SHRP2 SOLUTIONS
TOOLS FOR THE ROAD AHEAD

Minnesota Experience with GPR Based Rolling Density Meter

Shongtao Dai, MnDOT

Kyle Hoegh, MnDOT

Curt Turgeon, MnDOT

U.S. Department of Transportation
Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO

Acknowledgements

- FHWA/AASHTO – Steve Cooper
- GSSI
- TTI
- MnDOT district materials and constructions

Why MnDOT is interested in?

- MnDOT Uses Cores Density for Acceptance
  - Need a tool for continuous assessment: RDM
- Longitudinal Joint deterioration
- Paver Mounted Thermal Profiling
- Intelligent Compaction
- RDM in 2015 with Maine and Nebraska

MnDOT Equipment

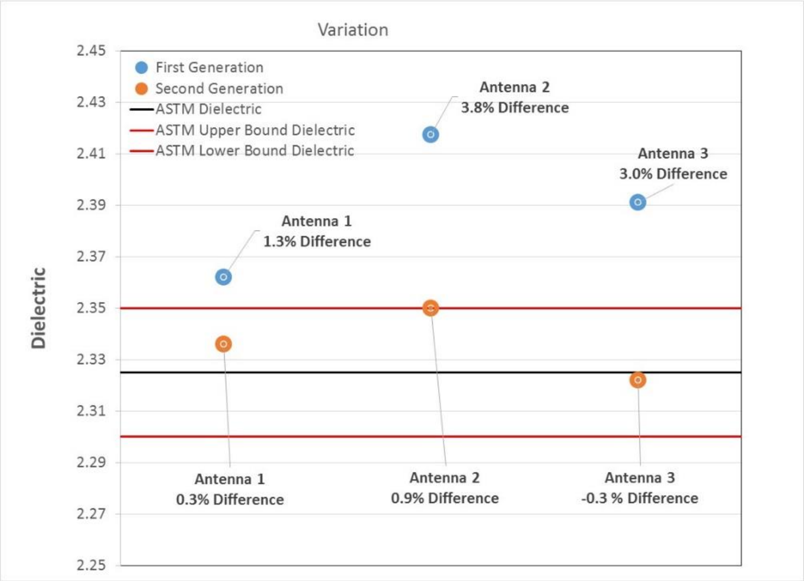
- Push Cart Type RDM

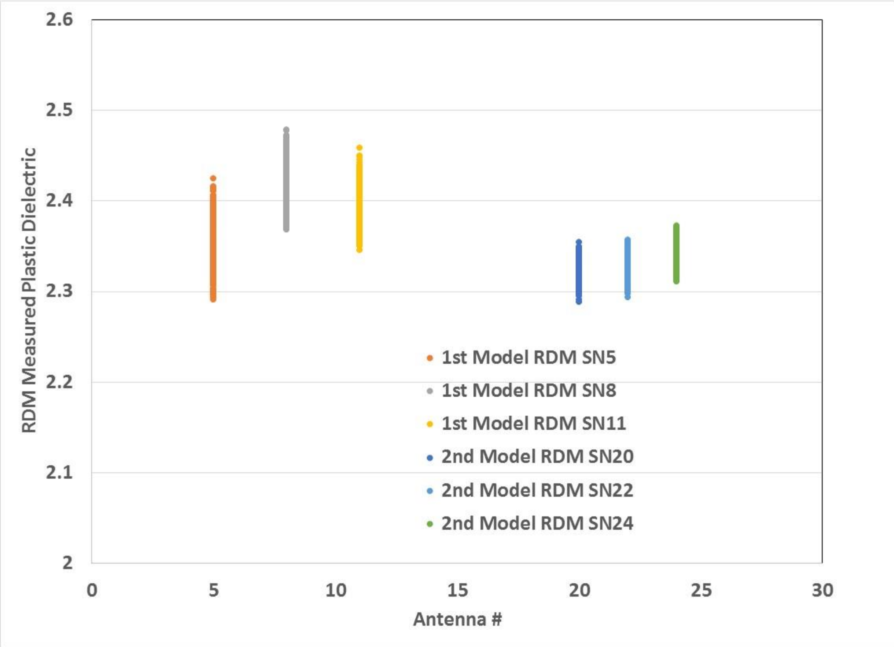
- Vehicle Mounted RDM

Equipment Calibration

- High Density Polyethylene (HDPE)
  - Reported dielectric: 2.3-2.35

$$\varepsilon_{HMA} = \left(\frac{1 + \frac{A_0}{A_P}}{1 - \frac{A_0}{A_P}} \right)^2$$

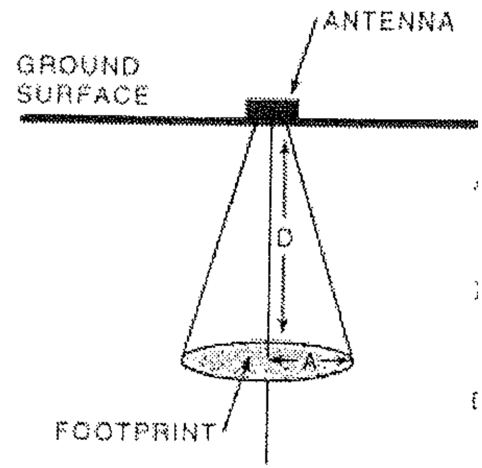


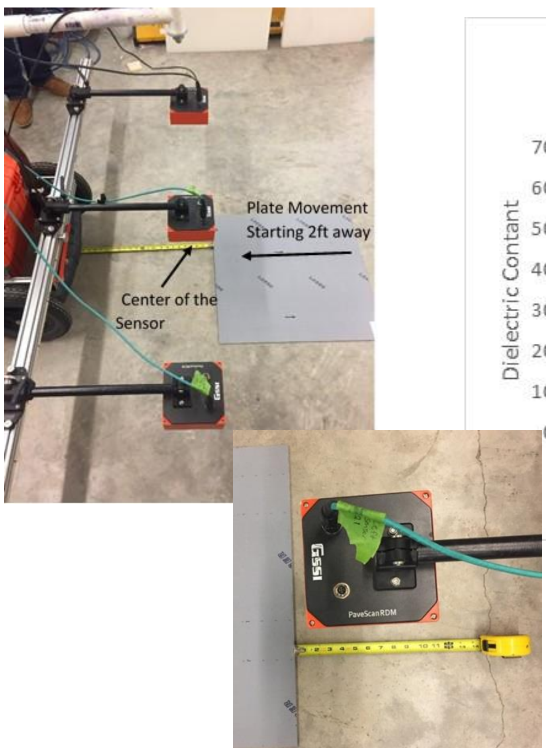


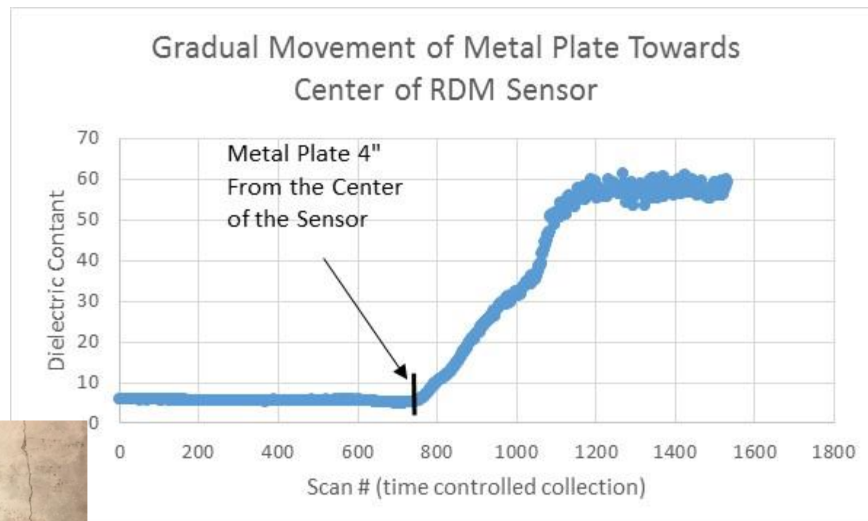
Footprint area of an antenna (Fresnel Zone)?

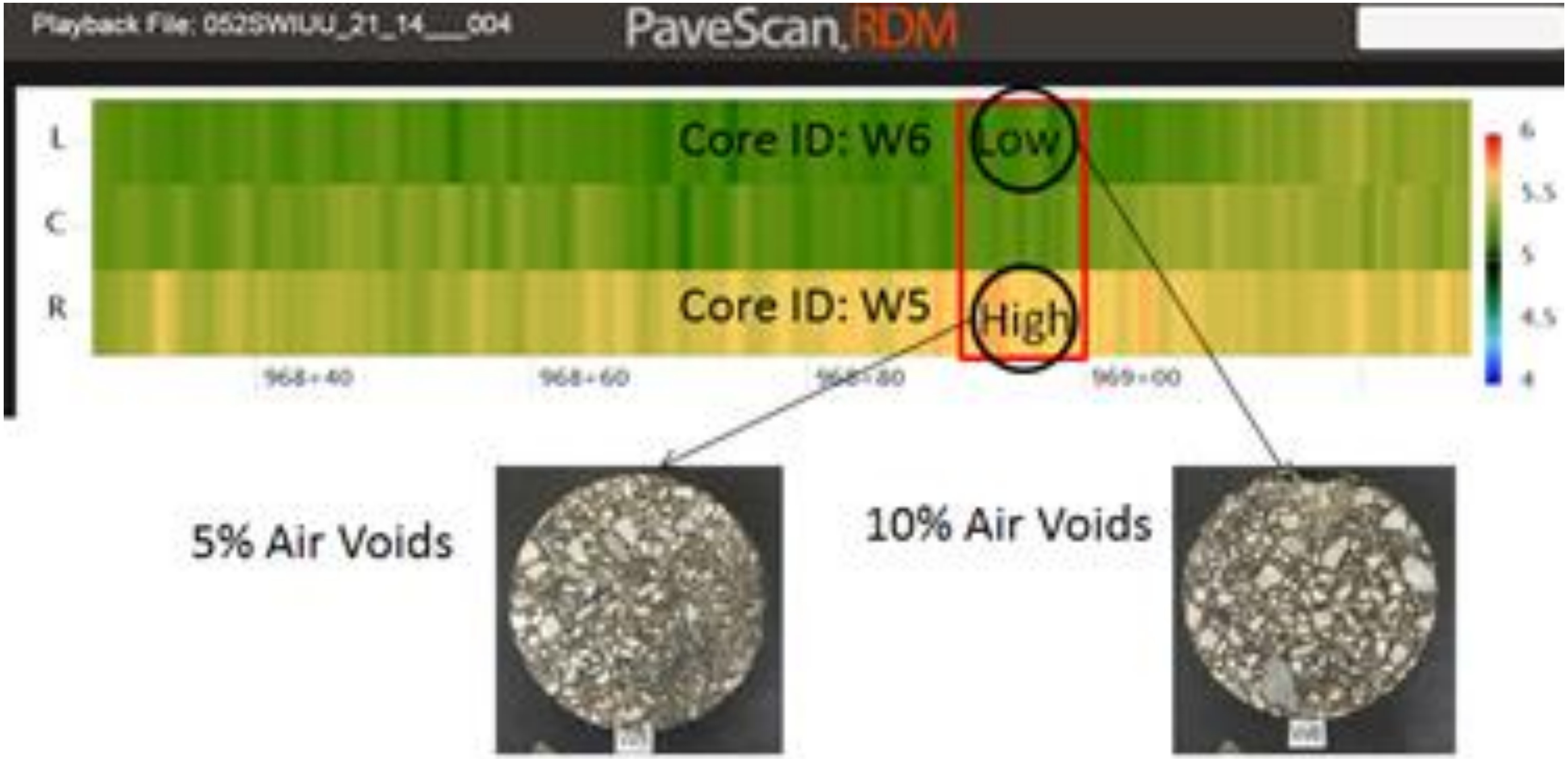
$$Fr \sim 0.5\ v\ (tr/fc)^{1/2}$$

D=12”, Fr (Radius) ~ 3.6” (for 2.7Ghz-RDM)



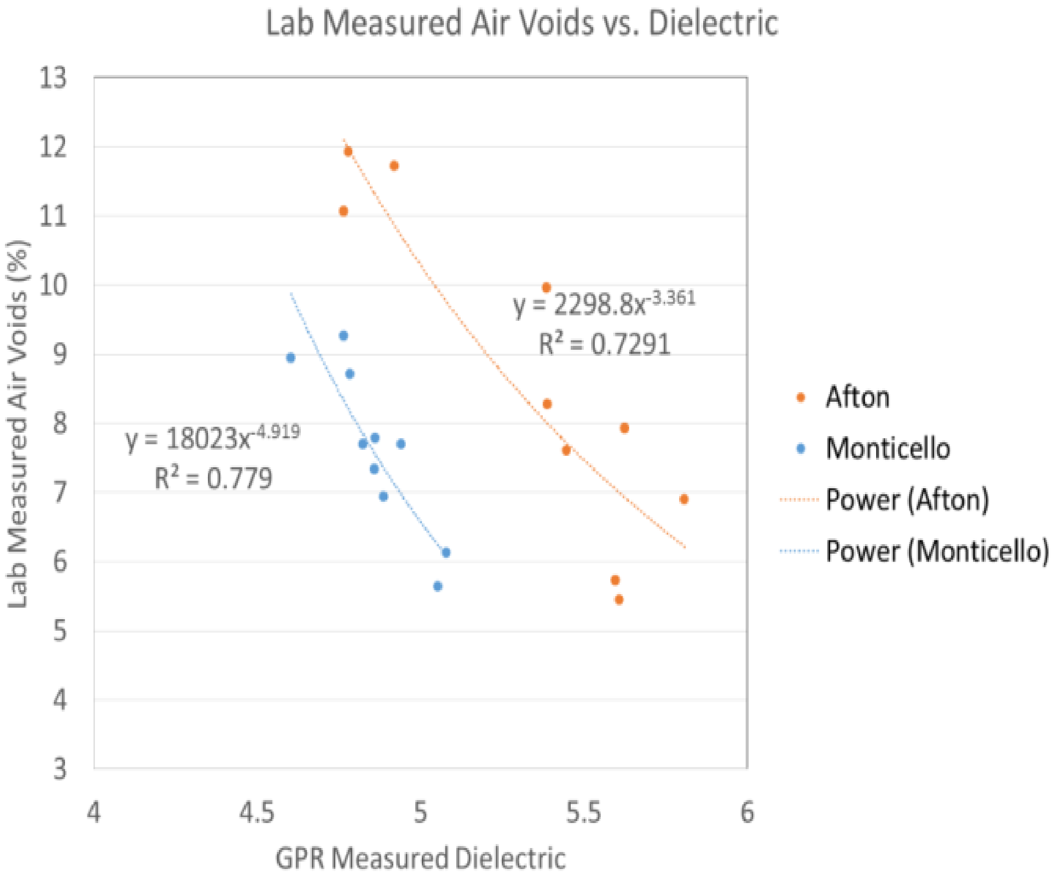






Playback File: 052SWIUU_21_14___004
PaveScan RDM
L
C
R
Core ID: W6
Low
Core ID: W5
High
968+40
968+60
968+80
969+00
6
5.5
5
4.5
4
5% Air Voids
10% Air Voids

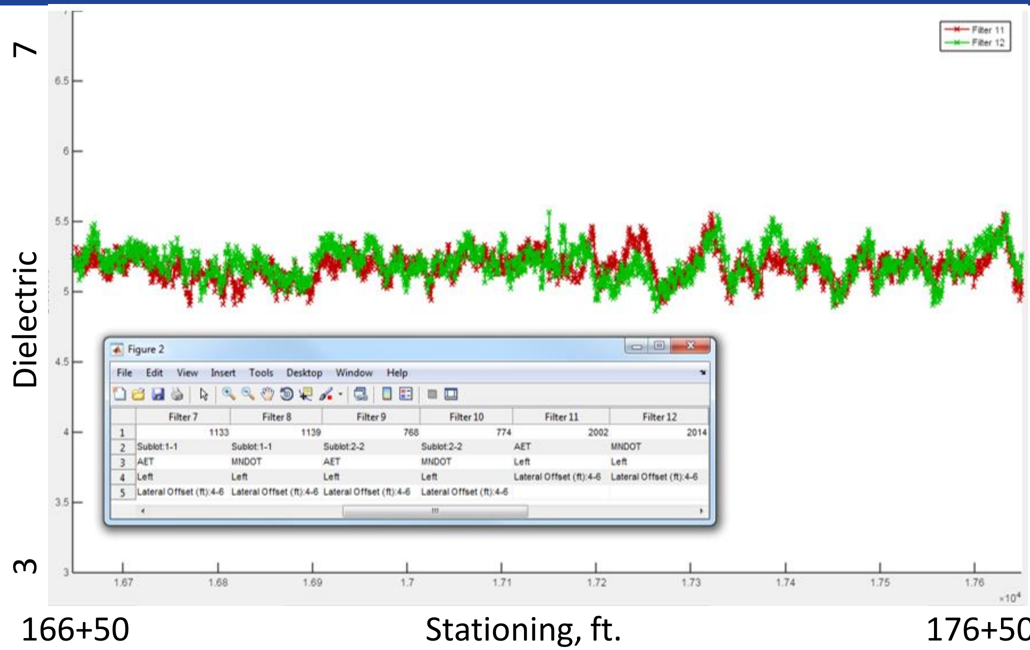
RDM Principal



- **Mainline Survey: multiple passes**

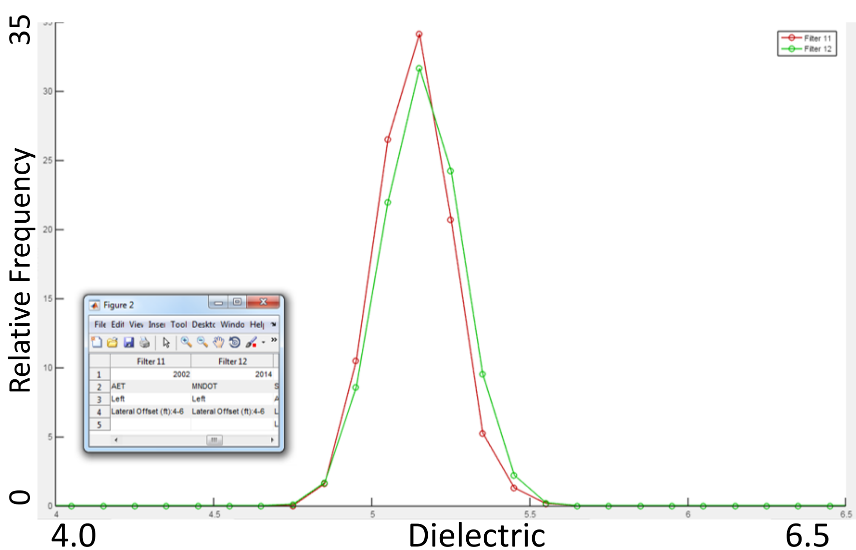
- **Joint Survey: one antenna close to joint**

Summary Field Use - Equipment Validation



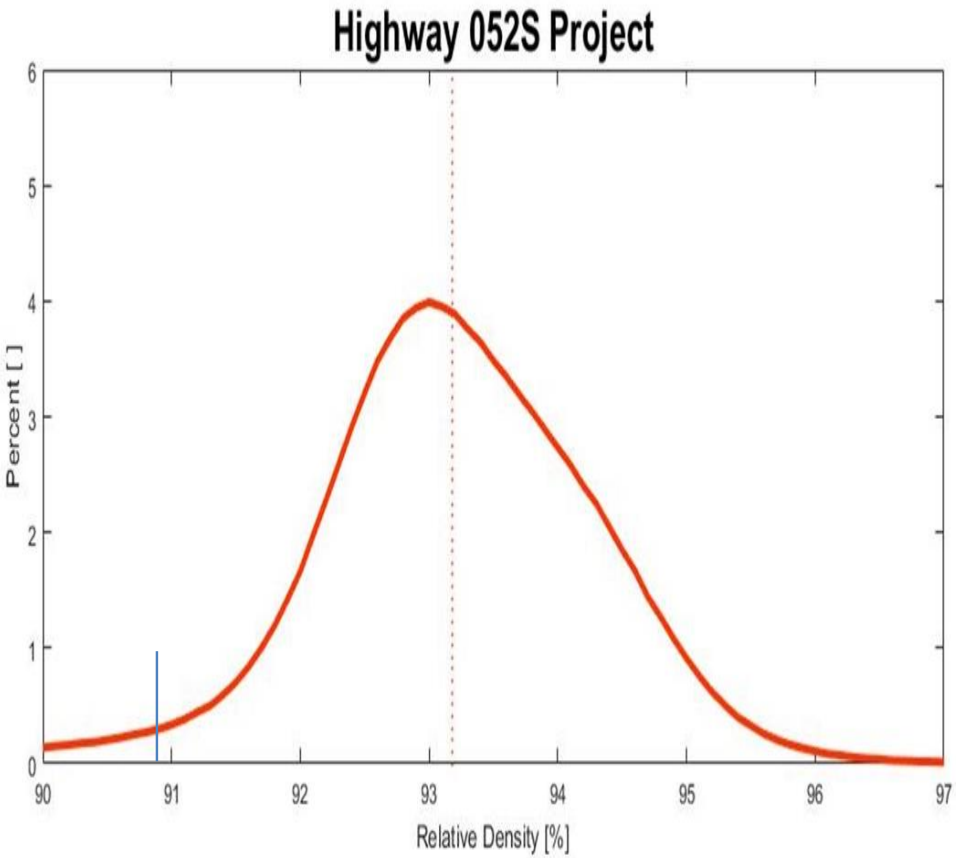
Green-MnDOT with Vehicle Mounted RDM

Red – Consultant with Walking Cart RDM



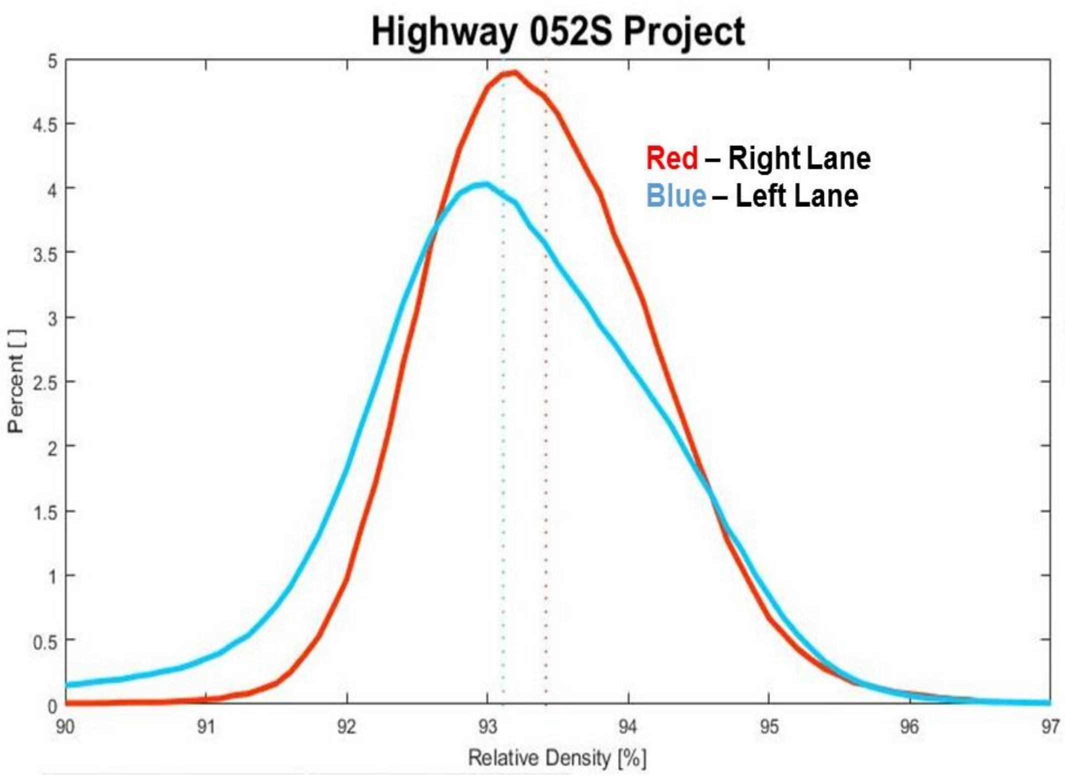
Histogram

- **Use histogram to assess uniformity and quality.**



- All Data Collected
  - **Sampling Rate = 0.4 in/scan.**
  - **> 26 million measurements**
  - **Analysis based on 4 in. moving average**
  - **Equivalent to >1 million cores**
- Summary Stats
  - **93.2% median density**
  - **STD: 1.18**
  - **97.5% locations density>90.8%**

Examples: TH 52 – Left and Right Mainline

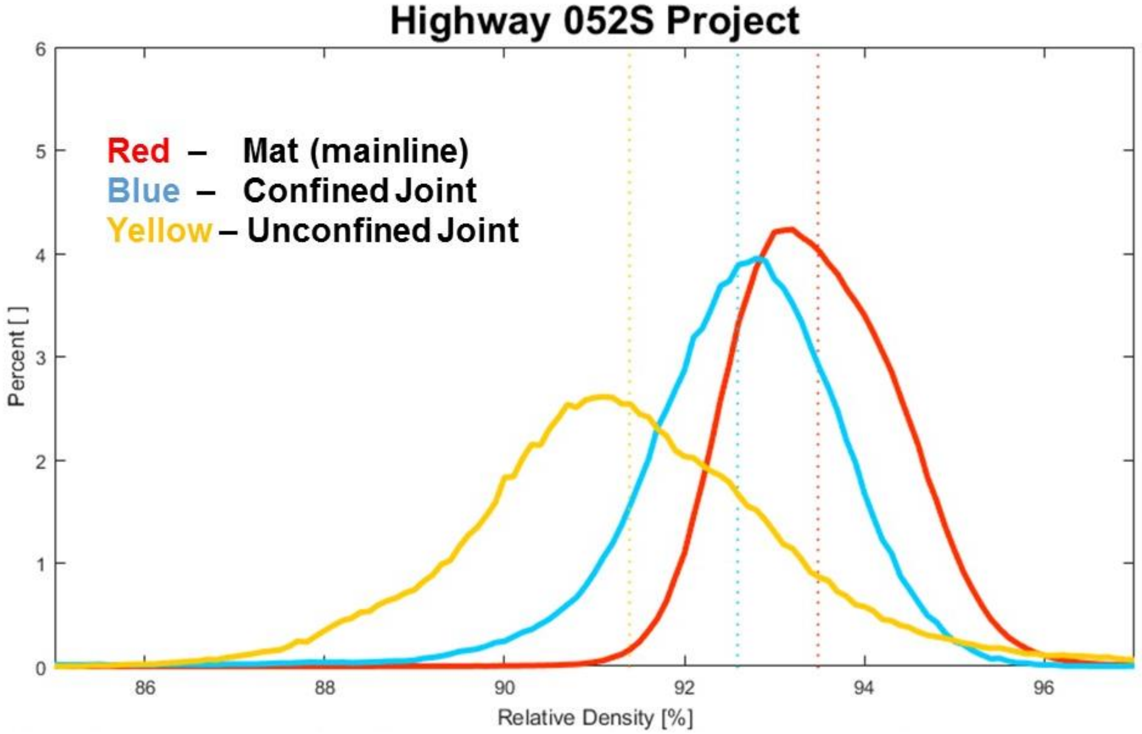


- Median Density
  - Right: 93.4%
  - Left: 93.1%
- STD: 0.92(R) and 0.96(L)
- 97.5% locations:

  > 91.6% (R)

  > 91.2% (L)

TH 52 – Longitudinal Joint

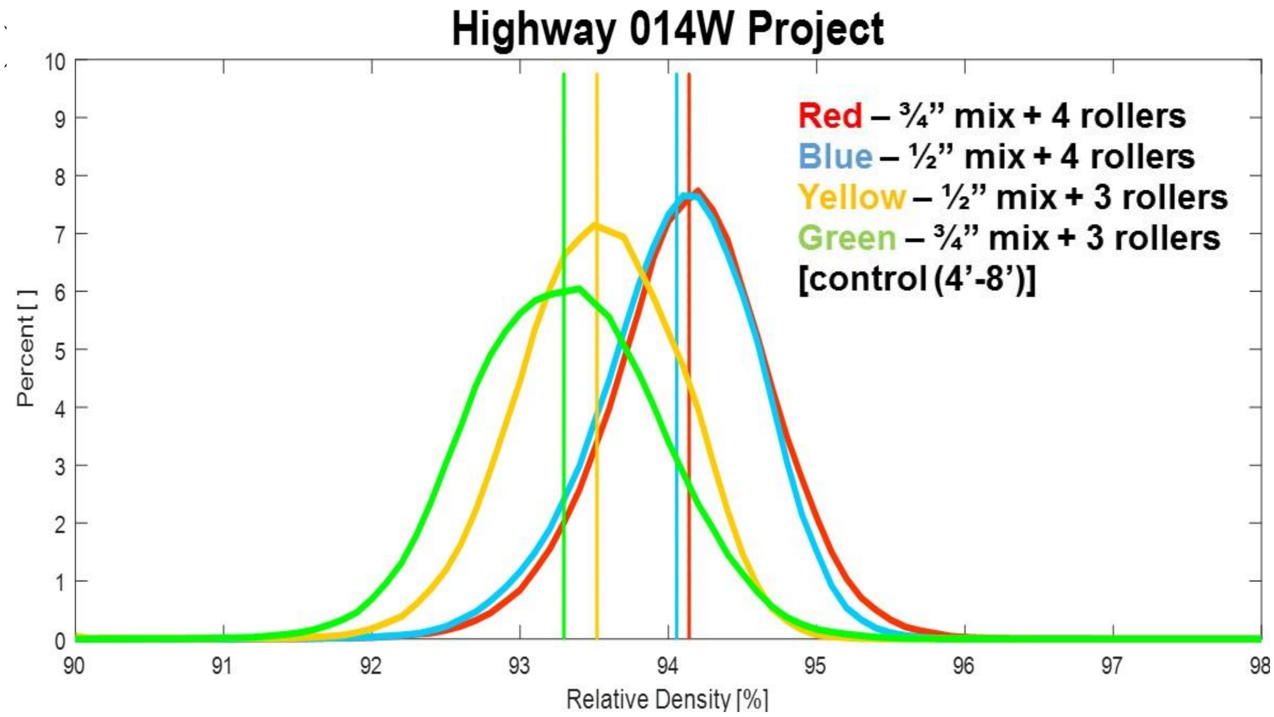


Top lift Mainline Average Density:

- Mat 93.5%
- Confined Joint 92.6%
- Unconfined Jnt 91.4%

TH 14 – Mainline

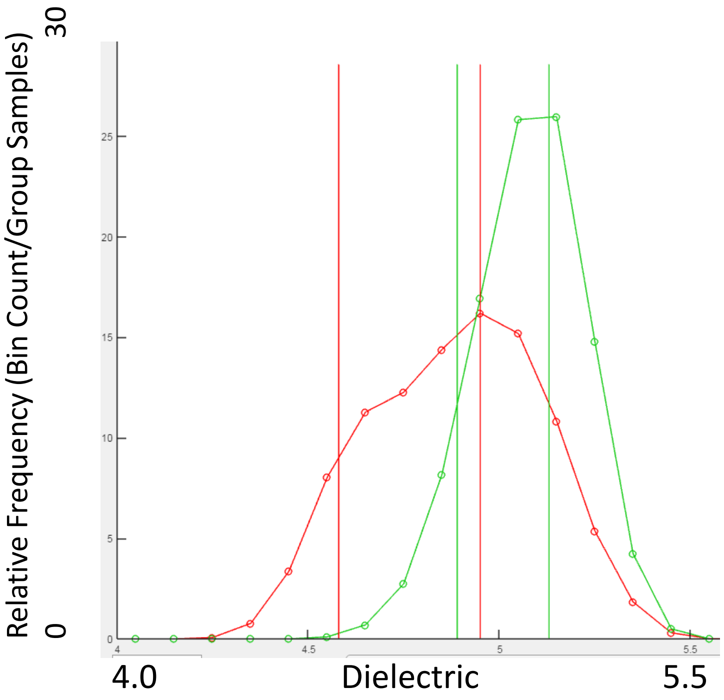
- Comparison of Test Sections
- Mix B (3/4-) to A(1/2-): not much difference on compaction.
- Adding a roller: density slightly increased on this project.



- Median Density:
  Blue: 94.1%
  Red: 94.2%
  Yellow: 93.5%
  Green: 93.3%

GPR Asphalt Compaction: Roller Technique Evaluation

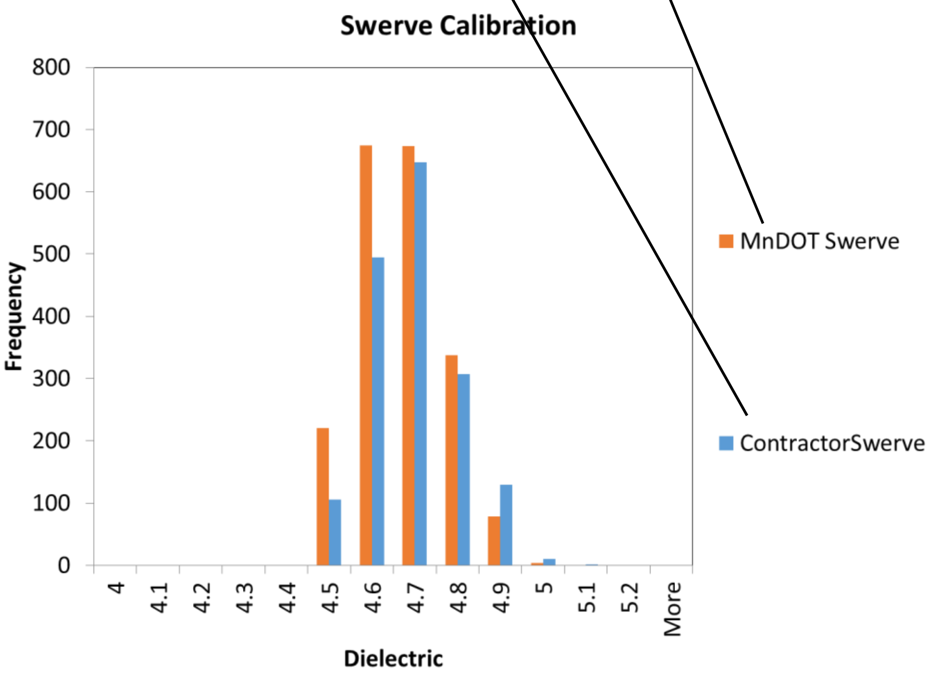
Group Name	Stationing range, ft.	Offset range, ft.	Color	Samples	Core Taken at 10th %, Air Void Content
Roller Technique #1	920+00 to 925+00	Centered on Joint	Red	1000	9.6%
Roller Technique #2	935+00 to 940+00	Centered on Joint	Green	1000	7.7%

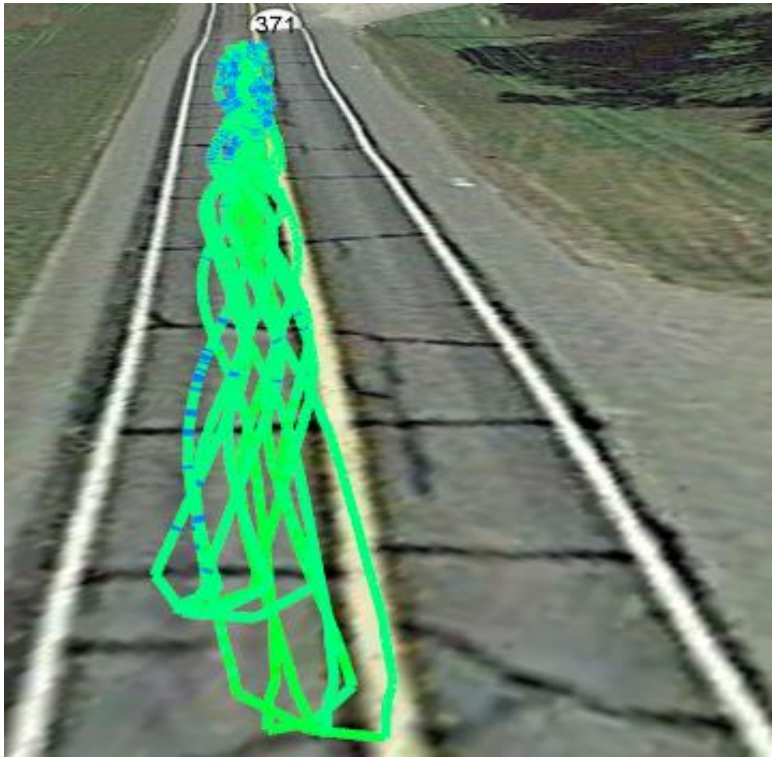


- Example 500 ft section where 2 different echelon breakdown roller techniques were used on the joint:
  - On-site RDM dielectric indicated greater compaction using technique 2
  - Core taken at 10th percentile indicated greater compaction in technique 2
- On-site dielectric can be used to give feedback as to what techniques are more effective for compaction

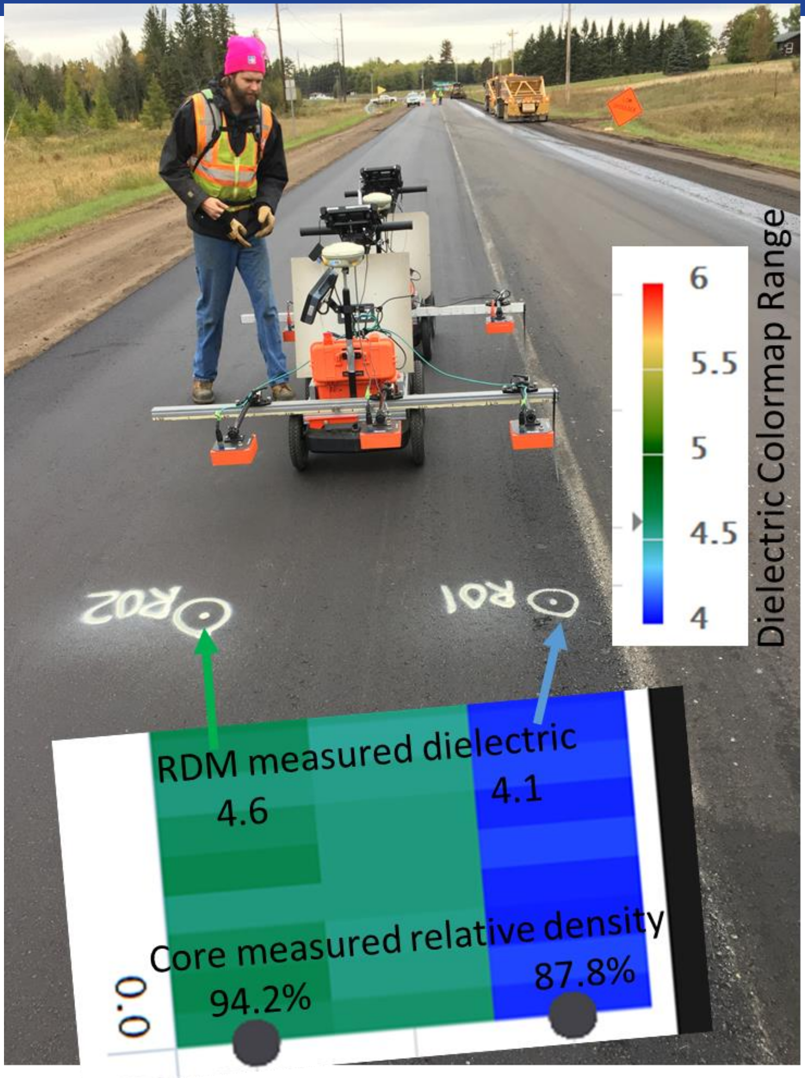
Summary Field Use: 2018 TH371 contractor experience – equipment validation

Good agreement between Contractor and MnDOT data:
Median dielectric difference in swerve tests less than 0.05





Summary Field Use – Equipment Use



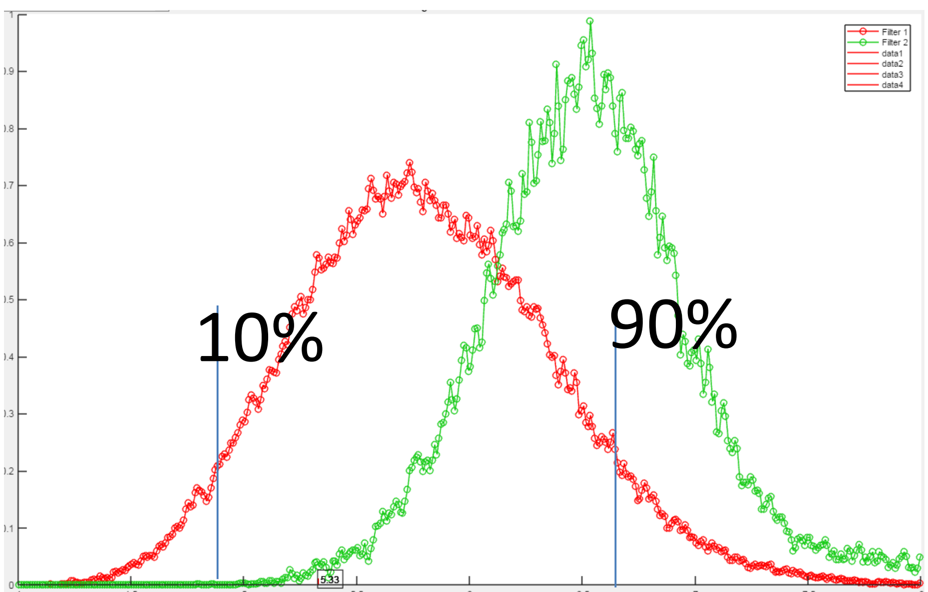
Contractor RDM1 real time display

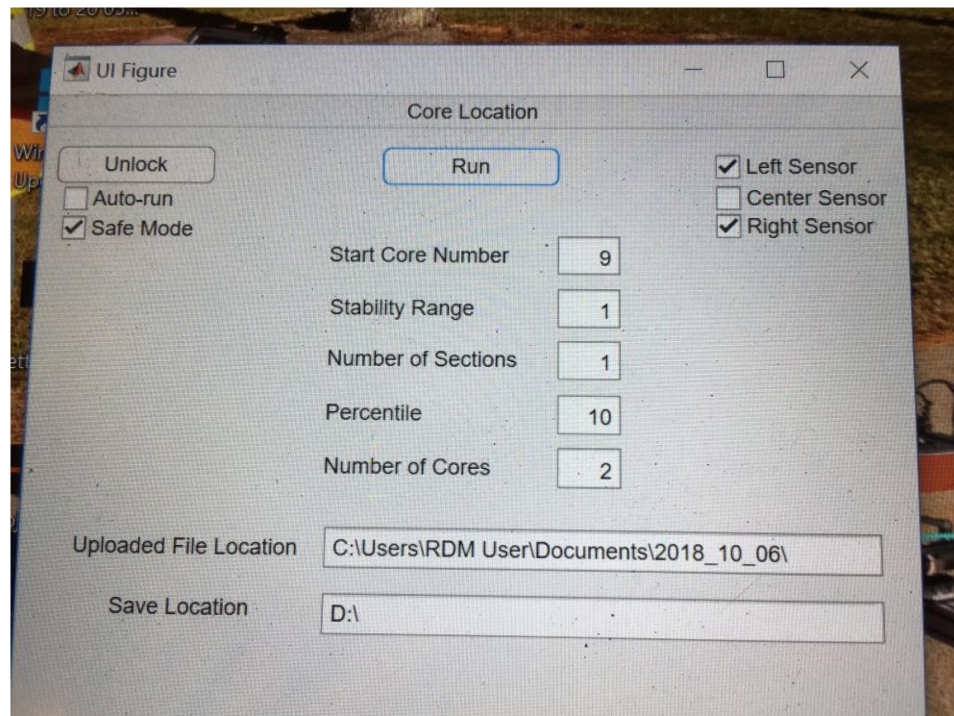
On-Site Feedback

- Contractor could identify low and high density locations
- R01 – dielectric 4.1
- R02 – dielectric 4.6
- Corresponded to 87.8% and 94.2% relative density respectively

Core Locator for Implementation

- ➢Automatic to identify core locations at the end of each paving day
  - ➢ At low and high dielectric locations
    - ➢ Ex: 10% and 90%





Core Locations Output

1. Core Number
2. Distance (ft)
3. Longitude (°)
4. Latitude (°)
5. Elevation (m)
6. Lateral Offset (ft)
7. Dielectric
8. Northing
9. Easting
10. Stability Difference
11. Percentile

- Also saved as a .xlsx file

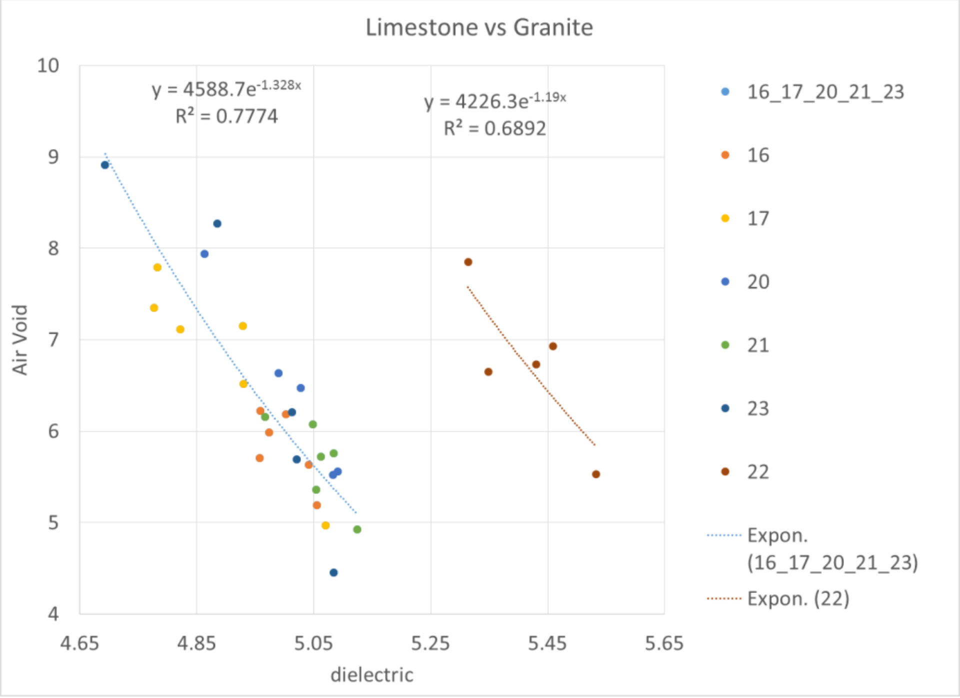
	Core number	Distance (ft)	Longitude (°)	Latitude (°)	Elevation (m)	Lateral Offset (ft)	Dielectric	Northing	Easting	Stability Difference	Percentile
1	R84.1	9785	43.7403	-93.7140	357.9600	-0.5000	5.4851	1.8768e+05	5.6237e+05	0.0601	10
2	R85.1	11016	43.7384	-93.7101	357.6800	-2.5000	8.0004	1.8700e+05	5.6340e+05	0.0733	90
3	R86.1	1.2754e+04	43.7357	-93.7047	356.0600	-0.5000	5.4209	1.8603e+05	5.6484e+05	0.0538	10
4	R87.1	1.1433e+04	43.7378	-93.7088	357.3900	-2.5000	7.7417	1.8676e+05	5.6374e+05	0.0464	91
5	R88.1	1.4217e+04	43.7333	-93.6998	356.4300	-2.5000	5.4010	1.8516e+05	5.6614e+05	0.0148	9
6	R89.1	1.4348e+04	43.7331	-93.6994	356.7300	-4.5000	5.7936	1.8509e+05	5.6625e+05	0.0654	90
7	R90.1	1.0089e+04	43.7396	-93.7127	357.8700	0.5000	5.3488	1.8745e+05	5.6271e+05	0.0701	10
8	R91.1	9808	43.7401	-93.7136	357.9300	23	5.8927	1.8760e+05	5.6248e+05	0.0675	90
9	R92.1	1.1628e+04	43.7373	-93.7079	357.1600	0.5000	5.1195	1.8659e+05	5.6399e+05	0.0155	10
10	R93.1	1.0657e+04	43.7388	-93.7109	357.7600	4.5000	5.7674	1.8713e+05	5.6318e+05	0.0461	90
11	R94.1	1.3948e+04	43.7337	-93.7006	355.8800	0.5000	5.0702	1.8531e+05	5.6592e+05	0.0575	10
12	R95.1	1.3935e+04	43.7338	-93.7007	355.8500	4.5000	5.5770	1.8531e+05	5.6591e+05	0.0051	89

Summary Field Use – Core Locator

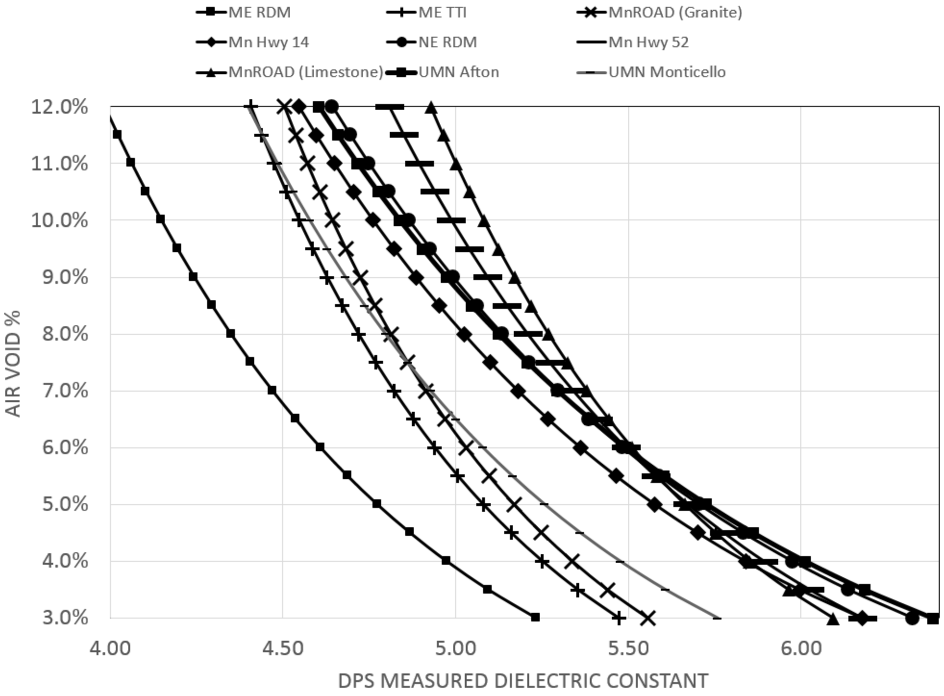
- automatically guide field person to the core location for coring

Conversion from Dielectric to Air Voids

Current Method: Field Empirical

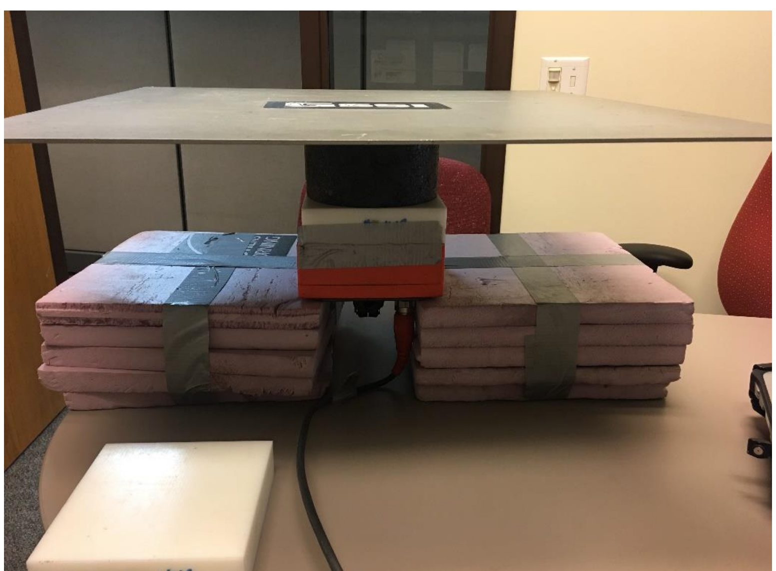


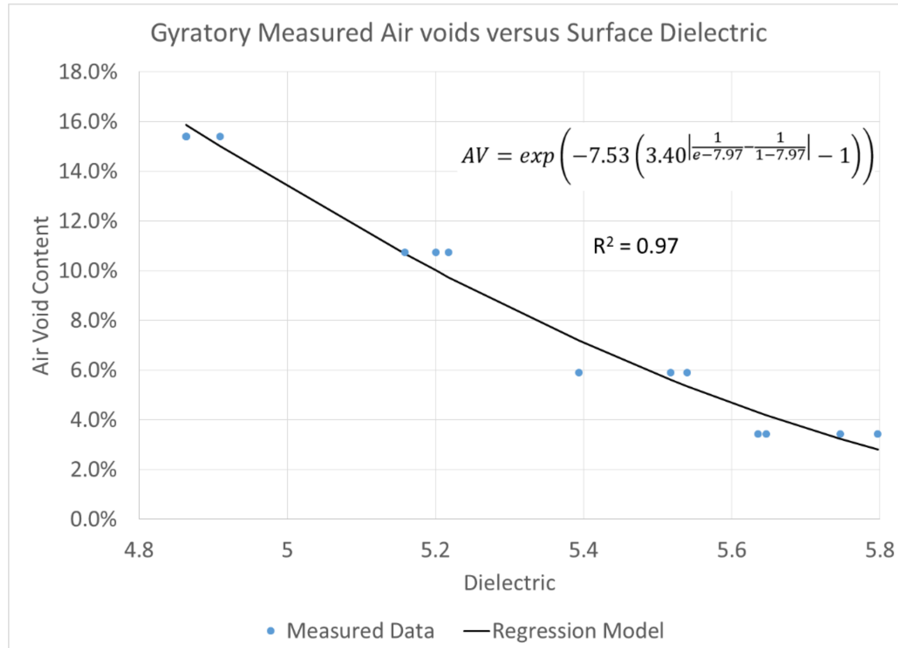
Theoretical Method: Mix Modeling



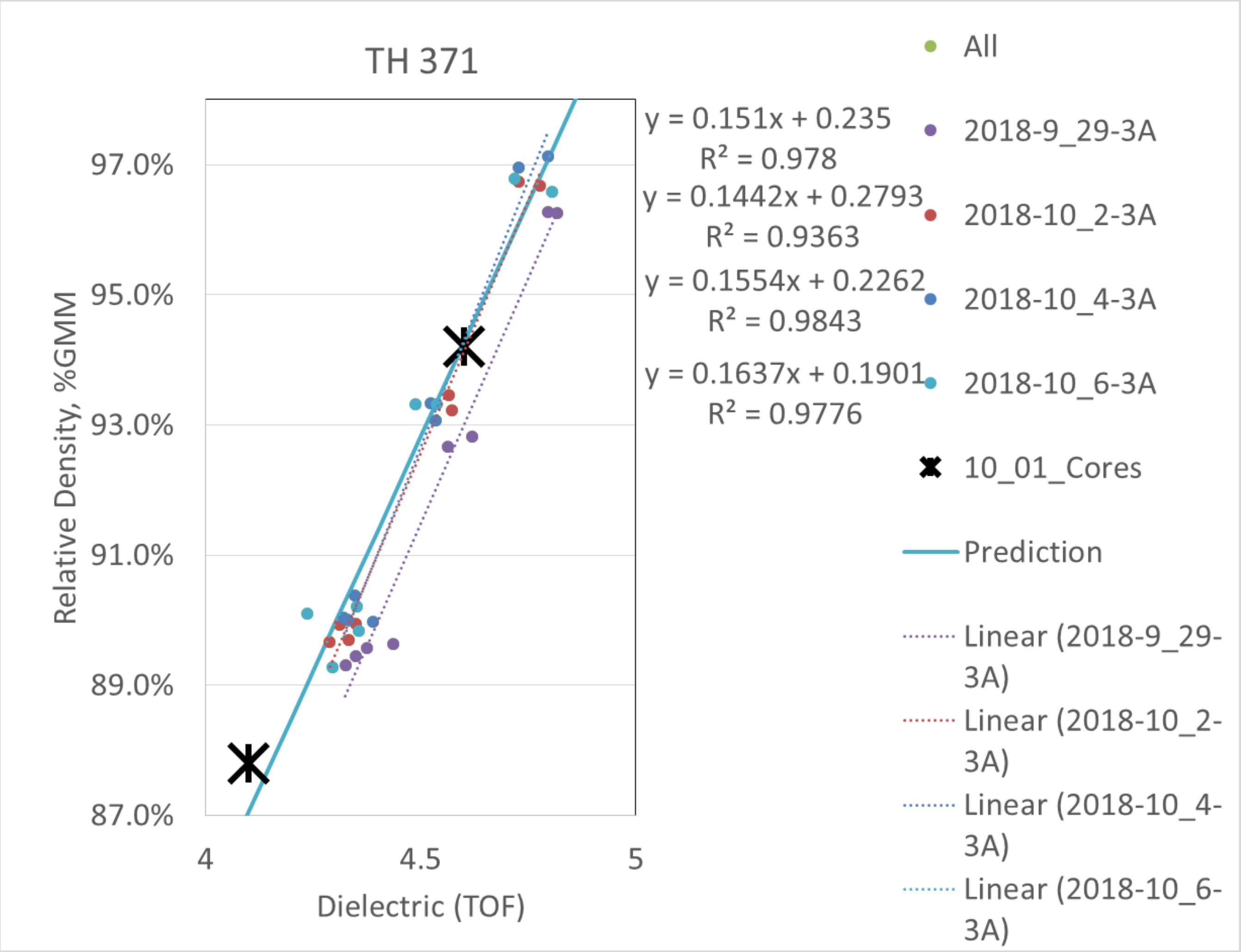
$$AV\% = Ae^{-B*dielectric}$$

Conversion from Dielectric to Air Voids: Laboratory Empirical





Conversion from Dielectric to Air Voids: Laboratory Empirical TH371



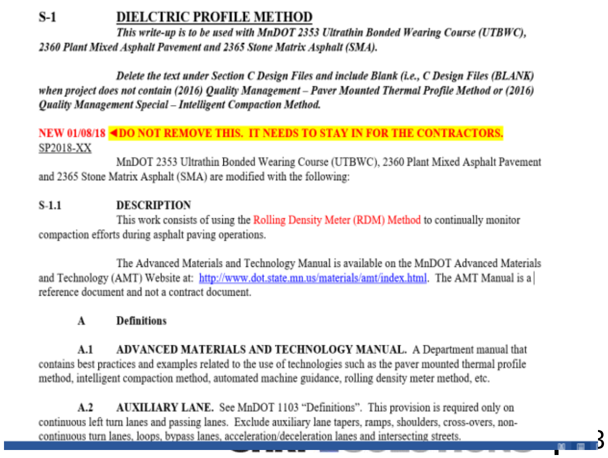
- All predictions based on gyratory pucks 10-1-2018 through 10-6-2018 predicted similarly
- Predictions based on 9-29-2018 under predicted air void content relative to others
- Field cores R01 and R02 from 10-1 confirmed October predictions

Activities

- Calibration of Equipment
- Field Testing:
  - 2016: TH52 and TH14: Surveyed about 18miles.
  - 2017: I35; Th52; Th22; Th60; CR86; Th110; CSAH13 and MnROAD
    - Hired American Engineering Testing (AET) to collect data
      - Educating consultant and contractors on this new technology
      - Testing application feasibility of vehicle mounted RDM system on construction projects.
  - 2018: "Ghost" specification and core locator – 1 or 2 projects

    TH47, TH14, TH109 and TH50 so far

    Work with GSSI on software improvements
- Research on Laboratory Calibration
  - Gyratory Specimen



S-1 DIELCTRIC PROFILE METHOD

This write-up is to be used with MnDOT 2353 Ultrathin Bonded Wearing Course (UTBWC), 2360 Plant Mixed Asphalt Pavement and 2365 Stone Matrix Asphalt (SMA).

Delete the text under Section C Design Files and include Blank (i.e., C Design Files (BLANK) when project does not contain (2016) Quality Management – Paver Mounted Thermal Profile Method or (2016) Quality Management Special – Intelligent Compaction Method.

NEW 01/08/18 ◄DO NOT REMOVE THIS. IT NEEDS TO STAY IN FOR THE CONTRACTORS.

SP2018-XX

MnDOT 2353 Ultrathin Bonded Wearing Course (UTBWC), 2360 Plant Mixed Asphalt Pavement and 2365 Stone Matrix Asphalt (SMA) are modified with the following:

S-1.1 DESCRIPTION

This work consists of using the Rolling Density Meter (RDM) Method to continually monitor compaction efforts during asphalt paving operations.

The Advanced Materials and Technology Manual is available on the MnDOT Advanced Materials and Technology (AMT) Website at: http://www.dot.state.mn.us/materials/amt/index.html. The AMT Manual is a reference document and not a contract document.

A Definitions

A.1 ADVANCED MATERIALS AND TECHNOLOGY MANUAL. A Department manual that contains best practices and examples related to the use of technologies such as the paver mounted thermal profile method, intelligent compaction method, automated machine guidance, rolling density meter method, etc.

A.2 AUXILIARY LANE. See MnDOT 1103 "Definitions". This provision is required only on continuous left turn lanes and passing lanes. Exclude auxiliary lane tapers, ramps, shoulders, cross-overs, non-continuous turn lanes, loops, bypass lanes, acceleration/deceleration lanes and intersecting streets.

Summary

- RDM is a good tool for mapping a continuous coverage of the relative compaction levels (higher dielectric = higher compaction)

- Histograms and general statistics can be used to give a complete assessments of the in-place compaction

- Immediate Feedback : Millions of Data Points

- Potential Uses:
  - Assess compaction density and uniformity for QC/QA.
  - Provide on-site feedback to contractor of high and low compaction locations that they can cross-check with differences in mix or paving strategies in those locations to determine optimal construction procedures
  - Identification of trends in the air void content maps that can be cross-checked with IC and other data to determine the most critical factors in achieving higher density

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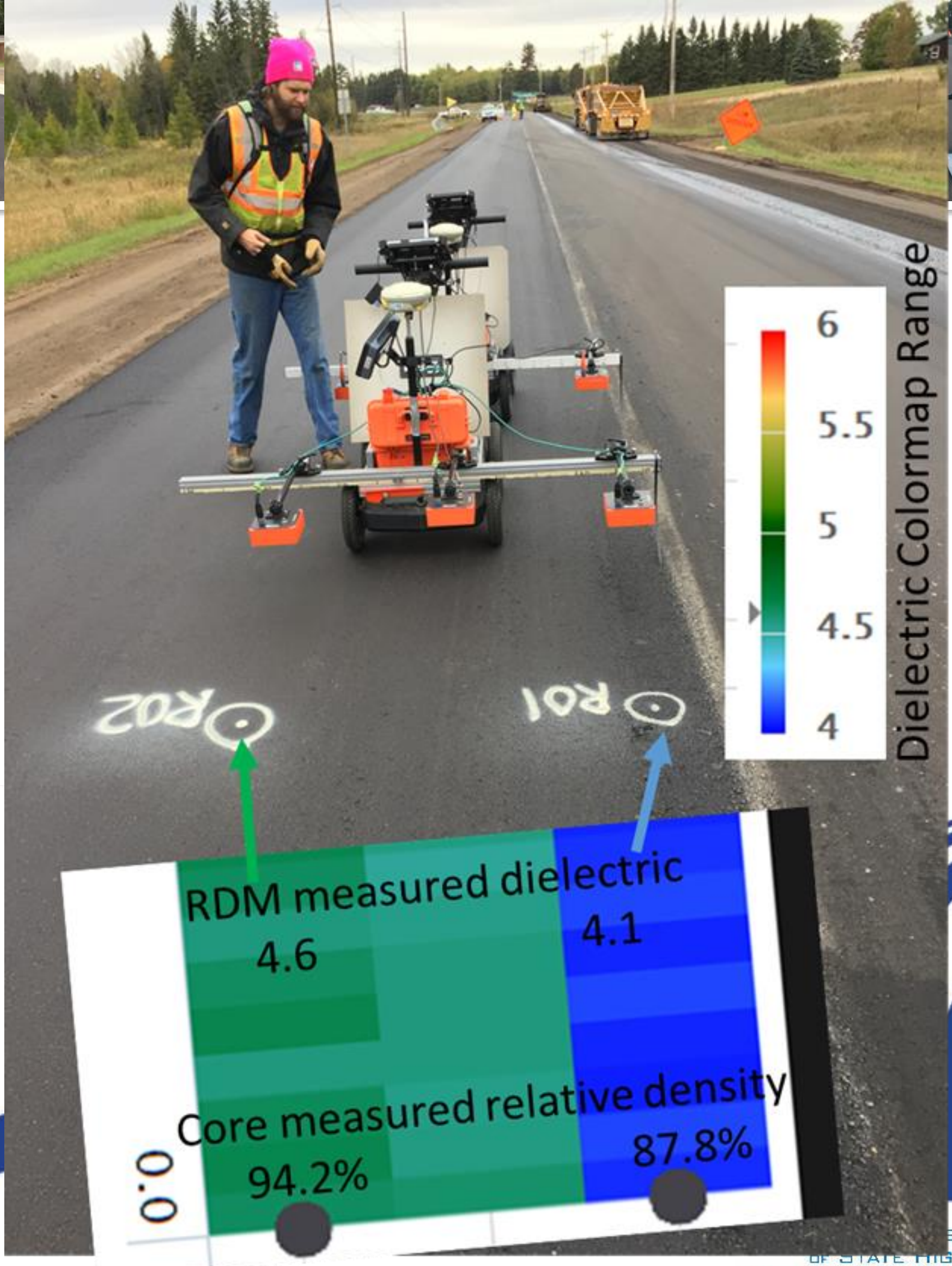
Thanks for your time and attention



Contractor RDM1 real time display

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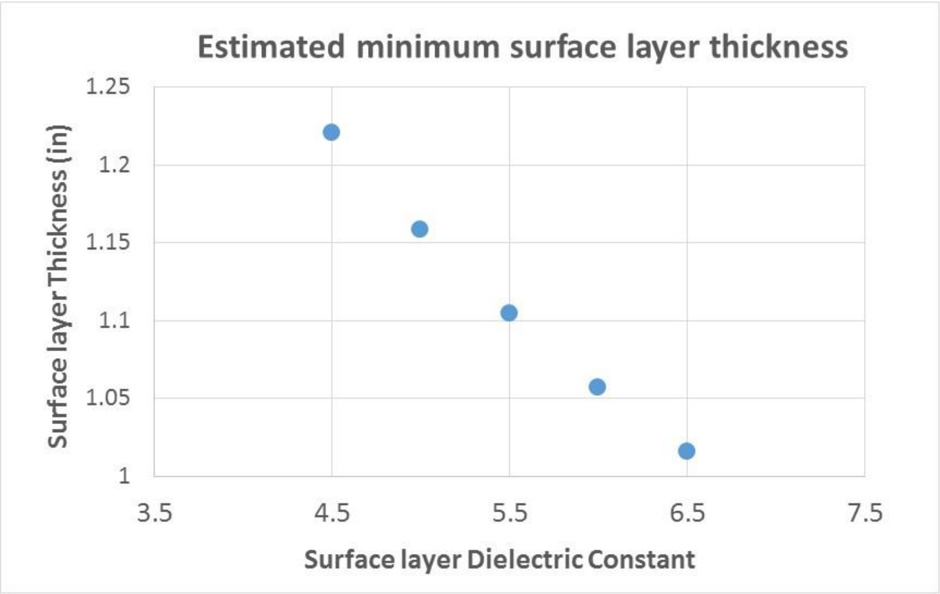
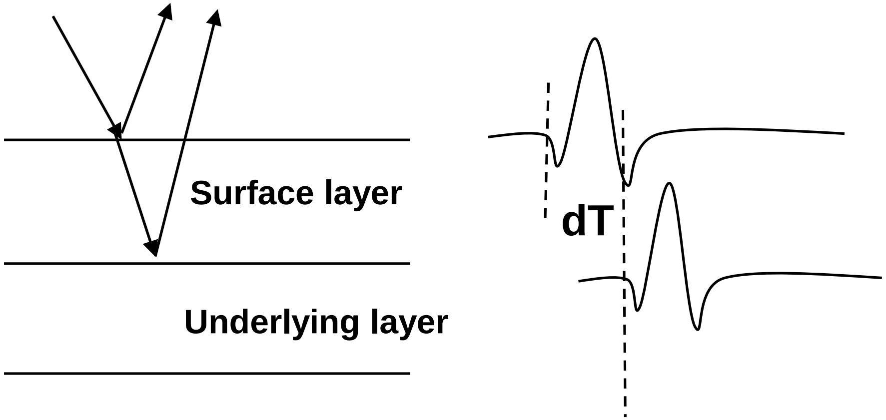
Aggregate Source	% of mix	% of mix
Powers BA Sand	32	30
Powers 1/2 Rock	26	26
Powers Dust	12	12
Powers 5/8 Rock	0	0
Swenson 3/4 Rock	0	0
Rap	30	32

- Underlying layer effect on surface measurement?
  - How thick does the HMA layer need to be so that the underlying layer (agg. base) has no effects?





$$h_1 = v^* \Delta t_1 / 2$$

$$v = c/\sqrt{\varepsilon_1}$$

dT ~ 0.439us