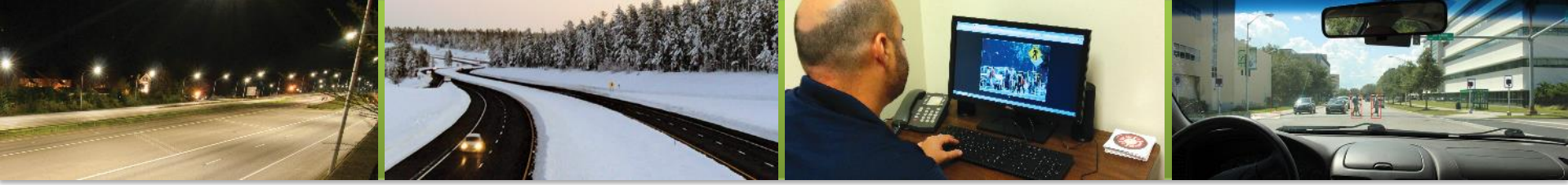

SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

Advanced Methods to Identify Asphalt Pavement Delamination (R06D) Ground Penetrating Radar (GPR)

New Mexico DOT

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Peer Exchange
August 1-3, 2018

New Mexico DEPARTMENT OF TRANSPORTATION
MOBILITY FOR EVERYONE

Texas A&M Transportation Institute

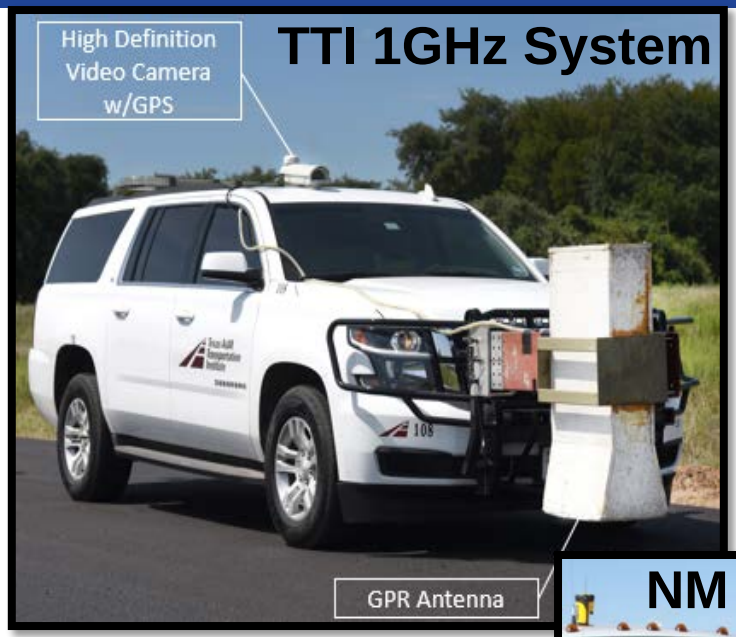
U.S. Department of Transportation
Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO

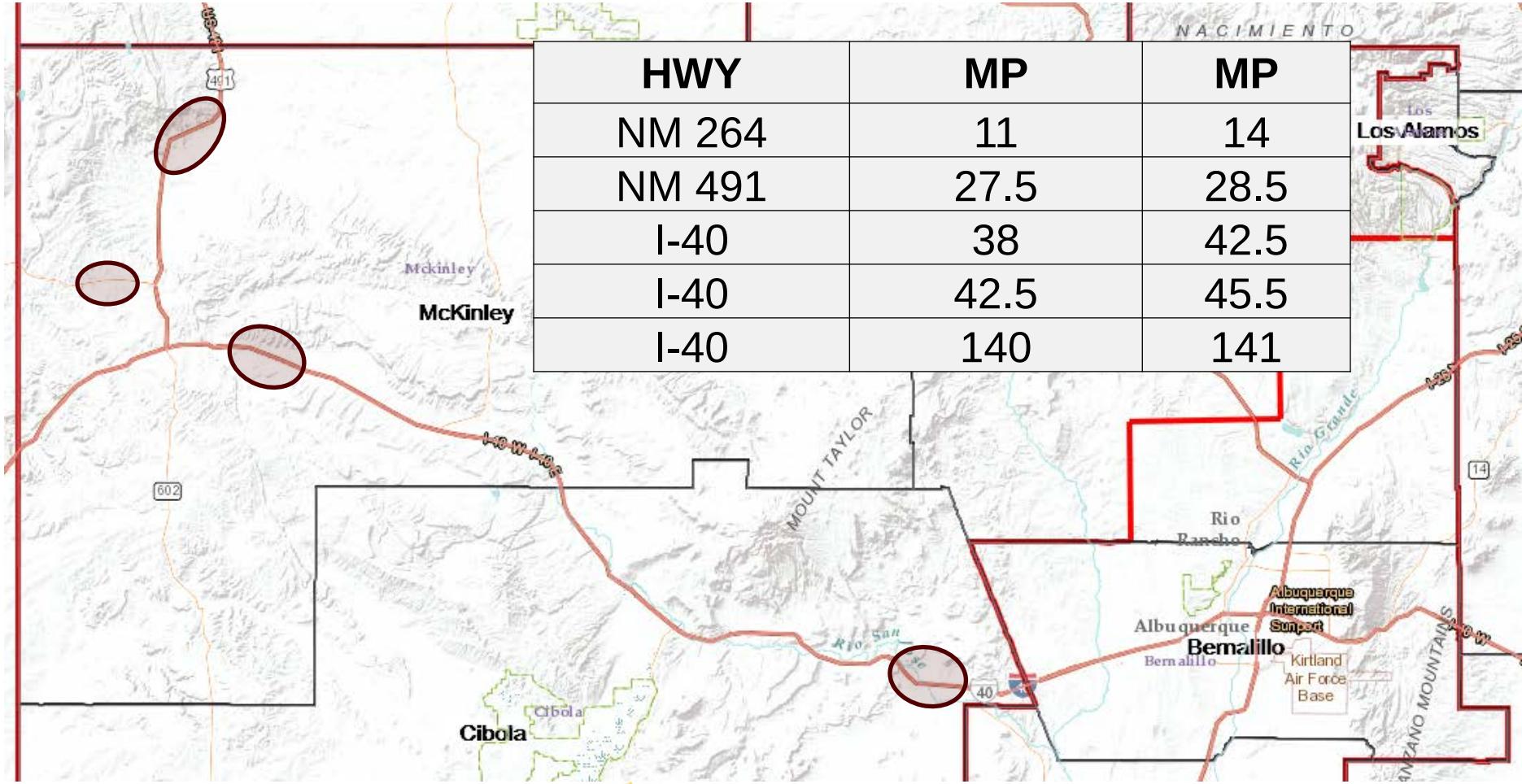
Outline

- System Comparison TTI 1 GHz, GSSI 2 GHz and 3D Radar
  - Dr. Hayat's Study for automated analysis
- Test Site Data Analysis TTI & 3D Radar comparison
  - Field Testing
- Other testing
  - Bridge Deck
  - Concrete Pavement
- Conclusions and Recommendations

GPR – Comparison to TTI & NM Systems



GPR Test Locations – New Mexico

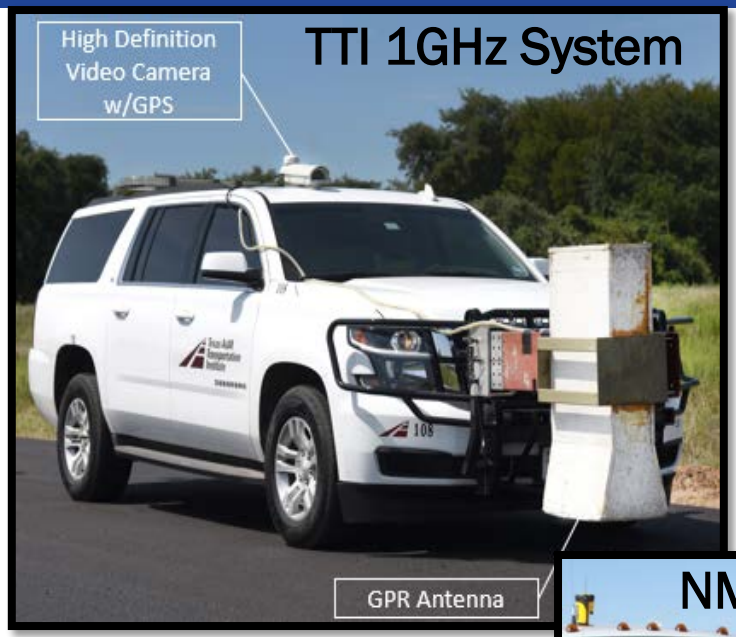


HWY	MP	MP
NM 264	11	14
NM 491	27.5	28.5
I-40	38	42.5
I-40	42.5	45.5
I-40	140	141

Comparison Criteria

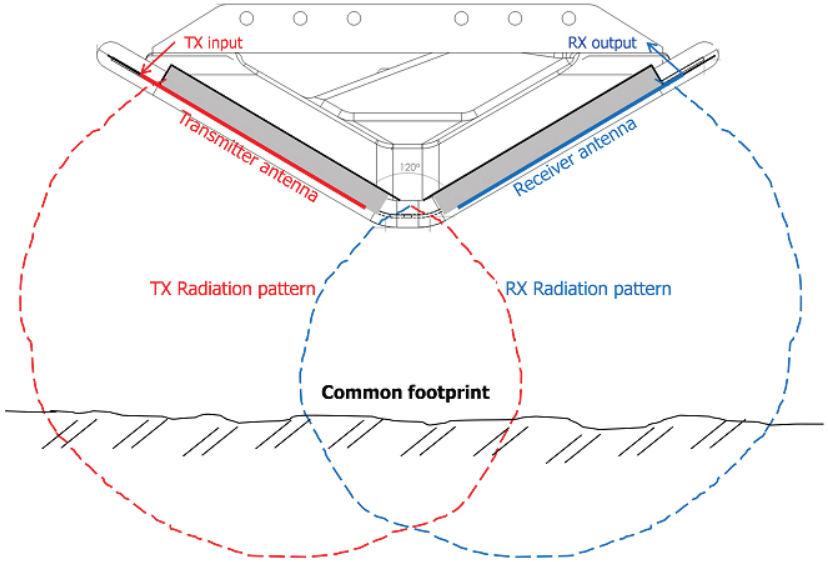
1. Ease of set-up, storage and operation
2. Quality of Data
3. Data storage
4. RFI or cell tower interference
5. Ease of data analysis
6. Best Pavement Applications
7. Ability to estimate Dielectric values
8. Data analysis time for detecting anomalies
9. Data analysis time for pavement layer thickness
10. Level of experience needed to analyze data
11. Ability to export files for use in other programs such as Excel
12. Reports
13. Cost
14. Ease of updating collection software, analysis software and system
15. Future applications
16. Other Capabilities
17. Synchronized Video (to assist with identifying defect locations)

Ease of Set-up, storage & operation

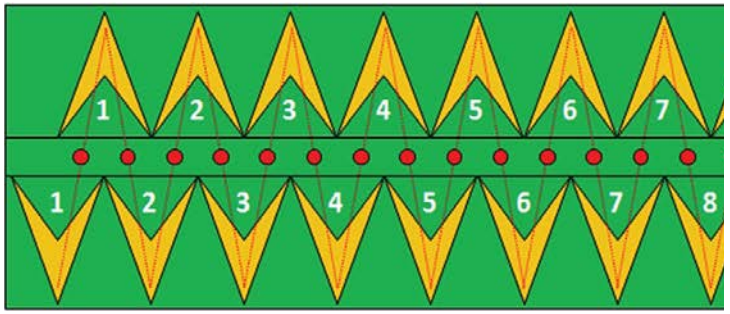


GPR – 3D Radar

3D-Radar Antenna Specifications	
Technical Specifications	DX1821 Antenna
Width	5.9 ft
Frequency Range	200-3000 MHz
Number Of Channels	21
Channel Spacing	3 in
Effective Scan	5.2 ft
Direct Wave Suppression	> 50 dB
Polarization	Linear (in-line direction)
Size	5.9'x1.9'x0.7'
Weight	61.7 lbs



Antenna Configuration



Example Scan Pattern

Collection Settings 3D Radar

3D-Radar Collection Settings					
Pavement Surface	**[2]Trigger Spacing**		**Time Window**	**Dwell Time**	**Max Speed**
	(in)	**(cm)**	**(ns)**	**(us)**	**(mph)**
Concrete & BRG	3.0	7.6	50	0.6	43.5
[1]concrete/flexible	6.0	15.5	50	0.6	89
Flexible	12.0	30.5	50	0.6	175

1. Use for concrete pavement when need to test at >45mph; use for flexible pavement when closer spacing is needed;
2. Trigger Spacing can be increased to 36” in order to save data storage and still provide adequate network level data. If spacing is adjusted, use multiples of 3".

Note: Collection settings are preliminary and final recommendations are still under review.

Data & Analysis

System	TTI	NM	3D
Data Quality	High Resolution	Med-High Res	Low Resolution
Storage (ex)	50,030 kb	274,948 kb	4,192,833 kb
RF (Interference)	None	Yes	Yes
Experience Needed	Basic	Basic	High Level due to filters
Software Ease of Use	Intuitive/Simple minimal training	Training needed	Training needed
Ability to Export & Report	Basic files to Excel	Basic files to Excel	Difficult
Calculate Dielectric	Yes, easy and quick	Yes, time consuming	No
Time (min) for Analysis anomalies | thickness	11:30 | 6:11	11:30 | 23:57	20:30 | 32:42

Data Analysis
Dr. Hayat's Study

- NMDOT contracted with Dr. Majeed Hayat to investigate an algorithm for distress detection based on GPR DATA.
  - Learn what things may indicate deterioration
  - Develop coefficients that can indicate deterioration
  - Compare results from coefficient analysis with ground truth data
  - Development of user interface
  - Determination of level of effort to use with 3D Radar
  - Further research to determine exact flagging thresholds are needed (currently using a statistical method to indicate what level of coefficient changes constitute deterioration)

Assumptions
Dr. Hayat's Study

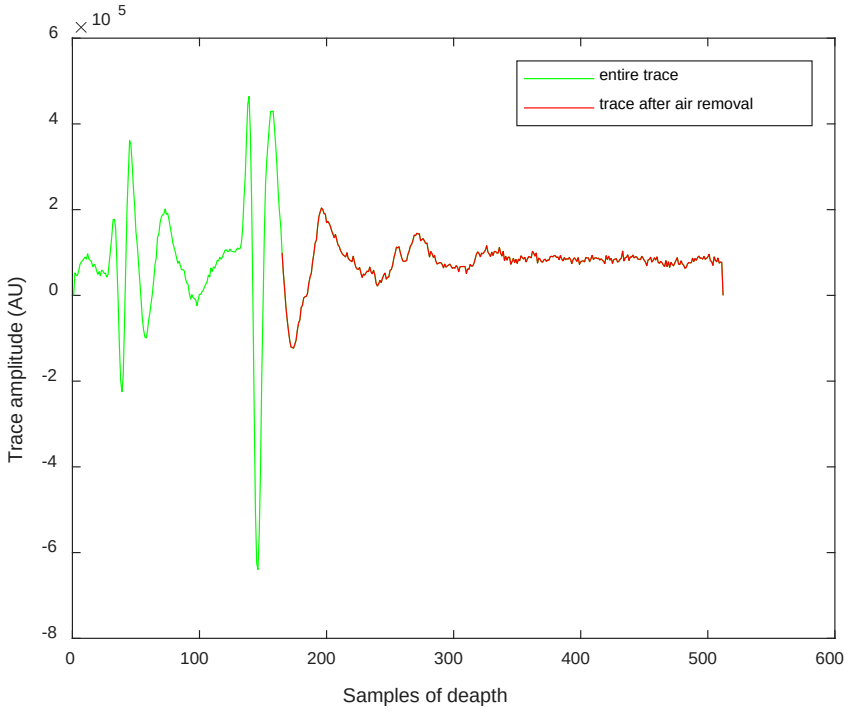
- Deterioration will be over a finite/small area i.e., not throughout the whole pavement section
- There should be changes visible between waves in adjacent GPR scans to indicate deterioration
- Stripping should show up as a "sudden" negative amplitude wave
- Sometimes positive waves that "suddenly" appear can be indicative of water in deterioration areas

Pre-processing removal of air Dr. Hayat's Study

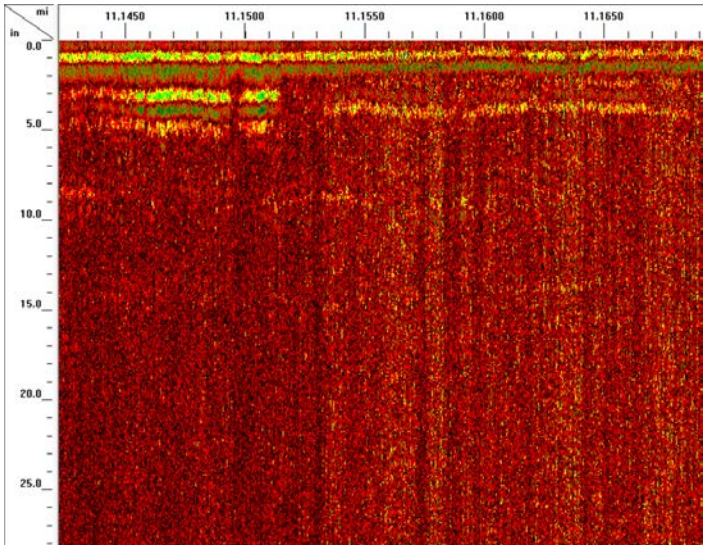
- Only reflections that result from interfaces AFTER the air-to-asphalt interface are used in the analysis

In the example shown (I40 WB), sample 180 to 512 are maintained and the earlier samples are discarded

The starting point is selected by inspection

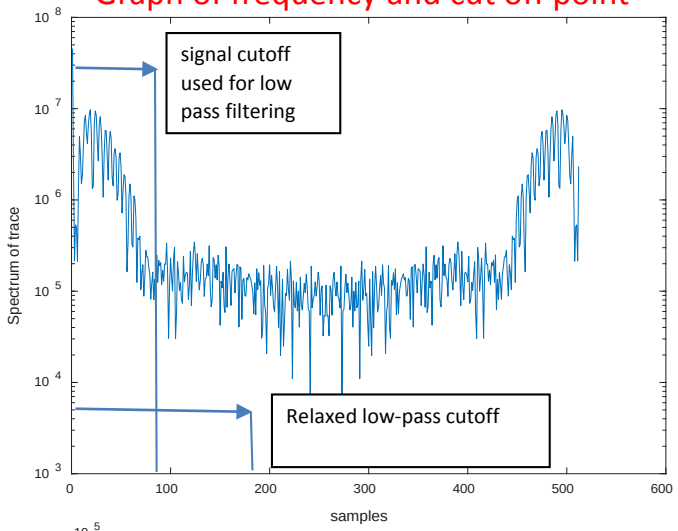


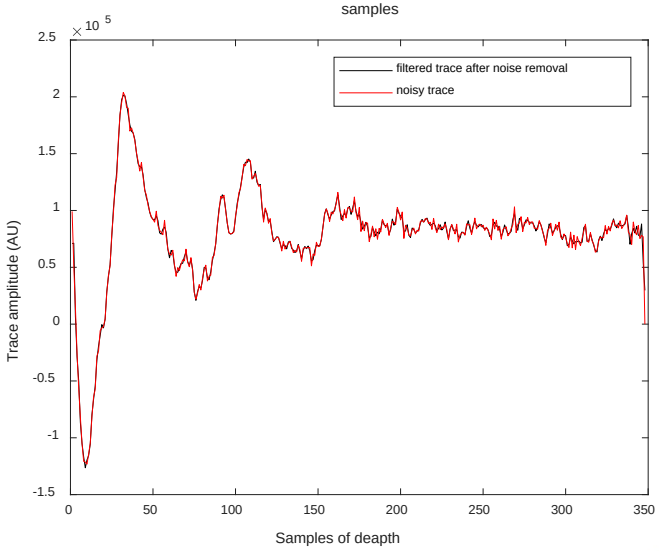
Pre-processing Filtering
Dr. Hayat's Study

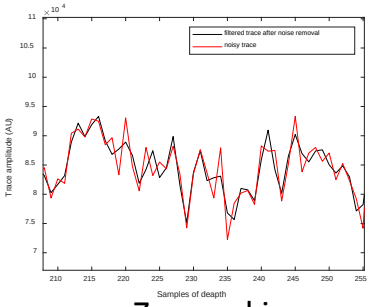


Graph of filtered vs. unfiltered wave from I-40

Graph of frequency and cut off point





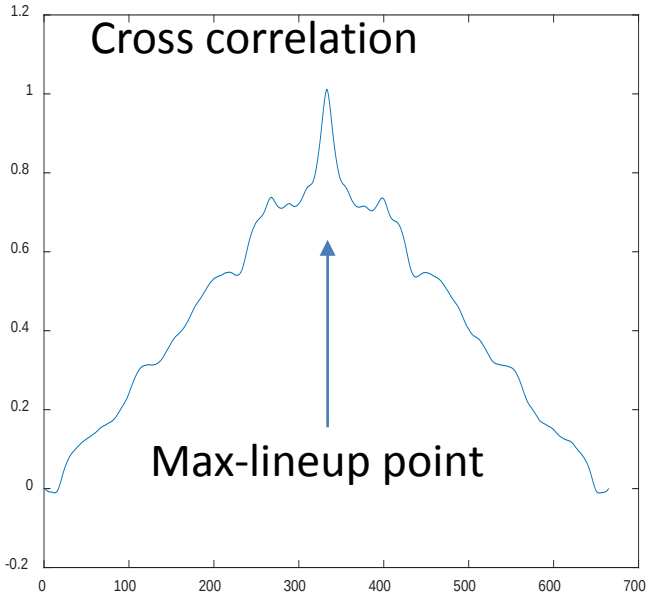


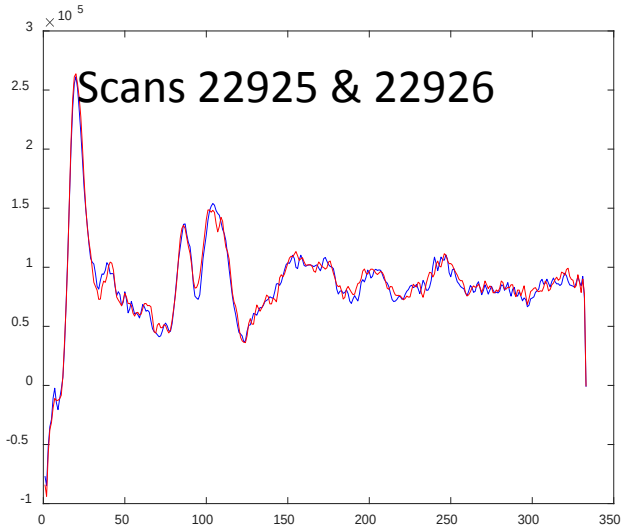
Zoomed in

Uniformity coefficients
Dr. Hayat's Study

Maximum cross correlation calculation:

- Every scan is shifted relative to the next scan, the two scans are multiplied, and integral is calculated
- Maximum area is obtained when maximum lineup is achieved
- This maximum integral is the cross correlation

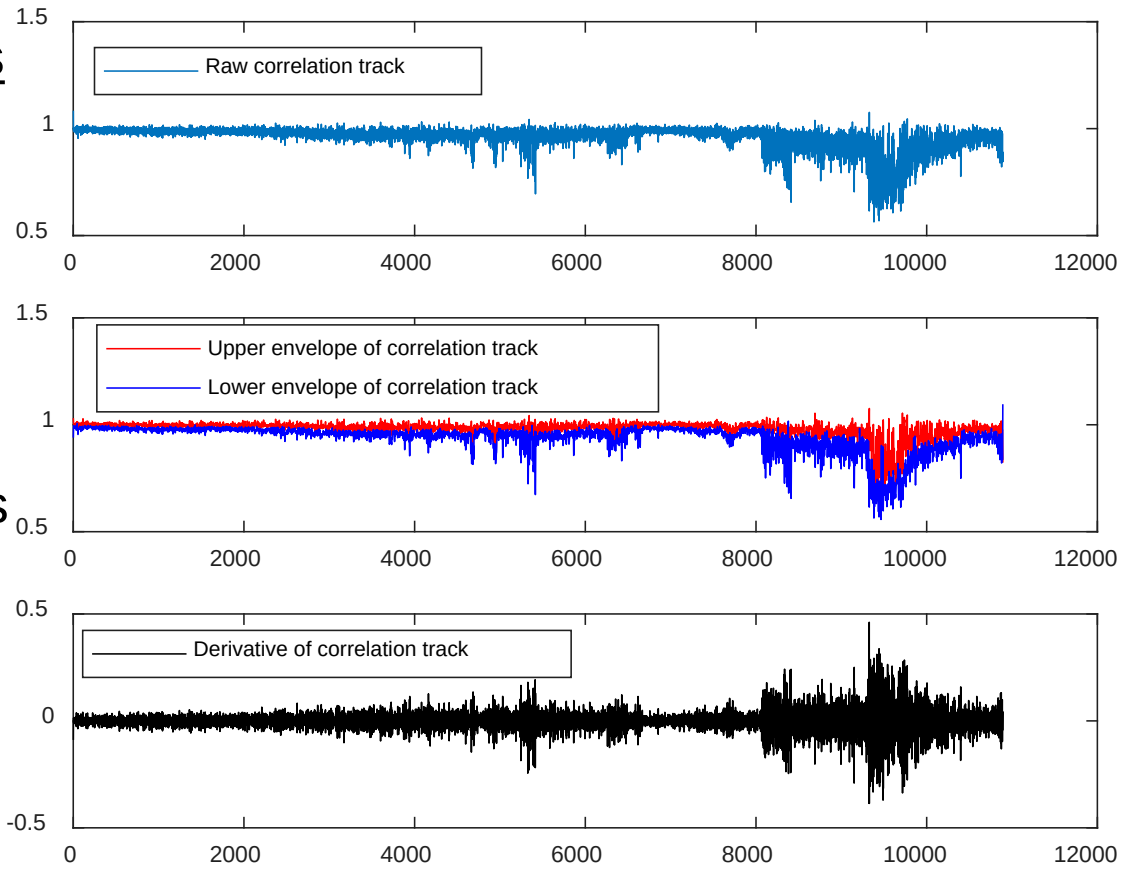




Uniformity coefficients
Dr. Hayat's Study

We can define a family of 3 correlation-based coefficients

- Raw correlation coefficient track (as described on the previous slide)
- Derivative of correlation coefficient track (with respect to scan number)
- Upper and lower envelopes of the correlation track

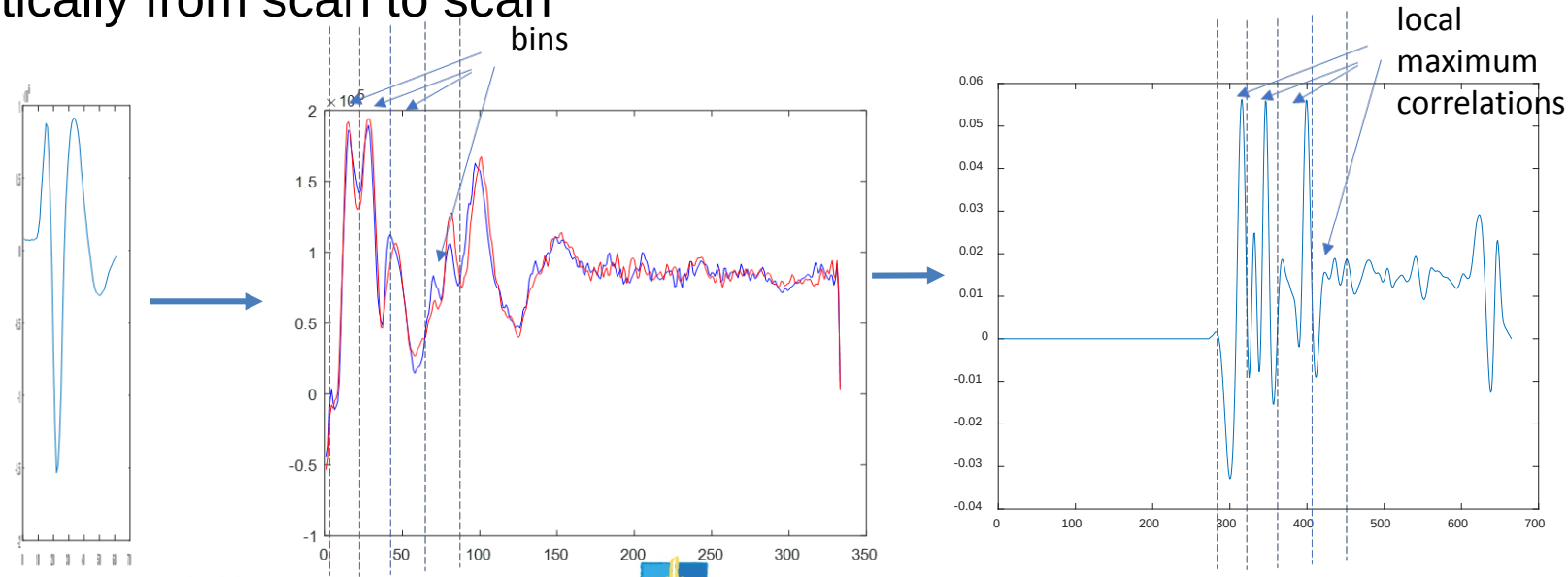


Positive/negative peak family
Dr. Hayat's Study

- Here, we look for the sudden presence of a positive peak or negative peak in the trace, where a "peak" is defined by the shape of the pulse from a metal plate reflection

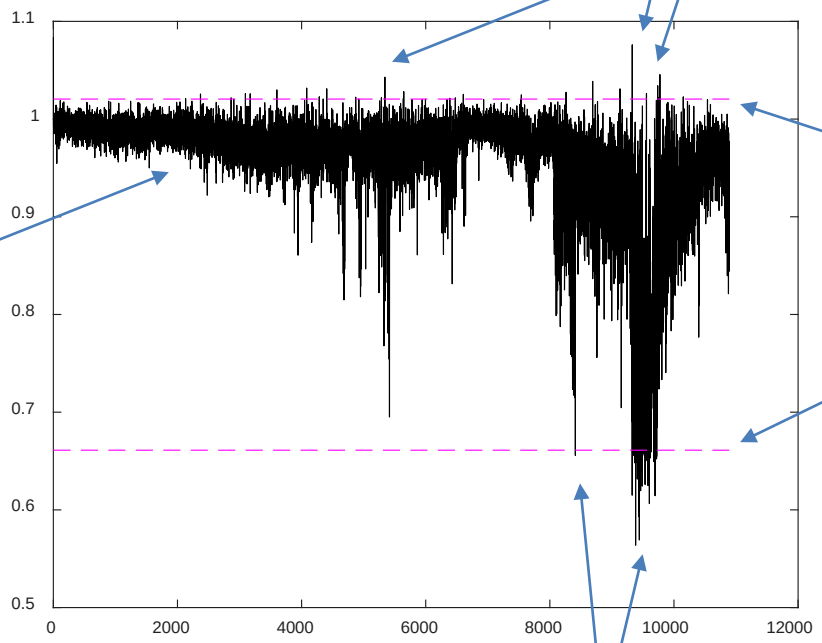
Negative peak
Dr. Hayat's Study

- We divide each scan into bins of length 20 samples (see middle figure)
- We look for the presence of a negative peak (left figure) in each bin
  - This is done by cross correlating a pulse (left) with each trace (middle)
  - The peak of the cross correlation over each bin is indicative of the presence of a negative peak in that bin (right)
- We announce a negative-peak detection if *any* of the local maxima changes drastically from scan to scan



Detection using the metric tracks
Dr. Hayat's Study

Detections



Cross-correlation track

Upper and lower thresholds are set for Detection

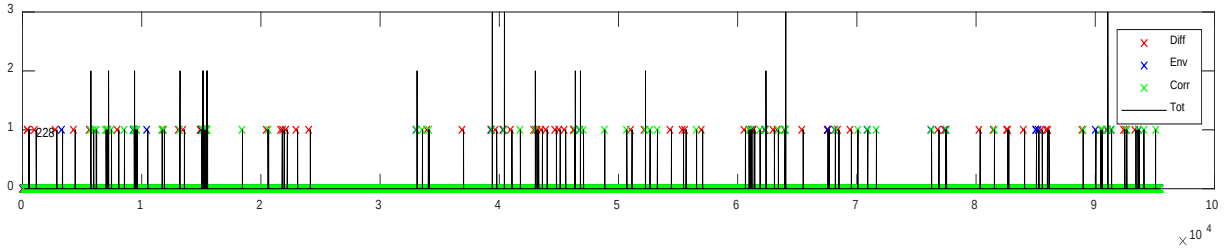
E.g., we look for the top and bottom 0.01 percent in the track values

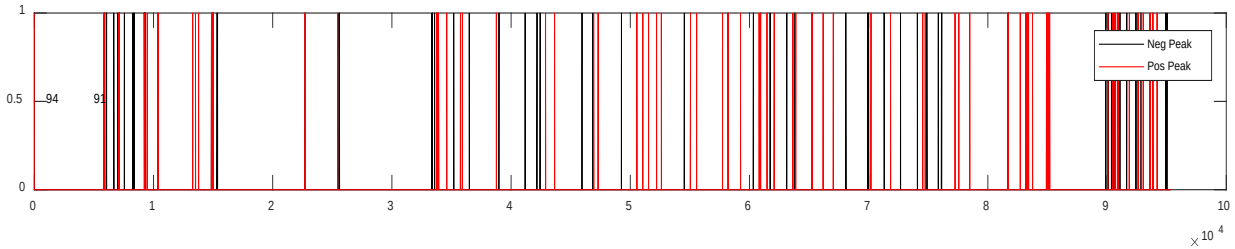
Detections

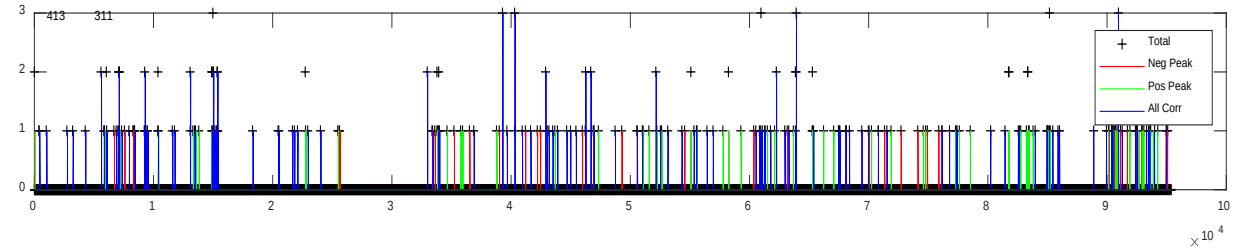
Detection using the metric tracks
Dr. Hayat's Study

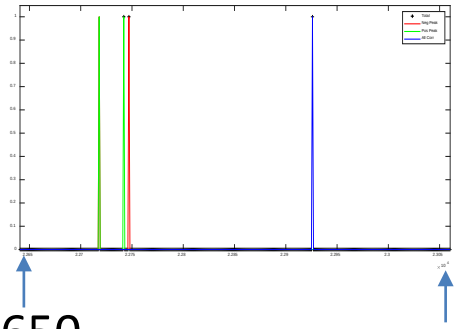
311 detected scans (no double counting)

- Top: detections resulting from changes in uniformity metrics over scans
- Middle: detections resulting from changes negative and positive peak metrics over scans
- Bottom: All together





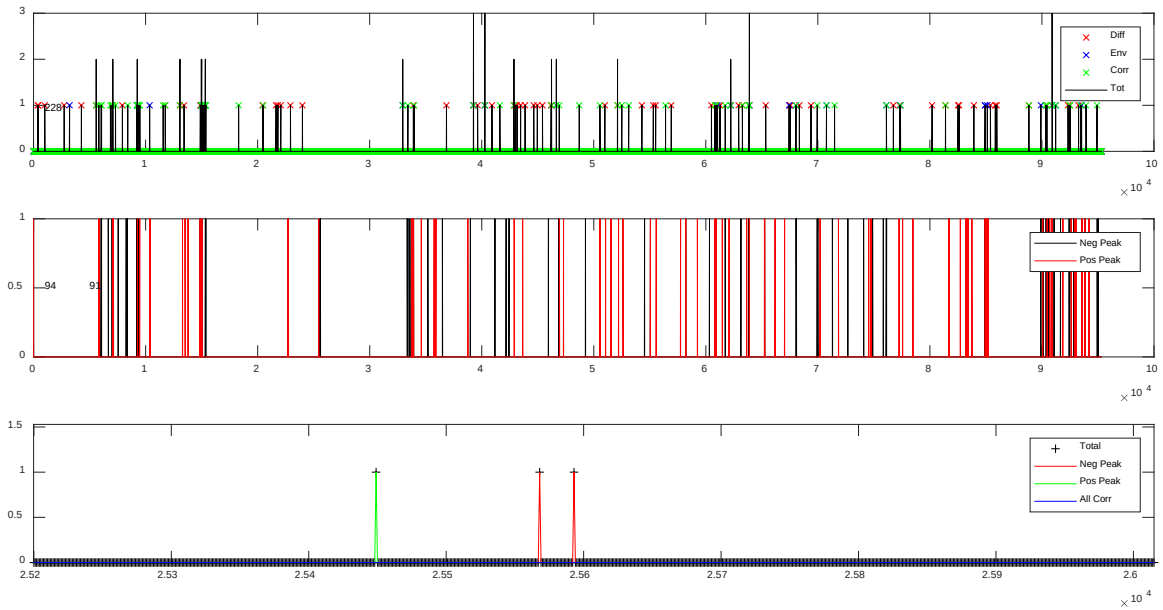




22650

23050

Old NM264 example
Dr. Hayat's Study

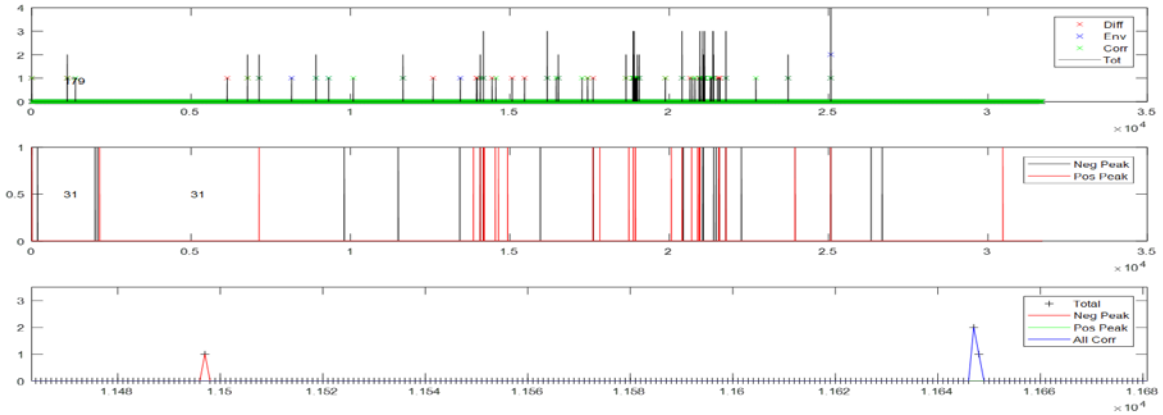


Scan ~ 25,500

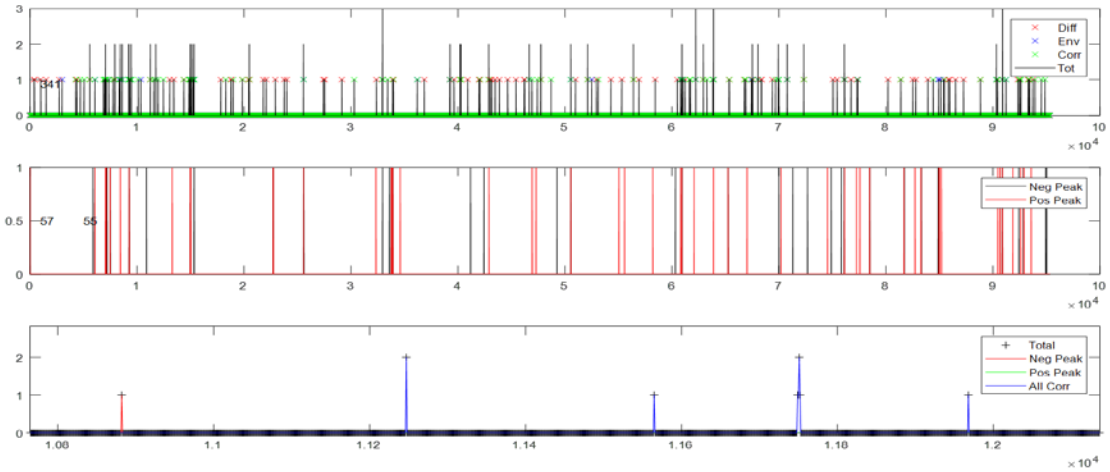
Scan ~ 25,800

New NM 264 Example
Dr. Hayat's Study

2017 scan



2015 scan



Scan ~ 11,600

Table of % error for old NM264
Dr. Hayat's Study

Direction	MP	core	scan #	Trigger	correct?
EB	10.735	Failure/patch	22,900	Yes	yes
EB	10.745	Debonding	23,200	No	No-but debonding
EB	10.82	Fatigue failure	25,500	yes	Yes
EB	10.825	Stripping	25,800	yes	Yes
EB	11.32	Deteriorated completely	41,200	No	No-GPR limitation?
EB	12.67	Intact	83,700	No	yes

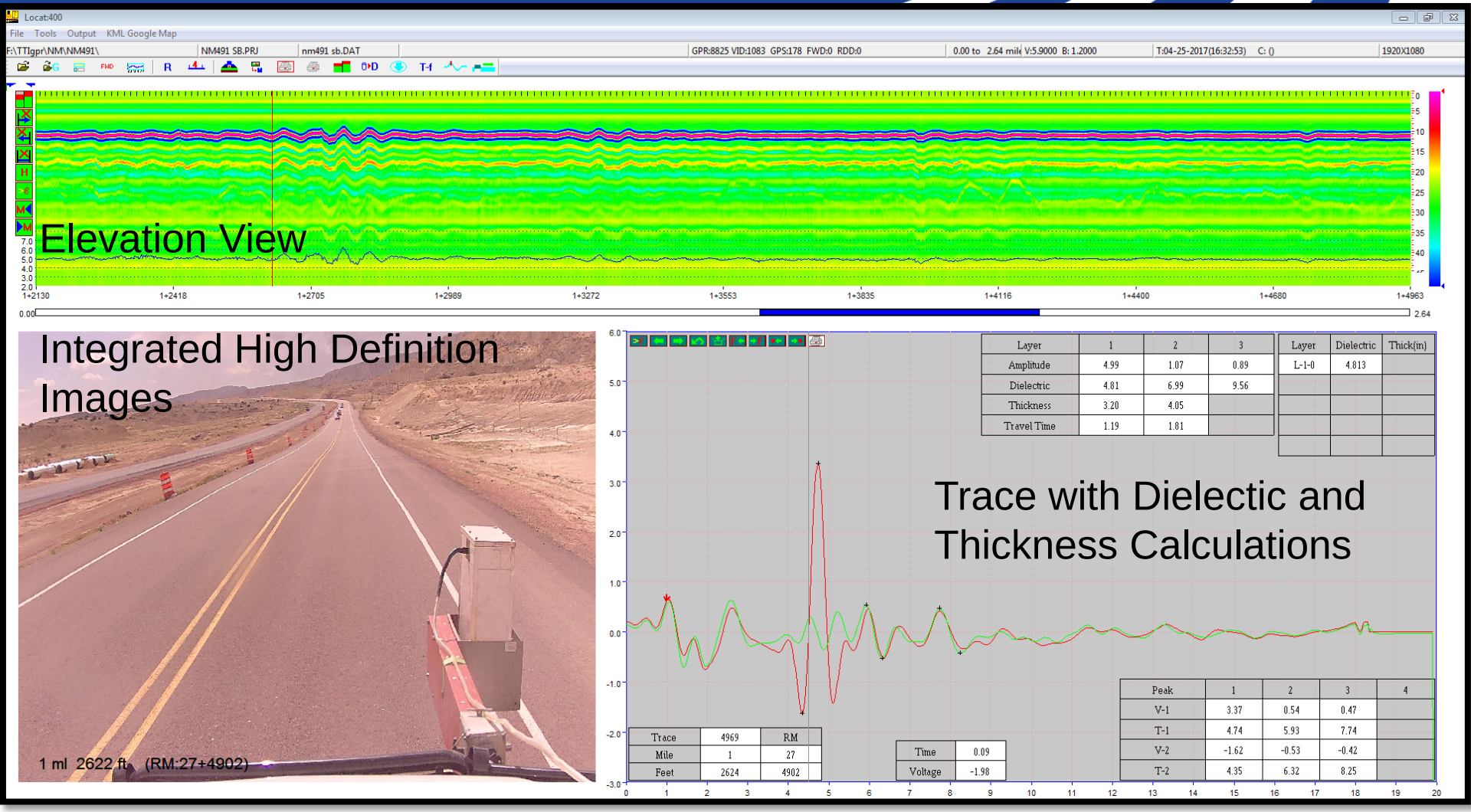
Table of % error for new NM 264
Dr. Hayat's Study

Direction	MP	core	scan #	Trigger scan #	correct?
WB	11.7	intact	24200		yes
WB	12.976	intact	10850		yes
WB	12.1	patch area	20000	20035	yes
WB	11.9	high air voids	22100	22103	yes
WB	11.3	intact	28400		yes
WB	11.2	intact	29450		yes
EB	11.1	high air voids	1054	1100	yes
EB	12.1	stripping	11600	11647	yes

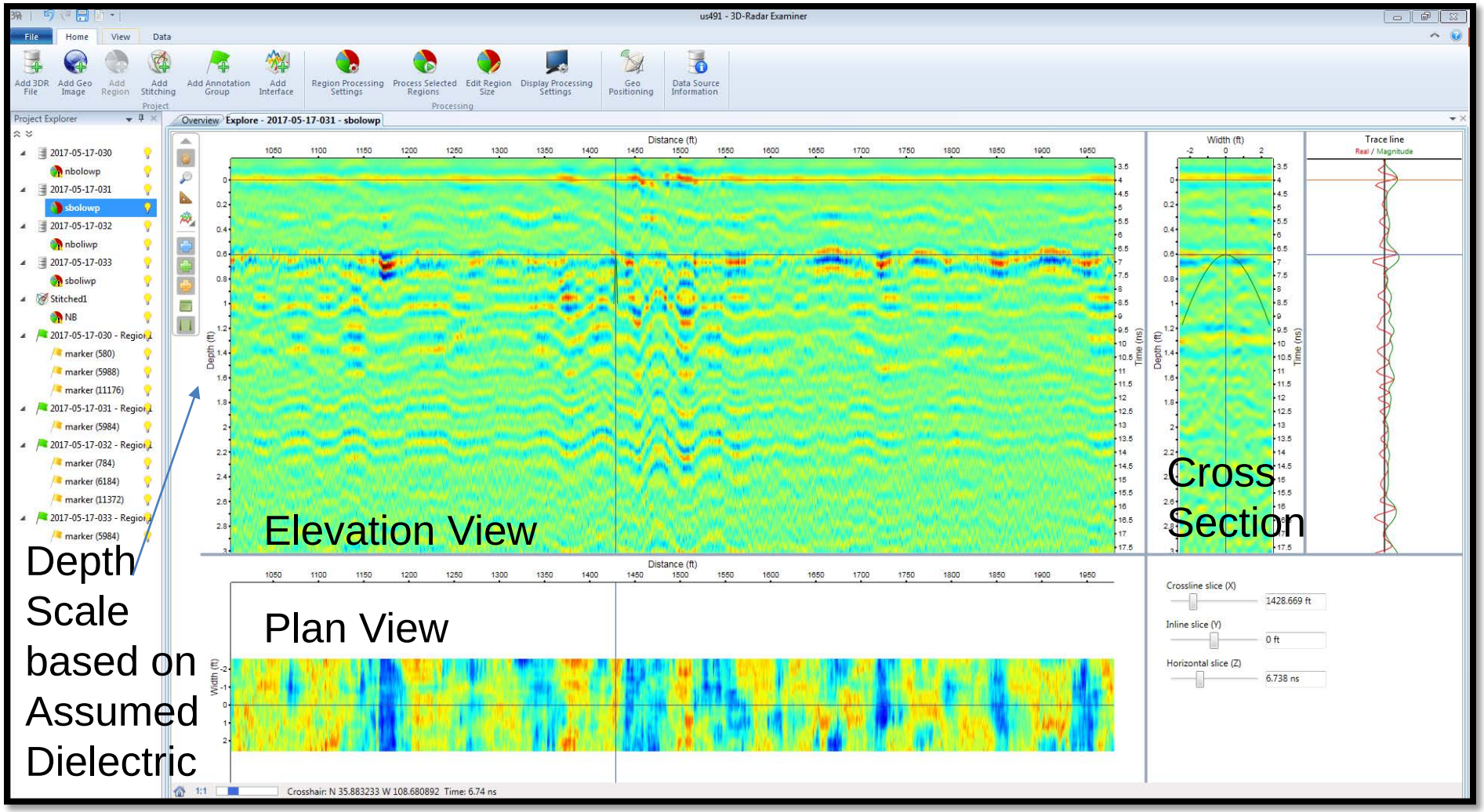
General Comparison

System	TTI	NM	3D
Cost	No Longer Available	~$175,000	~$230,000
Updates	n/a	New Equipment	Can Update
Collection	All Similar	All Similar	All Similar
Analysis	Easy	Moderate	Difficult
Future	n/a	n/a	Calculate Dielectric & depths

TTI – PaveCheck Software

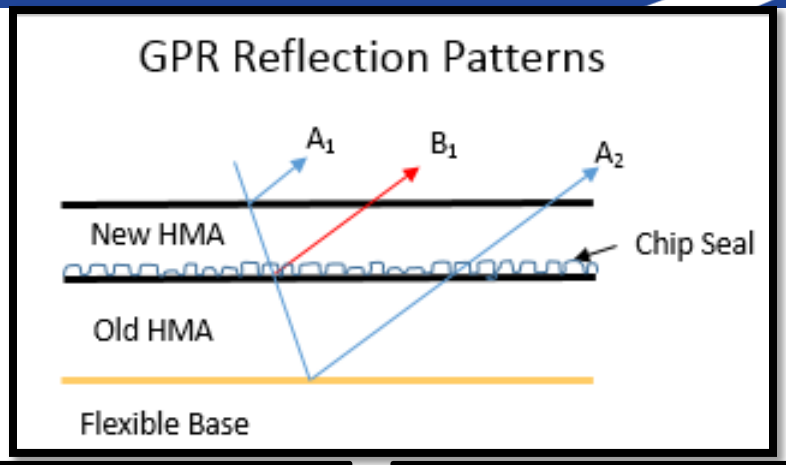


3D Radar Examiner Software



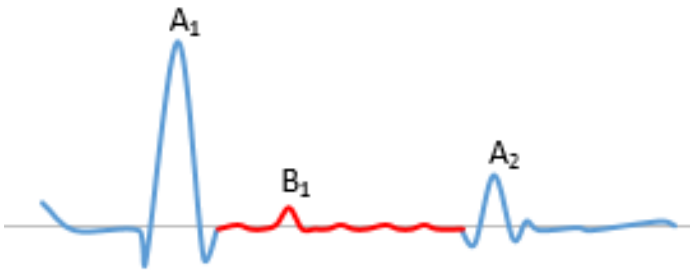
Depth Scale based on Assumed Dielectric

Trace Patterns



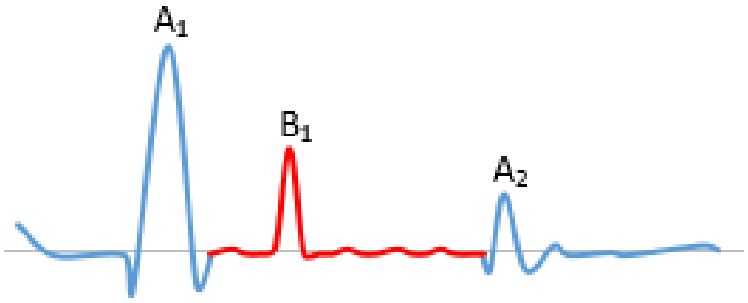
Case-1: Normal

B_1 Positive, very small reflection
Little dielectric contrast between new and old HMA

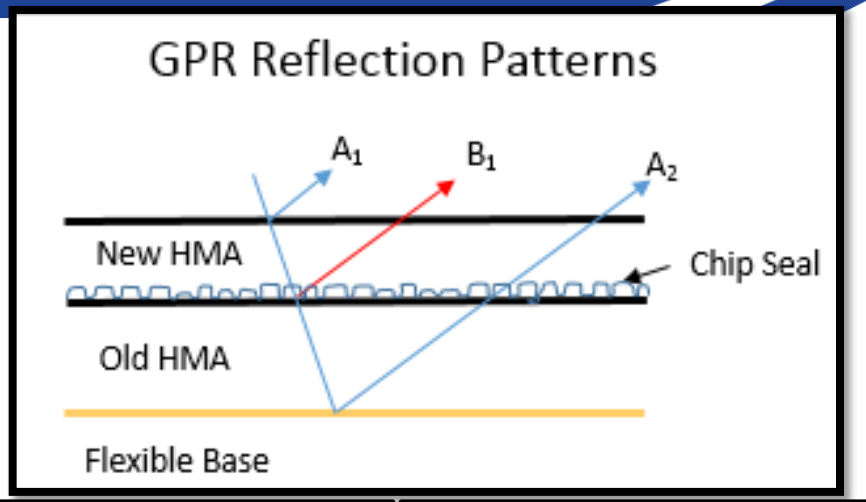


Case-2: Trapped Moisture

B_1 Large Positive reflection
A_2 reflection is smaller than B_1



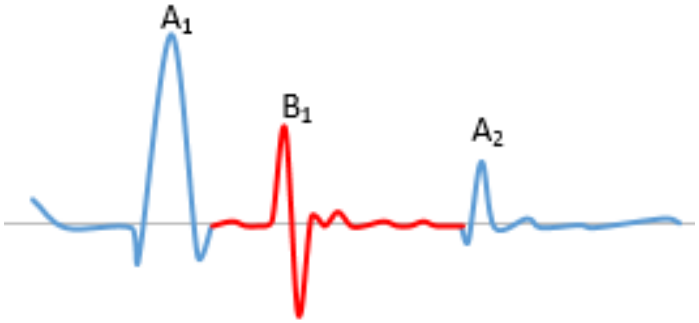
Trace Patterns



Case-3:

Thin Layer of Moisture on Top of Seal

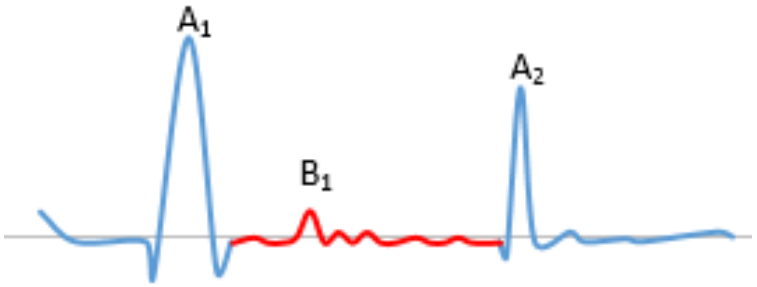
B_1 Overlapping Positive and Negative reflections



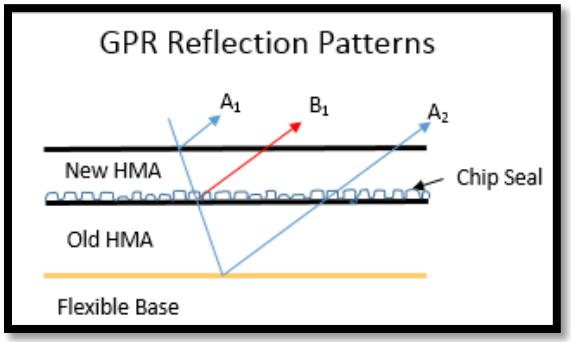
Case-4:

Moisture Trapped in Base Layer

A_2 Reflection increases significantly

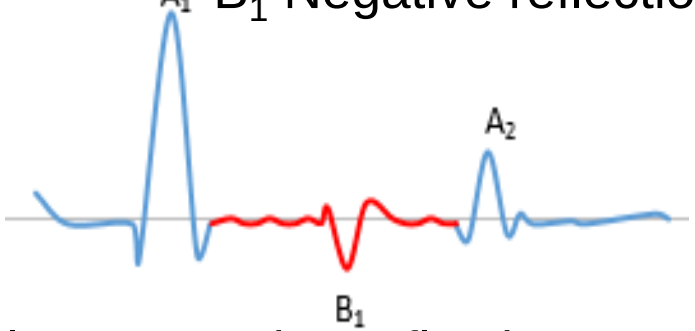


Trace Patterns



Case-5: Lower HMA Severely Deteriorated-Stripping

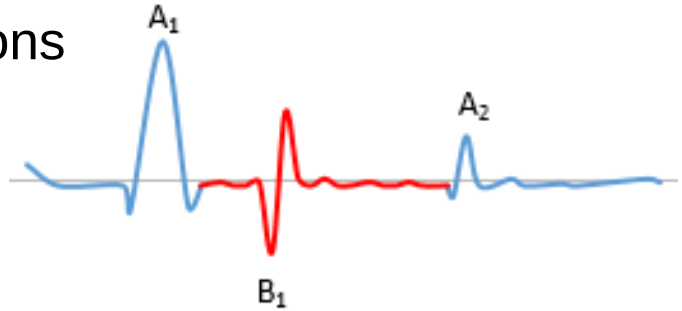
A_1 B_1 Negative reflections



Note: large negative reflections may be high void area, stripping or debonding

Case-6: Stripped Layer to Good HMA

B_1 Overlapping Negative and Positive reflections

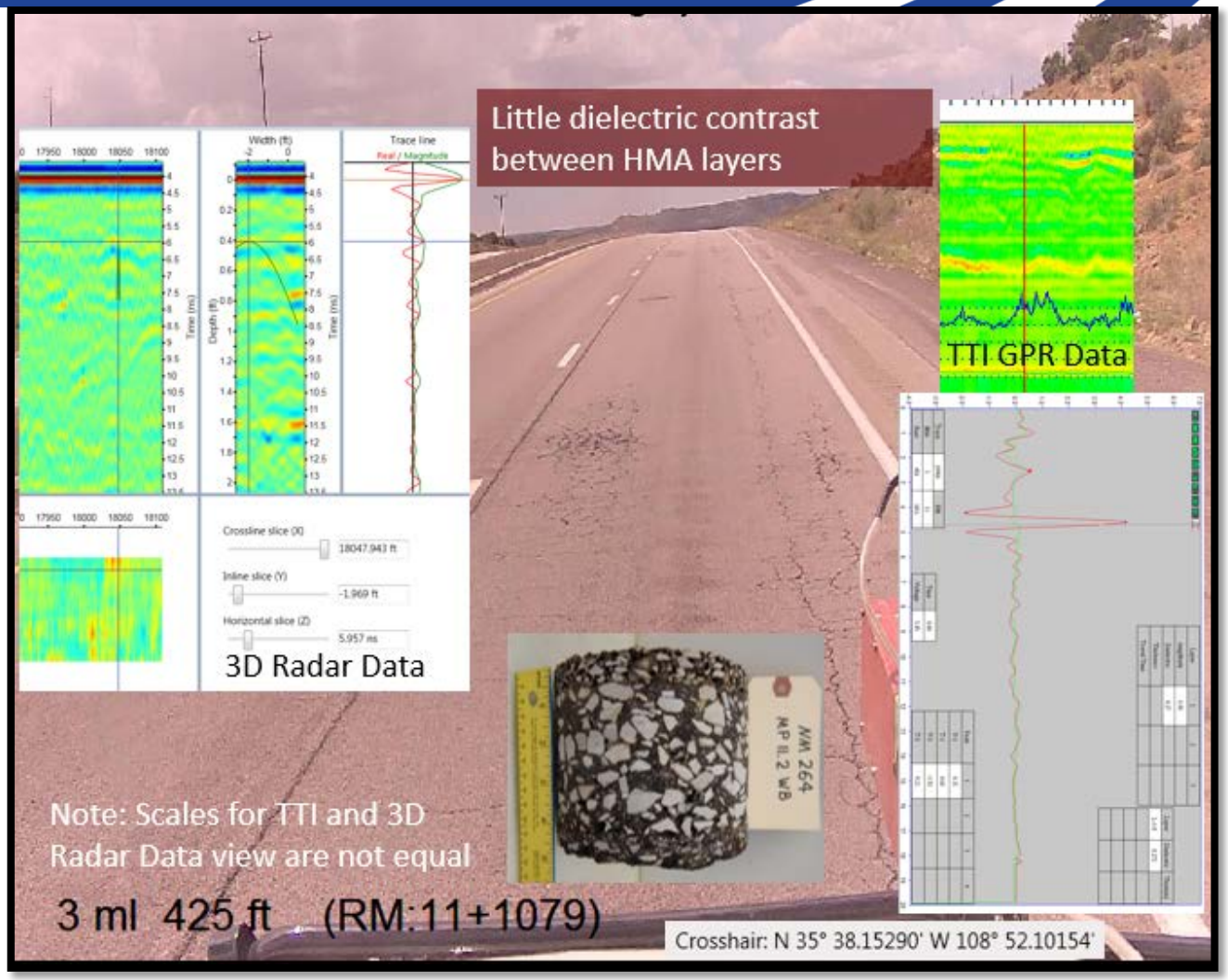


Note: Pattern may also appear when a Light weight aggregate Chip Seal is between good layers. No moisture present.

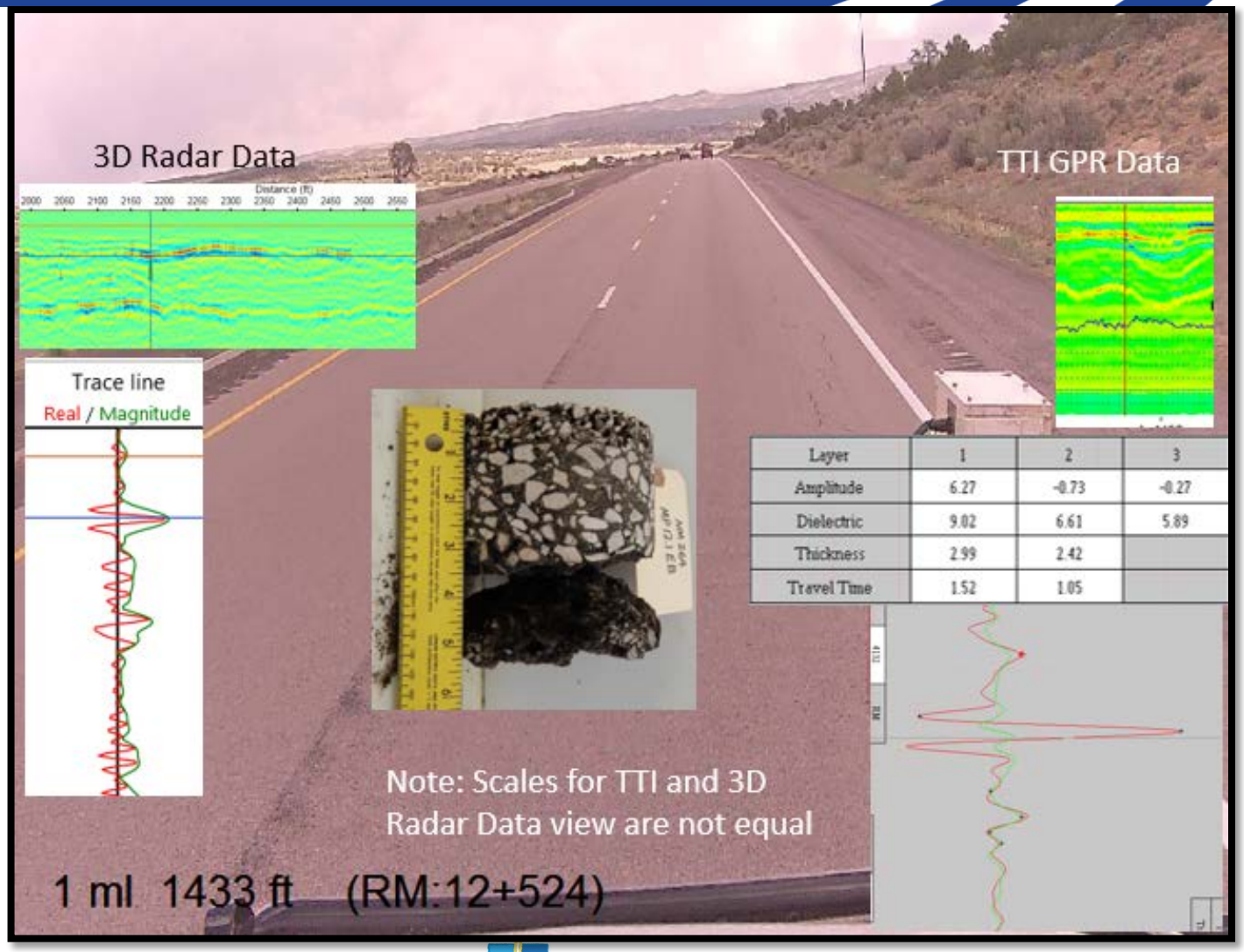
Overview


Distance (ft)
3D Radar
TTI GPR
Similar Patterns
Trace line
Real / Magnitude
3D Radar Trace
Similar to TTI GPR Trace
1 mi 2646 ft (RM:27+4877)

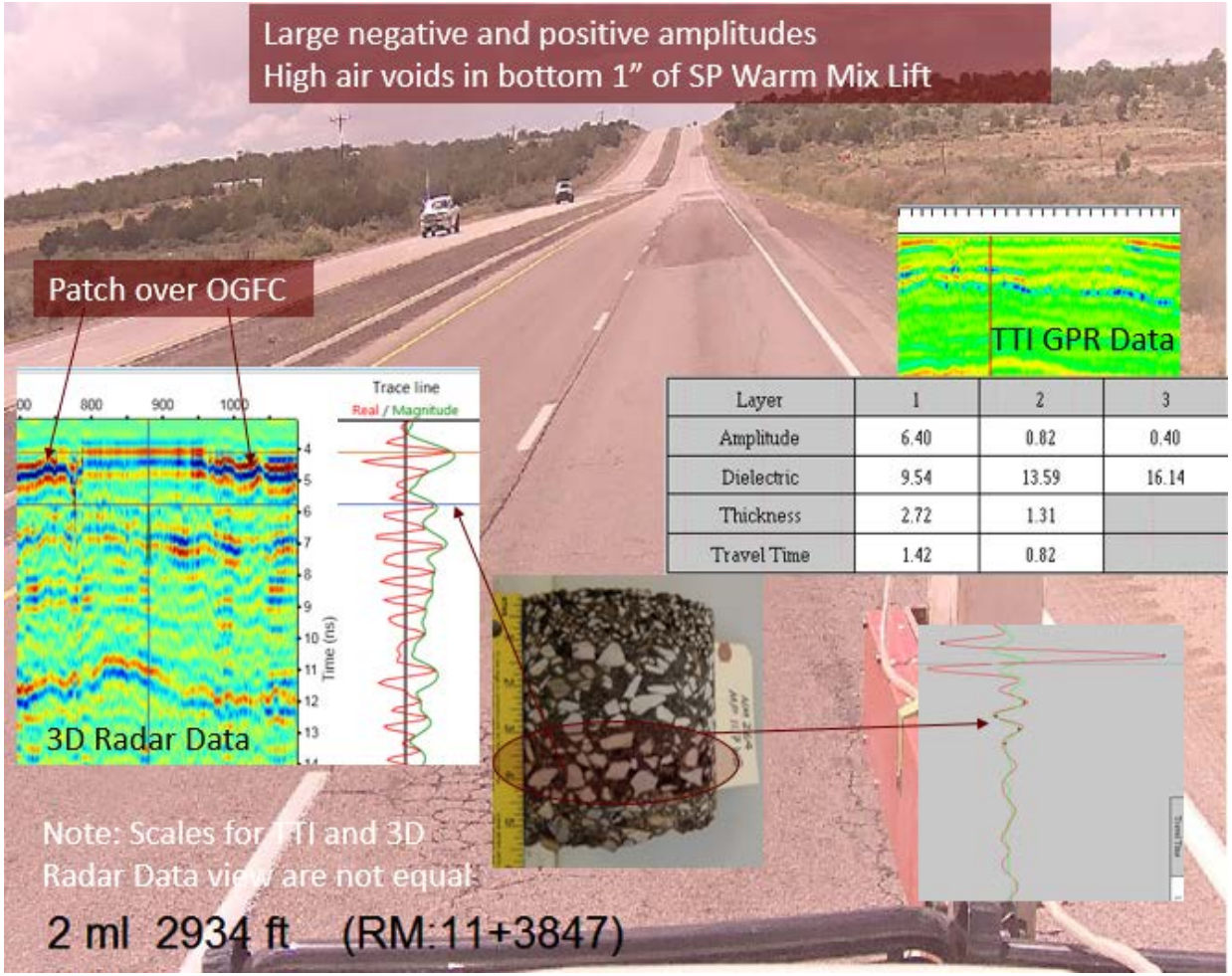
Comparison – District 6



Comparison - District 6

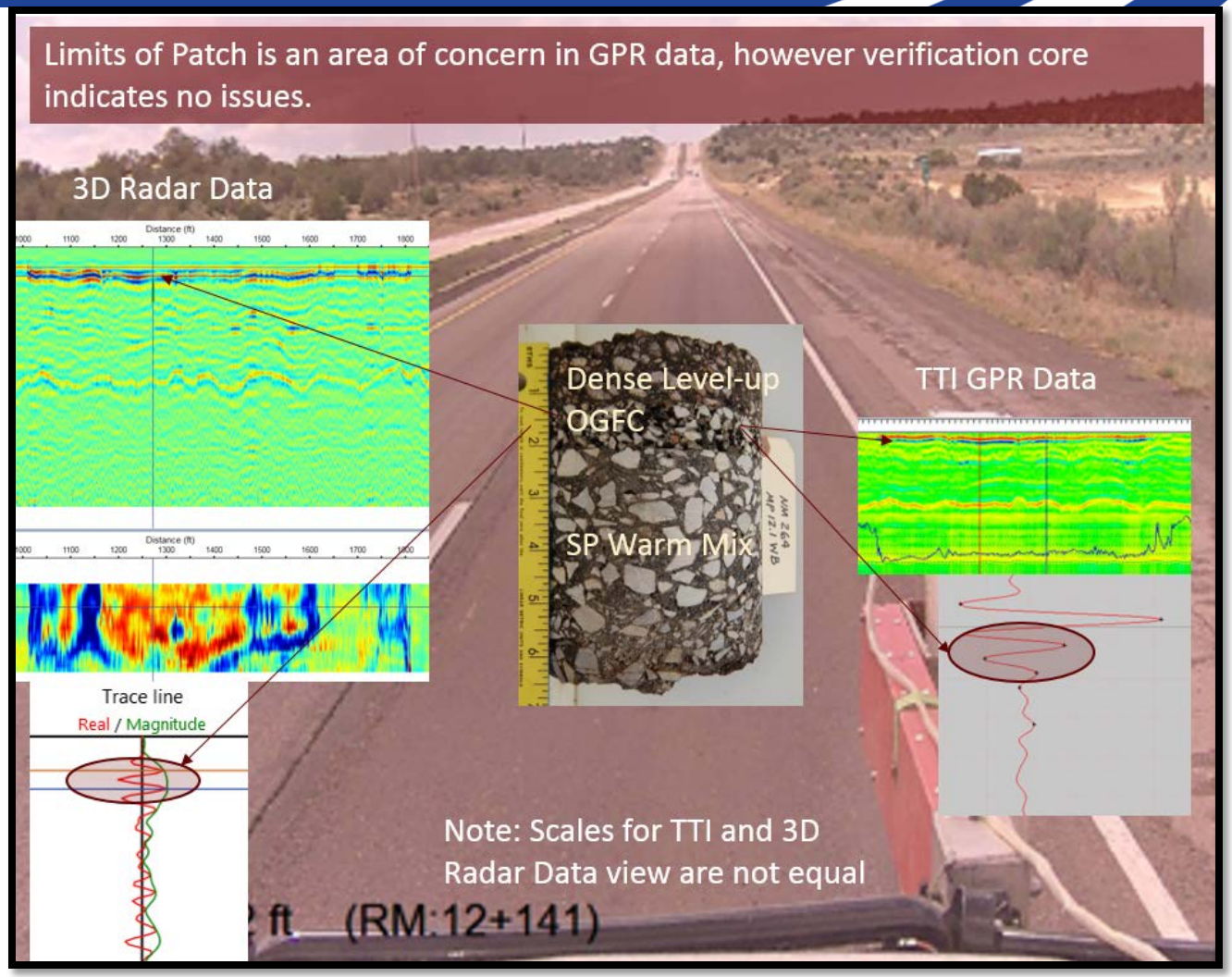


Comparison – District 6

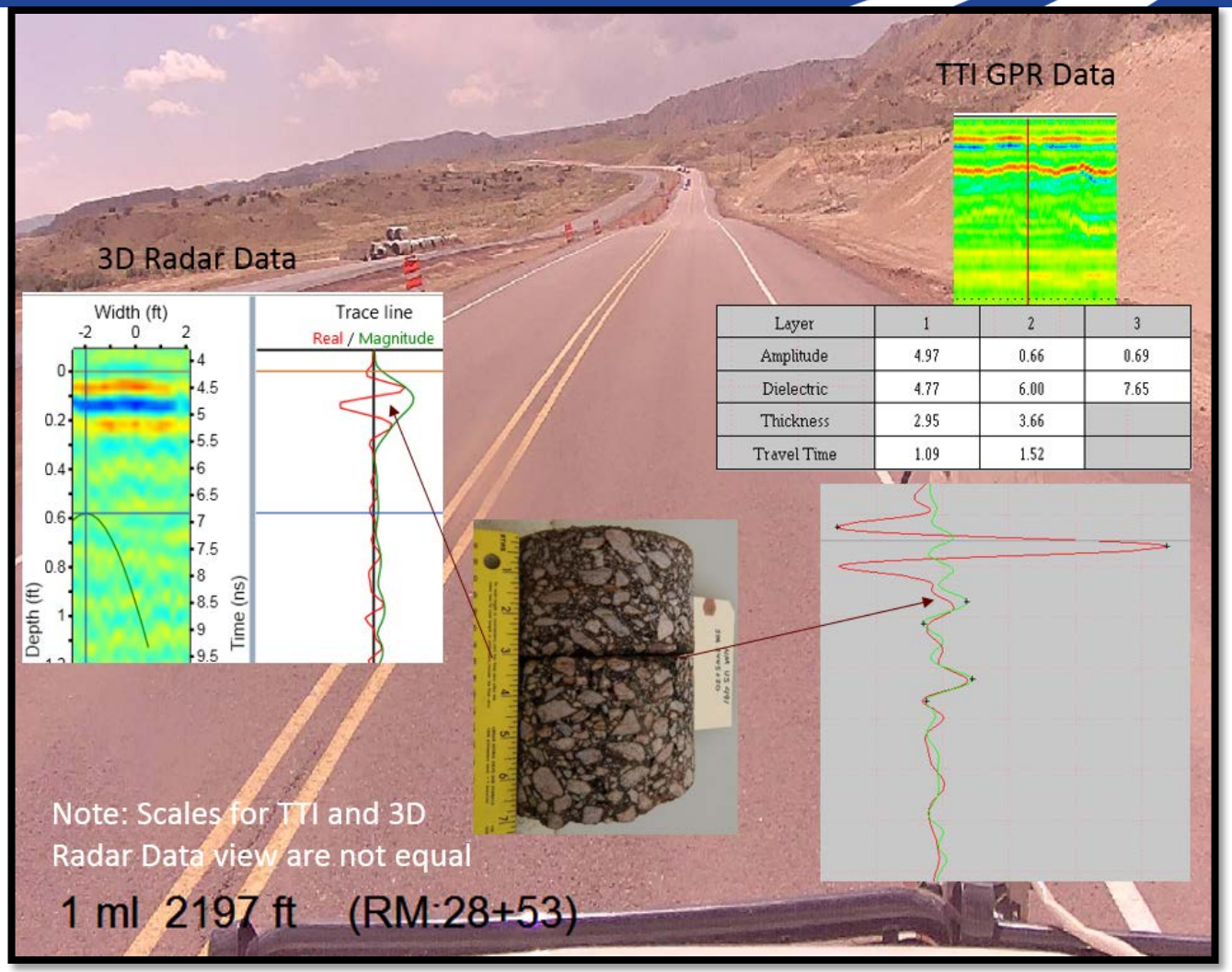


Layer	1	2	3
Amplitude	6.40	0.82	0.40
Dielectric	9.54	13.59	16.14
Thickness	2.72	1.31	
Travel Time	1.42	0.82	

Comparison - District 6

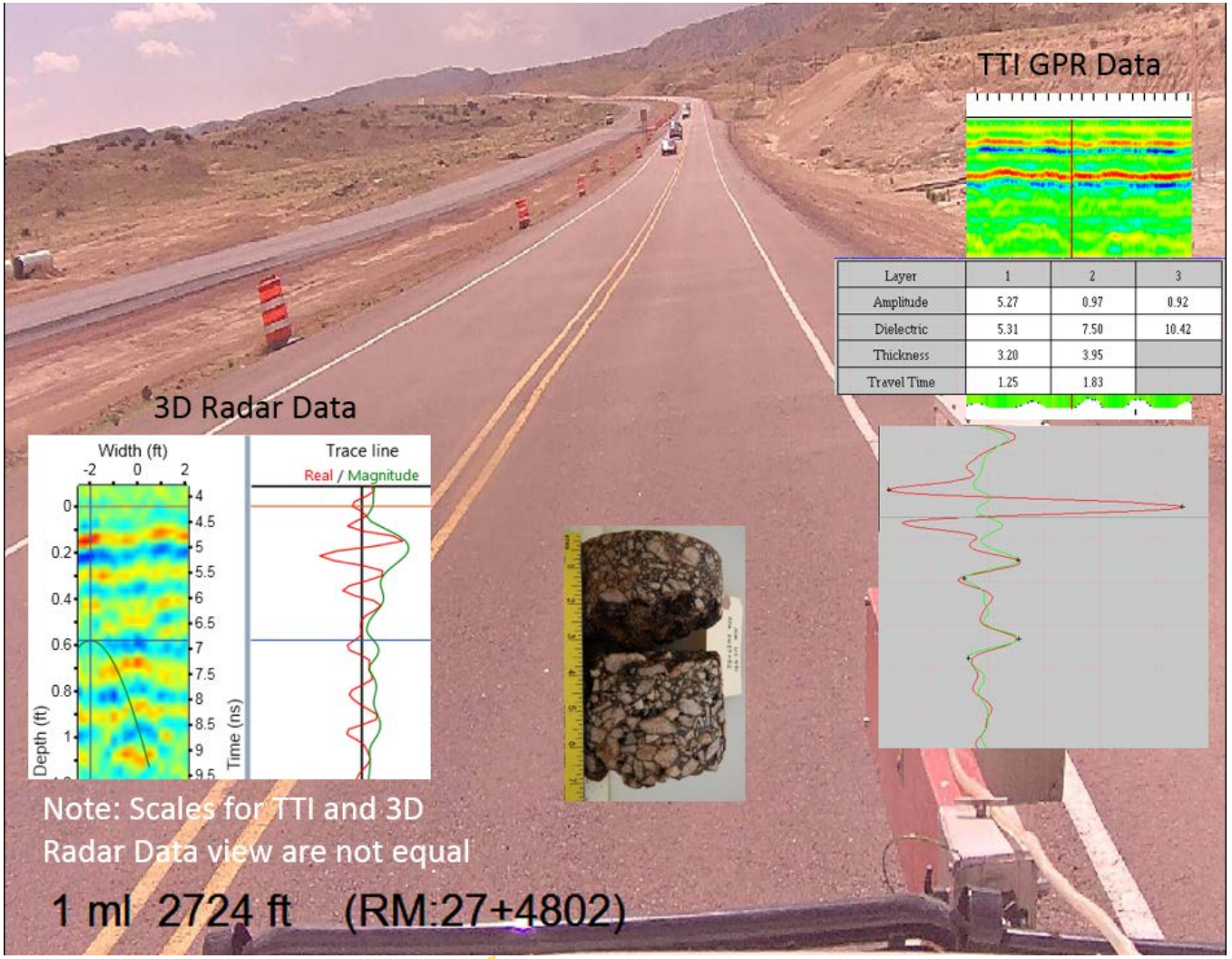


Comparison – District 6

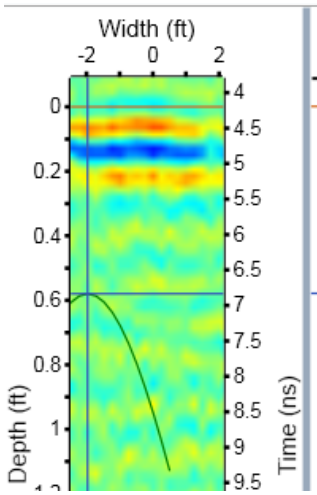


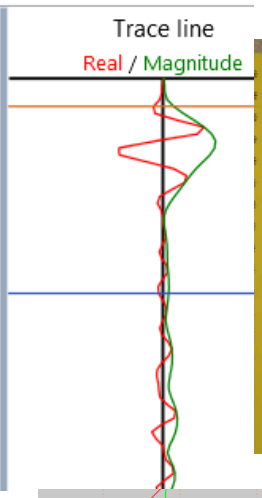
Layer	1	2	3
Amplitude	4.97	0.66	0.69
Dielectric	4.77	6.00	7.65
Thickness	2.95	3.66	
Travel Time	1.09	1.52	

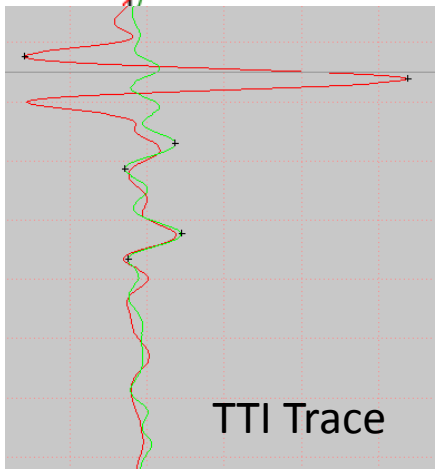
Comparison – District 6

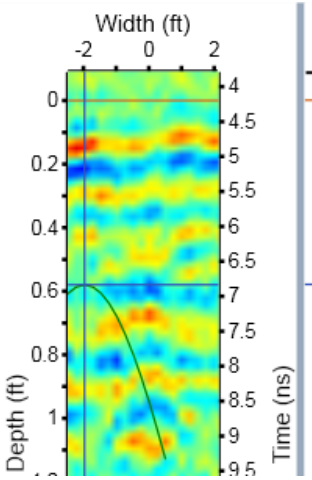


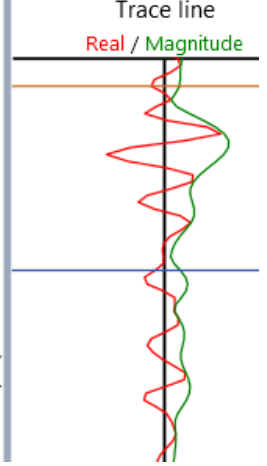
Comparison – District 6

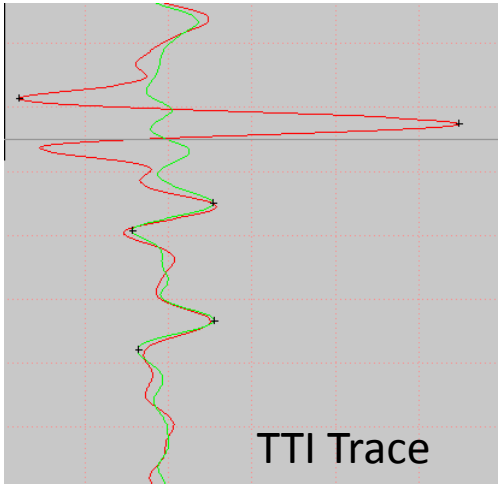




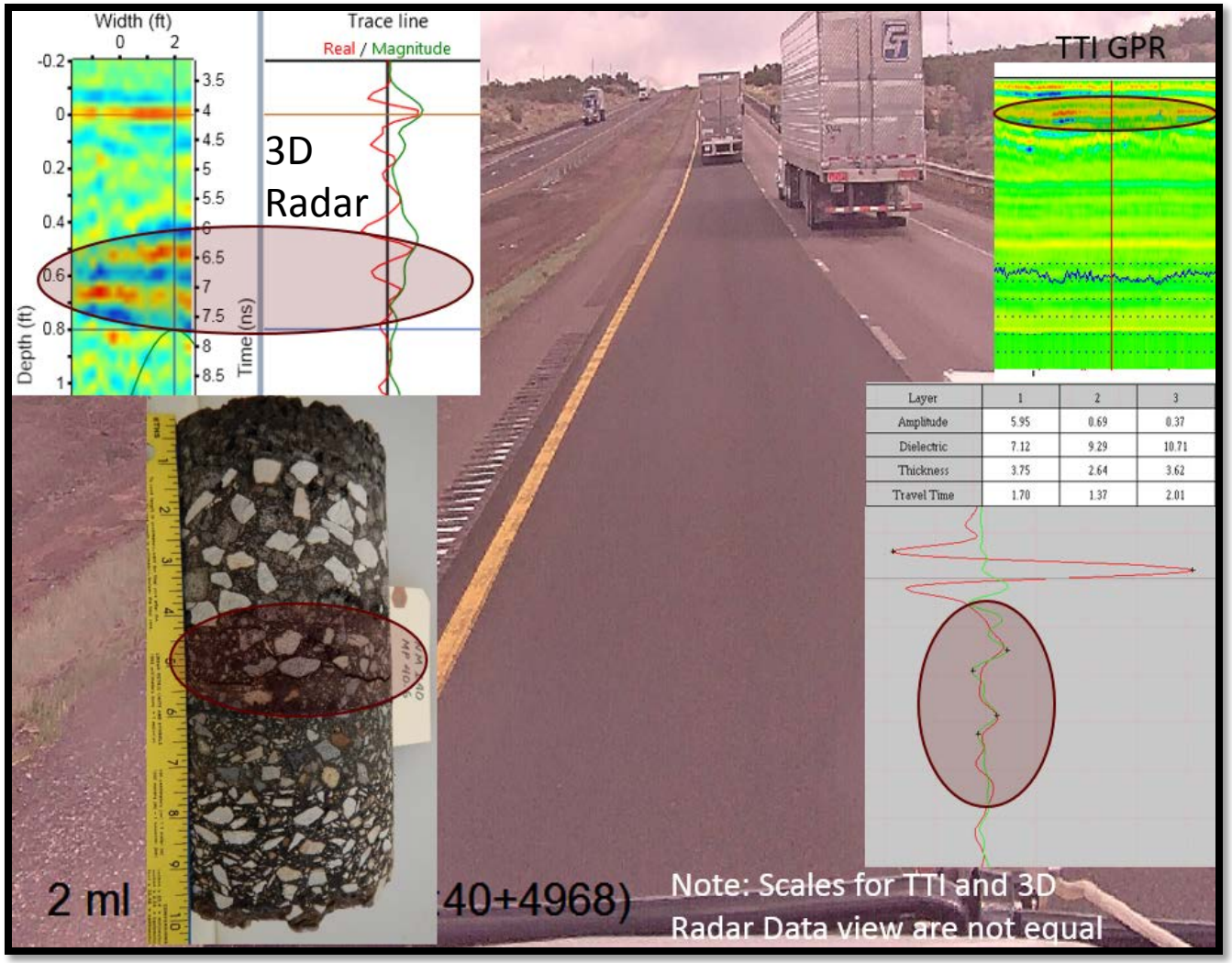




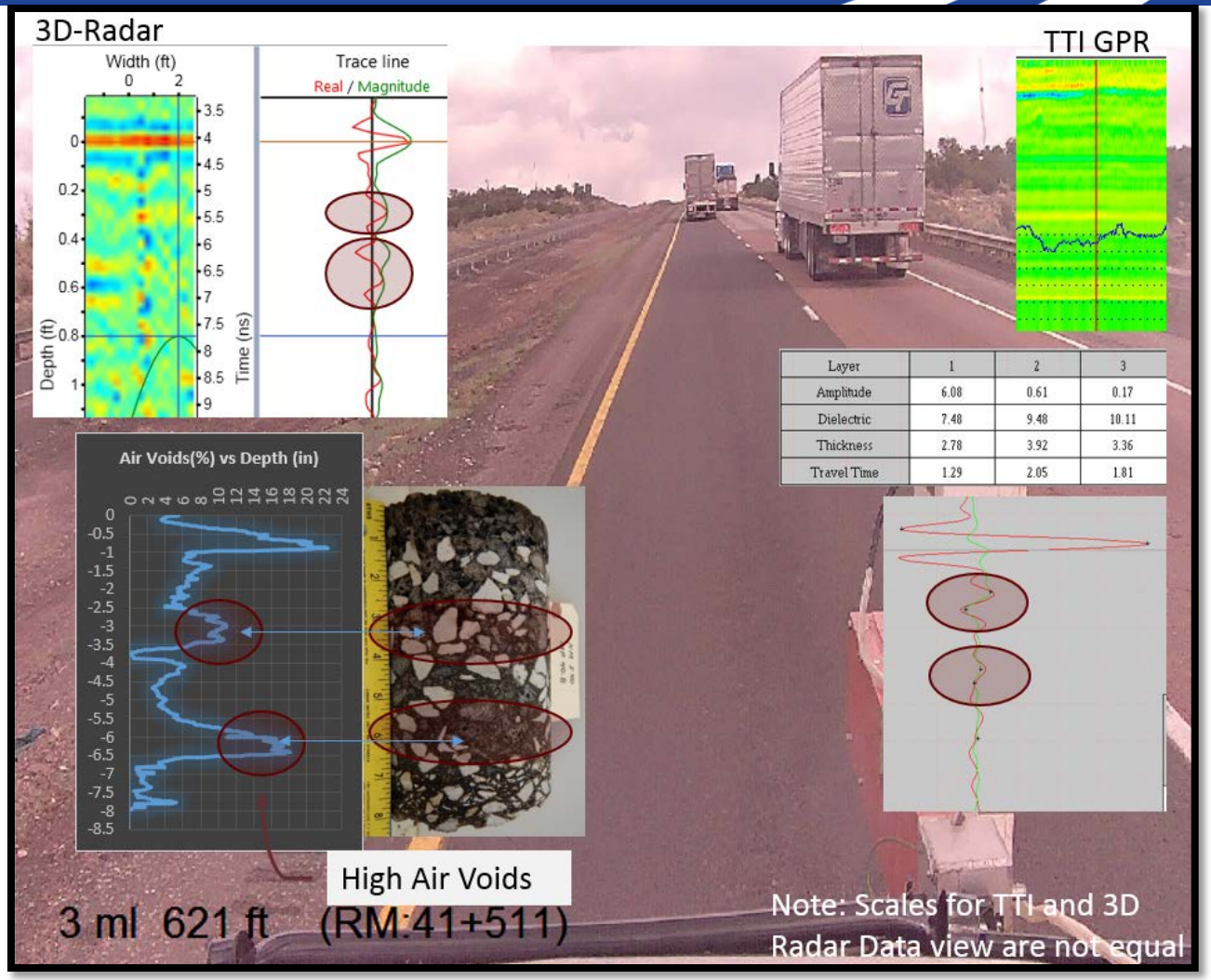




Comparison –District 6

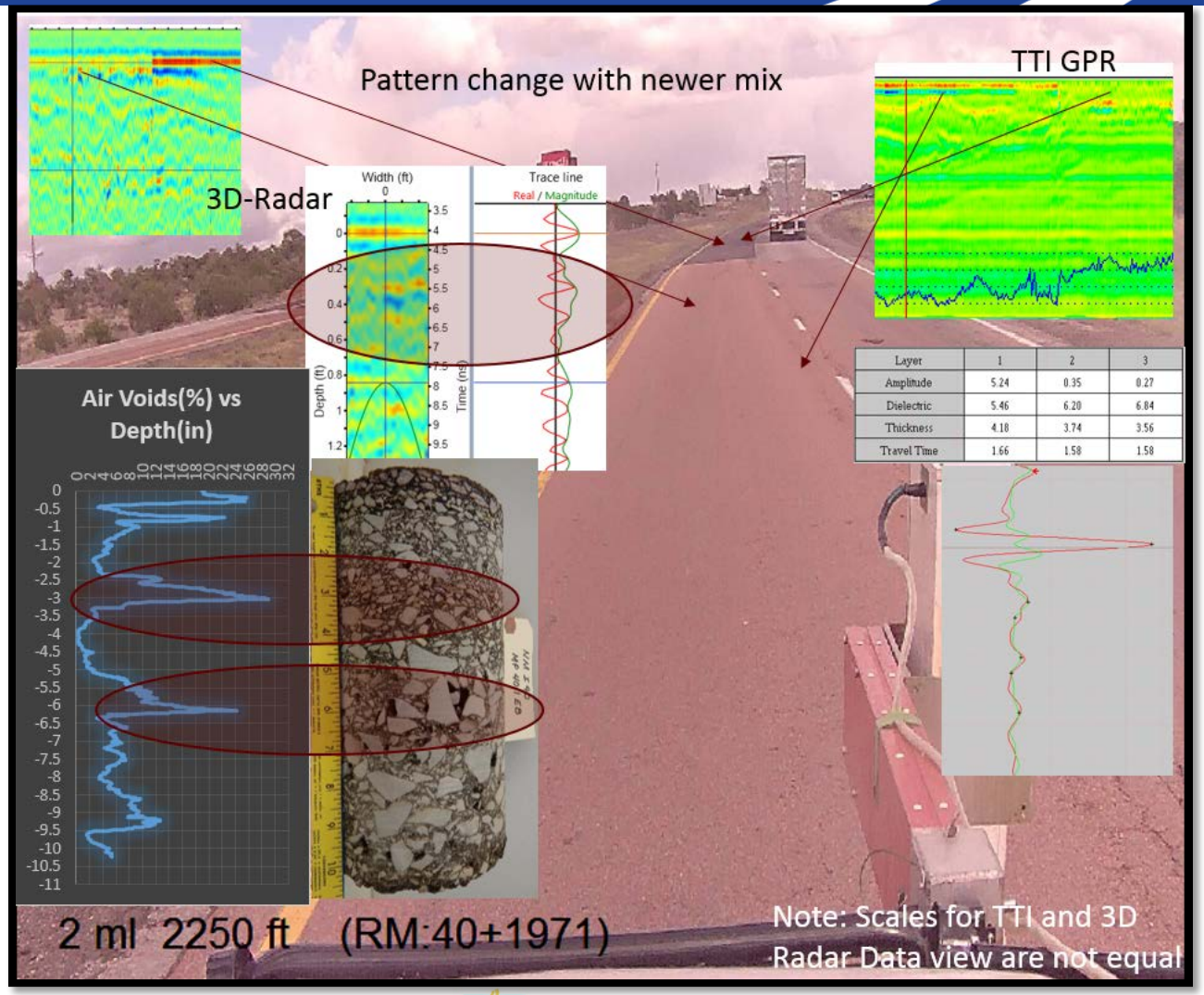


Comparison – District 6

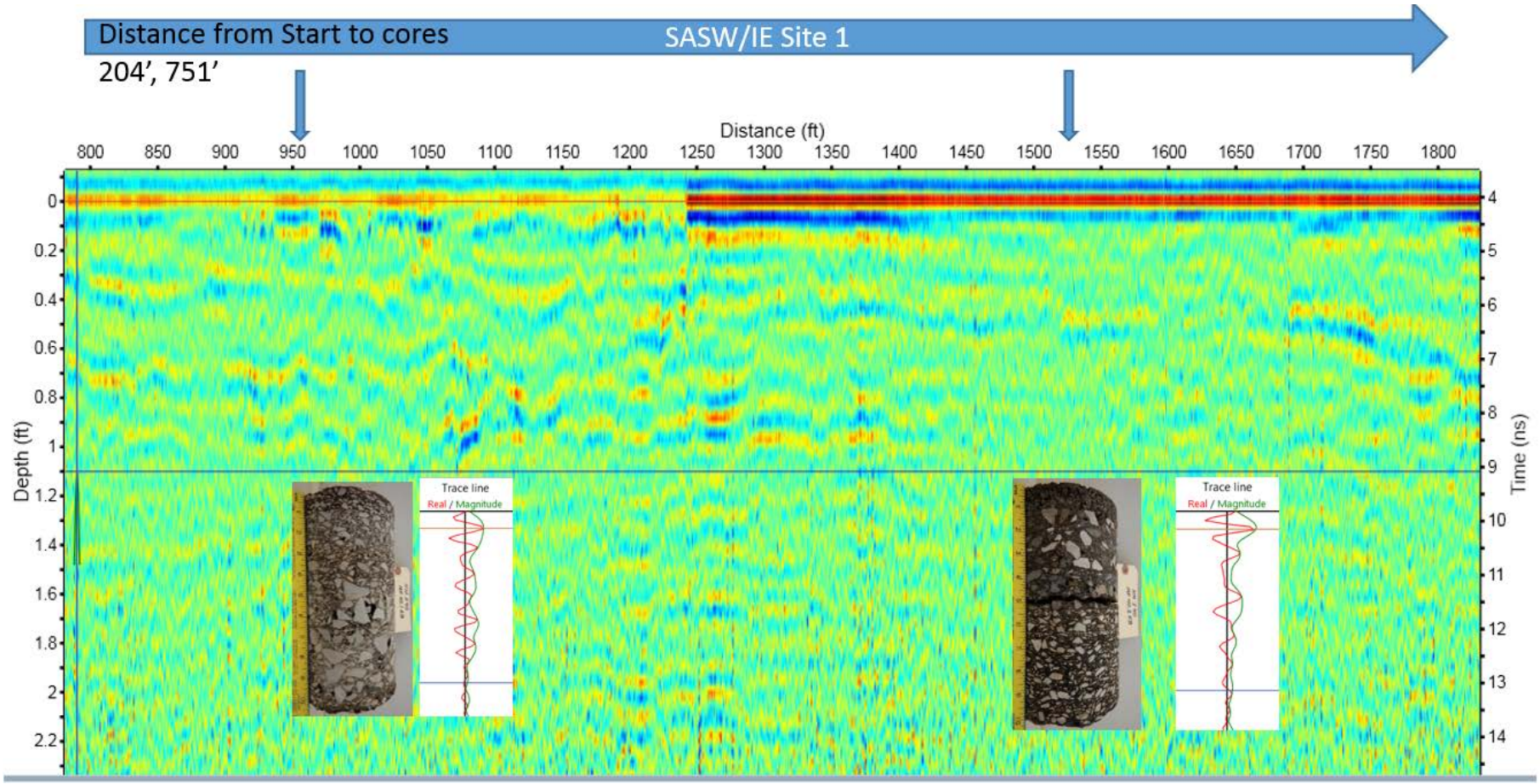


Layer	1	2	3
Amplitude	6.08	0.61	0.17
Dielectric	7.48	9.48	10.11
Thickness	2.78	3.92	3.36
Travel Time	1.29	2.05	1.81

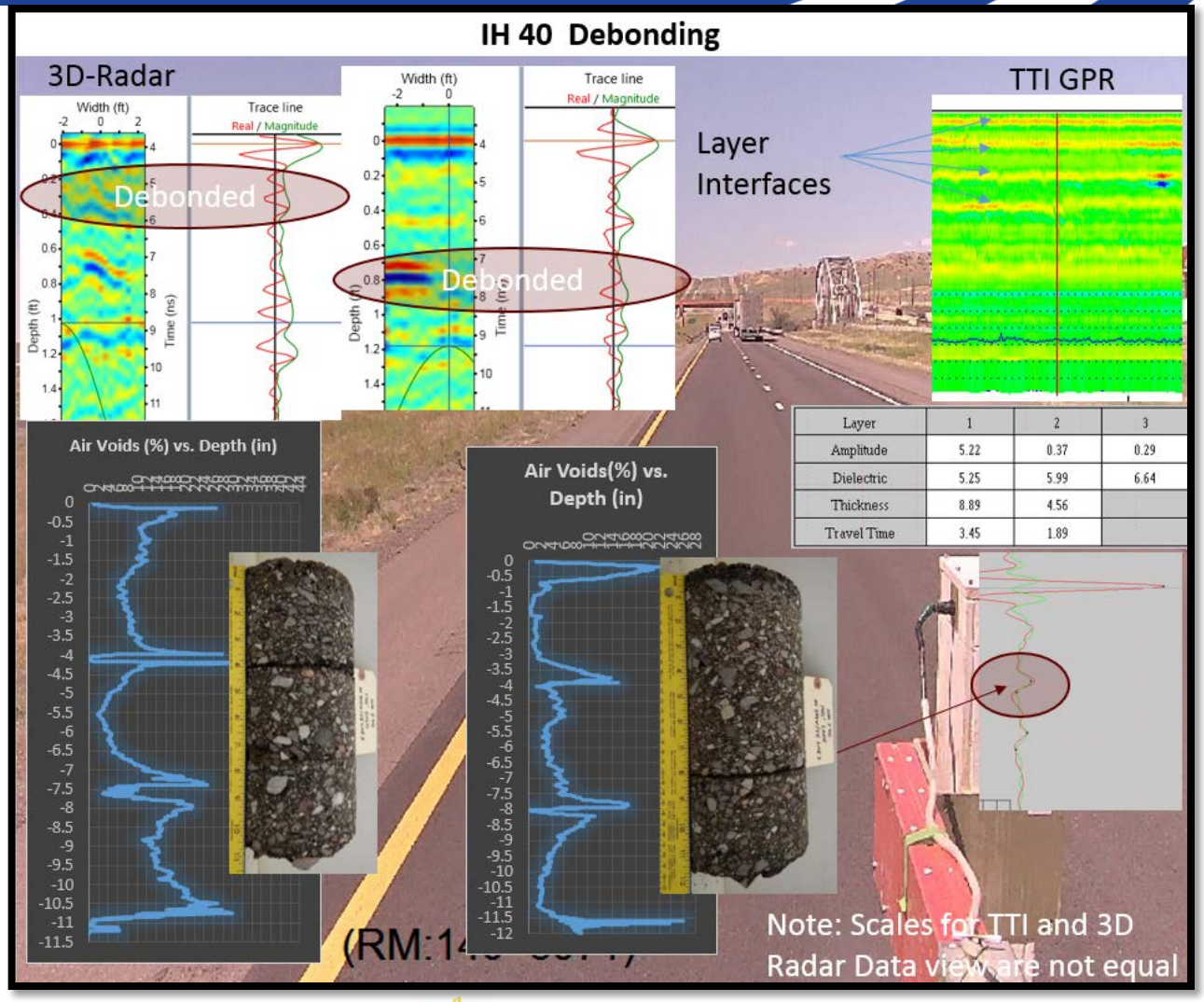
Comparison – District 6



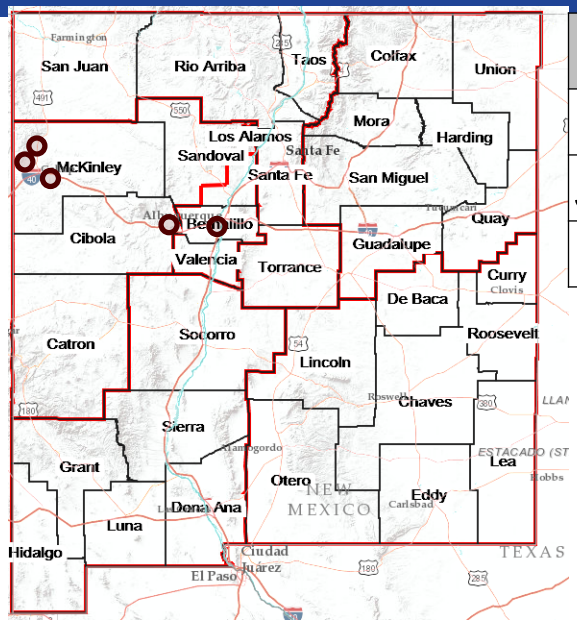
Comparison – District 6



Comparison – I40 District 3



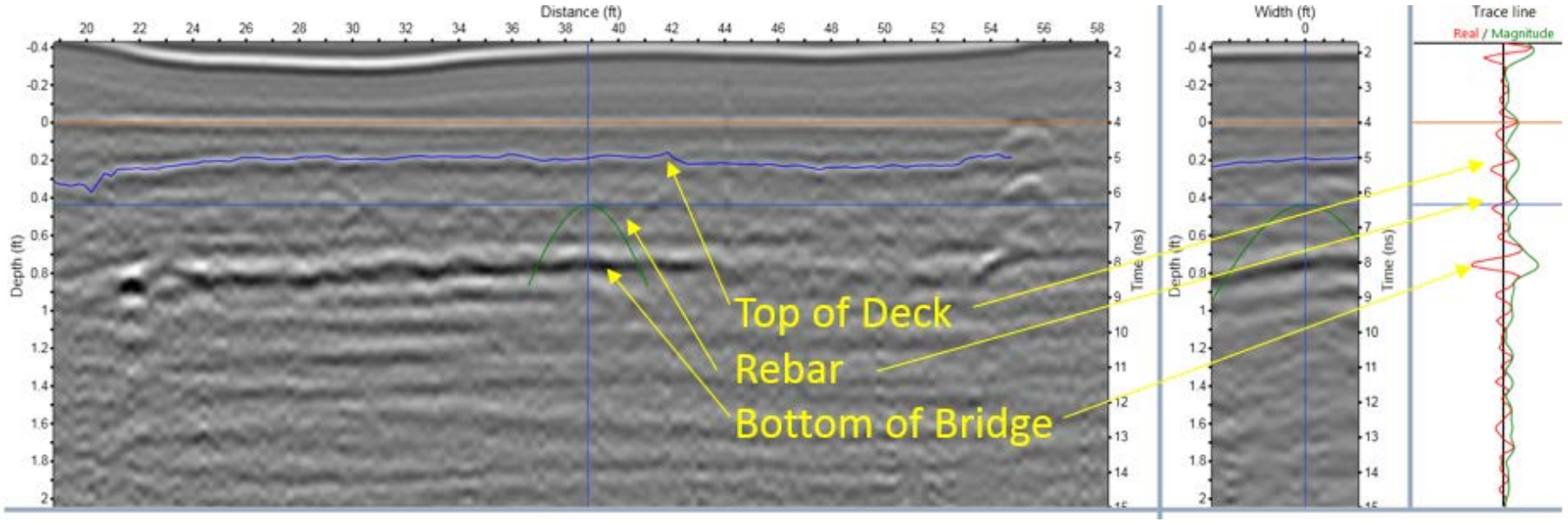
GPR Test Locations – Other
New Mexico



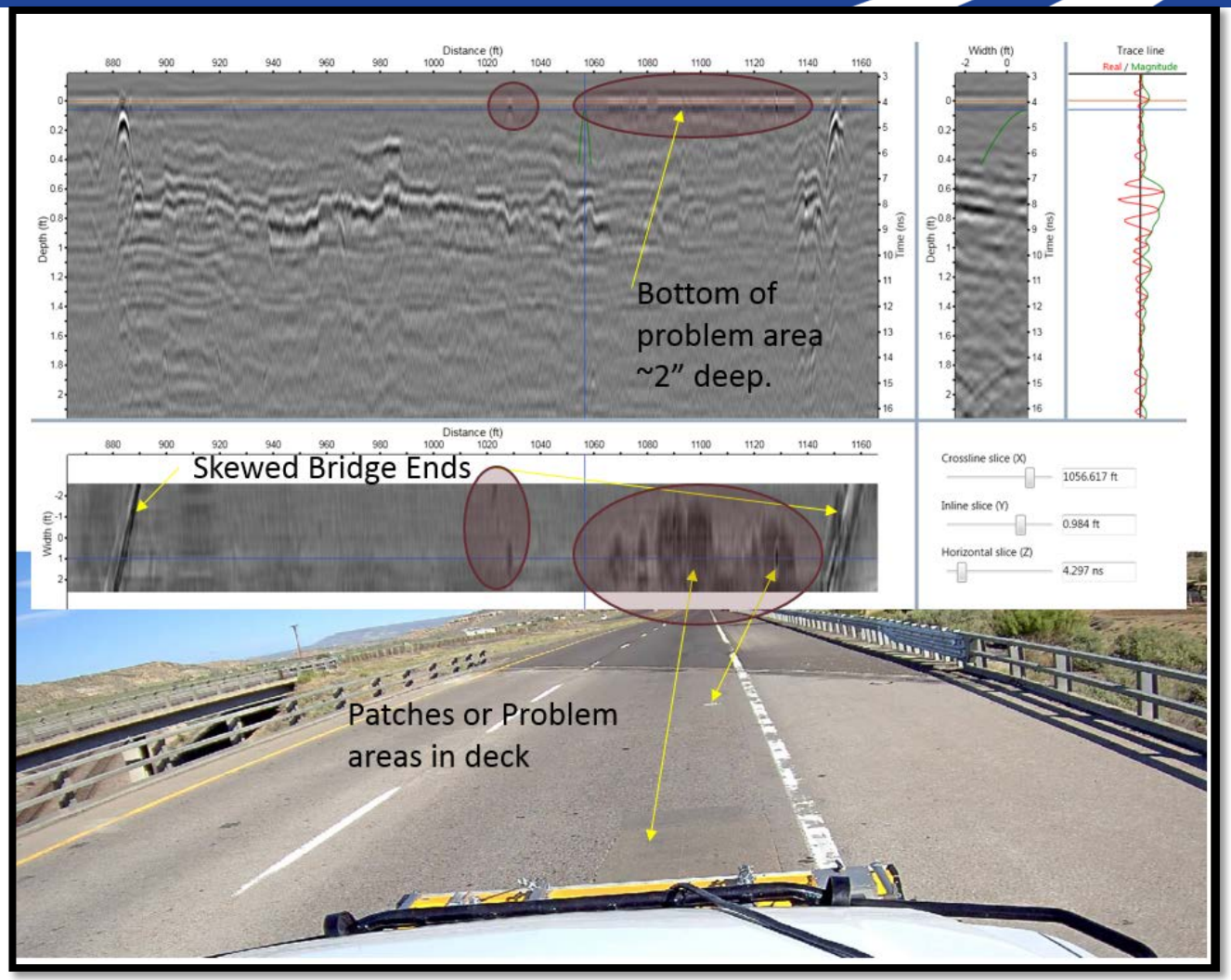
HWY	MP	MP	Comments
I-40	16	18	Conc – 4 lane
Jefferson Ave.	Metro Ave.	US491	Concrete
I-40	Ramps at Louisiana		Concrete

Bridge	Rdwy	Feature Intersected
9040	NM-309	BNSF Railroad
9013	61-Z000	Belen Highline Canal
6489	I-40 WBL	BNSF RAILROAD
8678	FR-4004	I-40 EBLS/WBLS @mp 39.9
6362	I-40 EBL	BNSF Railroad Spur
7157	NM-566	Rio Puerco/BNSF R/R
7158	NM-566	RIO PUERCO (NORTH FORK)

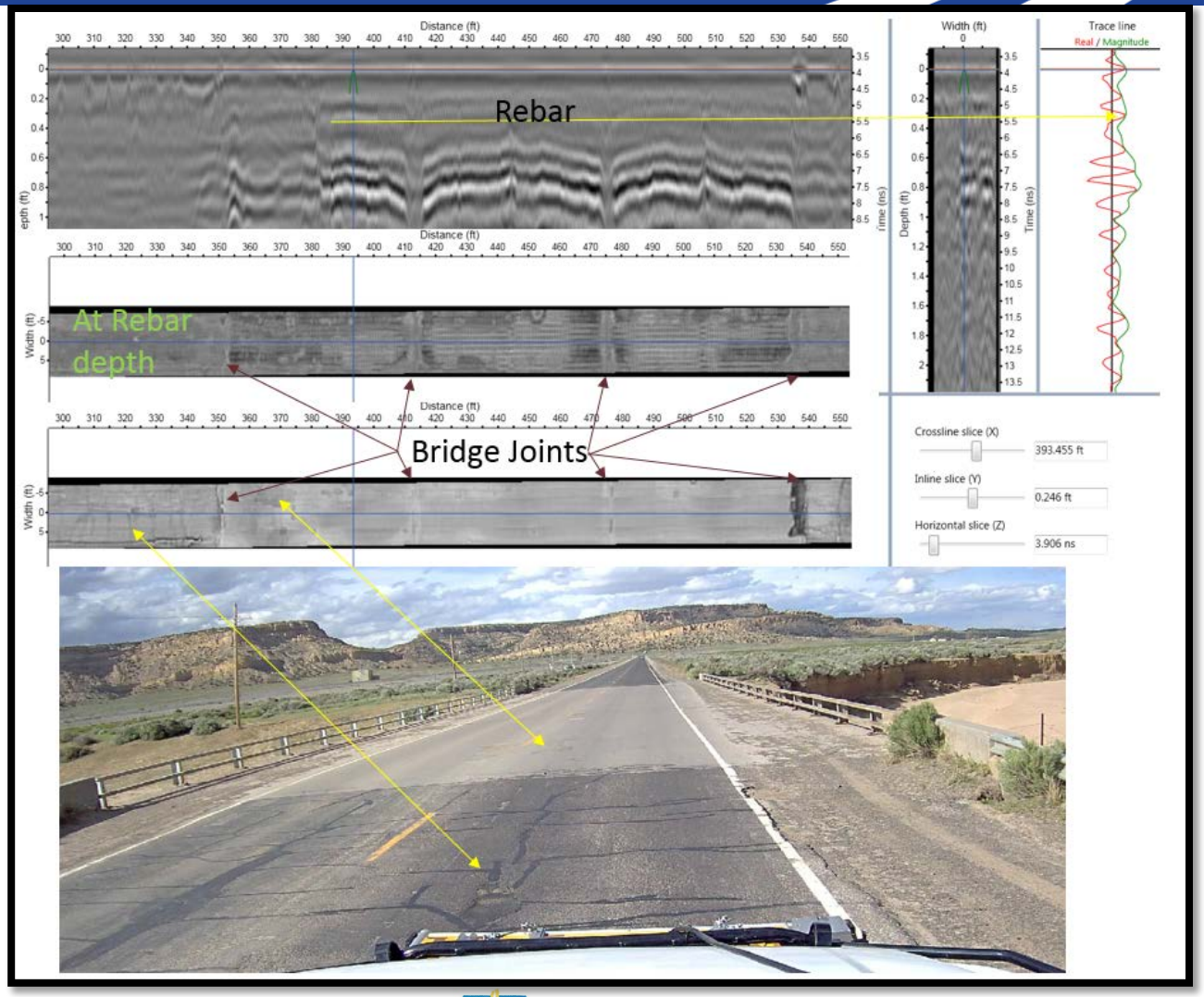
Bridge with Overlay



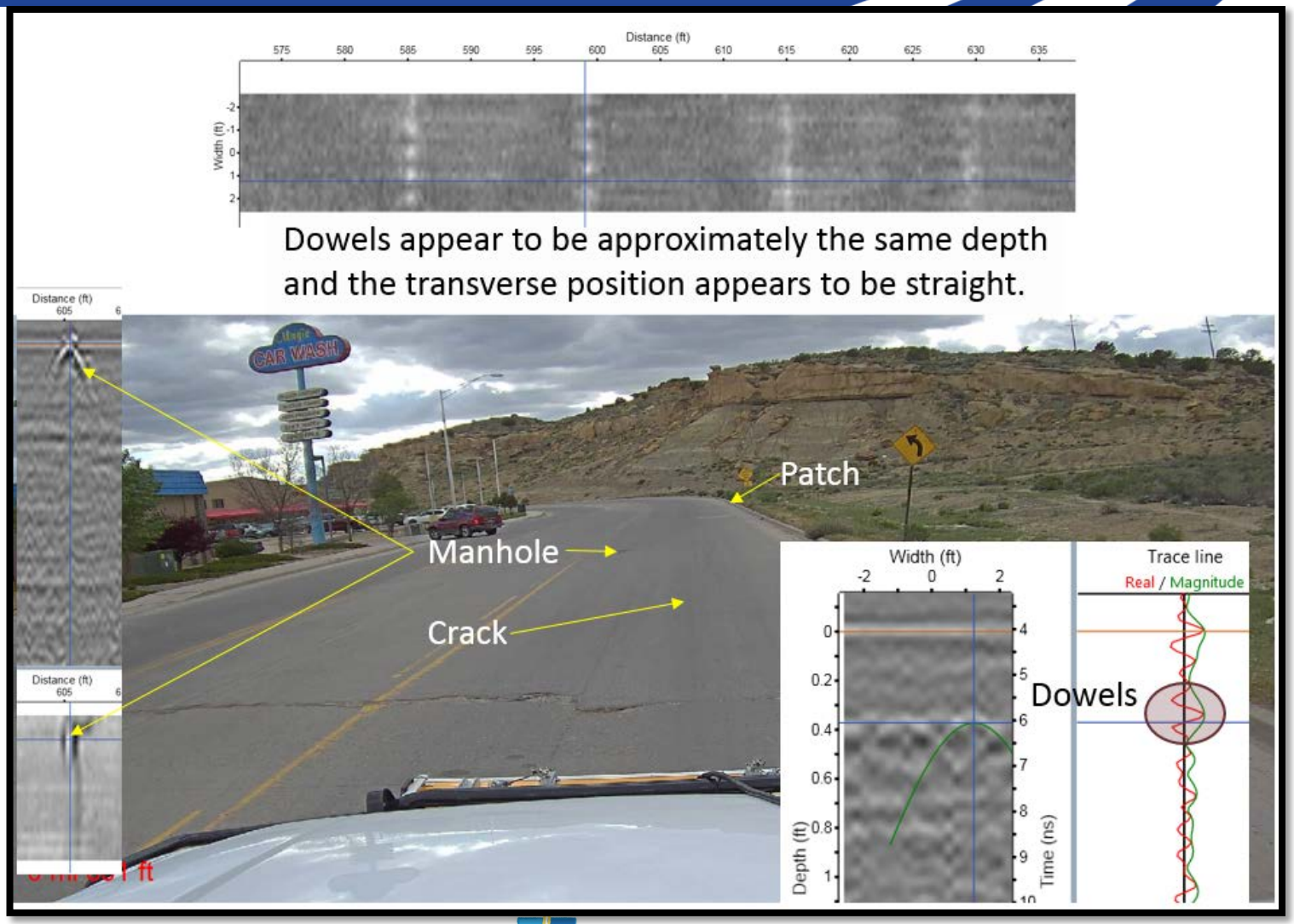
Bridge with Patching



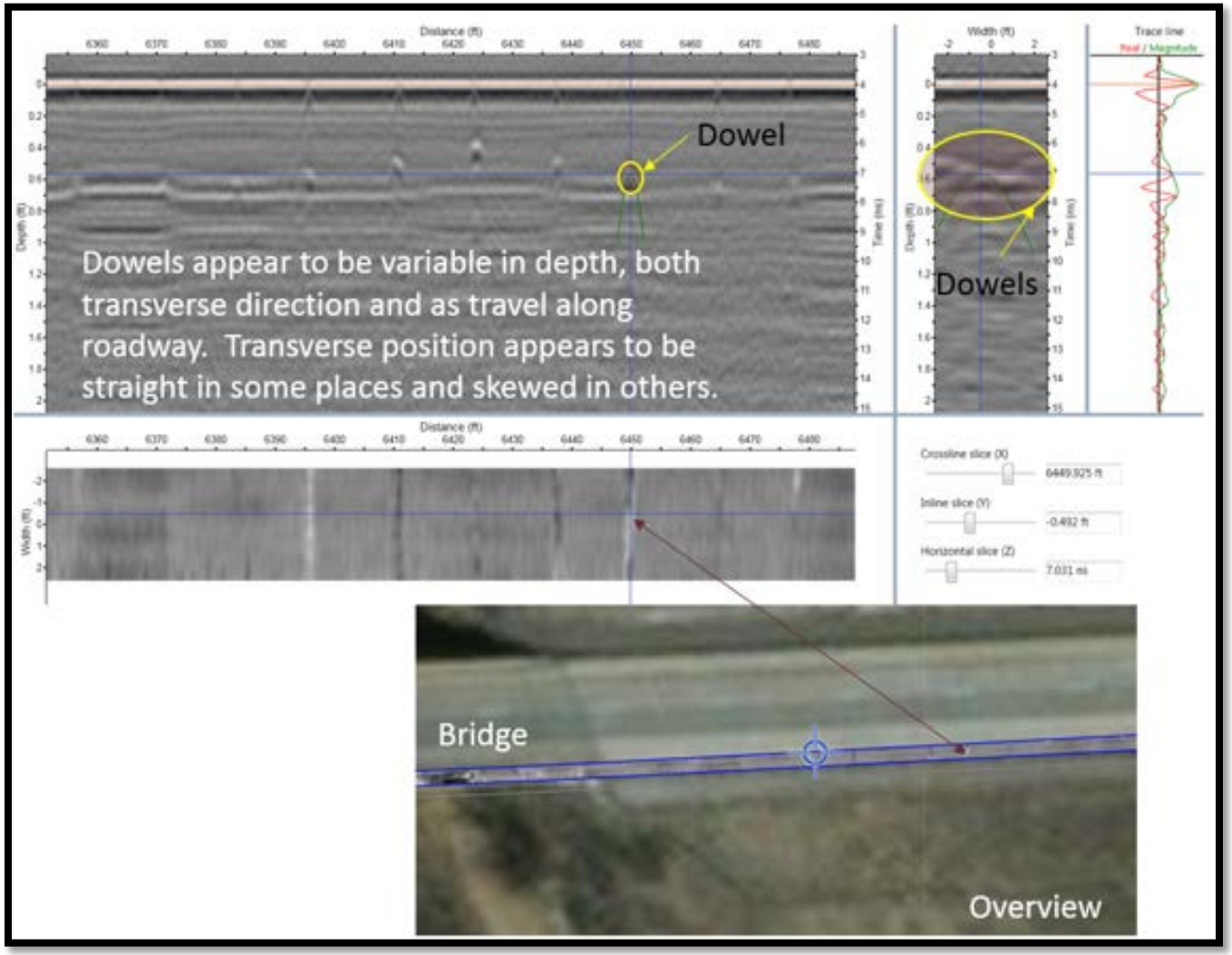
Bridge


Distance (ft)
Rebar
Width (ft)
Trace line
Real / Magnitude
Depth (ft)
Time (ns)
At Rebar depth
Bridge Joints
Crossline slice (X)
393.455 ft
Inline slice (Y)
0.246 ft
Horizontal slice (Z)
3.906 ns

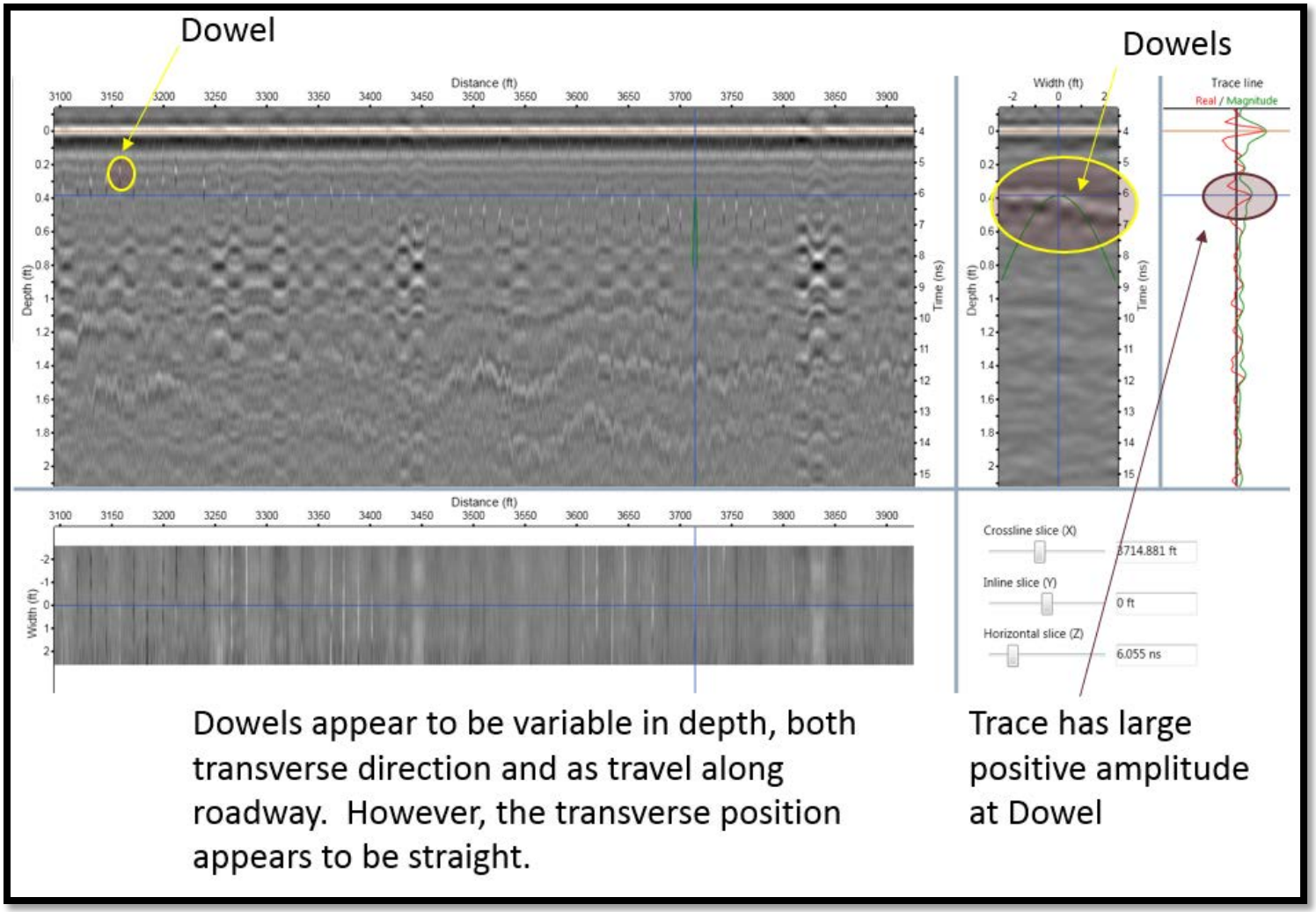
Concrete Pavement



Concrete Pavement



Concrete Pavement



Dowels appear to be variable in depth, both transverse direction and as travel along roadway. However, the transverse position appears to be straight.

Trace has large positive amplitude at Dowel

Conclusions - Concrete Pavement

Some potential uses to help with the forensic evaluation of concrete pavement are:

- Thickness of pavement. In some cases, the bottom of the concrete can be found.
- Analyze orientation of Dowel Baskets or Dowels
  - Skewed
  - Level
  - Depth
    - both transversely and as travel down the roadway.

Conclusions - Bridges

Some potential uses of this data to help with the forensic evaluation of bridge decks are:

- Depth of Bridge Deck overlay.
- Depth to Rebar.
- Find limits of surface irregularities
  - this was not able to be done on all bridges.
- Locations for Begin/End of Bridge and bottom of bridge deck.

Conclusions - Flexible Pavement

- In general the patterns follow the patterns we expect based on past experience.
  - The false patterns encountered, help justify the need to take verification cores.
- It is very difficult to distinguish between severity of deterioration/delamination.
  - While the patterns are similar, severe stripping tends to have much larger amplitude.

Recommendations

- Improve data storage efficiency for collection
- Examiner Software
  - Integrate video/images
  - Calculate dielectric and
  - Calculate layer thickness based on calculated dielectrics
- Continue to evaluate the 3D Radar System