MD-16-SHA-UM-4-04

MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

EFFECTIVE IMPLEMENTATION OF GPR FOR CONDITION ASSESSMENT AND MONITORING – PHASE 2

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16. Abstract

The Maryland Department of Transportation State Highway Administration (SHA) is currently using Ground Penetrating Radar (GPR) for assessing the condition of bridge decks (such as surface condition, rebar cover depth and location, and deck thickness). In the last year SHA initiated a task to survey eighty (80) bridge decks using 3D GPR. The equipment for the task included the 3DRadar DX 1821 and DXG1820 antenna array, a MkIV Geoscope, and 3dr Examiner Pro software. The equipment was procured from 3D-Radar (Chemring) and the Maryland Environmental Service (MES) provided the data collection and initial analysis. The university team provided overall project management and kept continuous interaction with SHA throughout the duration of the project in order to meet the project objectives and to obtain administrative and technical feedback. The technical reports reflecting the GPR data analysis for the 40 bridge decks were completed by the team. It was concluded that GPR can be used to monitor changes in bridge deck condition immediately after construction for quality assurance and acceptance testing, and provide the base line for potential time series analyses. This will enable long term rigorous performance monitoring of bridge decks for planning, maintenance, and rehabilitation activities.

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CHAPTER 1: INTRODUCTION

INTRODUCTION

The Maryland Department of Transportation State Highway Administration (SHA) is currently using Ground Penetrating Radar (GPR) for assessing the condition of bridge decks (such as surface condition, rebar cover depth and location, and deck thickness). In the last year SHA initiated a task to survey eighty (80) bridge decks using 3D GPR. The equipment for the task included the 3DRadar DX 1821 and DXG1820 antenna array, a MkIV Geoscope, and 3dr Examiner Pro software. The equipment was procured from 3D-Radar (Chemring) and the Maryland Environmental Service (MES) provided the data collection and initial analysis. This University of Maryland (UMD) project, in cooperation with Starodub Inc, had the following objectives:

i) Provide data analysis support for 40 bridge decks;

ii) Develop the analysis pipeline for producing structural reports according to the SHA template;

iii) Identify potential improvements to the current SHA template;

iv) Identify potential improvements in data processing methods for enhancing thematic analysis.

RESEARCH APPROACH

To achieve the objectives of this study the following tasks were undertaken.

Task 1: Project Management.

The project team kept continuous interaction with SHA throughout the duration of the project in order to meet the project objectives and to obtain administrative and technical feedback. The activities under this task included:

- Transfer of GPR data and KML format files from SHA to UMD and Starodub, Inc.
- Quality Assessment of .3dra files;
- Preparation of technical reports reflecting the GPR data analysis for the 40 bridge decks.

Task 2: 3D-Radar Analysis Support.

The activities under this task included:

- Perform data reduction of the 3dra files for the first bridge deck using Starodub's APE-2 software and analysis tools;
- Prepare structural report according to the SHA report template;
- Develop analysis pipeline for the remaining 39 bridge decks with the sequence of functions selected to produce the structural reports and visualization of results;
- Identify improvements to the current version of the SHA template for potential adoption into a Maryland Standard Method of Test (MSMT).

Task 3: Recommend Improvements & Enhancement of GPR Analysis for Bridge Decks

The work of this task was undertaken in parallel to the analysis in Task 2 for identifying potential improvements in GPR data analysis and interpretation of results. This work included recommendations on:

- Improvements in interpretation procedures of the GPR data collected with the 3D Radar.
- Further enhancement of the thematic maps (i.e., bridge deck surface condition, rebar cover depth and location, and deck thickness);
- Improvements in the data analysis process that may be used in developing an MSMT.

Task 4: Final Report

The development of this report incorporating the findings of this project.

ORGANIZATION OF THE REPORT

The first chapter presents the introduction, research approach and organization of this report. Chapter 2 presents the data analysis approach. Chapter 3 covers the analysis pipeline developed for the automation of GPR data analysis, and the components of the structural reports. Chapter 4 provides the conclusions and recommendations for improving GPR data analysis.

Chapter 2. 3D-Radar Data Analysis

2.1 GPR Database Assessment

The project started with a review of the GPR database generated from a subset of the bridge decks provided by SHA. The review included the analyses of:

- GPR data
  - Completeness of records;
  - Interference analysis;
  - Sampling rate review;
  - Environmental factors.

- GPS data:
  - Completeness of records;
  - Registration of GPR and GPS data;
  - Consistency in distances.

It was important to identify potential errors and make appropriate corrections in the GPR and GPS data sets. For example, bridge deck boundaries were used to eliminate the data points that fell outside of the boundaries, as shown in Figure 1. The boundaries across the data sets were expanded when piers, abutments, or other bridge deck features are present.

The impact of environmental factors needs to be considered in the assessment of the GPR data quality. When time elapsed between consecutive runs on a structure, the moisture change may affect GPR response.

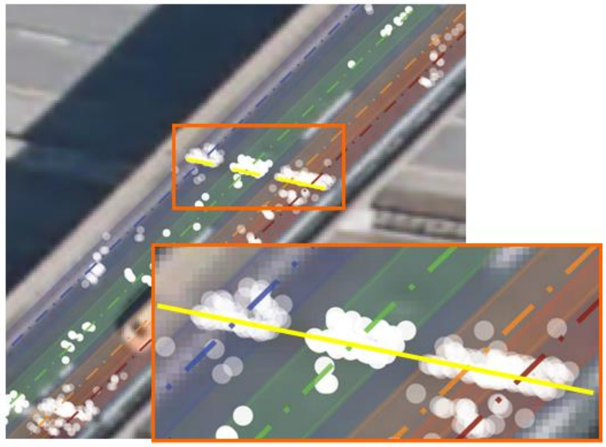

Figure 1. Visualization of Bridge Deck Boundaries: Example over a Pier.

An assessment of the spatial and temporal shift of the data collected in relation to the actual location of the bridge deck structure was conducted. As in the example of Figure 2, a temporal and lateral shift is evident. Thus, a time shift can be entered in the computations and the solution is improved. A hybrid correction method is used to estimate and apply the time shift along with corrections in the GPS records using both an internal and an external GPS, Figure 3.

In this project supplemental proprietary algorithms developed by Starodub for the APE-2 bridge deck analysis were used in the QC/QA data review along with the geoscope data quality tests. The QC/QA module of the APE-2 bridge deck analysis pipeline generates the completeness of the record report, interference report, sampling report, and a timeline for the data sets that can provide insight into environmental factors, primarily humidity and precipitations, at the time of data collection. The 3dra files are subjected to a complete review that utilizes proprietary algorithms to detect any degradation of the quality of the data.

In the case of environmental factors, other than external signal interference, each set of data runs are dated and a timeline provides the time span between the first and last data set. The time of data collection can be related to weather information of the nearest station such as humidity, precipitations. Consistent conditions are preferred within a data set for each bridge deck. Each scan is checked and any loss or missed information is identified in the reports for both GPR and GPS. The Pre-processing module repairs any interference detected in the QC/QA module using Starodub's proprietary algorithm.

2.2. Bridge Deck Boundaries' Detection and GPR Data Analysis

The bridge boundaries are detected in two steps: (i) matching the primary features to the structural components; and, (ii) estimating the location of the piers using dimensions listed in the bridge design plans, Figure 4.

The segmentation of the bridge deck into spans using GPR data cannot be fully automated since each case requires some level of customization. In the case of structure 0217803, Figure 5, three steps were required: (i) detect clusters; (ii) extract geometry of the steel frame from design plans; (iii) estimate position of the piers. The results still needed to be reviewed visually to confirm the general position of the piers. Cluster analyses were then used on the GPR data to match the bridge deck features, Figure 6. Once the clusters were matched to features on the bridge deck, the Hough transform was used to estimate their orientation, Figure 7. These linear patterns were used to define the boundaries of each span. Additional bridge deck features were identified based on the bridge design drawings. For example: the position of the piers was established with respect to cross-members of the steel frame below the bridge deck; the distances between the splices and piers were found in tables included in the design plans. A visual check of the final span boundaries were made after the data was plotted over the tiff image.

Once all the boundaries of a bridge deck were detected, Starodub analysis tools were used to detect the following parameters in the GPR step frequency data, Figure 8: Near Surface Marker, Near Rebar Marker, Top Rebar Cover, Deck thickness.

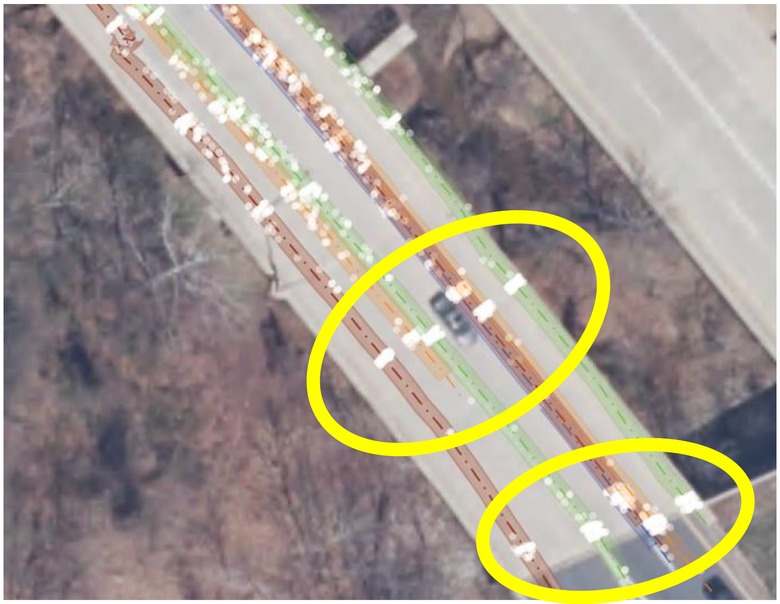

Figure 2. Temporal and Spatial Shift in GPR Data (structure 0217803)

Figure 3. Hybrid Correction for Temporal and Spatial Shift in GPR Data (structure 0217803)

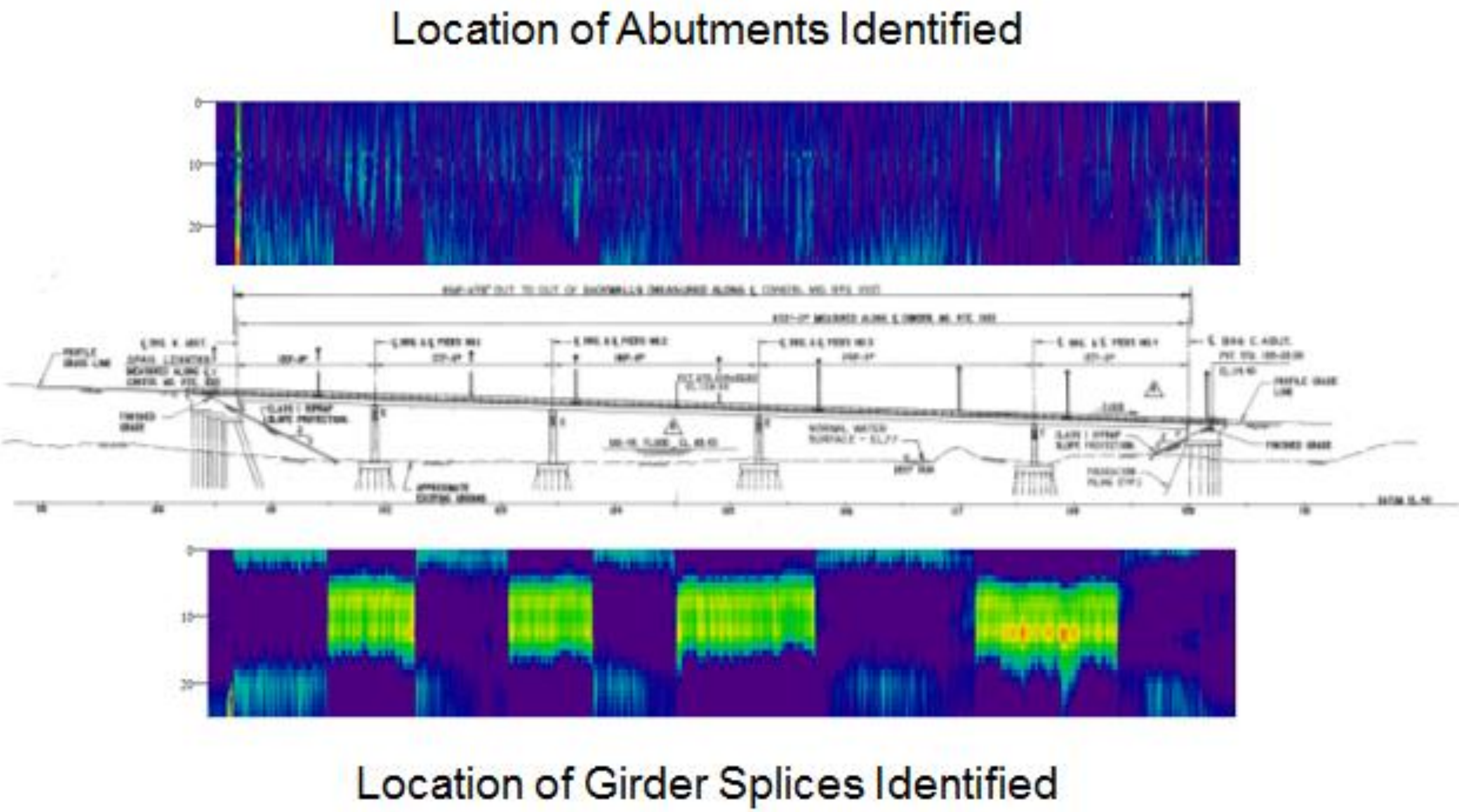

Figure 4. Bridge Boundaries Detection (Structure 0217803)

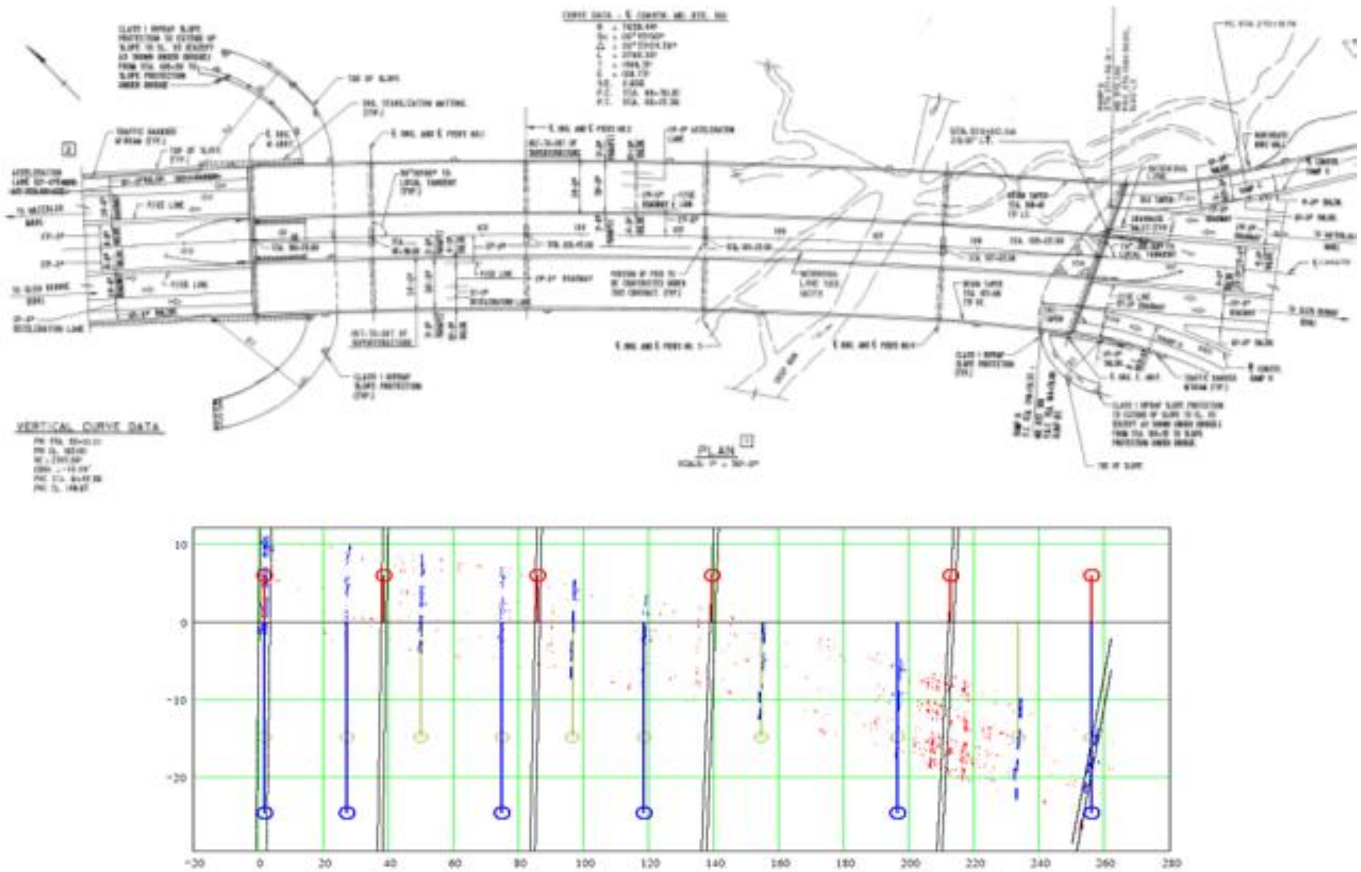

Figure 5. Bridge Deck Segmentation into Spans (Structure 0217803)

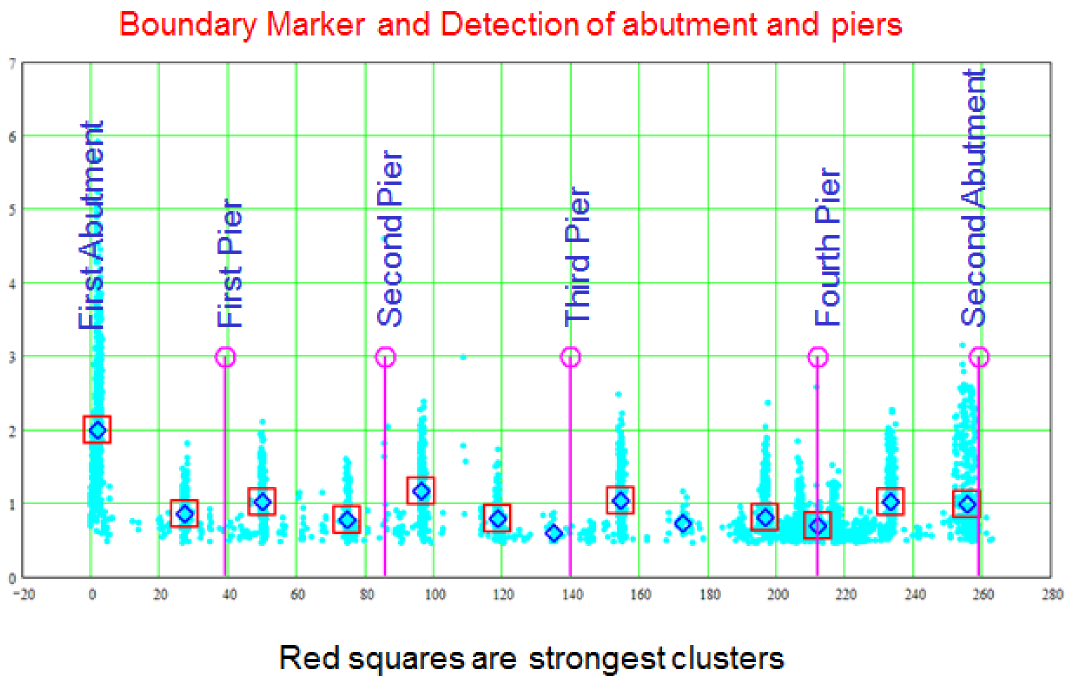

Figure 6. Cluster Analysis of GPR data (Structure 0217803)

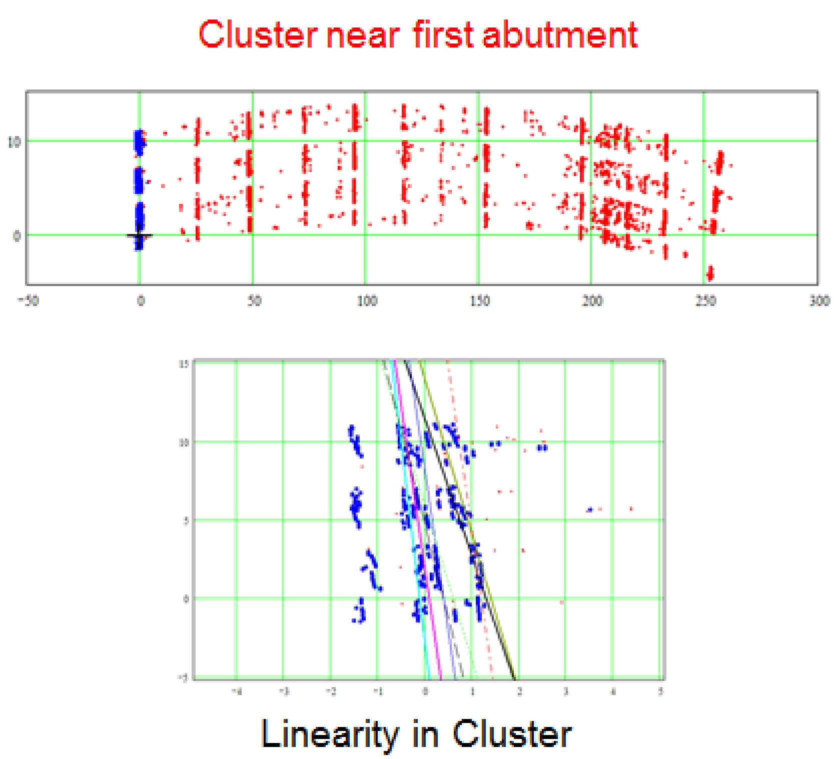

Figure 7. Hough Transform for Detection of Boundaries' Orientation (Structure 0217803)

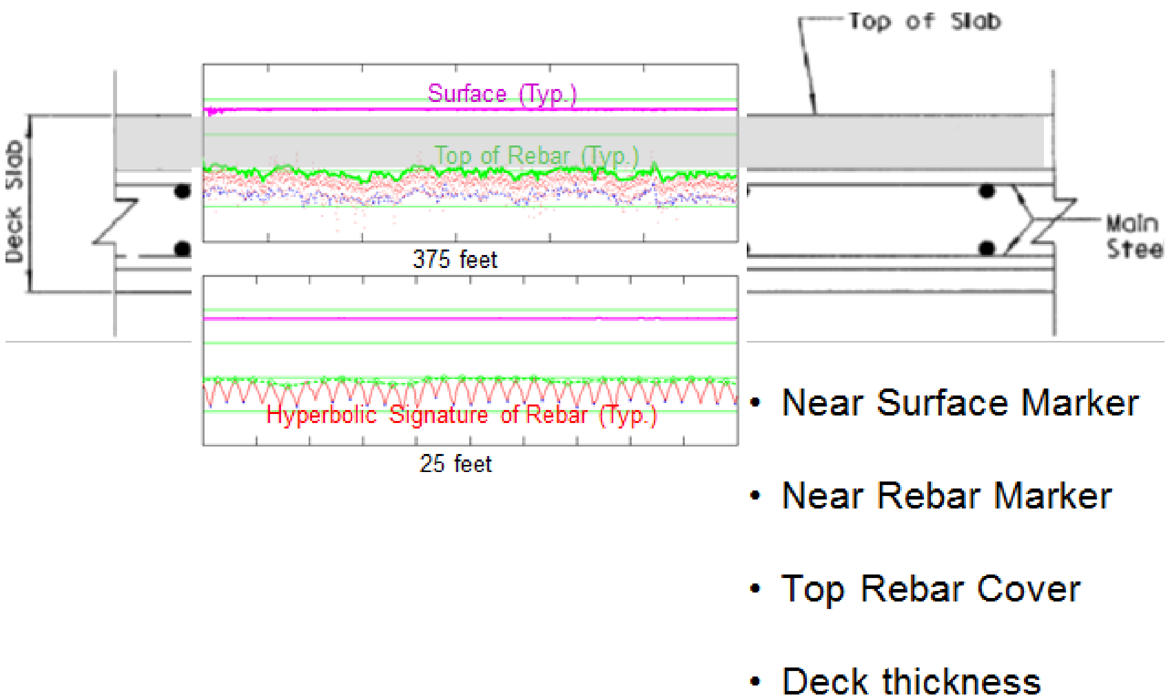

Figure 8. Example SF- GPR Computations

Chapter 3. GPR Data Analysis Pipeline & Structural Reports

3.1 GPR Data Analysis Pipeline

Since 80 bridge decks were inspected and 80 GPR data sets needed to be analyzed, database automation of the analysis was necessary. For this purpose Starodub analysis tools (developed prior to this project) applicable to the GPR data collected by SHA were organized in an analysis pipeline, Figure 9. The analysis pipeline is organized in 9 modules, and each module is presented in terms of Mode, Status, Input, Description, and Output.

Table 1 provides the "Standard Operating Procedures," a sequence of tasks established as part of the QC/QA process to produce the components of the structural reports. As indicated in this table some of the tasks are semi-automated: segmentation, project notes, and assembly of report.

3.2 Bridge Deck Structural Reports

Based on the original SHA template the bridge deck structural report format was developed by adding further analysis results. An example of such report is included in the appendix for structure 0320100. The structural reports are organized in the following sections:

- Cover page providing bridge deck information;
- Summary findings on bridge deck condition based on GPR data;
- KML file and bridge boundaries;
- Concrete surface condition;
- Concrete Cover;
- Deck thickness;
- Top-Rebar Spacing and Condition

Figure 10 shows the GPR Data collected by span on structure 217803 and the bridge deck boundaries developed following the procedures outlined in Chapter 2.

The concrete surface condition was documented using two primary statistics: the variance in surface elevation and an estimate of the near-surface dielectric permittivity computed with the first amplitude or first reflection at the surface of the bridge deck, as shown in Figure 11. The two plots combined, Figure 12, provides information needed to detect potential surface defects. The estimate of dielectric permittivity using the amplitude of the first surface reflection was calculated using the combination of the amplitude of the first surface reflection in the GPR data and a reference amplitude of the first surface reflection over a metal plate. For this project, no reference measurements were available. A synthetic replacement was produced from measurements made by Starodub with the same antenna array in the past.

The depth of top rebars detected was used to estimate the thickness of the concrete cover. With the common-offset test protocols used in this project, a virtual global calibration for all antennas (i.e., all samples estimate an overall dielectric property) was used to compute an estimate of depth from the time of propagation to and from the top rebars. Figure 13 shows the boundary in orange established with the apex of the hyperbolic SAR signal of each rebar. The source/criteria for top of rebar "marker" is the top of the hyperbolas at each rebar.

The thickness of the concrete cover was estimated as the distance between the surface and this apex-boundary Figure 14. Figure 15 provides an illustration of Starodub's automated hyperbola detection algorithm, and indicated the hyperbola superimposed on the features of interest in the GPR data. The numbers of false positives were minimized using Starodub's proprietary solution. The general concept/criteria for such processing is based on the analysis of each hyperbola in terms of signal strength, geometry, size of object that produces the hyperbola, and composition in terms of 3d linear continuity.

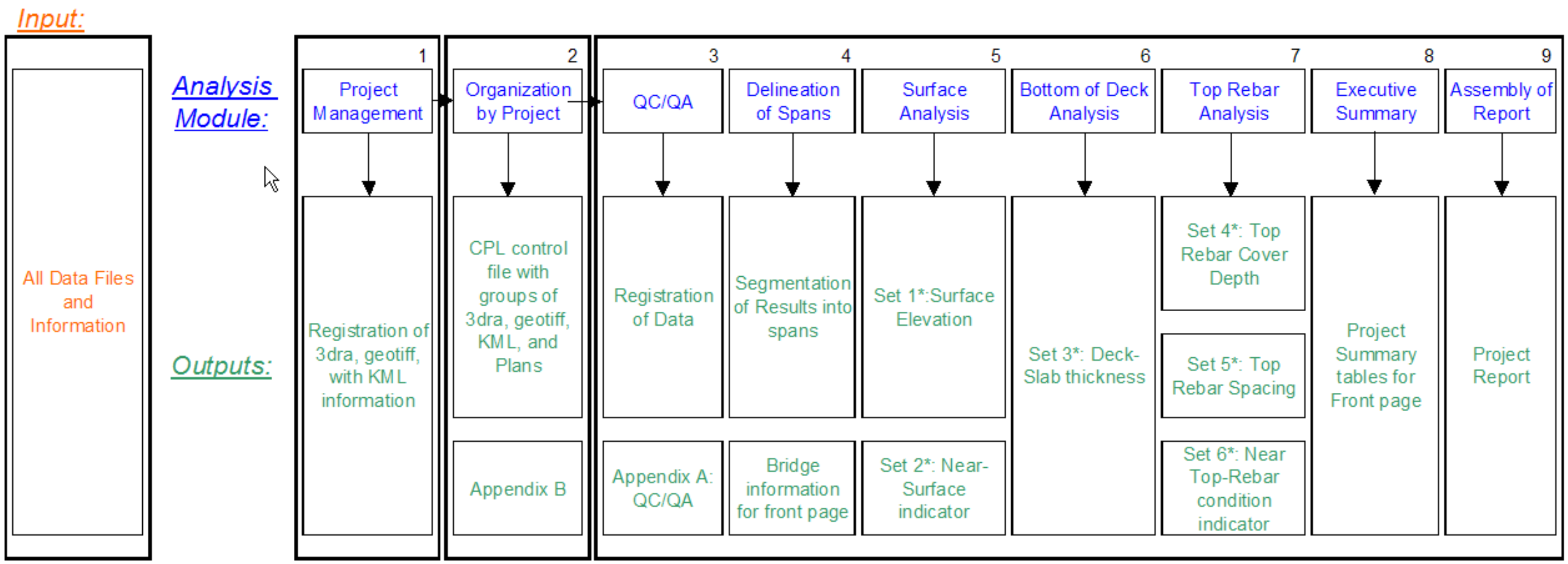

Figure 9. GPR Data Analysis Pipeline

Table 1. Standard Operating Procedures (SOP)

Task:	Mode	Information	Output
1. Review of Plans:	*Manual*	Abutments Piers	
a. Bridge layout		Stationing Angles	Working Table
b. Deck layout		Dimensions	
2. Review of Project Information from SHA database:	*Automated*	Project-Specific Information	
a. Project information for Page 1		Location Description	Document
b. Confirmation of location			
3. Preparation of Project Notes:	*Manual*	Standard and Special Notes	Document
a. Project-specific Notes for nine areas of report		Project-Specific features	
4. Pre-processing of 3dra files	*Automated*	Starodub Algorithms	Working Files
5. QC/QA of 3dra files:	*Automated*	Starodub Algorithms	Working Files
a. Run Automated Software			*Page 3*
b. Review Results			
c. Review Plot (Page 3)			
d. Preparation of Analysis and Visualization Controls	*Semi-Automated*	Thresholds Color Palettes	Project Controls
6. Segmentation of Results into Span/Sections:	*Semi-Automated*	Labeling Orientation	Working Files
a. Run semi-automated process			
using Abutment and Segmentation software tools.		Span Definition	
7. Concrete Surface Conditions:	*Automated*	Surface Elevation	*Page 4*
a. Run automated analysis software		Concrete Surface Indicator	*Appendix A*
b. Run automated visualization software			*Table 2*
8. Concrete Cover:	*Automated*	Concrete Cover	*Page 5*
a. Run automated analysis software			*Appendix B*
b. Run automated visualization software			*Table 3*
9. Deck Thickness:	*Automated*	Deck Thickness	*Page 6*
a. Run automated analysis software			*Appendix C*
b. Run automated visualization software			*Table 4*
10. Top-Steel Condition:	*Automated*	Rebar Spacing	*Page 7*
a. Run automated analysis software		Condition Indicator	*Appendix D*
b. Run automated visualization software			*Table 5*
11. Summary Table	*Automated*	Combine Tables	Summary Table 1
		into One Summary	Notes *Page 2*
12. Finalize Front Page	*Automated*	Gather Information	*Page 1*
		into One Summary	
13. Assemble Report:	*Manual*	Check and Assemble	*Report*
a. High Res Plots – Eventually for GIS.		Files	*Files*
b. Lower Resolution Plots for Report			
c. PDF Report			

Figure 10. GPR Data and Bridge Boundaries (structure 217803)

Surface height

Near-surface density indicator

Figure 11. Surface Analysis (structure 217803)

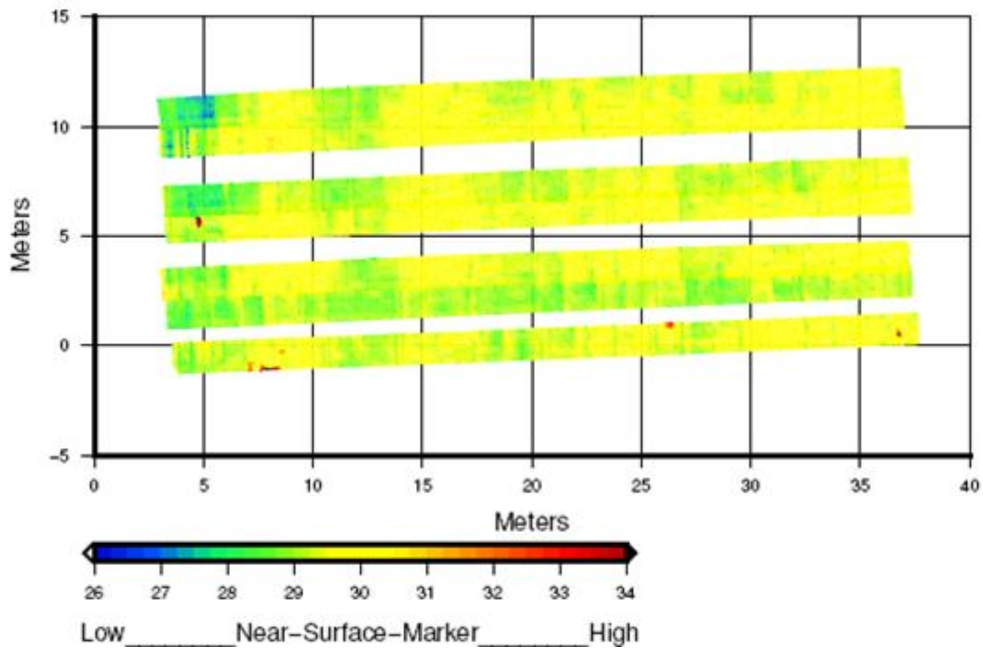

Figure 12. Surface Analysis (structure 217803 – span 1)

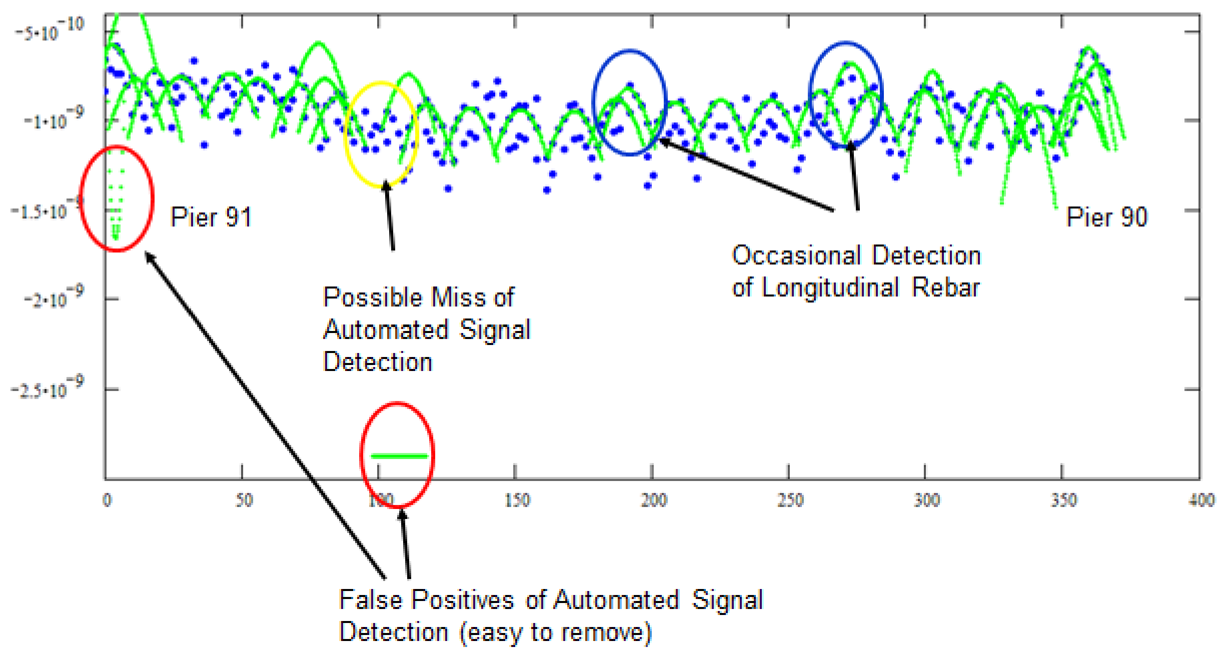

Figure 13. Top Rebar Boundary (in orange)

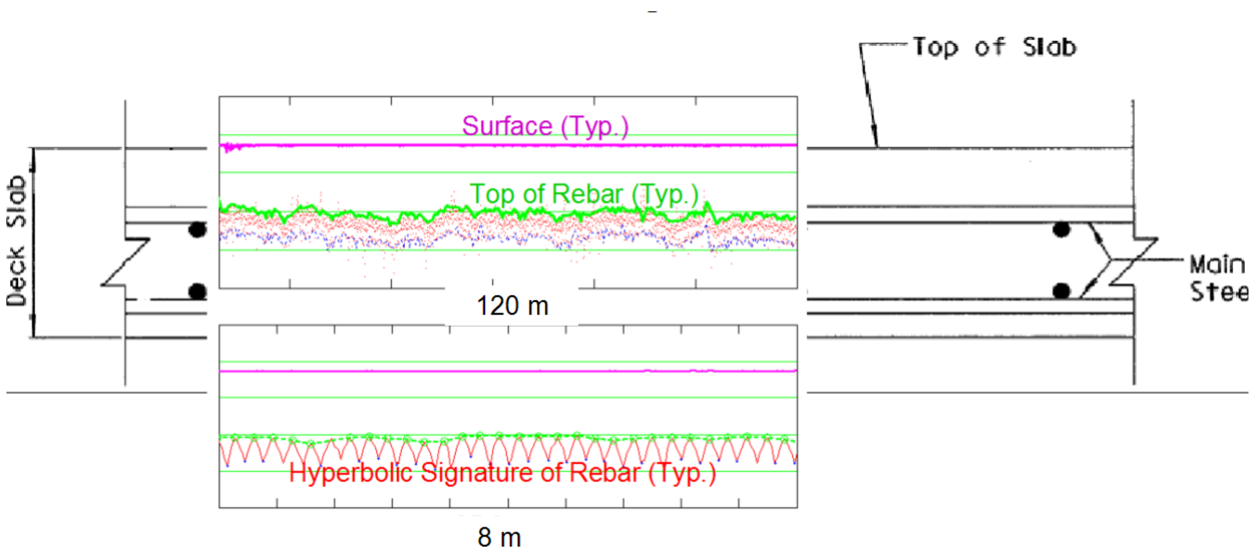

Figure 14. Top Rebar Cover

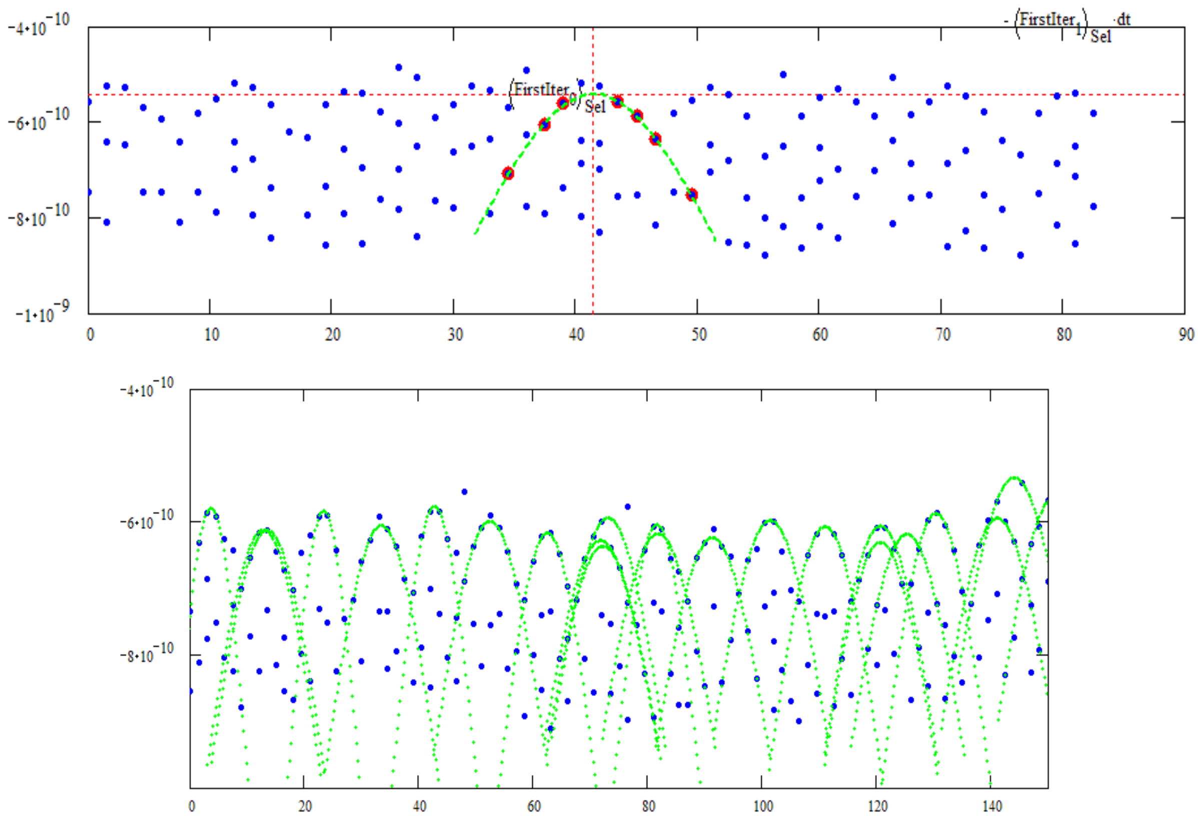

Figure 15. In Deck-Slab Analysis (variance in GPR statistics)

The thickness of the bridge deck was estimated by detecting the bottom of the concrete slab. With the common-offset test protocols used in this project, a virtual global calibration was used establish the computation of the estimate of depth from the time of propagation to and from the bottom of the slab, Figure 16.

The depth and location of each rebar was estimated based on an automated signal detection algorithm developed by Starodub, Inc. The automated algorithm identified the rebar signals first and other signals next, and created a radagram as in Figure 17. False positives were removed from the analysis (using a Starodub detection algorithm), including potential points near the interference patterns below the rebar based on criterion. The hyperbolic SAR signal of steel rebars was analyzed to estimate their condition. A rebar deterioration indicator was proposed to leverage the information in the variance of the following four primary parameters:

- Location using the apex of the signal;
- Depth using the time at the apex of the signal;
- Apparent dielectric constant using the signal; and,
- Strength or amplitude of the signal at the apex of the signal.

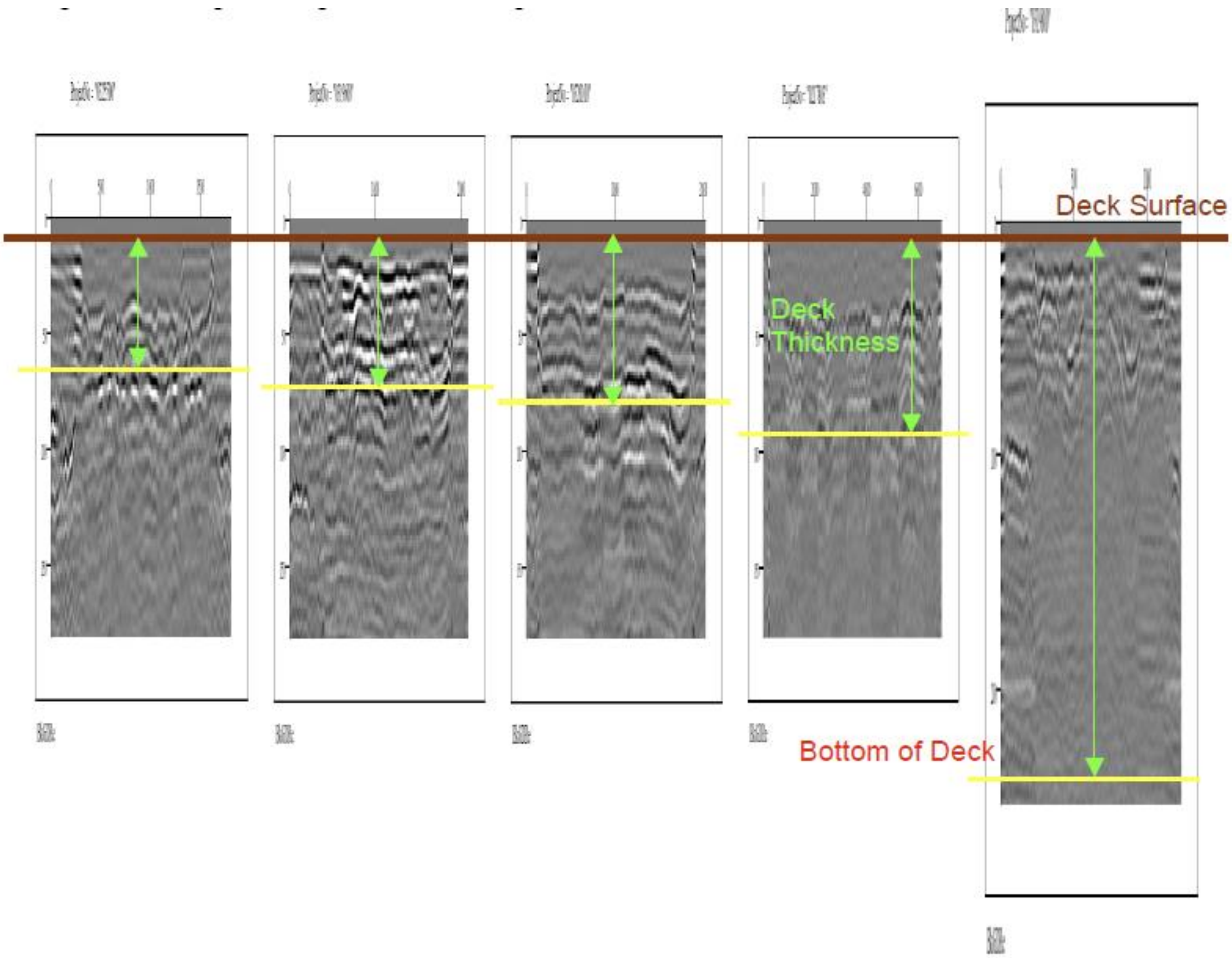

Figure 16 Signal Range for Increasing Thicknesses

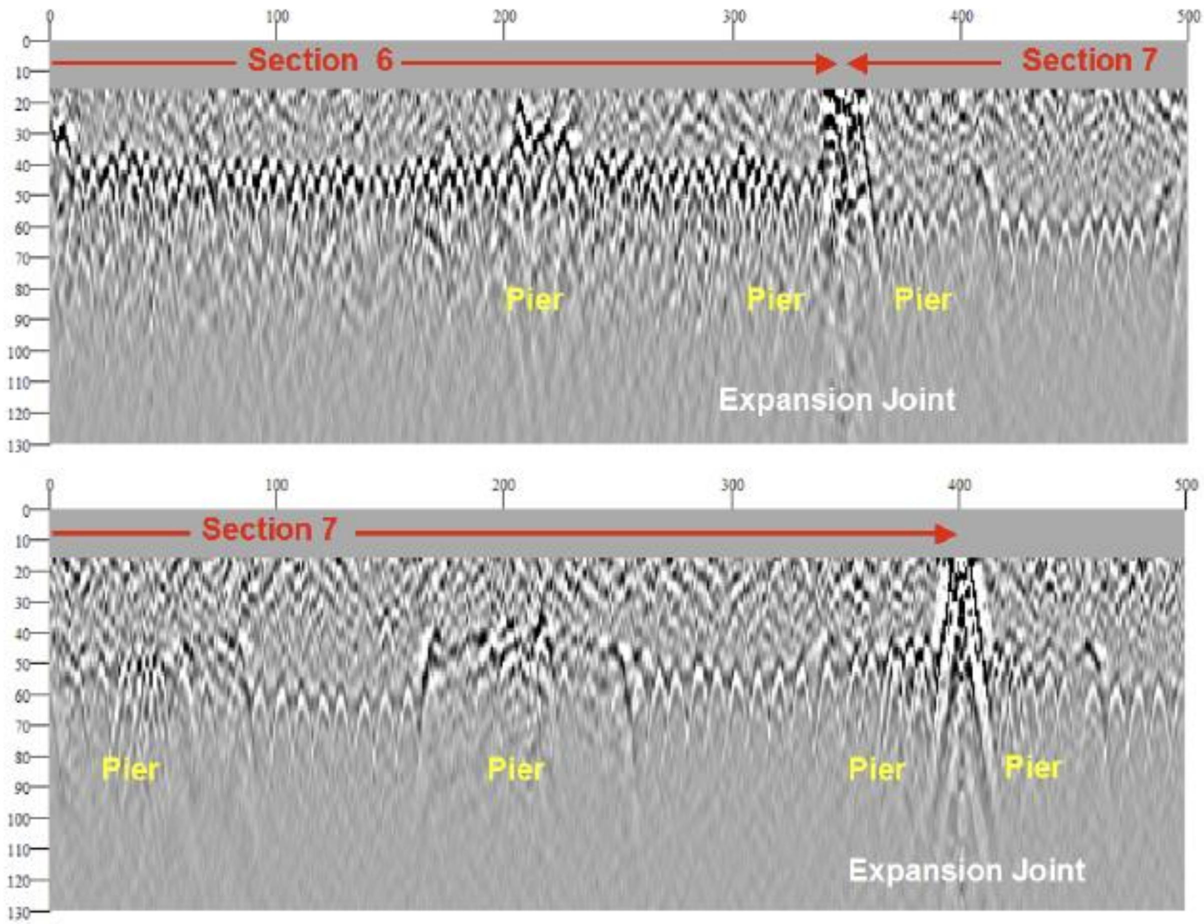

Figure 17. Radagram of Top Rebar Region

Chapter 4. Conclusions and Recommended Improvements in GPR Analysis

The primary objective of this project was to assist SHA in the 3D-Radar data analysis and provide recommendations for potential improvements. As described in the previous chapters the project team:

i) Provided data analysis support for 40 bridge decks;

ii) Developed the analysis pipeline for producing structural reports based on the SHA template;

iii) Incorporated several improvements to the current SHA template in the structural reports;

iv) Identified potential improvements in data processing methods for enhancing thematic analysis.

Among the recommended improvements proposed to SHA for the GPR analysis, the project team developed:

i) "Standard Operating Procedures" – A sequence of tasks established as part of the QC/QA process to produce the reports, as shown in Table 1. Most of these tasks are automated, while some project-specific tasks are semi-automated (segmentation, project notes, and assembly of report). The analysis pipeline is comprised of about 10 modules for analysis, 10 for visualization, and a few batch processing utilities for controlling and managing the flow of production, including cross-checking at the end of each module.

ii) "Error Analysis" – Table 2 provides a list of specific components related to the data collection and data analysis processes as reviewed by the project team, and the specific problems encountered in the review. The specific recommendations to overcome these issues are presented in the last column.

iii) "Status of Coding" – For each project, it is recommended to validate the completeness of the algorithms used in the analysis, including, as shown in Figure 9, (a) bridge deck segmentation method, (b) data processing and quality control procedures, (c) the software module outputs of thematic maps, (d) project cover page and summary of results table;

iv) QC/QA Procedures – The QC/QA tasks span over the entire analysis pipeline, as shown in Table 3. The information is presented in tabular form with four sections: output, processing, modules, and controls. The modules are organized as preparatory tasks, analysis tasks, and an editing task at the end of production. The manual inputs are identified as potential sources of errors and need to be carefully checked.

Complementing the GPR analysis recommendations provided in Chapter 2 and 3, it is also recommended to address the following:

i) GPR Calibration and Dielectric Properties - The metal plate calibration procedure is recommended in addition to the 3D-Radar factory calibration data, for estimating dielectric properties of materials. The procedure is documented in many publications (Goulias et.al., 2014) and included in a draft MSMT developed during the Phase I GPR study;

ii) Temporal and Spatial Shift Corrections - The SHA database is comprised of scans using the "common offset test protocol." The common offset implies that transmitter and receiver in each sample are at the same lateral position as much as possible, which in some cases may not be true, as shown in Figure 3. The spatial dimensions can be estimated with the GPR recorded times at each feature and used for these corrections;

iii) Detection of signal near surface – Some signals between the surface and the top of rebar were detected during analysis, as shown in Figure 18. These could be the interface between concrete and HMA layer, or deterioration of the concrete. These analyses require project-specific verification in order to classify the patterns;

iv) Detection of Buried Objects near Abutment – Strong features were detected in the GPR record where buried utilities may be underneath the approach slabs, as shown in Figure 19. These analyses also require project-specific verification in order to classify the patterns;

v) Documenting Patterns – Continuity in patterns across data sets on the same structure can be detected, as shown in Figure 20, and documented, and may include differences in texture due to weather conditions or data collection settings. Location and occurrence of patterns in each thematic map parameter may provide additional insights on the condition of a bridge deck, as shown in Figure 21. For example alternating low and high magnitudes in surface condition may indicate an area where moisture levels are higher in red and may be causing damage/ deterioration, as shown in Figure 22;

vi) Cataloging Patterns – To aid in pattern recognition and object detection in the various bridge deck projects it is recommended to develop a catalog of the GPR signal response in relation to the specific object under consideration. Some of these patterns were included in the Phase I GPR study report (Goulias et.al., 2014), while others were reported in the literature;

vii) "Surface Condition" is presented in terms of frequency markers, estimates of near surface dielectric constant, and estimated surface elevation. An arbitrary elevation threshold (i.e, ½ inch) may be used for detecting patches and potholes. Such analyses need to be further verified with actual data from the structures;

viii) Moisture Effects – Moisture affects the dielectric properties of the medium. As indicated in Chapter 2, when significant time elapsed between data collection runs, on the same bridge deck moisture adjustment should be considered. Various solutions were proposed in the literature, including the Short Time Fourier Transform (STFT) analysis for bridge deck GPR data covered in the Phase I GPR report (Goulias et. al. 2014);

Furthermore, SF-GPR can be used to monitor changes in bridge deck condition immediately after construction for quality assurance and acceptance testing, and provide the base line as an essential reference for potential time series analyses as the bridge deck deteriorates in time and in-service conditions. This will enable long term performance monitoring of bridge decks for planning, maintenance, and rehabilitation activities.

Acknowledgements

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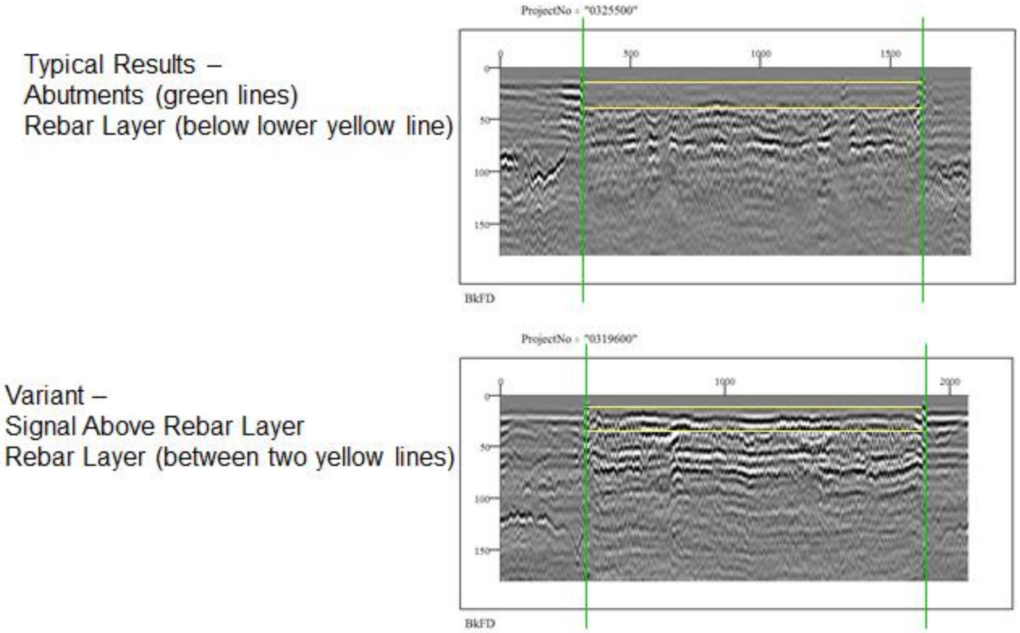

Figure 18. Detection of Signal Near Surface (structure 0325500)

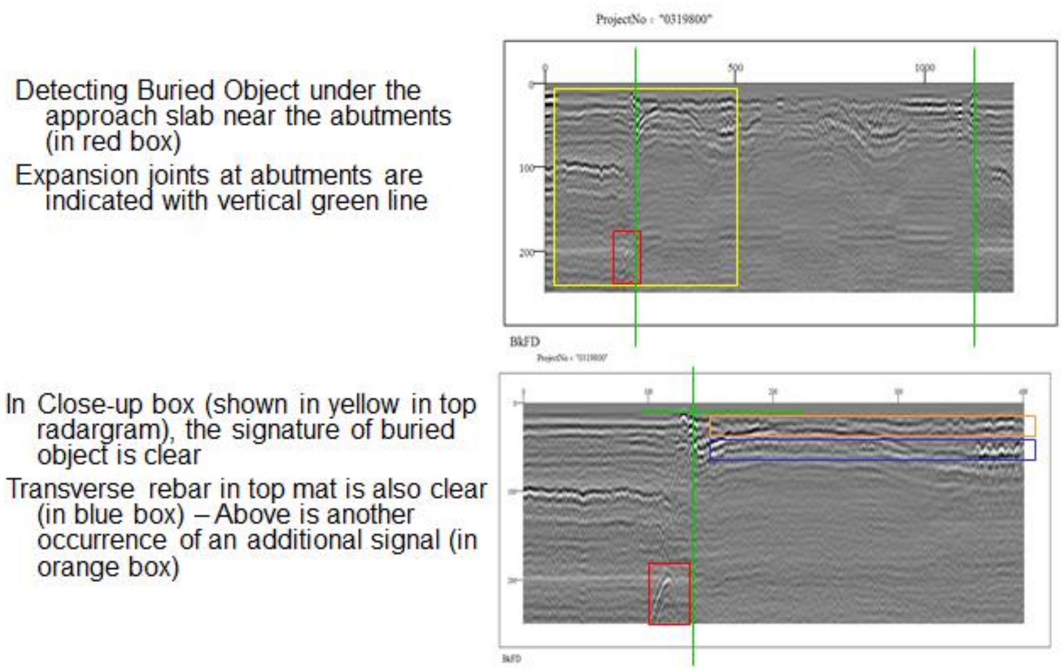

Figure 19. Detection of Buried Objects Near Abutment (structure 0319800)

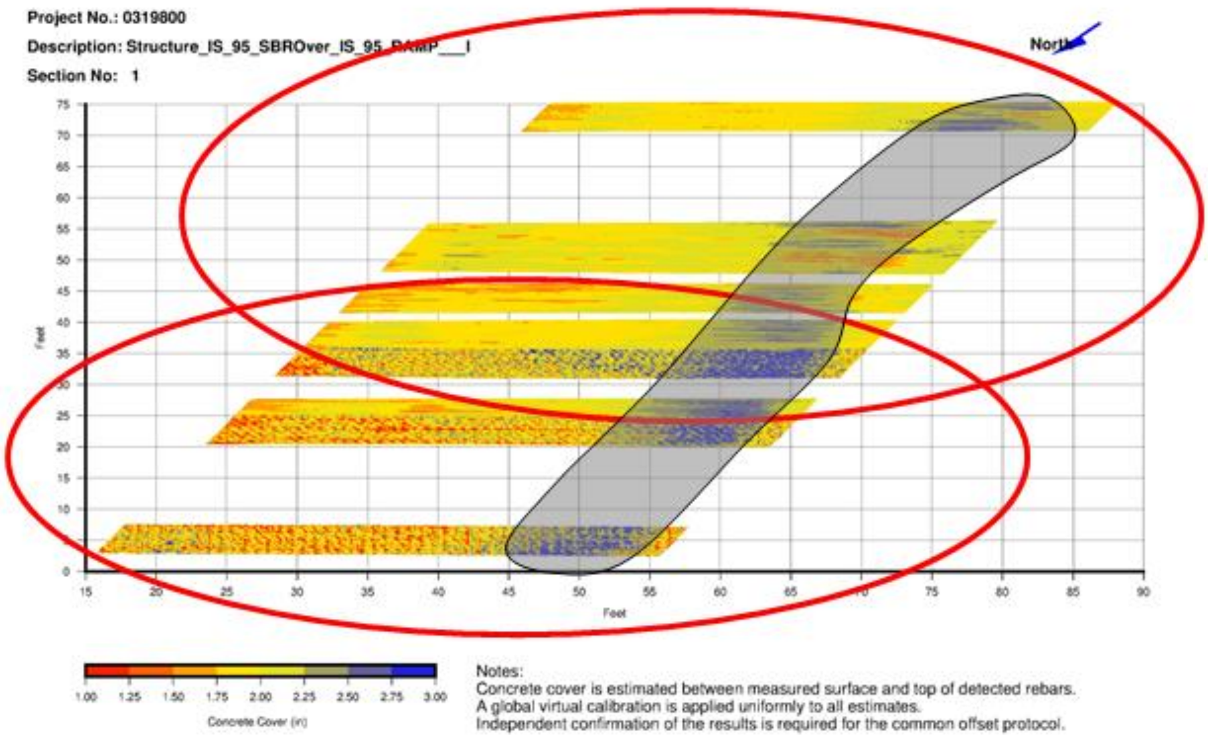

Figure 20. Documenting Patterns Across Data sets on a Bridge Deck (structure 0319800)

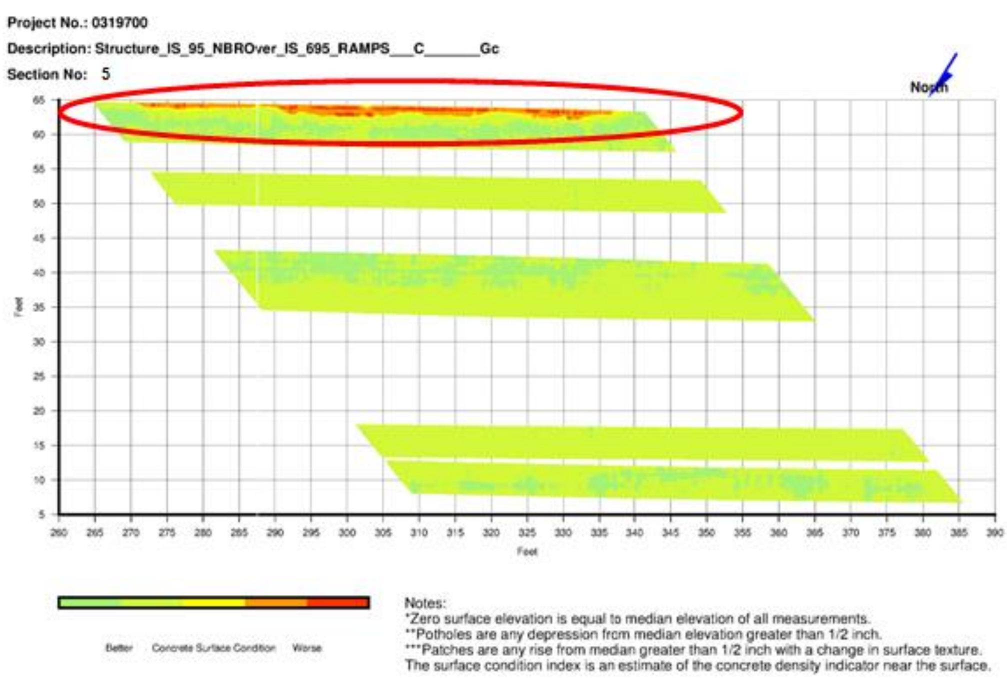

Figure 21. Documenting Patterns on a Bridge Deck (structure 0319700)

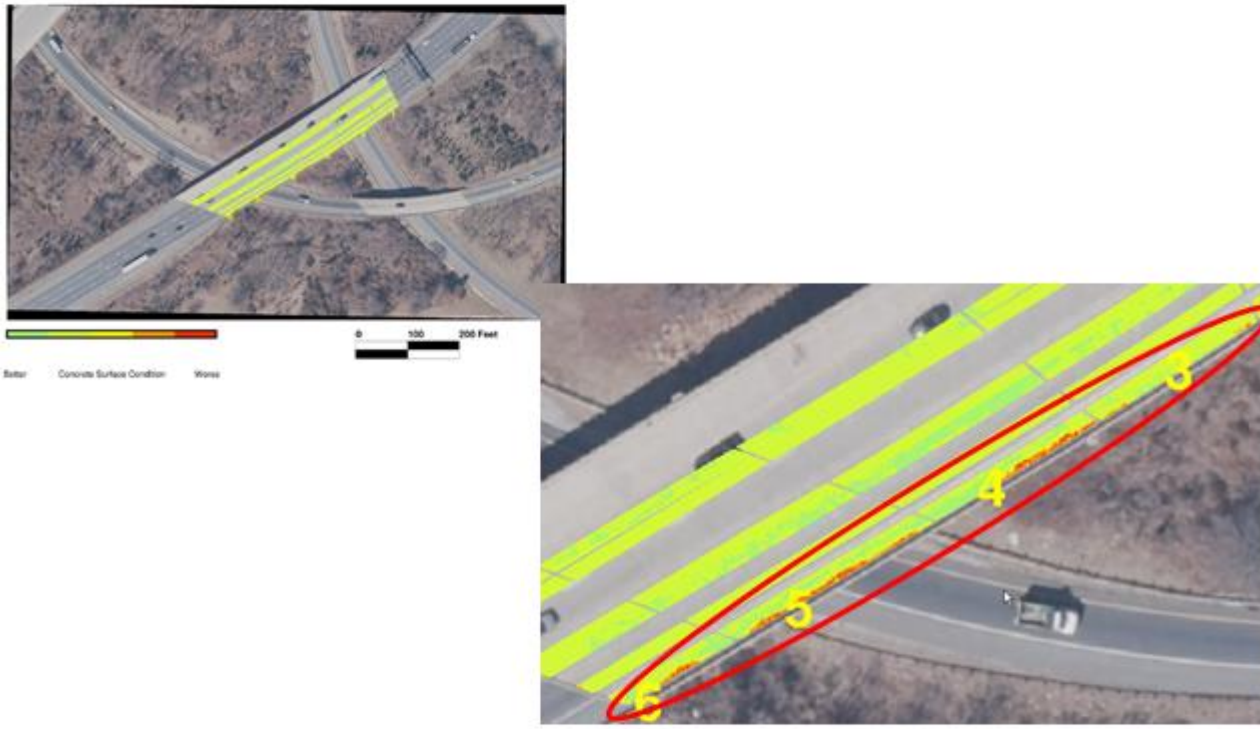

Figure 22. Moisture Concentration & Deterioration (structure 0319700)

Table 2 GPR Data Challenges and Recommendations

Data collection	GPS	Change in Constellation Data Run started late or stopped early	Avoid large time lapse between data collection runs or capture abutment signals in data
Data collection	Moisture content	Surface moisture	Avoid large time lapse between data collection runs or Allow enough time after precipitations before data or avoid data collection during precipitations
Data collection	Interference	Proximity to telecom, other transmission towers	Effect is a function of frequency step
Data collection	Percent Sampling	Missing areas in results	Collect sufficient data collection runs
Data collection	Boundaries	Orientation and detection of Abutments	Collect sufficient data collection runs
Data collection	Concrete cover	Accuracy	Consider other test protocols
Data collection	Deck thickness	Accuracy	Consider other test protocols
Data collection	Surface Elevation	Accuracy	Redesign antenna mount
Data analysis	Top rebar condition	Need verification	Perform validation, verification, and evaluation

Table 3. QC/QA Process

QUALITY CONTROL/ QUALITY ASSURANCE

	PREPARATORY TASKS					ANALYSIS TASKS							EDITING TASK
						Concrete Surface Condition		Concrete Cover	Deck Thickness	Top Rebar Condition		Summary	Binder Assembly
	Plans	Pre-Processing	Abutment Detection	Segmentation	QC/QA	Elevation	Dielectric	Depth to Top Rebar	Slab thickness	Spacing	Condition indicator	Table and Notes	Report
Output	Pier Position page 1	Data Access Formats	Registration	Spans/ Sections	page 3	Omitted	page 4 table Appendix A	page 5 table Appendix B	page 6 table Appendix C	page 7 table Appendix D		page 2 table	Combine pages Add page numbers
Processing	INTERMEDIARY WORKING FILES												
Modules													
Analysis	Spreadsheet	Module Worksheet	-- Worksheet	-- Worksheet	Module Worksheet	Module Worksheet	Module Worksheet	Module Worksheet	Module Worksheet	Module Workshee	Module Worksheet	Module --	-- --
Pre-Visualization	--	Module	--	--	Module	Module	Module	Module	Module	Module	Module	Module	--
Production of Visualization	--	Batch Files	--	--	Batch Files	Batch Files	Batch Files	Batch Files	Batch Files	Batch Files	Batch Files	Batch Files	--
Control													
Manual Input	Data from plans	None	Thresholds	Cluster Selection	None	None	None	None	None	None	None	Notes	Page Numbers
Quality Assurance	Visual over image Alignment computations Multiple sheets	Database of files	SNR Visual	Clusters Orientation Direction	Interference report Timeline Completeness Percent Sampling	Review	Review	Review	Review	Review	Review	Review	Review

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APPENDIX
EXAMPLE OF STRUCTURAL REPORT

3D GROUND PENETRATING RADAR REPORT **2016**

STRUCTURE NUMBER 0320100 **DATE** 15-Jan-16

STRUCTURE DECK CONDITION SURVEY

Inspection Type	Inspection Date (GPR)	Inspected By
Step-Frequency Ground-Penetrating Radar	9/21/2015	MES, Inc.

Weather Condition	Temperature (°F)	Humidity (%)

Structure Number	County	District	Office
0320100	Baltimore	4	--

Feature Carried	Feature Intersected
IS 95 RAMP G	IS 695

Material Type	Year Built / Constructed
Steel Continuous	1969

Structure Type Stringer/Multibeam or Girder

Structure Length (ft)	219	**Number of Abutment**	2
Roadway Width (ft)	28	**Number of Piers**	1
Deck Area (sf)	6,132	**Number of Sections**	-
		Number of Spans	2

Reference Point	**Northing**	**Easting**
NE Corner	39.251156	-76.68
SW Corner		

FINDING SUMMARY

Notes:

GPR data was collected by MES, Inc.
Data collection Protocols were established by MSHA.
Analysis completed by Starodub, Inc.
Coverage of data collection is approximately 43% of surface of bridge deck.
Starodub is performing this data analysis work under contract with the University of Maryland, College Park.
The report template was provided by MSHA.

Project 0320100 Summary Table

Section | Span No.

Summary of Results	1	2	Project
Average Surface Condition	7.2	7.3	7.2 - 7.3
Minimum Surface Condition	5.8	5.6	5.6 - 5.8
Maximum Surface Condition	39.2	40.4	39.2 - 40.4
Average Concrete Cover (in)	2.1	2.2	2.1 - 2.2
Average Deck Thickness (in)	8.5	8.4	8.4 - 8.5
Average Top Rebar Spacing (in)	6.8	5.5	5.5 - 6.8
Top Rebar Deterioration	2.9	3.0	2.9

See page 3 for definition and numbering of sections.

For concrete deterioration see page 4 for overall plan view and table of results and appendix A for detail plan views by span.

For concrete cover see page 5 for overall plan view and table of results and appendix B for detail plan views by span.

For deck thickness see page 6 for overall plan view and table of results and appendix C for detail plan views by span.

For top rebar condition see page 7 for overall plan view and table of results and appendix D for detail plan views by span.

North

BOUNDARIES – Bridge/Section/Span

Project: 0320100 Description: Structure_IS_95_RAMP___G__Over_IS_695 GPS Lat/Lon: 39.251156 76.680434

0320100_IS_95_RAMP_G_Over_IS_695_MD_SixInchImagery1_UTM.tif Distance = 274 feet

Notes:
Boundary Markers in white detected in GPR data.
Sections are numbered per inventory.
Data coverage outline shown.

0 100 200 Feet

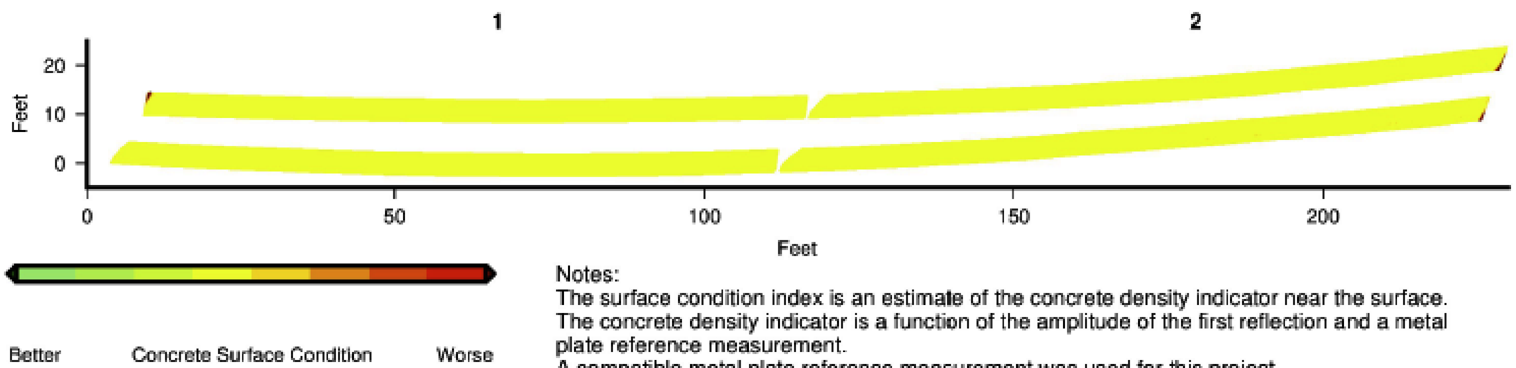
Concrete Surface Condition

Project: 0320100 Description: Structure_IS_95_RAMP___G__Over_IS_695 GPS Lat/Lon: 39.251156 76.680434

0320100_IS_95_RAMP_G_Over_IS_695_MD_SixInchImagery1_UTM.tif Distance = 274 feet

Section | Span No.

Concrete Surface Condition	1	2	Project
Average Condition	7.2	7.3	7.3
Minimum Condition	5.8	5.6	5.6
Maximum Condition	39.2	40.4	40.4
Median Condition	7.2	7.3	7.3



Notes:
The surface condition index is an estimate of the concrete density indicator near the surface.
The concrete density indicator is a function of the amplitude of the first reflection and a metal plate reference measurement.
A compatible metal plate reference measurement was used for this project.

Concrete Cover

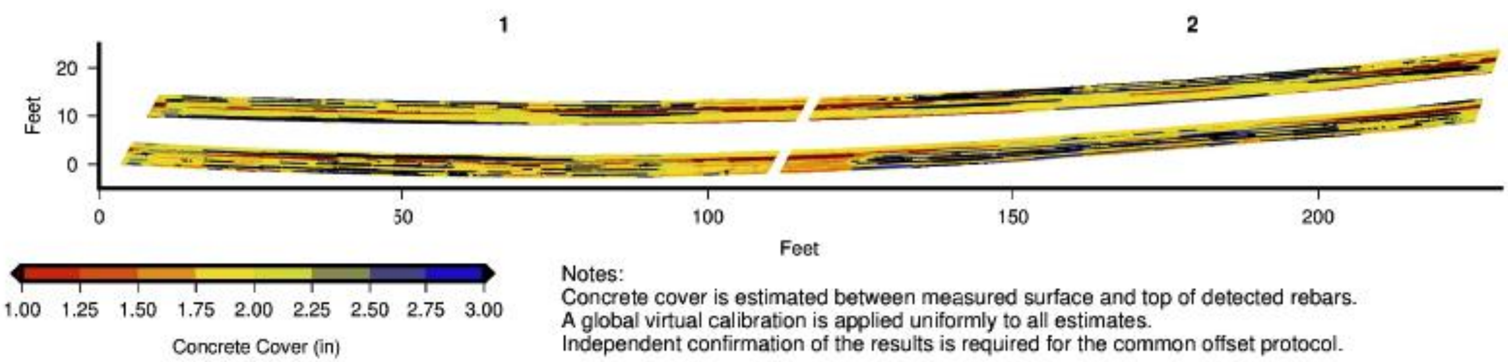
Project: 0320100   Description: Structure_IS_95_RAMP___G__Over_IS_695   GPS Lat/Lon: 39.251156 76.680434

0320100_IS_95_RAMP_G_Over_IS_695_MD_SixInchImagery1_UTM.tif Distance = 274 feet

North

Section | Span No.

Concrete Cover (in)	1	2	Project
Average	2.1	2.1	2.1
Minimum	0.4	0.4	0.4
Maximum	3.8	3.8	3.8



Notes:
Concrete cover is estimated between measured surface and top of detected rebars.
A global virtual calibration is applied uniformly to all estimates.
Independent confirmation of the results is required for the common offset protocol.

Deck Thickness

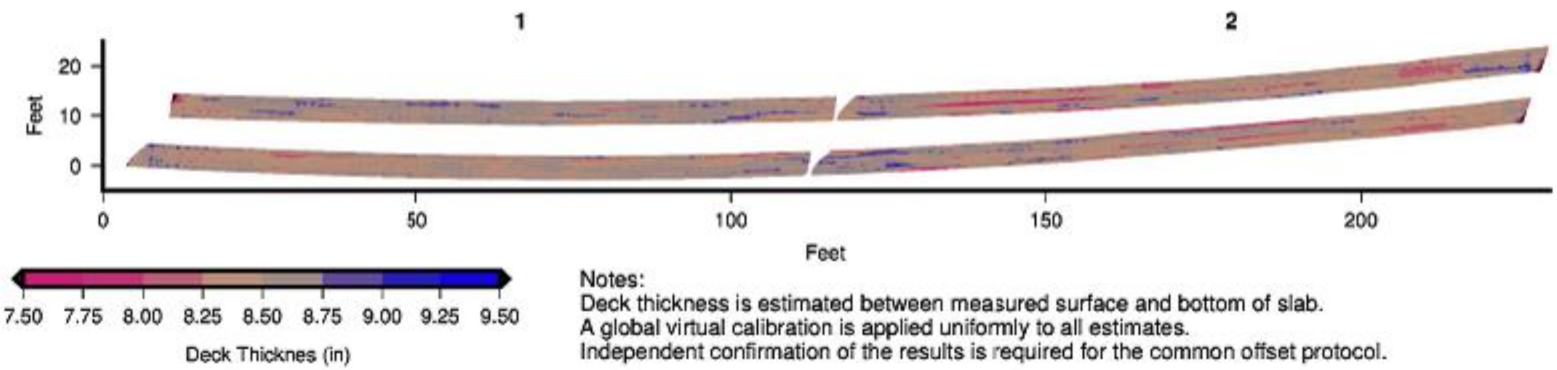
Project: 0320100 Description: Structure_IS_95_RAMP___G__Over_IS_695 GPS Lat/Lon: 39.251156 76.680434

0320100_IS_95_RAMP_G_Over_IS_695_MD_SixInchImagery1_UTM.tif Distance = 274 feet

North

Section | Span No.

Deck Thickness (in)	1	2	Project
Average	8.5	8.4	8.5
Minimum	8.0	3.5	3.5
Maximum	9.6	9.4	9.6



Notes:
Deck thickness is estimated between measured surface and bottom of slab.
A global virtual calibration is applied uniformly to all estimates.
Independent confirmation of the results is required for the common offset protocol.

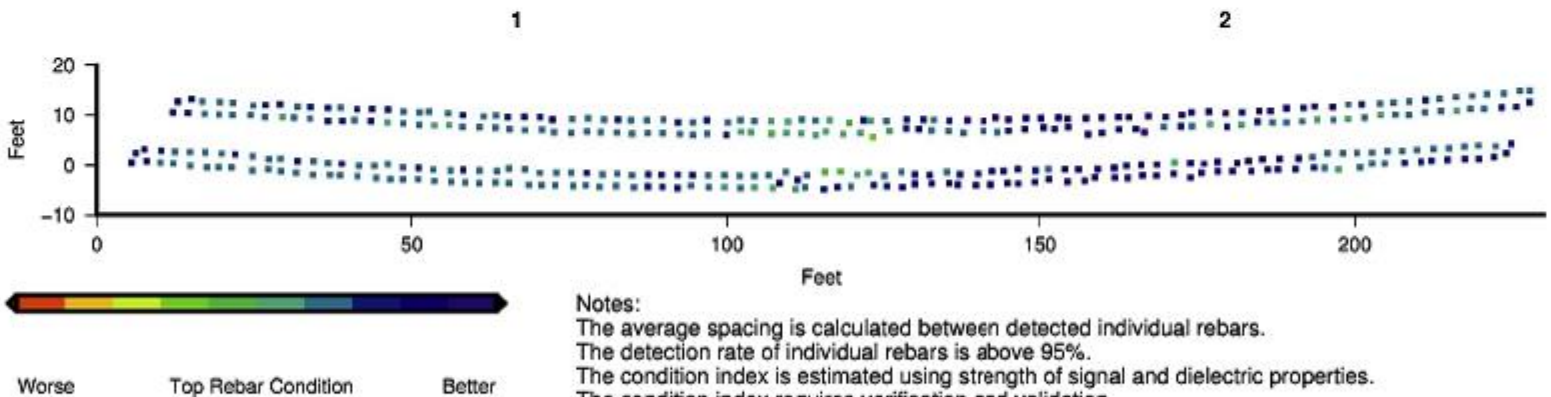
Top Rebar Condition

Project: 0320100 Description: Structure_IS_95_RAMP__G__Over_IS_695 GPS Lat/Lon: 39.251156 76.680434

0320100_IS_95_RAMP_G_Over_IS_695_MD_SixInchImagery1_UTM.tif Distance = 274 feet

Section | Span No.

Top Rebar Condition	1	2	Project
Average Rebar Spacing	6.8	5.5	6.2
Median Rebar Spacing	6.5	5.7	6.1
Minimum Rebar Spacing	3.8	3.8	3.8
Maximum Rebar Spacing	9.2	7.5	9.2
Higher Potential of Deterioration	2.9	3.0	2.9



Notes:
The average spacing is calculated between detected individual rebars.
The detection rate of individual rebars is above 95%.
The condition index is estimated using strength of signal and dielectric properties.
The condition index requires verification and validation.