

# 3D Data Applications at 1mm and at 60mph

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# PaveVision3D Ultra Approach

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- Multiple Sensors (8 3D Cameras)
- 3D Profile Line Rate to 30,000/s
- Complete Coverage of Pavement Lane
  - True 1mm at Any Data Collection Speed up to 60MPH (100KM/H)



# Data Rate & Power at 60MPH

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- Single Computer
- Data Rate for 3D Only
  - $4000 \times 2 \times 28000 = 224,000,000$  bytes, 224 MB/sec before compression
  - Continuous for a few hours non-stop
- Advantage
  - Low Power < 1000 watts in all
  - Complete Coverage at True 1mm



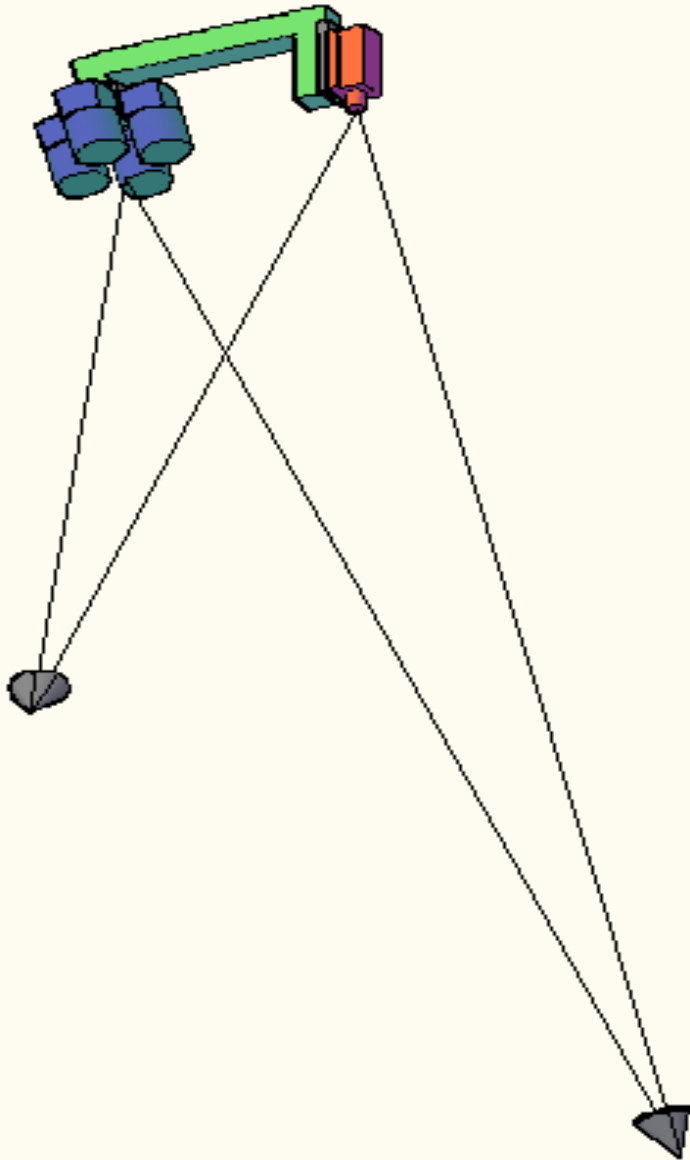
# Data Compression & Management

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- Raw Data from All Sensors
  - Over 10GB per Mile
- 2D Compression: JPG/JPG2000
- 3D Compression
  - Proprietary Compression: over 10:1
- Production Data to Computer Storage: 1GB per Mile
- Relational Database Driven



# PaveVision3D Ultra Design



# PaveVision3D Ultra



# PaveVision3D Ultra



# Virtual Pavement

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- 1mm Pavement Surface in All Three Dimensions
- High-Precision IMU
  - Grades
  - Horizontal Curves
  - Cross-Slope





# PaveVision3D Ultra Applications

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## □ Now

- Cracking, Rutting, IRI, Macro-Texture (MPD, MTD)
- Safety Analysis: High-Friction, Rumble Strips, Hydroplaning/Grooving
- Virtual Surface for Visualization

## □ In Progress

- Longitudinal Profiling
- Comprehensive Evaluation of Distresses
- Comprehensive Performance Metric



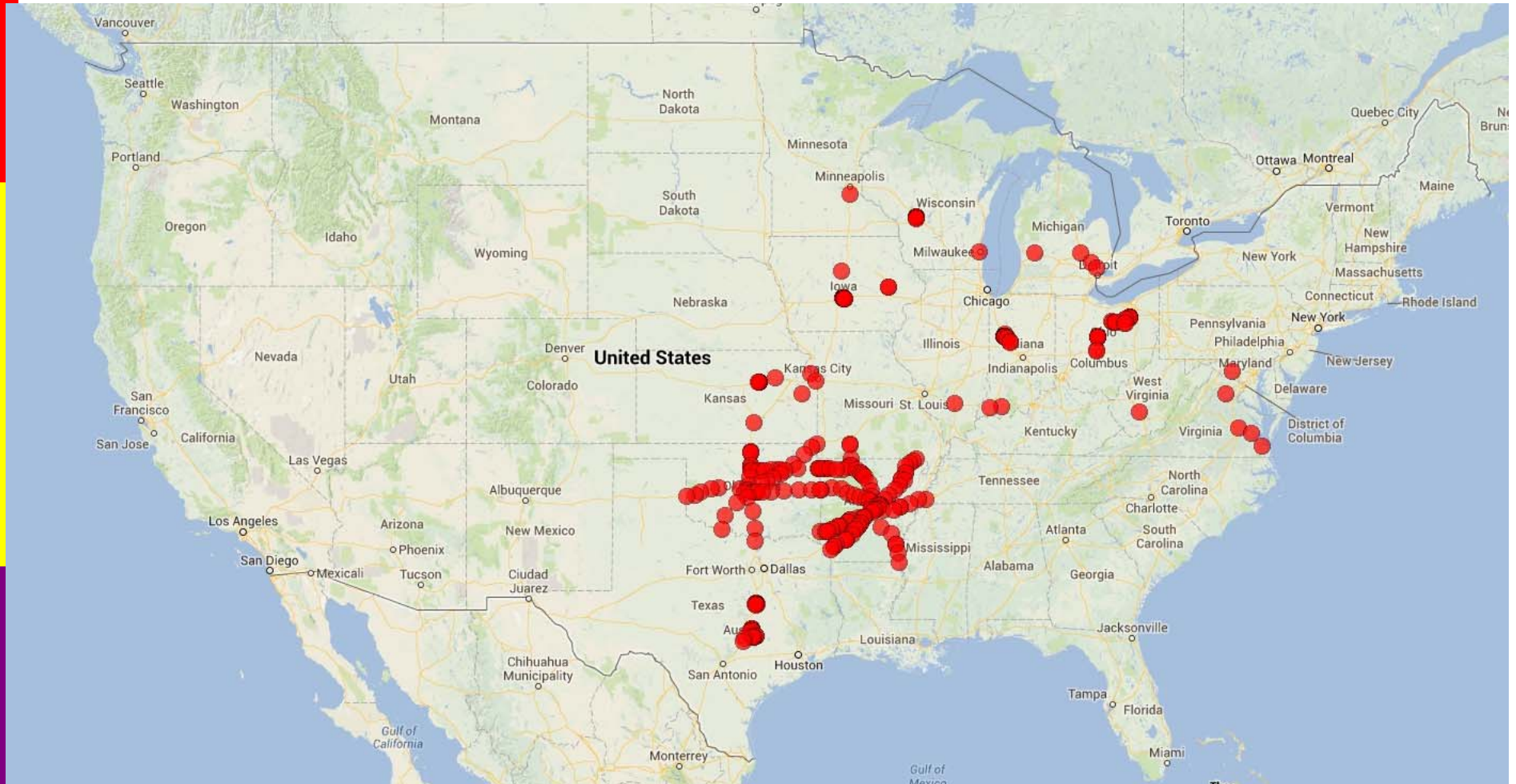
# Example Projects/Applications

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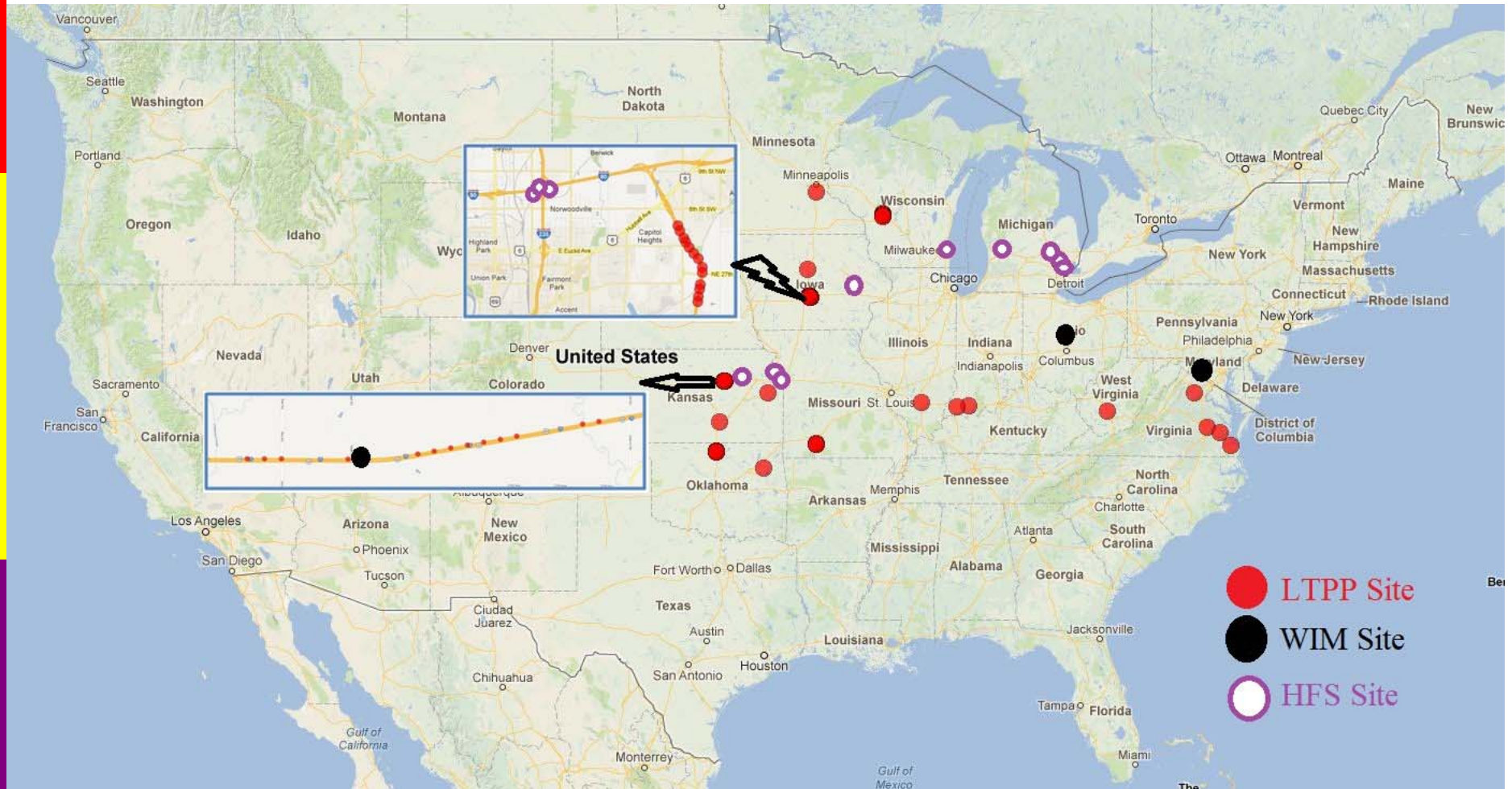
- Arkansas DOT
- Oklahoma DOT
- INDOT
- TxDOT Project 6663 Phase II
- Ohio DOT
- LTPP Sites, some with WIM
- High Friction Surface
- Next Generation Concrete Surface (NGCS)



# Example Projects in 2012

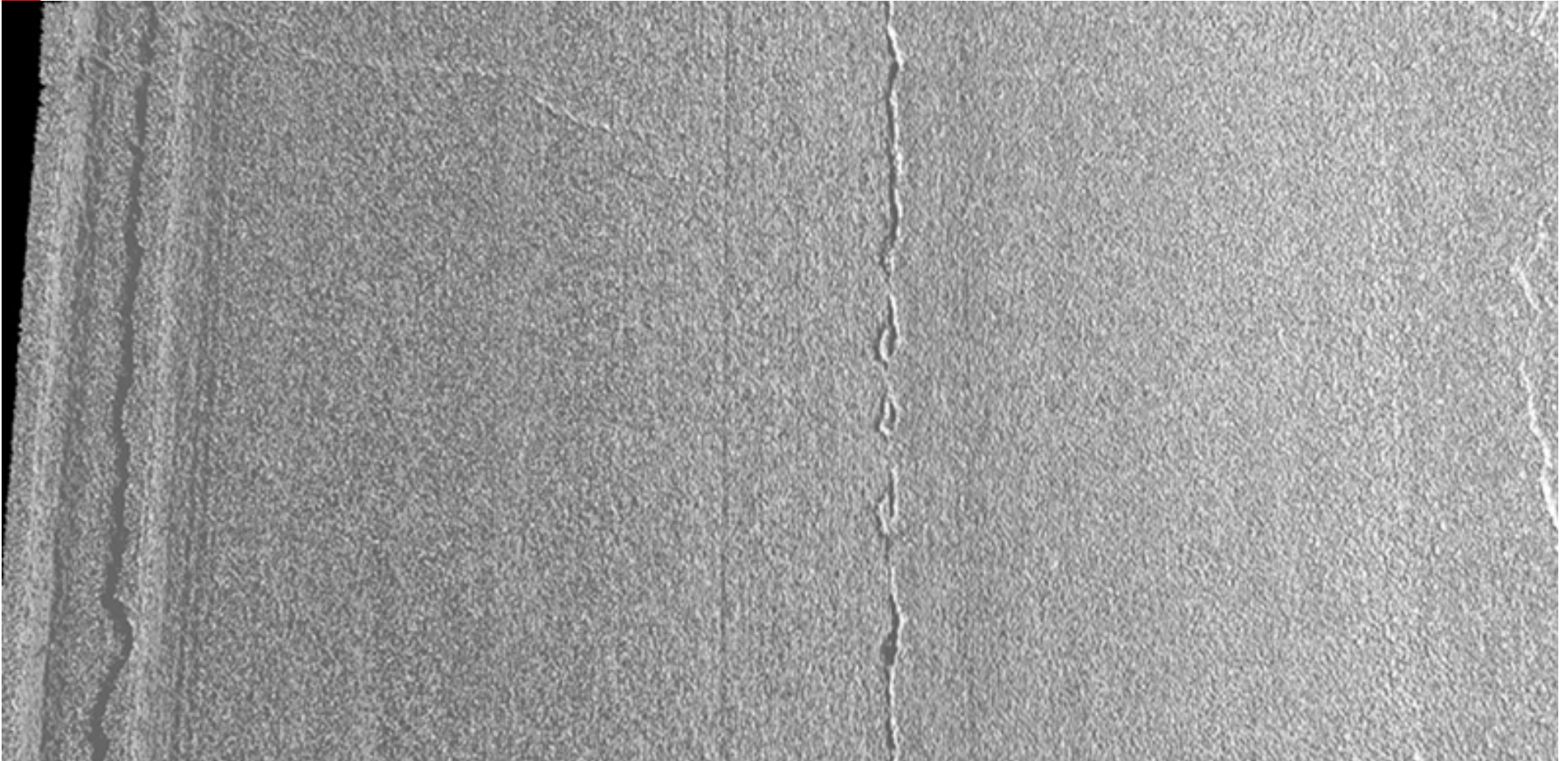


# Data Collection of LTPP Sites



# Comparison on the Same Pavement

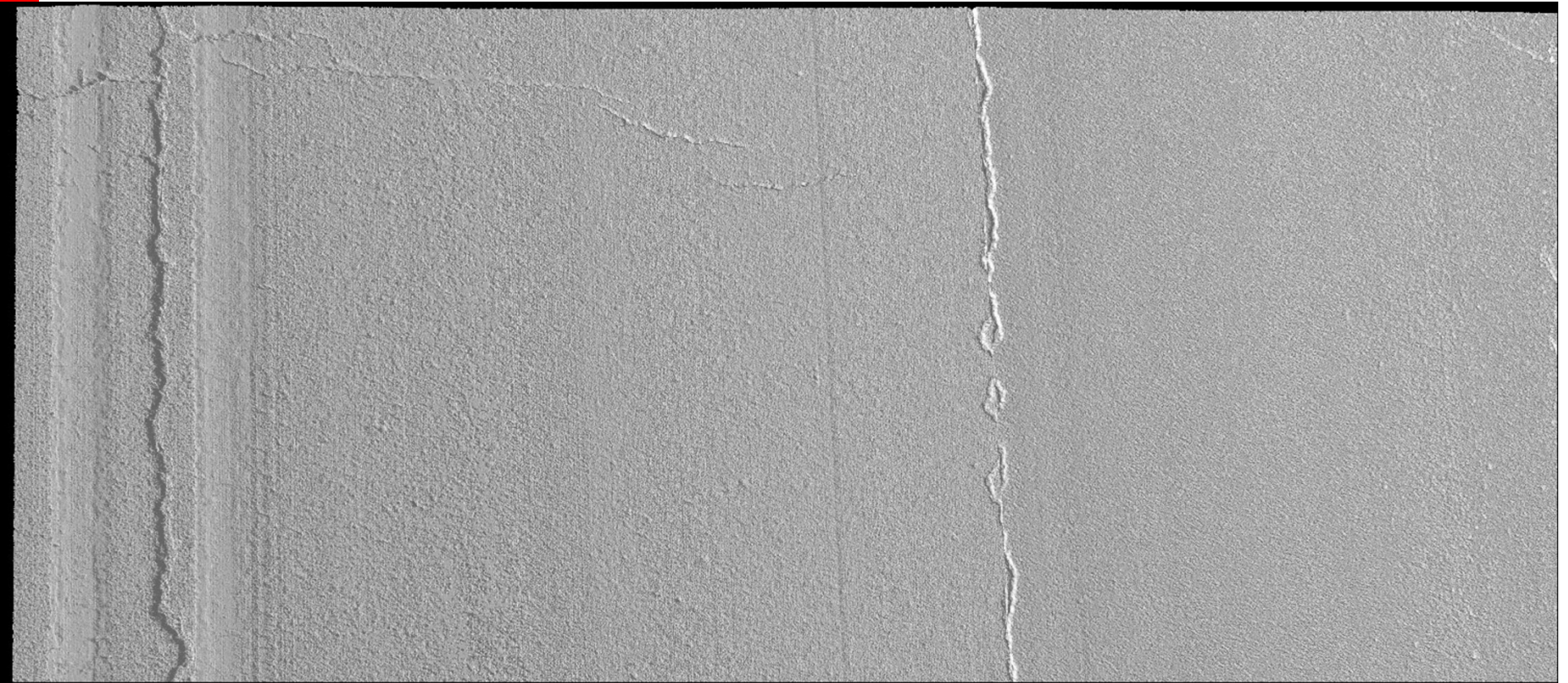
□ 7000 3D Profiles/Sec



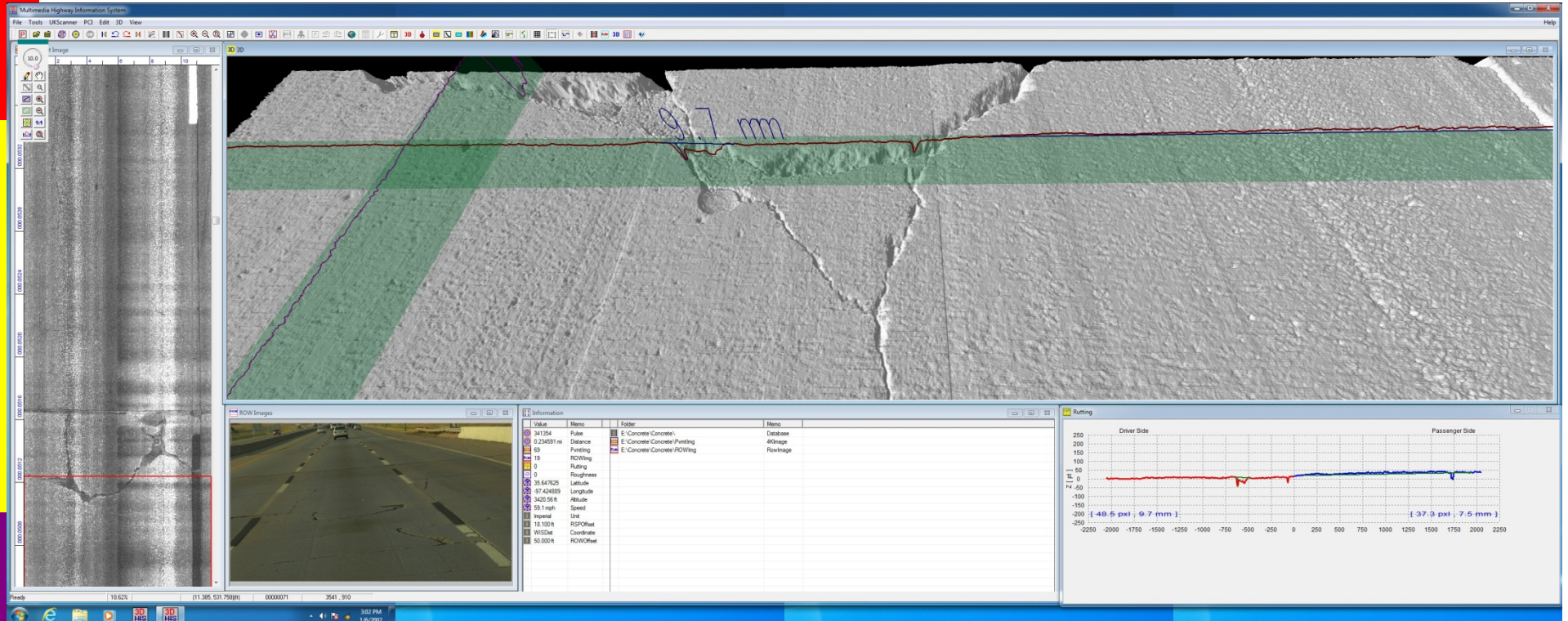
# Comparison on the Same Pavement

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□ 28,000 3D Profiles/Sec

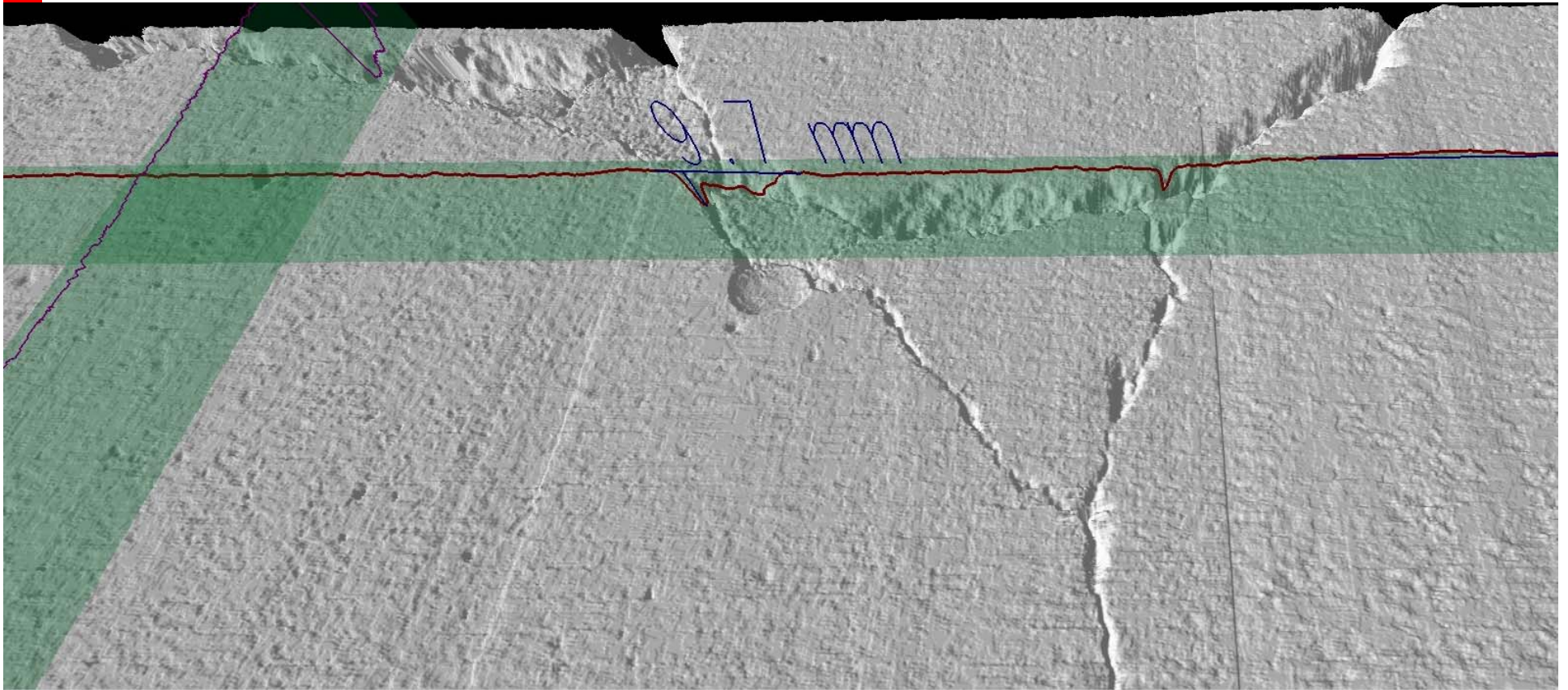


# 3D Data at 60MPH, Concrete



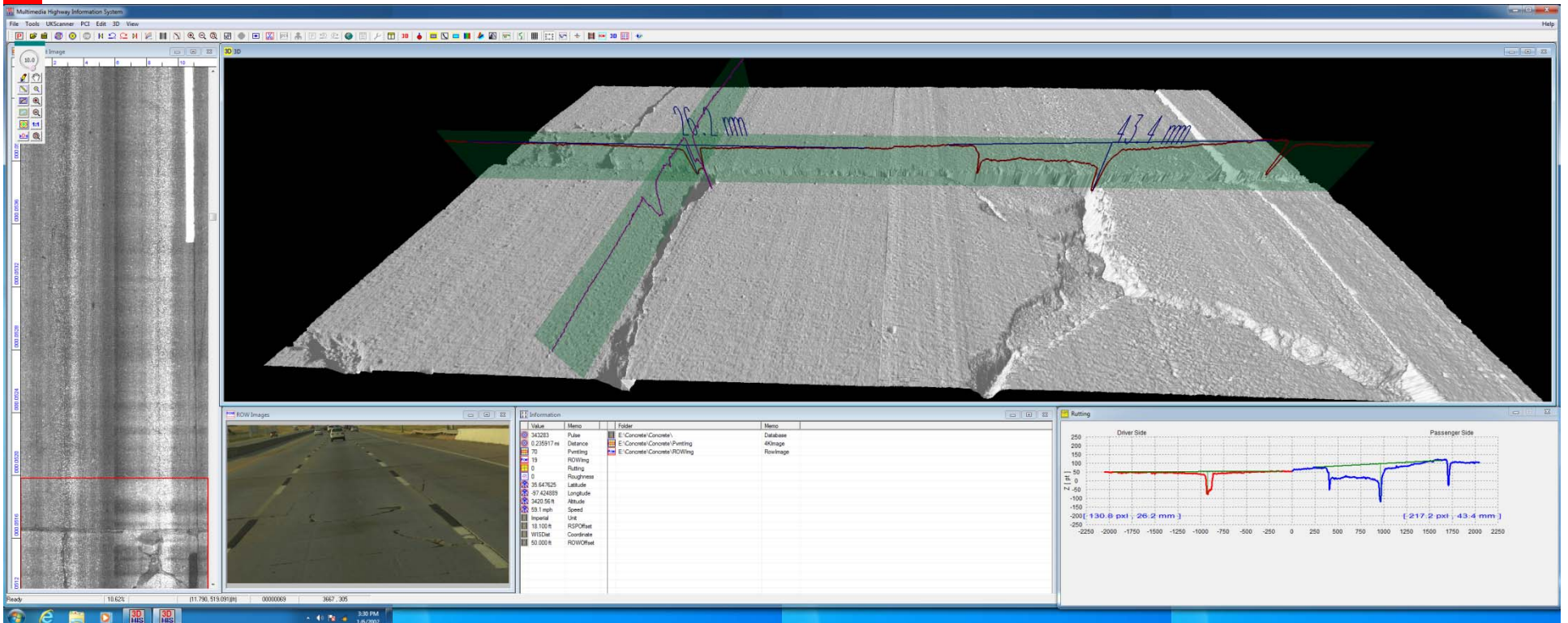
# 3D Data at 60MPH, Zoomed-In

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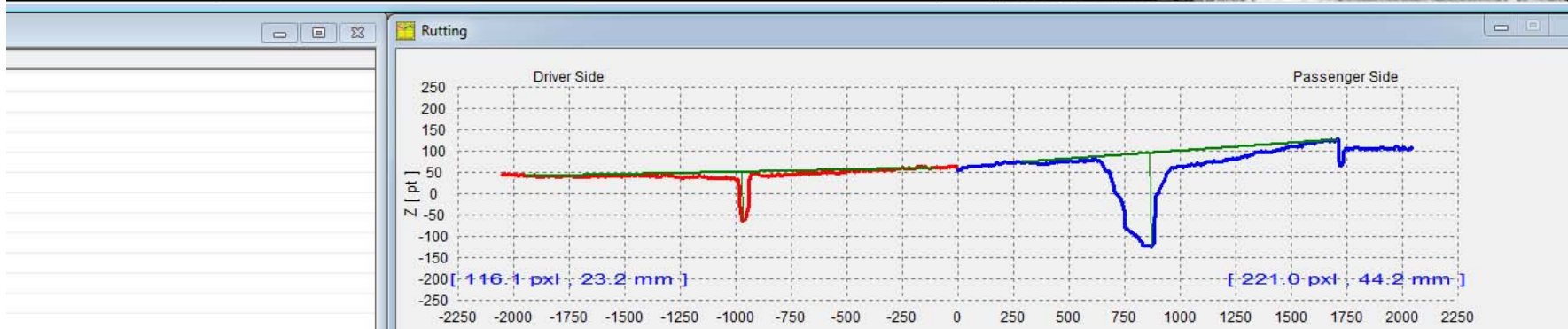
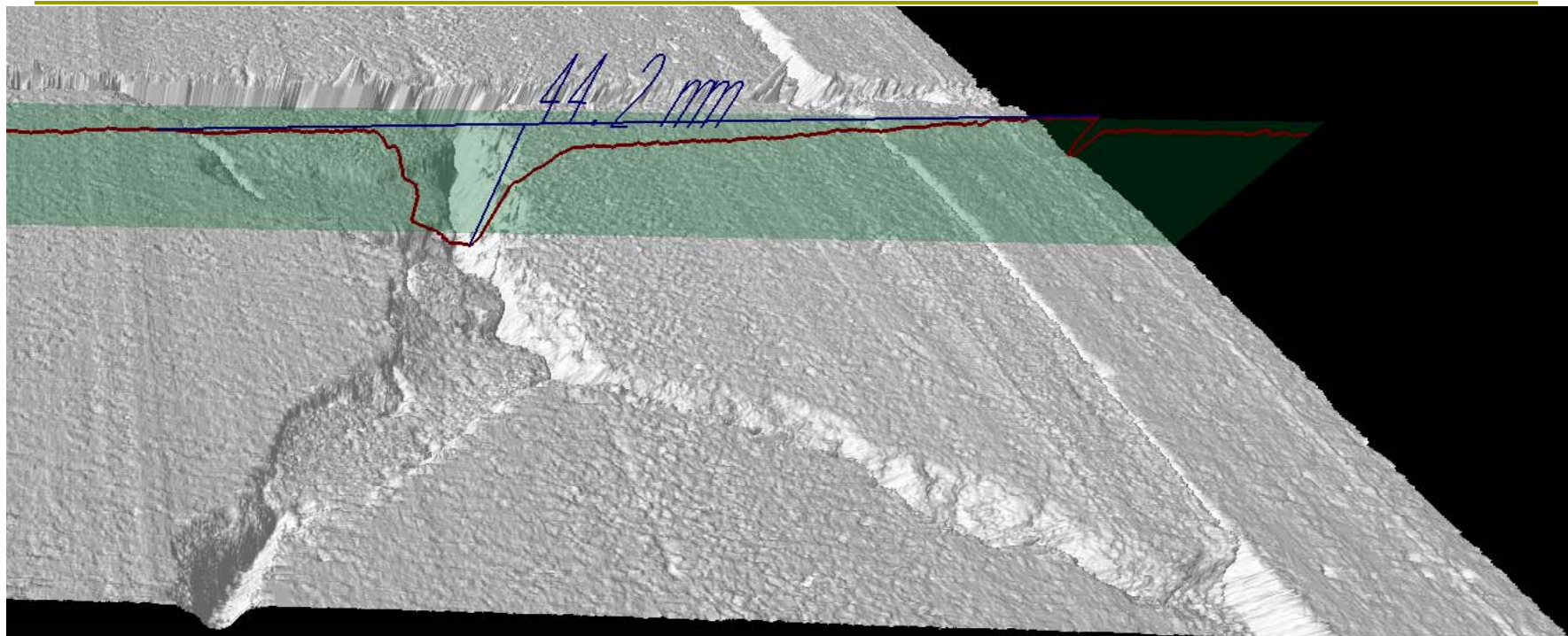




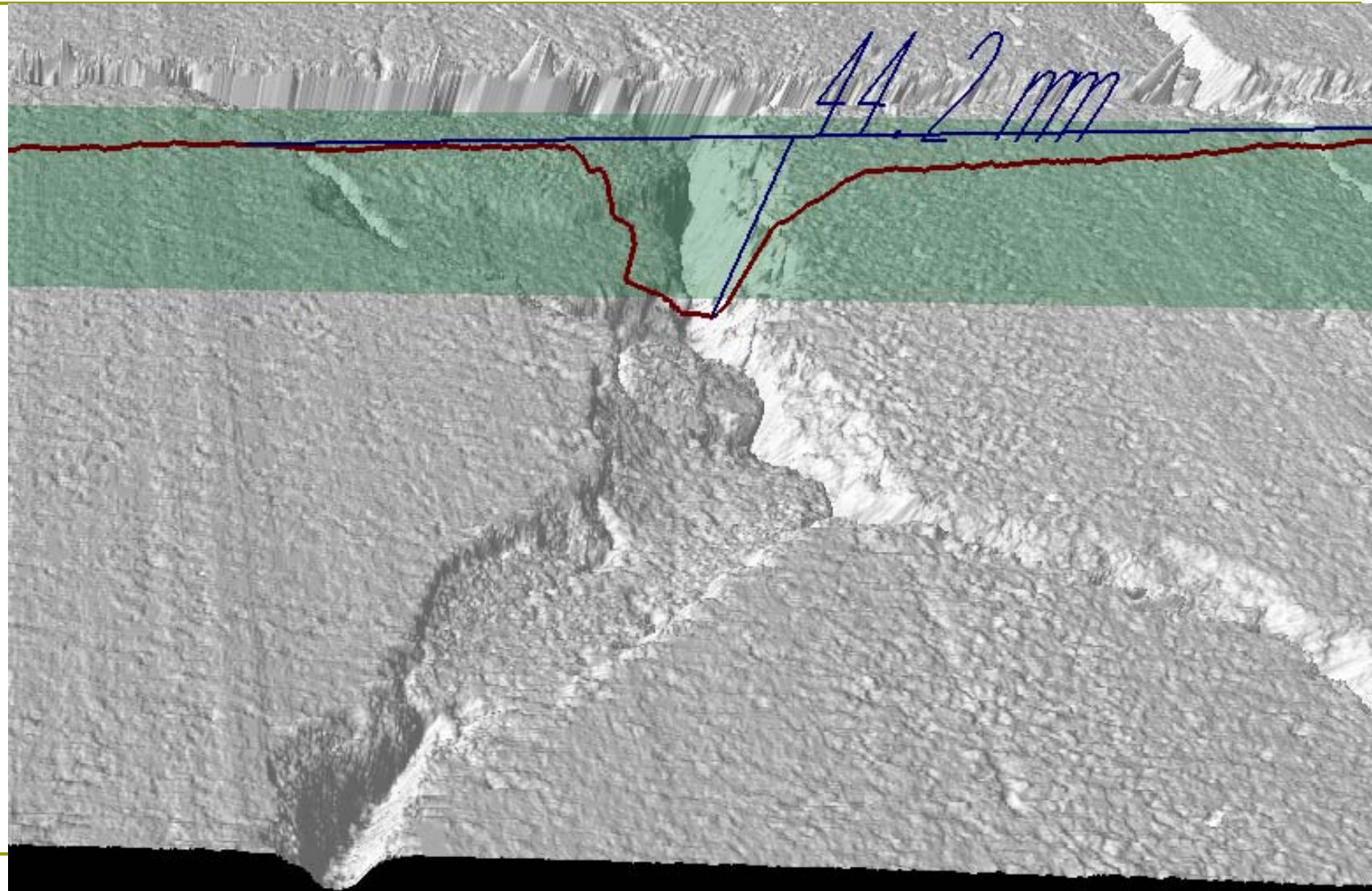
# 3D Data at 60MPH, Concrete



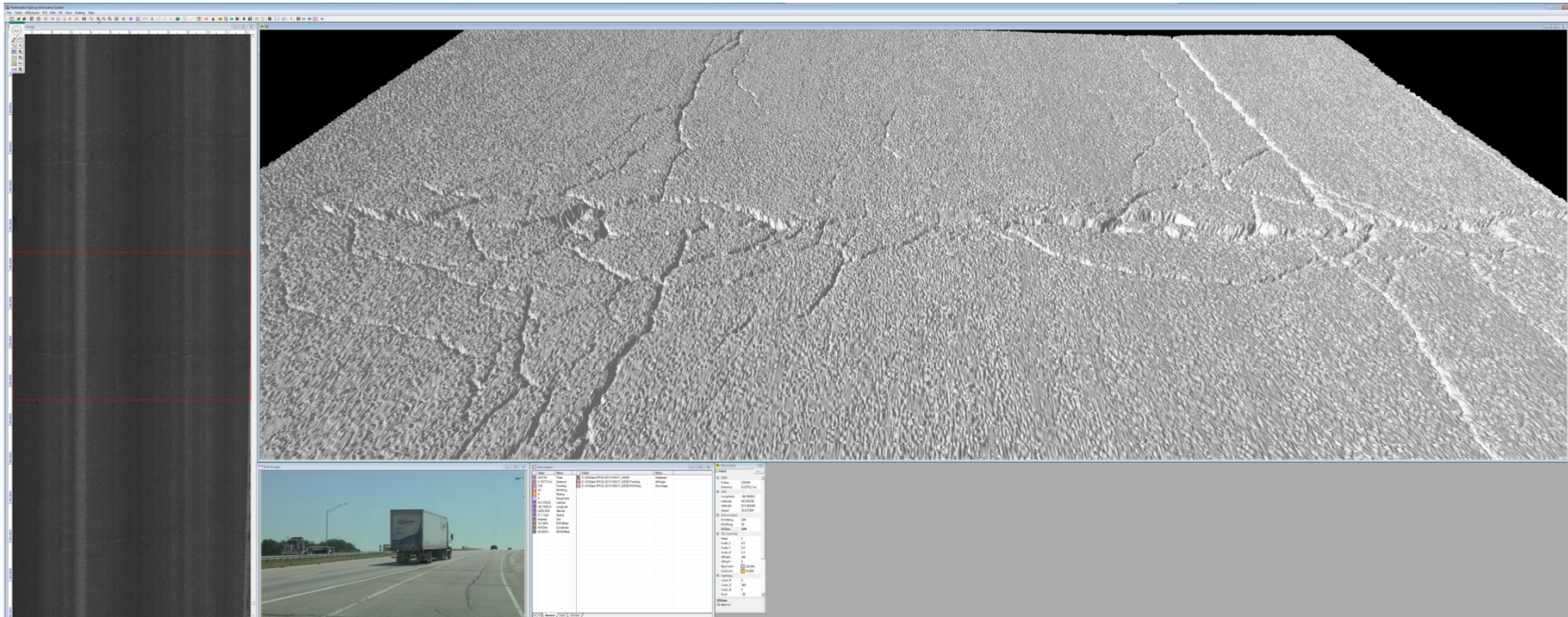
# 3D Data at 60MPH, Zoomed-In



# 3D Data at 60MPH, Close-Up

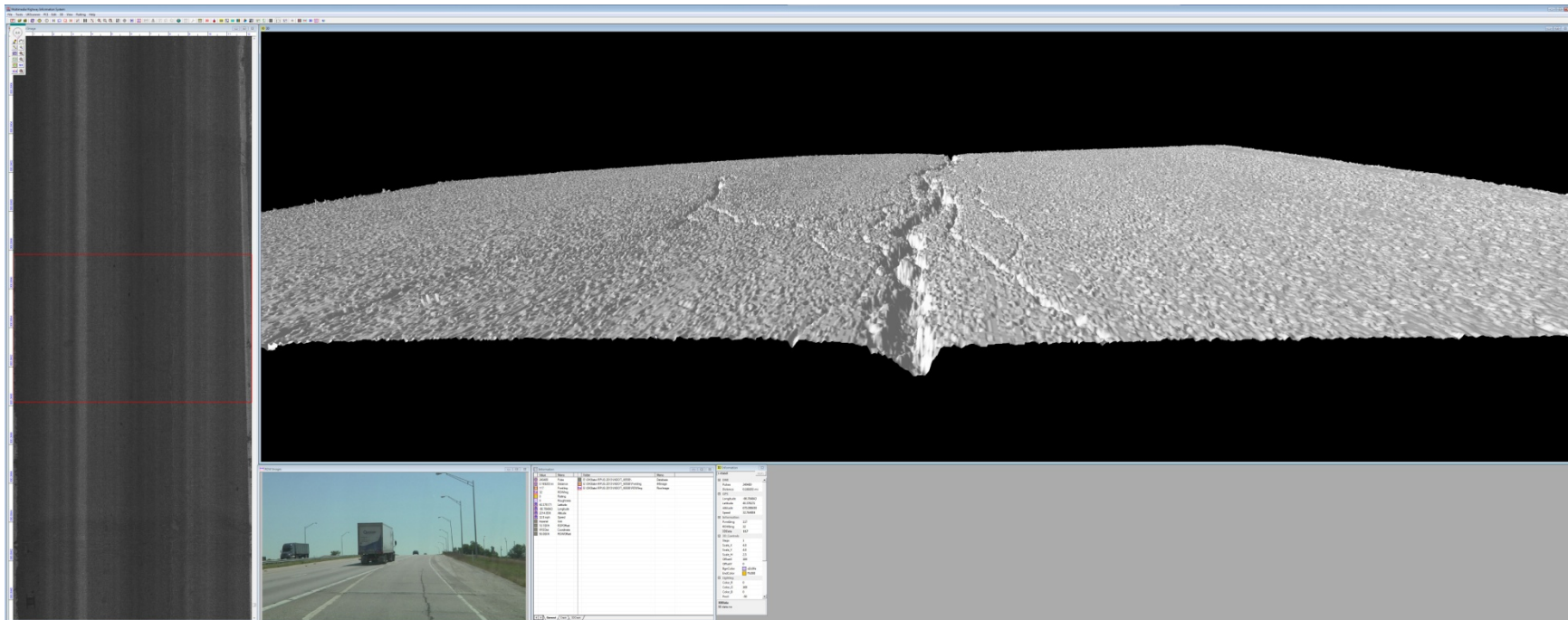


# 3D Data at 60MPH, Asphalt

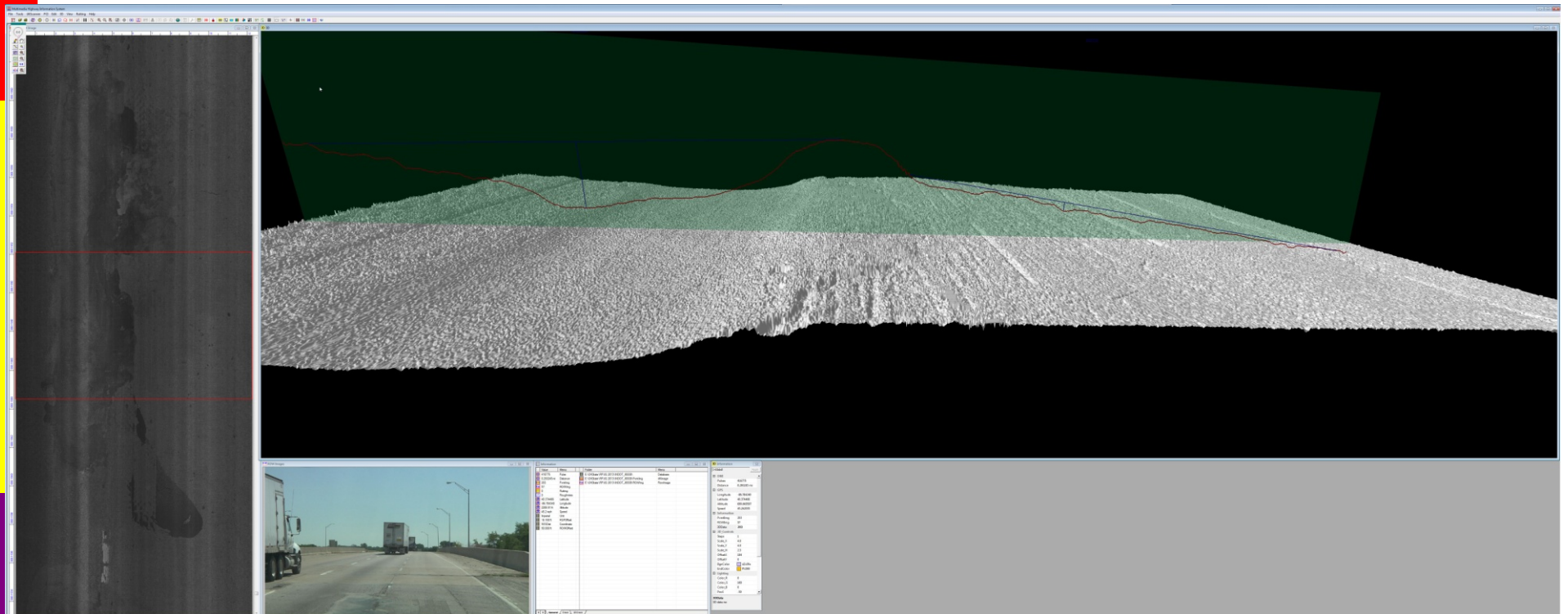


# 3D Data at 60MPH, Crack Depth

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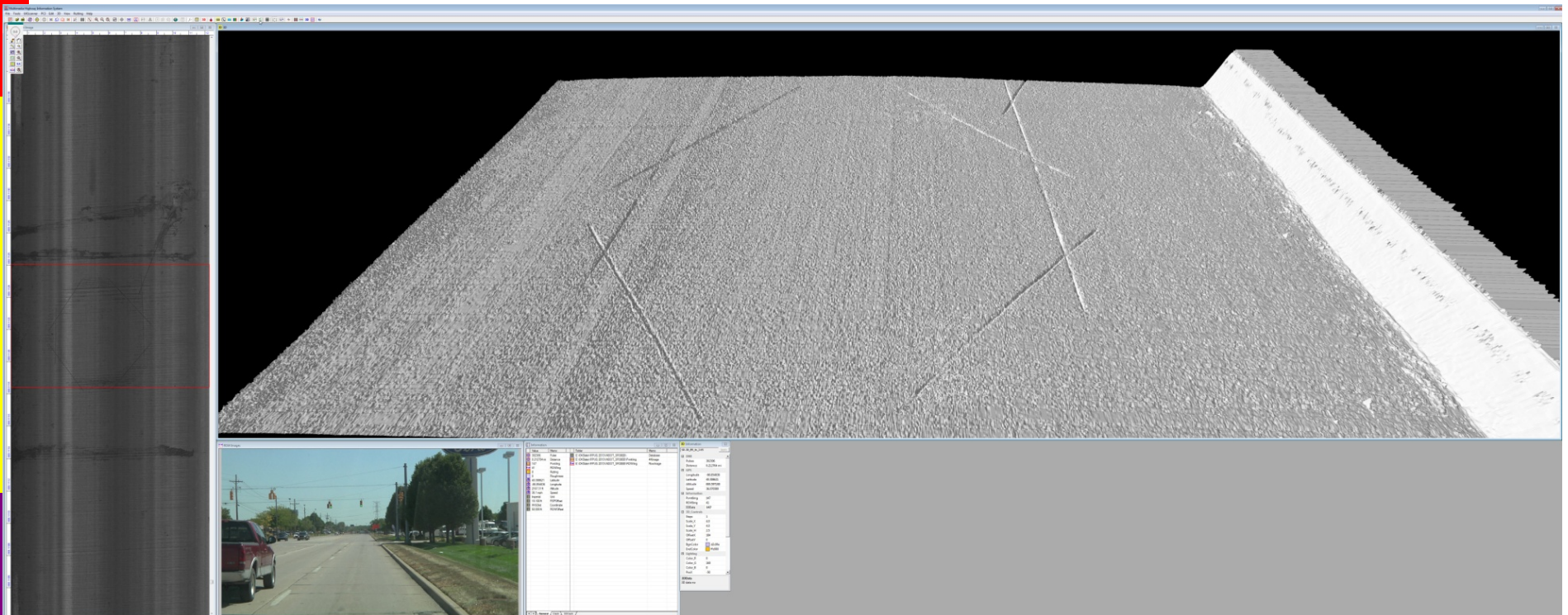


# 3D Data at 60MPH, Rutting

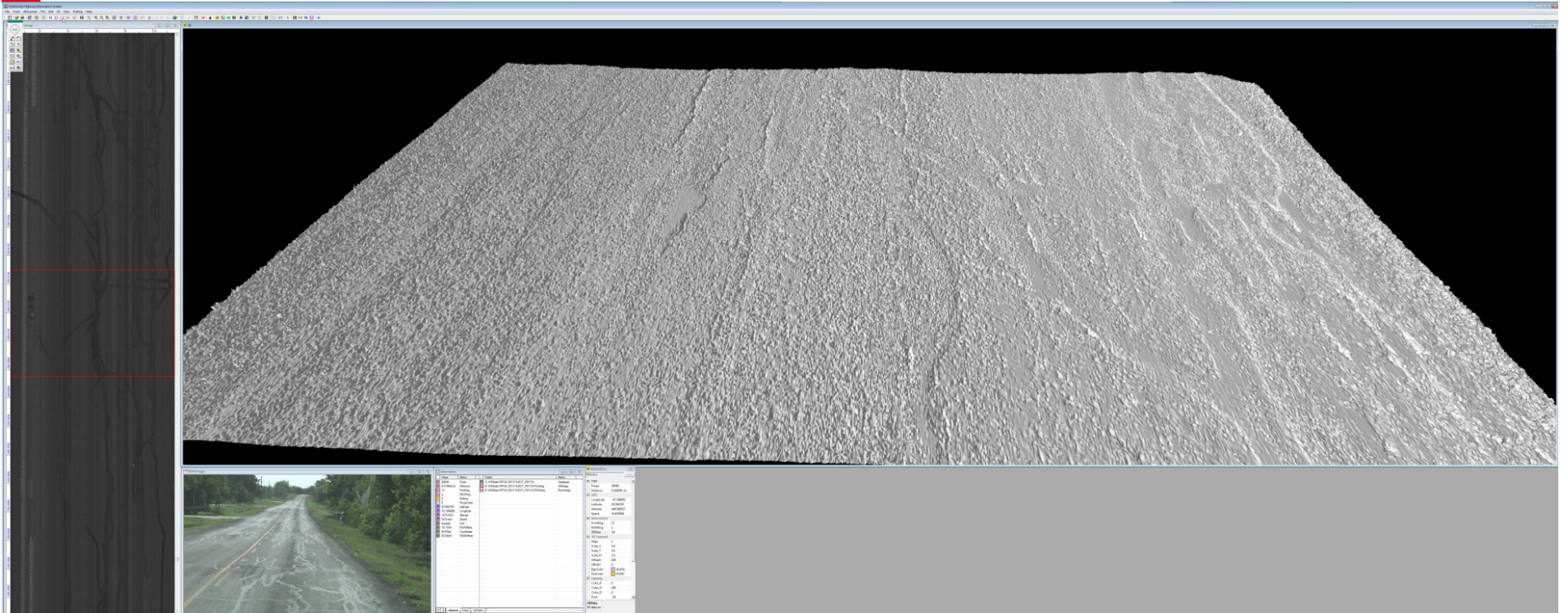


# 3D Data at 60MPH, Cuts

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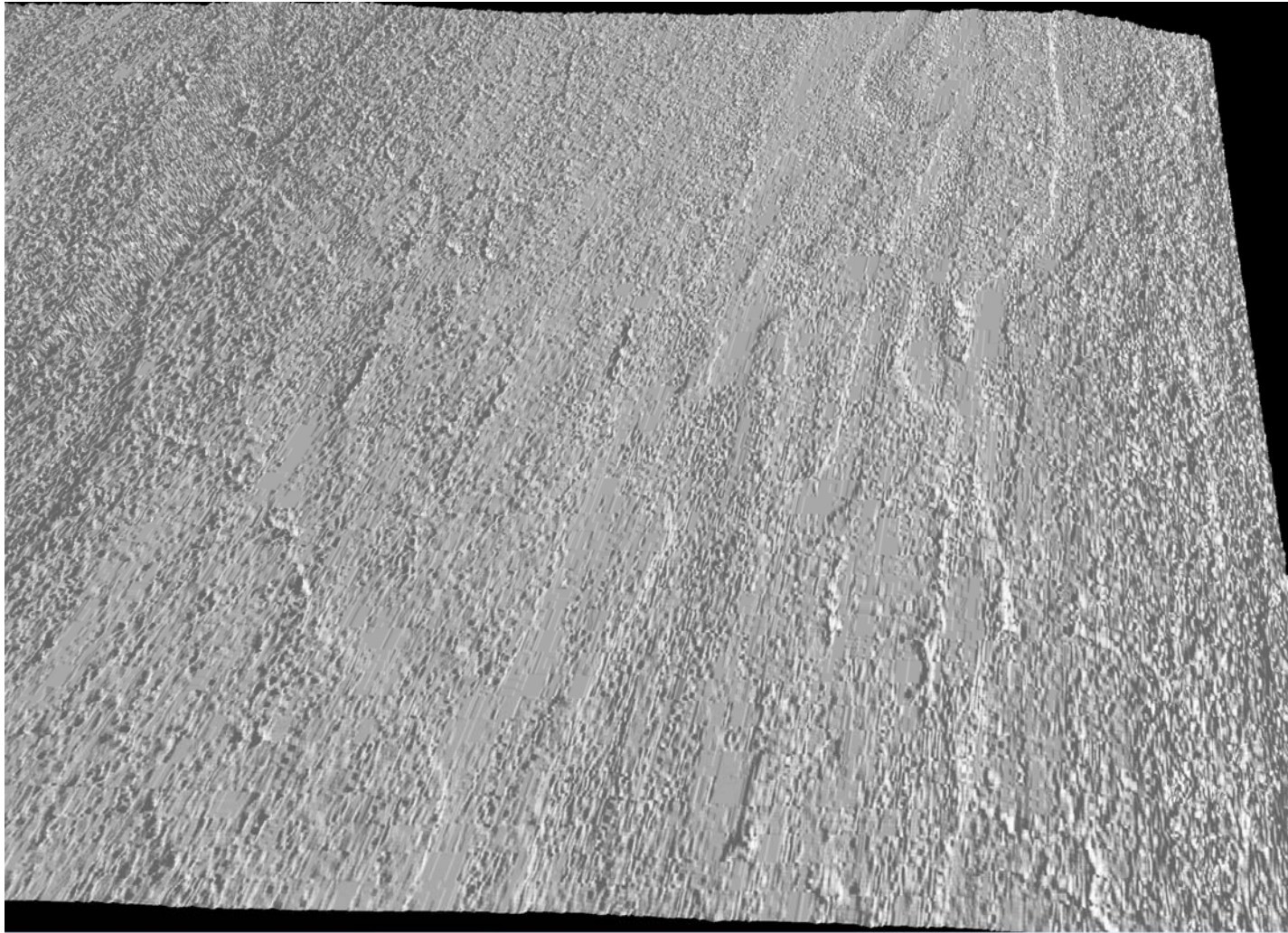
# 3D Data at 60MPH, Sealed Cracks





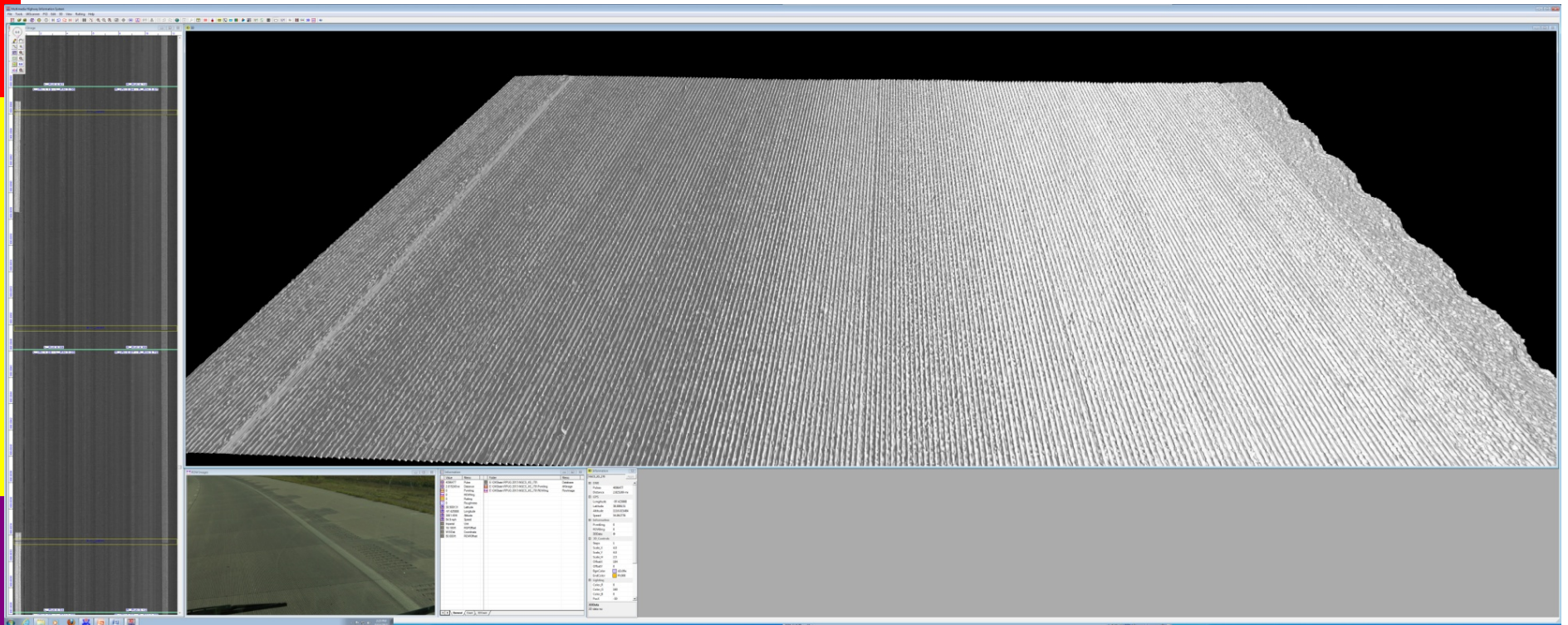
# 3D Data at 60MPH, Sealed Cracks

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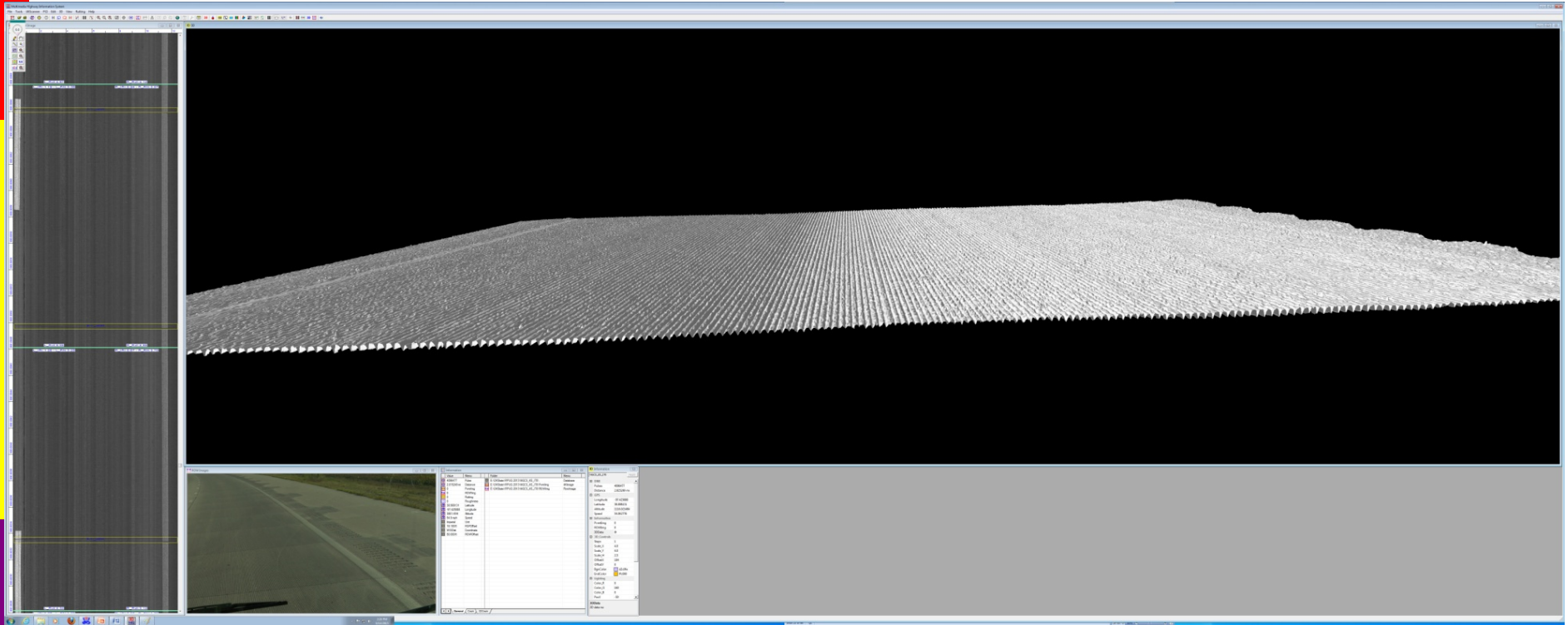
# 3D Data at 60MPH, NGCS

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# 3D Data at 60MPH, NGCS

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# At 60MPH, Transitioning, HFS

Multimedia Highway Information System

File Tools UKScanner PCI Edit 3D View Rutting Help

Pavement Image

3D 3D

ROW Images

Information

Value	Memo	Folder	Memo
358704	Pulse	C:\Users\phdlqiang\Desktop\2012-11-06, LTP...	Database
0.246514	Distance	C:\Users\phdlqiang\Desktop\2012-11-06, LTP...	4KImage
93	Pvmflmg	C:\Users\phdlqiang\Desktop\2012-11-06, LTP...	RowImage
27	ROWlmg		
0	Rutting		
0	Roughn...		
43.035389	Latitude		
-87.928062	Longitude		
4435.64	Altitude		
36.3	Speed		
Imperial	Unit		
18.100	RSPOffse		
WISDist	Coordinat		
50.000	ROWOf...		

Ready 14.50% (1,129, 708.167)(H) 00000095 351, 1446



# At 60MPH, Transitioning. HFS

Multimedia Highway Information System

File Tools UKScanner PCI Edit 3D View Rutting Help

Pavement Image

3D 3D

ROW Images

Information

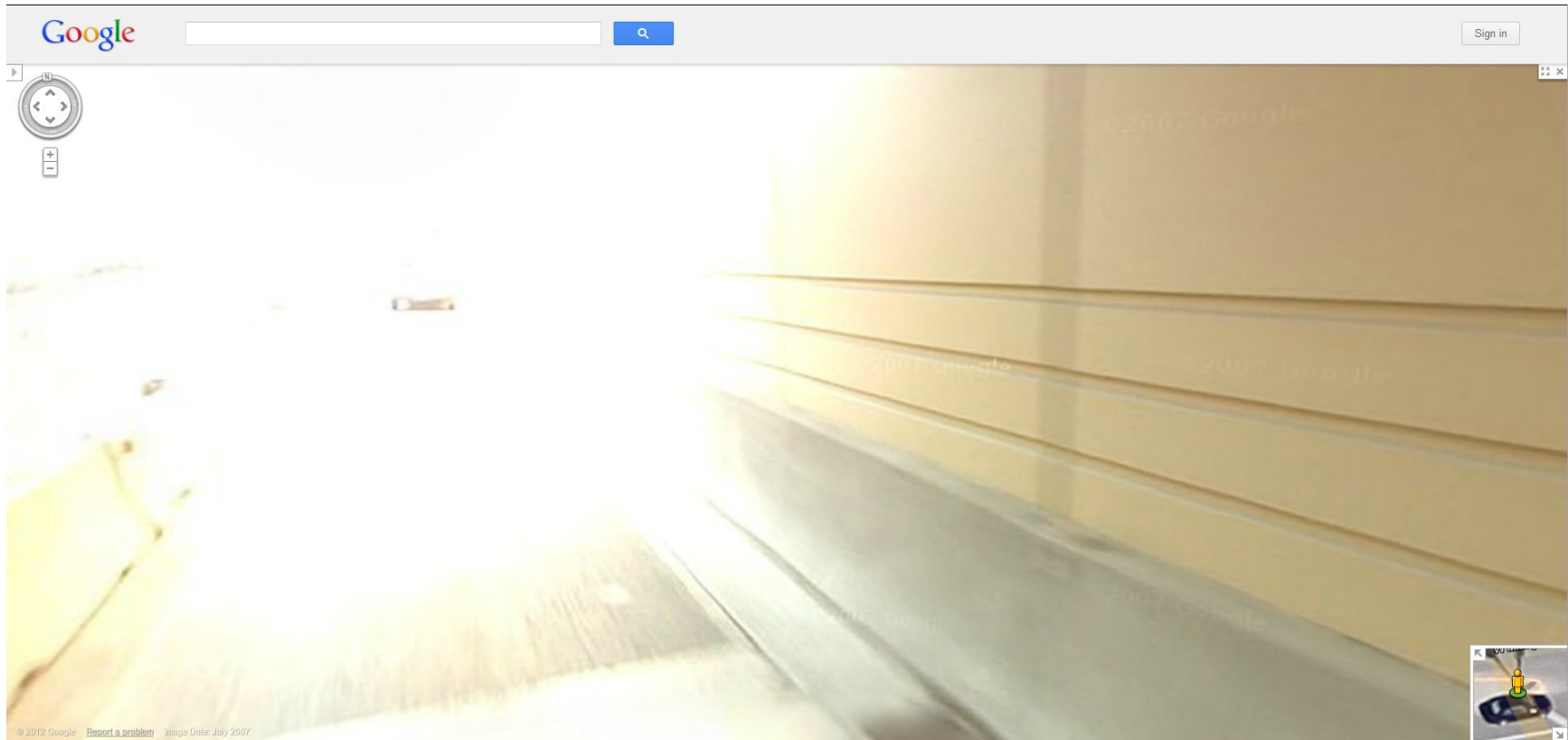
Value	Memo	Folder	Memo
495872	Pulse	C:\Users\phdliqiang\Desktop\2012-11-06, LTP...	Database
0.340781 m	Distance	C:\Users\phdliqiang\Desktop\2012-11-06, LTP...	4KImage
160	Pvmitimg	C:\Users\phdliqiang\Desktop\2012-11-06, LTP...	RowImage
46	ROWImg		
0	Rutting		
0	Roughn...		
43.035210	Latitude		
-87.926361	Longitude		
4431.66 ft	Altitude		
35.2 mph	Speed		
Imperial	Unit		
18.100 ft	RSPOffse		
WISDist	Coordinat		
50.000 ft	ROWOf...		

Ready | 14.50% | (0.064, 1206.364)(N) | 00000162 | 20.1365



# Google Image at the Same HFS

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# 3D Data at 60MPH (100KM/h)

The screenshot displays the Multimedia Highway Information System interface. It features a 3D view of a road surface, a 2D pavement image, and a vehicle image. The 3D view shows a textured surface with a red line indicating a specific location. The 2D pavement image shows a close-up of the road surface. The vehicle image shows a car on a road. The Information panel on the right contains a table with the following data:

Value	Memo	Folder	Memo
490372	Pulse	C:\Users\phdliqiang\Desktop\2012-11-06, LTP...	Database
0.337002 m	Distance	C:\Users\phdliqiang\Desktop\2012-11-06, LTP...	4KImage
41	Pvmtimg	C:\Users\phdliqiang\Desktop\2012-11-06, LTP...	RowImage
12	ROWImg		
0	Rutting		
0	Roughn...		
37.508587	Latitude		
-77.253799	Longitude		
105.15 ft	Altitude		
55.0 mph	Speed		
Imperial	Unit		
18.100 ft	RSPOffse		
WISDist	Coordinat		
50.000 ft	ROWof..		



# 3D Data at 60MPH (100KM/h)

The screenshot displays the Multimedia Highway Information System interface. The main window is titled 'Multimedia Highway Information System' and contains several panes:

- Pavement Image:** A large window showing a grayscale image of a road surface. A red horizontal line is drawn across the image, indicating a specific cross-section.
- 3D 3D:** A window showing a 3D point cloud of the road surface, corresponding to the red line in the Pavement Image window. The surface is rendered in a light gray color.
- ROW Images:** A window showing a perspective view of the road surface, corresponding to the red line in the Pavement Image window. The image shows lane markings and a guardrail.
- Information:** A window displaying metadata for the selected data. The table below shows the information displayed in this window.

Value	Memo	Folder	Memo
2866971	Pulse	C:\Users\phdliqiang\Desktop\2012-11-06, LTP...	Database
1.970287 m	Distance	C:\Users\phdliqiang\Desktop\2012-11-06, LTP...	4KImage
93	Pymfmg	C:\Users\phdliqiang\Desktop\2012-11-06, LTP...	RowImage
27	ROWImg		
0	Rutting		
0	Roughn...		
38.989967	Latitude		
-97.000618	Longitude		
3620.60 ft	Altitude		
55.0 mph	Speed		
Imperial	Unit		
18.100 ft	RSPOffs		
WISDist	Coordinat		
50.000 ft	ROWOf...		





# 3D Data at 60MPH (100KM/h)

Multimedia Highway Information System

File Tools UKScanner PCI Edit 3D View Rutting Help

Pavement Image

3D 3D

ROW Images

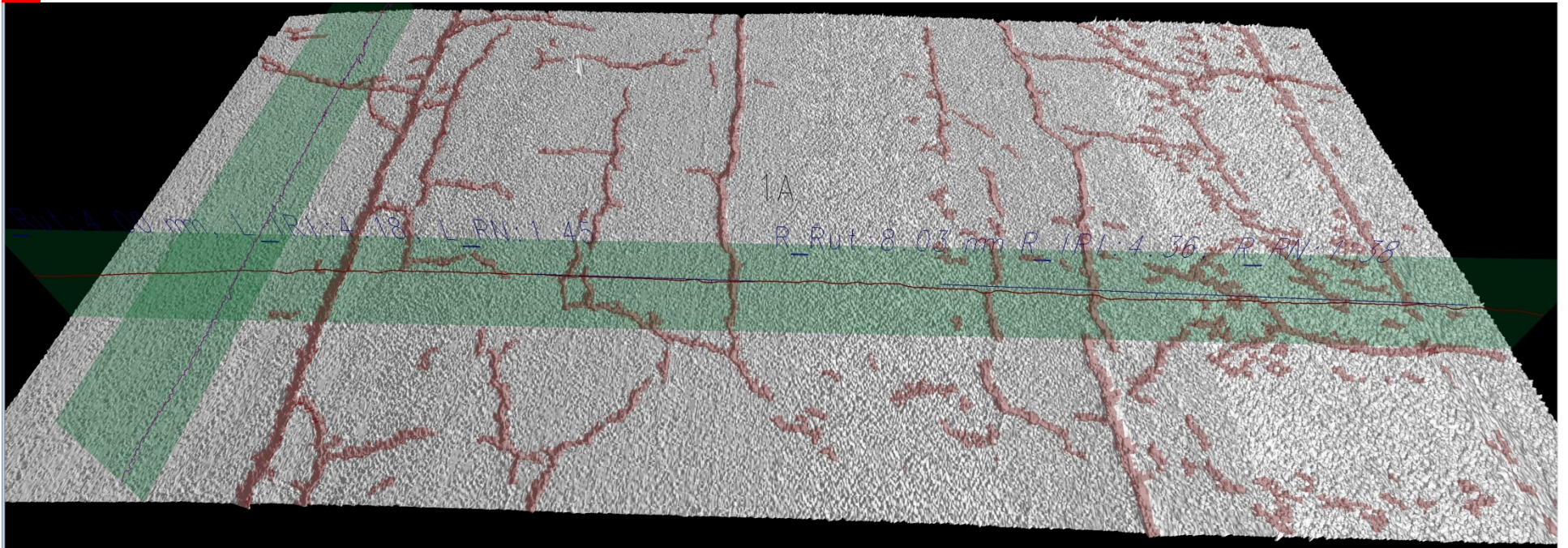
Information

Value	Memo	Folder	Memo
646549	Pulse	C:\Users\phdliqiang\Desktop\2012-11-06. LTP...	Database
0.444332 r	Distance	C:\Users\phdliqiang\Desktop\2012-11-06. LTP...	4KImage
43	Pvmlimg	C:\Users\phdliqiang\Desktop\2012-11-06. LTP...	RowImage
12	ROWimg		
0	Rutting		
0	Roughn...		
39.329498	Latitude		
-77.510490	Longitude		
1237.49 ft	Altitude		
55.0 mph	Speed		
Imperial	Unit		
18.100 ft	RSPOffse		
WISDist	Coordinat		
50.000 ft	ROWOf...		

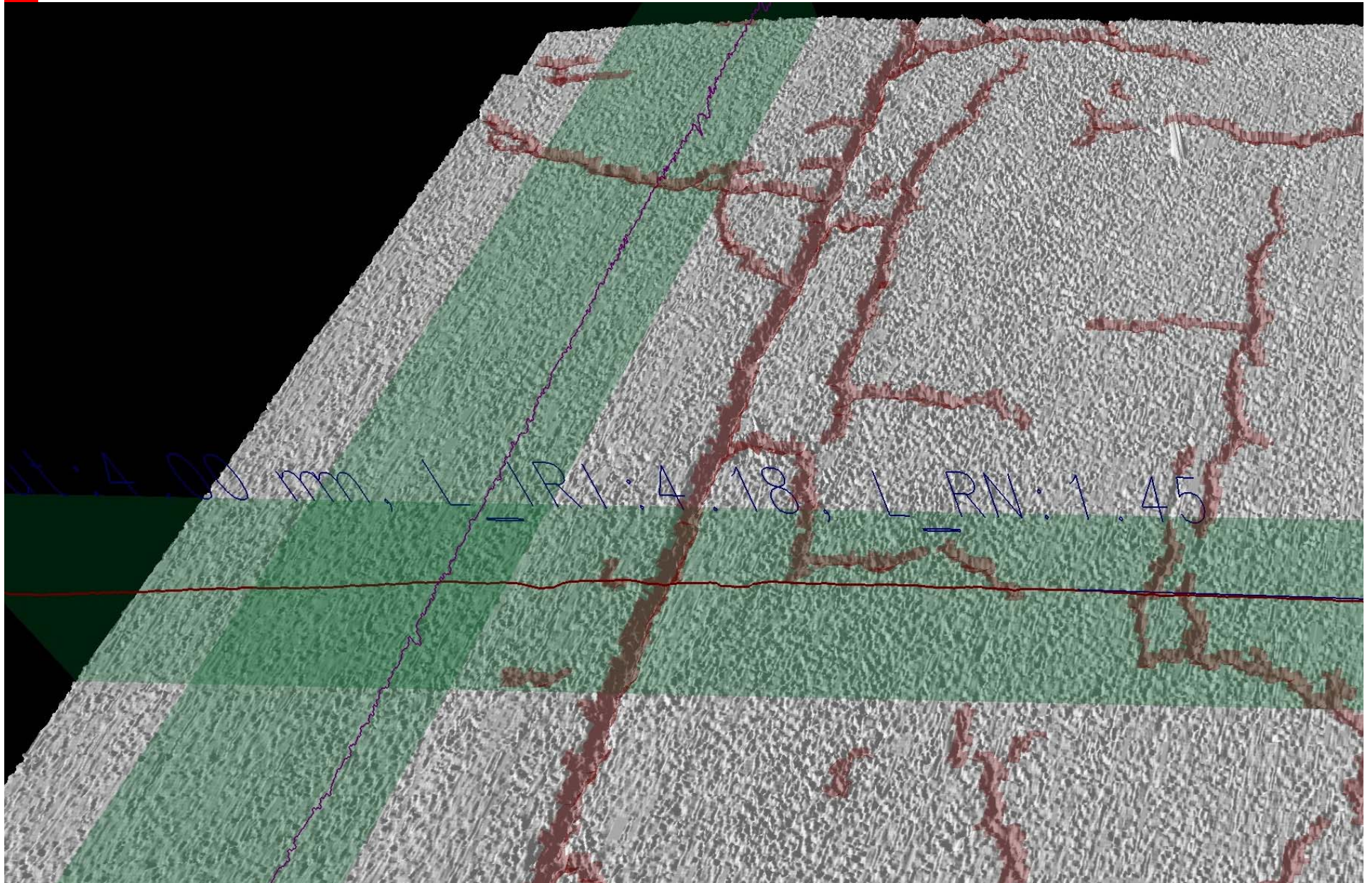
Ready 14.50% (11.195, 329.053)(t) 00000044 3482, 1477



# Cracking & Profiling



# Zoomed-In, Cracking & Profiling



# MPD, Drainage, Groove, & Rutting

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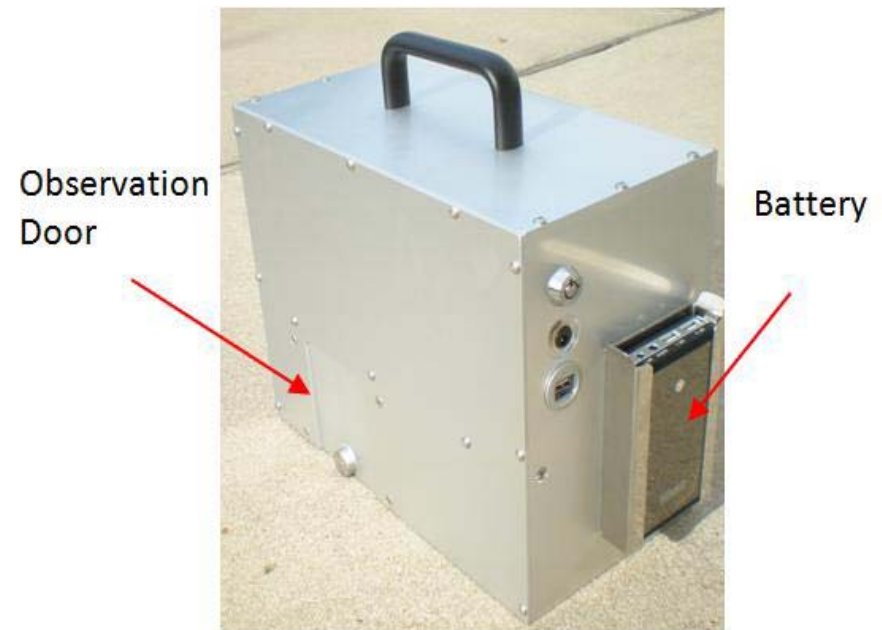
- ❑ Comparisons of Pavement Surface Texture Measurements with LS-40 Surface Analyzer
- ❑ Surface Drainage Evaluation Using IMU and 1mm 3D Texture Data
- ❑ Automated Groove Identification and Measurement
- ❑ Evaluation of Pavement Transverse Deformation Based on AASHTO PP69-10



# LS-40 Pavement Surface Analyzer

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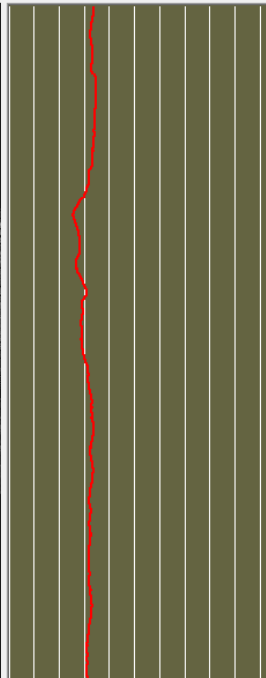
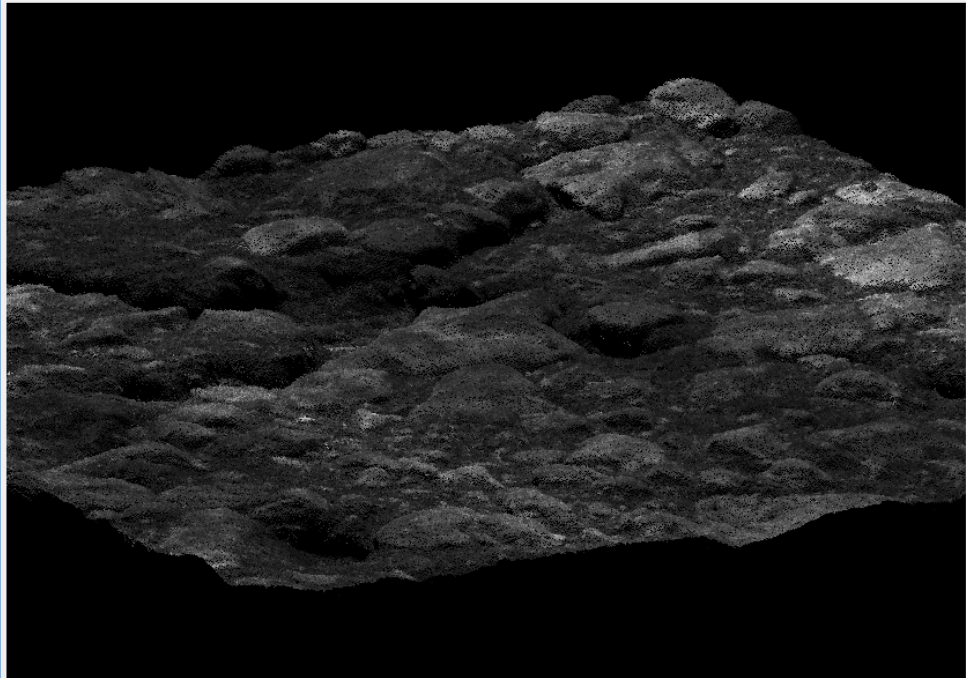
- Scanned Area:
  - 4.5" long by 4" wide
- Data Pixel Quantity
  - 2048 x2448
- Horizontal Resolution
  - 0.056mm



# LS-40 Software Interface

LS-40 Texture Scanner 1.03

Measurement Parameters			Texture Data				Exit	
Stage: Not Found!	Calibration: Loaded		MPD: 2.90	APD: 7.77	PRO: 000.00	MAX: 4.48	X=0000, Y=0000	Exit
Camera: Not Found!	Index: 0	Rate: 10.0	ETD: 2.52	SPH: 4.13	STD: 0.597	MIN: 0.00	B=0000, R=0000	

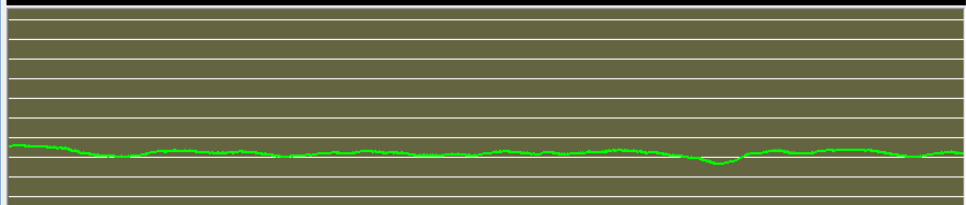


<< H >>  Video Live

Property Measure

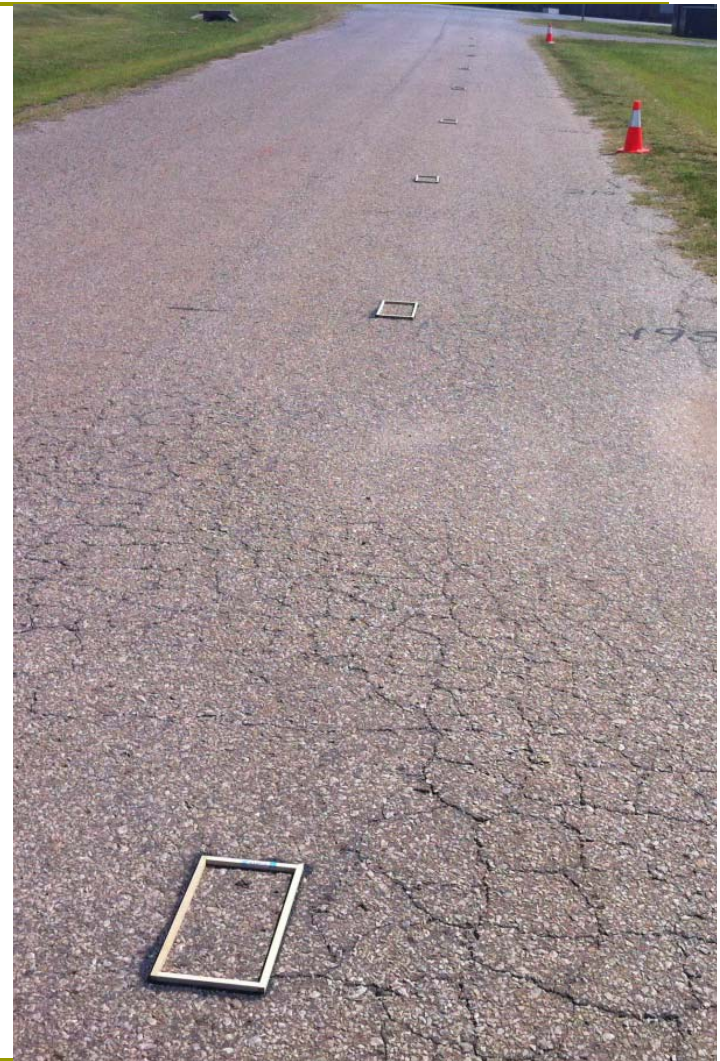
Process Config

Save Load

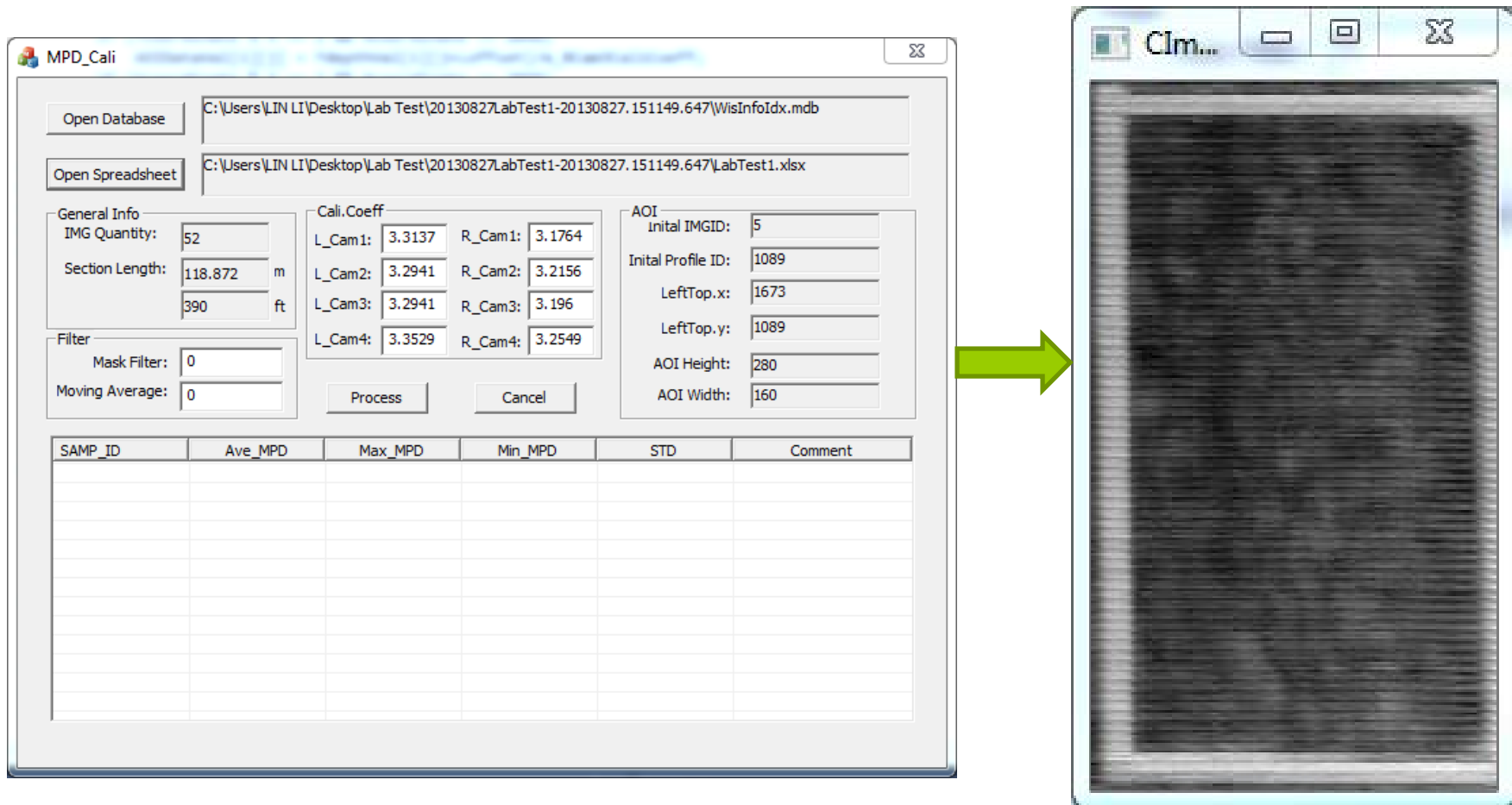


# Experimental Setup

- 21 areas marked on pavement
  - Evenly spaced (15ft)
  - 1ft long by 6 in wide
- Texture Measurements
  - Within marked area
  - LS40 MPD: static 5 runs
  - PaveVision3D MPD: two speeds, 10 runs each



# PaveVision3D Texture Analysis



The screenshot displays the MPD\_Cali software interface. The window title is "MPD\_Cali". It features several input fields and buttons:

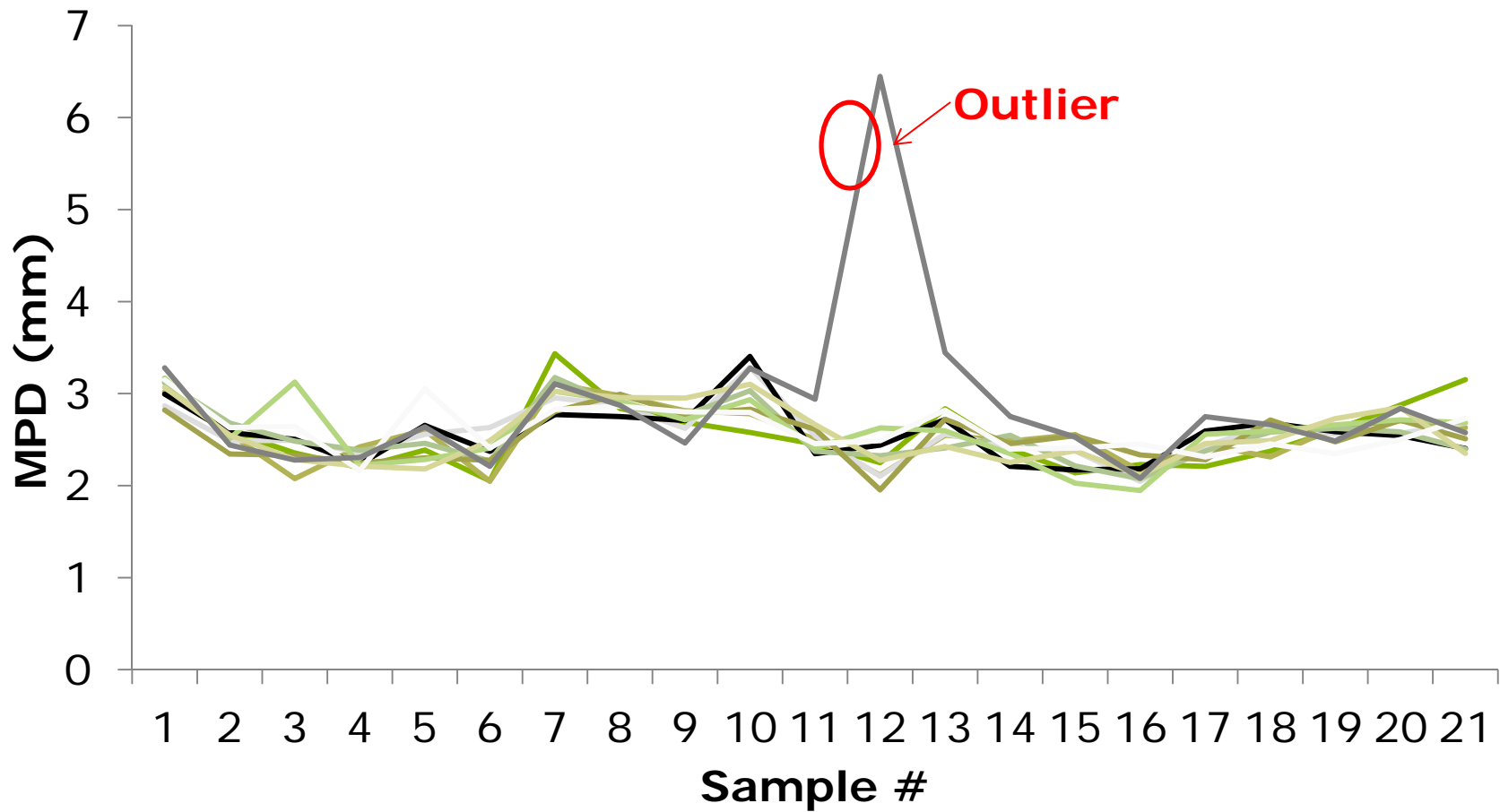
- Open Database:** C:\Users\LIN LI\Desktop\Lab Test\20130827\LabTest1-20130827.151149.647\WisInfoIdx.mdb
- Open Spreadsheet:** C:\Users\LIN LI\Desktop\Lab Test\20130827\LabTest1-20130827.151149.647\LabTest1.xlsx
- General Info:** IMG Quantity: 52; Section Length: 118.872 m / 390 ft
- Filter:** Mask Filter: 0; Moving Average: 0
- Cali.Coeff:** L\_Cam1: 3.3137, R\_Cam1: 3.1764, L\_Cam2: 3.2941, R\_Cam2: 3.2156, L\_Cam3: 3.2941, R\_Cam3: 3.196, L\_Cam4: 3.3529, R\_Cam4: 3.2549
- AOI:** Inital IMGID: 5, Inital Profile ID: 1089, LeftTop.x: 1673, LeftTop.y: 1089, AOI Height: 280, AOI Width: 160

Buttons for "Process" and "Cancel" are visible. Below the configuration fields is a table with the following columns: SAMP\_ID, Ave\_MPD, Max\_MPD, Min\_MPD, STD, and Comment. The table is currently empty.

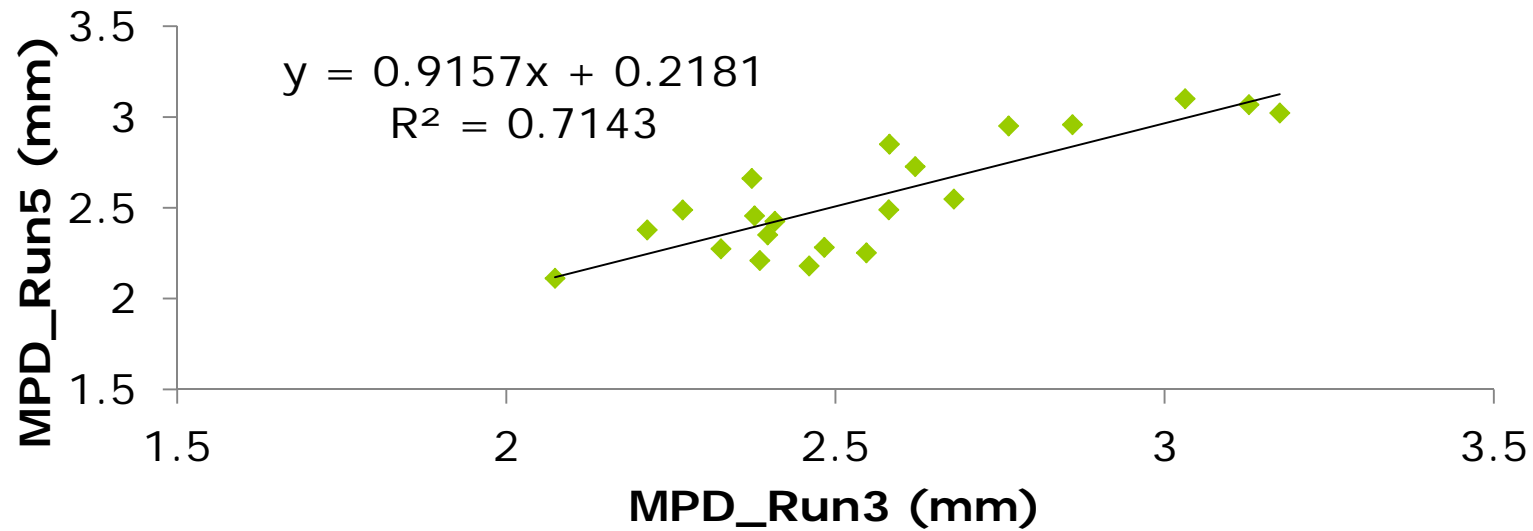
A green arrow points from the "Process" button to a window titled "Cim..." which displays a grayscale texture analysis image.



# PaveVision3D MPD (7mph)

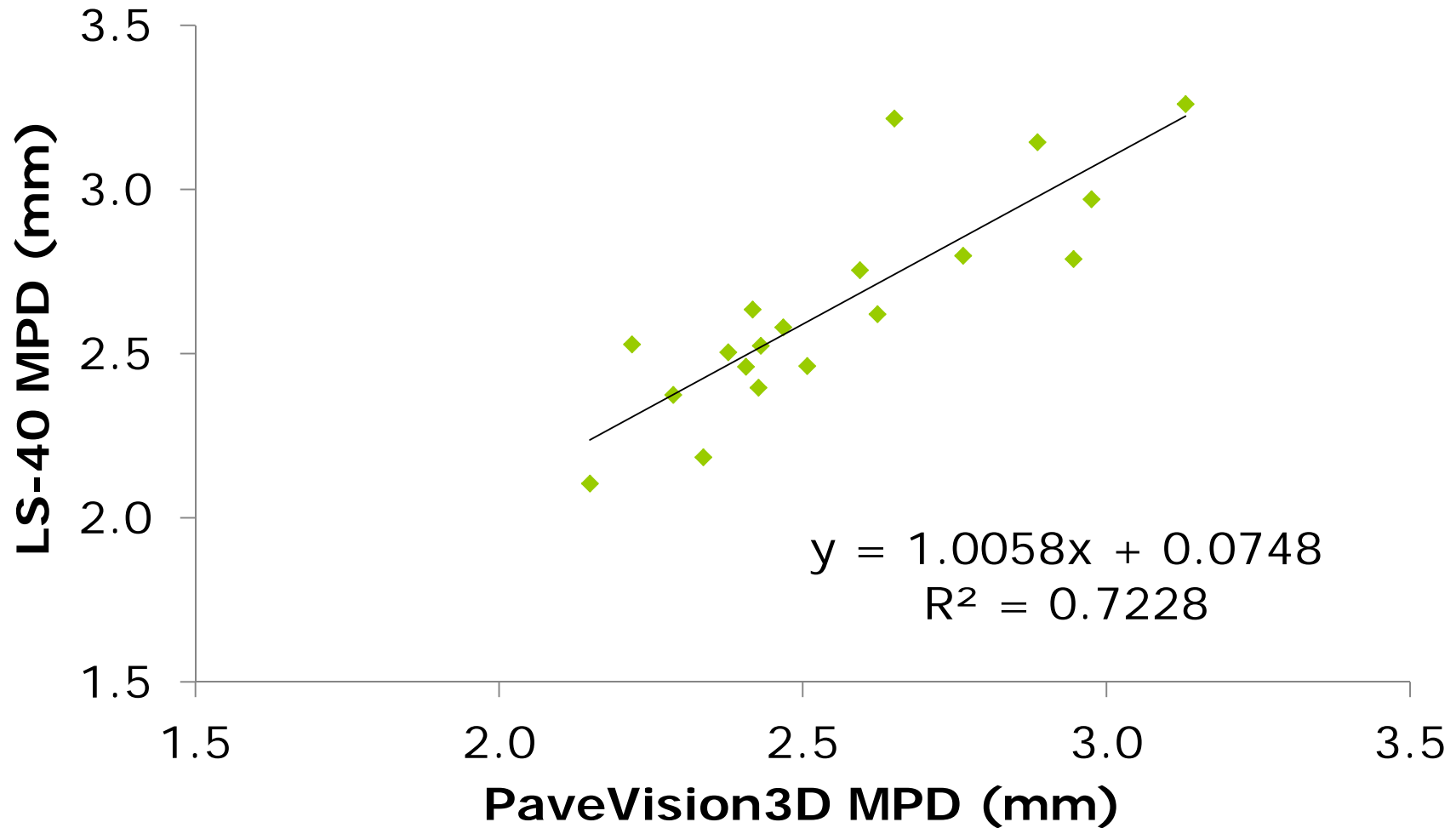


# Correlation Analysis (7mph)

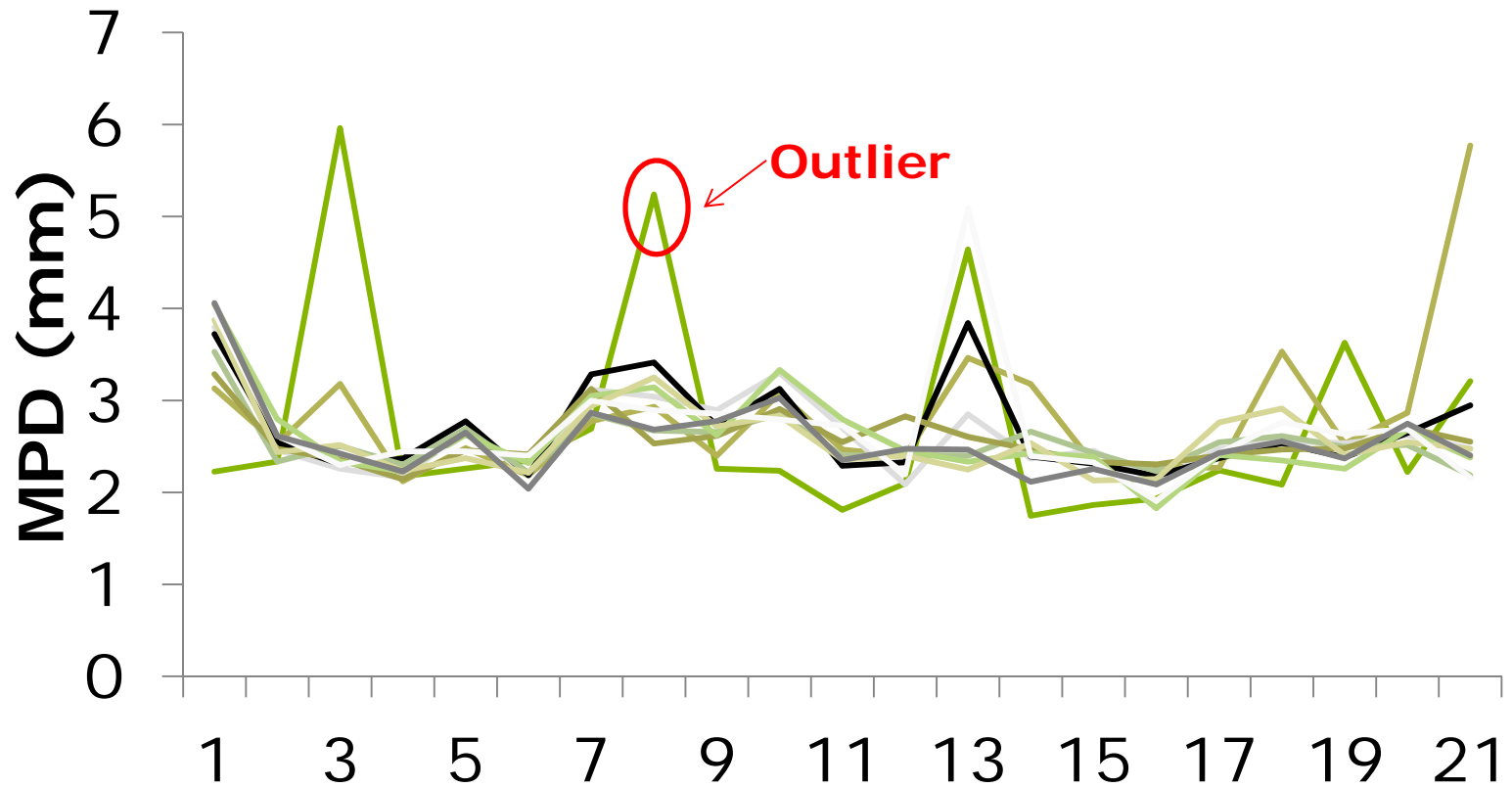


	run 1	run 2	run 3	run4	run5
run 1	1				
run 2	0.68	1			
run 3	0.66	0.63	1		
run 4	0.56	0.34	0.46	1	
run 5	0.63	0.55	0.71	0.61	1

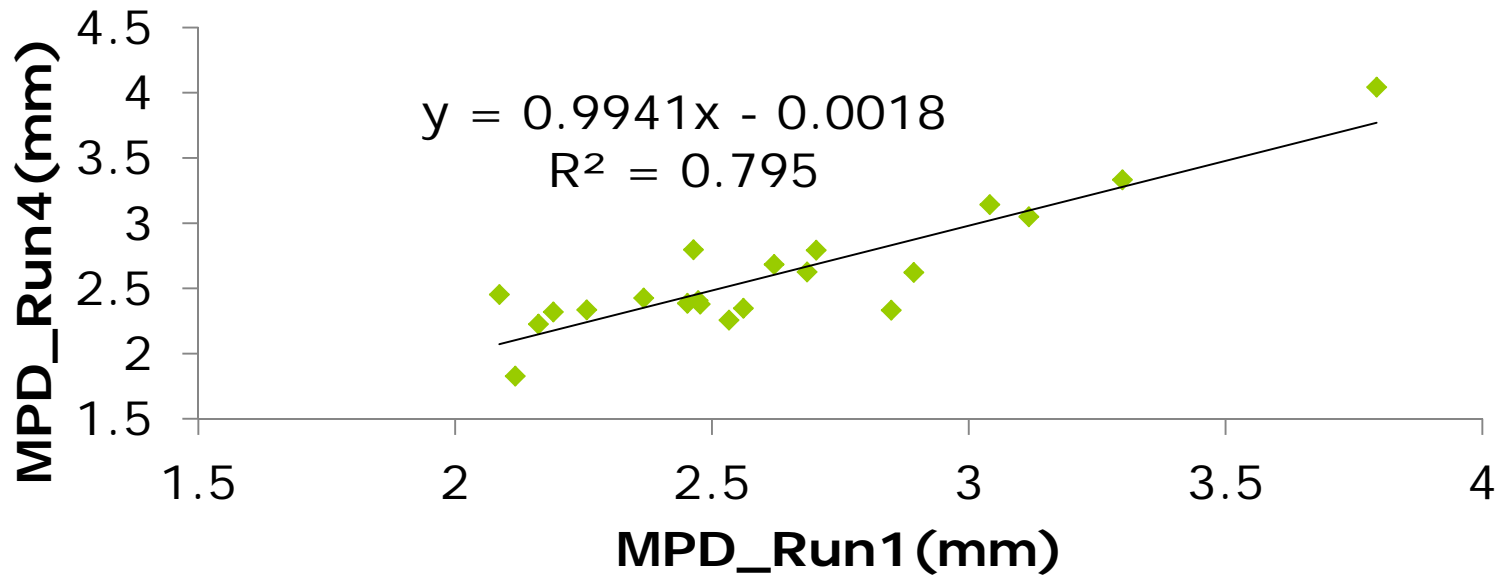
# Comparison Analysis (7mph)



# PaveVision3D MPD (15mph)



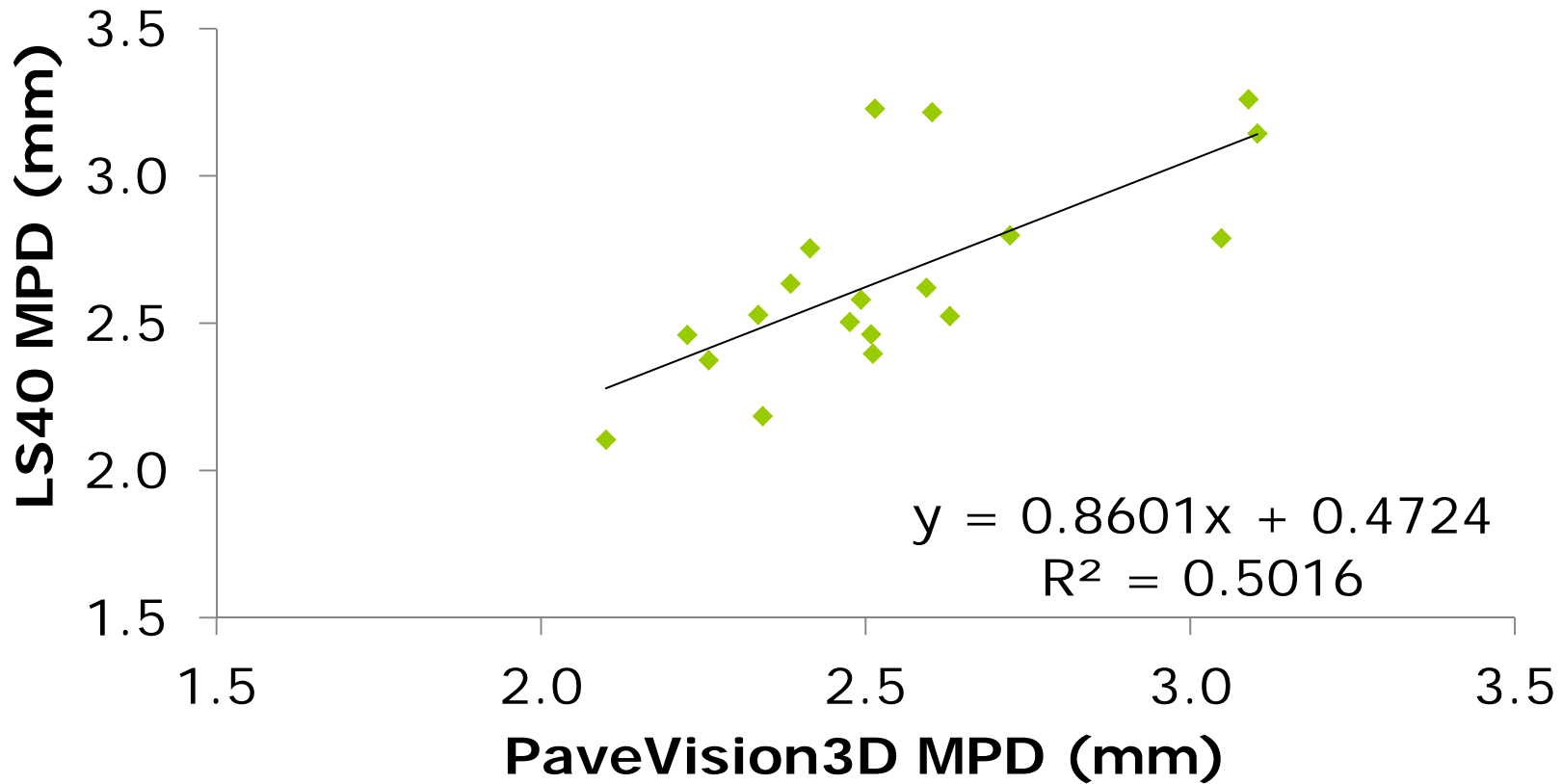
# Correlation Analysis (15mph)



	run 1	run 2	run 3	run 4	run 5
run 1	1				
run 2	0.67	1			
run 3	0.72	0.35	1		
run 4	0.80	0.43	0.71	1	
run 5	0.64	0.38	0.76	0.69	1



# Comparison Analysis (15mph)



# Drainage Evaluation

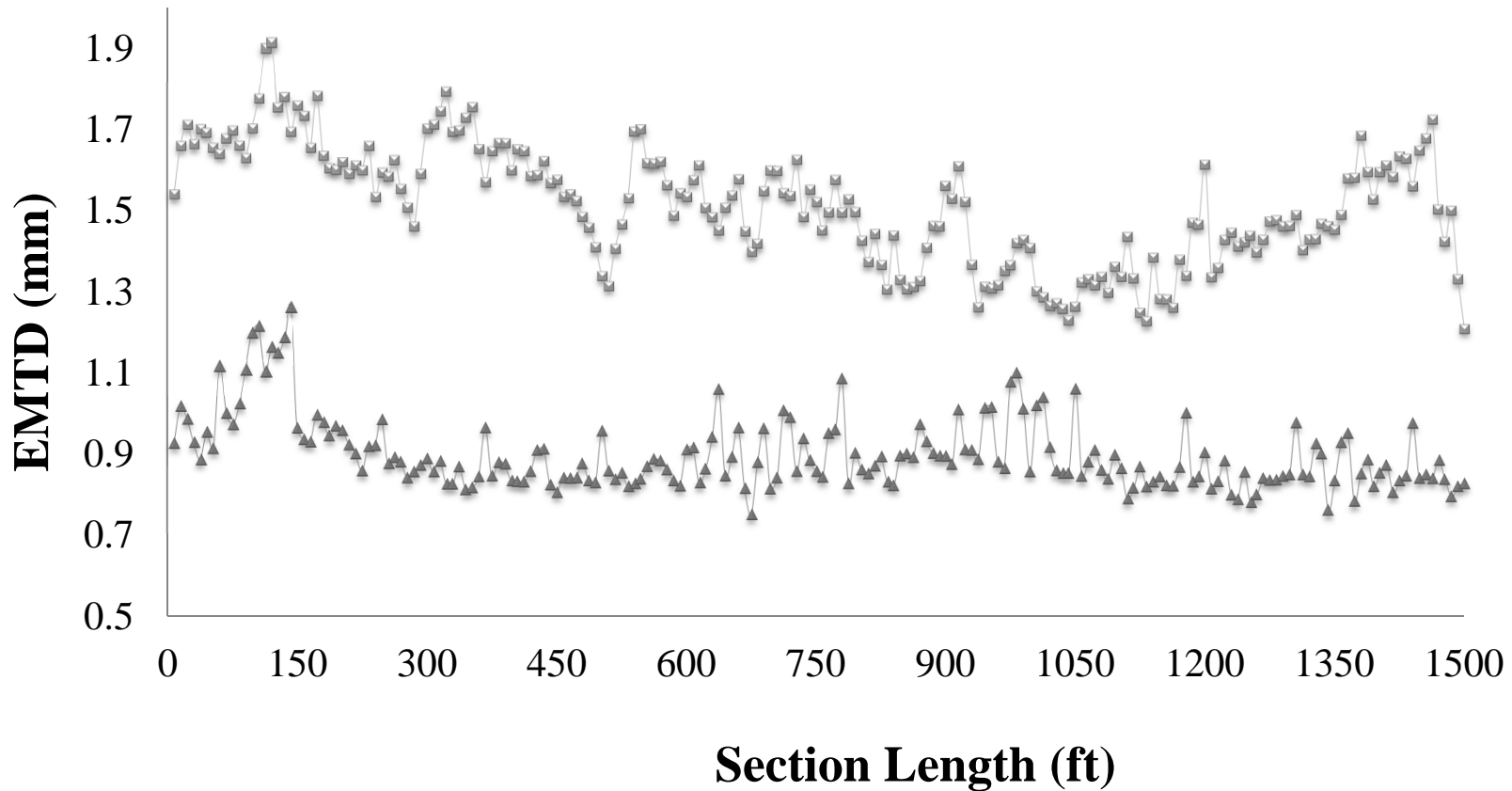
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- Inertial Measurement Unit (IMU)
  - Consisting of accelerometers and fiber-optic gyroscopes
  - Collecting positioning, cross slope and vertical slope data
- PaveVision3D Texture Data
- Hydroplanning Speed Model
  - Water film depth: pavement type, cross slope, vertical grade, rain intensity



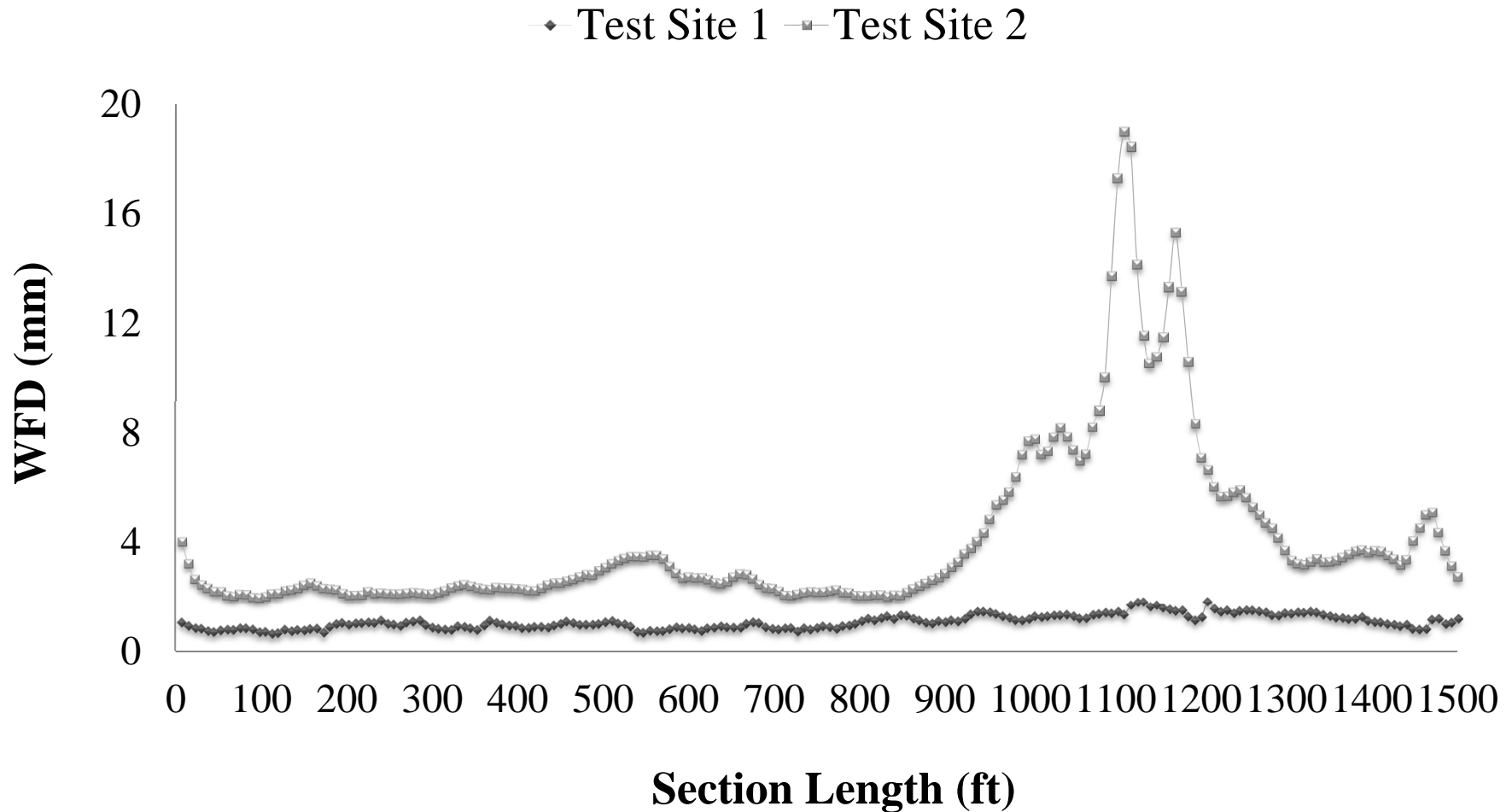
# Drainage Evaluation Test Results

—■— Test Site 1 —▲— Test Site 2

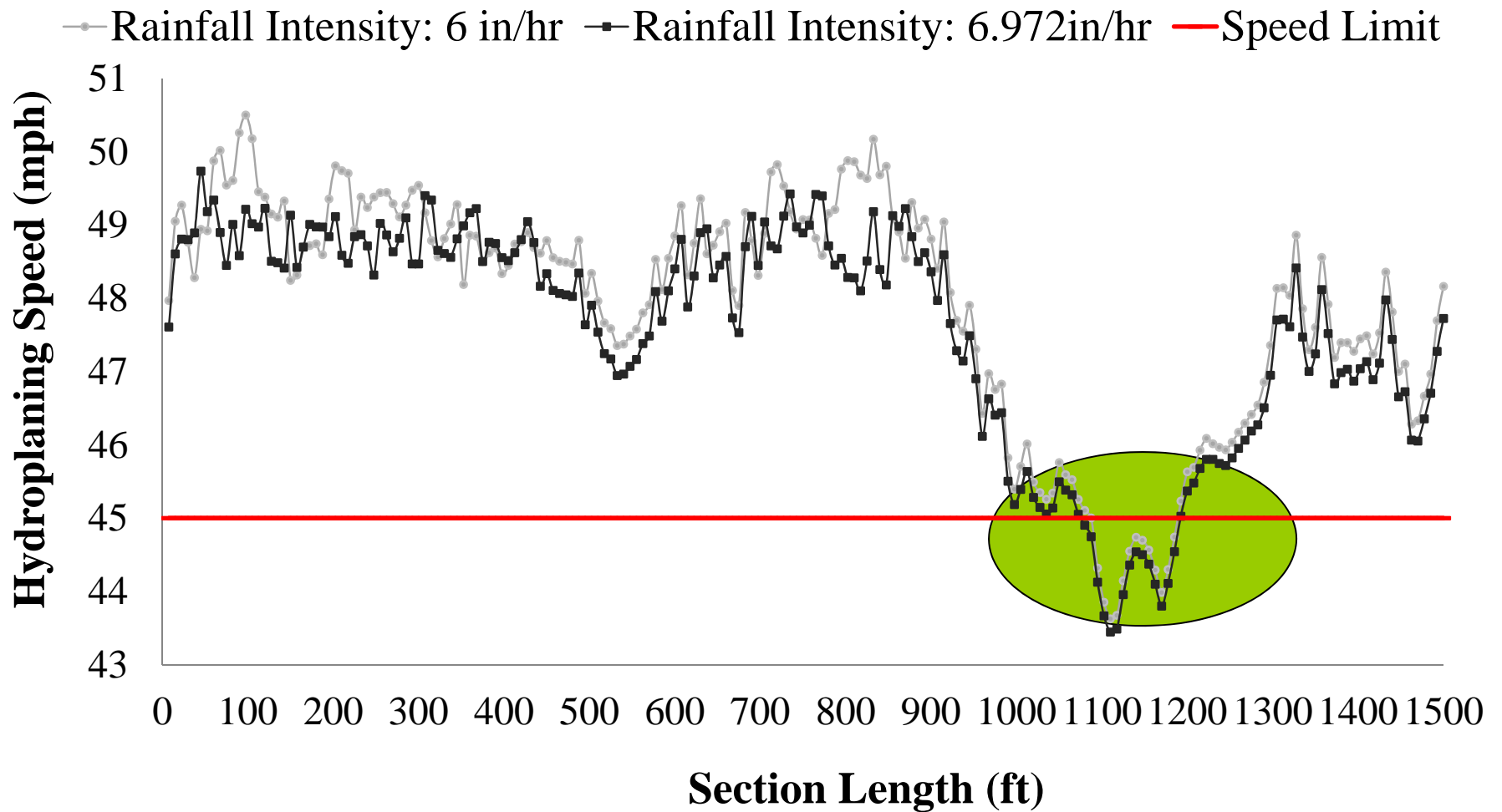




# Drainage Evaluation Test Results



# Drainage Evaluation Test Results



# Grooves: Airfield & Highway Pavements

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- Produces adequate skid resistance
- Prevents the occurrence of hydroplaning
- FAA Advisory Circular(AC) No. 150/5320-12C
  - Requirements for pavement groove dimension and performance
  - Needs to periodically evaluate runway groove performance
- Highway grooves
  - No standard



# Groove Evaluation Approach

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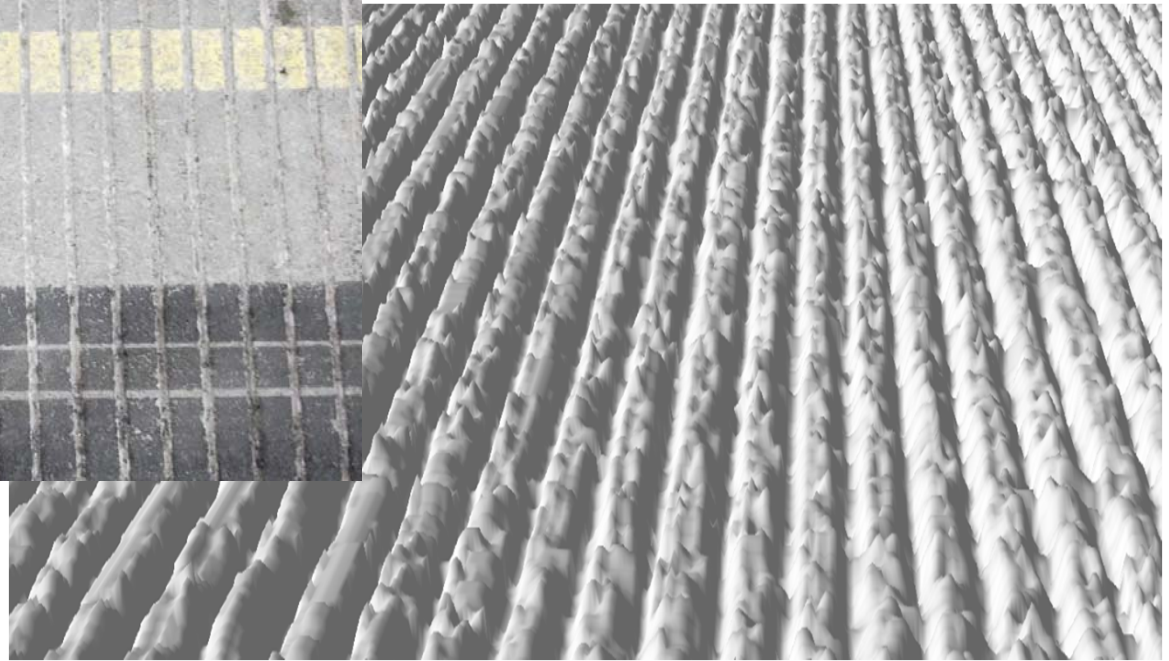
- To develop an algorithm to automatically estimate groove dimensions
  - Groove Depth, Width, and Spacing
- To evaluate groove performance
  - Calculated groove dimensions
  - Groove configuration, and
  - Standard groove evaluation guidelines



# Grooving

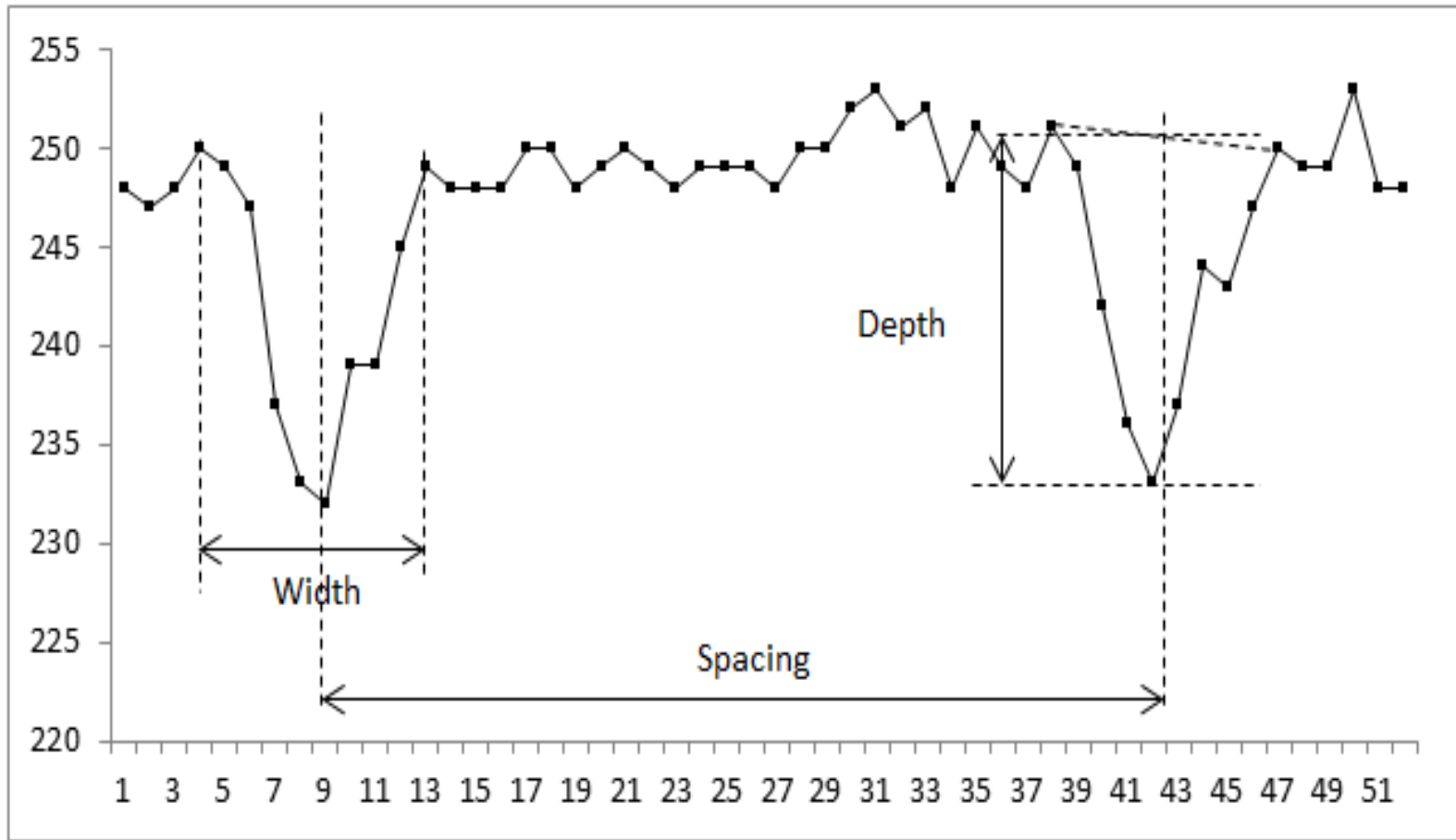


FAA NAPTF  
(Transverse)



NGCS (Longitudinal)

# Groove Dimensions



# Software Interface

**TexGroove**

Input Group  
 Open DataBase Image Quantity: 169 Section. Length: 86.528 m or 283.885 ft Profile Sele Lane Width(mm): 4016 Demo

Initialization  
 Sampling Initial Img ID: 142 Sam. Len: 4096 mm AOI(mm): Start: 900 End: 1000

Pass Filter  
 Low: 1040 High: 10 Cali.Coeff L.Verti: 2.5523 Long.Int: 1.098 R.Verti: 2.5224 Trans.Int: 1

Rec.Gro Eva

Gro.Dim	Depth	Width	Recomm. Percent
>3/16 in.	92.76	98.78	>90
>1/4 in.	52.23	86.05	>60
>5/16 in.	7.784	8.098	<10

Output Para  
 Depth  Width  Spacing

Stat. Info  
 Max.Iden: 101 Min Iden: 98  
 STD: 0.741 Iden.Quant: 100

Process Pause Resume Forward Backward Close

**Original and Filtered(G) Groove Shape**  
 Image ID: 00000149\_L.raw  
 4096 mm

**Rectangular Groove Dimension**  
 Identified Groove Number: 100  
 Identified Joint Number: 1  
 4096 mm

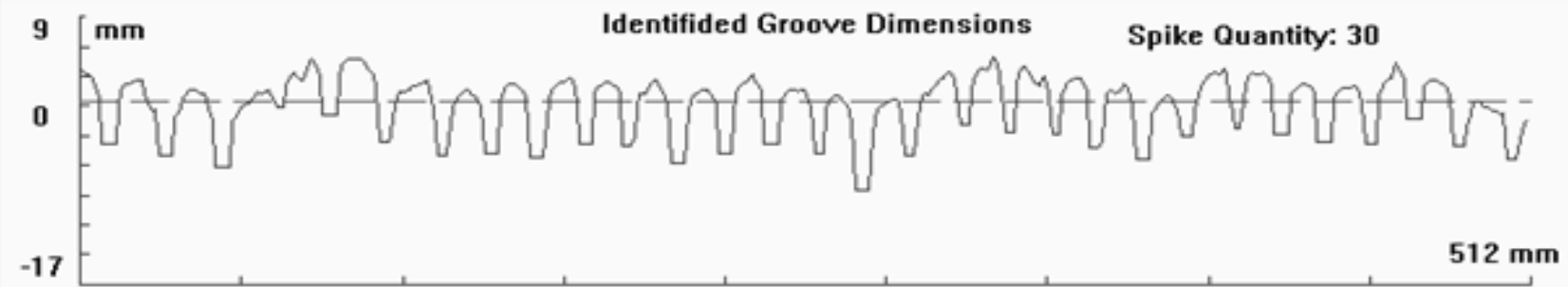
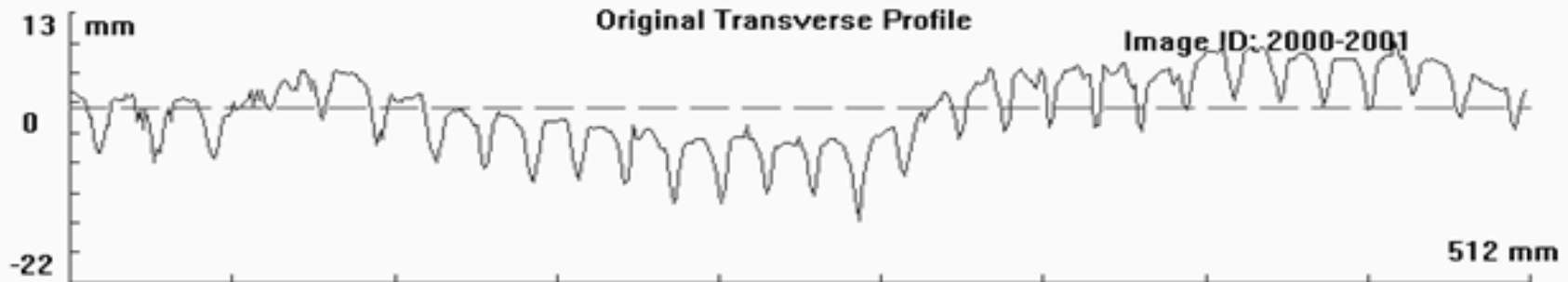
White-No Groove, Red-Low, Gray-Normal, Yellow-High

GD  
 GW  
 GS

Current Progress:



# Identification Results





# Evaluation of AASHTO PP69-10

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- ❑ Network Data Collection Using PaveVision3D Ultra
- ❑ Implement AASHTO PP69-10 Rutting Parameters
- ❑ Evaluate their Relationships and Propose a comprehensive Measure(s)



# AASHTO PP69-10 Rutting Protocol

No.	Attribute	Acronym
1	Total Deformation Permillage	TDP
2	Left Deformation Permillage	LDP
3	Right Deformation Permillage	RDP
4	Left Rut Depth (mm)	LRD
5	Right Rut Depth (mm)	RRD
6	Left Rut Width (mm)	LRW
7	Right Rut Width (mm)	RRW
8	Left Rut Area (square mm)	LRA
9	Right Rut Area (square mm)	RRA
10	Total Number of Water Entrapment Points	TNW
11	Total Water Entrapment Depth (mm)	TWD
12	Total Water Entrapment Width (mm)	TWW



# 1mm Rutting Data

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- Source
  - More than 100 miles NHS in AR
  - US65N and US70E
- 9000+ profiles
- Each profile 12 attributes
- Distribution of attributes
  - Slightly skewed or normally distributed



# Evaluation Methodology

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- Correlation Analysis
  - Examine preliminary relations
  - Correlation Matrix
- Linear Regression Analysis



# Correlation Matrix (Standardized)

	TDP	LDP	RDP	LRD	RRD	LRA	RRA	LRW	RRW	TNW	TWD	TWW
TDP	1.00	0.89	0.90	0.54	0.46	0.52	0.45	0.27	-0.02	0.25	0.27	0.36
LDP	0.89	1.00	0.67	0.57	0.36	0.54	0.40	0.29	0.07	0.31	0.24	0.33
RDP	0.90	0.67	1.00	0.48	0.50	0.45	0.50	0.23	0.01	0.28	0.28	0.31
LRD	0.54	0.57	0.48	1.00	0.28	0.93	0.31	0.73	0.00	0.22	0.24	0.63
RRD	0.46	0.36	0.50	0.28	1.00	0.26	0.88	0.08	0.52	0.17	0.46	0.20
LRA	0.52	0.54	0.45	0.93	0.26	1.00	0.27	0.82	-0.04	0.20	0.24	0.66
RRA	0.45	0.40	0.50	0.31	0.88	0.27	1.00	0.10	0.70	0.19	0.44	0.21
LRW	0.27	0.29	0.23	0.73	0.08	0.82	0.10	1.00	-0.03	0.16	0.13	0.78
RRW	-0.02	0.07	0.01	0.00	0.52	-0.04	0.70	-0.03	1.00	0.17	0.31	0.00
TNW	0.25	0.31	0.28	0.22	0.17	0.20	0.19	0.16	0.17	1.00	0.35	0.18
TWD	0.27	0.24	0.28	0.24	0.46	0.24	0.44	0.13	0.31	0.35	1.00	0.19
TWW	0.36	0.33	0.31	0.63	0.20	0.66	0.21	0.78	0.00	0.18	0.19	1.00



# Correlation Results

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- Strong linear relations  
(correlation coefficient  $> 0.7$ ):
  - TDP & LDP
  - TDP & RDP
  - LRD & LRA
  - RRD & RRA
- Weak linear relations (correlation coefficient  $< 0.3$ )



# Establish Quantitative Relations

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- Traditional Measures
  - Rutting depth (LRD & RRD)
- New Measures in PP69-10
  - Rutting width (LRW & RRW)
  - Rutting area (LRA & RRA)
  - Water related (TNW, TWD, & TWW)



# Regression Analysis Results

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- Feasible and reliable to use rutting depth to predict rutting area measures
- Other attributes: not robust to predict with rutting depth





# Conclusions

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- Sensor Technology: Completed
- Challenges to the Team & Industry: Software Solutions
  - To be beautiful, & also usable
  - Virtual representation with both geometric & geographical accuracy
  - Total Solution: possible!

