1. Introduction
The objective of this project is to evaluate the condition of the 14 bridge decks listed in Attachment A, which are located in the Jacksonville area. The deck condition evaluations were carried out using infrared thermography (IR), ground penetrating radar (GPR), and high resolution video imaging. Impact echo and hammer sounding were also used to augment the IR and GPR results. The deck condition information will be utilized by RS&H and FDOT (District 2) to plan future maintenance and rehabilitation efforts.

2. Data Collection
The IR and GPR survey work took place on May 2nd and 3rd. The weather conditions were sunny to partly cloudy with temperatures in the mid-80’s to low-90’s (°F). The impact-echo (IE) testing and hammer sounding was completed on June 6th, using the preliminary results of the IR and GPR analyses to target a minimum of 10 locations per bridge deck. Infrared data was collected for 11 decks, and GPR and IE data was collected for select lanes of 9 decks as prescribed by Florida DOT (see Attachment A for details). The IR, GPR, and IE equipment used for this project is shown in Attachment B.

2.1 Infrared Thermography (IR)
The infrared thermography survey was carried out according to ASTM D 4788 – 03 (2013) using a 320 x 240 pixel FLIR Systems Model A-40 infrared camera and a Garmin 1080p VIRB video camera, both mounted to an elevated platform on top of the survey vehicle and operated remotely from within the vehicle. Data was collected from 10 AM to 5 PM, ensuring maximum temperature differentials caused by delamination.

The infrared data was collected in a series of passes across each deck, moving at approximately 50 mph. For a typical interstate deck with 2 lanes and left and right shoulders, the survey requires four passes—one in each lane and one in each shoulder. Each pass covers a deck width of 12 to 15 feet. The IR camera is connected to an electronic distance measuring instrument (DMI) and set to record an image for every foot of travel.

2.2 Ground Penetrating Radar (GPR)
The GPR surveys were carried out according to ASTM D 6087-08 using a dual 1 GHz horn antenna system manufactured by GSSI, Inc. of Nashua, NH. The GPR data was collected in a series of lines spaced 3 feet transversely across the width of each deck at speeds up to 55 mph. A typical 40-foot-wide deck would have 13 lines of data, each representing a cross sectional slice of the deck at a particular offset. The DMI distance data is continuously recorded into each GPR record, so that each GPR data scan has an associated distance.

2.3 Impact-Echo (IE)
The impact-echo testing was carried out according to ASTM C1383-15 using an Olson Instruments NDE-360 unit. A total of 114 locations were tested, with a minimum of 10 locations for each of the
prescribed decks to confirm the infrared and GPR results. Test locations were selected using the preliminary results of the GPR and IR analyses.

3. Data Processing and Analysis

3.1 Infrared Thermography (IR)

The infrared data is reviewed simultaneously with the video data to differentiate delaminated areas from surface features (discoloration, oil stains, sand and rust deposits, etc.) that appear in the infrared, but are unrelated to subsurface conditions. Figure 1 shows an example of delaminated areas as they appear in a single image of infrared data and in the corresponding visual data. For analyzing this data, a horizontal slice is taken from each image, calibrated so that it captures an area that is 1 foot in the direction of travel. Sequential slices are then stitched together to create a single strip image for each pass. The strip image for each pass is placed next to those of adjacent passes to produce a composite thermal image of the entire deck as shown in Figure 2 (bridge 720079).

![Delaminated areas](image1.png)

**Figure 1. Sample Infrared and Visual images**

The white blotchy areas on the IR image of Figure 2 indicate delaminations. These are "hot spots" where the surface temperatures are higher due to the thermal barrier produced by the delaminations. Surface staining/discoloration can also produce “hot spots” unrelated to subsurface conditions. The darker the color of the deck surface, the higher the emissivity and corresponding surface temperature. Figure 3 shows the stained areas highlighted in Figure 2 as they appear in the visual data.

Thermal images such as those shown in Figure 2 have been created for each bridge surveyed under this project. For the analysis, the delaminated and debonded areas that appear in each image are delineated and quantified. Areas where the IR data was obscured (by shadows, staining, water, debris, etc.) were also mapped and quantified. When calculating the delamination percentage for each deck, the obscured area was first subtracted from the total area to account for the reduction in useful data.

3.2 Ground Penetrating Radar (GPR)

The GPR analysis is carried out with Infrasense's proprietary software wnDECAR® using the following steps:

1. Identification of the beginning and the end of the deck in each radar file, and check of the radar distance measurement against the known length and other features within the deck;
2. Identification of features (top rebar, bottom of deck) that appear as dielectric discontinuities in the GPR data (see example data, Figure 4);
3. Setup of the analysis for all of the passes for a given deck, computation of concrete dielectric constant, rebar depth, and concrete attenuation;

The analyzed GPR data is presented in the form of contour plots. The potential areas of delaminated and scaled concrete are identified by a threshold, which is calculated from statistics of the analyzed
data. Figures 4 and 5 show samples of GPR data used for the condition assessment. Figure 4 is a sample of GPR data recorded along the left wheel-path of the inside lane of bridge 720174. Note that the reflections from the rebar and deck bottom are both strong (relatively high amplitude) and uniform throughout the length of the pass.

Figure 4. Sample GPR data from bridge 720174 (left lane).

Figure 5 provides a sample of GPR data recorded in the shoulder of the southbound direction of bridge 720323, showing typical signs of deterioration. The weakening of the reflection (attenuation) from the top rebar layer and the bottom of the deck is an indication of corrosion, chloride contamination, and possible delamination.

Figure 5. GPR data from Bridge 720323 showing typical signs of deterioration.

3.3 Impact-Echo (IE)

Impact-echo testing was carried out at 114 locations to validate the IR and GPR results. Test locations were selected using the preliminary condition maps. The impact-echo test provides a resonant frequency associated with the thickness of the deck slab. If the slab is intact, the thickness data is clear, and should correspond with the expected slab thickness. If the slab is delaminated, the thickness data is unclear and generally does not correspond to the thickness of the slab. Figure 6 provides example data from both a sound and delaminated location. Note that the thickness scale on these plots is in feet. The thickness in plot (a) corresponds to the expected thickness (sound), where the thickness in plot (b) is very different (delaminated). The impact-echo results were subsequently used to calibrate the preliminary IR and GPR results and produce the final version of the condition maps presented in Attachment C.
4. Results

The results of the nondestructive deck evaluations include the summary table in Attachment A, and the condition and rebar-depth maps provided as Attachment C. These results were obtained using the combination of infrared thermography (IR), ground penetrating radar (GPR), and impact-echo (IE) prescribed by Florida DOT, District 2. Of the 14 bridges, 6 were surveyed using IR, GPR and IE, 5 were surveyed using IR only, and the remaining 3 were surveyed using GPR and IE. The GPR and IE testing were limited to select lanes for 7 of the decks (see Attachment A for details). Note that the quantities provided in Attachment A are reported as a percentage of the surveyed area, accounting for the presence of physical obstructions (lane closures) and thermal obstructions (staining, shadows, debris).

The final condition maps (Attachment C) show the combined results of the IR, GPR and IE surveys. The mapped conditions include: delaminations detected by IR and shown as red hatched polygons; deterioration detected by GPR and shown as blue to magenta areas; and patching detected in the IR and visual data and shown as green hatched polygons. Diamond icons are used to define the impact-echo test locations; with green diamonds designating IE results that show the deck in good condition, and red diamonds designating IE results indicative of delamination. The IE results correlate with the final IR and GPR results at 87 of the 114 IE test locations (76%). A majority of the IE results that don’t correlate with the final condition maps (22 of 27) are GPR "false positives". These are areas where the GPR is likely detecting precursor conditions, such as chloride contamination and corrosion activity, that have not yet manifested into delaminations detectable by IE testing (or sounding).

Given that IR detects existing delaminations, whereas GPR detects a mix of precursor conditions and delaminations, the correlation between the results of the two methods varies. To quantify the level of correlation between the GPR and IR results for each bridge, we used the following definitions:

- **Good Correlation**: GPR and IR generally detect the same areas of distress (>80% correlation).
- **Reasonable Correlation**: GPR and IR generally detect some common distress areas (>50% correlation).
- **Limited Correlation**: GPR and IR generally detect very few common distress areas (>25% correlation).

Table 1 shows the correlation between the IR and GPR results for the 6 bridges where both methods were used to evaluate the deck conditions. The table shows 3 of the decks to have "good" correlation, 2 "reasonable" correlation, and 1 "limited" correlation.

<table>
<thead>
<tr>
<th>Bridge #</th>
<th>IR delams (&gt;10sf) within GPR survey area</th>
<th>IR delams that overlap GPR deterioration areas</th>
<th>IR delams adjacent to a GPR deterioration area (i.e. within 5')</th>
<th>IR delams that correlate with GPR deterioration areas</th>
<th>Correlation Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>720200</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>Good (7/7=100%)</td>
</tr>
<tr>
<td>720071</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>Good (5/6=83%)</td>
</tr>
<tr>
<td>720072</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>Limited (1/6=17%)</td>
</tr>
<tr>
<td>720036</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>7</td>
<td>Good (7/7=100%)</td>
</tr>
<tr>
<td>720132</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>Reasonable (3/5=60%)</td>
</tr>
<tr>
<td>720323</td>
<td>8</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>Reasonable (6/8=75%)</td>
</tr>
</tbody>
</table>

Based on the data collection and analysis efforts carried out for this project, we can draw the following conclusions regarding the ability of IR and GPR to provide an indication of bridge deck deterioration:

- The IR and GPR results correlated with impact-echo results at 76% of the test locations.
- Of the 6 bridges where both IR and GPR testing were conducted on the same deck area, the two methods correlated reasonably well with each other.
5. References


# Bridge Deck Survey Results Summary

<table>
<thead>
<tr>
<th>Bridge ID</th>
<th>Feature On</th>
<th>Feature Under</th>
<th>Roadway Area (sq ft)</th>
<th>IR Target Lanes</th>
<th>GPR Target Lanes</th>
<th>Delamination Quantity with Infrared (%)</th>
<th>Deterioration Quantity with GPR (%)</th>
<th>Avg. Rebar Depth (in.)</th>
<th>IE Correlation with Final GPR/IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>720200</td>
<td>I-10 WB (SR-8)</td>
<td>CSXRR</td>
<td>16226</td>
<td>ALL</td>
<td>Outside Lane Only</td>
<td>2.9%</td>
<td>15.00%</td>
<td>2.9</td>
<td>10 of 12</td>
</tr>
<tr>
<td>720071</td>
<td>SR-105</td>
<td>Myrtle Creek</td>
<td>2890</td>
<td>ALL</td>
<td>ALL</td>
<td>5.1%</td>
<td>10.6%</td>
<td>3.0</td>
<td>14 of 15</td>
</tr>
<tr>
<td>720072</td>
<td>SR-105</td>
<td>Simpson Creek</td>
<td>2893</td>
<td>ALL</td>
<td>ALL</td>
<td>3.8%</td>
<td>6.2%</td>
<td>4.5</td>
<td>13 of 16</td>
</tr>
<tr>
<td>720097</td>
<td>US-ALT-1 (SR-115)</td>
<td>8th St. &amp; CSXRR</td>
<td>58503</td>
<td>All West Bound Lanes</td>
<td>N/A</td>
<td>3.6%</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<td>720055</td>
<td>US-ALT-1 (SR-115)</td>
<td>CSX RR</td>
<td>46924</td>
<td>All East Bound Lanes</td>
<td>N/A</td>
<td>5.4%</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>720036</td>
<td>US-ALT-1 (SR-115)</td>
<td>US-17 (SR-5)</td>
<td>13363</td>
<td>All West Bound Lanes</td>
<td>Outside Lane and Shoulder</td>
<td>3.0%</td>
<td>6.30%</td>
<td>2.9</td>
<td>8 of 14</td>
</tr>
<tr>
<td>720132</td>
<td>US-ALT-1 (SR-115)</td>
<td>11th St.</td>
<td>12848</td>
<td>All East Bound Lanes</td>
<td>Inside Lane and Shoulder</td>
<td>2.7%</td>
<td>4.40%</td>
<td>2.5</td>
<td>8 of 10</td>
</tr>
<tr>
<td>720488</td>
<td>SR-228 (Leg E)</td>
<td>Adams St. from Hart Ramp</td>
<td>53383</td>
<td>ALL</td>
<td>N/A</td>
<td>4.1%</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>720033</td>
<td>SR-115</td>
<td>Trout River</td>
<td>41860</td>
<td>All South Bound Lanes</td>
<td>N/A</td>
<td>3.4%</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>720079</td>
<td>SR-10A</td>
<td>Palmetto St.</td>
<td>9786</td>
<td>ALL</td>
<td>N/A</td>
<td>5.4%</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>720232</td>
<td>I-10 EB (SR-8)</td>
<td>CSX RR</td>
<td>19190</td>
<td>ALL</td>
<td>Inside Lane Only</td>
<td>3.6%</td>
<td>18.30%</td>
<td>3.1</td>
<td>12 of 14</td>
</tr>
<tr>
<td>720257</td>
<td>I-95 NB</td>
<td>Church St.</td>
<td>7250</td>
<td>N/A</td>
<td>Outside NB Lane and Inside Ramp</td>
<td>N/A</td>
<td>28.00%</td>
<td>2.1</td>
<td>11 of 13</td>
</tr>
<tr>
<td>720300</td>
<td>I-95 NB</td>
<td>Union St.</td>
<td>9660</td>
<td>N/A</td>
<td>NB Exit Ramp</td>
<td>N/A</td>
<td>12.20%</td>
<td>2.3</td>
<td>6 of 10</td>
</tr>
<tr>
<td>720174</td>
<td>I-95 NB</td>
<td>8th St.</td>
<td>14646</td>
<td>N/A</td>
<td>Outside NB Lane and Shoulder</td>
<td>N/A</td>
<td>3.70%</td>
<td>1.9</td>
<td>5 of 10</td>
</tr>
</tbody>
</table>
ATTACHMENT B
Equipment used for Deck Evaluations

- GPR Equipment
- IR Equipment
- GPR Antennas
- DMI
- IR Camera
- Video Camera
- Impact-Echo Testing Equipment

Test Head
Readout Device
ATTACHMENT C
Deck Condition Maps
Area Not Surveyed with Delamination Detected with Infrared
Area Not Surveyed with GPR and Impact Echo
Impact Echo Test - Good Condition
Impact Echo Test - Delamination/Deterioration

GPR Evaluated - Concrete Deterioration
Increasing Severity
Rebar Depth (Inches)

Direction of Travel
Scale: 1 inch = 25 feet

IR Results

South Abutment B1 B2 B3 B4 B5 B6 B7 B8 B9 B10
Distance from S. Abutment (ft)

North Abutment B10 B11 B12 B13 B14 B15 B16 B17 B18 B19
Distance from S. Abutment (ft)
West Abutment Pier 1 Pier 2 East Abutment

Distance from W. Abutment (ft)

West Abutment Pier 1 Pier 2 East Abutment

Distance from W. Abutment (ft)

Infrasense, Inc.
21-G Olympia Avenue,
Suite 45, Woburn,
Massachusetts 01801

Sheet 1 of 1

Analyzed by: KJS
Reviewed by: AJC
Completed: 06/6/2016

GPR Results

Rebar Depth

Delamination Detected with Infrared
Patching
Area Not Surveyed with GPR and Impact Echo
Impact Echo Test - Good Condition
Impact Echo Test - Delamination/Deterioration

Direction of Travel

Scale: 1 inch = 25 feet

GPR Evaluated - Concrete Deterioration

Increasing Severity

Rebar Depth (Inches)
Area Not Surveyed with Delamination Detected with Infrared

Rebar Depth (Inches)

GPR Evaluated - Concrete Deterioration

Increasing Severity

Patching

Area Not Surveyed with GPR and Impact Echo

Impact Echo Test - Delamination/Deterioration

Good Condition

Direction of Travel

Scale: 1 inch = 15 feet

Deck Condition Evaluation

SR-105
Bridge ID: 720072
RS&H Florida Scanning Project, Project No. 101-3098-012

Infrasense, Inc.

21-G Olympia Avenue, Suite 45, Woburn,
Massachusetts 01801

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Analyzed by: KJS
Reviewed by: AJC
Completed: 06/06/2016
Infrasense, Inc.
21-G Olympia Avenue,
Suite 45, Woburn,
Massachusetts 01801

Sheet 1 of 1

Scale: 1 inch = 15 feet

Analyzed by: KJS
Reviewed by: AJC
Completed: 06/6/2016

Direction of Travel

Area Not Surveyed with Delamination Detected with Infrared
Delamination/Deterioration

Delamination Detected with Infrared
Impact Echo Test - Good Condition
Impact Echo Test - Delamination/Deterioration

GPR Results

Rebar Depth

GPR Evaluated - Concrete Deterioration
Increasing Severity
Rebar Depth (Inches)

Distance from South Abutment (ft)

RS&H Florida Scanning Project,
Project No. 101-3098-012

Deck Condition Evaluation
I-95 Northbound
Bridge ID: 720174

Increasing Severity
GPR Evaluated - Concrete Deterioration
Rebar Depth (Inches)

Distance from South Abutment (ft)
Analyzed by: KJS
Reviewed by: AJC
Completed: 06/6/2016

Direction of Travel

Area Not Surveyed with Delamination Detected with Infrared
Rebar Depth Detected with Infrared
GPR Evaluated - Concrete Deterioration
Patch

Rebar Depth (Inches)

Increasing Severity

Survey limit to exit ramp

GPR Results

Table: GPR Results

<table>
<thead>
<tr>
<th>Rebar Depth</th>
<th>GPR and Impact Echo</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Good Condition</td>
</tr>
<tr>
<td>6</td>
<td>Delamination/Deterioration</td>
</tr>
</tbody>
</table>

Survey limit to exit ramp
Area Not Surveyed with Delamination Detected with Infrared

Delamination/Deterioration

Increasing Severity

Good Condition

Impact Echo Test -

Patching

Impact Echo Test -

Area Not Surveyed with GPR and Impact Echo

Direction of Travel

Scale: 1 inch = 25 feet
Distance from Bridge Abutment 8A (ft)

Bridge Abut. 8A 9A 10A 11A 12A 13A

IR Results

Analyzed by: KJS
Reviewed by: AJC
Completed: 06/6/2016

Infrasense, Inc.
21-G Olympia Avenue,
Suite 45, Woburn,
Massachusetts 01801

Sheet 1 of 2

Direction of Travel

GPR Evaluated - Concrete Deterioration

Delamination Detected with Infrared

Increasing Severity

Patching

Area Not Surveyed with GPR and Impact Echo

Impact Echo Test - Good Condition

Impact Echo Test - Delamination/Deterioration

Rebar Depth (Inches)

Scale: 1 inch = 25 feet

Increasing Severity

Direction of Travel

Deck Condition Evaluation

SR-228 (Leg E)
Bridge ID: 720488
RS&H Florida Scanning Project,
Project No. 101-3098-012

Infrasense, Inc.
21-G Olympia Avenue,
Suite 45, Woburn,
Massachusetts 01801

Analyzed by: KJS
Reviewed by: AEC
Completed: 06/6/2016

Sheet 1 of 2
Infrasense, Inc.
21-G Olympia Avenue, Suite 45, Woburn, Massachusetts 01801

IR Results

Sheet 2 of 2

Direction of Travel

GPR Evaluated - Concrete Deterioration

Increasing Severity

Rebar Depth (Inches)

Area Not Surveyed with GPR and Impact Echo

Impact Echo Test - Good Condition

Delamination/Deterioration

Scale: 1 inch = 25 feet

Increasing Severity

Delamination Detected with Infrared

Patching

Good Condition

Delamination/Deterioration

IR Results

Direction of Travel

Distance from Bridge Abutment 8A (ft)

RS&H Florida Scanning Project, Project No. 101-3098-012

SR-228 (Leg E)
Bridge ID: 720488

Analyzed by: KJS
Reviewed by: AJC
Completed: 06/6/2016

Increasing Severity

Delamination Detected with Infrared

Patching

Good Condition

Delamination/Deterioration

Direction of Travel

Distance from Bridge Abutment 8A (ft)