Welcome to Oregon
And a Look at Our R06A Experience

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Thank You

Bruce Johnson  State Bridge Engineer
Kevin Chesnik, Applied Research Associates
FHWA, AASHTO and their representatives in attendance
Mike Goff, ODOT Region 2 Bridge Inspector,
Jeff Swanstrom, ODOT Senior Bridge Inspector (Ret.)
John Adkins, ODOT Region 4 Bridge Inspector,
Debera-Jean Murdoch, Procurement Coordinator,
Andrew Blower, ODOT Corrosion Protection Engineer
Liantao Xu, Region 1 Senior Bridge Designer,
George Bornstedt, Region 5 Senior Bridge Designer,
Bryan Mast, Region 3 Bridge Maintenance Manager
Benjamin King, Region 3 Senior Construction Coordinator
Our maintenance crews, and D&H Flagging.
Our contracting Partners, especially
Adam Carmichael at Infrasense
Paul Fuchs at ThermalStare
Dennis Sack, Yajai Tinkey, from Olson Engineering
The Reader/ Listener
Introduction

1. Background & our inventory
2. Our initial strategy
3. Results and case studies
4. How that initial strategy has changed during this process
5. The near future of NDE on bridge decks
6. Potential applications on tunnels

Image 3: FC inspection of NB Interstate Bridge
Corrosion Related-
Determine whether the defects are in fact, “Corrosion Related”. If any of the following conditions exist, the bridge inspector needs to instigate the specified actions:
1. Concrete Deck Element is in **condition state 3**, chain drag and map the bridge deck.
2. Concrete Deck Element is in **condition state 4**, take cores and test quality of deck materials.

**Condition state 3:**
1. Delams/ Spall > 1”
2. Cracks: > 0.009” or < 1’ apart
3. Exposed rebar w/ measurable section loss
4. Rutting causing > 1” deep ponding
5. Coarse aggregate loose or popped out

**Condition State 4:**
1. Anything Warranting Structural Review
OREGON DOT Bridge Design Manual

QUANTITY ESTIMATES

Class 2 Deck Preparation (SC Overlays only)

A deck survey is recommended to confirm the estimated quantity of both Class 2 and Class 3 Deck Preparation. Chain drag, *infrared scan, impact echo or ground penetrating radar* (GPR) [are] acceptable methods of performing a deck survey.

- **When at least the bottom half of deck is still sound**
- **~$270/ yd²** (2017 cost data)

Class 3 Deck Preparation (SC Overlays only)

- **When concrete beyond mid-depth needs removal**
- **~$650/ yd²**
### Background

A table showing data for different categories (Deck, Superstructure, Substructure, Culvert#) with NBI Rating (N, μ, σ) for various years and ratings. The table includes:

- **Years at 8**
  - Deck: 1899, μ: 8.72, σ: 6.49
  - Substructure: 2031, μ: 10.92, σ: 7.30
  - Culvert#: 35, μ: 5.35, σ: 3.24

- **Years at 7**
  - Deck: 1354, μ: 12.12, σ: 6.55
  - Superstructure: 1308, μ: 11.49, σ: 6.50
  - Substructure: 1372, μ: 11.51, σ: 7.05
  - Culvert#: 91, μ: 6.49, σ: 3.23

- **Years at 6**
  - Deck: 230, μ: 9.13, σ: 5.75
  - Superstructure: 154, μ: 9.20, σ: 5.35
  - Substructure: 232, μ: 9.28, σ: 5.69
  - Culvert#: 85, μ: 6.80, σ: 3.05

- **Years at 5* and**
  - Deck: 18, μ: 9.44, σ: 5.86
  - Superstructure: 6, μ: 8.50, σ: 4.11
  - Substructure: 14, μ: 9.71, σ: 5.26
  - Culvert#: 21, μ: 4.35, σ: 0.00

- **Years at 4* and**
  - Deck: 21, μ: 5.52, σ: 3.38
  - Superstructure: 10, μ: 2.70, σ: 5.50
  - Substructure: 18, μ: 6.33, σ: 4.29

*Included if 4 is current rating

# only 10 years of data and included if current rating

**Included in N only if dropped**

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**Deck**

A histogram showing the distribution of bridges for a specific year, labeled as **Years at 5**. The x-axis represents the number of years at 5, and the y-axis represents the number of bridges.
**Background**

**SD Deck Count - 12 year dwell**
As of 2017

![Graph showing SD Deck Count - 12 year dwell as of 2017](chart_2)

**Deck Elements Health Index by year and group**
As of 2017

![Graph showing Deck Elements Health Index by year and group as of 2017](chart_3)

**HI for Deck or Superstructure or Substructure**

\[
HI = \sum \left( \frac{\text{Element Quantity}_{CS-1} \cdot (1)}{\sum \text{Total Element Quantity} \cdot \text{Element Weight}} + \frac{\text{Element Quantity}_{CS-2} \cdot (2/3)}{\sum \text{Total Element Quantity} \cdot \text{Element Weight}} + \frac{\text{Element Quantity}_{CS-3} \cdot (1/3)}{\sum \text{Total Element Quantity} \cdot \text{Element Weight}} \right)
\]
“Network Level” High-Speed, GPR, IR, HD Video

“Project Level” Impact Echo & Chain Drag (with lane closure)
**Costs**

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

**Chart 4**
**GPR:**
- ASTM D6087-08
- Dual 2Ghz Horns, GSSI, Inc.
- 3’ Transverse increments
- 40’ = 13 lines
- May, July 2017
- 70°-87° F;
- 11:00AM – 6:30 PM
- 4 passes/ 2 lanes + shoulder
- ≤ 60 mph

**IR:**
- ASTM D4788-03 (2013)
- 640x480 FLIR Model A655sc
- Sony a7 4K camera
- May, July 2017
- 70°-87° F;
- 11:00AM – 6:30 PM
- 4 passes/ 2 lanes + shoulder
- ≤ 50 mph
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<thead>
<tr>
<th>BRIDGE_ID</th>
<th>YEARBUILT</th>
<th>MATERIALMAIN</th>
<th>DESIGNMAIN</th>
<th>DKSURFTYPE</th>
<th>DKRATING</th>
<th>Notes</th>
<th>INF_Del</th>
<th>INF_GPR</th>
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<th>CS3</th>
<th>DK_HI</th>
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<td>1956</td>
<td>2 Concrete</td>
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<td>4</td>
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<td>16%</td>
<td>16%</td>
<td>83%</td>
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<td>71%</td>
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<td>Stringer/Girder</td>
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<td>4</td>
<td></td>
<td>3%</td>
<td>14%</td>
<td>19%</td>
<td>0%</td>
<td>94%</td>
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<td>1964</td>
<td>3 Steel</td>
<td>15 Movable Lift</td>
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<td>29%</td>
<td>40%</td>
<td>1%</td>
<td>86%</td>
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<tr>
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<td>1971</td>
<td>6 P/S Concre</td>
<td>05 Multiple Box Beam</td>
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<td>7%</td>
<td>22%</td>
<td>55%</td>
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<td>83%</td>
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<td>08114</td>
<td>1958</td>
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<td>5 Epoxy Overlay</td>
<td>6</td>
<td>Large shadow from tree at west end of deck</td>
<td>3%</td>
<td>21%</td>
<td>70%</td>
<td>16%</td>
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<td>IR data limited due to extensive tree shadows.</td>
<td>10%</td>
<td>10%</td>
<td>3%</td>
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<td>8%</td>
<td>14%</td>
<td>37%</td>
<td>2%</td>
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<td>1955</td>
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<td>09 Truss-Deck</td>
<td>1 Monolithic</td>
<td>6</td>
<td>Extensive cracking throughout</td>
<td>5%</td>
<td>7%</td>
<td>2%</td>
<td>0%</td>
<td>99%</td>
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<tr>
<td>17225</td>
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<td>05 Multiple Box Beam</td>
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<td>13%</td>
<td>50%</td>
<td>0%</td>
<td>85%</td>
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<td>6%</td>
<td>8%</td>
<td>42%</td>
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CS2 > GPR Defects, IR Delams > CS3
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<th>DK HI</th>
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<td>12%</td>
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<td>1972</td>
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<td>11%</td>
<td>1%</td>
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<td>09632A</td>
<td>1972</td>
<td>Steel</td>
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<td>Epoxy Overlay</td>
<td>3%</td>
<td>9%</td>
<td>2%</td>
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<td>5%</td>
<td>20%</td>
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<td>3 Latex Concrete/Similar</td>
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<td>25%</td>
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<td>1972</td>
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<td>Slab</td>
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<td>6%</td>
<td>26%</td>
<td>7%</td>
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<td>1969</td>
<td>Steel</td>
<td>Continuous</td>
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<td>6%</td>
<td>17%</td>
<td>13%</td>
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<td>19865</td>
<td>2004</td>
<td>Steel</td>
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<td>11%</td>
<td>10%</td>
<td>18%</td>
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<td>20743</td>
<td>2009</td>
<td>Prestressed Concrete</td>
<td>Multiple Box Beam</td>
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<td>Infrared effectiveness limited due to depth of rebar &gt;4.5 inches</td>
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<td>10%</td>
<td>1%</td>
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<tr>
<td>20742</td>
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<td>Prestressed Concrete</td>
<td>Multiple Box Beam</td>
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<td>Significant amount of debris along both shoulders</td>
<td>8%</td>
<td>5%</td>
<td>14%</td>
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GPR Defects, IR Delams > CS2

09635A – Outlier, (CS2 cracking/ CS3 Rutting)
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<td>Columbia R &amp; N Hayden Isl Dr, Hwy 1 NB (Interstate)</td>
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<tr>
<td>07864A</td>
<td>Hwy 1 over 16th Street (Landess Rd)</td>
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<tr>
<td>08221A</td>
<td>Hwy 1 NB over Knox Butte Rd (North Albany Intchg)</td>
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<td>08221B</td>
<td>Hwy 1 NB over Hwy 58 NB (North Albany Intchg)</td>
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<td>07865A</td>
<td>Hwy 1 over Taylor Ave</td>
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<td>08828</td>
<td>Hwy 9 over POTB RR at MP 59.32</td>
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<td>02349</td>
<td>Lake Lytle Outlet, Hwy 9</td>
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<td>Columbia R &amp; N Hayden Isl Dr, Hwy 1 SB (Interstate)</td>
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<td>Tanner Creek, Hwy 2 WB</td>
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<th>YEARBUILT</th>
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<th>DESIGNM</th>
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<td>AIN</td>
<td></td>
<td></td>
<td>INF_ Del</td>
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<td>Continuous</td>
<td>01 Slab</td>
<td>3 Latex Concrete/Similar</td>
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<td>1955</td>
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<td>03 Girdler-Floorbeam</td>
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<td>1958</td>
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<td>04 Tee Beam</td>
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<td>1938</td>
<td>7 Wood or Timber</td>
<td>02 Stringer/Girdler</td>
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<td></td>
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<tr>
<td>1958</td>
<td>3 Steel</td>
<td>Continuous</td>
<td>15 Movable - Lift</td>
<td>3 Latex Concrete/Similar</td>
<td>6</td>
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<td>1963</td>
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<td>02 Stringer/Girdler</td>
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<td>1958</td>
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<td>1950</td>
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<td>Continuous</td>
<td>02 Stringer/Girdler</td>
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<td></td>
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CS2 > GPR Defects, IR Delams > CS3

Table 4
Coring indicates chloride content **above** initiation threshold—not indicated with high-speed GPR scans.

**Initial Results – Bridge 02071A**

**Chloride Profile**

- Curve Fit
- Corr. Threshold
- Rebar Depth
- Core 1
- Core 2
- Core 3
- Core 4
- Core 5
- Core 6

**Chloride Concentrations (Curve Fit, 6 Cores)**

**Figure 9**

**Location of core 5**

0 20 40 60 80 100 120 140 160 180 200
Distance from Bent 1 (ft)

Bent 1 Pier 1

**Figure 10**

**Location of core 3**

200 220 240 260 280 300 320 340 360
Distance from Bent 1 (ft)

Pier 2 Bent 2

Chart 5  Evaluation of in-service Bridge Decks using Chloride Analysis
Initial Results – Bridge 01377A

Chart 6  Evaluation of in-service Bridge Decks using Chloride Analysis

Cores 3 & 4

Image 4: Coring the NB Interstate Bridge

Figure 12
Initial Results – Bridge 01377A

**Figure 13**

- Cores 11,12

- Chart 6 Evaluation of in-service Bridge Decks using Chloride Analysis

**Figure 14**

- Cores 9,10

- Pier 4

- Chloride Profile
Coring indicates chloride content below initiation threshold—not indicated with high-speed GPR scans

4 samples (locations unknown)

ADT: 66,150 (NB Only)
Results – Field Validation – Bridge 02349

Figure 17: Chain drag and impact echo on Br 02349.
Results – Impact Echo Tools

ASTM C1383-15
P-Wave speed/ Thickness Measurement in concrete slabs

Olson Instruments NDE 360 unit and CTG-2 unit

“Typical velocity \([C_{p\_plate}]\) for concrete (12,000 ft/s)”

\[ C_{p\_plate} = 0.96 \ C_p \]

= 0.96 * P-wave speed
<table>
<thead>
<tr>
<th>Bridge</th>
<th>Area surveyed (ft²)</th>
<th>ODOT DELAM (ft²)</th>
<th>% delam'ed</th>
<th>Matches (ft²)</th>
<th>% matching</th>
<th>% False negative</th>
<th>Infrasense Delam. (ft²)</th>
<th>% delam'ed</th>
<th>Matches ODOT (ft²)</th>
<th>% matching</th>
<th>% False Positive</th>
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<td>173</td>
<td>2.66%</td>
<td>64.8</td>
<td>37.5%</td>
<td>62.5%</td>
<td>740</td>
<td>11.39%</td>
<td>65</td>
<td>8.8%</td>
<td>91.2%</td>
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<td>08958F</td>
<td>17340</td>
<td>40</td>
<td>0.23%</td>
<td>29</td>
<td>72.5%</td>
<td>27.5%</td>
<td>1018</td>
<td>5.87%</td>
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<td>2.8%</td>
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<td>25.0%</td>
<td>75.0%</td>
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<td>0.4%</td>
<td>99.6%</td>
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<td>102</td>
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<td>14</td>
<td>13.7%</td>
<td>86.3%</td>
<td>261</td>
<td>7.88%</td>
<td>14.8</td>
<td>5.7%</td>
<td>94.3%</td>
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<tr>
<td>07404</td>
<td>13200</td>
<td>75</td>
<td>0.57%</td>
<td>12</td>
<td>16.0%</td>
<td>84.0%</td>
<td>596</td>
<td>4.52%</td>
<td>11.2</td>
<td>1.9%</td>
<td>98.1%</td>
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</tbody>
</table>

Chain Drag Results vs Infrared Scanning to determine delamination quantities/ location
November 27- December 2, 2017
Measurements ±10%
Routine Inspection:
Thin Overlay Recommended
(CS2 Efflorescence
Polished aggregates in wheel paths
Extensive CS1 Cracking)

Deck sealed previously
Conditions: 42°, foggy, moderate fast traffic

Delamination detected by ODOT chain drag survey 12/1
No delaminations detected

Figure 23

Concrete Cover

Figure 24
Results – Vets Bridge (07404) I-5 over S. Umpqua River

Conditions: 42°, foggy, moderate fast traffic

Figure 25
Exposed rebar
1' x 2'
1' x 2'

Figure 26
Exposed rebar
1' x 1'
1' x 1' spall
1' x 1'

Concrete Condition Legend
- Deterioration detected by GPR
- Delamination detected by IR
- IE (delam)
- IE (no delam)
- Patching
- Not detectable by IR / GPR

Orientation
- Direction of traffic

Quantity Summary
- Delamination (IR): 1611 sq. ft., 5.5%
- Deterioration (GPR): 2084 sq. ft., 7.1%
- Patching (Visual): NA, 0.0%

General Information
- Bridge ID: 07404
- I-5 SB over S Umpqua R
- Analyzed by: GCJC
- Reviewed by: EG
- Completed: 2004
- Sheet: 3 of 3

Other Notes: 12/1
Not surveyed: 12/1

2 of 3
I didn’t see anything on the surface. I dragged my chain over it several times,

Although this isn’t the exact spot, this could be what’s going on (report recommended patching several like it)
Results – Vets Bridge (07404) I-5 over S. Umpqua River

conditions: 42°, foggy, moderate fast traffic

Vets Bridge (I-5 near Roseburg)
Monolithic Concrete – Deck Truss

Delamination detected by ODOT chain drag survey 12/1

No delaminations detected

Other Notes 12/1

Not surveyed 12/1

Concrete Condition Legend

<table>
<thead>
<tr>
<th>Condition</th>
<th>Legend</th>
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<td>Deterioration</td>
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<tr>
<td>detected by IR</td>
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<td>IE (delam)</td>
<td>Patching</td>
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<tr>
<td>IE (no delam)</td>
<td>Not detectable by IR / GPR</td>
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</table>

Orientation

Distance from Bent 1 (ft)

Quantity Summary

<table>
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<tr>
<th>Condition</th>
<th>sq. ft.</th>
<th>%</th>
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<tbody>
<tr>
<td>Delamination (IR)</td>
<td>1611</td>
<td>5.5</td>
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<tr>
<td>Deterioration (GPR)</td>
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<td>7.1</td>
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<tr>
<td>Patching (Visual)</td>
<td>NA</td>
<td>0.0</td>
</tr>
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</table>

General Information

Bridge ID: 07404
I-5 SB over S Umpqua R

Analyzed by: GCNJ
Review and Approval: CJP

Completed: 3 of 3

Sheet 1 of 1
Hairline map cracking prior to seal

Shade from a Cottonwood (?) South end ~ 6pm summertime
Spall with exposed rebar appears as Delam of different shape on map
### Results – Vets Bridge (07404) I-5 over S. Umpqua River

**Final Repair**

<table>
<thead>
<tr>
<th>VETS Bridge</th>
<th>ODOT₁</th>
<th>ODOT₂</th>
<th>Vendor₁</th>
<th>ODOT₃</th>
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<td>Southbound Only</td>
<td>Chain Drag SB</td>
<td>Routine</td>
<td>Infrared</td>
<td>GPR SB</td>
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<td>Bridge</td>
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<td>Inspection</td>
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<td>08203B</td>
<td>13200</td>
<td>37039</td>
<td>29300</td>
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<td>Area Surveyed</td>
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<tr>
<td>75</td>
<td>15</td>
<td>1573.6</td>
<td>596</td>
<td>2084</td>
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<tr>
<td>% Delam/Deteriorated</td>
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<tr>
<td>0.57%</td>
<td>0.04%</td>
<td>5.37%</td>
<td>4.52%</td>
<td>7.1%</td>
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<tr>
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<td>12</td>
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<tr>
<td>% Matching</td>
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<td>16.0%</td>
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<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Most repairs on south side of bridge, no class 3 prep**
Conclusions:

NDE estimates > actual quantities > chain drag
Thin wearing surface (25% CS3)
40 ft² of CS2 Spalls
1985 overlay
PPC overlay sometime since
Better Delamination Correlation
14% Delamination

Note slight shifting of well-established patching locations

Conclusions: SB Deck to be replaced (2021)
Conventional (static) Infrared vs Long-term Infrared

Figure 33
Infrared- “Ultra Time Domain”
Principle: two day/night cycles rather than a sliver of time
To create time-lapsed thermal measurements
- Chain drag dramatically under-detects defects
- Intact cores agreed with IR results
Three options for bridge based (in part) on NDE results

1. Replace the overlay if deck is sound
2. Apply PPC overlay to extend life 15-20 years
3. Replace the entire bridge

Routine Inspection: Top Flange
- 3% CS3 (rust staining)
- 12% CS2 (soffit cracking)
- Spalls, exposed rebar
- LMC overlay Sealed (2104)
- Column spalls & cracks
- Two, 2-3 hour shoulder closures
  - $1800
- 48 Hour duration

- Significantly more expensive than high-speed
  - ~$1.75/ft²
  - ~¢1.75/ft²
- Chain drag, coring also performed (outside R06A)
- One sample used to calibrate IR-UTD
Processed for subsurface structural details
Structural view with identified defects
Processed for surface defects
• **3rd Party Inspection ~25% delaminated:**
  - NB: 1700 ft² of Delamination
  - SB: 1400 ft² of Delamination
  - 0.007% - 0.022% chlorides from core samples
  - (deemed not sufficiently close to the 0.04% threshold)
  - 4,000 – 8,600 psi

• **Long Term Infrared (~5.6% delaminated, more precisely drawn)**
  - NB: 500 ft²
  - SB: 460 ft²
  - Core sample sent to potentially calibrate depth of delamination

• **Recall High-speed infrared (~7% delaminated, 13% defect by GPR)**
Q: How long is the coast of Britain?
A: It depends on the size of your measuring stick.

(Why it would be helpful to have an agreed upon standard)

Conclusions:

- Chain drag/coring and long-term IR make the same recommendation: replace structural overlay
- But: because of life cycle costs/roadway & traffic control
  - ADT: 121,000
- Decision was made to replace whole structure with thicker deck
- So we won’t actually get a direct relation to quantities
- We will get a cost-effective bridge
Routine Inspection: RC Deck

- 30% CS2 (Delamination, cracking, rutting)
- 1% CS3 (Exposed rebar, cracking)

Maintenance Recommendations:
- Rehab deck (2017)
- Patch spalls/exposed rebar (2007)
- 1% CS3 (Exposed rebar, cracking)
Chloride Profile

Chart 7  Evaluation of in-service Bridge Decks using Chloride Analysis

Cores 3, 4

Lift span interference

Figure 47
Cores 1, 2
Conclusions:

**Chain Drag Quantities:**
- 219 ft² delams (0.1%)
- 322 ft² Exposed Rebar (0.1%)
- 1400 ft² CS3 Cracking (0.5%)
- 34,800 ft² CS2 Cracking (13%)

**High-Speed:**
- 1676 ft² Delam (IR) (6%)
- 78,000 ft² Defective (GPR) (29%)

**Solution**
Overlay (awaiting quantities) & Cathodic Protection
Traffic noise proved to limit effectiveness of the human ear as a sensor—with or without earplugs.

(NRR 29 are standard earplugs, which reduces noise level \((29-7)/2 = 11 \text{ dB}\) and performance is better at high-frequency sound (8000 Hz vs. 125 Hz.)

“Flexural oscillation of a delaminated area is typically in a 1 to 3 kHz Range.”

Manual Sounding – Note earplugs
Sounding
Robot-Assisted Bridge Inspection Tool

5 instruments for recording; 1 laser scanner for navigation
Ultrasonic Surface Wave
ksi (lower is worse)

Electric Resistivity
kOhm (High Resistivity is Worse)

Impact Echo
Hz (lower is worse)
The Future

**GPR**

$dB$ (lower = less cover)

---

**Cover Depth**

(In.) Can we get to ± 0.5 inches?

---

**Repair Areas**

Serious, Poor
Fair, Good = CS1, 2, 3, 4, etc.? Or Class 1, 2, 3 removal?
The Future

- Our current platforms can fly for approx. 20 mins per battery set
- We do not own a thermal camera at this point, but the off the shelf option is a FLIR XT camera @ $10k
- Photos can be shot at a fixed interval and analyzed on free desktop software provided by FLIR
- We are just starting to research the idea of a tethered UAS option. This would allow for a constant power and data feed to keep the UAS in the air for extended periods of time. I am submitting a research proposal to study the effectiveness of this solution.

-Christopher Harris PE,
ODOT Engineering Automation

Wind and airspace restrictions remain limiting factors for drone inspection – not the cameras or the payload capacity

Figure 56
• Network-wide strategies and high-speed methods are not in our near-future, full-scale implementation plans

• That said, we are still calibrating the raw data for more meaningful definitions and precise, reliable defect quantities
  • Shared interest between agencies and contractors in fine-tuning data \(\rightarrow\) defect translations.

• We have already seen how more intensive NDE methods can inform specific decisions on bridges for which there is planned work and avoid large quantity-related, change order costs (on the order of $100,000)

• Thankful for the opportunity to explore these options and learn from other states
Questions for the group

1. Have you discovered reliable techniques for determining depth of delamination (below half thickness)?

2. Do you have well-defined contract or procedure language for your results?
   1. What does “good”, “fair”, “poor”, “severe” mean?
   2. How do you otherwise interpret or quantify these terms?

3. Your best methods for sharing these results with other parts of your agency?

4. Any recommendations on standardizing?
   1. Units of measurement
   2. Environmental limitations
2. Oregon Department of Transportation, *Bridge Design Manual*
3. Oregon Department of Transportation, *Bridge Cost Data 2017*
4. Blower, Andrew S. *Evaluation of in-service Bridge Decks using Chloride Analysis*
   Oregon Department of Transportation SHRP2 R19A Service Life Design Study – Phase II, 2017
5. Federal Highway Administration Research and Technology, Non Destructive Evaluation Web Manual
6. Gillins, Daniel T. Parrish, Christopher, Gillins, Matthew, Simpson, Chase *Eyes in the Sky: Bridge Inspections with Unmanned Aerial Vehicles* 2018
   https://ww.oregon.gov/ODOT/Programs/ResearchDocuments/SPR787_Eyes_in_the_Sky.pdf