SPR-Part B
MD-20-SHA/UM/4-54

MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

MARYLAND DEPARTMENT OF TRANPORTATION
STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

OPTIMIZING FIELD DATA COLLECTION & DEVELOPING ADVANCED GPR PROCESSING MODULES

Dimitrios G. Goulias

UNIVERSITY OF MARYLAND

FINAL REPORT

April 2020

This material is based upon work supported by the Federal Highway Administration under the State Planning and Research program. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Federal Highway Administration or the Maryland Department of Transportation. This report does not constitute a standard, specification, or regulation.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. MD-20-SHA/UM/4-54	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Optimizing Field Data Collection & Developing Advanced GPR Processing Modules		**5. Report Date** April 2020 **6. Performing Organization Code**
7. Author(s) Dr. Dimitrios G. Goulias		**8. Performing Organization Report No.**
9. Performing Organization Name and Address University of Maryland Department of Civil and Environmental Engineering College Park, Maryland 20742		**10. Work Unit No.** **11. Contract or Grant No.** SHA/UM/4-54
12. Sponsoring Agency Name and Address Maryland Department of Transportation (SPR) State Highway Administration Office of Policy & Research 707 North Calvert Street Baltimore MD 21202		**13. Type of Report and Period Covered** SPR-B Final Report (December 2017-December 2019) **14. Sponsoring Agency Code** (7120) STMD - MDOT/SHA
15. Supplementary Notes		

16. Abstract

Over the past several years Maryland Department of Transportation State Highway Administration (MDOT SHA) developed a Ground Penetration Radar (GPR) data collection plan for bridge decks. GPR data was collected and analyzed to monitor several hundred bridge decks. MDOT SHA worked with the Maryland Environmental Services (MES) and the University of Maryland (UMD) to develop new analysis modules for concrete delamination and HMA overlay condition and evaluate the feasibility of higher-speed protocols for SF-GPR data collection. A bridge deck condition assessment model (BDCAM) was developed to estimate the deck condition and condition state. Deck condition is defined based on a fuzzy model of the various levels of defect and deterioration of the deck. The UMD study concluded that the BDCAM model estimates agree with the NBI values for 90.9% of the 219 bridge decks analyzed within two levels of the condition scale. The comparison of BDCAM analysis with state inspection deck reports for eight bridges provided consistent conclusions for seven out of the eight cases, all in the "fair" category. The study also concluded that it is possible to increase the GPR data acquisition speed from 10 mph to 13 mph on driving lanes with low surface roughness (IRI less than 100).

17. Key Words	**18. Distribution Statement**
GPR, SF-GPR, bridge deck, Ground Penetrating Radar.	This document is available from the Research Division upon request.

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
None	None	27	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

Over the last two years the Maryland Department of Transportation State Highway Administration (MDOT SHA) has developed a successful Ground Penetration Radar (GPR) data collection plan for bridge decks. Based on state-of-the-art GPR data collection methods and improved interpretation analysis developed and implemented in the Phase II study MDOT SHA is able to monitor several hundred bridge decks over a short period of time versus a limited number of structures monitored in the past using the traditional inspection methods. Furthermore, the development and use of automation modules in Phase II further increased productivity and accuracy of GPR data analysis.

In this Phase III project, a separate MDOT SHA contract with the Maryland Environmental Services (MES) and the Phase II subcontractor, Starodub, was issued to address: i) the development of new analysis modules for delamination and hot mix asphalt (HMA) overlay thickens and condition, and, ii) feasibility of higher-speed protocols for SF-GPR data collection. Thus, the research under the University of Maryland (UMD) task focused on the review and assessment of the proposed new GPR analysis modules developed in the MES/Starodub task, as well as an assessment of the impact of higher speed data collection protocol.

RESEARCH APPROACH

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

Task 1: Project Management.

The UMD team coordinated closely with MDOT SHA throughout the project in order to assess the effects of higher GPR testing speed (Task 2) and validation and verification of the new data elements (Task 3). Quarterly progress reports were prepared and submitted. Participation in project meetings coordinated by MDOT SHA with MES/Starodub were attended for monitoring the overall GPR data collection, analysis, and module development under the MES/Starodub contract.

Task 2. Review & Assessment of Higher-Speed Protocols on SF-GPR Data Analysis

Up to 2018 the MDOT SHA data collection with SF-GPR was based on the common-offset transmitter-receiver pattern in the antenna array and with a sampling interval of approximately 1.5 inches. With 20 transmitter-receiver pairs, the speed of acquisition was about 10 mph. Under the MES/Starodub contract a new testing protocol was tested based on the common mid-point (CMP) synthetic aperture. The objective of the new testing protocol was to allow higher speed of data collection, thus reducing monitoring time and cost. The scope of the UMD task was to review and analyze the possibility of alternative data collection speeds. The analysis results are presented in Chapter 2 of this report.

Task 3. Review & Assessment of New Modules for SF-GPR Bridge Deck Analysis

The analysis methods and modules developed in Phase II involved a two-stage processing method for existing SF-GPR databases. The first stage produces individual reports for each bridge deck in a database. The second stage assembles a set of tables for all bridge decks. This information is used to establish the parameters required for estimating the bridge deck condition and eventually compare the results to existing indices established for the National Bridge Inventory (NBI) system. The current MDOT SHA standard operating procedures (SOPs) are based on a data collection protocol adopted in 2015. There are five distinct processes in the use of SF-GPR for bridge decks:

1. Data collection;
2. Computation of data elements for each bridge deck;
3. Development of reference metric to estimate each data element;
4. Definition of parameters for a ranking model for all bridge decks or for each type of bridge decks to assess state and level of deterioration; and,
5. Remediation matrix based on data elements and state and level of deterioration.

In Phase II work was undertaken to develop and implement the third and fourth processes. An example of ranking model using the NBI condition index of bridge deck was presented at the 2017 Transportation Research Board annual meeting (Gagarin et. al., 2017, 2019). The work under the separate MES/Starodub contract was to enhance the GPR analysis and deterioration assessment of bridge decks by including additional elements of the thickness of HMA overlay and delamination assessment. The objective of the UMD task was to review and assess the updated 2019 SF-GPR data analysis pipeline which includes the new modules for HMA overlay and delamination assessment. Task 3 included the following subtasks:

3.1. Literature Review

The research team conducted a literature review on the state of practice with SF-GPR over the last three years to capture recent development in data analysis, related to HMA overlay and delamination. The Phase II GPR data analysis with data collected in 2016 using 2015 SOPs show that additional development was possible, using common mid-point (CMP) and multiple signal classification (MUSIC) algorithms.

3.2. Review of New Data Elements within the revised 2019 SF-GPR analysis pipeline.

In this subtask, the research team in coordination with Starodub reviewed the revised 2019 SF-GPR analysis pipeline which included the new data modules.

Task 4: Final Report

The research team developed this final report that includes all deliverables and analyses as described in Tasks 2 and 3.

CHAPTER 2. REVIEW & ASSESSMENT OF HIGHER-SPEED PROTOCOLS ON SF-GPR DATA ANALYSIS

The objective was to assess whether the SF-GPR testing protocol allows for higher speed of data collection without significantly compromising data quality and interpretation. The speed of acquisition is a function of three parameters that control data acquisition for a given set of transmitter-receiver antenna pairs: the sampling distance interval between each scan; the dwell time for the duration of data collection; and, the time window for integration of the data received for each frequency step that establishes the frequency-step reported. The evolution of the MDOT SHA SF-GPR data collection protocol since 2015 are listed in Table 1.

Table 1. SF-GPR settings for MDOT SHA data collection protocols

Year	Number of Transmitter-Receiver Antenna Pairs	Dwell Time (μs)	Frequency Step (MHz)	Start Frequency (MHz)	End Frequency (MHz)	Sampling Distance Interval (in)	Deployment Period
2015	20	2	8	150	1998	1.53	2015-2016
2017	34	2	8	150	1998	1.84	2017
2018	24	1.5	8	150	1998	2.56	2018-Present

Criteria for Selection of Dwell Time and Time Window Levels

The 3D-GPR system can operate at different settings that impact the data acquisition speed. Two of the parameters used by 3D-GPR are the dwell time and the time window, as defined in its documentation:

"The integration time" is the time spent sending the entire frequency range for a single trace:

$$\tau = t_{dwell}\ N_{freq} = t_{dwell}\ BW / \Delta f \qquad (1)$$

where t_{dwell} is the dwell time (the time spent on each frequency), N_{freq} is the number of distinct frequencies in a trace, BW is the total bandwidth and Δf is the frequency step. The frequency step is not set directly. Instead there is a setting for “time window.” The time window is defined as half of the range for a given frequency step, so the relationship becomes:

$$\tau = t_{dwell}\ t_{win}\ 2\ BW \qquad (2)$$

where t_{win} is the time window.

Increased integration time will result in improved penetration and can be achieved by either increasing the dwell time or increasing the time window or a combination of both. However, in order to improve the efficiency of data collection, the lowest dwell time and time window values are established for a specific application that are sufficient to produce the quality and completeness of signals necessary for the analysis. For the application of concrete bridge decks, the region of activity for the GPR signals is between the surface and the bottom of the deck, across the width of the roadway from edge to edge of the curbs, and between the start and end of the bridge deck, at the expansion joints. The thickness of the deck varies from 7 to 15 inches. The rebar spacings for the top and bottom mats vary from 5 to 14 inches. The denser the steel the lower the quality of signals below the top mat. The concrete deck may have overlay (asphalt or concrete) that further disperse the power transmitted into the deck.

Control Parameter for Assessing Effects of Data Acquisition Speed

The current selection of 24 transmitter-receiver antenna pairs (Figure 1) is the minimum required to track the rebar across the width of the pavement and deploy three CMP bank approximately 18 inches apart. The data collected using a dwell time of 0.6 microseconds and a time window of 62.5 nanoseconds was selected for the 2019 GPR surveys since it was judged to be able to provide acceptable GPR signal quality. It was also concluded that any additional reduction in dwell time or time window causes losses in signal presence and strength that adversely impact layer tracking, rebar detection, rebar tracking, and CMP measurement estimates. Collecting data across the width of the roadway from curb to curb is an essential requirement for completeness of condition assessment. Thus, sampling distance interval is the only remaining parameter that can be varied beyond the changes from 1.53 inches in 2015 and 2016, to 1.84 inches in 2017, to 2.56 inches in 2018 and 2019.

Governing Algorithm for Assessing Effects of Data Acquisition Speed

There are over 100 algorithms in the MDOT SHA GPR data analysis that register, fuse, and analyze GPS, GPR, and distance measurement intervals following the Starodub modules. Distinct structural features in the GPR data are also registered with known boundaries on the bridge deck, for example, expansion joints or bridge piers. Among these algorithms, the most critical in terms of interpretation accuracy to an increase in sampling distance interval is the rebar detection algorithm. The next most sensitive algorithm is the expansion joint detection. Starting with the largest value deployed, the upper range is estimated approximately as one third of the rebar spacing. The rebar spacing rarely falls below 11 inches and thus the range of values of interest is between one to four inches. The corresponding range of speed is 10 to 20MPH. Starodub has reported in the Phase II analysis that without the use of the rebar detection algorithm there is no concern if speed is increased to 30MPH with a sampling distance interval close to six inches. It was also reported that the signal at smaller expansion joints at the abutments is degraded but still detectable. The relative position of the expansion joint is less accurate (resolution is approximately equal to half the sampling distance interval), however it was reported that is still better than the accuracy of absolute position estimated with GPS.

Effects of Data Acquisition Speed

With sampling distance interval as the primary control parameter, the top steel cover (TSC) and presence of Hot Mix Asphalt (HMA) or Latex Modified Concrete (LMC) overlay are two other data elements that could impact the success rate of detection and measurement of hyperbolas for each rebar. Elevation and condition are two additional surface parameters that are computed in the SF-GPR analysis that impact the detection regardless of sampling distance interval. For TSC which includes the thickness of overlays, the range observed so far has been one to three and a half inches. More than three quarters of all decks reviewed in three years have a TSC close to two and a half inches. Figure 2 is an example of a cross-section for the majority of the 219 bridge decks included in the 2018-2019 GPR surveys and assessed with the 2019 SF-GPR analysis pipeline. For the assessment of data acquisition speed TSC was selected at two and a half inches. With the presence of an overlay, the energy at the rebar is reduced. The impact is observed on the amplitude and some in the phase of the signal received. It is possible that less hyperbola points are detected the further the antenna moves away from the rebar. The example presented herein is one with an asphalt (HMA) overlay, the worst-case scenario related to overlays. Finally, the diameter of the rebar is another parameter that affects the detection and data elements associated with the rebar. The shape of the hyperbola is affected as well by the strength of the signal received. The most common sizes of transverse rebar are #4, #5, and #6. In this case the bridge deck had #5 bars. The rebar detection algorithm first identifies the region of activity near the top rebar and fuses the detected hyperbolas in the two planar dimensions.

In order to demonstrate the impact of sampling distance interval on the detection of hyperbolas, random samples of data triggers were selected from the GPR database. Most samples have consistent signals with evenly spaced rebars as shown in Figure 3.

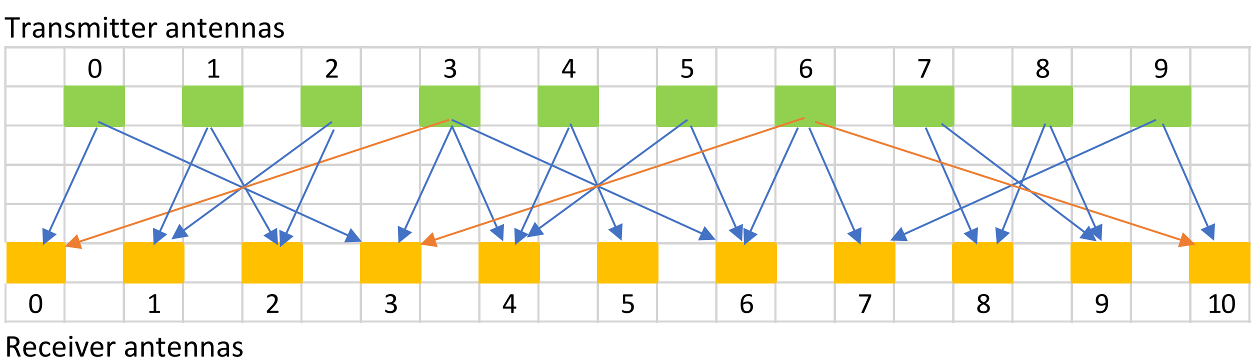


Figure 1. SF-GPR 24 transmitter-receiver antenna pairs

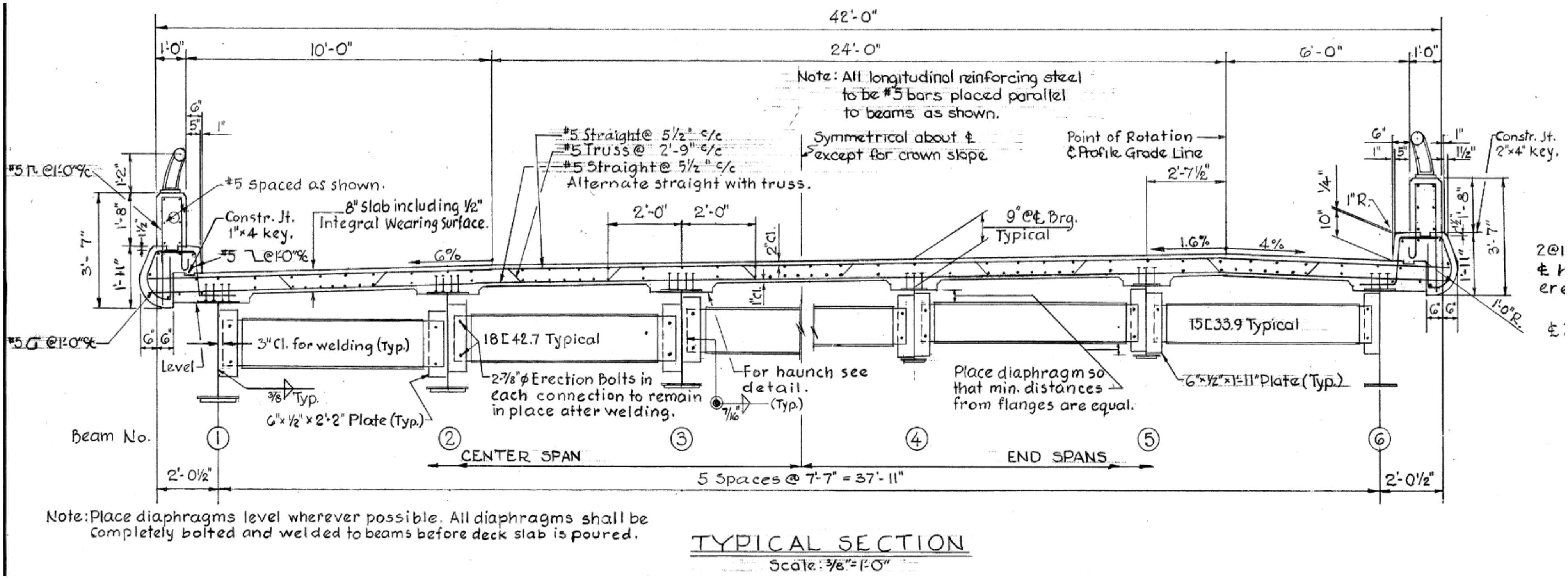


Figure 2. Cross-section of a typical bridge deck

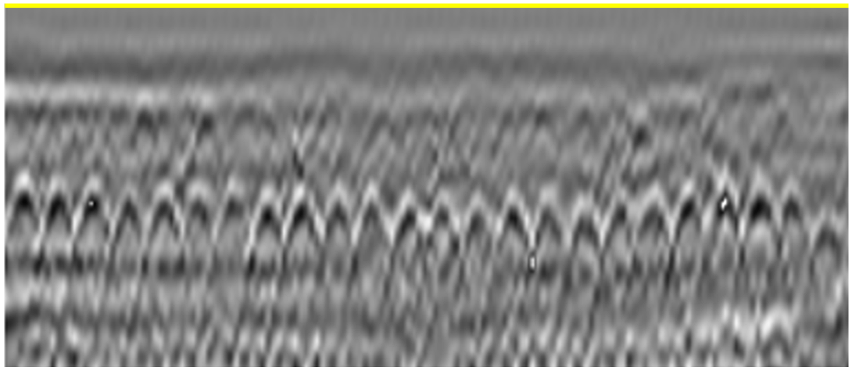
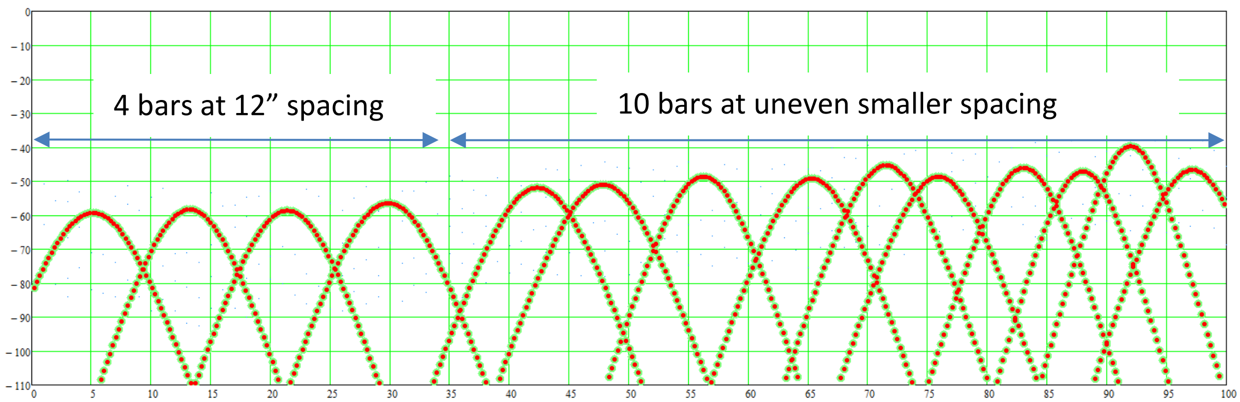


Figure 3. Example B-scan profile of rebar detection (x-axis) versus time of propagation (y-axis) for a bridge deck with overlay
Note: twenty four #5 rebars spaced at 12”, top steel cover of 2.5”

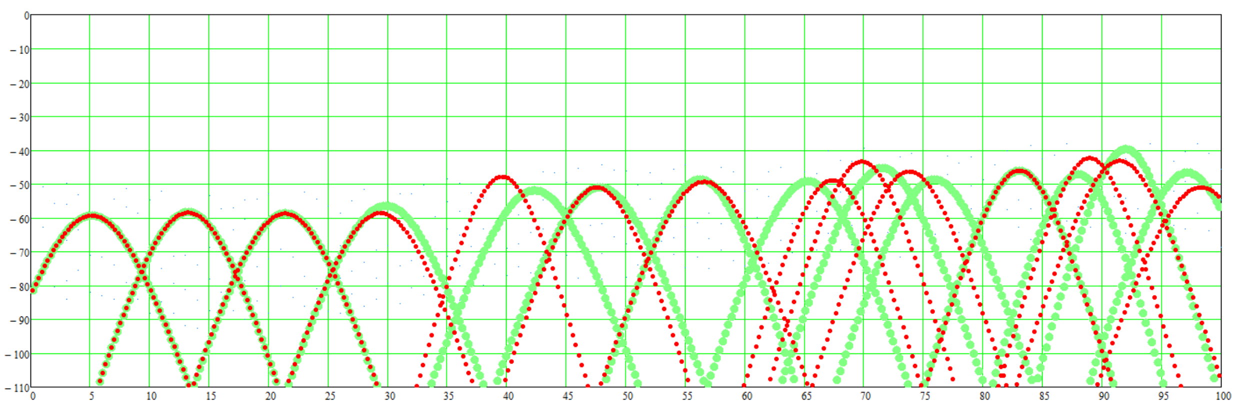
For comparative analysis a bridge deck with two sub-sections with distinct differences in condition, both in terms of spacing and top steel cover condition was selected and reported herein, Figure 4. The first third consists of four rebars spaced at 12 inches and the last two thirds has ten rebars with uneven smaller spacing, on average close to 6 inches. The last two thirds include defects between and near the top rebar, acting as a source of noise. As seen in Figure 4, all rebars were accurately detected at a sampling interval of dx=1.5” and all rebars were also detected at a sampling interval of dx=3.0” and within one-inch accuracy (Table 2). However, some rebars were not be detected at a sampling interval dx= 4.5”. Given that rebar is detected across antenna pairs by fusing the detection results from all data collection runs, the impact of the uncertainty of individual detection sets is reduced. The steel spacing maintains stability at dx=3.0” and degrades near dx=4.5.” This result is consistent throughout the entire database.

Table 2. Rebar detection in function of sampling interval dx.

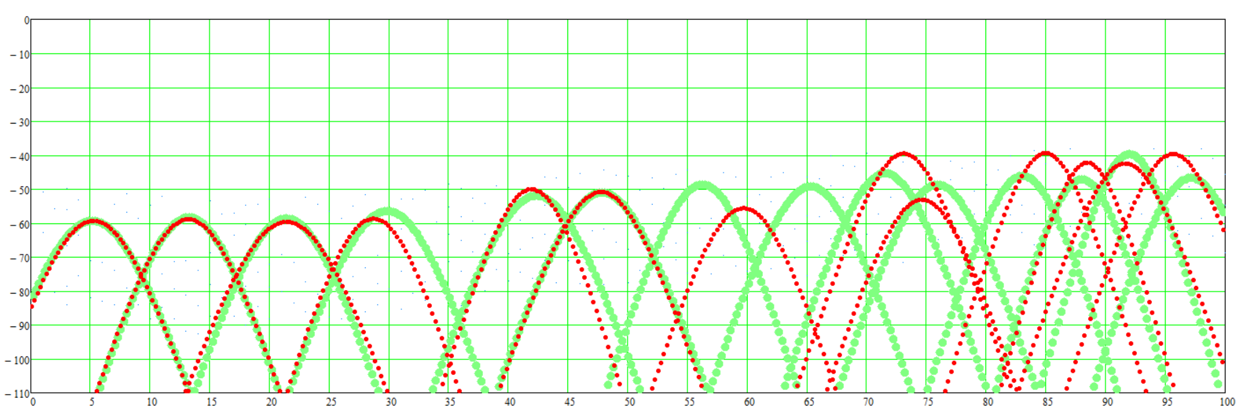
Case	Sub-Section 1 – 4 rebars		Sub-Section 2 – 10 rebars	
	Detection	Match	Detection	Match
dx = 3.0”	4 rebars	100%	10 rebars	100%
dx = 4.5”	4 rebars	100%	9 rebars	90%



dx = 1.5”



dx = 3.0”



dx = 4.5”

Figure 4. Rebar detection (red hyperbolas) matching ground truth conditions (green).

CHAPTER 3. REVIEW & ASSESSMENT OF NEW MODULES FOR SF-GPR BRIDGE DECK ANALYSIS

Literature Review

The research team conducted a literature review on the state of practice with GPR-SF over the last three years to capture any recent development in data analysis pertinent to HMA overlay and delamination, and the use of common mid-point (CMP) method. This review was to complement the knowledge after the extensive review that was conducted during the Phase II of the study (Goulias et al., 2014, Pailes et.al., 2013, Perkins et. al., 2000, Scott et. al., 2003 and 2015, Tinkey et. al., 2013).

A study by Zhao et. el., (2016) used extended CMP (XCMP) with SF-GPR to detect the dielectric properties and asphalt layer thickness. The configurations were based on the transmitting and receiving antennas that share the same midpoint (Table 3). The 3D-GPR antenna DX1821 (Figure 5) has a pattern, gain, and impedance nearly constant over a wide frequency range. The governing equations are based on geometry of configuration and they are not necessarily stable, meaning that a small perturbation in the inputs could have a huge influence on the outputs. Therefore, Whittaker-Shannon interpolation was applied to convert the data from frequency domain to time domain and increase the time domain sampling rate. Alternative XCMP patterns were used to identify which setup provides the most accurate GPR interpretation results in relation to measured asphalt layer thickness from design and cores. The study indicated that specific XCMP patterns provided accurate asphalt layer thickness detection within 0.2 inches (5 mm) accuracy which meets construction tolerance.

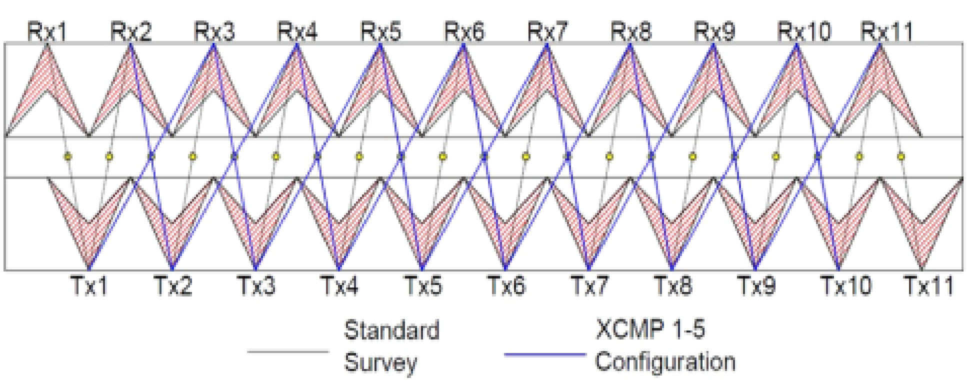


Figure 5. DX 1821 Antenna Array Layout and CXMP configurations (Zhao et.al., 2016).

Table 3. CXMP configurations (Zhao et.al., 2016).

	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5
Configuration	XCMP 1–3	XCMP 1–5	XCMP 1–7	XCMP 3–5	Standard
Distance between 1st Tx/Rx pair (m)	0.446	0.446	0.446	0.369	0.446
Distance between 2nd Tx/Rx pair (m)	0.369	0.578	0.685	0.578	–

A study by Zhao et. el., (2018) used multiple signal classification (MUSIC) algorithm to increase the resolution of 3D-GPR signals, such that thin asphalt overlay thickness can be accurately estimated. The XCMP method requires accurate determination of the peak location in the GPR signal which maybe challenging for thin asphalt concrete, AC, layers. Thus, to increase the resolution of the GPR signals alternative resolution techniques were proposed. A full-scale AC overlay section was built with design thickness ranging from 2 to 8 inches (50 to 200 mm). Steel plates were embedded in the pavement layers to increase the reflection amplitude. The proposed MUSIC algorithm was then applied to the XCMP signals. Signal preprocessing techniques including data cleaning and spatial smoothing were first performed to increase the signal to noise ratio (SNR). The predicted AC layer thicknesses were then compared with ground truth values from the overlay construction. While the regularization method's time delay estimation (TDE) may not always provide enough accuracy in precision when the XCMP method is used, the MUSIC algorithm increases the resolution of the GPR signals collected from thin AC overlays and achieve higher accuracy and precision. The maximum absolute AC layer thickness prediction error, when the MUSIC algorithm was applied, was 0.15 inch (4 mm).

A study by Ihamouten et. al. (2018) investigated the full-waveform inversion (FWFI) of SF-GPR radar waves (i.e., inversion in the frequency domain instead of inverse Fourier transform) to estimate the dielectric and geometric properties of tack coats in pavements. To achieve this the following steps were undertaken: develop a laboratory experimental study to assess the response of SF-GPR in various emulsions and thicknesses (dielectric and geometric characterization); validate results with numerical modeling; and, develop SF-GPR data processing algorithms to link dielectric characteristics with emulsion quantities for various specimens. Following these initial steps, several two-layer slabs were designed, with variable emulsion quantities, thicknesses and compaction. The result showed that the presence of emulsion at the interface decreased the wave propagation velocity. The emulsion quantity had an influence on the estimated layer thicknesses. Overall, the results of this preliminary research work prove that the FWFI approach is suitable for describing wave propagation through multi-layered media since there is a correlation between dielectric susceptibility and emulsion quantity.

Review of Revised SF-GPR Analysis Pipeline incorporating New Data Elements

In this task the research team in coordination with Starodub reviewed the revised SF-GPR analysis pipeline which incorporates the new data modules: (i) thickness and condition of the HMA overlay and (ii) delamination potential. Figure 6 is an example of a profile radagram of a three-span bridge. The extent of areas of activity are color-coded. The abutments and piers are shown in blue, the overlay-concrete interface in red, the top steel in green, and the bottom steel in orange. Each data element is generated using several GPR interpretation algorithms involving dimensional filters, detection and fusion algorithms. The revised SF-GPR analysis pipeline is presented in Figure 7. Details of its components were included in the Phase II report (Goulias 2016) based on the initial SF-GPR analysis pipeline. The final summary report for each bridge deck, by span, and for all spans is shown in Figure 8. The summary report includes two types of data elements: (a) bridge deck information data, and, (b) bridge deck condition data. Appendix A presents the latest version of the data analysis modules, with details on how each bridge deck condition parameter is detected using the SF-GPR data. It specifically includes:

- GPR Inputs;
- Bridge deck condition parameters
    - Concrete Surface Condition (SC)
    - Surface Elevation (SE)
    - Overlay Thickness (OT)
    - Overlay Condition (OC)
    - Top Steel Cover (TC)
    - Above Steel Condition (ASC)
    - Top Steel Condition (TSC)

- o Below Steel Condition (BSC)
- o Deck Thickness (DT)
- o Bottom Steel Cover (BC)

- Percent Deficient & Fuzzy Sets for Defining Condition Membership Functions;
- Fuzzy-Set Model.

Above Steel Condition (ASC), Top Steel Condition (TSC) and Below Steel Condition (BSC) are pertinent to delamination detection while the analysis modules pertinent to the thickness and condition of the HMA overlay are Overlay Thickness (OT) and Overlay Condition (OC).

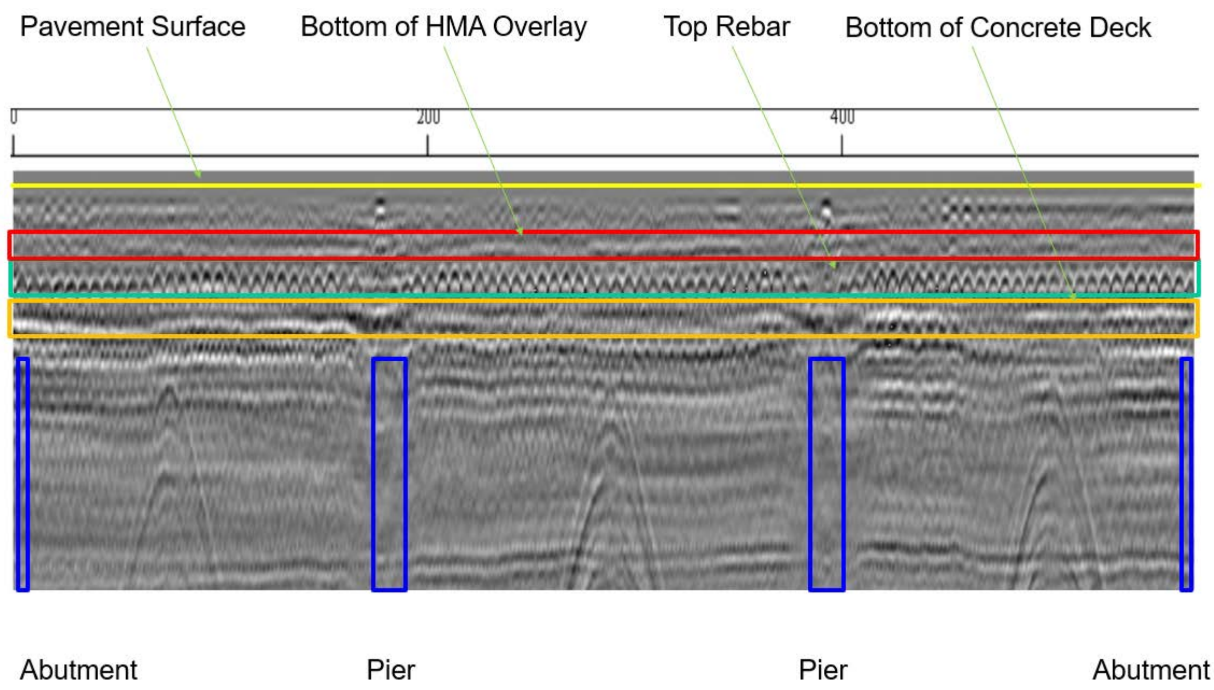
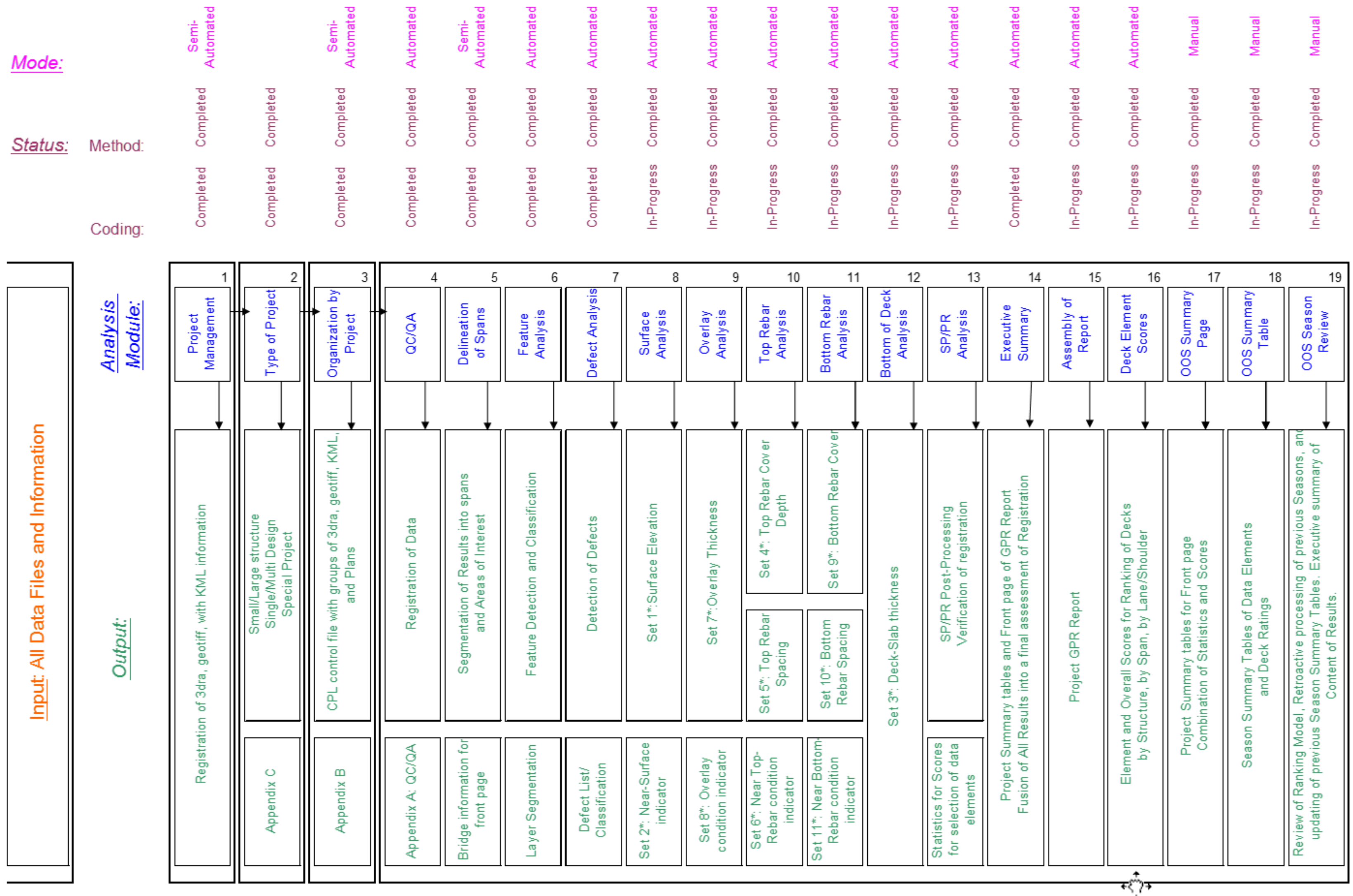


Figure 6. Example Profile View (B-scan) of three-span bridge deck.



*Note: Each set comprises three types of plots and tabulation of results by span

Figure 7. 2019 SF-GPR Analyses Pipeline

OFFICE OF STRUCTURES
GROUND PENETRATING RADAR FOR BRIDGE DECKS

Bridge Data Information Sheet

Date of Last GPR Survey: *12/3/2018*
Bridge Number: *2303300* Sub-Structure: - Span: *3*
Location: District: 1 County: Worcester County
Feature Carried: *'MD 90 '*
Feature Intersected: *'NORFOLK SOUTHERN RR '*

General Bridge Deck Data

Number of Spans: *3* Total Length: *51.0* *ft* Total Area: *2244* *sf*

Bridge Deck Surface: ☑ Bare Concrete ☐ HMA ☐ LMC ☐ Other, specify

Data Element	Average	Minimum	Maximum	Per Plan
Deck Thickness (DT)	*7.97*	*7.43*	*8.41*	*8*
Overlay Thickness (OT)	-	-	-	-
Top Steel Cover (TC)	*2.33*	*0.71*	*5.34*	*2*
Top Steel Spacing (TS)	*7.55*	*4.34*	*9.83*	*10*
Bottom Steel Cover (BC)	-	-	-	-

Notes:

Bridge Deck Condition Data

Data Element	Previous GPR Report		Last GPR Report		Note/ Recommendation
	Date:	-	Time Elapsed:	-	
	Percent Deficient*	Condition Rating**	Percent Deficient*	Condition Rating**	
Surface Elevation (SE)	-	N/A	45	Marginal	
Surface Condition (SC)	-	N/A	16	Acceptable	
Overlay Condition (OC)	-	N/A	-	N/A	
Above Top Steel (ASC)	-	N/A	13	Very Good	
Top Steel Condition (TSC)	-	N/A	2	Very Good	
Below Top Steel (BSC)	-	N/A	2	Very Good	
Overall Score (1-9) ***	-		6		
Overall State (1-4) ***	-		2		

*Percent Deficient is estimated using Reference Conditions for each data element.
**Condition Ratings are established using Percent Deficient using the following scale:
Very Good Good Acceptable Marginal Poor N/A
*** Overall Score and State are estimated using a combination of data elements

Notes:

For more information, go to GPR Report: *2303300_GPR_Report.PDF*

Figure 8. Example of GPR summary page

Bridge Deck Condition Assessment Model (BDCAM)

The bridge deck condition assessment model (BDCAM) estimates the deck condition and condition state using the SF-GPR data elements estimated using the 2019 SF-GPR analysis pipeline presented in Figure 7. Deck condition is defined based on a fuzzy model of the various levels of defect and deterioration of the deck. Figures 9 and 10 present the processing levels hierarchy and corresponding data analysis elements in the BDCAM model. Level 1 estimates the condition near the surface (Surface Condition), in the cover (Cover Condition), and near the top mat of steel (Rebar Condition). Level 2 combines cover and rebar conditions to estimate the Structural Condition. Finally, surface and structural condition are input to the estimate of deck condition and condition state, Level 3. For this first version of the BDCAM model, the weight of each input is equal.

The fuzzy-sets for a selection of data elements are input in a fuzzy model to compute higher-level data elements that summarize the information captured by the GPR data. The proposed fuzzy model is under review by the MDOT SHA Office of Structures, briefly described in Appendix A. Below is a list of associations of measured data elements to produce an estimate of an overall score for the condition of the deck using GPR data in two forms of presentation. First the levels of association are listed, Figure 9, and second, the hierarchy of data elements up to the overall scores are presented, Figure 10. The details of the analysis modulus are described in Appendix A as well.

Level 1:

Surface Condition [SC] & Surface Elevation [SE] → SURFACE CONDITION

Top Steel Cover [TC], Above Steel Condition [ASC] &
if applicable, Overlay Condition [OC] → COVER CONDITION

Top Steel Condition [TSC] &
Below Steel Condition [BSC] → REBAR CONDITION

Level 2:

COVER CONDITION & REBAR CONDITION → STRUCTURAL CONDITION

Level 3:

SURFACE CONDITION & STRUCTURAL CONDITION → Overall Scores

Figure 9. Processing levels in BDCAM model

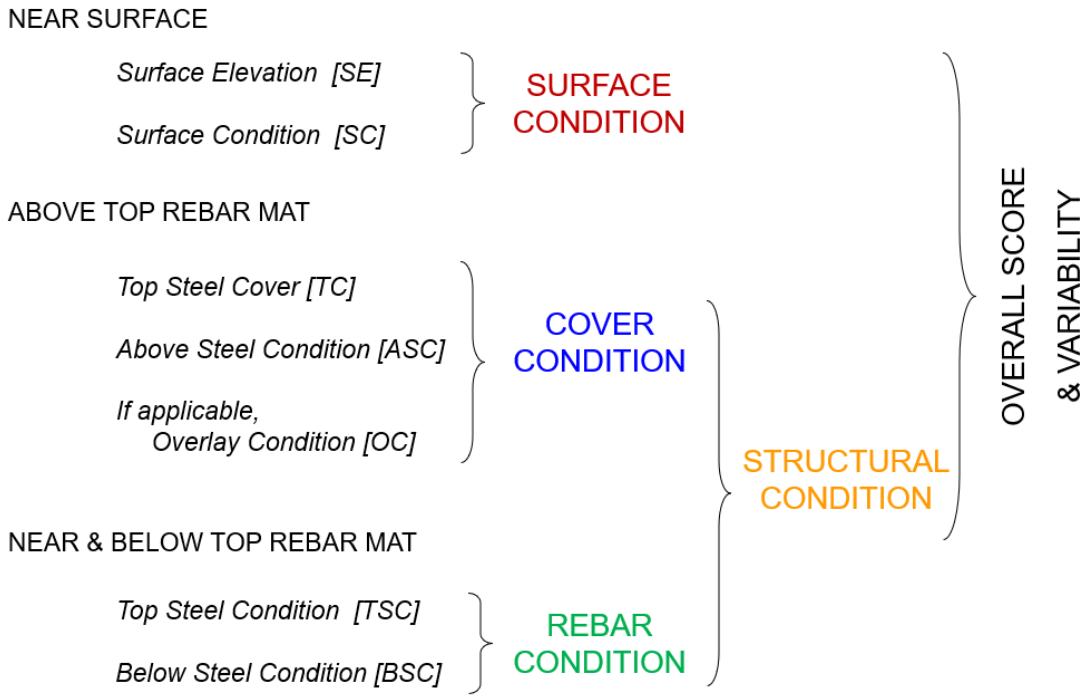


Figure 10. Hierarchy and correspondence of GPR data elements in BDCAM model

Ground Truth Conditions and the National Bridge Inventory (NBI)

The scope of the initial "ground truth" assessment includes deck rating and condition state, CS, data from the Long-Term Bridge Performance (LTBP) database. Significant verification work has been completed by the states and Federal Highway Administration (FHWA) on such data. Figure 11 presents an overview of the LTBP database and condition definitions used. There are 2,552 MDOT SHA bridge entries into the database. Figure 12 presents an example of the bridge deck condition state data for Maryland.

From the 2018 and 2019 SF-GPR database collected by MES about 219 bridge decks have been analyzed with the revised 2019 SF-GPR analysis pipeline. These represent bridge decks where: the same equipment (GPR, GPS, DMI) was used; antenna was at the right height from the bridge deck surface throughout the entire data collection time; surveys were collected with appropriate protocol and data collection speed. The LTBP database query for the 219 Maryland bridge decks analyzed with the revised 2019 SF-GPR analysis pipeline provided the following results: from the 197 bridges corresponding to 219 bridge decks, three bridge decks are missing information, and all have concrete surface except 62 of them with HMA overlay and 13 with LMC overlay.

Figure 13 presents a histogram of the deck conditions for all the 219 bridge decks according to the BDCAM analysis. The condition of all the bridge deck spans (853 spans for the 219 bridge decks) was used for comparing the BDCAM with the NBI deck condition and condition state (Figure 14). The results are tabulated in Table 4 per bridge deck and per span entry. The BDCAM estimates agree with the NBI values reported as of August 2019 for 90.9% of the 219 decks within two levels of the condition scale. Based on feedback with inspectors and bridge engineers, it is well accepted that the reported NBI deck condition values can be within two levels of the scale from the actual condition of the deck. Also, the final BDCAM model settings will be based on the values defined by bridge engineers based on all decks in the GPR database. The current settings in the BDCAM model reflects equal weights of the relative importance of defects and deterioration near the surface, within the top steel cover, near the top mat of rebar, and below the top mat of rebar. Such settings could be adjusted by MDOT SHA structural engineers to better represent the importance of each parameter on the overall bridge deck condition and rating.

Table 4. Percent true, false positive, false negative for deck and span conditions, for three tolerance levels

Bridge Decks (219)

Tolerance	% False Positive	% True	% False Negative
Within 1 NBI rating	3.2	62.1	34.7
Within 2 NBI rating	0.5	90.9	8.6
Within 3 NBI rating	0	96.8	3.2

Span Entries (853)

Tolerance	% False Positive	% True	% False Negative
Within 1 NBI rating	4.1	60.7	35.2
Within 2 NBI rating	0.7	90.9	8.4
Within 3 NBI rating	0	97.2	2.8

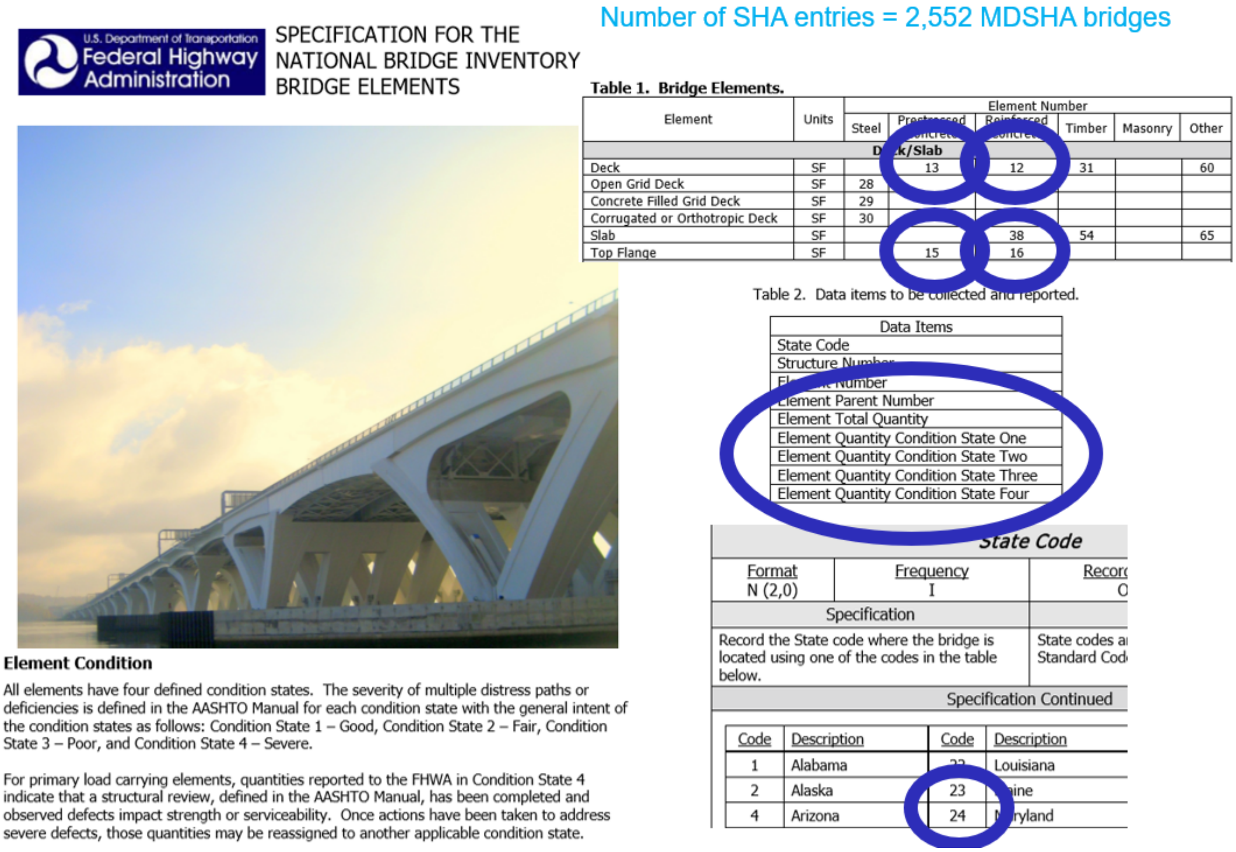


Figure 11. Source of information and definitions for initial ground truth

	A	B	C	D	E	F	G	H	I
1	STATE	STRUCNUM	EN	TOTALQTY	CS1	CS2	CS3	CS4	EPN
2	24	100000010001010	12	4353	4343	10	0	0	
3	24	100000010004010	12	4269	4259	10	0	0	
4	24	100000010059010	12	6350	6340	10	0	0	
5	24	100000010060010	12	118440	65945	52495	0	0	
6	24	100000010061010	12	2833	2733	100	0	0	
7	24	100000010072010	12	922	922	0	0	0	
8	24	100000010077013	12	18674	18664	10	0	0	
9	24	100000010077014	12	14050	14050	0	0	0	
10	24	100000010087010	12	22205	22165	40	0	0	

Figure 12. Condition state data
Note: Maryland= 24; Superstructure =12; Condition State 1 = CS1.

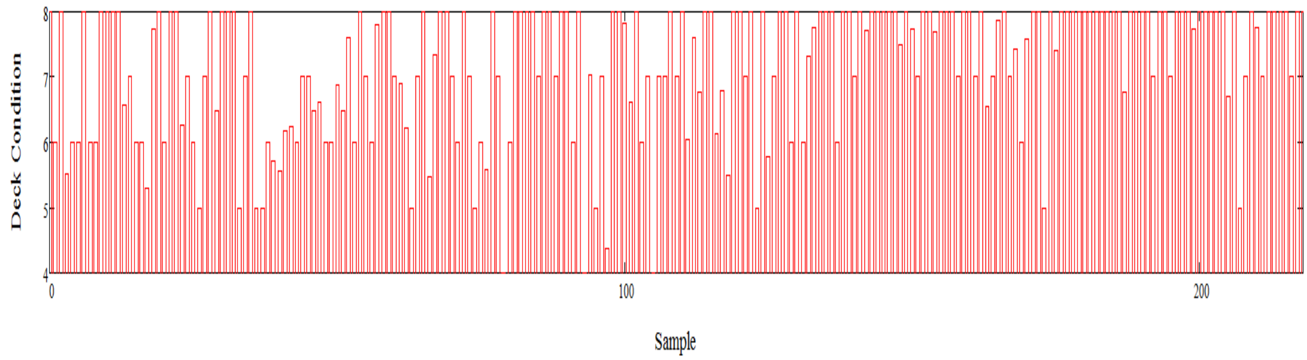


Figure 13. Bridge Deck Condition from BDCAM analysis, 219 bridge decks

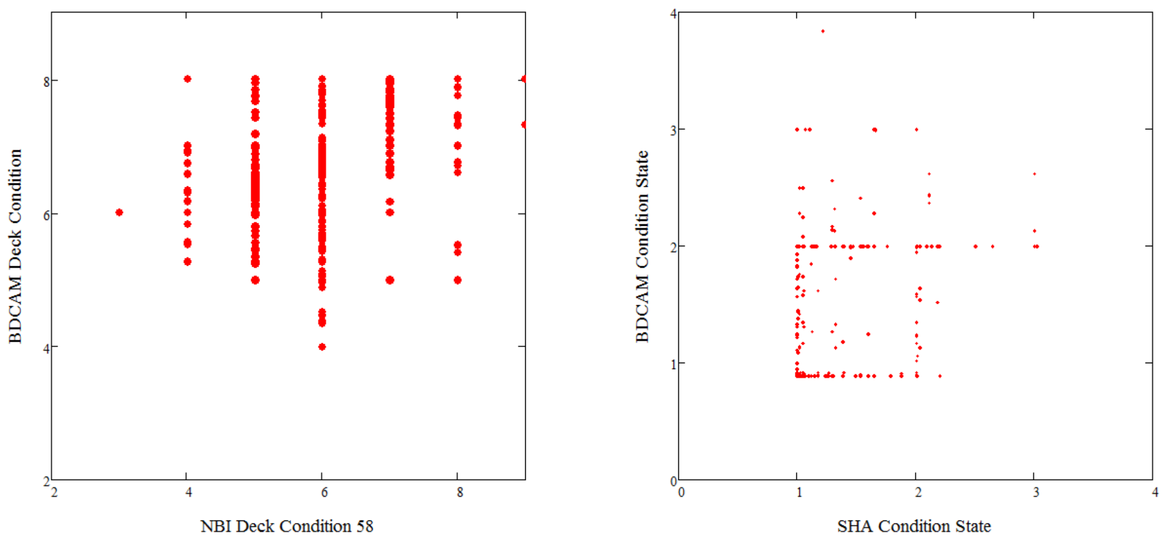


Figure 14. Comparison of BDCAM and NBI Ground Truth for deck condition & condition state.

Review of Bridge Deck State Inspection Reports with NBI and BDCAM

Eight bridges were identified with bridge deck inspection reports and were surveyed with SF-GPR and analyzed with the 2019 SF-GPR analysis pipeline. The details of the bridge deck locations and BDCAM analyses results, as well as the state inspection reports, are included in Appendices B and C. Based on the review of the inspection reports the content of information varies from bridge to bridge and the time elapsed since the reports were prepared ranges from August 2013 to April 2017. Three of the eight inspection reports are approximately 2.5 years old, and five inspections more than five years old. Some inspections were limited to abutments and substructure. Bridge deck inspection reports have a map of the core locations and pictures of the bore holes with results of chloride testing. A percentage of sound concrete was reported for the inspection component. The inspection reports do show some level of deterioration of the deck components consistent with the deck condition ratings from both the BDCAM and NBI databases. Tables 5 and 6 provide the NBI and BDCAM condition states, while the location and scope, the general information and the detailed condition assessment from the BDCAM GPR analyses are included in Appendix B. The review of the condition ratings, Table 5, shows consistent results except for bridge 2108500. The BDCAM estimate for this deck condition is 6 and the NBI deck condition is 4 or poor. The BDCAM estimate would be classified as a false negative, fair (6) instead of poor (4) since its estimate is lower than the NBI value. The BDCAM and NBI values of all other bridges are equal or within one condition rating of each other, all in the fair condition range.

Table 5. NBI and BDCAM Bridge Deck Condition Rating for Bridges with inspection reports

Bridge Number	Processing Batch	District	Bridge Rating	Length	Square Footage	NBI	BDCAM		Year repaired
0700300	G12	District_2	Fair	86	11,033	5	6	1933	-
1701102	G12	District_2	Fair	52	5,883	5	5	1967	-
1701202	G12	District_2	Fair	52	3,899	6	6	1967	-
1701302	G12	District_2	Fair	52	6,421	6	7	1967	-
2108500	F	District_6	Poor	54	5,229	4	6	1965	-
2202100	G11	District_1	Fair	47	8,991	5	6	1972	-
2202401	G11	District_1	Fair	45	6,063	5	5	1974	2017
2202402	G11	District_1	Fair	45	6,148	6	5	1974	-

Note: NBI (Deck 58); BDCAM (Super 59)

Table 6. Condition State Data for Bridge with Inspection Reports

Bridge Number	Processing Batch	District	Total Number	CS1	CS2	CS3	CS4
0700300	G12	District_2	11036	0	10030	1006	0
1701102	G12	District_2	5716	3031	2664	21	0
1701202	G12	District_2	3906	1756	2148	2	0
1701302	G12	District_2	6426	5496	885	45	0
2108500	F	District_6	-61828	-61828	-61828	-61828	-61828
2202100	G11	District_1	6611	4965	1322	324	0
2202401	G11	District_1	6106	6106	0	0	0
2202402	G11	District_1	3139	524	1487	1128	0

CHAPTER 4. SUMMARY & CONCLUSIONS

The development of analysis modules for delamination and HMA overlay were incorporated in the 2019 SF-GPR analysis pipeline. The BDCAM model estimates agree with the NBI values for 90.9% of the 219 bridge decks analyzed within two levels of the condition scale. The current settings in the BDCAM model reflects equal weights of the relative importance of defects and deterioration near the surface, within the top steel cover, near the top mat of rebar, and below the top mat of rebar. Thus, such settings could be adjusted to reflect Maryland conditions for all or specific bridge deck types improving accuracy of prediction. The comparison of BDCAM analysis with state inspection deck reports for eight bridges provided consistent conclusions for seven out of the eight cases, all in the “fair” category.

Until 2018 the MDOT SHA SF-GPR data collection was based on the common-offset transmitter-receiver pattern in the antenna array, with a sampling interval of approximately 1.5 inches. With 20 transmitter-receiver pairs, the speed of acquisition was about 10 mph. In 2019 a new testing protocol was adopted based on the CMP synthetic aperture. The data acquisition speed for the 2019 data collection protocol is 10 mph for all conditions with a dx=2.5”. The analysis presented in Chapter 2 indicated that sampling interval up to dx=3.0” provides accurate steel rebar detections, representing the governing algorithm in SF-GPR analysis for bridge deck applications. This is also true when an HMA overlay is present on the bridge deck. With a dx=3.0” data collection speed can be increased to 13 mph. Beyond that signal degrades affecting detection accuracy of steel spacing.

FUTURE WORK

The current settings in the BDCAM model reflect equal weights of the relative importance of defects and deterioration near the surface, within the top steel cover, near the top mat of rebar, and below the top mat of rebar. The weights could be adjusted to better represent the importance of each parameter on the overall bridge deck condition. The relative importance of such condition parameters should be defined once all bridge decks in the MDOT SHA SF-GPR database are analyzed with the 2019 SF-GPR analysis pipeline.

The percent coverage, the equipment, and operator errors impact the consistency of the results. Percent coverage in the SF-GPR database varied from 20 to 100 percent, and there were changes in equipment in the 2017 to 2019 seasons. Operator discrepancies such as starting collection late, ending collection too soon, lowering antenna late, or lowering antenna partially have an impact on GPR data. The impact of such effects should be examined in the future work and proper operator training modules should be developed.

Currently the data acquisition speed for the 2019 GPR data collection protocol is 10 mph for all conditions (with a dx=2.5”). The surface roughness is one of the limiting factors for speed of data acquisition. The smoother the surface of the deck, the faster the speed. The data acquisition speed of 10 mph is acceptable for all roughness conditions. The adoption of any higher data collection speeds needs to be further examined considering the following practical recommendations:

a. Driving lanes with low surface roughness (IRI ≤ 100): If two CMP banks (3’ sampling laterally) are used instead of three (2’ laterally), the data acquisition speed can be increased to 12 mph. If dwell time is reduced to 1.0 μs from 1.5 μs, the data acquisition speed can be increased to 15 mph. If sampling distance interval is increased to 3.25” from 2.5”, the data acquisition speed can be increased to 13 mph. If some loss of accuracy in rebar detection is acceptable, a data acquisition speed of 30 mph is possible.
b. Driving lanes with higher surface roughness (IRI > 100): Since surface roughness is a limiting factor, the operator should slow down to 5 mph or less for bumps and potholes on the deck.
c. Shoulders (median and outer): the data acquisition speed is always limited to 10 mph due to potential debris and anomalies on pavement surface. For data collection runs near curbs a reduced speed to 5 mph or less is recommended.

REFERENCES

Al-Qadi, I.L., Lahouar, S., “Part 4: Portland Cement Concrete Pavement: Measuring Rebar Cover Depth in Rigid Pavements With Ground Penetrating Radar,” Transportation Research Record: Journal of the Transportation Research Board, 2005, pp. 81-85.

Gagarin N., Makemson J., Goulias D., Cutts R., and Andrews J. “Condition Assessing of Concrete Bridge Decks Using Step-Frequency Ground Penetration Radar.” 2017 Transportation Research Board Annaul Meeting, January 2017.

Gagarin N., Goulias D., Makemson J., Cutts R., and Andrews J. “Development of Novel Methodology for Assessing Bridge Deck Conditions Using Step Frequency Antenna Array Ground Penetration Radar.” *Journal of Performance of Construction Facilities*, ASCE, December 2019. DOI: 10.1061/(ASCE)CF.1943-5509.0001365.

Goulias D., and Scott M. “Effective Implementation of Ground Penetrating Radar (GPR) for Condition Assessment & Monitoring of Critical Infrastructure Components of Bridges and Highways.” Maryland SHA, Hanover, MD, 2014.

Goulias D., “Effective Implementation of Ground Penetrating Radar (GPR) for Condition Assessment & Monitoring.” Maryland SHA, Hanover, MD, 2016.

Ihamouten A., Bosc A., Guan, B., Le Bastard C., Fauchard C., Lambot S., and Dérobert X. “Full-waveform inversion using a stepped-frequency GPR to characterize the tack coat in hot-mix asphalt (HMA) layers of flexible pavements.” NDE &E International, 95:17-25, 2018. https://doi.org/10.1016/j.ndteint.2017.12.006

Pailes, B.M., Gucunski, N., Brown, M., “Correlation of Non-destructive Testing Results to Improve Assessment of Corrosion and Corrosion Damage of a Reinforced Concrete Deck,” Proceedings of the Transportation Research Board 92nd Annual Meeting, Washington, D.C., January 13-17, 2013.

Perkins, A.D., Amrol, J.J., Romero, F.A., Roberts, R.L., “DOT Specification Development Based on Evaluation of Ground-Penetrating Radar System Performance in Measuring Concrete Cover (Reinforcement Depth) on New Bridge Deck Construction,” Structural Materials Technology

IV: an NDT Conference, Editor: Sreenivas Alampalli, New York State Dept. of Transportation, March 2000, pp. 53-60.

Scott, M., Rezaizadeh, A., Delahaza, A., Santos, C.G., Moore, M., Graybeal, B., Washer, G., "A Comparison of Nondestructive Evaluation Methods for Bridge Deck Assessment," Nondestructive Testing and Evaluation International, Vol. 36, 2003, pp. 245-255.

Scott M., and Goulias D."Quantitative Bridge Deck Evaluation Using Emerging Ground Penetrating Radar Data Collection and Analysis." 16th European Bridge Conference and Exhibition. Edinburg, UK, June 25, 2015.

Tinkey, Y., Miller, P., Leonard, M., Pott, A., Olson, L., "Bridge Deck Scanning for Condition Assessments of Bare Concrete and Asphalt Overlaid Decks," Proceedings of the Transportation Research Board 92nd Annual Meeting, Washington, D.C., January 13-17, 2013.

Zhao S., and Al-Qadi I. "Development of an analytic approach utilizing the extended common midpoint method to estimate asphalt pavement thickness with 3-D ground-penetrating radar." NDE &E International, 78: 29-36, 2016. DOI: https://doi.org/10.1016/j.ndteint.2015.11.005

Zhao S., and Al-Qadi I. "Super-Resolution of 3-D GPR Signals to Estimate Thin Asphalt Overlay Thickness Using the XCMP Method." IEEE Transactions on Geoscience and Remote Sensing PP(99):1-9 · August 2018. DOI: 10.1109/TGRS.2018.2862627

APPENDIX A

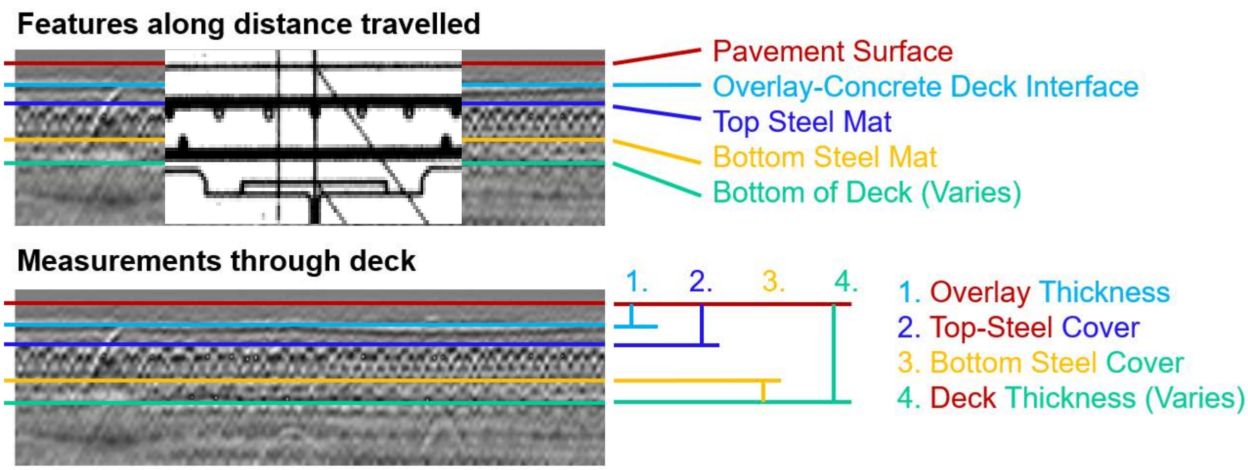
2019 SF-GPR ANALYSIS MODULES (BDCAM)

Revised 6 December 2019

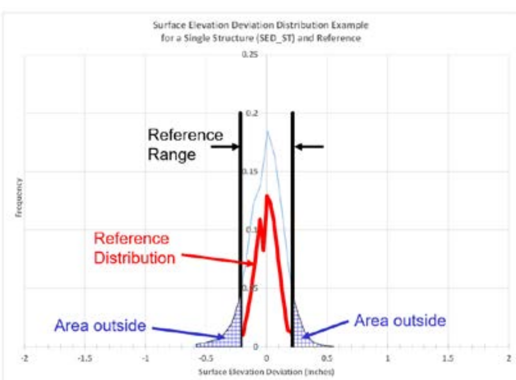
GPR Information Overview

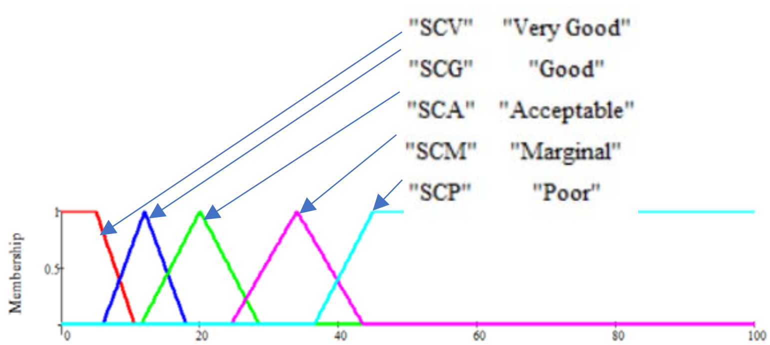
1. **GPR Input**

Region of activity in GPR data is between the surface and the bottom of the deck as shown in the profile views below.



2. **Data Elements Reported near GPR Features**
   a) *Pavement Surface*: Surface Condition [1] (Near Surface Dielectric Permittivity) and Surface Elevation [2]
   b) *Overlay-Concrete Deck Interface*: Overlay Thickness [3], and Overlay Condition [4] (Indication of Defect and/or Debonding)
   c) *Top Steel Mat*: Top Steel Cover [5], Top Steel Condition [6] (Indication of Delamination)
   d) *Bottom Steel Mat*: Bottom Steel Cover [7]
   e) *Bottom of Deck*: Deck Thickness [8]
3. **Data Elements Available:** Rebar Spacing [9]
4. **Data Elements under development:** Indication of Corrosion of Top Steel [10], Vertical Cracking [11], Bottom Steel Condition [12]
5. **Percent Deficient and Fuzzy Sets**





Percent deficient – Concrete Surface Condition

A Reference Distribution and Range for is established for each data element (see figure). It represents the best condition of a new deck as close to the condition free of defects and deterioration. For a given set of measurement, the percent area that falls outside the reference is estimated. The larger the area, the greater the potential for deterioration. Membership functions are defined to represent the increasing change from the reference captured in the percent deficient. For the data element shown in the figure above, there are five fuzzy sets that represent “very good”, “good”, “acceptable”, “marginal”, and “poor” ratings.

6. Fuzzy-Set Model (Revision 2)

The fuzzy-sets for a selection of measured data elements are input in a fuzzy model to compute higher-level data elements that summarize the information captured by the GPR data. A proposed fuzzy model is under development with the participation of the Office of Structure. Below is a list of associations of measured data elements to produce an estimate of an overall score for the condition of the deck using GPR data in two forms of presentation. First the levels of association are listed, and second, the hierarchy of data elements up to the overall scores are presented.

Level 1:

Surface Condition [SC] & Surface Elevation [SE] → SURFACE CONDITION

Top Steel Cover [TC], Above Steel Condition [ASC] & if applicable, Overlay Condition [OC] → COVER CONDITION

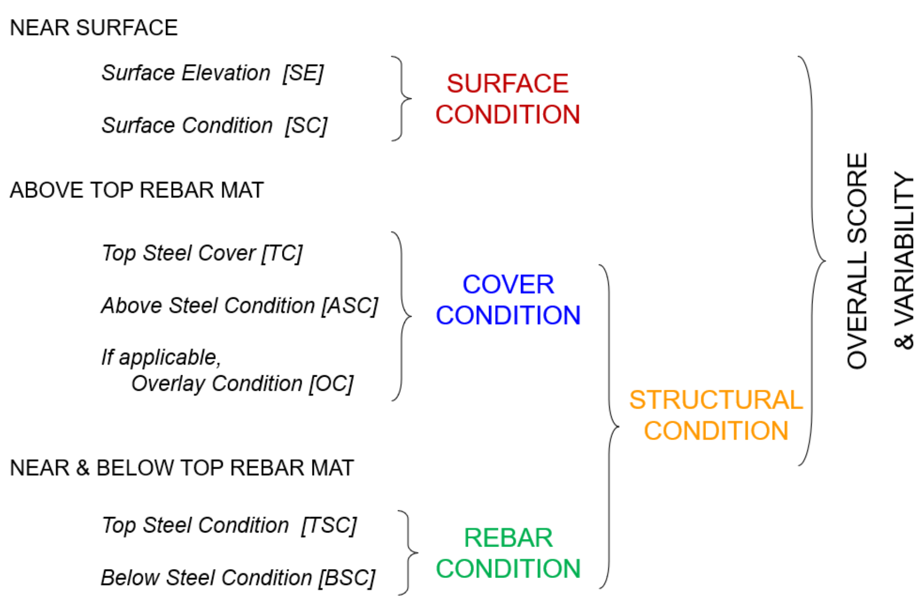
Top Steel Condition [TSC] & Below Steel Condition [BSC] → REBAR CONDITION

Level 2:

COVER CONDITION & REBAR CONDITION → STRUCTURAL CONDITION

Level 3:

SURFACE CONDITION & STRUCTURAL CONDITION → Overall Scores



7. GPR Information Details

A one-page document is provided for each measured data element below. Note that the data elements included were prepared using the 2017, 2018, and 2019 MDSHA GPR database.

Revised 1 December 2019
GPR Information Details
[1] Concrete Surface Condition (SC)

Definition

The surface condition is an estimate of the variance in material consistency near the surface of the deck using the near surface dielectric permittivity measured by the GPR sensor.

Element Rating

The Element ratings are based on the percentage of measurements outside a reference that captures the condition expected in measurements of a deck in very good condition. (see GPR Information Summary for additional information)

Very Good: The material near the surface is homogeneous and comparable to the condition of a new deck.

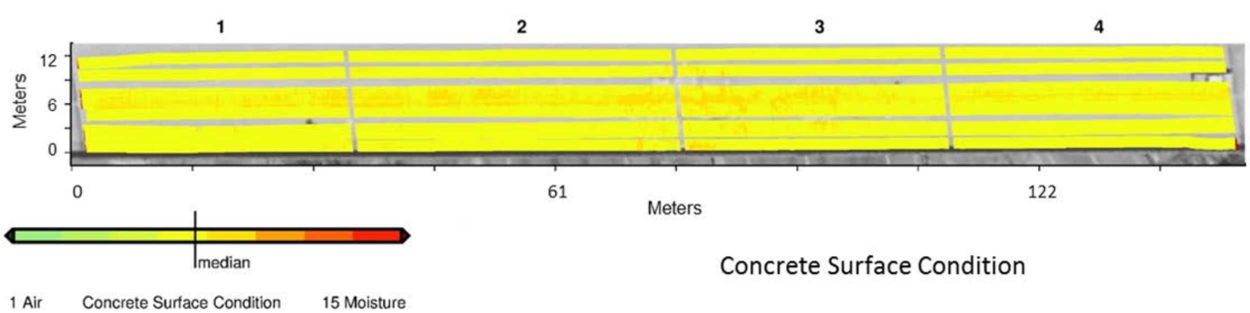
Good: A small percentage of measurements indicate a deviation from the condition of a new deck. There is no concern about exposure of the top steel mat to moisture and corrosive chemical agents. There is no impact on the ride quality over the deck.

Acceptable: A greater percentage of measurements indicate a deviation from the condition of a new deck. There is a minimal potential for some exposure of the top steel mat to moisture and corrosive chemical agents. There is some minor loss of ride quality over the deck.

Marginal: There is an increased risk of exposure of the top steel mat to moisture and corrosive chemical agents. Recommend review of condition of top steel mat for indication of deterioration. There is an impact on the ride quality over the deck.

Poor: The material near the surface is heterogeneous most likely due to significant surface defects. This is an indication of variance in material quality, including density, voids, and/or cracking. There is a significant loss of ride quality over the deck. Check condition of top steel mat for potential indication of corrosion, delamination, and initiated vertical cracking. May require repair/remedial action.

Example



Concrete Surface Condition

Technical

The surface condition is measured using estimates of near surface dielectric permittivity. It is a function 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.

Revised 1 December 2019
GPR Information Details
[2] Surface Elevation (SE)
Definition

The surface elevation is an estimate of the vertical deviation from the surface of the deck in inches or centimeters. Depressions (e.g. potholes, cracks) have negative surface elevations, and protrusions (e.g. bumps, overfilled patches) positive.

Element Rating

The Element ratings are based on the percentage of measurements outside a reference that captures the condition expected in measurements of a deck in very good condition. (see GPR Information Summary for additional information)

Very Good: There are no measured defects in the surface profile. The surface profile is homogeneous and comparable to the condition of a new deck.

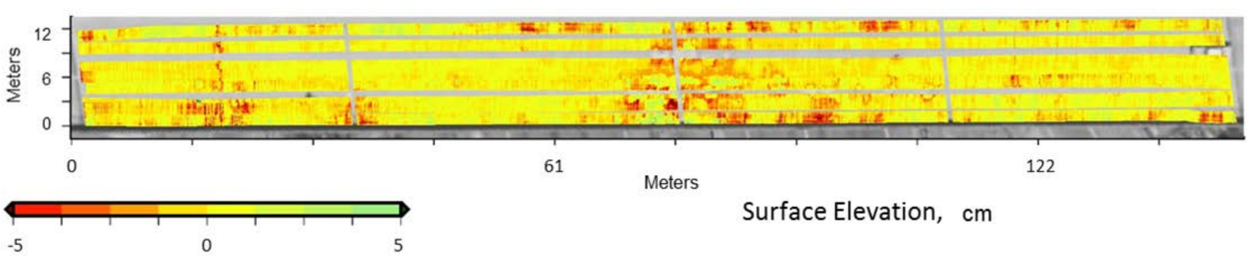
Good: A small percentage of measurements indicate a deviation from the condition of a new deck. There is no impact on the ride quality over the deck.

Acceptable: A greater percentage of measurements indicate a deviation from the condition of a new deck. There is some loss of ride quality over the deck. There is a potential risk of exposure of the top steel mat to moisture and corrosive chemical agents.

Marginal: There is a noticeable adverse impact on the ride quality over the deck. Recommend review of condition of top steel mat for indication of deterioration. May require repair/remedial action.

Poor: There are significant surface defects due to potholes and patches. There is a significant loss of ride quality over the deck. Check condition of top steel mat for potential indication of corrosion, delamination, and initiated vertical cracking. Requires repair/remedial action.

Example



Technical

The vertical distance between the GPR antenna and the surface of the deck is estimated using the first surface reflection. The estimates are calibrated using the common-mid-point method. The surface elevation is computed as a reference height of the GPR antenna with respect to the surface of the deck minus the calibrated vertical distances. Bumps have a positive surface elevation and potholes negative.

Revised 1 December 2019
GPR Information Details
[3] Overlay Thickness (OT) – UNDER REVIEW

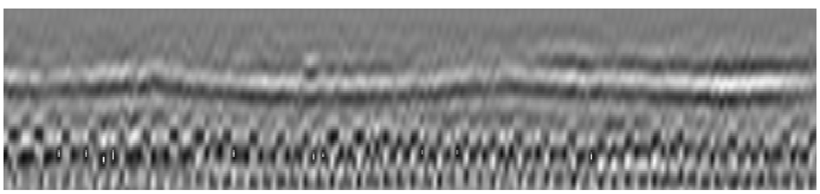
Definition

If there is an HMA or concrete overlay detected during the pre-processing of the GPR data, its thickness is estimated between the surface and the overlay/concrete-deck interface feature in the GPR measurement. The overlay thickness is reported in inches.

Element

The Element ratings are based on the percentage of measurements outside a reference that captures the condition expected in measurements of a deck in very good condition. (see GPR Information Summary for additional information)

Example

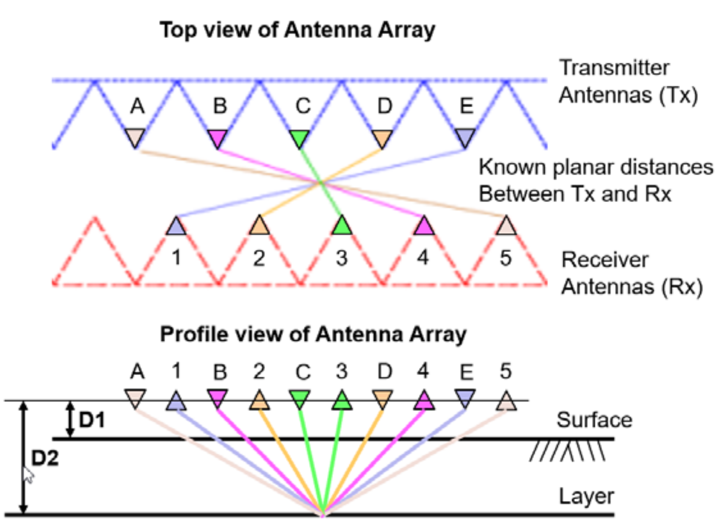


Pavement Surface

Overlay-Concrete Deck Interface

Top Steel Mat

Technical



The thickness of the overlay is estimated as the vertical distance between the surface and the overlay/concrete-deck interface. The estimates of thickness are calibrated using the common-mid-point (CMP) method based on geometric triangulation. The figure on the left shows five lateral offsets of five different transmitter-receiver pairs. Note that all five lines cross at a common-mid-point. The distance D2 is estimated using the five measurements, knowing the five lateral offsets. The thickness of the overlay is D2-D1, where D1 is estimated using a similar triangulation.

Revised 1 December 2019
GPR Information Details
[4] Overlay Condition (OC) – UNDER REVIEW
Definition

If there is an HMA or concrete overlay detected during the pre-processing of the GPR data, its condition is estimated using the dielectric permittivity near the overlay/concrete-deck interface feature in the GPR measurement and the signal strength of the GPR reflection at the interface. The overlay condition is a dimensionless parameter ranging from 1 (best) to 10 (worst).

Element Rating

The Element ratings are based on the percentage of measurements outside a reference that captures the condition expected in measurements of a deck in very good condition. (see GPR Information Summary for additional information)

Very Good: The condition of the overlay is homogeneous and comparable to a new deck in very good condition.

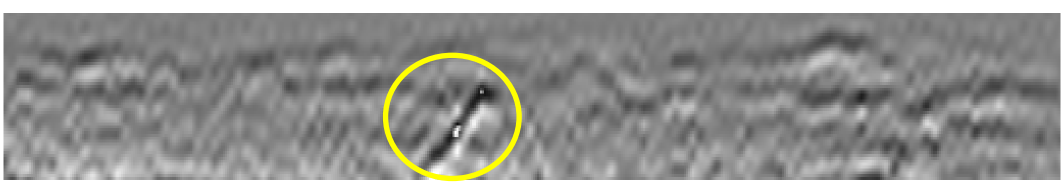
Good: A small percentage of condition of the overlay indicate a deviation from the reference range. There is no apparent defect in the overlay of the deck.

Acceptable: A greater percentage of measurements indicate a deviation from the design thickness of the overlay. There may be some minor defect in the overlay of the deck.

Marginal: Recommend review of surface elevation for evidence of depression/potholes, potentially due to deterioration of the overlay due to debonding or surface damage. Also review the overlay condition for evidence of defects and indication of debonding at the interface between the overlay and the top of concrete deck.

Poor: A greater percentage of measurements indicate a deviation from reference range. Check surface elevation for evidence of depression/potholes. Also check the overlay condition for evidence of defects and indication of debonding at the interface between the overlay/concrete-deck interface. May require repair/remedial action.

Example: Defect in Overlay Layer



Technical

The condition of the overlay is estimated using an estimate of the dielectric permittivity and signal strength of the GPR reflection at/near the overlay/concrete-deck interface. The estimates are computed and calibrated using the common-mid-point method.

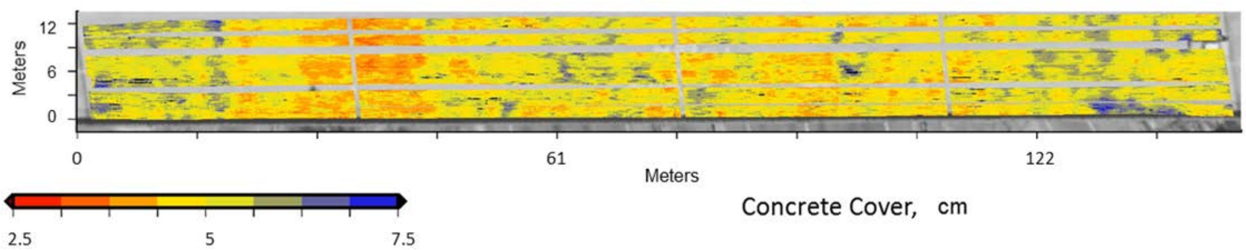
Revised 1 December 2019
GPR Information Details
[5] Top Steel Cover (TC)
<u>Definition</u>

The top steel cover is estimated between the surface and the top steel mat features in the GPR measurement. The top steel cover is reported in inches.

<u>Element</u>

The Element ratings are based on the percentage of measurements outside a reference that captures the condition expected in measurements of a deck in very good condition. (see GPR Information Summary for additional information)

<u>Example</u>



<u>Technical</u>

The top steel cover is estimated as the vertical distance between the surface and the top-steel mat interfaces. The estimates are computed and calibrated using the common-mid-point method. See

Revised 1 December 2019
GPR Information Details
[6] Above Steel Condition (TSC)
Definition

The top steel condition is estimated using the dielectric permittivity near the top steel mat interface feature in the GPR measurement and the signal strength of the GPR reflection at the interface. The top steel condition is a dimensionless parameter ranging from 1 (best) to 10 (worst).

Element Rating

The Element ratings are based on the percentage of measurements outside a reference that captures the condition expected in measurements of a deck in very good condition. (see GPR Information Summary for additional information)

Very Good: The condition of the top-steel mat is homogeneous and comparable to a new deck in very good condition.

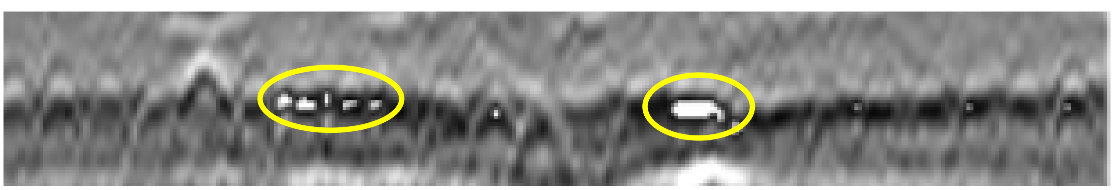
Good: A small percentage of condition of the top-steel mat indicates a deviation from the reference range. There is no apparent defect on the surface of the deck.

Acceptable: There may be some initial delamination near the top steel mat. A greater percentage of measurements indicate a deviation from the design thickness of the overlay. There may be some minor defect on the surface of the deck.

Marginal: There is evidence of defects near the top steel mat. Recommend review of surface elevation for evidence of depression/potholes, potentially due to deterioration caused by delamination near the top steel mat, and initial vertical cracking to the surface. May require remedial action.

Poor: A greater percentage of measurements indicates a deviation from reference range and the presence of defects near the top steel mat. Check surface elevation for evidence of depression/potholes, potentially due to deterioration caused by delamination near the top steel mat, and vertical cracking to the surface. May require repair action.

Example: Defect between Top Rebars – Indication of Delamination



Technical

The condition of the top steel mat is estimated using an estimate of the dielectric permittivity and signal strength of the GPR reflection at/near the top-steel mat interface, at and between the rebars. The estimates are computed and calibrated using the common-mid-point method.

Revised 1 December 2019
GPR Information Details
[7] Top Steel Condition (ASC)

Definition

The top steel condition is estimated using the dielectric permittivity near the top steel mat interface feature in the GPR measurement and the signal strength of the GPR reflection at the interface. The top steel condition is a dimensionless parameter ranging from 1 (best) to 10 (worst).

Element Rating

The Element ratings are based on the percentage of measurements outside a reference that captures the condition expected in measurements of a deck in very good condition. (see GPR Information Summary for additional information)

Very Good: The condition of the top-steel mat is homogeneous and comparable to a new deck in very good condition.

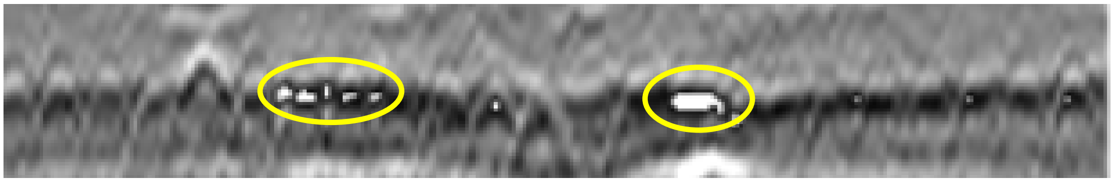
Good: A small percentage of condition of the top-steel mat indicates a deviation from the reference range. There is no apparent defect on the surface of the deck.

Acceptable: There may be some initial delamination near the top steel mat. A greater percentage of measurements indicate a deviation from the design thickness of the overlay. There may be some minor defect on the surface of the deck.

Marginal: There is evidence of defects near the top steel mat. Recommend review of surface elevation for evidence of depression/potholes, potentially due to deterioration caused by delamination near the top steel mat, and initial vertical cracking to the surface. May require remedial action.

Poor: A greater percentage of measurements indicates a deviation from reference range and the presence of defects near the top steel mat. Check surface elevation for evidence of depression/potholes, potentially due to deterioration caused by delamination near the top steel mat, and vertical cracking to the surface. May require repair action.

Example: Defect between Top Rebars – Indication of Delamination



Technical

The condition of the top steel mat is estimated using an estimate of the dielectric permittivity and signal strength of the GPR reflection at/near the top-steel mat interface, at and between the rebars. The estimates are computed and calibrated using the common-mid-point method.

Revised 1 December 2019

GPR Information Details

[8] Below Steel Condition (BSC)

Definition

The top steel condition is estimated using the dielectric permittivity near the top steel mat interface feature in the GPR measurement and the signal strength of the GPR reflection at the interface. The top steel condition is a dimensionless parameter ranging from 1 (best) to 10 (worst).

Element Rating

The Element ratings are based on the percentage of measurements outside a reference that captures the condition expected in measurements of a deck in very good condition. (see GPR Information Summary for additional information)

Very Good: The condition of the top-steel mat is homogeneous and comparable to a new deck in very good condition.

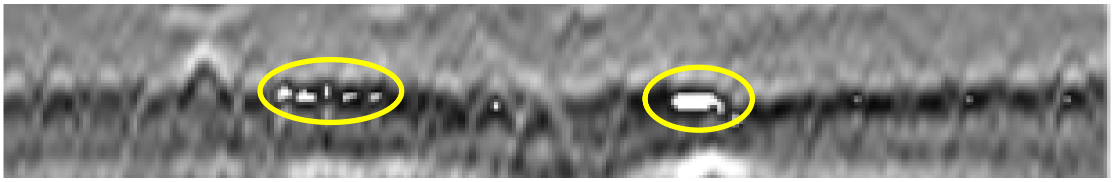
Good: A small percentage of condition of the top-steel mat indicates a deviation from the reference range. There is no apparent defect on the surface of the deck.

Acceptable: There may be some initial delamination near the top steel mat. A greater percentage of measurements indicate a deviation from the design thickness of the overlay. There may be some minor defect on the surface of the deck.

Marginal: There is evidence of defects near the top steel mat. Recommend review of surface elevation for evidence of depression/potholes, potentially due to deterioration caused by delamination near the top steel mat, and initial vertical cracking to the surface. May require remedial action.

Poor: A greater percentage of measurements indicates a deviation from reference range and the presence of defects near the top steel mat. Check surface elevation for evidence of depression/potholes, potentially due to deterioration caused by delamination near the top steel mat, and vertical cracking to the surface. May require repair action.

Example: Defect between Top Rebars – Indication of Delamination



Technical

The condition of the top steel mat is estimated using an estimate of the dielectric permittivity and signal strength of the GPR reflection at/near the top-steel mat interface, at and between the rebars. The estimates are computed and calibrated using the common-mid-point method.

Revised 1 December 2019 GPR Information Details

[9] Deck Thickness (DT)

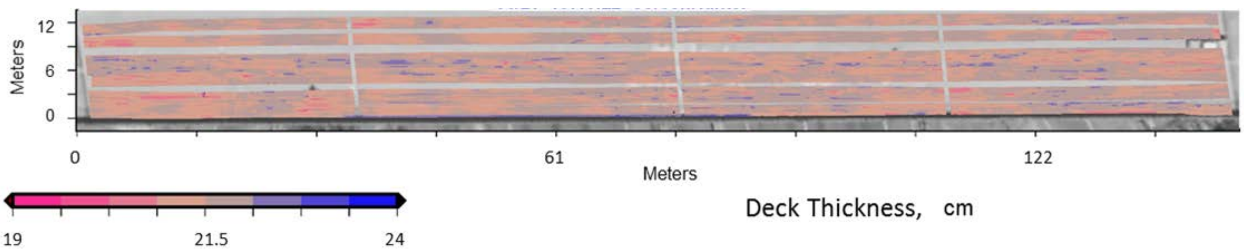
Definition

The deck thickness is estimated between the surface and the bottom of deck interface feature in the GPR measurement. The overlay thickness is reported in inches.

Element

The Element ratings are based on the percentage of measurements outside a reference that captures the condition expected in measurements of a deck in very good condition. (see GPR Information Summary for additional information)

Example



Technical

The deck thickness is estimated as the vertical distance between the surface and the bottom of deck interfaces. The estimates are calibrated using the common-mid-point method.

Revised 1 December 2019
GPR Information Details
[10] Bottom Steel Cover (BC)

Definition

The bottom steel cover is estimated between the bottom of deck and the bottom steel mat features in the GPR measurement. The bottom steel cover is reported in inches.

Element Rating

The Element ratings are based on the percentage of measurements outside a reference that captures the condition expected in measurements of a deck in very good condition. (see GPR Information Summary for additional information)

Very Good: There are no detectable areas where the bottom steel cover deviates from the design specifications. The bottom steel cover is homogeneous and comparable to the condition of a new deck.

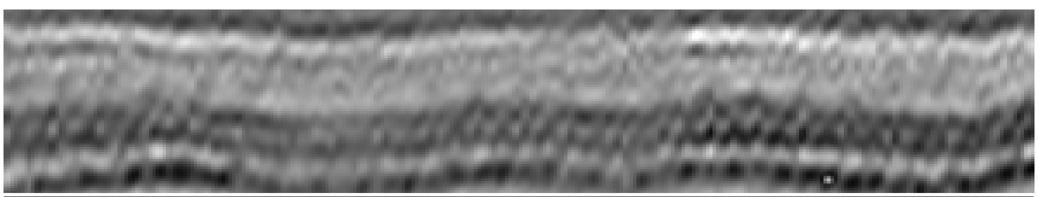
Good: A small percentage of bottom steel cover indicate a deviation from the design requirement.

Acceptable: A greater percentage of measurements indicate a deviation from the design requirement. There is some minor defect on the surface of the deck. The percentage is based on the bottom steel cover that are less than the design requirement.

Marginal: Marginal bottom-steel cover. Recommend review of deck thickness.

Poor: Poor bottom-steel cover. Check deck thickness. May require repair/remedial action.

Example



Top Steel Mat
Bottom Steel Mat
Bottom of Deck

Technical

The bottom steel cover is estimated as the vertical distance between the bottom of deck and the bottom-steel mat interfaces. The estimates are computed and calibrated using the common-mid-point method.

APPENDIX B

BRIDGE DECK LOCATION INFORMATION & BDCAM ANALYSES RESULTS

Bridge decks with State Inspection Reports Location and analyzed with BDCAM

Location and Scope							
	Bridge Number:	Sub-Structure:	Span:	Location:			
Date of Last GPR Report:	Bridge Number 7-digits	Sub-Structure	Span Number	District	County	Feature Carried	Feature Intersected
11/8/2018	0700300	-	1	2	Cecil County	'US 1 '	'OCTORARO CREEK '
11/8/2018	0700300	-	2	2	Cecil County	'US 1 '	'OCTORARO CREEK '
11/8/2018	0700300	-	All	2	Cecil County	'US 1 '	'OCTORARO CREEK '
6/5/2019	1701102	-	1	2	Queen Anne's County	'US 301 SB '	'MD 290 '
6/5/2019	1701102	-	2	2	Queen Anne's County	'US 301 SB '	'MD 290 '
6/5/2019	1701102	-	3	2	Queen Anne's County	'US 301 SB '	'MD 290 '
6/5/2019	1701102	-	All	2	Queen Anne's County	'US 301 SB '	'MD 290 '
6/5/2019	1701202	-	1	2	Queen Anne's County	'US 301 SB '	'RED LION BRANCH '
6/5/2019	1701202	-	2	2	Queen Anne's County	'US 301 SB '	'RED LION BRANCH '
6/5/2019	1701202	-	3	2	Queen Anne's County	'US 301 SB '	'RED LION BRANCH '
6/5/2019	1701202	-	All	2	Queen Anne's County	'US 301 SB '	'RED LION BRANCH '
6/5/2019	1701302	-	1	2	Queen Anne's County	'US 301 SB '	'UNICORN BRANCH '
6/5/2019	1701302	-	2	2	Queen Anne's County	'US 301 SB '	'UNICORN BRANCH '
6/5/2019	1701302	-	3	2	Queen Anne's County	'US 301 SB '	'UNICORN BRANCH '
6/5/2019	1701302	-	All	2	Queen Anne's County	'US 301 SB '	'UNICORN BRANCH '
6/6/2019	2108500	-	1	6	Washington County	'MD 68 '	'WINCHESTER & WESTERN RR '
6/6/2019	2108500	-	2	6	Washington County	'MD 68 '	'WINCHESTER & WESTERN RR '
6/6/2019	2108500	-	3	6	Washington County	'MD 68 '	'WINCHESTER & WESTERN RR '
6/6/2019	2108500	-	All	6	Washington County	'MD 68 '	'WINCHESTER & WESTERN RR '
12/4/2018	2202100	-	1	1	Wicomico County	'US 13 RAMP 'C' (5)'	'US 13 BU '
12/4/2018	2202100	-	2	1	Wicomico County	'US 13 RAMP 'C' (5)'	'US 13 BU '
12/4/2018	2202100	-	3	1	Wicomico County	'US 13 RAMP 'C' (5)'	'US 13 BU '
12/4/2018	2202100	-	4	1	Wicomico County	'US 13 RAMP 'C' (5)'	'US 13 BU '
12/4/2018	2202100	-	All	1	Wicomico County	'US 13 RAMP 'C' (5)'	'US 13 BU '
11/28/2018	2202401	-	1	1	Wicomico County	'US 13 NB '	'MD 350 '
11/28/2018	2202401	-	2	1	Wicomico County	'US 13 NB '	'MD 350 '
11/28/2018	2202401	-	3	1	Wicomico County	'US 13 NB '	'MD 350 '
11/28/2018	2202401	-	All	1	Wicomico County	'US 13 NB '	'MD 350 '
11/28/2018	2202402	-	1	1	Wicomico County	'US 13 SB '	'MD 350 '
11/28/2018	2202402	-	2	1	Wicomico County	'US 13 SB '	'MD 350 '
11/28/2018	2202402	-	3	1	Wicomico County	'US 13 SB '	'MD 350 '
11/28/2018	2202402	-	All	1	Wicomico County	'US 13 SB '	'MD 350 '

General bridge deck information for bridges with inspection reports

			General Bridge Deck Data																							
Bridge Number:	Sub-Structure:	Span:					Deck Thickness (DT)				Overlay Thickness (OT)				Top Steel Cover (TC)				Top Steel Spacing (TS)				Bottom Steel Cover (BC)			
Bridge Number 7-digits	Sub-Structure	Span Number	Number of Spans	Total Length	Total Area	Bridge Deck Surface	Average	Maximum	Minimum	Per Plan	Average	Maximum	Minimum	Per Plan	Average	Maximum	Minimum	Per Plan	Average	Maximum	Minimum	Per Plan	Average	Maximum	Minimum	Per Plan
																							-	-	-	1
0700300	-	1	2	101	5050	Bare Concrete	15.012151	92264	0	15	-	-	-	-	2.285433	5.091125	0.054285	2.5	27.396008	64.557341	6.849002	11	-	-	-	-
0700300	-	2	2	101	5050	Bare Concrete	15.005045	42326	0	15	-	-	-	-	2.597484	5.08519	0.041453	2.5	21.925174	45.204639	5.481293	11	-	-	-	-
0700300	-	All	2	202	10100	Bare Concrete	15.008539	92264	0	15	-	-	-	-	2.444039	5.091125	0.054285	2.5	24.660591	64.557341	5.481293	11	-	-	-	-
1701102	-	1	3	43	1656	HMA	9.044701	9.562749	8.780488	9	1.974335	2.369202	1.579468	2	3.287713	4.179485	0.950152	3.5	7.5	10.058832	4.941168	10	-	-	-	-
1701102	-	2	3	47	1810	HMA	9.016154	9.412417	8.674058	9	1.927408	2.31289	1.541926	2	3.490995	4.651531	1.751864	3.5	8.030303	11.18029	3.81971	10	-	-	-	-
1701102	-	3	3	47	1810	HMA	8.986783	9.191574	8.549002	9	1.829259	2.195111	1.463407	2	3.645835	4.599451	2.132903	3.5	8.022388	10.94296	4.05704	10	-	-	-	-
1701102	-	All	3	137	5275	HMA	9.016857	9.562749	8.549002	9	1.913099	2.295719	1.53048	2	3.469052	4.651531	0.950152	3.5	7.850897	11.18029	3.81971	10	-	-	-	-
1701202	-	1	3	30	1110	HMA	9.006412	9.347364	7.53845	9	1.842073	2.210488	1.473659	2	3.602756	5.005502	1.446514	3.5	9.924242	15.223558	2.48106	10	-	-	-	-
1701202	-	2	3	30	1110	HMA	8.946831	9.161229	7.269735	9	1.849935	2.219922	1.479948	2	3.434379	4.256305	1.255763	3.5	11.964286	17.050745	2.991071	10	-	-	-	-
1701202	-	3	3	30	1110	HMA	9.011719	9.360472	7.904165	9	1.909708	2.291649	1.527766	2	3.566131	4.288173	0.653862	3.5	10.078125	13.107068	2.519531	10	-	-	-	-
1701202	-	All	3	90	3330	HMA	8.987726	9.360472	7.269735	9	1.866362	2.239634	1.493089	2	3.532945	5.005502	0.653862	3.5	10.655551	17.050745	2.48106	10	-	-	-	-
1701302	-	1	3	50	1925	HMA	8.996464	9.190087	8.749085	9	2.291747	2.750096	1.833398	2	3.546612	5.710635	1.10171	3.5	7.668919	10.205446	4.794554	10	-	-	-	-
1701302	-	2	3	50	1925	HMA	8.998801	9.274993	8.422135	9	1.892269	2.270722	1.513815	2	3.318846	4.397799	1.279518	3.5	7.098765	9.80595	5.19405	10	-	-	-	-
1701302	-	3	3	50	1925	HMA	8.984562	9.249648	8.626162	9	1.82364	2.188369	1.458912	2	3.395201	4.814817	1.850199	3.5	7.328767	10.028223	4.971777	10	-	-	-	-
1701302	-	All	3	150	5775	HMA	8.99324	9.274993	8.422135	9	1.971168	2.365402	1.576935	2	3.418742	5.710635	1.10171	3.5	7.365484	10.205446	4.794554	10	-	-	-	-
2108500	-	1	3	38	1672	HMA	9.017402	9.38926	8.672798	9	1.798052	2.157663	1.438442	2	3.489464	5.402584	2.062592	3.5	11.46598	18.57718	2.866495	11	-	-	-	-
2108500	-	2	3	35	1540	HMA	8.994317	9.382729	8.664629	9	1.730057	2.076069	1.384046	2	3.31309	5.222926	1.707392	3.5	13.726489	20.189967	3.431622	11	-	-	-	-
2108500	-	3	3	38	1672	HMA	9.020961	9.377293	8.501016	9	1.778095	2.133714	1.422476	2	3.216384	4.697119	2.126276	3.5	9.827592	13.694238	3.149512	11	-	-	-	-
2108500	-	All	3	111	4884	HMA	9.011351	9.38926	8.501016	9	1.769775	2.12373	1.41582	2	3.338592	5.402584	1.707392	3.5	11.673354	20.189967	2.866495	11	-	-	-	-
2202100	-	1	4	32	976	Bare Concrete	7.487048	7.658537	7.270754	7.5	-	-	-	-	1.458074	2.830357	0.279555	2	10.419891	14.727687	3.147313	11	-	-	-	-
2202100	-	2	4	103	3142	Bare Concrete	7.561522	8.066268	7.101194	7.5	-	-	-	-	2.272433	4.991628	0.395652	2	8.783094	11.655554	4.844446	11	-	-	-	-
2202100	-	3	4	96	2928	Bare Concrete	7.520687	7.960705	7.182927	7.5	-	-	-	-	2.254296	4.489614	0.271488	2	8.520182	11.44492	5.05508	11	-	-	-	-
2202100	-	4	4	32	976	Bare Concrete	7.460296	7.874796	7.281369	7.5	-	-	-	-	1.673798	2.728593	0.231875	2	10.574632	14.639793	3.235207	11	-	-	-	-
2202100	-	All	4	263	8022	Bare Concrete	7.524733	8.066268	7.101194	7.5	-	-	-	-	2.089145	4.991628	0.395652	2	9.57445	14.727687	3.147313	11	-	-	-	-
2202401	-	1	3	32	1264	LMC	8.030041	9.130977	7.597354	8	-	-	-	-	2.172737	3.187712	0.757979	2	13.129578	33.259676	3.282395	11	-	-	-	-
2202401	-	2	3	76	3002	LMC	8.019965	9.280665	7.367334	8	-	-	-	-	1.519843	4.512319	0.121419	2	8.602496	11.493078	5.006922	11	-	-	-	-
2202401	-	3	3	32	1264	LMC	8.025862	9.168079	7.755637	8	-	-	-	-	2.136092	3.054108	1.286557	2	15.390433	22.902517	3.847608	11	-	-	-	-
2202401	-	All	3	140	5530	LMC	8.023786	9.280665	7.367334	8	-	-	-	-	1.821504	4.512319	0.121419	2	12.374169	33.259676	3.282395	11	-	-	-	-
2202402	-	1	3	32	1264	Bare Concrete	7.997454	8.499749	7.413655	8	-	-	-	-	2.172134	3.302161	0.917581	2	12.48587	18.459448	3.121468	11	-	-	-	-
2202402	-	2	3	76	3002	Bare Concrete	8.013161	8.405962	7.30656	8	-	-	-	-	1.73155	4.449164	1.099497	2	8.69766	11.563476	4.936524	11	-	-	-	-
2202402	-	3	3	32	1264	Bare Concrete	7.990593	8.438118	7.430295	8	-	-	-	-	2.377011	3.516583	1.437572	2	14.34143	21.967322	3.585358	11	-	-	-	-
2202402	-	All	3	140	5530	Bare Concrete	8.004423	8.499749	7.30656	8	-	-	-	-	1.979437	4.449164	0.917581	2	11.841653	21.967322	3.121468	11	-	-	-	-

Bridge deck condition assessment for bridges with inspection reports

			Last report													
Bridge Number:	Sub-Structure:	Span:	Surface Elevation (SE)		Surface Condition (SC)		Overlay Condition (OC)		Above Top Steel (ASC)		Top Steel Condition (TSC)		Below Top Steel (BSC)			
Bridge Number 7-digits	Sub-Structure	Span Number	Percent deficient	Condition Rating	Percent deficient	Condition Rating	Percent deficient	Condition Rating	Percent deficient	Condition Rating	Percent deficient	Condition Rating	Percent deficient	Condition Rating	Overall Score (1-9)	Overal State (1-4)
0700300	-	1	54.125822	Poor	18.053507	Acceptable	-	N/A	9.614656	Very Good	0.458305	Very Good	3.122931	Very Good	5	2
0700300	-	2	51.242673	Poor	16.522897	Acceptable	-	N/A	8.974776	Very Good	0.507409	Very Good	3.26635	Very Good	5.334230343	2
0700300	-	All	51.808027	Poor	17.301513	Acceptable	-	N/A	9.28842	Very Good	0.48545	Very Good	3.200029	Very Good	5.279569578	2
1701102	-	1	61.807192	Poor	0	Very Good	0	Very Good	12.191352	Very Good	0.447766	Very Good	2.001094	Very Good	6	2
1701102	-	2	78.817037	Poor	0	Very Good	0	Very Good	10.93856	Very Good	0.787014	Very Good	1.985579	Very Good	6	2
1701102	-	3	61.009936	Poor	0	Very Good	0	Very Good	14.587623	Good	0.217186	Very Good	2.392433	Very Good	6	2
1701102	-	All	64.366798	Poor	0	Very Good	0	Very Good	12.471967	Very Good	0.552565	Very Good	2.212427	Very Good	6	2
1701202	-	1	29.594579	Marginal	1.678027	Very Good	1.597363	Good	7.162823	Very Good	0.433914	Very Good	2.406755	Very Good	6.237334219	2
1701202	-	2	30.6764	Marginal	2.463161	Very Good	1.392823	Good	12.930957	Very Good	0.66765	Very Good	3.71007	Very Good	6	2
1701202	-	3	32.979618	Marginal	1.297338	Very Good	1.619005	Good	14.875417	Good	0.933902	Very Good	3.712038	Very Good	6	2
1701202	-	All	31.176786	Marginal	2.10295	Very Good	1.527827	Good	11.363816	Very Good	0.778765	Very Good	3.415242	Very Good	6	2
1701302	-	1	27.809305	Acceptable	0.245497	Very Good	0.819647	Good	9.950276	Very Good	1.293831	Very Good	1.302028	Very Good	6.60950694	2
1701302	-	2	13.83162	Acceptable	0.246949	Very Good	0.335189	Very Good	4.909262	Very Good	1.444329	Very Good	0.996067	Very Good	7	2
1701302	-	3	34.470845	Marginal	0.522112	Very Good	0.464647	Very Good	9.122535	Very Good	1.93146	Very Good	1.259624	Very Good	6	2
1701302	-	All	27.776223	Acceptable	0.607814	Very Good	0.572527	Very Good	8.096606	Very Good	1.806101	Very Good	1.215826	Very Good	6.615847339	2
2108500	-	1	24.723884	Acceptable	7.1537	Good	0.000461	Very Good	4.126067	Very Good	2.819662	Very Good	4.543233	Very Good	6	2
2108500	-	2	26.342676	Acceptable	6.824276	Good	0.00279	Very Good	4.668462	Very Good	3.43209	Very Good	4.370049	Very Good	6	2
2108500	-	3	26.126463	Acceptable	5.184598	Very Good	0	Very Good	4.072836	Very Good	3.098401	Very Good	4.390777	Very Good	6.339449541	2
2108500	-	All	25.907414	Acceptable	6.692078	Good	0	Very Good	4.340554	Very Good	3.110141	Very Good	4.441523	Very Good	6	2
2202100	-	1	4.471733	Very Good	2.325738	Very Good	-	N/A	2.338189	Very Good	0.378386	Very Good	0.657341	Very Good	8	0.889260861
2202100	-	2	13.78738	Acceptable	2.298941	Very Good	-	N/A	18.470668	Good	6.585094	Acceptable	11.102442	Acceptable	6	2.140598378
2202100	-	3	13.751905	Acceptable	2.414049	Very Good	-	N/A	17.701568	Good	4.902052	Good	8.410586	Good	6	2.174402602
2202100	-	4	6.596872	Very Good	2.532896	Very Good	-	N/A	1.17932	Very Good	1.280482	Very Good	1.082396	Very Good	7.737562111	1.269914442
2202100	-	All	12.518513	Good	10.211483	Good	-	N/A	22.505394	Acceptable	6.2554	Acceptable	13.567977	Acceptable	5.722137596	2.555724808
2202401	-	1	43.424046	Marginal	39.148983	Poor	-	N/A	2.606696	Very Good	0.761373	Very Good	1.115724	Very Good	5	2
2202401	-	2	33.663888	Marginal	38.158141	Poor	-	N/A	16.386454	Good	0.030656	Very Good	0.010478	Very Good	5	2
2202401	-	3	41.400731	Marginal	39.701609	Poor	-	N/A	2.271153	Very Good	0.678828	Very Good	0.819737	Very Good	5	2
2202401	-	All	41.68763	Marginal	44.740592	Poor	-	N/A	9.83328	Very Good	0.793995	Very Good	1.38491	Very Good	5	2
2202402	-	1	30.255382	Marginal	11.898782	Good	-	N/A	2.58839	Very Good	0.70654	Very Good	0.744217	Very Good	6	2
2202402	-	2	26.728305	Acceptable	12.331376	Good	-	N/A	3.873698	Very Good	0	Very Good	0.002852	Very Good	6	2
2202402	-	3	32.90375	Marginal	18.347768	Acceptable	-	N/A	2.268231	Very Good	0.869671	Very Good	0.64819	Very Good	6	2
2202402	-	All	34.12259	Marginal	16.82999	Acceptable	-	N/A	4.94949	Very Good	0.807529	Very Good	0.101291	Very Good	6	2

APPENDIX C

MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION
FIELD EXPLORATIONS DIVISION
BRIDGE DECK CONDITION SURVEYS

MARYLAND STATE HIGHWAY ADMINISTRATION
FIELD EXPLORATIONS DIVISION

BRIDGE NO: 0700300

LOCATION: US 1 over Octoraro Creek

DATE CONSTRUCTED: 1933

DATE TESTED: August, 2016

TYPE OF STRUCTURE: Steel girder approximately 200 feet long 50 feet wide with one pier and two abutments. These dimensions are based on the clear roadway.

OBSERVATION: The pier and both abutments and appear to be in poor condition. All have numerous cracks throughout with a several spalled areas.

TYPE OF TEST(S):

CORROSION SURVEY: Shown in Exhibit 1, 2, and 3.

CHLORIDE SURVEY: Shown in Exhibit 1 and 2.

BORING SURVEY: Shown in Exhibits 1 and 2.

TEST SITE LOCATIONS: Shown in Exhibit 3

RECOMMENDATIONS: This recommendation is based on a materials evaluation. After a visual inspection was completed we proceeded to perform a corrosion survey, boring survey and chloride testing. Based on these evaluations, we have concluded that the pier and both abutments need rehabilitation. Rehabilitation would require the concrete to be removed to a minimum depth of 5.0 in. for the pier 5.0 in. for both abutments or to sound concrete. Placement of a high density nonporous concrete should be used to prevent further moisture penetration. However due to the high chloride content at the five inch level complete removal should be considered.

Prepared by: Andre' Pridgen

MARYLAND STATE HIGHWAY ADMINISTRATION
FIELD EXPLORATIONS DIVISION

STRUCTURE NO: 1701102

LOCATION: US 301 SB over MD 290

DATE CONSTRUCTED: 1967

DATE TESTED: April 2017

TYPE OF STRUCTURE: Steel Beam Bridge approximately 137 feet long, 40 feet wide, with 2 abutments and 2 bents. These dimensions are based on the clear roadway width.

TYPE OF SURFACE: A 2.0 Bituminous wearing surface on a Concrete deck approximately 7.0 inches.

OBSERVATION: The right lane appears to be in poor condition with numerous patches throughout the deck surface. The underside of the deck appears to be in fair condition with a few spalled areas, but the expansion dams are in poor condition with numerous cracks and some efflorescence.

TYPE OF TEST(S):

CORROSION SURVEY: Shown in Exhibit 1, 2, and 3.

CHLORIDE SURVEY: Shown in Exhibit 1 and 2.

BORING SURVEY: Shown in Exhibits 1 and 2.

TEST SITE LOCATIONS: Shown in Exhibit 3.

PACHOMETER SURVEY: A pachometer survey not performed due to the presence of a bituminous overlay.

DELAMINATION SURVEY: A delamination survey was not conducted due to the presence of a bituminous overlay.

RECOMMENDATIONS: The following recommendations are based on a materials evaluation. After a visual inspection was completed, we proceeded to perform a corrosion, chloride, and boring survey. Based on these evaluations, we have concluded that the deck is in a deteriorated state. We recommend rehabilitation for the span of this structure. Rehabilitation would require the concrete to be removed to a minimum depth of 3.0 inches or to sound concrete and replaced with a high-density nonporous concrete, to prevent moisture penetration. However, test sites QA-01, QA-03 and QA-09 may need additional concrete removed. Based on conditions existing at the time of testing and without rehabilitation the life expectancy of this deck is 2 to 5 years. The life expectancy of a bridge deck is the estimated time remaining before the deck becomes a safety hazard or a hindrance to traffic caused by continuous maintenance.

Prepared by: Andre' Pridgen

MARYLAND STATE HIGHWAY ADMINISTRATION
FIELD EXPLORATIONS DIVISION
BRIDGE DECK CONDITION SURVEY

STRUCTURE NO:	1701202
LOCATION:	US 301 SB over Red Lion Branch
DATE CONSTRUCTED:	1967
DATE TESTED:	April, 2017
TYPE OF STRUCTURE:	Steel beam bridge approximately 87 feet long 40 feet wide with 2 abutments and 2 piers. These dimensions are based on the clear roadway.
TYPE OF SURFACE:	Bituminous wearing surface ranging in thickness from 1.5 to 2.0 inches concrete deck approximately 7.0 inches thick.
OBSERVATION:	The Bridge is covered with concrete patches but the underside is in good condition

TYPE OF TEST(S):	**CORROSION SURVEY:**	Shown in Exhibit 1, 2, and 3.
	CHLORIDE SURVEY:	Shown in Exhibit 1 and 2.
	BORING SURVEY:	Shown in Exhibits 1 and 2.
	TEST SITE LOCATIONS:	Shown in Exhibit 3.

RECOMMENDATIONS: This recommendation is based on a materials evaluation. After a visual inspection was completed, we proceeded to perform a corrosion, chloride and boring survey. Based on these evaluations, we have concluded that deteriorated concrete should be removed along with its chloride contaminates. It is our recommendation that rehabilitation be done to this bridge. Rehabilitation would require the concrete to be removed to a minimum depth of 3.5 inches or to sound concrete. Placement of a high density nonporous concrete should be used to prevent further moisture penetration. Additional concrete will need to be removed in the vicinity of test sites QA-02 and QA-03. Based on conditions existing at the time of testing and without rehabilitation the life expectancy of this span is 0 to 3 years. The life expectancy of a bridge deck is the estimated time remaining before the deck becomes a safety hazard or a hindrance to traffic caused by continuous maintenance

Prepared by: Al Hymiller

MARYLAND STATE HIGHWAY ADMINISTRATION
FIELD EXPLORATIONS DIVISION

STRUCTURE NO: 1701302

LOCATION: US 301 SB over Unicorn Branch

DATE CONSTRUCTED: 1967

DATE TESTED: April 2017

TYPE OF STRUCTURE: Steel Beam Bridge approximately 147 feet long, 40 feet wide, with 2 abutments and 2 bents. These dimensions are based on the clear roadway width.

TYPE OF SURFACE: Bituminous wearing surface ranging in depth from 1.75 to 2.5 inches on a Concrete deck approximately 7.0 inches.

OBSERVATION: The deck appears to be in poor condition with numerous cracks and patches and a few spalled areas throughout the deck surface. The underside of the deck appears to be in good condition with one spalled area with exposed rusted rebar.

TYPE OF TEST(S):

CORROSION SURVEY: Shown in Exhibit 1, 2, and 3.

CHLORIDE SURVEY: Shown in Exhibit 1 and 2.

BORING SURVEY: Shown in Exhibits 1 and 2.

TEST SITE LOCATIONS: Shown in Exhibit 3.

PACHOMETER SURVEY: A pachometer survey not performed due to the presence of a bituminous overlay.

DELAMINATION SURVEY: A delamination survey was not conducted due to the presence of a bituminous overlay.

RECOMMENDATIONS: The following recommendations are based on a materials evaluation. After a visual inspection was completed, we proceeded to perform a corrosion, chloride, and boring survey. Based on these evaluations, we have concluded that the deck is in a deteriorated state. We recommend rehabilitation for the span of this structure. Rehabilitation would require the concrete to be removed to a minimum depth of 3.0 inches or to sound concrete and replaced with a high density nonporous concrete, to prevent moisture penetration. Based on conditions existing at the time of testing and without rehabilitation the life expectancy of this deck is 2 to 5 years. The life expectancy of a bridge deck is the estimated time remaining before the deck becomes a safety hazard or a hindrance to traffic caused by continuous maintenance.

Prepared by: Andre' Pridgen

MARYLAND STATE HIGHWAY ADMINISTRATION
FIELD EXPLORATIONS DIVISION
BRIDGE DECK CONDITION SURVEY

STRUCTURE NO: 2108500

LOCATION: MD 68 over Winchester and Western RR

DATE CONSTRUCTED: 1965

DATE TESTED: October 2014

TYPE OF STRUCTURE: Steel beam bridge approximately 111 feet long 44 feet wide, with 2 abutments and 2 piers. These dimensions are based on the clear roadway width.

TYPE OF SURFACE: Concrete deck approximately 7.0 inches thick with 2" bituminous overlay.

OBSERVATION: Bituminous overlay is in moderate to poor condition with cracks and patches. Span one contains low severity transverse cracks throughout the surface, medium to high severity alligator cracking on the WB shoulder and along Abutment A and a low severity patch in the median area. Span two contains several full depth patches with moderate to severe alligator cracking and moderate to severe transverse cracking in the areas surrounding the patches. Ninety percent of the patches are in WB lane one of span two. The underside of WB lane one in span two has plywood under several full depth patches. The WB shoulder of span three has moderate to severe alligator cracking, lane one has a few small surface cracks and spalled areas and there is a medium severity patch in the median with a few low severity surface cracks. The EB lane one of span three has a small rut with low severity alligator cracking near Abutment B. All three spans in the EB direction have a low severity joint reflective crack.

TYPE OF TEST(S):

CORROSION SURVEY: Shown in Exhibit 1, 2, and 3.

CHLORIDE SURVEY: Shown in Exhibit 1 and 2.

BORING SURVEY: Shown in Exhibits 1 and 2.

TEST SITE LOCATIONS: Shown in Exhibit 3.

PACHOMETER SURVEY: A pachometer survey was not performed.

DELAMINATION SURVEY: A delamination survey was not performed.

RECOMMENDATIONS: This recommendation is based on a materials evaluation. After a visual inspection was completed, we proceeded to perform a chloride and boring survey. Based on these evaluations, it is our recommendation that complete removal and replacement for the deck of this structure be done. Based on conditions existing at the time of testing and without rehabilitation the life expectancy of this deck is 0 to 3 years. The life expectancy of a bridge deck is the estimated time remaining before the deck becomes a safety hazard or a hindrance to traffic caused by continuous maintenance.

Prepared by: Al Hymiller

MARYLAND STATE HIGHWAY ADMINISTRATION
FIELD EXPLORATIONS DIVISION
BRIDGE DECK CONDITION SURVEY

BRIDGE NO: 2202100

LOCATION: US 13 Ramp 'C' over US 13/15

DATE CONSTRUCTED: 1972

DATE TESTED: September, 2013

TYPE OF STRUCTURE: Concrete girder, Steel girder bridge approximately 263 feet long 30 feet 6 inches wide having two abutments and three piers. These dimensions are based on the clear roadway width.

TYPE OF SURFACE: Bare concrete deck approximately 7.5 inches thick.

OBSERVATION: The deck appears to be in poor condition with numerous cracks throughout the entire deck surface and one very large patch in the travel lane. The underside of the deck that was exposed has cracking and efflorescence, the majority of the deck has stay in-place forms.

TYPE OF TEST(S):

CORROSION SURVEY: Shown in Exhibit 1, 2, and 3.

CHLORIDE SURVEY: Shown in Exhibit 1 and 2.

BORING SURVEY: Shown in Exhibits 1 and 2.

TEST SITE LOCATIONS: Shown in Exhibit 3.

PACHOMETER SURVEY: A pachometer survey was performed on the existing bare deck sections to determine the minimum depth of concrete cover from the top of the existing bare deck to the upper layer of reinforcing steel. The depth of cover ranged from 1.0 to 3.0 inches with an average of 2.0 inches.

DELAMINATION SURVEY: A delamination survey was conducted and about 25 % of the deck is delaminated.

RECOMMENDATIONS: The following recommendations are based on a materials evaluation. We recommend rehabilitation for the deck of this structure. Rehabilitation would require the concrete to be removed to a minimum depth of 3.5 inches or to sound concrete and replaced with a high density nonporous concrete, to prevent moisture penetration. Additional concrete will need to be removed in the vicinity of test site WI-02, WI-09, WI-10, WI-11, WI-18, WI-20, and WI-22. The visual, corrosion survey, chloride survey and boring survey indicate this deck is in a deteriorated state and chloride contaminated. Based on conditions existing at the time of testing and without rehabilitation the life expectancy of this deck is 1 to 5 years. The life expectancy of a bridge deck is the estimated time remaining before the deck becomes a safety hazard or a hindrance to traffic caused by continuous maintenance.

Prepared by: Andre Pridgen

MARYLAND STATE HIGHWAY ADMINISTRATION
FIELD EXPLORATIONS DIVISION
BRIDGE DECK CONDITION SURVEY

STRUCTURE NO: 2202401

LOCATION: US 13 NB over MD-350

DATE CONSTRUCTED: 1974

DATE TESTED: August, 2013

TYPE OF STRUCTURE: Steel beam, Concrete girder. Bridge approximately 140 feet long 39 feet 6 inches wide, with 2 abutments and 2 piers. These dimensions are based on the clear roadway width.

TYPE OF SURFACE: Concrete deck approximately 8.0 inches thick.

OBSERVATION: Spans 1 and 3 have longitudinal cracks running thru out. There is at least one crack in each span that is a full depth crack and both of them are on the shoulder at the abutments. The face of the abutment is cracked up and may need attention also. Span number-2 has metal stay-in-place forms that appear to be in good shape

TYPE OF TEST(S):

CORROSION SURVEY: Shown in Exhibit 1, 2, and 3.

CHLORIDE SURVEY: Shown in Exhibit 1 and 2.

BORING SURVEY: Shown in Exhibits 1 and 2.

TEST SITE LOCATIONS: Shown in Exhibit 3.

PACHOMETER SURVEY: A pachometer survey was performed on the existing bare deck sections to determine the minimum depth of concrete cover from the top of the existing bare deck to the upper layer of reinforcing steel. The depth of cover on the NBR ranged from 1.5 to 3.0 inches with an average of 2.11 inches.

DELAMINATION SURVEY: A delamination survey was conducted and about 35 % of the deck is delaminated.

RECOMMENDATIONS: This recommendation is based on a materials evaluation. After a visual inspection was completed, we preceded to perform a chloride and boring survey. Based on these evaluations, we have concluded that deteriorated concrete should be removed along with its chloride contaminates. It is our recommendation that rehabilitation be done to this structure. Rehabilitation would require the concrete to be removed to a minimum depth of 3.5 inches or to sound concrete. However due to the high chloride content at the 5.0 inch level complete removal may need to be considered. Placement of a high density nonporous concrete should be used to prevent further moisture penetration. Additional concrete will need to be removed in the vicinity of test sites HO-01, HO-14, HO-16, and HO-22. Based on conditions existing at the time of testing and without rehabilitation the life expectancy of this deck is 0 to 3 years. The life expectancy of a bridge deck is the estimated time remaining before the deck becomes a safety hazard or a hindrance to traffic caused by continuous maintenance.

Prepared by: Al Hymiller

MARYLAND STATE HIGHWAY ADMINISTRATION
FIELD EXPLORATIONS DIVISION
BRIDGE DECK CONDITION SURVEY

STRUCTURE NO: 2202402

LOCATION: US 13 S.B. over MD-350

DATE CONSTRUCTED: 1974

DATE TESTED: August, 2013

TYPE OF STRUCTURE: Steel beam, Concrete girder. Bridge approximately 140 feet long 39 feet 6 inches wide, with 2 abutments and 2 piers. These dimensions are based on the clear roadway width.

TYPE OF SURFACE: Concrete deck approximately 8.0 inches thick.

OBSERVATION: The concrete girder spans 1 and 3 have longitudinal cracks running the length of the spans. Several of these are full depth cracks. Span number-2 has metal stay-in-place forms that appear to be in good shape.

TYPE OF TEST(S):

CORROSION SURVEY: Shown in Exhibit 1, 2, and 3.

CHLORIDE SURVEY: Shown in Exhibit 1 and 2.

BORING SURVEY: Shown in Exhibits 1 and 2.

TEST SITE LOCATIONS: Shown in Exhibit 3.

PACHOMETER SURVEY: A pachometer survey was performed on the existing bare deck sections to determine the minimum depth of concrete cover from the top of the existing bare deck to the upper layer of reinforcing steel. The depth of cover on the NBR ranged from 1.5 to 3.0 inches with an average of 2.2 inches.

DELAMINATION SURVEY: A delamination survey was conducted and about 30 % of the deck is delaminated.

RECOMMENDATIONS: This recommendation is based on a materials evaluation. After a visual inspection was completed, we proceeded to perform a chloride and boring survey. Based on these evaluations, we have concluded that deteriorated concrete should be removed along with its chloride contaminates. It is our recommendation that complete removal be done to the concrete girder spans 1and 3 and rehabilitation for span-2. Rehabilitation for span-2 of the SB deck would require the concrete to be removed to a minimum depth of 2.5 inches or to sound concrete. Placement of a high density nonporous concrete should be used to prevent further moisture penetration. Based on conditions existing at the time of testing and without rehabilitation the life expectancy of this deck is 0 to 3 years. The life expectancy of a bridge deck is the estimated time remaining before the deck becomes a safety hazard or a hindrance to traffic caused by continuous maintenance.

Prepared by: Al Hymiller