2020

WEBINAR SERIES

RPUG

Road Profile Users' Group

# Highway Speed Macrotexture: Spot vs Line Laser

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# Outline

- History of FDOT Laser Use
- Line Laser Study
- Results
- Precision
- Summary

# FDOT's Mission

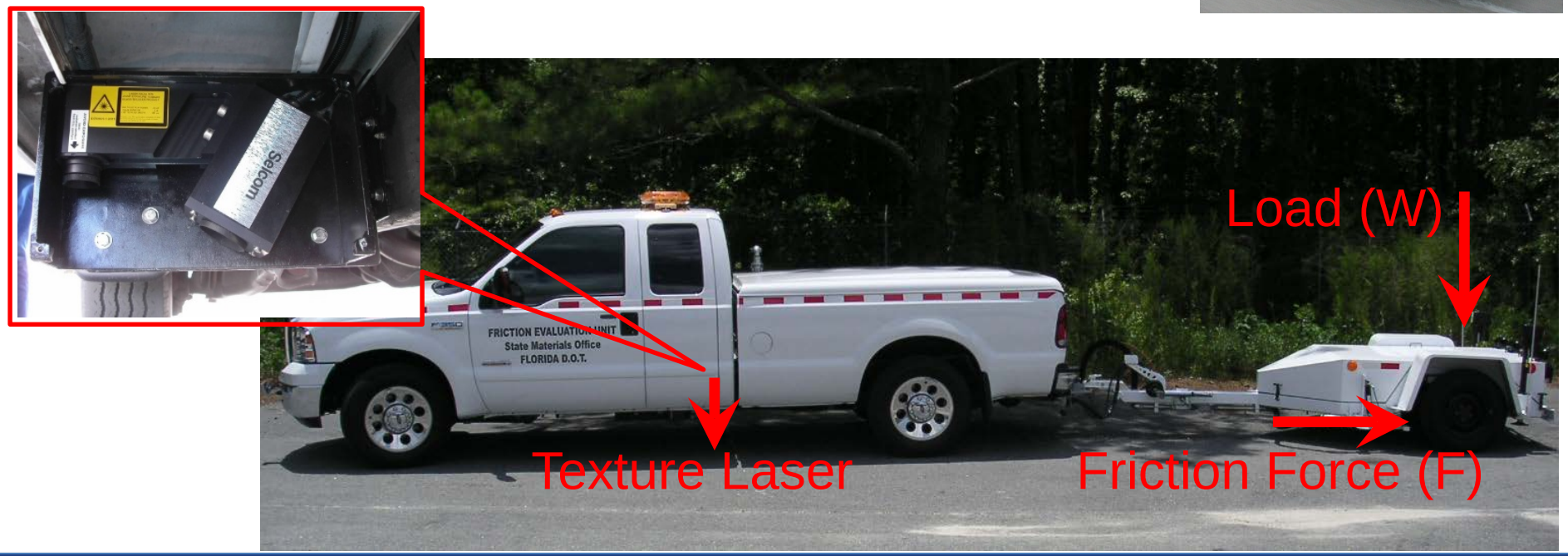
- Goal - Utilize high speed non-contact laser-based technology for surveying pavement systems
- High Speed Mobility
- Reduce Motorist Conflict
- Continuous
- Pavement Performance
- Safety

# Using Macrotexture Data for Roadway Safety

- Roadway Departures
- Friction
- Texture
- Hydroplane

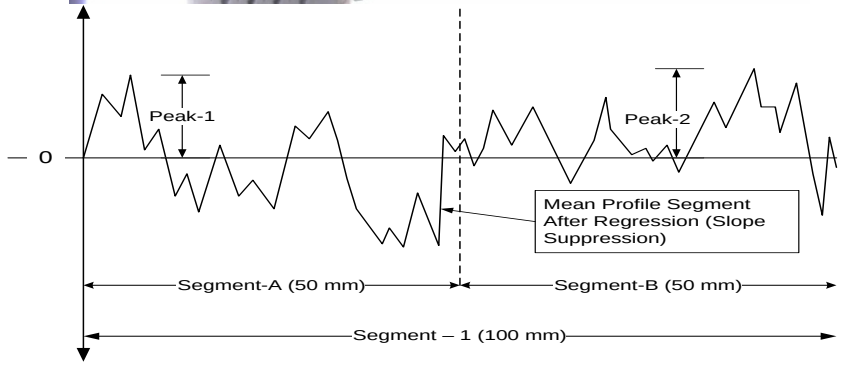
# 2005-2018 Monitoring – Locked Wheel Tester

- Implemented 13 years
- Friction - ASTM E-274
- High Speed (up to 60 mph)
- Point Laser Texture (64 kHz)



# Point Laser Summary

- 62 kHz Sample Rate
  - Point Size (0.5 mm)
  - 3 Second Samples
  - Continuous
  - Up to 60 mph
- ASTM E 1845
  - Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth (MPD)

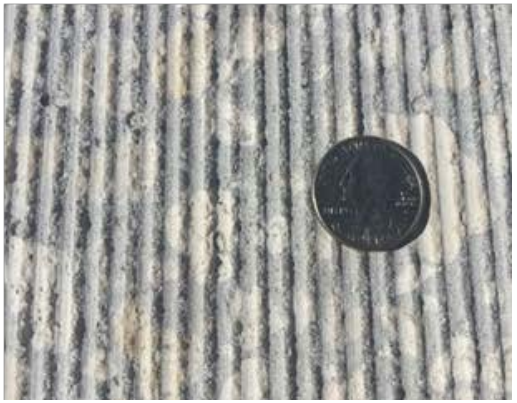

ASTM E 1845-01: Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth

Mean Segment Depth $_{\text{Segment-1}}$ = (Peak-1 + Peak-2)/2

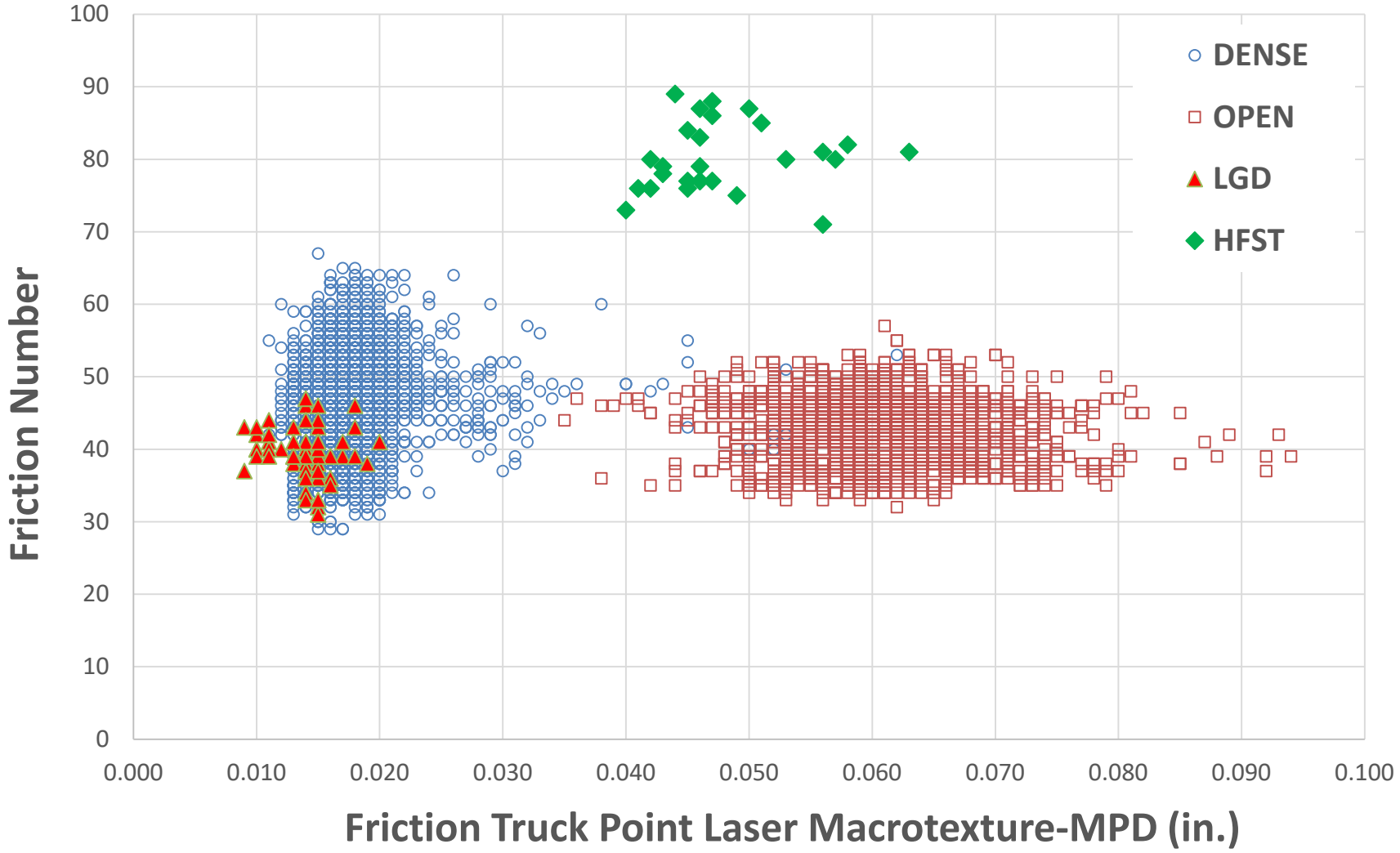
$$MeanSegmentDepth_{Section} = \frac{\sum_{1}^{n} MeanSegmentDepth_{Segment-i}}{n}$$

# Florida Texture Catalog

- Collect FN and MPD
  - New Construction
  - Overlay
  - Inventory
- Surface Types Include
  - OGFC
  - DGFC
  - Concrete (Mainline & Bridge)
  - HFST

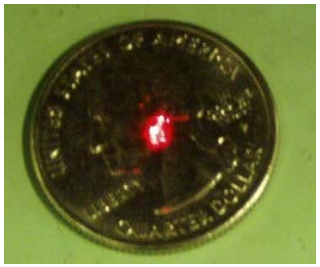
# Friction Number vs. Macrotexture Data

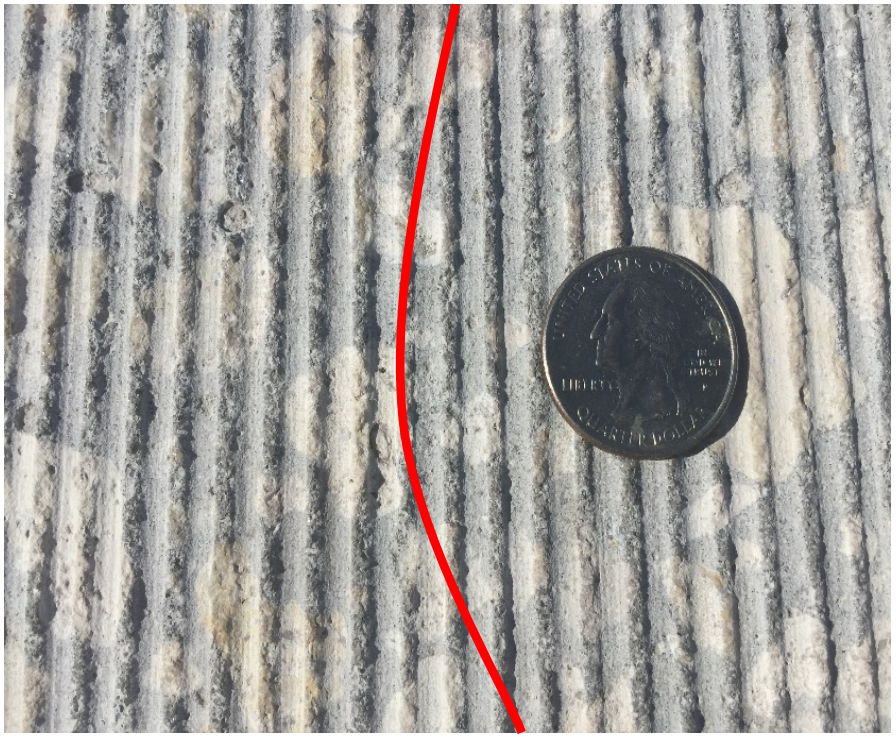


# Accuracy: High Speed Point Laser vs. CTM

# Point Laser Challenges on Concrete

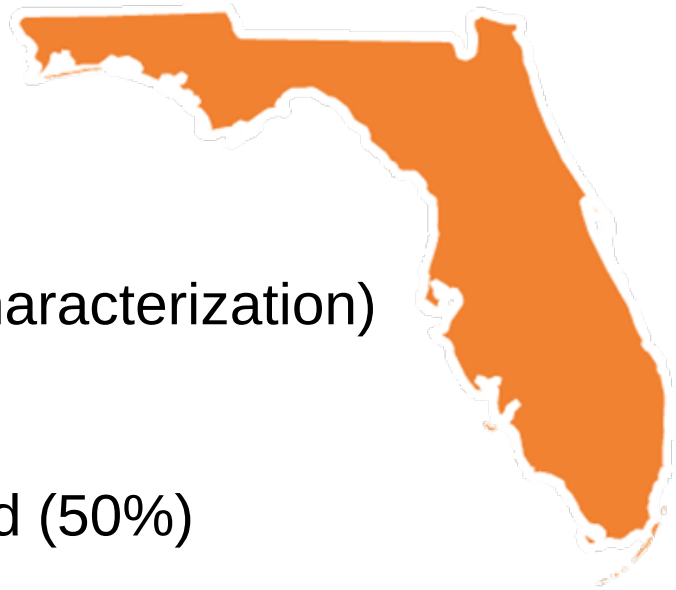
- All new concrete pavements are longitudinally ground
- LGD surface texture improves drainage and friction
- Anisotropic texture has challenges for lasers with a small footprint





# Point Laser Lessons Learned (13 Years)

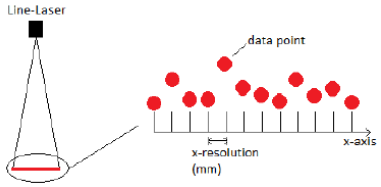
- Pros
  - Up to 64 kHz
  - Up to Continuous 2D data collection
  - Speed 30 – 60 mph
  - Accuracy – 99% w/CTM
  - Reliable
  - Implemented
  - Asphalt (Dense and Open Grade Characterization)



- Cons
  - Poor correlation underestimated rigid (50%)
  - Limited to wheelpath
  - Certain laser frequencies are being phased out

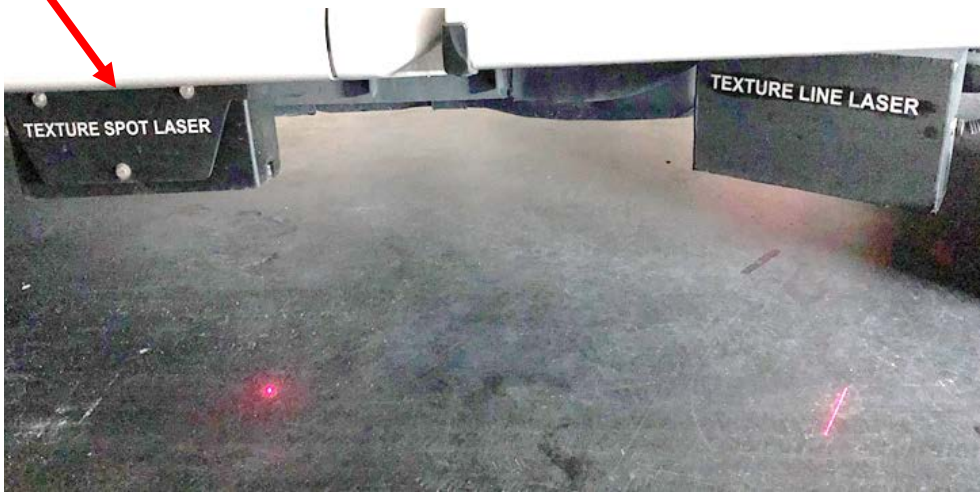
# 2020 Line Laser Study

- Goal: Accurately measure asphalt and concrete macrotexture
- Two Test Systems (Unit 12 & 13)
- Integrate point and line laser technology
- Evaluate 15 Sites
  - 5 DGFC
  - 5 OGFC
  - 5 Rigid LGD
- CTM Reference Equipment
- Precision Estimates



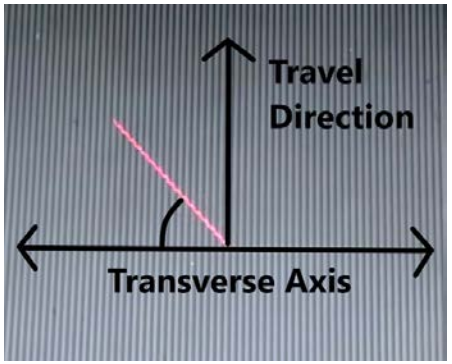

# Point and Line Laser Sensors

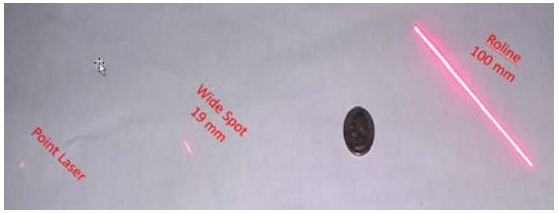

- Wheel Path
- Recycled 64 kHz Point Laser
- 5 kHz Line Laser
  - 100 mm line
  - 400 points per line
  - Adjustable (20 Hz) line sampling

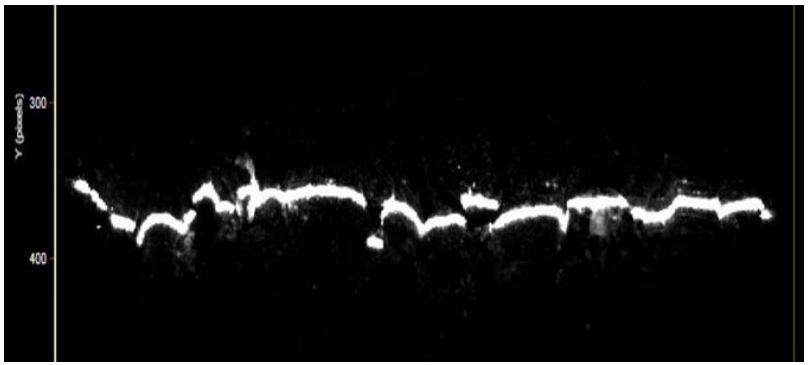


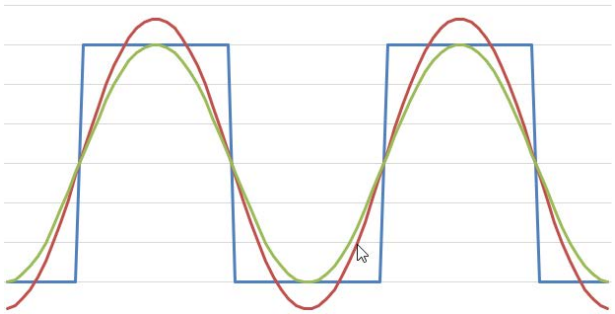
# Sensitivity Analysis

- Exposure Rate (Outliers)
- Raw Data – Low Pass Filtering
- Dropouts
- Line Laser Orientation



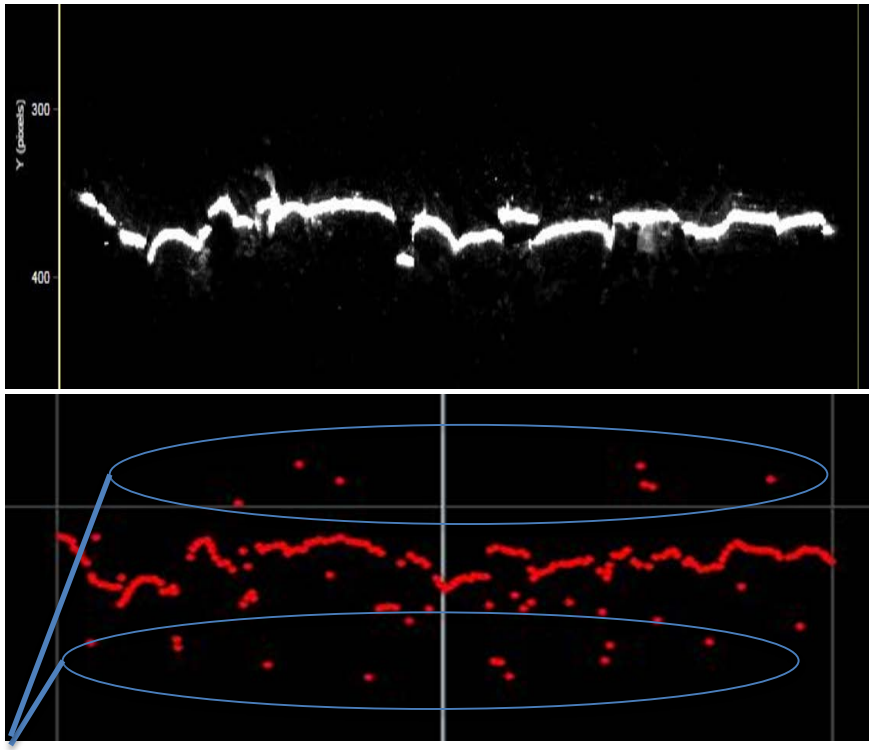



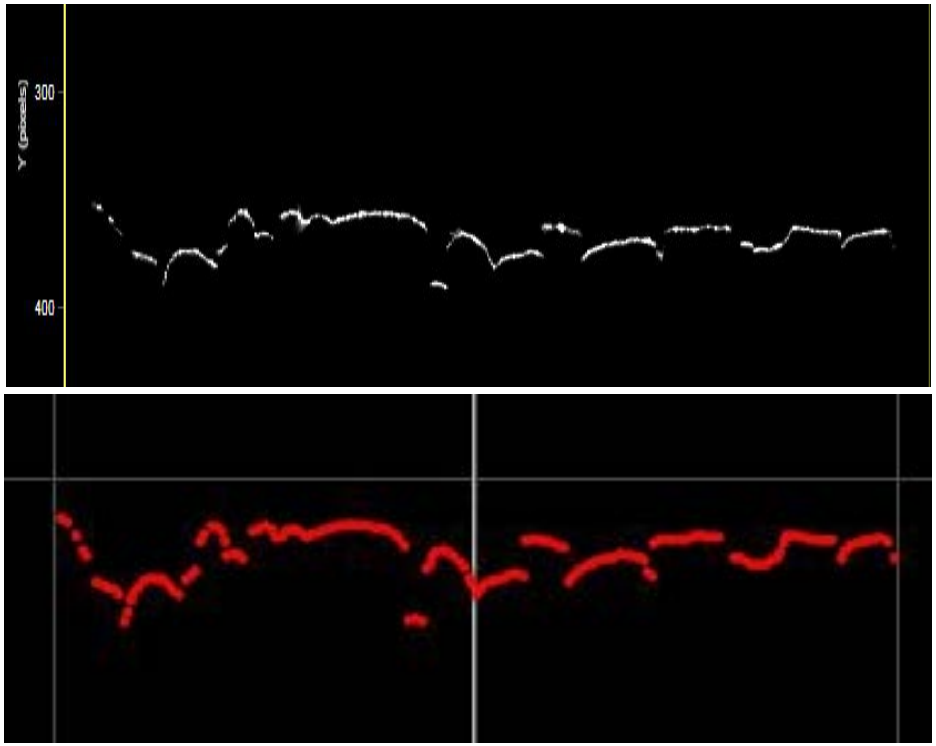
# Line Laser Exposure Rate (Shutter Speed)

- The optimal sensor exposure time varies based on pavement type/color.
- The line laser utilizes a dynamic exposure range to automatically select the “best-fit” exposure time based on pavement color being analyzed (~ 20 to 200 *μs)*
- Darker surfaces require longer exposure times to capture return light.

# Unprocessed Laser Exposure of Sample

- *Image of laser light received off open-grade surface (top) and the corresponding raw data points calculated by the line laser sensor (bottom)*





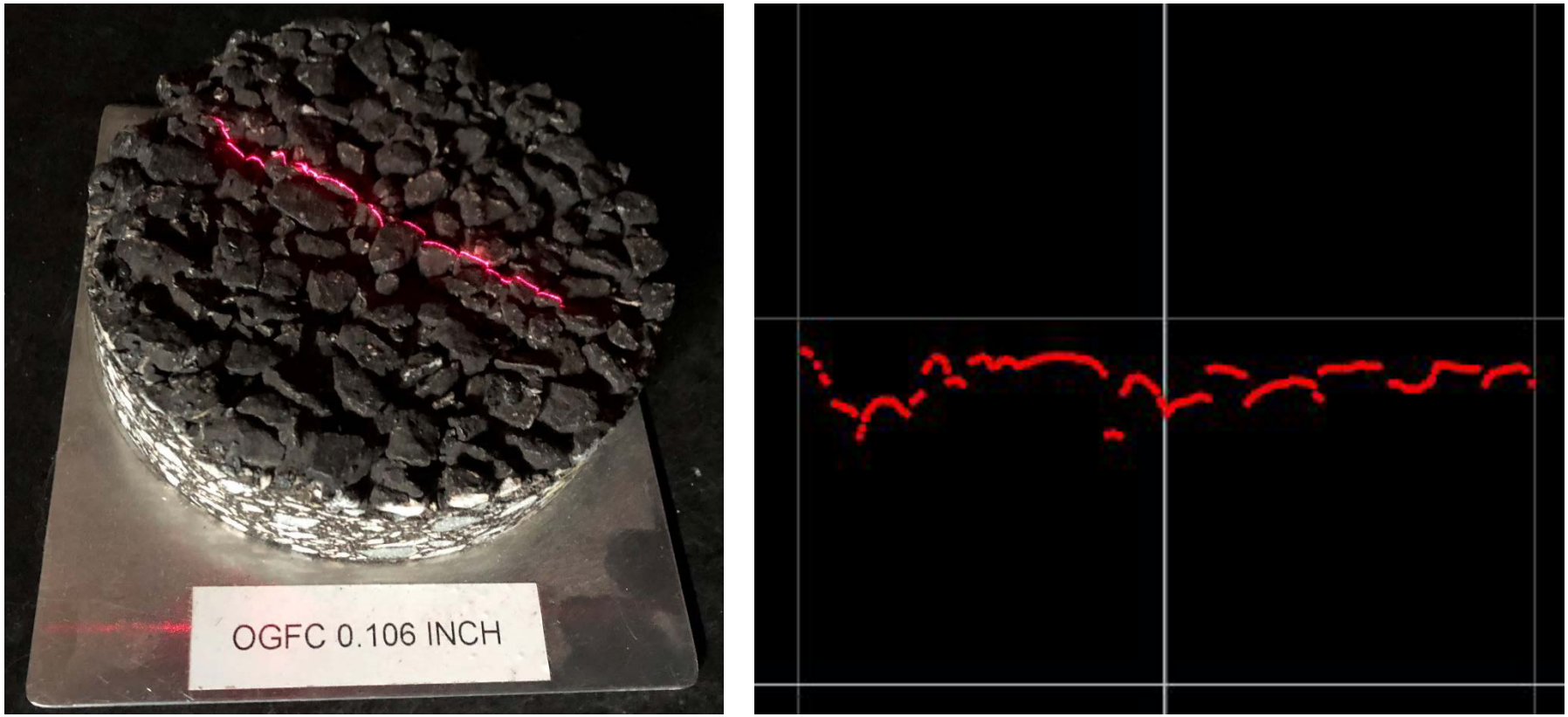



outliers

*Overexposed (200 µs)*

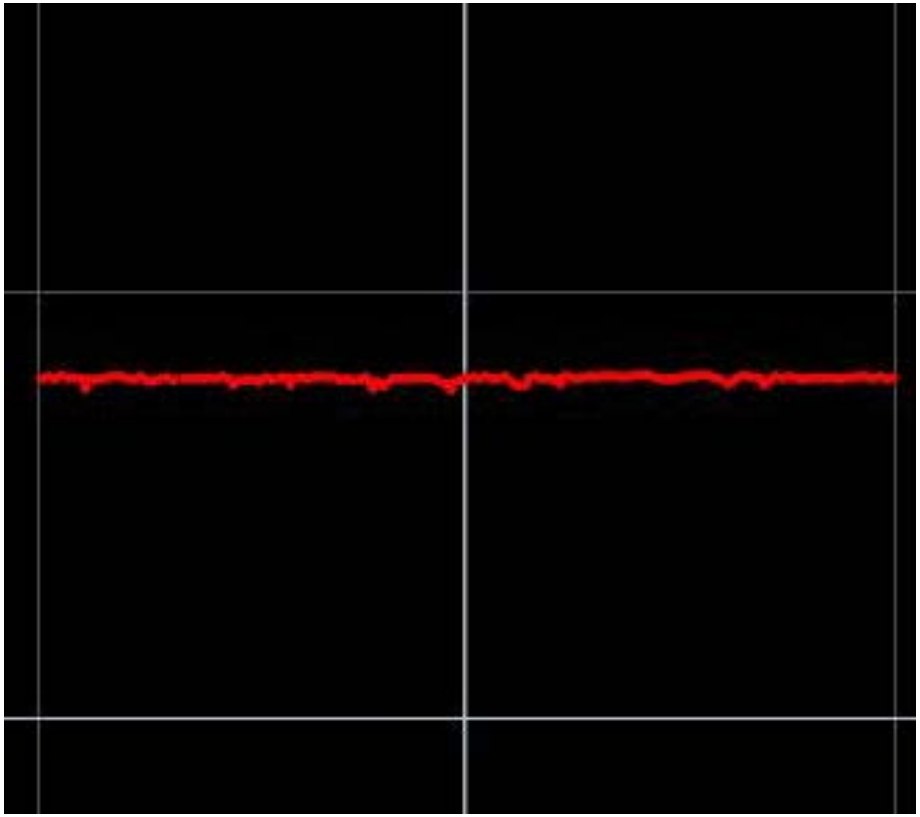
*Optimized exposure (65 µs)*

# Line Laser on Open-Grade Pavement



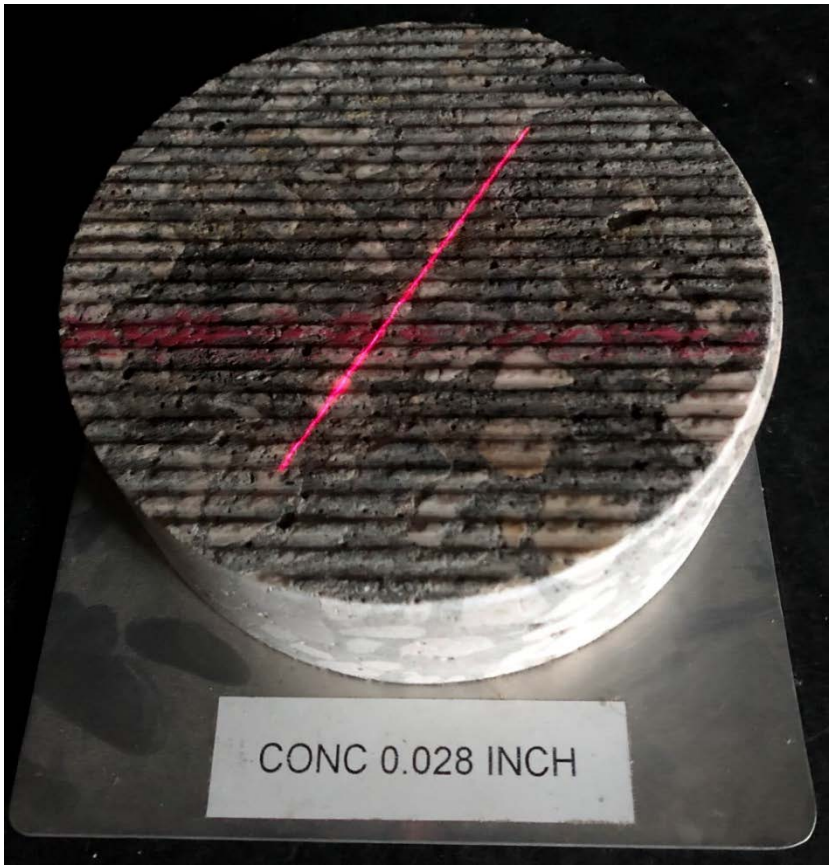

*Open-grade sample and the corresponding data points captured by the line laser (optimum exposure time 60 – 80 µs)*

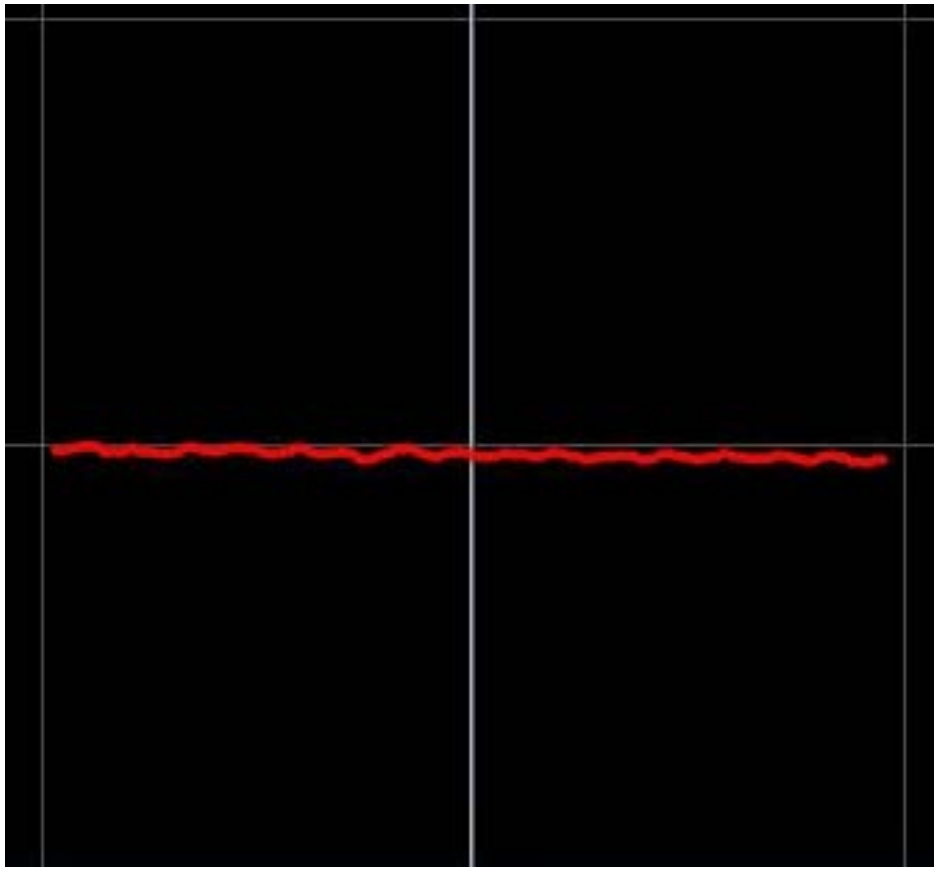
# Line Laser on Dense-Grade Pavement

*Dense-grade sample and the corresponding data points captured by the line laser (optimum exposure time 40 – 70 µs)*

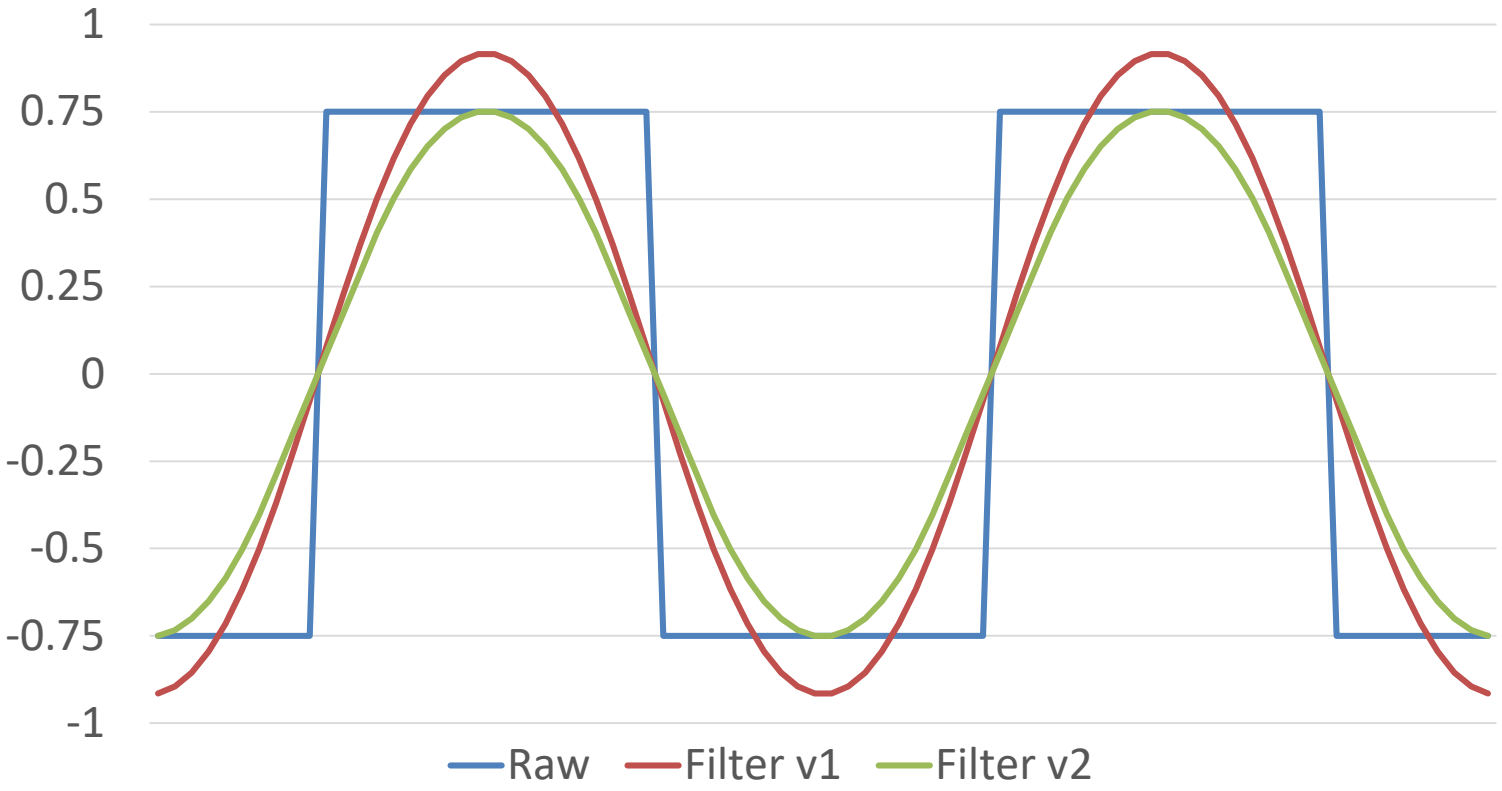
# Line Laser on LGD Concrete



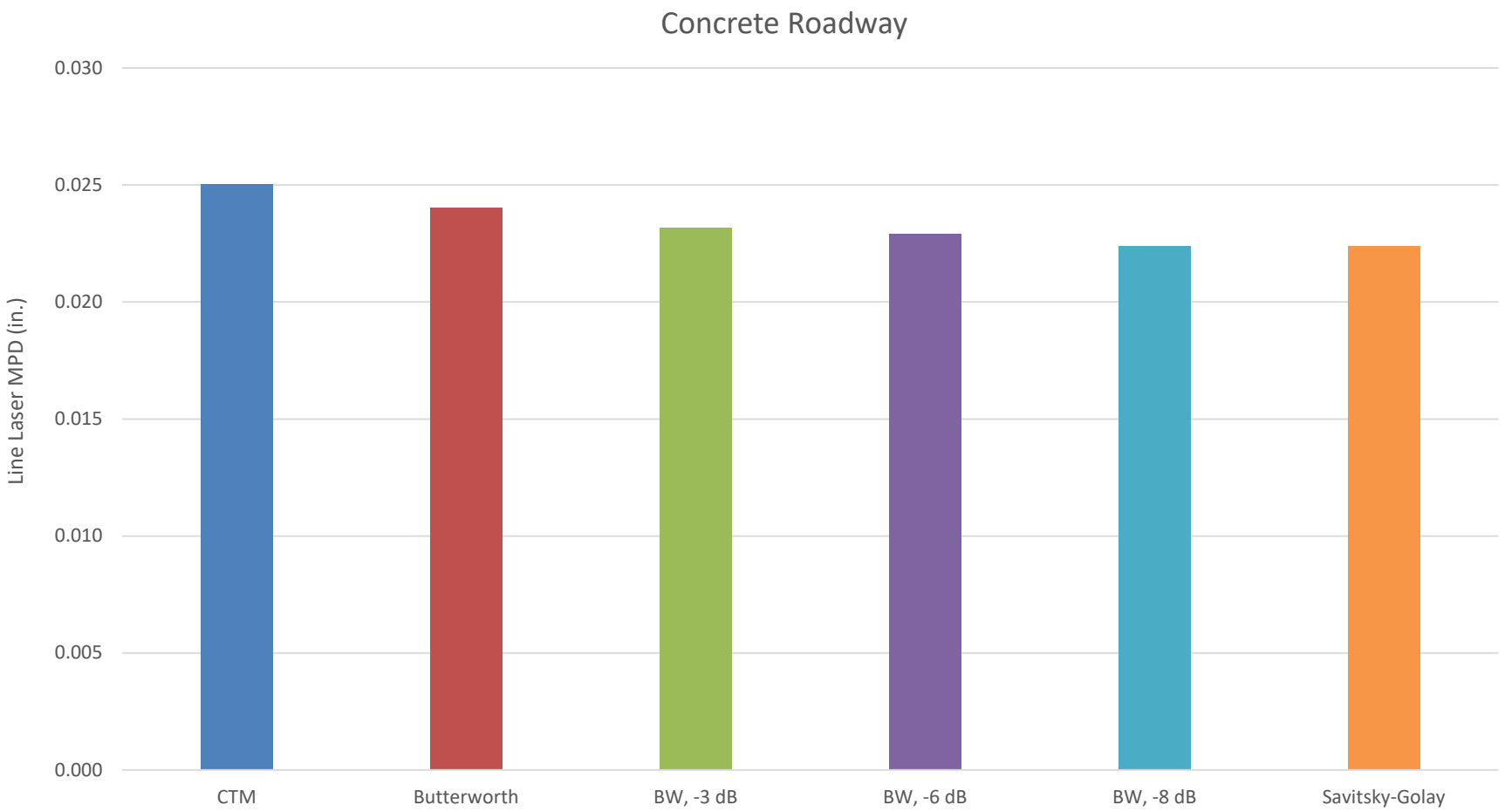
*Concrete sample and the corresponding data points captured by the line laser (optimum exposure time 20 – 30 µs)*

# Effect of Lowpass Filtering on Reference Plate




Filter v1: Butterworth (better fit for dynamic testing)
Filter v2: Savitsky-Golay (better fit for static testing)

# Comparing Lowpass Filters (Highway Speed)



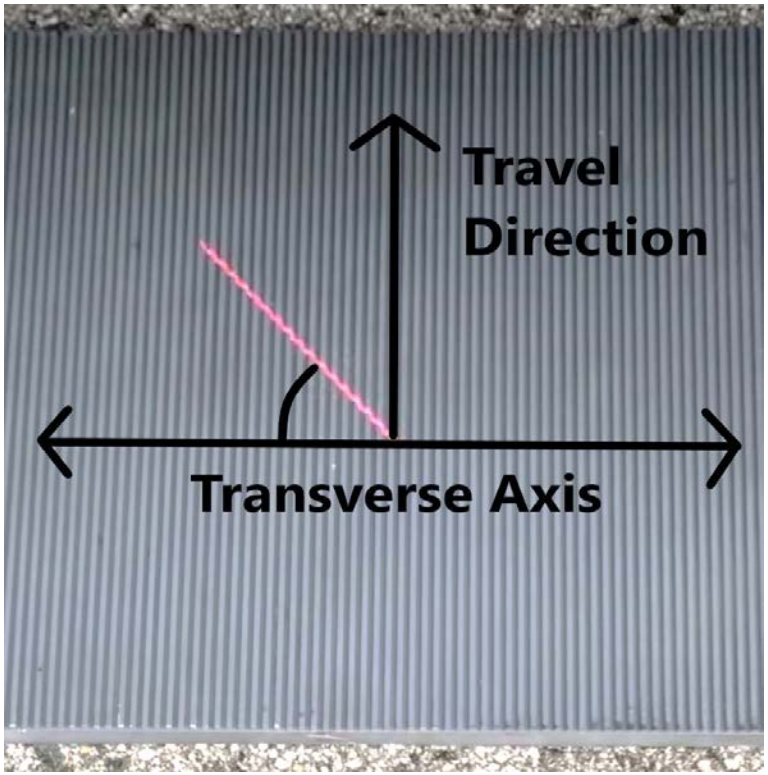
# Data Point Dropouts (Missing Data)

- Dropout points are data points (height measurements) that the laser sensor fails to capture.
- Standard Recommends:
  - Less than 10% error
- Point and Line Laser
  - Vertical Range

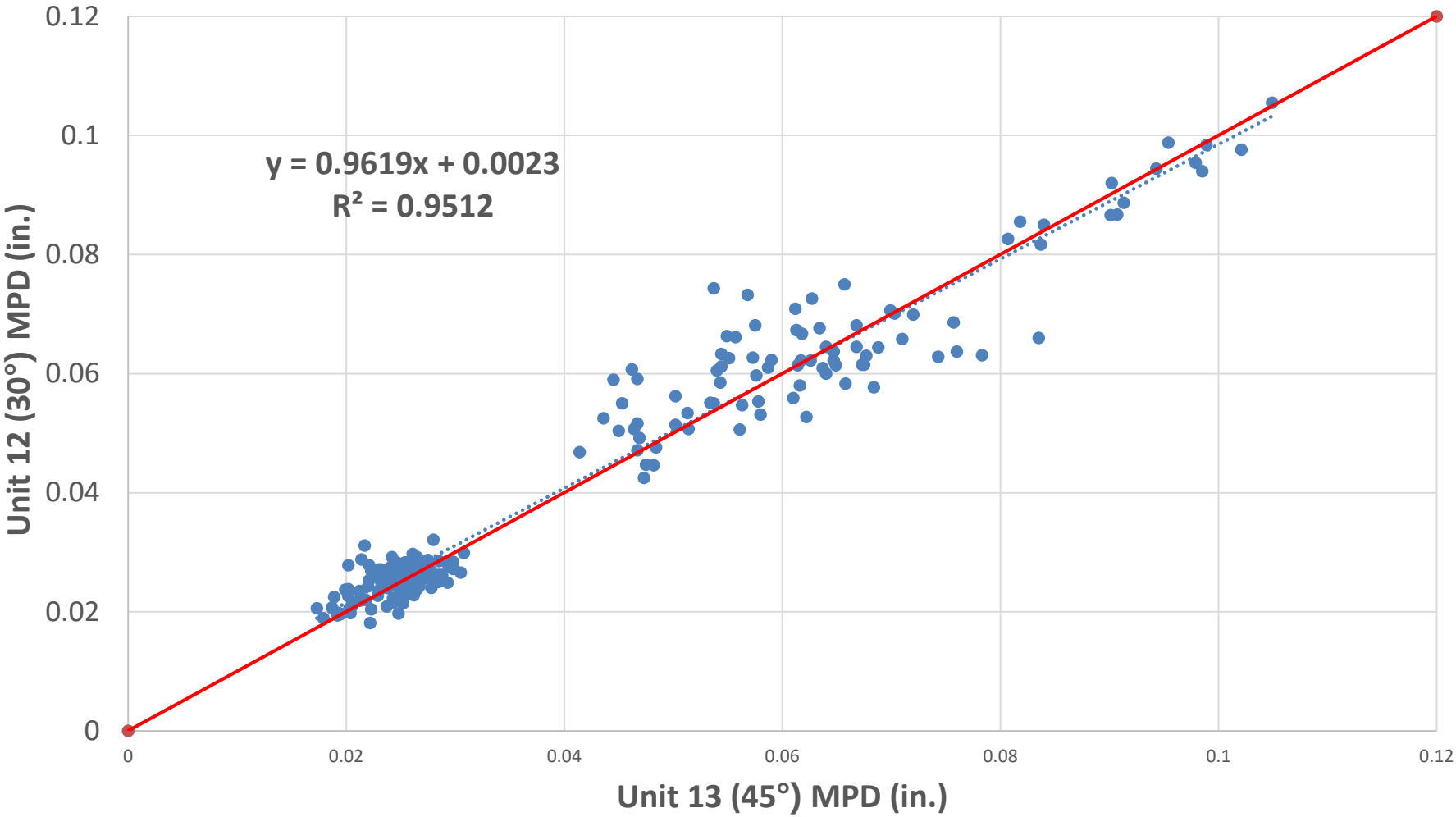
| % Data Dropouts | | |
|---|---|---|
| | Line | Spot |
| OGFC | 0.002% | 5.52% |
| DGFC | 0.007% | 1.46% |
| Rigid | 0.001% | 1.89% |
| Average | 0.004% | 2.95% |

# Line Laser Emission Angle

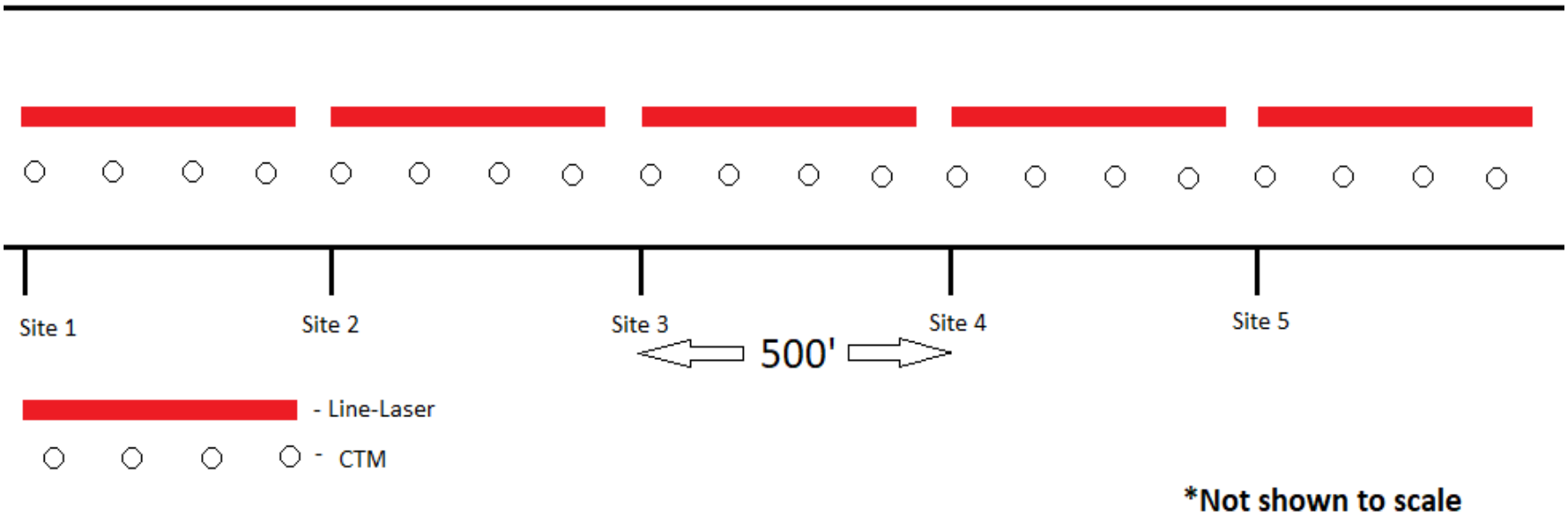
- The line laser is mounted at an angle to capture both longitudinal and transverse periods of texture.
- The line laser shown was mounted at either 30˚ or 45˚ angle relative to the vehicle's transverse axis.
- Differences between the two orientations were found to be negligible.



# Comparing Line Laser Angles - 30º vs 45º

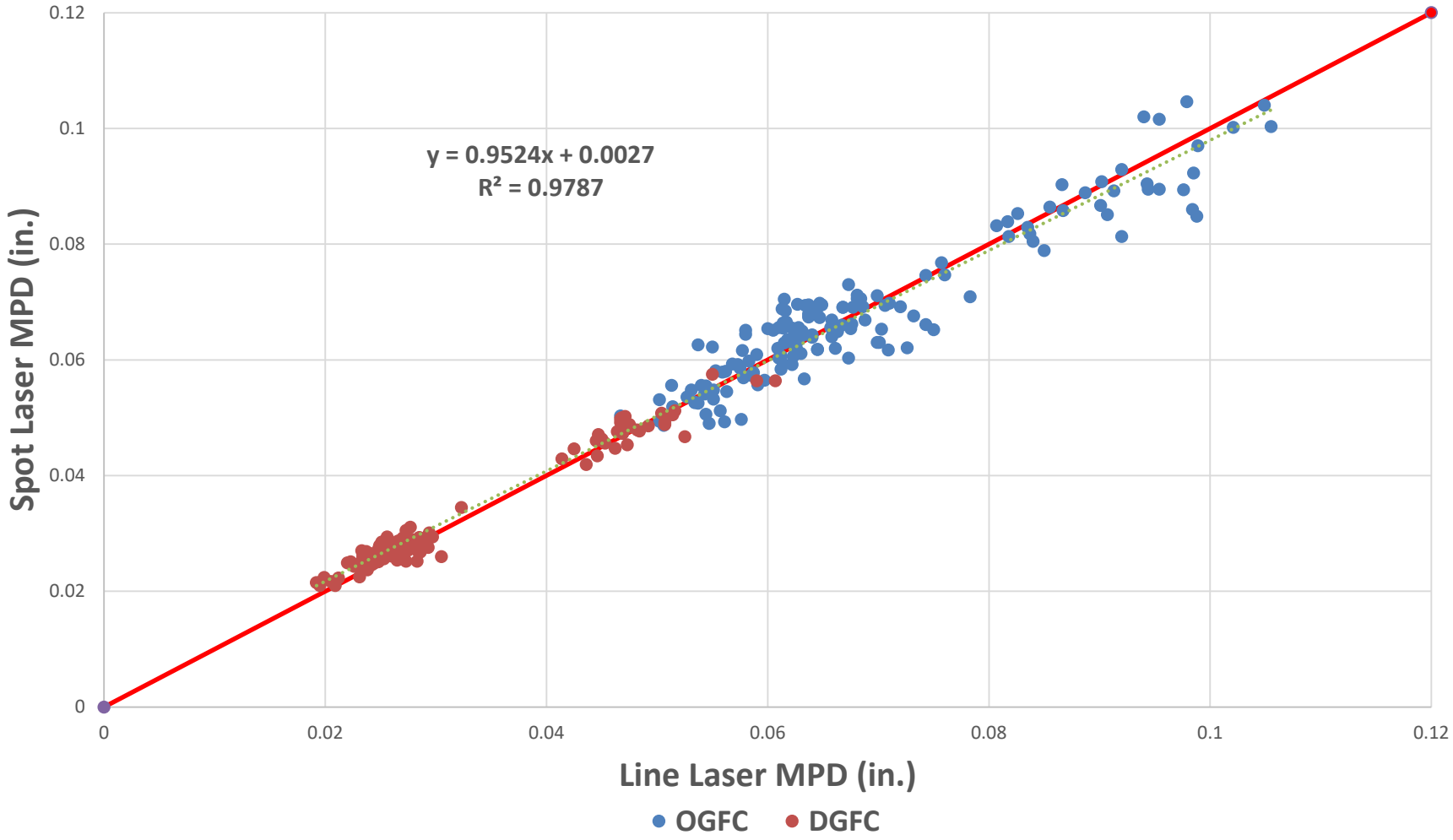


# Field Test Plan

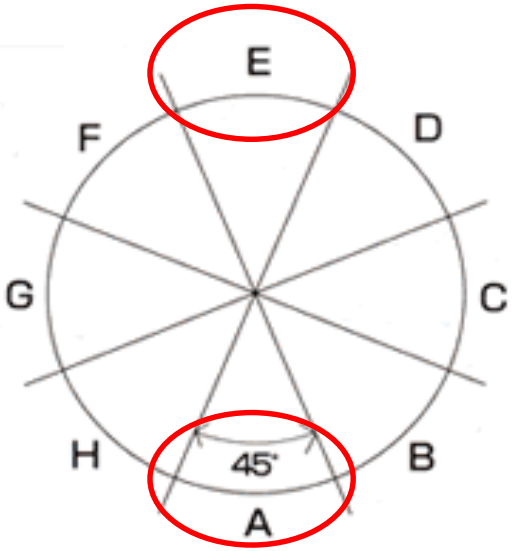



- Evaluate 15 Projects – (5) DGFC, (5) OGFC, (5) Rigid LGD
- CTM – (15) projects, (5) sites/project, (4) test points/site, (3) repeat measurements at each location. (900 data points)
- Point and Line-Laser – (15) projects, (5) sites/project, (3) repeat measurements at each location. (180 data points)

# Line vs. Spot Lasers on Flexible Pavement



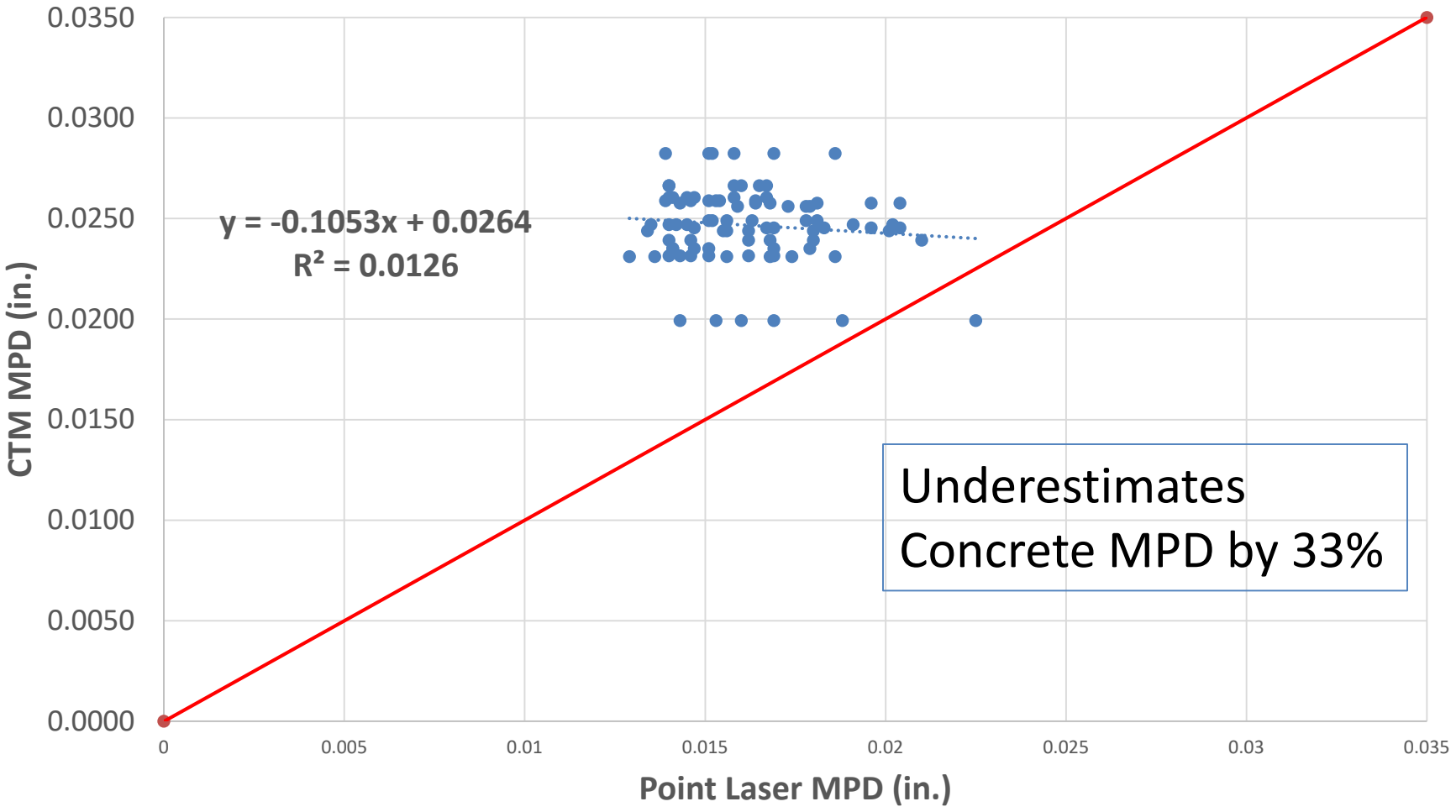
# Comparing the CTM with Point and Line Laser on Concrete



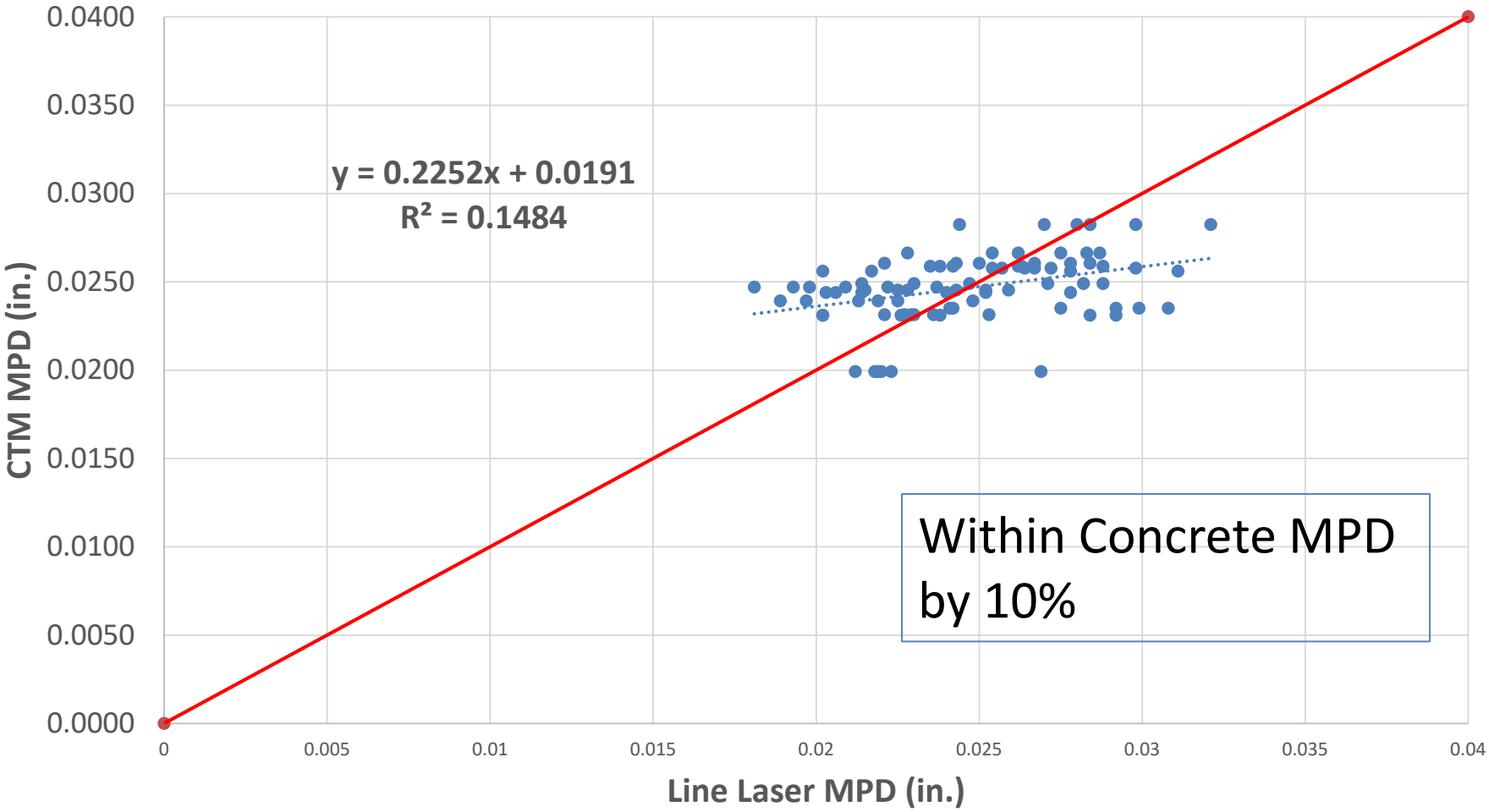


- Removing segments A and E from the CTM comparison on concrete had improved agreement with the line laser by approximately 5%.
- A and E were removed on concrete because the CTM's spot laser runs nearly parallel with the longitudinal texturing of concrete in these segments.

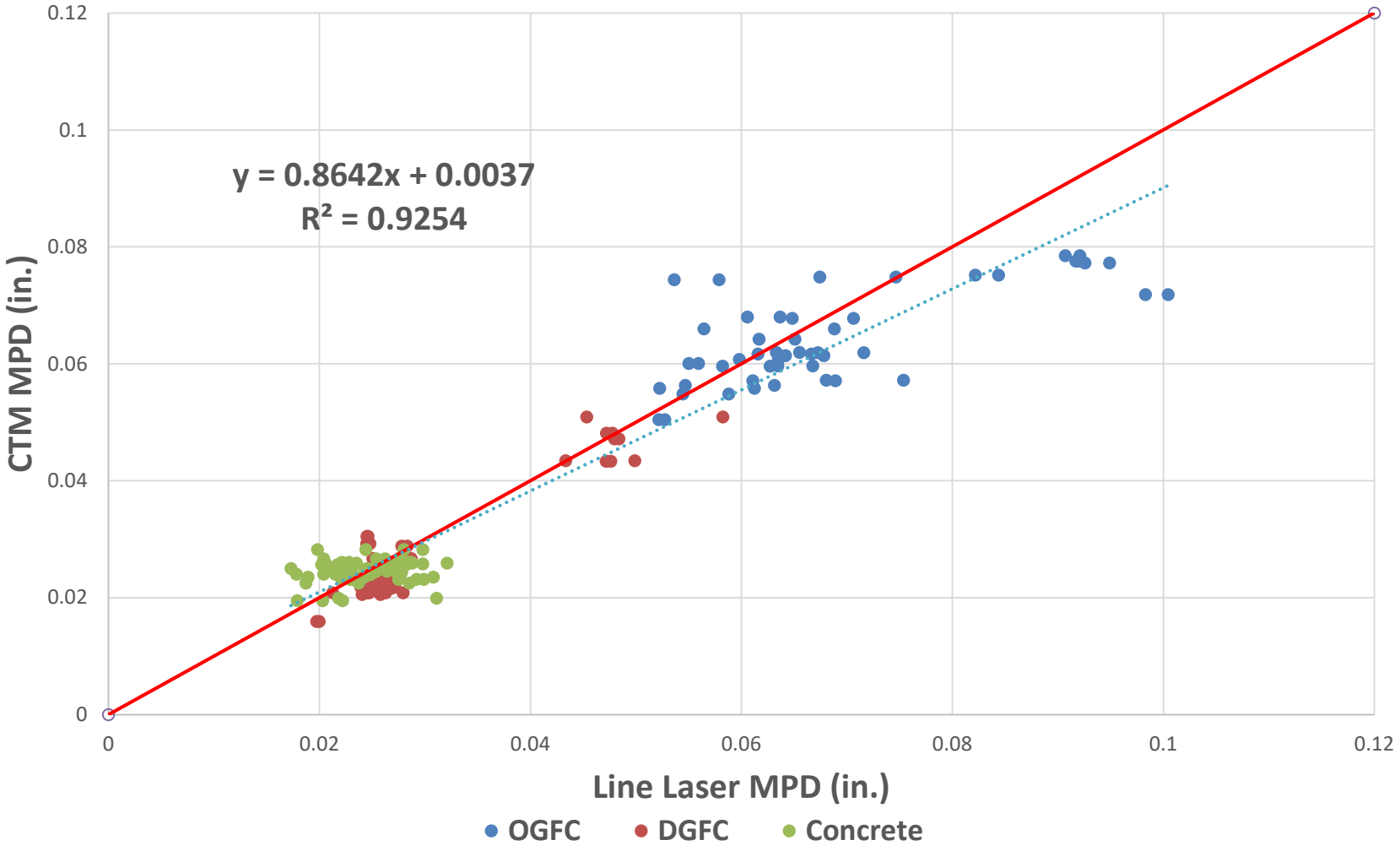
# Point Laser and CTM on Rigid Pavement



# Line Laser vs. CTM on Rigid Pavement



# Line Laser vs. CTM on All Pavement Types



# Precision

## Line Laser

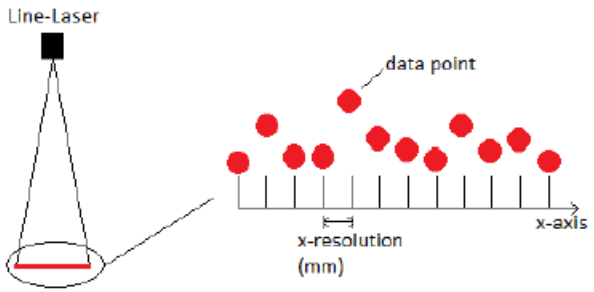
| Pavement Type | Mean, $\bar{x}$ (in) | Repeatability Standard Deviation, $\sigma_{St.Dev.}$ (in) | Reproducibility Standard Deviation, $\sigma_{St.Dev.}$ (in) | Repeatability Coefficient of Variation, COV | Reproducibility Coefficient of Variation, COV | 95% CI Repeatability Limit, *r* (in.) | 95% CI Reproducibility Limit, *R* (in.) |
|---|---|---|---|---|---|---|---|
| OGFC | 0.068 | 0.005 | 0.006 | 6.1% | 7.5% | 0.014 | 0.017 |
| DGFC | 0.030 | 0.002 | 0.003 | 5.3% | 6.5% | 0.006 | 0.008 |
| Concrete | 0.025 | 0.003 | 0.003 | 10.5% | 11.3% | 0.008 | 0.008 |
| **All Combined** | **0.044** | **0.004** | **0.004** | **6.8%** | **8.0%** | **0.010** | **0.012** |

## Spot Laser

| Pavement Type | Mean, $\bar{x}$ (in) | Repeatability Standard Deviation, $\sigma_{St.Dev.}$ (in) | Reproducibility Standard Deviation, $\sigma_{St.Dev.}$ (in) | Repeatability Coefficient of Variation, COV | Reproducibility Coefficient of Variation, COV | 95% CI Repeatability Limit, *r* (in.) | 95% CI Reproducibility Limit, *R* (in.) |
|---|---|---|---|---|---|---|---|
| OGFC | 0.068 | 0.004 | 0.005 | 5.2% | 6.8% | 0.012 | 0.014 |
| DGFC | 0.031 | 0.001 | 0.002 | 3.4% | 5.3% | 0.004 | 0.007 |
| Concrete | 0.016 | 0.002 | 0.002 | 9.4% | 12.1% | 0.005 | 0.006 |
| **All Combined** | **0.042** | **0.003** | **0.004** | **5.5%** | **7.4%** | **0.008** | **0.010** |

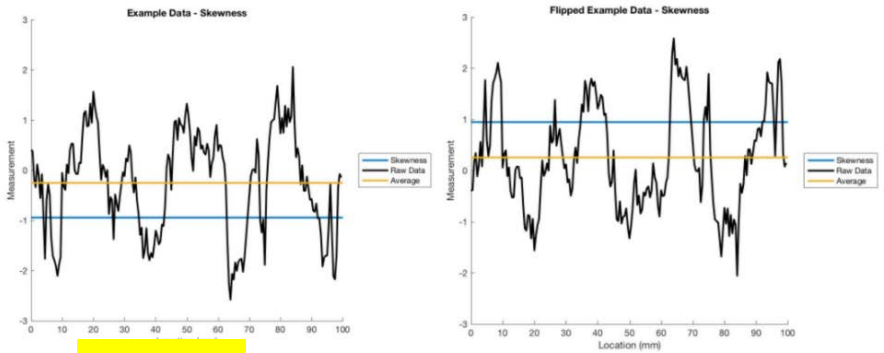
# Optimized Line-Laser Settings

1. **Lowpass Filtering Method**: Butterworth
2. **Exposure:** Dynamic Range (20 µs – 80 µs)
3. **Sampling Rate:** 20 Hz
4. **Z-Resolution (Height Precision):**
   - Less than 0.05 mm
5. **X-Resolution (Line Point-Spacing):**
   - Interval (~0.25 mm)

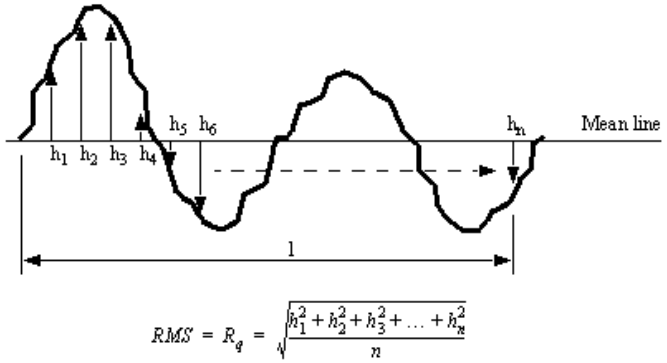


# What are the most appropriate indicators for your pavement surfaces?

- Mean Profile Depth (MPD): $MPD = \frac{(Segment\ 1\ Peak + Segment\ 2\ Peak)}{2} - Average\ Height$

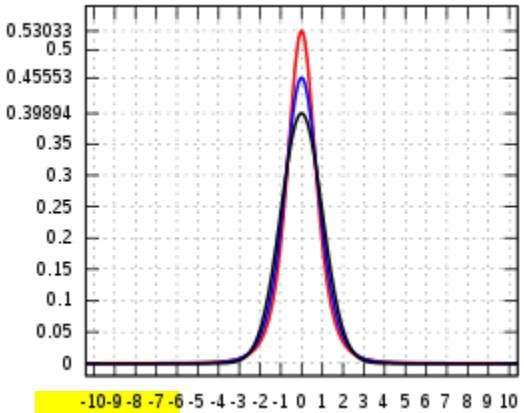



Skewness (https://tinyurl.com/y2a22f72)

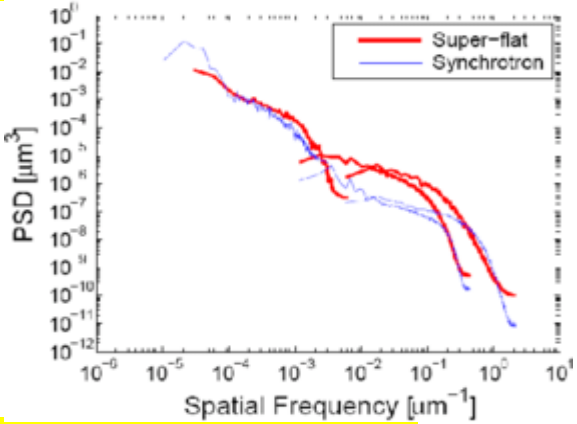



$$RMS = R_q = \sqrt{\frac{h_1^2 + h_2^2 + h_3^2 + \ldots + h_n^2}{n}}$$

Root Mean Square (RMS) (https://tinyurl.com/y366q6eb)




Kurtosis (https://tinyurl.com/ycnh8pvn)




Power Spectral Density (PSD) (https://tinyurl.com/y2a22f72)

# Questions?