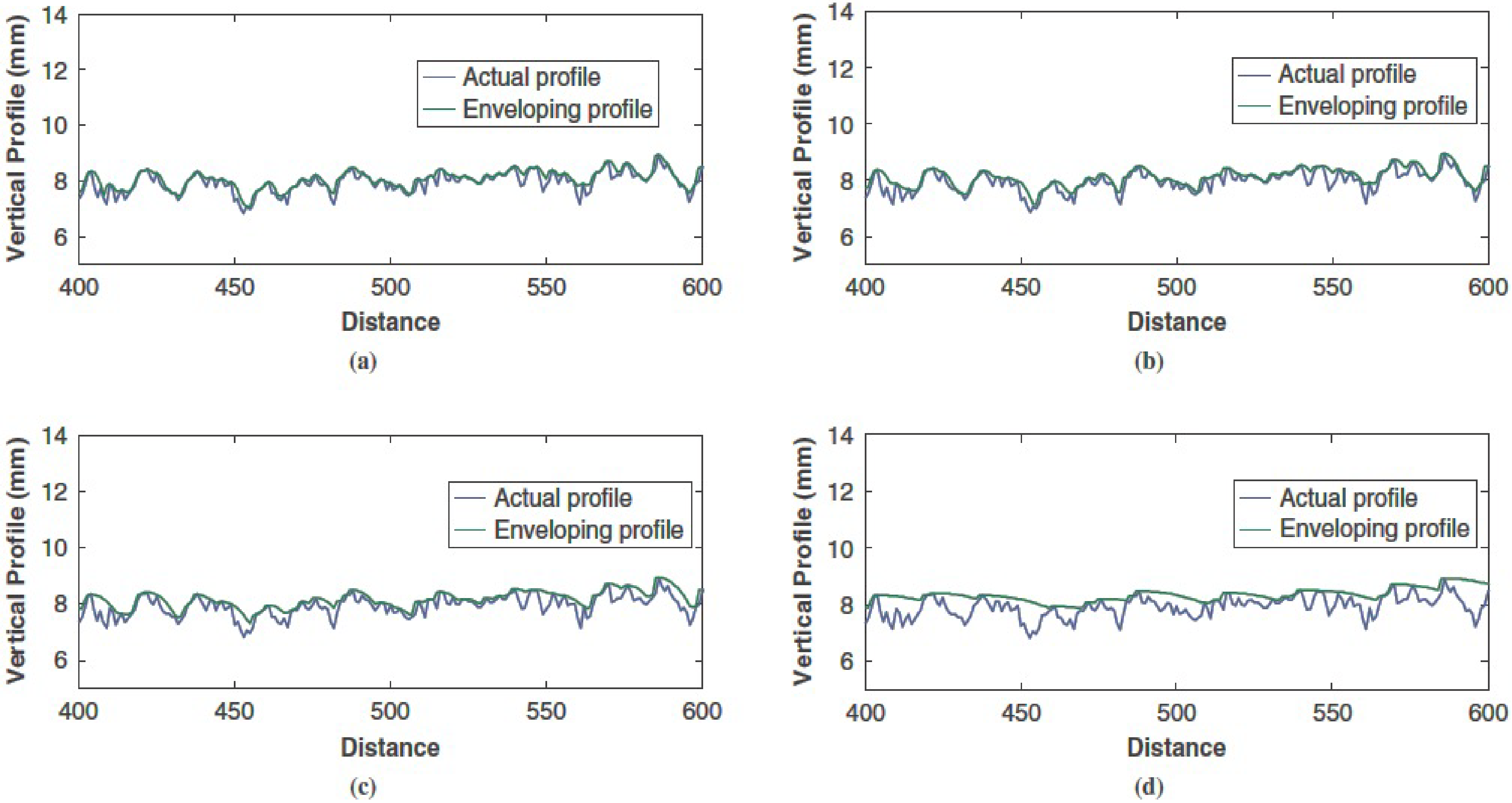
# Example of 3-D Texture Data




Source: Ames Laser Texture Scanner (2013)

# Enveloping Profiles




Example enveloping tire profiles on 100 mm segment of SMA in SW Virginia;
a – d show increasing tire stiffnesses
Source: Mogrovejo et al. (2016)

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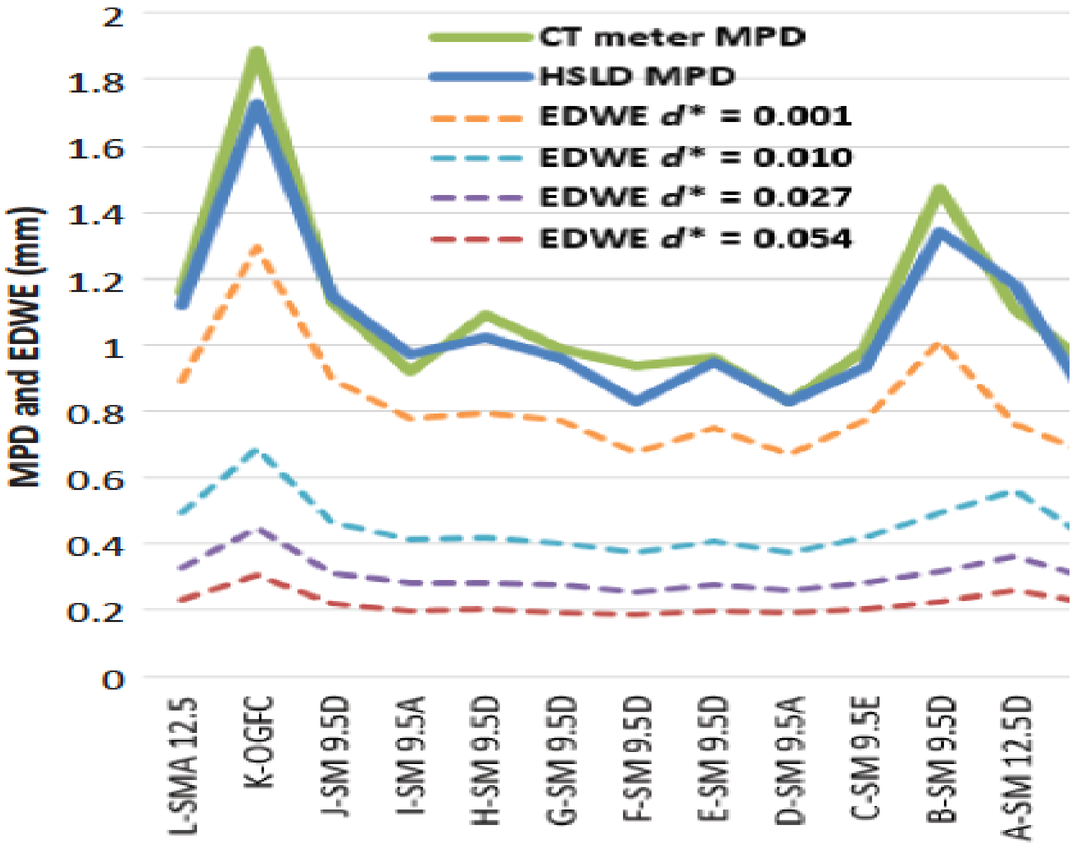
# Enveloping Profiles (cont)




MPD vs EDWE for select Smart Road segments

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# Emerging Macrotexture Parameters (cont)

| Parameter | Reference | Strength | Limitatio |
|---|---|---|---|
| HHT - Huang–Hilbert transform | Rado and Kane (2014) | Good correlation to friction | Limited testin intense post-processing |
| Summit Analysis | Le Gal et al. (2008) | In depth analysis of macrotexture asperities | Intense post-processing; limited testing |
| 3D Void Volume | Sanders et al. (2014) | High resolution 3D data | Very sensitive outliers |
| Geometric Statistical Methods<br>□ Avg roughness ($R_a$)<br>□ Mean Square Roughness ($R_q$)<br>□ Skewness ($R_{sk}$)<br>□ Kurtosis ($R_{ku}$) | ISO 4288 (1996),<br>ISO 4287 (1997),<br>ASME B46.1 (2009) | Common set of tools available to multiple disciplines | Not widely us in common pavement surf vernacular |
| Tortuosity | Praticò et al. (2017) | Use in pervious and porous pavements | Difficult to characterize o network level |
| Rugosity | Du Preez (2015) | Relates micro and macrotexture | Difficult to characterize o network level |

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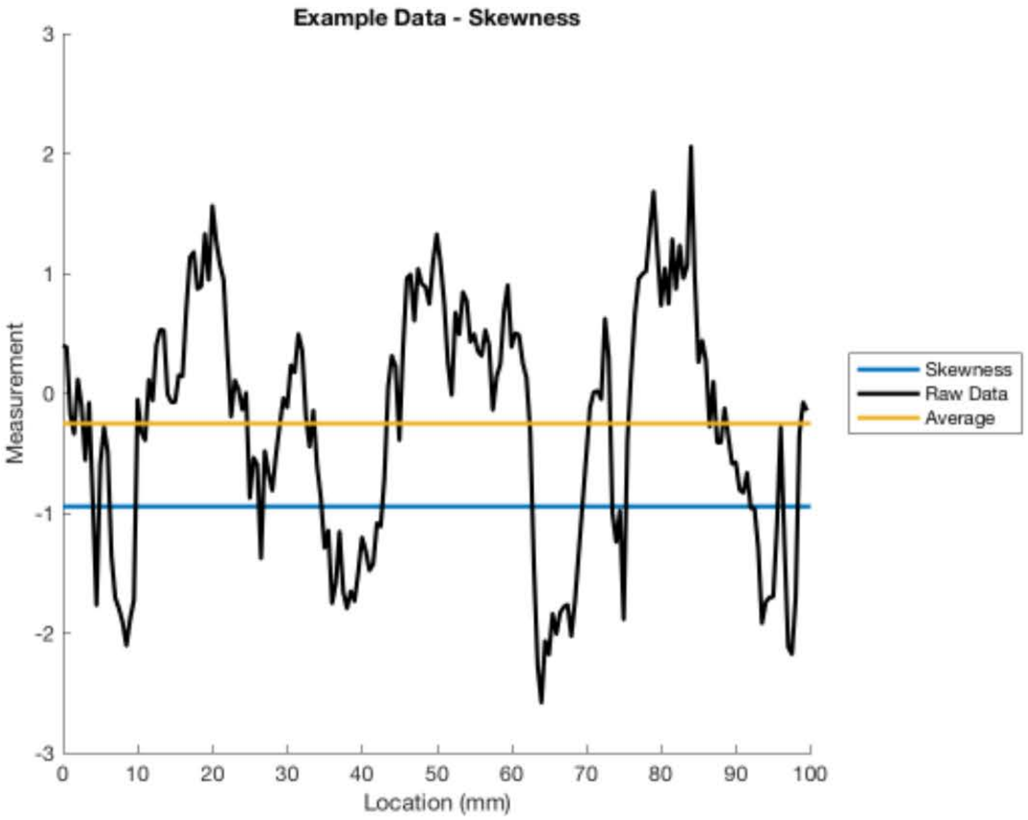
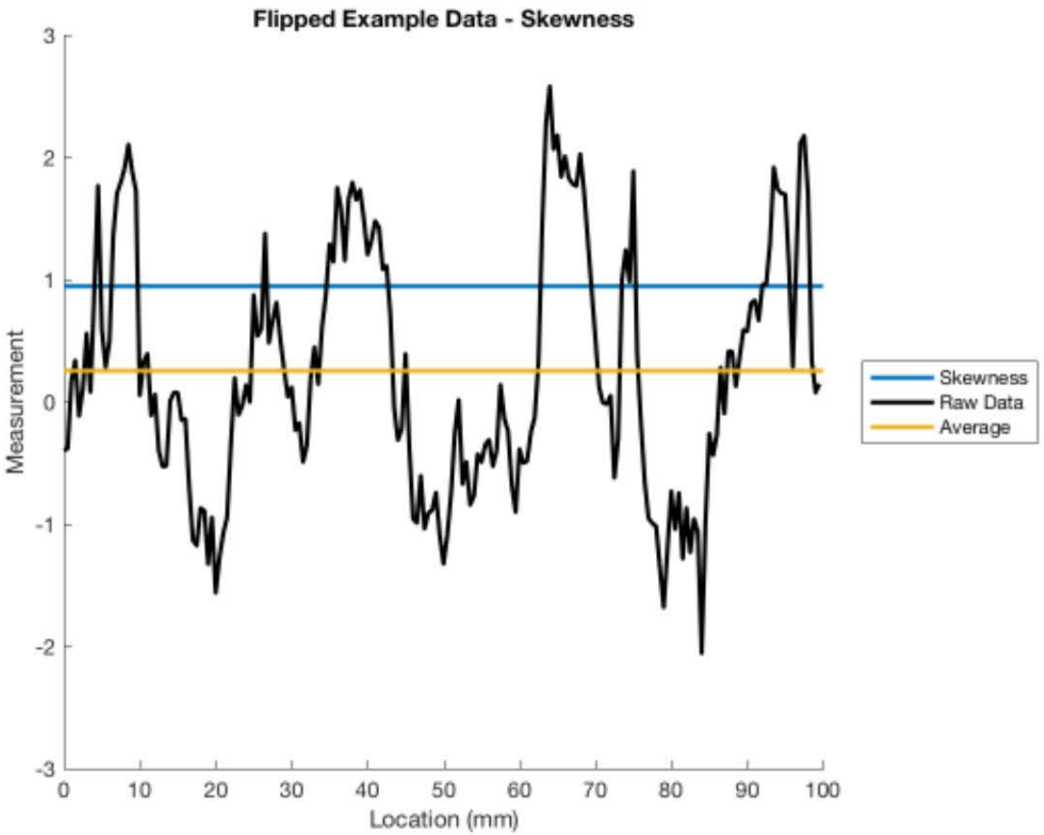
# 3rd Statistical Moment: Skewness




(a)




(b)

Examples of (a) positive and (b) negative macrotexture (negative skewness indicates negative macrotextures)

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# Operationalizing macrotexture data collection

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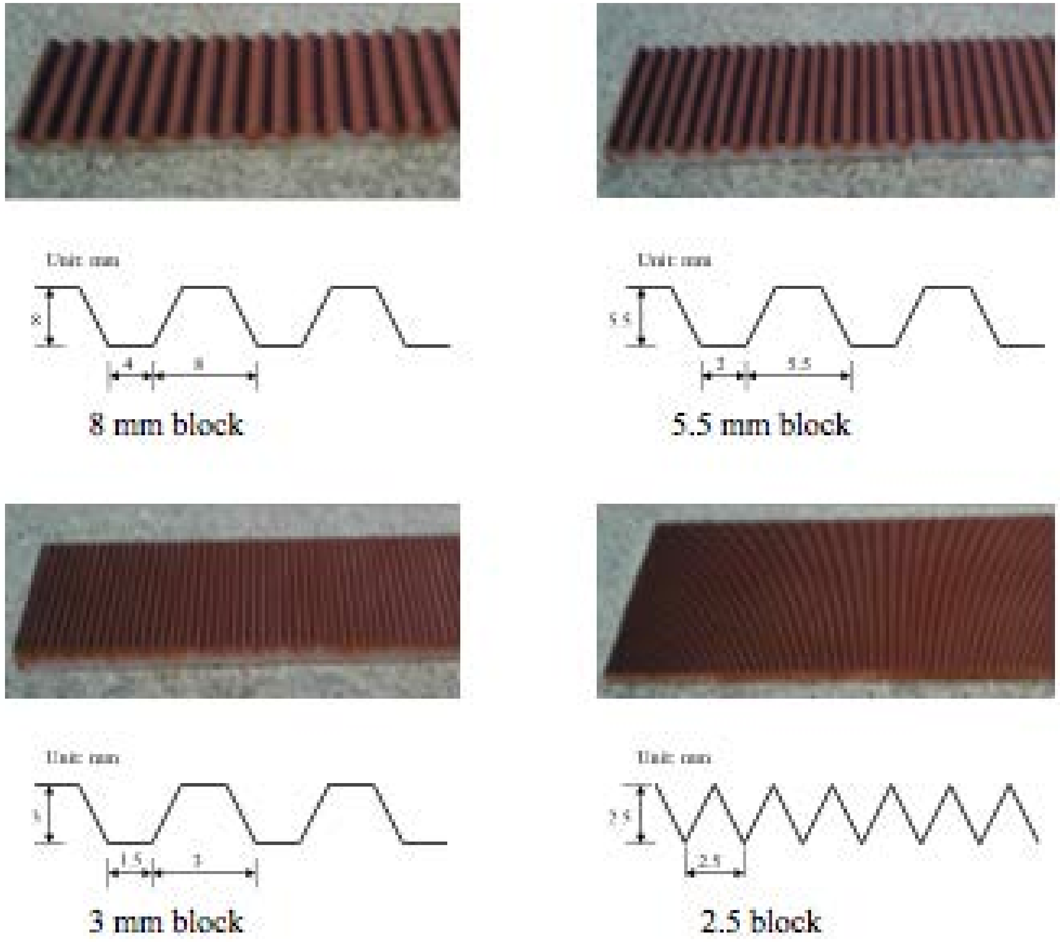
# Reference Surfaces: Machined Plates

- ✓ Huang et al. (2013) used machined stee surfaces (Figure 3) that were tested with several different laser configurations. Us of the steel surfaces in the study also determined optimal travel speed for the laser/camera system used.
- ✓ Use of these artificial surfaces affixed to or inlaid with the pavement surface may require moving sensors to avoid damaging the host vehicle’s tires, the equipment, or the surfaces. Materials less damaging than steel (e.g., aluminum, ceramics, etc.) have been proposed.




Huang, Y., Copenhaver, T., Hempel, P., and Mikhail, M. (2013). "Development of Texture Measurement System Based on Continuous Profiles from Three-Dimensional Scanning System." Transportation Research Record: Journal of the Transportation Research Board(2367), pp 13–22.

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# Reference Surfaces: ARRB “Texture Jig”

- ✓ A mechanism was designed and manufactured to simulate a profile moving rapidly underneath the laser sensor using a disk with known dimensions.
- ✓ A variable speed DC motor was coupled to a spinning disk and a rotary pulse generator with a toothed timing belt. Note that a different sized cog was used to drive the pulse generator or distance measuring instrument (DMI) from the cog used to drive the disk. The cog sizes were not harmonically related. This was to ensure a more ‘random’ sampling. i.e. the physical sampling points would be different on each rotation.


Wix, R., and Leschinski, R. "How Coarse was my Texture?" Proc., 24th ARRB Conference, ARRB.

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# Operational & Environmental Factors Affecting Data Collection

- ✓ Speed
  - –Data typically collected in the time domain (i.e., 64 samples/sec)
  - –Varying speed effects sampling interval
  - –Sensor exposure time may not be fast enough (i.e., 64kHz **max**)
- ✓ Ambient Light
  - –Ambient light may effect data collected
- ✓ Pavement Color
  - –Dark surfaces (i.e., asphalt) do not reflect light as well as lighter
  - –Dark and shiny surfaces (i.e., newly laid asphalt) are especially difficult to collect quality data

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# Operational & Environmental Factors Affecting Data Collection (cont)

- ✓ Temperature
  - –ISO 13473-1 indicates testing should not occur immediately after paving due to temperature differentials over the new surface
- ✓ Age
  - –Macrotexture can increase on AC surfaces and decrease on PCC surfaces with age
  - –Age may affect frequency of network testing
- ✓ Pavement Distress
  - –Can effect data and calculated parameters
  - –Cracking, rutting, spalling, raveling

# Operational & Environmental Factors Affecting Data Collection (cont)

- ✓ Transverse Variability
  - –Wheelpath vs. non-travelled surface
  - –Longitudinal engineered texturing (i.e., brush, tine, groove)
- ✓ Surface moisture
  - –Wet surface affects return of transmitted energy
  - –Moisture can accumulate on the sensor’s receiver
  - –Optical testing must not be accomplished on wet surfaces

# Operational & Environmental Factors Affecting Data Collection (cont)

- ✓ Vehicle dynamics
  - – Must remove movement of vehicle for accurate measurement
  - – Accomplished real time via Inertial Measurement Units
- ✓ Direction of data collection
  - – Line lasers can be oriented in various configurations
    - Parallel to direction of travel
    - Perpendicular to direction of travel
    - At any angle in-between

# Who’s doing it?

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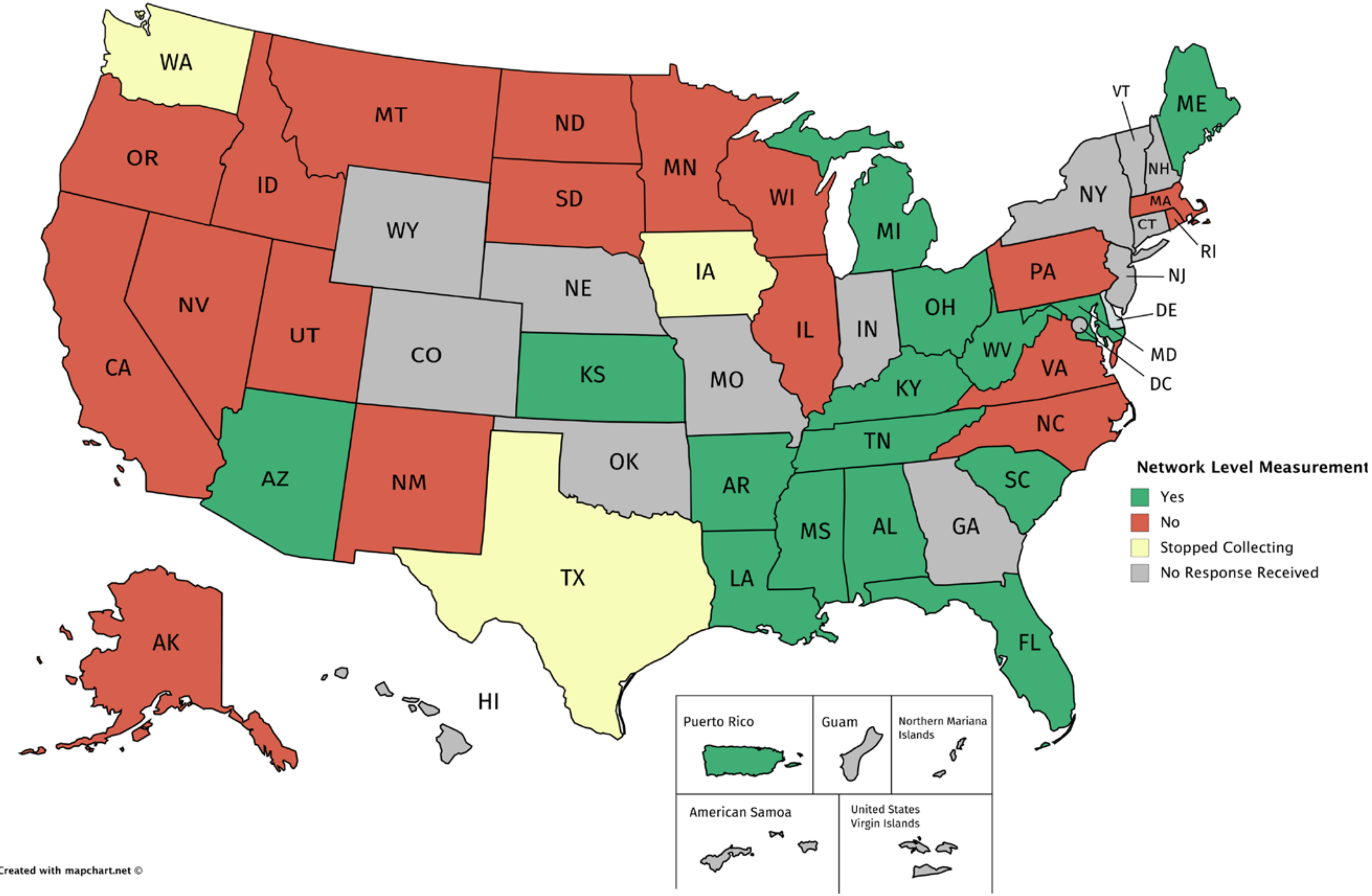
# States Collecting Network Level Macrotexture

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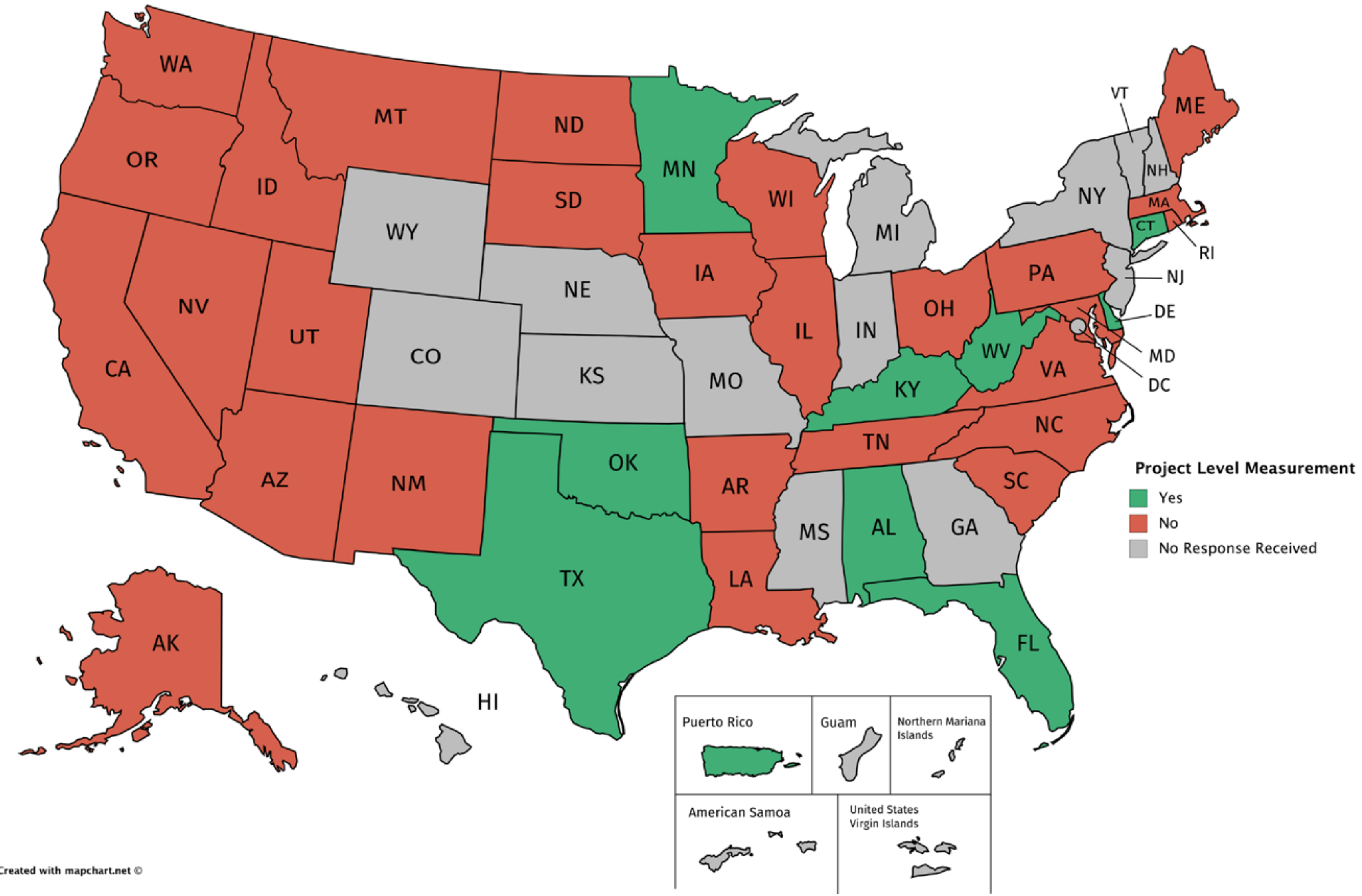
# States Collecting Project Level Macrotexture

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# Equipment Used by DOTs to Gather Macrotexture Data

| Macrotexture Method | Network Level | Project Level |
|---|---|---|
| Volumetric | | |
| Sand patch | 1 | 6 |
| Grease patch | 0 | 0 |
| HydroTimer | 0 | 2 |
| Manual | | |
| Profile recorder | 0 | 0 |
| Stationary Laser Systems | | |
| C.T. Meter | 1 | 7 |
| ELAtextur | 0 | 0 |
| Laser Texture Scanner | 0 | 3 |
| DSRM | 0 | 0 |
| Stationary Optical imaging systems | | |
| Stereo Vision System | 0 | 0 |
| Photometric stereo | 0 | 0 |
| Pavement Surface Imager[2] Mark ½ | 0 | 0 |
| Walking Speed Laser System | | |
| ARRB Walking Profiler | 0 | 0 |
| TM2 Texture Meter, | 1 | 2 |
| ROBOTEX | 0 | 0 |
| High Speed Laser Equipment (HSLE) | | |
| HSLE-SSL (Single spot laser) | 10 | 4 |
| HSLE-LL (Line laser) | 1 | 1 |
| 3-D Laser/ camera | 7 | 1 |
| Other | | |
| Florida texture meter | 0 | 1 |
| ARAN Pave 2D Laser Rut Measurement System (64 kHz) | 0 | 1 |
| In house 3-D system | 0 | 1 |
| Contour/ tire depth gauge for tined and grooved surfaces | 0 | 1 |

# Parameters Used By States

| Parameter | Network Level | Project Level |
|---|---|---|
| Mean Texture Depth (MTD) | 7 | 7 |
| Mean Profile Depth (MPD) | 7 | 6 |
| Root Mean Square (RMS) | 2 | 3 |
| Estimated Texture Depth (ETD) | 0 | 3 |
| Other | | |
| Skewness, Kurtosis, PSD | 1 | 0 |
| Digital Sand Patch (LCMS) | 1 | 0 |

# Upcoming Equipment Comparison

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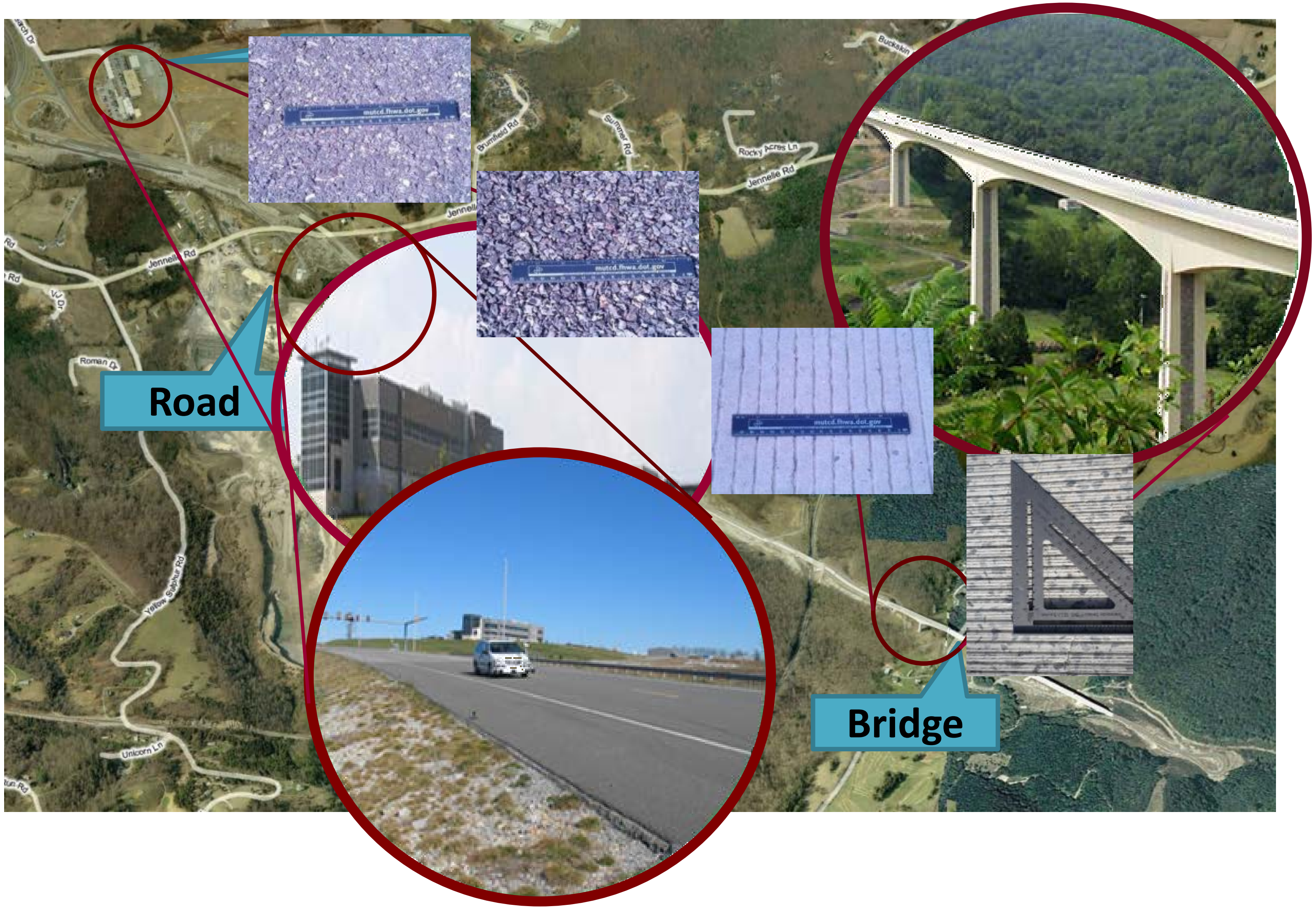
# The Virginia Smart Road – April 2018

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# Upcoming Equipment Comparison

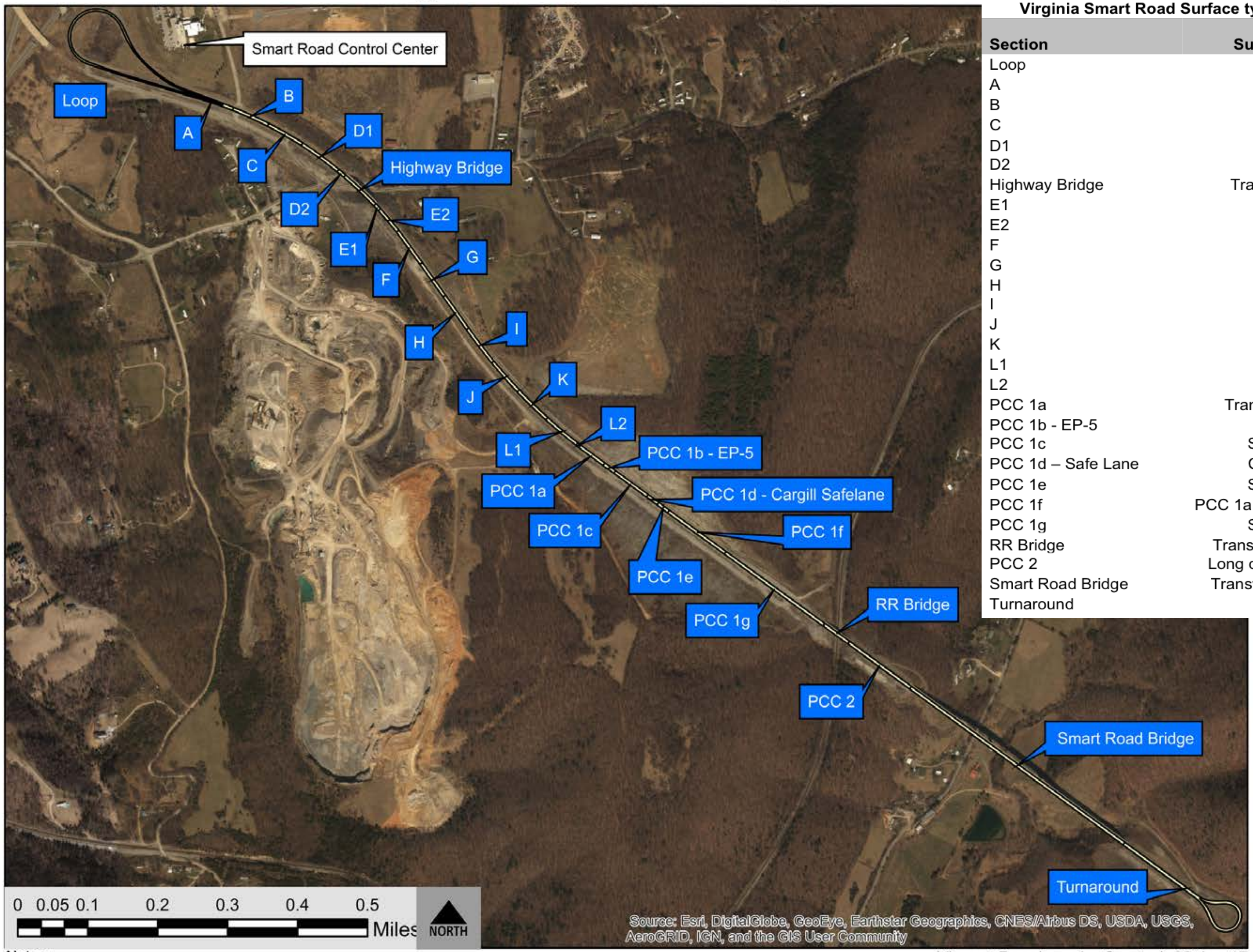
- ✓ The Virginia Smart Road

- ✓ Reference measurements

Surfaces:

- ✓ Dense-graded asphalt concrete
- ✓ Stone-matrix asphalt (SMA)
- ✓ Open graded friction course (OGFC)
- ✓ Continuously reinforced tinned concrete
- ✓ Jointed tinned concrete
- ✓ Longitudinally ground concrete
- ✓ Longitudinally ground and grooved concrete

# Virginia Smart Road - Surface Types




**Virginia Smart Road Surface types sections - East to West Travel**

| Section | Surface Description | Approx. Length (ft) |
|---|---|---|
| Loop | DG HMA | 2366 |
| A | SM-12.5D | 347 |
| B | SM-9.5D | 296 |
| C | SM-9.5E | 292 |
| D1 | SM-9.5A | 343 |
| D2 | SM-9.5A | 64 |
| Highway Bridge | Transverse tined PCC | 315 |
| E1 | DG HMA | 51 |
| E2 | SM-9.5D | 218 |
| F | SM-9.5D | 303 |
| G | SM-9.5D | 303 |
| H | SM-9.5D | 303 |
| I | SM-9.5A | 314 |
| J | SM-9.5D | 292 |
| K | OGFC | 302 |
| L1 | SMA-12.5 | 297 |
| L2 | DG HMA | 29 |
| PCC 1a | Transverse tined CRCP | 228 |
| PCC 1b - EP-5 | EP-5 | 100 |
| PCC 1c | Same as PCC 1a | 305 |
| PCC 1d – Safe Lane | Cargill Safe Lane | 100 |
| PCC 1e | Same as PCC 1a | 100 |
| PCC 1f | PCC 1a long. grooved & ground | 533 |
| PCC 1g | Same as PCC 1a | 921 |
| RR Bridge | Transverse grooved CRCP | 232 |
| PCC 2 | Long diamond ground JPCP | 583 |
| Smart Road Bridge | Transverse Grooved CRCP | 2000 |
| Turnaround | DG HMA | 2275 |

Vincent Bongioanni; Created: 22 Jun 17

Notes:
1. Sectioning and distances are for the "uphill" direction (East to West)
2. When travelling "downhill" (West to East), Section PCC 1b is the Cargill Safelane and PCC 1d is the EP-5; PCC1f is the same surface type as PCC 1a. Downhill distances vary slightly

# Questions?