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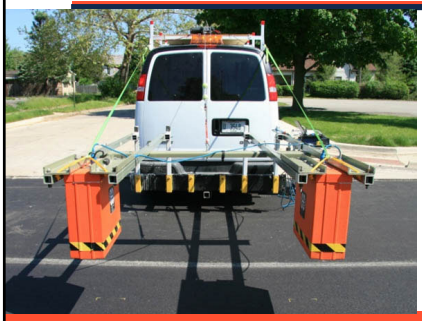
Moisture Content and Density of Cold In-Place Recycled Layer



Imad L. Al-Qadi

12/09/2020

"Where Excellence and Transportation Meet"

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Acknowledgement

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  - John Senger, TRP chair
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- ICT Engineers: Uthman M. Ali and Greg Renshaw
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Introduction

Cold in-place recycling (CIR) of AC pavement is a rehabilitation technique applied by many states

One of the challenges is timely moisture content measure-ments

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CIP In-Situ Tests to Open the Road

- **Structural Capacity Gaining**: LWD, DCP
- **Nondestructive Testing**: Nuclear Gauge
- **In-Situ Density/ Moisture**: Sand cone
- **Continuous, Rapid, and Good Coverage**: Ground-Penetrating Radar

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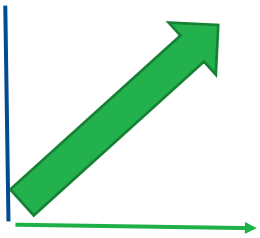
GPR for Moisture Content Monitoring

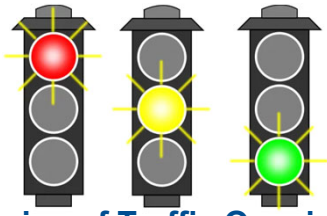
- Field Tests
- Simulation
- Statistical Analysis

Dielectric Constant

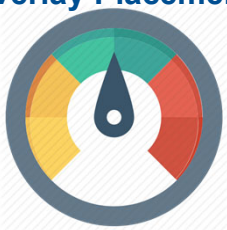
Moisture Content

Dielectric Constant-Moisture Content Relationship





Timing of Traffic Opening/ Overlay Placement



Moisture Content/ Density Prediction

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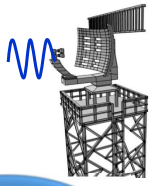
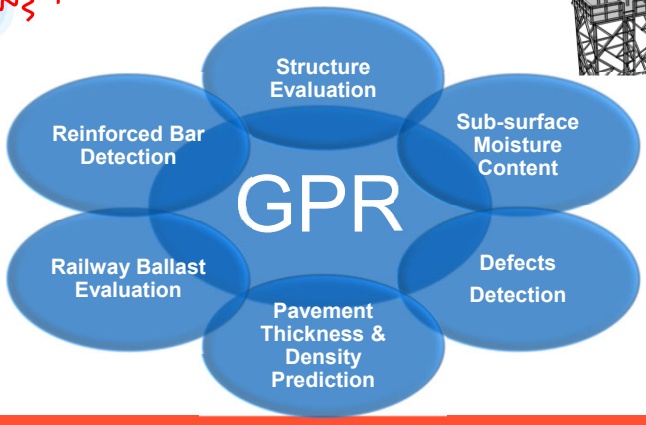
GPR Is A Special Kind of RADAR





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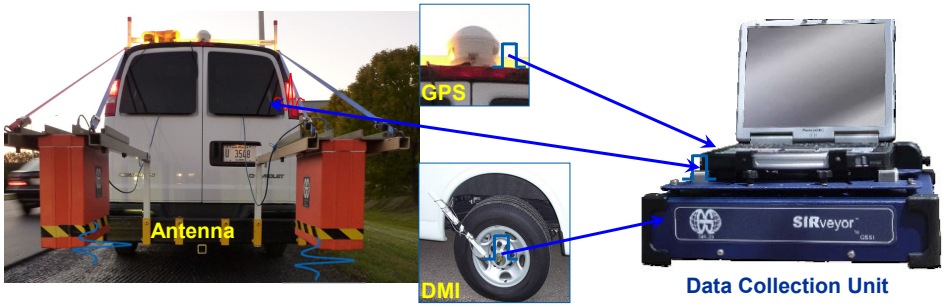
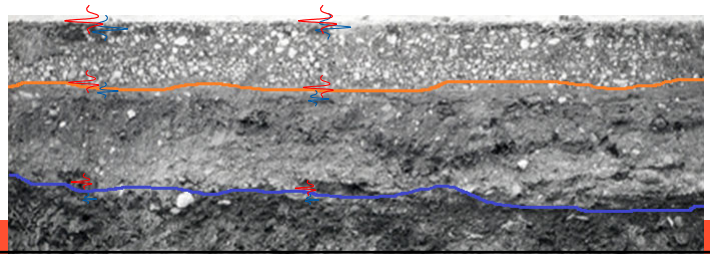
GPR: How Does It Work?





Transmitted Signal

Reflected Signal

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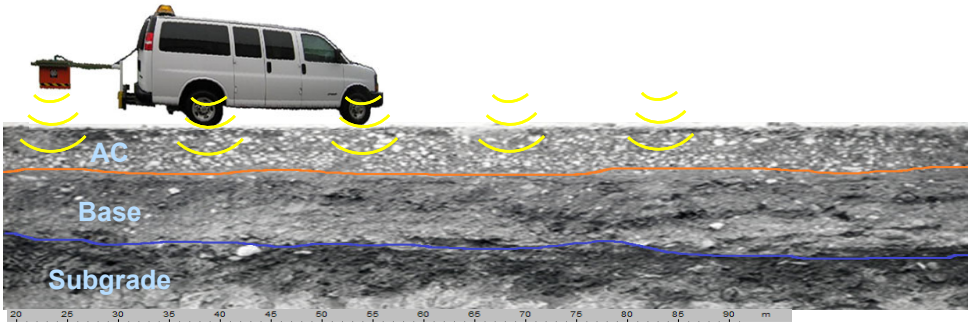
Thickness Profile



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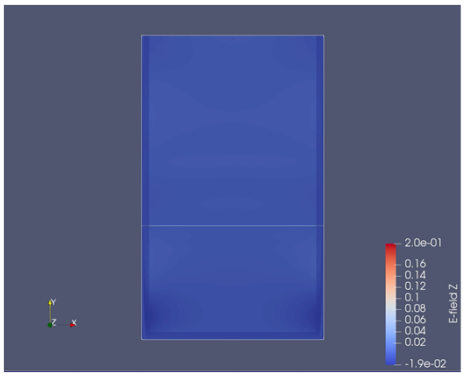
EM Wave Propagation

EM propagation speed depends on the dielectric constant of the medium (for non-magnetic, loss-less material)

$$v = \frac{c}{\sqrt{\varepsilon_r}}$$

- v: propagation velocity
- c: speed of light in free space
- ε_r: dielectric constant of the medium

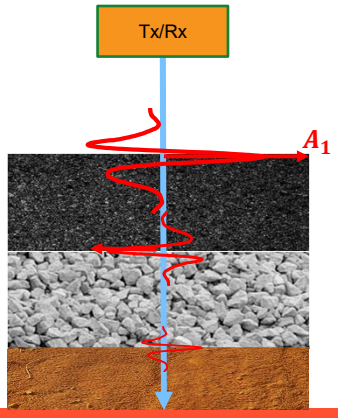


GPR Test Principles

Reflection Amplitude Method (Current Phase)

$$Dielectric\ constant: \quad \epsilon = \left(\frac{1+\frac{A_p}{A_c}}{1-\frac{A_p}{A_c}}\right)^2$$

A_1 for Dielectric Constant Prediction



Asphalt Mixture Density Prediction

Asphalt Mixture Components


AC
ε_{AC}

=

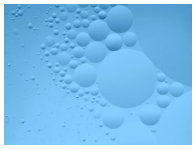

Binder
ε_b, V_b

+


Aggregate
ε_s, V_{se}

+ Air
ε_a, V_a

+


Moisture
ε_w, V_w

Electromagnetic (EM) Mixing Theory

- The bulk dielectric constant of a mixture is a function of the dielectric and volumetric properties of its components
- There is a physical relation between the asphalt mixture's dielectric constant and density/moisture content

Density Estimation

- **Specific Gravity Models: $G_{mb} = f(\varepsilon_{AC})$**
  - Enable the prediction of asphalt mixture bulk specific gravity (G_{mb}) from its GPR-predicted dielectric constant (ε_{AC})

- **Al-Qadi, Lahouar, and Leng (ALL) Model:**

$$G_{mb} = \frac{\frac{\varepsilon_{AC} - \varepsilon_b}{3\varepsilon_{AC} - 2.3\varepsilon_b} - \frac{1 - \varepsilon_b}{1 - 2.3\varepsilon_b + 2\varepsilon_{AC}}}{\left(\frac{\varepsilon_s - \varepsilon_b}{\varepsilon_s - 2.3\varepsilon_b + 2\varepsilon_{AC}}\right)\left(\frac{1 - P_b}{G_{se}}\right) - \left(\frac{1 - \varepsilon_b}{1 - 2.3\varepsilon_b + 2\varepsilon_{AC}}\right)\left(\frac{1}{G_{mm}}\right)}$$

- G_{mm} = maximum specific gravity of asphalt mixture
- P_b = asphalt content (%)
- G_{se} = effective specific gravity of aggregate
- ε_b = dielectric constant of binder
- ε_s = dielectric constant of aggregate

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Field Testing during Covid-19

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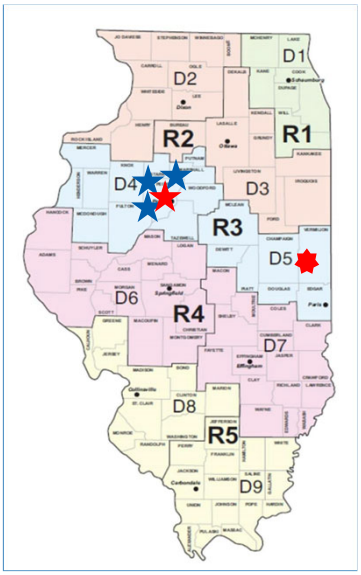
Field Test Sites



- IL-91
- IL-100
- **IL-61**
- IL-116

CIR

- RT-509

CCPR

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Sampling and Sand Cone

Sample Collection for Moisture Content

Sand Cone Test for Density

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LWD and DCP Tests

Light Weight Deflectometer* for Modulus Estimation

Asphalt and Unbound LWD

Dynamic Cone Penetrometer for Shear Strength Estimation

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GPR Tests

- Measurement on the copper plate
- Measure the same spots on pavement each time

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IL-61 Project Details

- Total length = 4.003mi
- Two-lane two-way road (1 lane in each direction)
- Existing cross slope is 1.5%
- Existing lanes 13-ft wide and 3-ft/7-in shoulders
- CIR starts at Station 827+50, ends at Station 1039+05
- CIR depth is 4in
- Engineered emulsions

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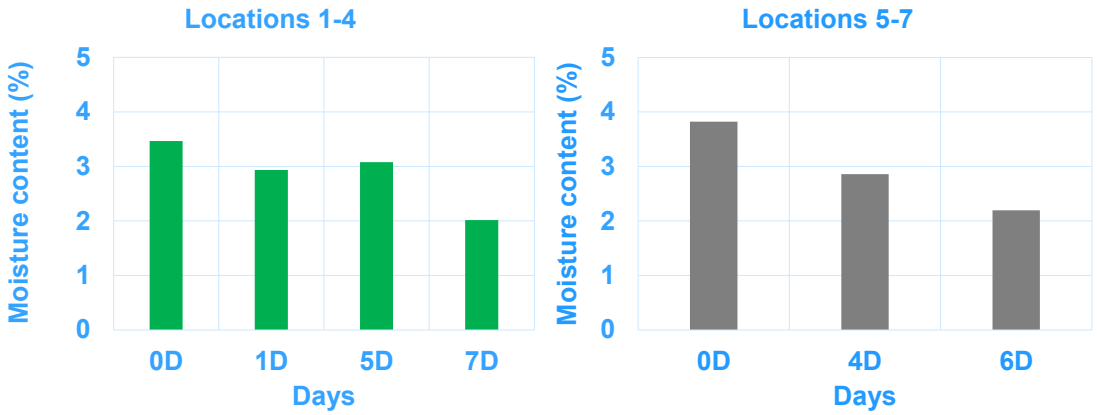
MC Progression Averaging Locations



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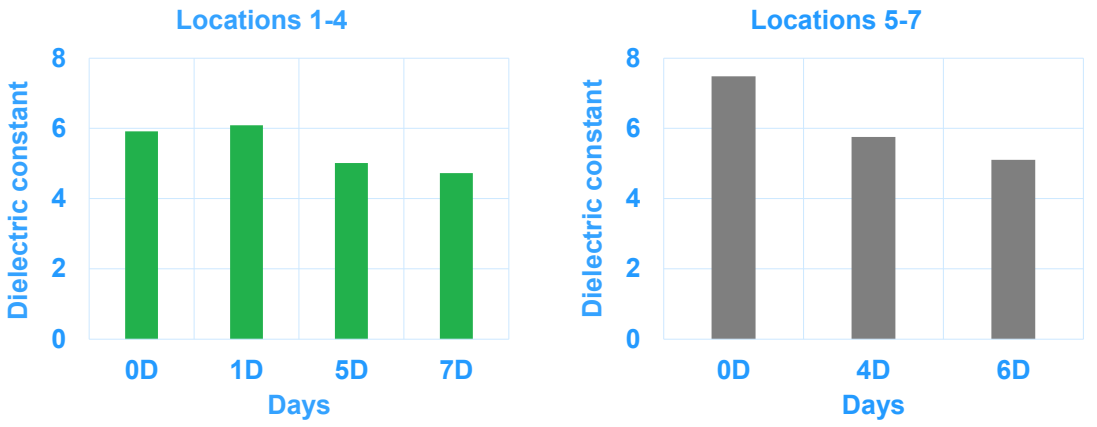
Dielectric Constant Progression - Average



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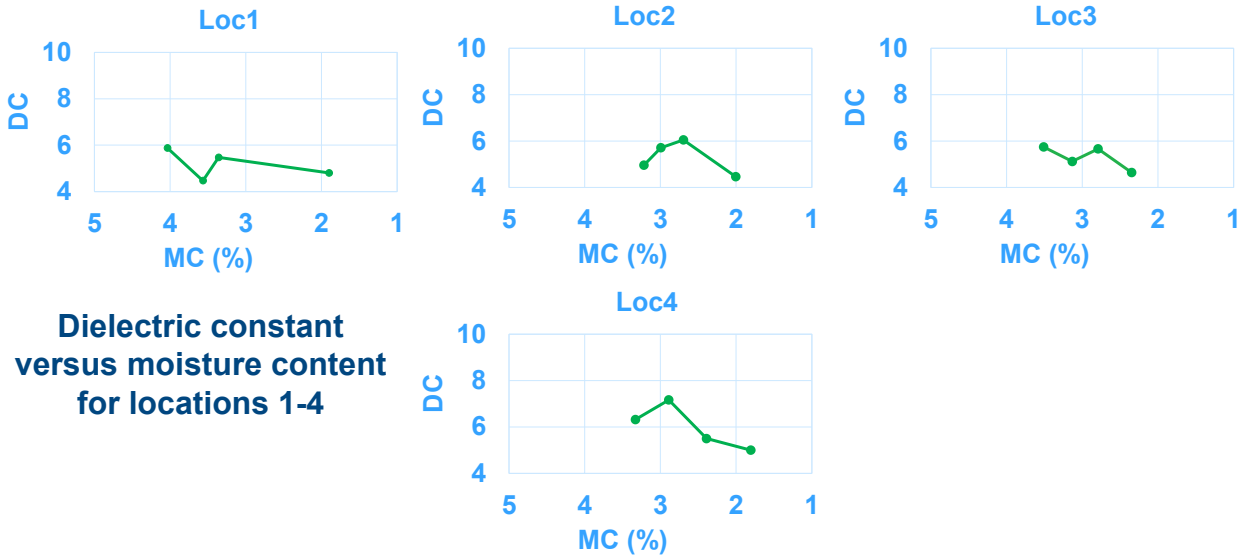
DC-MC Relationship



Dielectric constant versus moisture content for locations 1-4

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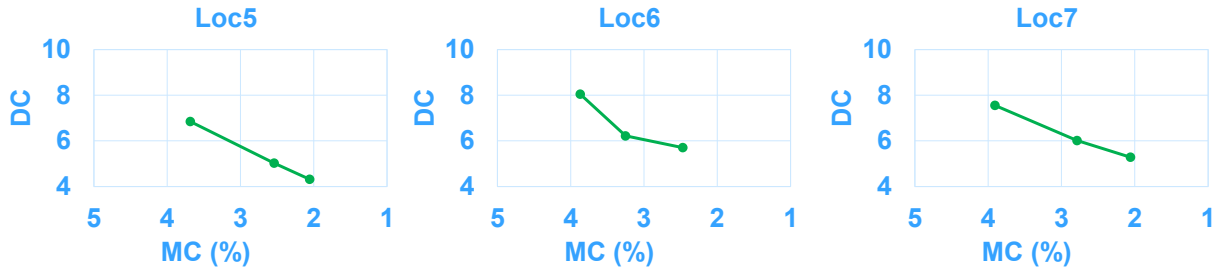
DC-MC Correlation



Dielectric constant versus moisture content from each location.

Locations 5-7

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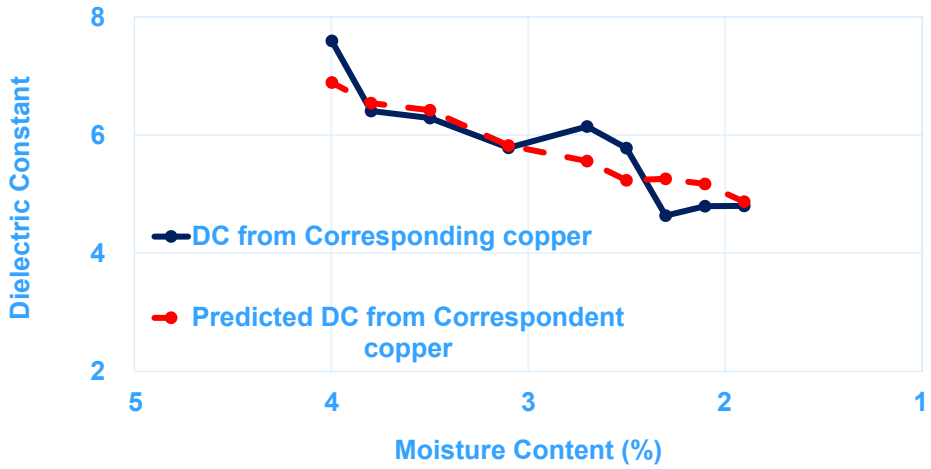
Implementation of Mixture Theory

Dielectric constant predictions from mixture theory correlates to moisture content better than predictions from the field test



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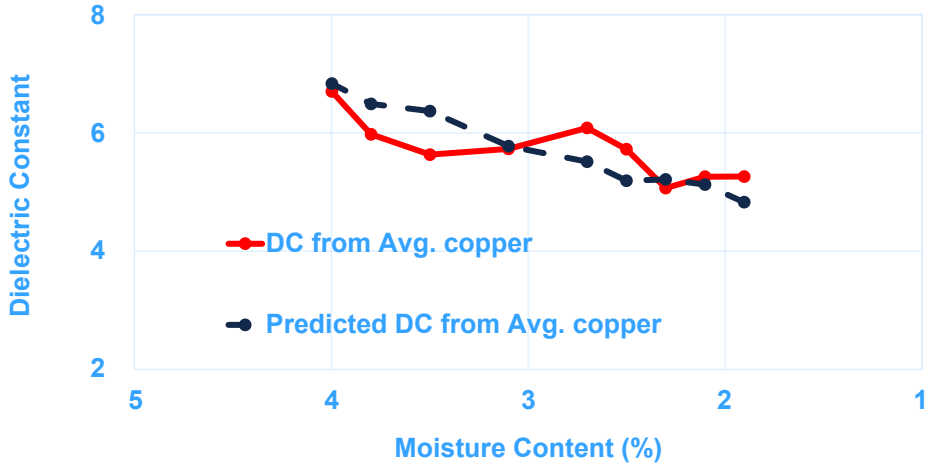
Implementation of Mixture Theory

Dielectric constant predictions from mixture theory correlates to moisture content better than predictions from the field test



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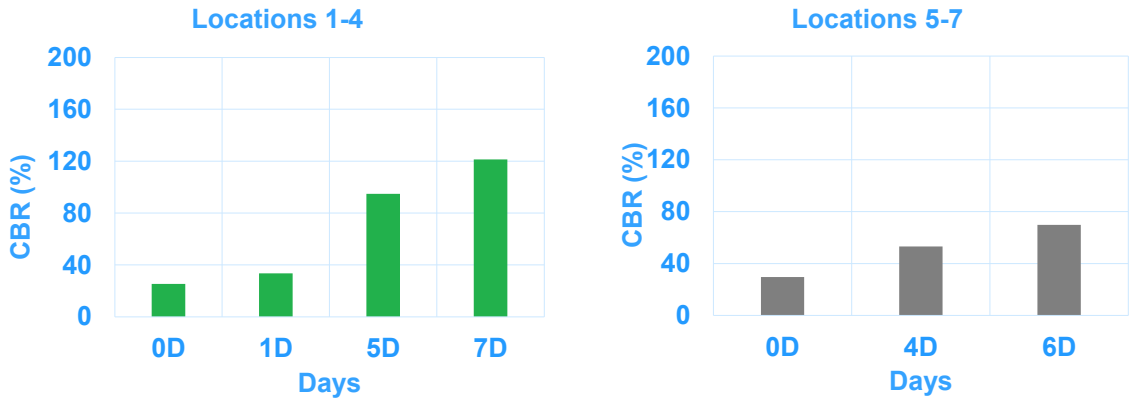
DCP Progression Averaging Locations



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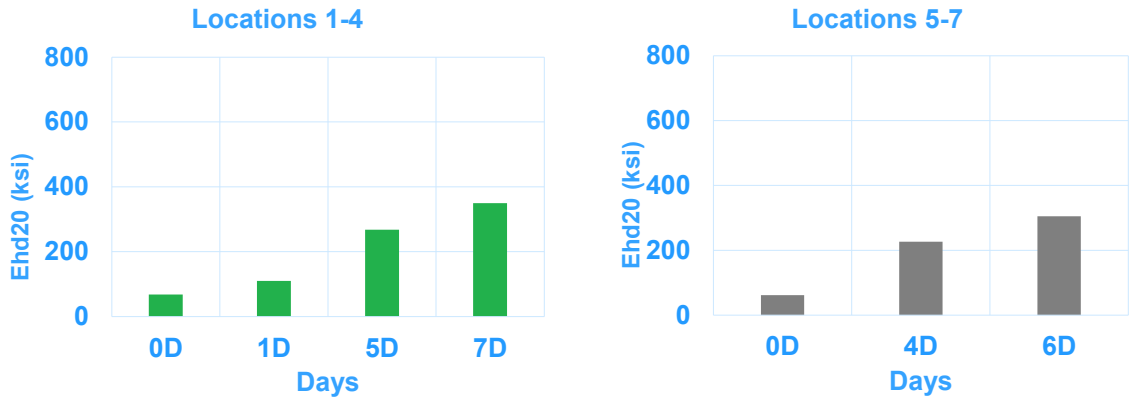
LWD Progression - Averaging Locations



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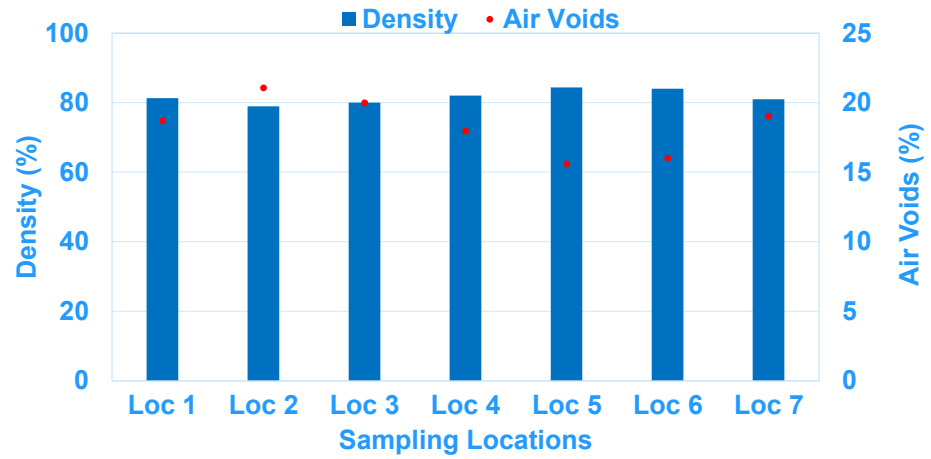
Density Per Location from Sand Cone



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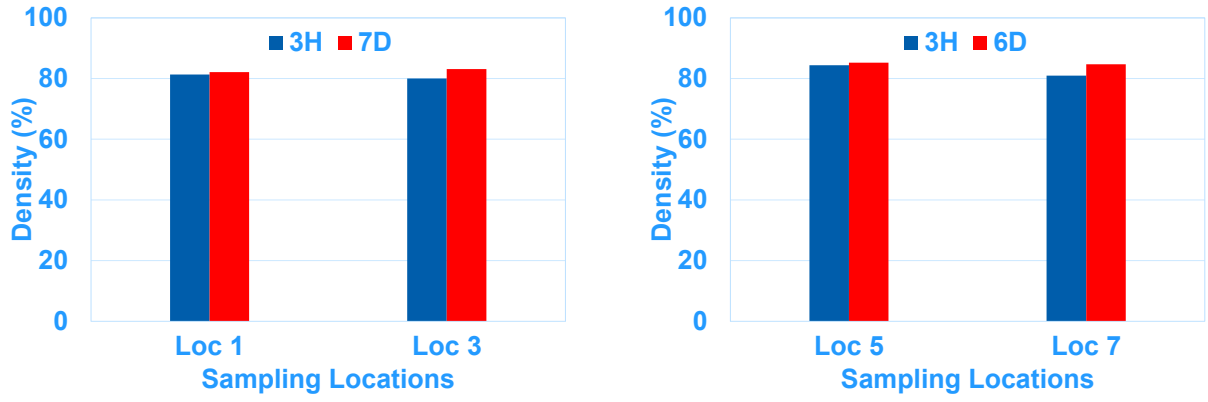
Density Progression from Sand Cone



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CCPR Project

- Total length = 2.854mi
- Two-lane two-way PCC road (1 lane in each direction)
- Existing lanes 12-ft wide and (3+1)-ft shoulders
- Existing cross slope is 1.5%
- Engineered emulsions
- CCPR layer thickness 3in

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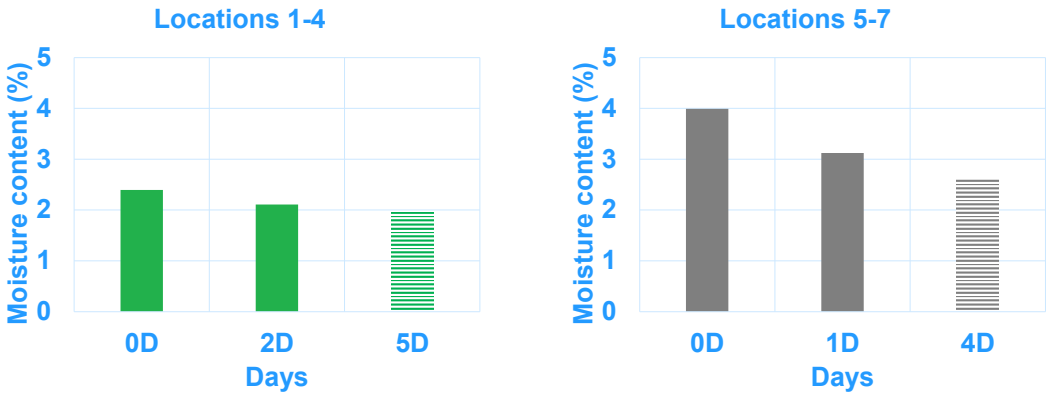
Moisture Content Average Progression

- Pattern fill indicates rain even on previous day



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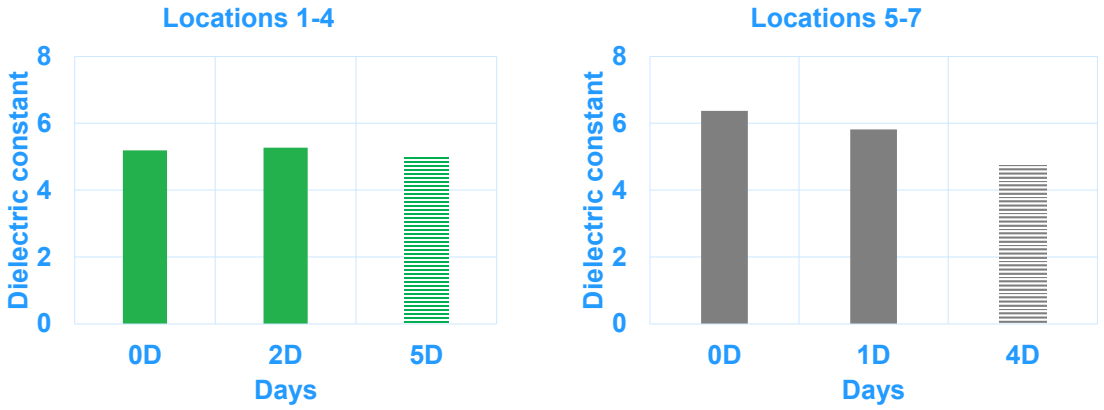
DC Progression - Averaging Locations

- Averaged dielectric constant trend



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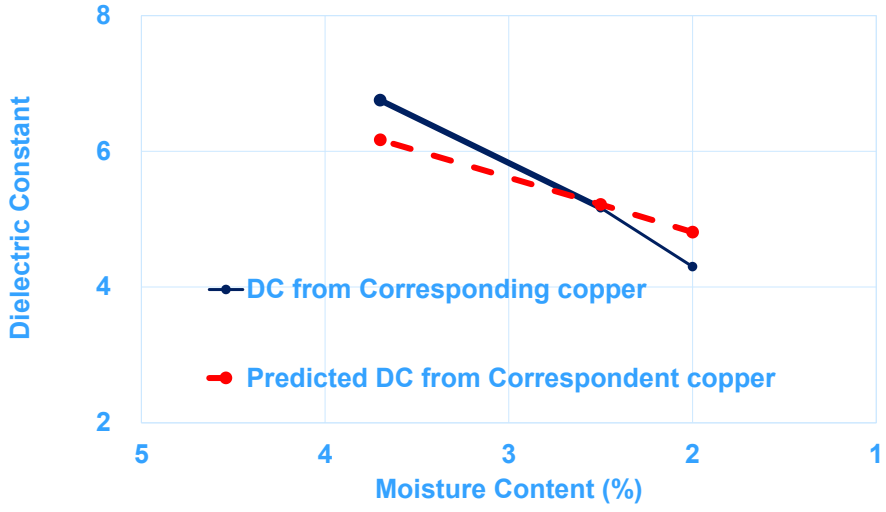
Implementation of Mixture Theory



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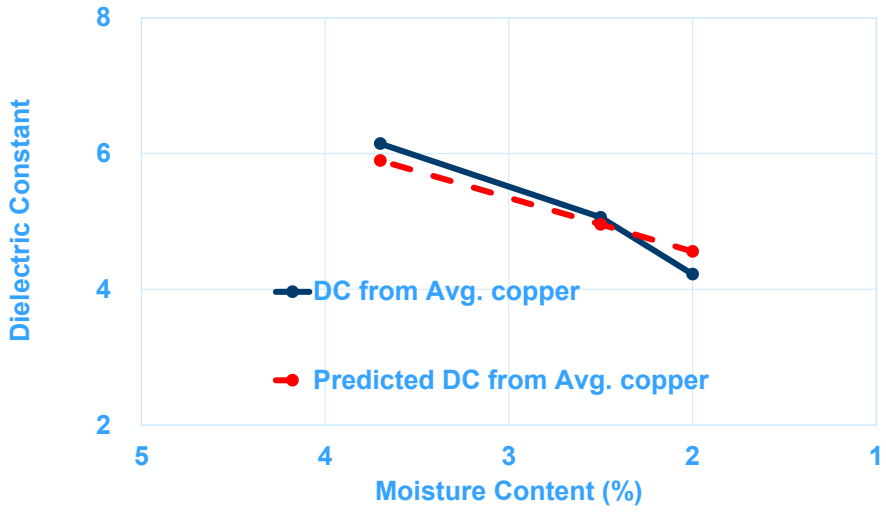
Implementation of Mixture Theory



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Summary

- A decrease in CIP moisture content leads to an increase of CIR mixture stiffness
  - *DCP, LWD, and Sand Cone are good techniques to predict CIP curing*
  - *Time consuming, localized, and limited coverage*
- GPR may be used to predict CIP dielectric constant that could be correlated to moisture content
- A preliminary mixture theory model for CIP is being developed to predict moisture content

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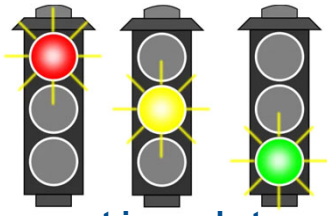
GPR for Moisture Content Monitoring

Dielectric Constant

Mixture Theory



Pavement is ready to open

Moisture Content/ Density Prediction

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THANK YOU

Any Questions?

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