Moisture Content and Density of Cold In-Place Recycled Layer

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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 measurements.

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
GPR for Moisture Content Monitoring

- Field Tests
- Simulation
- Statistical Analysis

Dielectric Constant-Moisture Content Relationship

Timing of Traffic Opening/Overlay Placement

Moisture Content/Density Prediction

GPR Is A Special Kind of RADAR

Structure Evaluation

Reinforced Bar Detection

Railway Ballast Evaluation

Pavement Thickness & Density Prediction

Sub-surface Moisture Content

Defects Detection
GPR: How Does It Work?

Data Collection Unit

Transmitted Signal

Reflected Signal

Thickness Profile

AC

Base

Subgrade
EM Wave Propagation

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

\[ v = \frac{c}{\sqrt{\varepsilon}} \]

- \( v \) = propagation velocity
- \( c \) = speed of light in free space
- \( \varepsilon \) = dielectric constant of the medium

GPR Test Principles

Reflection Amplitude Method (Current Phase)

Dielectric constant:

\[ \varepsilon = \left( 1 + \frac{A_p}{A_c} \right)^2 \]

\( A_1 \) for Dielectric Constant Prediction

- Air
- Surface Layer \( \varepsilon_1 h_1 \)
- Base Layer \( \varepsilon_2 h_2 \)
Asphalt Mixture Density Prediction

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 ($\varepsilon_{AC}$)

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

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

- $G_{mm}$ = maximum specific gravity of asphalt mixture
- $\varepsilon_{b}$ = dielectric constant of binder
- $\varepsilon_{s}$ = dielectric constant of aggregate
- $P_b$ = asphalt content (%)
- $G_{se}$ = effective specific gravity of aggregate
Field Testing during Covid-19

Field Test Sites

- IL-91
- IL-100
- IL-61
- IL-116
- RT-509

CIR
CCPR
Sampling and Sand Cone

Sample Collection for Moisture Content  Sand Cone Test for Density

LWD and DCP Tests

Light Weight Deflectometer* for Modulus Estimation  Dynamic Cone Penetrometer for Shear Strength Estimation

Asphalt and Unbound LWD
GPR Tests

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

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
### MC Progression Averaging Locations

#### Locations 1-4

- **Moisture content (%)**
  - Days: 0D, 1D, 5D, 7D
  - Graph showing moisture content progression over days.

#### Locations 5-7

- **Moisture content (%)**
  - Days: 0D, 4D, 6D
  - Graph showing moisture content progression over days.

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### Dielectric Constant Progression - Average

#### Locations 1-4

- **Dielectric constant**
  - Days: 0D, 1D, 5D, 7D
  - Graph showing dielectric constant progression over days.

#### Locations 5-7

- **Dielectric constant**
  - Days: 0D, 4D, 6D
  - Graph showing dielectric constant progression over days.
DC-MC Relationship

Dielectric constant versus moisture content for locations 1-4

DC-MC Correlation

Dielectric constant versus moisture content from each location.

Locations 5-7
Implementation of Mixture Theory

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

Dielectric Constant

Moisture Content (%)

DC from Corresponding copper

Predicted DC from Correspondent copper

Dielectric constant predictions from mixture theory correlates to moisture content better than predictions from the field test.
DCP Progression Averaging Locations

Locations 1-4

Locations 5-7

LWD Progression - Averaging Locations

Locations 1-4

Locations 5-7
Density Per Location from Sand Cone

Density Progression from Sand Cone
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

Moisture Content Average Progression

- Pattern fill indicates rain even on previous day

Locations 1-4

Locations 5-7
DC Progression - Averaging Locations

- Averaged dielectric constant trend

**Locations 1-4**

<table>
<thead>
<tr>
<th>Days</th>
<th>Dielectric constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>0D</td>
<td>4</td>
</tr>
<tr>
<td>2D</td>
<td>6</td>
</tr>
<tr>
<td>5D</td>
<td>8</td>
</tr>
</tbody>
</table>

**Locations 5-7**

<table>
<thead>
<tr>
<th>Days</th>
<th>Dielectric constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>0D</td>
<td>8</td>
</tr>
<tr>
<td>1D</td>
<td>6</td>
</tr>
<tr>
<td>4D</td>
<td>4</td>
</tr>
</tbody>
</table>

Implementation of Mixture Theory

**Dielectric Constant vs. Moisture Content (%)**

- DC from Corresponding copper
- Predicted DC from Correspondent copper
Implementation of Mixture Theory

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
GPR for Moisture Content Monitoring

Dielectric Constant → Mixture Theory → Moisture Content/ Density Prediction

Pavement is ready to open

THANK YOU
Any Questions?

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