Bridge Deck and Pavement Evaluation

Using Ground Penetrating Radar, Infrared Thermography and High Resolution Imaging Technology

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April 11, 2017

2017 NACE
National Association of County Engineers
Cincinnati, Ohio

Penetradar IRIS GPR and ThermaMap IRT
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• Topics to be Discussed
  ➢ General Discussion of NDT Methods
  ➢ Basic Theory
  ➢ Case Studies of Actual Uses
So What are GPR, IRT and HRI?

- **GPR** is downward looking radar designed to penetrate solid non-metallic materials. It’s an active device that sends a signal into the ground and from the return echoes, information on the structure and properties of the material can be determined.

- **IRT** is a thermal mapping technique using special cameras developed to view the infrared frequency spectrum. These devices make detailed, precision temperature measurements in the IR bands and are useful in determining heat flow and temperature differential between objects. IRT is a passive sensor and relies on external heating from solar radiation.

- **HRI** is high resolution imaging technology currently using one or more 4k resolution cameras to document the features of materials or objects. It can be accomplished using still cameras or video.

- Used together to provide a comprehensive assessment of condition of structure
Background

- GPR & IRT for infrastructure evaluation first introduced in the late 1970’s, early 1980’s
- GPR & IRT are mature technologies and have been investigated and endorsed by many organizations such as FHWA, NCHRP, SHRP and foreign highway organizations
- Utilized by many US State DOT’s
How these Technologies can be used by County Engineers

- Routine Inspections – County roads
- Diagnostics – Determine cause of a problem (i.e. overlay failure, etc)
- Early Identification of Potential Problems – Voids
- Quality Control – on paving projects; monitor asphalt thickness, ensure compaction of HMA
- Project Cost Estimation – bridge deck repairs, estimate area and quantities, reduce cost overruns
TYPICAL USES IN PAVEMENT & BRIDGE DECK EVALUATION

• Corrosion Induced Delamination in Reinforced Bridge Decks
• Pavement Thickness & Depth of Reinforcement
• Voids Beneath Rigid Pavements
• Water Saturated Base & Subbase
• Detection of Cracks / Deterioration
• Detection of Subsurface Pipes, Drains, Pavement Cuts
• Other Applications – Tunnels, Runways, Parking Ramps, etc
Advantages of GPR/IRT/HRI for Evaluation of Bridge Decks & Pavements

- Non-Destructive
- Non-Contacting
- Fast Inspection Speed (up to 55MPH)
- Provide Information on Surface Condition & Internal Condition
- Cost Effective
Penetradar Corporation

- IRIS GPR
- IRT Systems
- HRI Systems
- Vehicle Inspection Systems
- R&D – SHRP, NASA, NVESD
Ground Penetrating Radar
Ground Penetrating Radar

RADAR

Radio Detection And Ranging
Theory – Generation of a GPR Waveform

GPR - Generation of Radar Waveforms

Air $\varepsilon_0 = 1$
Asphalt $\varepsilon_1 = 6$
Concrete $\varepsilon_2 = 8$
Base Material $\varepsilon_3 = 10$
Theory – Generation of a GPR Waveform

<table>
<thead>
<tr>
<th>2 Layer Media</th>
<th>Vt Polarity</th>
<th>Vr Polarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_2 &lt; \varepsilon_1$</td>
<td>noninvert</td>
<td>noninvert</td>
</tr>
<tr>
<td>$\varepsilon_2 &gt; \varepsilon_1$</td>
<td>noninvert</td>
<td>invert</td>
</tr>
<tr>
<td>$\varepsilon_2 = \varepsilon_1$</td>
<td>noninvert</td>
<td>no reflection</td>
</tr>
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</table>
Theory – Generation of a GPR Waveform

(Left) GPR Transmitter Waveform Monocycle Signal (Signal actually generated)

(Right) Actual GPR Waveform
GPR Measurement of Layer Thickness (X) Based on Transit Time of Radar Wave (T) and Radar Wave Velocity (V)

\[ X = V \times T \]
Theory – Generation of a GPR Waveform

- GPR Detection of Deteriorated Concrete is Based on Measurement of Signal Attenuation in the Material
- SHRP C101 Research
- +/- 10 % accurate in determining delamination quantity
• GPR Detection of Voids Beneath Rigid Pavement

• Could be Air or Water-Filled
Theory – Generation of a GPR Waveform

Pavement Cross Section

GPR Pavement Profile Along with Corresponding Pavement Cross Section
Ground Penetrating Radar

OVERVIEW

• GPR Configuration
  • Non-contacting antennas (500MHz to 2.5GHz)
  • 100 Hz scan rate (or greater)
  • 4 Antenna array

• Data Collected as Individual Scans

• Data Analysis and Results in Numerical (Spreadsheet) or Graphical (plan-view map)

GPR bridge deck evaluation. Probable areas of delamination shown as green-yellow-red
Infrared Thermography & High Resolution Imaging
Infrared Thermography

Principles of Operation

IRT is based on measurement of thermal gradient

- Heat Flow - Hot to Cold
- Thermal Radiation a function of Emmissitivy, Conductivity
- For Bridge Decks requires external heating source
Infrared Thermography

HRI and IRT on a Bridge Deck Showing Delaminations – 1.4MB
IRT Plan-View Image is Created From Radiometric Image Data from an Ensemble of IRT Frames
Using Infrared Thermography for QA/QC on HMA Paving Projects

- IRT can monitor temperature of HMA placement to ensure proper compaction
Infrared Thermography

OVERVIEW

• Infrared Camera
  • 640 x 480 resolution (or greater)
  • NETD < 40 mK (noise equivalent temperature difference)
  • 30 Hz scan rate
  • Radiometric data

• Data Collected at Highway Speed, in a Continuous Swath of One Pass per Lane

• Results are converted from forward-view to plan-view.

IRT bridge deck evaluation shown. Delaminations appear as “red” areas
High Resolution Imaging

- High Resolution Video Camera
  - 4k optical resolution (3840 x 2160 pixel = 8.3M pixel)
  - 120Hz scan rate
  - Image Stabilized

- High speed image recording (50MPH)
  - Collected in forward-view
  - Converted to plan-view (top-view)
High Resolution Imaging

High Resolution Image of a Bridge Deck – Zoom In
Bridge Deck and Pavement Evaluation
Using GPR – IRT – HRI Technologies

Applications Discussed

- GPR Pavement Layer Thickness Measurement
- IRT Bridge Deck Evaluation
- GPR & HRI Bridge Deck Evaluation
Bridge Deck and Pavement Evaluation
Pavement Layer Thickness Measurement

GPR PAVEMENT INSPECTION

Pavement Layer Thickness Measurement
$X = VT$

$X$: Thickness of Material Layer  
$V$: Velocity of RF Propagation in Material  
$T$: Travel Time through Material (one Way)
Velocity of Propagation (V)

In Free Space

\[ V = C = 3 \times 10^{10} \text{ cm/sec} \]

In Dielectric Materials

\[ V = \frac{C}{\sqrt{\varepsilon_{rn}}} \]

C = Speed of Light

\( \varepsilon_{rn} \) = Relative Dielectric Constant of Material n
Relative Dielectric Constant

\[
\varepsilon_{rn} = \left[ \frac{(E_i - E_r) \sqrt{\varepsilon_{rn-1}}}{(E_r + E_i)} \right]^2
\]

\( \varepsilon_{rn} \) = relative dielectric constant of material n

\( \varepsilon_{rn-1} \) = relative dielectric constant of material n-1

\( E_i \) = voltage of signal incident to material n

\( E_r \) = voltage of signal incident to material n
Velocity of RF Propagation in Dielectric Materials

\[ \text{Velocity} = \frac{C}{\sqrt{\varepsilon_{rn}}} \]

\[ \text{Velocity} = C \frac{(E_r + E_i)}{(E_i - E_r) \sqrt{\varepsilon_{rn-1}}} \]
Measurement of Transit Time Through Material

- $T =$ Time for Radar Wave to Travel from Top to Bottom
- Transit Time of Signal ($2T$) is Measured
- $T = \frac{1}{2}$ Transit Time
Thickness of Material Layer

\[ X = VT \]

\[ X = C \frac{(E_r + E_i)}{(E_i - E_r) \sqrt{\varepsilon_{rn-1}}} T \]
Pavement Layer Thickness Measurement Case Study
I-87 Tappan Zee Bridge Approach to NYS Thruway

- **Problem:**
  - Pavement With Multiple Asphalt Layers of Unknown Thickness
  - Knowledge of Thickness Required for Rehabilitation

- **Design Specifications**
  - 6 Traffic Lanes
  - 3 inch Bituminous
  - 9 inch PC Concrete
Bridge Deck and Pavement Evaluation
Pavement Layer Thickness Measurement

I-87 Tappan Zee Bridge Approach to NYS Thruway

GPR Survey
- 4 Air-coupled monostatic horn antennas (1ns/1GHz)
- 18 Scans
- Survey Speed 50MPH
- Data Collection Time <1Hr
ColorPro® Color Profile Plot

- ColorPro® Color Profile Plot shows variation in layers as color –vs- depth –vs- distance
- Shown is One (1 of 18) Longitudinal GPR Scans Collected
- Blue lines correspond to asphalt and/or PCC layers
- GPR found Asphalt thickness far greater than 3 inch design

0.5 mile length
IRIS Mapping Software® puts GPR Scans Together to Form an X-Y Plan-view Map of Pavement

- In This Case Asphalt Thickness Ranged From 3 inch to Over 27 inches
Comparison of Average GPR Thickness and 11 Core Samples

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<tr>
<th>LOCATION</th>
<th>CORE THICKNESS</th>
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<tr>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>3.75</td>
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<td>12.5</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>11</td>
<td>16.5</td>
</tr>
</tbody>
</table>

- Average GPR Thickness for Survey = 10.5 Inch
- Average Core Thickness (11 Samples) = 10.45 Inch
- Deviation = 0.5%
Conclusions

- GPR Provided Quantitative Information on Pavement Structure, Thickness and Profile which Helped Determine the Proper Rehabilitation Strategy
- GPR is the **only** method that is capable of providing detailed information on both the longitudinal and transverse asphalt depth profile
Bridge Deck and Pavement Evaluation
IRT Bridge Deck Evaluation

IRT Bridge Deck Evaluation
Concrete Delamination in Bridge Decks

- IRT Detects Fracture Plane Based on Temperature Differential Between Delamination and Surrounding Deck
- Solar Radiation is Used as Heating Source
IRT Bridge Deck Evaluation
Case Study
Route F over Stinson Creek, Callaway County, MO

**Problem:**
- Detection of Delamination at Top Reinforcement
- Considerable surface distress and prior patching of shallow delamination – probable deck deterioration
- Asphalt overlay prevents conventional testing – Difficult to predict repair quantity and cost

**Solution:**
- IRT was selected to locate delamination

**Design Specifications**
- 2 Traffic Lanes + Shoulders
- 1.5 inch Bituminous Overlay
- 8 inch PCC Deck, 1-7/8 Concrete Cover
Top side view of deck appeared in poor condition. There were popouts, with loss of material and efflorescence, deteriorated joints. Transverse and longitudinal cracks present.
Case Study: IRT Bridge Deck Evaluation

IRT Survey
- Late Morning Data Collection
- Data Collection Time less 30 minutes
- Suitable Weather Conditions

Results of Survey
- 9% Delamination
- 91% Sound Concrete
- 15.0% Type 2 Repairs
Infrared Thermographic Map of Bridge Deck

- Colorized Mapping of Radiometric Data
- Red color (warm areas) show delaminations,
- Blue (cool areas) show patches, lane lines and curbs
Infrared Thermographic Map of Bridge Deck

- After Thresholding – Red/Yellow/Green areas remain showing delamination and deck defects – 9.1%
Conclusions

- IRT can provide a cost effective solution to quantifying bridge deck delamination and identifying specific defect areas
Bridge Deck and Pavement Evaluation
GPR & HRI Bridge Deck Evaluation

GPR & HRI Bridge Deck Evaluation
Bridge Deck and Pavement Evaluation
GPR & HRI Bridge Deck Evaluation

- Detect Concrete Delamination
- Detect Freeze-Thaw Damage
- Detect Debonded LMC and Concrete Overlays
- Asphalt Overlay Thickness
- Concrete Cover Over Top Reinforcing Bars
Bridge Deck and Pavement Evaluation
GPR & HRI Bridge Deck Evaluation

Asphalt-Concrete Interface
Top Layer Rebars
Bottom Layer Rebars
Deck Surface
Deck Bottom
Delamination at Top Layer of Rebars
High Conductivity Concrete with Moisture and Chloride
Bridge Deck and Pavement Evaluation
GPR & HRI Bridge Deck Evaluation

GPR & HRI Bridge Deck Evaluation
Case Study
• **Problem:**
  - Determine the cause of early failure of a new LMC overlay placed in 2014. Possibly caused by debonded overlay, corrosion induced delamination?
  - Considerable surface distress observed in new overlay, excessive cracks & spalls

• **Solution:**
  - Conduct GPR investigation to detect debonded overlay and delamination at top reinforcement then compare to HRI surface image for correlation of defects

• **Design Specifications**
  - 4 Traffic Lanes
  - 1.5 inch LMC Overlay, 8 inch PCC Deck
Top side view of the Elmwood Avenue bridge deck appeared in poor condition. There was excessive cracking and spalling was observed in the overlay, which was unexpected considering its age.
Case Study: GPR & HRI Bridge Deck Evaluation

GPR Survey
• 22 Antenna Scans Total
• Survey time < ½ hour
• Data analyzed for delamination and debonding

HRI Survey
• 1 Pass in each direction, collected concurrent with GPR

Results of Survey
• 5.3% Delamination
• 13.1% Debonded Overlay
• 8.7% Surface Distress
Bridge Deck and Pavement Evaluation
GPR & HRI Bridge Deck Evaluation
Bridge Deck and Pavement Evaluation
GPR & HRI Bridge Deck Evaluation
Conclusions

- Both Debonding and Delamination were found to be a problem in the Elmwood Avenue deck
- Major areas of both delamination and surface distress were found in span 4
- Surface distress appeared to be more closely correlated with delamination.
- Therefore, surface distress probably the result of delamination
- Only possible through use of combination of GPR and HRI
Bridge Deck and Pavement Evaluation
Using GPR – IRT – HRI Technologies

ASTM D6087-97/03
Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using GPR

AASHTO TP36
Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Pulsed Radar

SHRP C-101 Project
Condition Evaluation of Concrete Bridges Relative to Reinforcement Corrosion: Method for Evaluating the Condition of Asphalt-Covered Decks

SHRP Product No. 2015 - Ground Penetrating Radar for Evaluation of Asphalt Covered Bridge Decks

ASTM D4748-87
Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short Pulse Radar

ASTM D4788-03
Standard Test Method for Detecting Delaminations in Bridge Decks Using Infrared Thermography
Bridge Deck and Pavement Evaluation
Using GPR – IRT – HRI Technologies

THANK YOU