Nondestructive Testing Technologies for Concrete Bridge Decks (R06A)

Dennis Sack, Olson Engineering SME
Randy Strain, Indiana Department of Transportation
Corey Withroe, Oregon Department of Transportation
Kathy Crowell, New Mexico Department of Transportation

Webinar
April 30, 2019
R06A Webinar Agenda

• AASHTO Introduction
• FHWA Introduction
• NDT of Bridge Decks moving forward
  - Hoda Azari (FHWA)
• R06A NDT background on GPR, Impact Echo and Infrared Cameras – Dennis Sack - SME
• State Experiences - Indiana DOT
• State Experiences - Oregon DOT
• State Experiences – New Mexico DOT
• Questions & Answers
Focus Areas

**Safety**: fostering safer driving through analysis of driver, roadway, and vehicle factors in crashes, near crashes, and ordinary driving

**Reliability**: reducing congestion and creating more predictable travel times through better operations

**Capacity**: planning and designing a highway system that offers minimum disruption and meets the environmental and economic needs of the community

**Renewal**: rapid maintenance and repair of the deteriorating infrastructure using already-available resources, innovations, and technologies
SHRP2 Implementation:
INNOVATE. IMPLEMENT. IMPROVE.

$155 million

FUNDING ASSISTANCE

63

SHRP2 SOLUTIONS

430+

PROJECTS IMPLEMENTED

DOT

52 Recipients

MPO/LOCAL

30 Recipients

UNIVERSITY

12 Recipients

FEDERAL/TRIBAL

7 Recipients

RENEWAL

230+

CAPACITY

100+

RELIABILITY

90+

SAFETY

11

SHRP2 SOLUTIONS | 4
SHRP2 Implementation:
INNOVATE. IMPLEMENT. IMPROVE.

- **304,406** PARTICIPANTS ENGAGED
- **12,378** OUTREACH ACTIVITIES
- **16,629** HOURS TECHNICAL ASSISTANCE

**RESULTS**

*Save lives, money, and time*
- Bridges being built more quickly
- Smoother traffic flows and less congestion
- Reduced construction costs
- Safer roadways
- Smarter environmental reviews
Challenge

• To find non-destructive ways to analysis bridge and tunnel deterioration

Solution

Using technologies such as:
• Ground Penetrating Radar
• Infrared Thermography
• Surface Waves
• Impact Echo
Round 4 had 8 State DOT awards and Round 7 had 14 State DOT awards. The support consisted of:

- Technical Assistance for Rounds 4 and 7
- Field visits and training for State DOT’s
- Peer Exchange workshop in Portland Oregon Jan. 30, 2019
• Round 4 states for R06A began in 2014.
  
  – Louisiana
  – Virginia
  – Indiana
  – Iowa
  – Florida
  – Pennsylvania
  – Oregon
  – Missouri
• 14 states completed their Round 7 testing, validating, and purchasing of various NDT technologies like Infrared Cameras and GPR.

- Alabama
- Arkansas
- Delaware
- Georgia
- Hawaii
- Iowa
- Kentucky
- North Carolina
- California
- North Dakota
- Nebraska
- New Mexico
- New York
- Oregon
Ongoing Projects

• Technology Evaluation:
  NDE techniques on bridge decks with overlay
  Conventional and Phased-array UT for Steel and weld inspection
  Unmanned Arial System (UAS)

• Technology Development/Enhancement:
  Non-contact impact echo
  Magnetic NDE for prestressed girder
  Magnetic NDE for internal PT tendons
  Use of high resolution imaging techniques for condition assessment and damage detection of bridges
  Data fusion and visualization
FHWA Resources to States
• Provide concise and unbiased guidance to help practitioners identify the NDE technologies that can serve their specific need.
• URL: https://fhwaapps.fhwa.dot.gov/ndep/
Virtual NDE Lab

Interactive Data Portals

- Impact Echo (IE)
- Ultrasonic Surface Waves (USW)
- Infrared Thermography (IRT)
- Ground Penetrating (GPR)
- Electrical Resistivity (ER)
- High-Resolution Imaging (HRI)

Experimental Results

The impact-echo method is based on monitoring the surface displacements associated with the arrival of the P-wave as it undergoes multiple reflections between the top and bottom surfaces. The measured voltage, proportional to the surface displacement, is plotted against the time as the waveform. Response spectrum is also presented by absolute Fast Fourier transform based on the chosen range of waveforms. The frequencies corresponding to the dominant amplitude peak for each spectrum are collected to form the contour map with colors, where:

- blue colors indicate regions dominated by a low-frequency response referring to shallow delamination,
- red colors indicate regions dominated by a high-frequency response referring to intermediate delamination,
- orange indicates the regions of deep delamination,
- light blue, green and light yellow colors indicate the normal or non-detected solid regions.
Technical Assistance

- Piece of concrete falls off Bay Bridge tunnel in Feb 2016
- Request From Caltrans for independent validation of sounding results
Moving Forward

• Potential pooled fund projects:
  • Integrating NDE Technologies into condition rating and asset management
  • Documenting NDE best practices and owner-defined return on investment
  • Further advancing and improving the NDE technologies
  • Developing AASHTO specification on data collection and analysis of NDE technologies
  • Developing training and education material for NDE technologies
NDT Methods for Bridge Decks Summary and Discussion

Dennis A. Sack, P.E.
Larry D. Olson, P.E.
Olson Engineering
Challenge: Evaluating the Full Range of Deterioration Types

Deterioration of Interest
- Delamination
- Corrosion
- Vertical cracking
- Degradation
<table>
<thead>
<tr>
<th>NDT Technique</th>
<th>Mode of Deterioration Detected</th>
<th>System</th>
<th>Resolution</th>
<th>Lane Closure</th>
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<tr>
<td>IE</td>
<td>1) Deeper cracks</td>
<td>1) Scanning</td>
<td>High Grid size</td>
<td>Yes</td>
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<tr>
<td></td>
<td>- top and bottom rebar mat</td>
<td>2) Point by Point</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>2) Shallow delamination</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3) Concrete degradation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- ASR/DEF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Freeze thaw</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPR</td>
<td>1) Corrosion</td>
<td>1) Air coupled</td>
<td>Lower High</td>
<td>No</td>
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<tr>
<td></td>
<td>2) Cracks (if filled with deicing salt)</td>
<td>2) Ground coupled</td>
<td>High</td>
<td>Yes</td>
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<tr>
<td></td>
<td>3) Concrete degradation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR</td>
<td>Shallow delamination</td>
<td>1) Truck mounted</td>
<td>High</td>
<td>No</td>
</tr>
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<td></td>
<td>- Top and bottom</td>
<td>2) Handheld</td>
<td>High</td>
<td>Yes</td>
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<tr>
<td>Resistivity</td>
<td>Corrosion</td>
<td>Point by Point</td>
<td>Grid size</td>
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<td>Half Cell/GP</td>
<td>Corrosion</td>
<td>Point by Point</td>
<td>Grid size</td>
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<td>Cracks</td>
<td>Point by Point</td>
<td>Grid size</td>
<td>Yes</td>
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<td>SASW</td>
<td>1) Vertical cracks</td>
<td>1) Scanning</td>
<td>High Grid size</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>2) Concrete degradation</td>
<td>2) Point by point</td>
<td></td>
<td>Yes</td>
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<tr>
<td>Sounding</td>
<td>Only shallow delamination</td>
<td>Manual</td>
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</table>
• Ground Penetrating Radar (GPR)

• Infrared Thermography (IR)

• Impact Echo and Impact Echo Scanning (IE and IES)

• Scanning Spectral Analysis of Surface Waves (SASW)
  – (for asphalt overlaid concrete)
Infrared Thermography Testing

- Most commonly performed on concrete and concrete overlaid bridge decks
- Can detect delaminations at only the top rebar mat (unless done from the deck bottom)
- Cannot “see” through debonded overlays
- Not sensitive to rebar or chlorides in concrete (results will often NOT match GPR results)
- Results will generally show larger areas of delamination and incipient delamination compared to chain dragging
- Requires correct thermal environment to be effective (results affected by shading, weather, time of day, etc.)
IR Testing Performed on a Bridge Deck
Infrared Imaging with Low-Cost Hand-held IR Camera

- FLIR-1 Hand-Held IR Cameras
### Hand-Held IR Examples

**FLIR**

#### MEASUREMENTS (°F)

| Spot   | 85.6 |

#### PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Distance</td>
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<tr>
<td>Relative humidity</td>
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<tr>
<td>Atmospheric temperature</td>
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<tr>
<td>Transmission</td>
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<tr>
<td>Lat.</td>
<td>N 41° 49.72'</td>
</tr>
<tr>
<td>Long.</td>
<td>W 93° 34.73'</td>
</tr>
</tbody>
</table>

- Deck Spall and Nearby Delamination
- Deck Paint Marks PLUS Nearby Small Delaminations (above and below paint)
IR Bridge Inspection Planner
Web Tool

Impact Echo Testing

- Most commonly performed on concrete and concrete overlaid bridge decks
- Can detect delaminations at BOTH the top and bottom rebar mats when testing from the top
- Cannot “see” through debonded overlays
- Not sensitive to rebar or chlorides in concrete (results will often NOT match GPR results)
- Results will generally show larger areas of delamination and incipient delamination compared to chain dragging
Impact Echo Test for Delamination/Cracking/Thickness of Decks

\[ D = \frac{bVp}{2f} \]

- \( D \) = Thickness
- \( b \) = Shape Factor (0.96 for slab)
- \( Vp \) = Compressional Wave Velocity
- \( f \) = Echo Frequency

Note – near test-surface delaminations produce a low frequency/thick resonance that corresponds to hollow, drummy sound in chain dragging in top few inches.
IE Thickness Plot vs. 100 ft Distance for a scan line on a bridge deck

~300mm Approach Slab

~ 200mm Bridge Deck

Time Domain IE Signal at left cursor (Top Plot) and Frequency Domain Echo Depth Resonance=8.3 inches (Bottom Plot)
Overall IE Scanning Result Map from a Bridge Deck – Showing Beams and Deck Areas

Length measured from South End of Approach Slab (ft)

Distance measured from East End of Deck (ft)
SASW Testing

• Most commonly performed on asphalt-overlaid bridge decks

• Can detect delaminations in concrete under asphalt

• Requires accurate asphalt thickness information for best results
Spectral Analysis of Surface Waves Method (SASW)

- Acoustic method – measures the propagation speed of surface waves with various wavelengths
- Short wavelength waves sample shallow, longer wavelengths sample deeper
- Allows the measurement of the velocity profile versus depth into the structure, which can be related to the strength and condition of the concrete versus depth
Bridge Deck Scanner with IE/SASW on Cart on Virginia Asphalt Overlaid Deck
Findings – Bonded Asphalt on Sound Concrete
Sound Concrete with Asphalt Debonding
Bonded Asphalt on Concrete with Top Delamination
Debonded Asphalt / Concrete with Bottom Delamination
Ground Truthing - Hydrodemolition to Reveal Delaminations
GPR Testing

• Most commonly performed on concrete and concrete overlaid bridge decks

• Can detect chlorides and areas of likely future corrosion and subsequent delamination

• NOT always sensitive to current cracking and delaminations unless the cracks or delaminations have salts, corrosion products, or other GPR-reflective material present (results will often NOT match IE, IR or Sounding results)

• Can also map out rebar depth and geometry
Description of the GPR Method

Reflection test
- Using electromagnetic waves
- Sending tiny pulse of energy through its antenna
- Reflecting back from different material or anomalies.

A rapid nondestructive testing method
- Ground Contact (single antenna and multiple antennas)
- Air Horn (multiple antennas)
Physical Principle
Physical Principle (continued)

Reflection Concept

Plane Reflector

Point Reflector
Physical Principle (continued)
GPR, Chain Drag and IE Test Results Comparison

GPR Test Results

Test Results from Sounding

IE (Scanning Test Results)
Example Equipment (Ground Contact Antennas)

3D Radar

MALA

GSSI

IDS

Sensors and Software
Example Equipment (Air Horn Antennas)

- 3D Radar
- GSSI
- IDS Georadar
Deterioration Modes Detected By GPR Testing

- Locations with a dielectric contrast between the two materials (indicative of material property changes)
- Large concrete cracks/voids (air filled)
- Smaller gaps/voids filled with salty water – larger dialectic contrast
- Corrosion, high chlorides, or rust byproducts indicated by lower amplitude reinforcement reflections due to diffraction by rust byproducts as well as attenuation by chlorides
Performances of GPR Test on Concrete Bridge Decks

- **Speed** of data collection - Rapid and reliable
- **Analysis** - Takes more time and requires a high level of expertise
- **Ease of Use** - Requires significant expertise and training
- **Cost** – Moderate-to-expensive system
- **Repeatability** - Repeatable test
- **Accuracy** – Good (better with ground-coupled antennas)
Limitation of GPR Testing on Bridge Decks

- Detect delaminations **only when** they are epoxy-impregnated and/or filled with water/salt in decks
- **De-icing salts** can limit the depth of signal penetration (but this attenuation is used to map high-chloride areas)
- **Limited test results** – cannot provide any information about the mechanical properties of the concrete (strength, modulus, etc.).
- **FCC restrictions**
- Need **validations** from other NDE methods or ground truth
Limitations (continued)

- **Cannot “see”** through dense rebar
- **Does not directly detect cracks** – need “conductive” cracking (water-filled)
- **Depth of air voids** can not usually be estimated
- **Depth of the penetration** depends on the antenna frequency
  - 2600 MHz – 12-15 inch max penetration in concrete
  - 1500 MHz – 18 inch max penetration in concrete
  - 400 MHz – 6 – 10 foot penetration in concrete
Thank you, and please contact us if you have specific questions about any of these test methods
Indiana Department of Transportation

Ground Penetrating Radar Bridge Deck Testing
Randy Strain
• Resource International, Inc. is in the process of completing our first contract of non-destructive bridge deck testing using ground penetrating radar.

• The contract included testing for 230 bridge decks.

• The bridges were selected by the INDOT Bridge Asset Engineers and Bridge Inspection Supervisors.
Bridge Deck constructed in 1994  25 year old deck  Deterioration less than 10%
Bridge deck constructed in 1994 – 25 year old bridge deck
Deterioration just over 10%
INDOT NDT

I65-68-7910
Bartholomew County
Complex Bridge built with a latex overlay

The deterioration is just over 10%

The structure is 20 years old.
IN DOT NDT

• In order to obtain a 28 day yield strength of 4000 psi 658 pounds of cement is used in the mix design.

• Indiana is known for its’ Indiana Limestone, also know as Bedford Limestone.

• Bedford Indiana has been noted to have the highest quality quarried limestone in the United States.

• Wonderful product for building products.

• Not a great stone for obtaining a high strength concrete.
• It appears that building a bridge deck with an overlay may not provide additional protection to the deck. The shrinkage cracks from the deck seem to extend into the overlay.

• Our best protection with our current mix design is to allow the shrinkage cracks to form and the provide protection with a polymeric concrete bridge deck overlay.

• Designing a concrete mix to overcome the shrinkage cracks increases the cost of the concrete by about four and a half times.
• 41-42-5935 BSBL

• 9.7% highly deteriorated
• 38.2% total deterioration
• 48 year old deck
• 24 year old 2nd overlay
• Structure is programmed to be rehabilitated in 2020. The inspector rated the deck a low 6 by notation and recommend the deck be replaced.
Preliminary statistical findings

- Bridges with approximately 10% deterioration should be considered to be in fair condition.

- Bridges with approximately 10% – 20% deterioration may require further testing.

- Bridges with greater than 20% deterioration should be considered in poor condition.
The relation between percent deterioration and percent patching is not a one to one correlation.

This graph is an approximation of the relationship.
When and how often should testing be done?

- The deterioration appears to be minor in bridge decks less than twenty years old.
- The deterioration in latex overlays appears to follow very closely to the same time line.
- The bridge inspectors cannot accurately determine the condition of the bridge decks by visual inspection. A large amount of the deterioration is simply not visible.
- Using NDT at the appropriate time line can assist in the proper evaluation of the bridge deck.
INDOT NDT

• INDOT Bridge Inspectors can use the NDT results to more accurately rate bridge decks.

• Percentage of deterioration does not directly correlate to bridge deck patching.

• Ground penetrating radar is a valuable tool for screening bridge decks.

• The correlation of deterioration percentage to patching has not been accurately determined.
INDOT NDT

• In 2019 we would like to use different methods of NDT and perform quality assurance on the bridge desks tested.

• Perhaps in order to minimize traffic disruption, the touch based NDT might be performed on the bridge deck shoulder then the traffic lanes can be tested at highway speeds.

• Several bridge decks will be followed through the construction contract in order to obtain the correlation between percentage deterioration to bridge deck patching.

• The upper limit of deterioration needs to be identified.
OREGON DOT’s PILOT PROJECTS USING NONDESTRUCTIVE TESTING TECHNIQUES for BRIDGE DECK INSPECTION

Corey Withroe
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Median age: 52 years
1. Can we find things the trained eye can’t see?
   - Corrosion, delaminations, debonding

2. Can we distinguish bridges that need immediate attention from those that can wait 5-10 years?

3. Can we reduce costs—deck inspections/ surveys especially?

4. Are certain types of bridges responding differently?
   - Thin decks/ overlays/ mag chloride
Non-Destructive Evaluation

Prevailing NDE techniques for concrete bridge decks

- **Ground Penetrating Radar (GPR)**
- **Infrared Thermography (IR)**
- **Impact Echo (IE)**
- **Chain Drag**
Phase 1 – High Speed
Results – Interstate Bridge

Chloride Profile

Chloride by mass of concrete (%) vs. Depth (in)

Chloride Threshold

Pier 10

Deterioration detected by GPR
Chloride Profile

Chloride by mass of concrete (%)

Depth (in)

Chloride Threshold

Rebar Depth

Core Location

Deterioration detected by GPR
Delamination detected by IR
Patching
Area not ground-truthed
Delam. detected by Chain Drag
What is this? Nothing on the Surface.

Oh.
I-84, Snake River

Chain Drag

28K ft²
4.2% delam.

Thermal Inertia

10.0% delam.
Replace Deck?

Replace Overlay?

Replace Bridge?

$50\times$ high-speed
Costs

- High-Speed Surveys: 28%
- Mobilization/Management: 8%
- Field Validation: 10%
- Traffic Control: 10%
- Analysis: 44%

Machine Learning could help here.
Ground-Penetrating Radar

![Ground-Penetrating Radar Image](image)

- Time (ns)
- Depth (in)
- Distance (ft)
- Two-Way Traveltime (ns)

**Ground-Penetrating Radar**

**Filtered/Enhanced**

**unfiltered**
1. Can we find things the trained eye can’t see?
   • Corrosion, delaminations, debonding

1a. Yes, but not accurate enough— or cost-effective on a network level. More calibration is needed.

Can show you rebar depths, and where to investigate further.

2. Can we distinguish bridges that need immediate attention from those that can wait 5-10 years?

2a. Yes, and that will be our focus going forward. Less useful in other situations.
3. Can reduce costs—deck surveys especially?
   3a. Won’t replace inventory surveys or destructive testing yet—but can give better repair quantities—and save money by limiting change orders.
   High-speed techniques may be useful if you absolutely can not close a lane.

4. Are certain types of bridges responding differently over time?
   - Thin decks/ overlays/ mag chloride
   4a. Inconclusive, defects correlate between CS2 & CS3
   Less of a focus for us, we’ll continue to look at bridges on project basis.
The Future
SHRP2 R06A
NDT Bridge Decks
= primarily GRP

Kathy Crowell, NMDOT
Dr. Brad Weldon, NMSU
Daniel Diaz, NMSU

special thanks to:
Shane Kuhlman, NMDOT State Bridge Engineer
Dr. Manuel Celaya, Advanced Infrastructure Design
Agenda

• Introduction
• Start with the end in mind
• Things of interest
• Details / Pretty Pictures
• Conclusions
Why NMSU

Ground Penetrating Radar (GPR) for Concrete Bridge Deck Evaluation

Daniel E. Diaz
Dr. Brad D. Weldon

Department of Civil Engineering, New Mexico State University
Why GPR
Existing Equipment

Air Coupled (2 Antenna’s)  2Ghz Frequency

Ground Coupled (4 Antenna’s, 2/freq.)  400Mhz and 900Mhz Frequency

NMDOT CURRENT EQUIPMENT- SIR 30
Existing Equipment
At the end of the day, we intended to create a capability that we did not previously have.

The capability needed to be readily accessible through our bridge inspection contract with NMSU.

AND:
pretty pictures are required
NMDOT does use chlorides (deicing salts) – but not in the whole state

Unique and variable deterioration models

Various and often unintentional overlays
Things of Interest

• $14M in bridge preservation funds controlled by the State Bridge Engineer
• NMDOT is moving towards condition based prioritization using BrM

• Estimating quantities is not very scientific – we pay by actual quantity
• Difficulties in correlating preservation scope and budget
Nine Bridges

6134
6840 (bad deck)
6932
6939 (slab)
7032 (latex overlay + UHPC)

7113
7299
8845 (base)
8852
GPR Evaluation Results: Bridge 8845
NMDOT Typical Prestressed Girder
GPR Evaluation Results: Bridge 8845

- AASHTO Prestressed Girder

- From most current inspection report:
  - Deck: 7
  - Superstructure: 7
  - Substructure: 7

- Deck inspection reports:
  - Isolated transverse and longitudinal cracks up to 1/32” with light leaching (Underside)
  - Transverse and vertical cracks up to 1/16” with light leaching (Deck edges)
GPR Evaluation Results: Bridge 8845
GPR Evaluation Results: Bridge 6840

- AASHTO Prestressed Girder

- From most current inspection report:
  - Deck: 4
  - Superstructure: 5
  - Substructure: 6

- Deck inspection reports:
  - Transverse and longitudinal cracks up to 1/8” with heavy leaching (deck edges); transverse and longitudinal cracks up to 1/16” with heavy leaching and rust stains near joints
Reflection amplitudes picks, X and Y location coordinates, and two-way travel time are obtained using Radan 7.
GPR Evaluation Results: Excel Processing Bridge 6840

- Information obtained from Radan 7 exported to Excel for further processing
GPR Evaluation Results: Bridge 6840
GPR Evaluation Results: Bridge 6939 (slab)
GPR Evaluation Results: Bridge 6939

• Concrete Slab Bridge – Asphalt Overlay

• From most current inspection report:
  – Deck: 5
  – Superstructure: 5
  – Substructure: 6

• Deck inspection reports:
  – Vertical, horizontal, transverse and map cracks up to 1/4” (deck edges); transverse and map cracks up to 1/16”, areas of moderate leaching, and spalls up to 6” by 5” (Underside)
GPR Evaluation Results: Bridge 6939
“Normal Deck”

- It works to help determine whether a deck is a preservation candidate versus replacement.
“Slab Deck”

- Good as first pass
- Second pass (more detailed) really necessary as DEPTH of the areas of concern is critical to decision / quantity
Overlay

- Seems to work in “seeing through” asphalt
- Seems to work with “seeing through” epoxy overlay (by extension, will likely work with polyester overlay)
- Does NOT seem to work with latex modified overlay
Successful Project

• We learned a lot
• We developed a capability that we did not previously have (implementation)
• Research value, published research, and developed engineering talent
Executive Summary

GPR is not the magic bullet

But it has value when applied appropriately

Decision must be project specific (bridge type, data need)
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