DEPARTMENT OF TRANSPORTATION

Continuous Bituminous Pavement Stripping Assessment Through Non-destructive Testing

Background

Stripping is a critical pavement subsurface distress affecting bituminous pavement systems: full-depth bituminous and composite (especially bituminous over concrete) systems. In full-depth bituminous pavements, stripping is caused by moisture infiltration in the pavement system, leading to the loss of bond between the aggregate particles and the asphalt binder composing the mixture. The bond failure leads to the formation of an unbonded mixture and ultimately reduces the pavements bearing capacity. In bituminous overlays, stripping is generally caused by moisture trapped in the interface above the concrete. Over the years, substantial progress has been made in developing bituminous mixtures less prone to stripping, thanks mainly to improved material selection tools, anti-stripping additives, modified asphalt binders, and improved drainage practices. However, stripping continues to be a predominant issue because the new stripping resistant mixtures are placed on top of old bituminous mixtures that are likely to be affected by stripping.

Stripping leads to the formation of potholes, cracking, slippage cracking, tearing, and ultimately reduced strength and serviceability of pavements if not detected and addressed early. The most challenging aspect of stripping is that it initiates at the bottom or middle of bituminous layers and propagates upward. Hence, it is almost impossible to detect and quantify at early stages through visual inspections or traditional pavement forensic investigation tools. Once the problem manifests itself on the top surface of the pavement, it is generally too late for minor localized treatments. The lack of appropriate diagnostic tools for stripping makes developing proper pavement rehabilitation plans challenging. For instance, without knowing the stripping's extent, severity, and depth, it becomes difficult to select an appropriate mill-depth for a new overlay or a proper rehabilitation strategy (i.e., full reconstruction, mill and overlay, cold recycling).

Fortunately, new advanced non-destructive evaluation (NDE) technologies are becoming increasingly accessible and suitable for solving complex pavement issues. The Strategic Highway Research Program 2 (SHRP2) study R06D (Heitzman, et al. 2012) vetted the capability of several NDE technologies to evaluate pavements affected by delamination: stripping and debonding. Debonding is a similar type of failure that occurs when the tacking between the pavement layers (lifts) is inadequate. However, the affected layers generally remain physically quasi-intact in debonding, while the layers exhibit full or partial deterioration in stripping. Out of eight (8) vetted tools, two (2) provide promising results for identifying and quantifying stripping: the 3D-Ground Penetrating Radar (3D-GPR), an air-launched antenna array with frequency sweep measurements and the Impact Echo/Spectral Analysis of Surface Waves (IE/SASW) scanning system. Among these two technologies, 3D-GPR had the added advantage of providing continuous full-lane width data collected in a single pass at safe traffic traveling speeds. In particular, the ability of 3D-GPR to scan full-lane width resulted in higher chances of detecting stripping locations than more traditional single-channel 1D-GPR systems. While in the case of debonding, 3D-GPR was not that effective and offered good information only in wet conditions. The IE/SASW was most effective at identifying discontinuities when the pavement was cold and stiff. When the R06D was conducted, the IE/SASW testing required lane closure and did not provide continuous full-lane coverage.

After the R06D study, several states (FL, TX, NM, CA, KY and MN) participated in an Implementation Assistance Program (IAP) sponsored by FHWA and AASHTO, aimed at determining if the 3D-GPR and the IE/SASW technologies met "proof of concept" and were ready for national implementation. The study concluded that the 3D-GPR system met the criteria for high-speed data collection. The IE/SASW system demonstrated significant improvement in data collection speed but still requires lane closure. The IAP identified several drawbacks and concerns that need to be addressed to effectively use 3D-GPR in detecting stripping at project and network levels. The recommended needs for improvements are listed below:

- Develop standard practices for testing pavement using 3D-GPR and other companion NDE technologies such as Traffic Speed Deflectometer and Falling Weight Deflectometer
- Establish proper equipment calibration and data quality verification (i.e., coring locations and numbers) procedures to improve the accuracy of the output
- Develop a standard algorithm for automatic detection of stripping using 3D-GPR data. At present, the analysis of GPR data for detecting stripping mainly relies on visual examinations of GPR images performed by experienced operators. Hence, the current approach is highly time-consuming, expensive and subjective.
- Determine the need and benefits of linking the 3D-GPR data to other NDE technologies. 3D-GPR alone cannot identify stripping all the time and at all subsurface moisture conditions. In addition, 3D-GPR is not readily available to most road agencies. Hence, it is important to continue evaluating other NDE technologies that could fill in the blank spots of 3D-GPR. The other NDE technologies proposed for this study are TSD, FWD, 1D-GPR, IE/SASW, and PASP.
- Develop implementation plans for agencies and promote the use of 3D-GPR for testing stripping
- Facilitate communication between vendors and agencies to enable vendors to make improvements on their hardware and software
- Establish a national user group to provide a venue for experts of NDE technologies to advance the use of GPR and other NDE technologies in local and national road authorities.

In September 2021, FHWA sponsored a very well attended Virtual Peer Exchange to gather updates on Post-R06D advancements from state agencies, universities, research institutions, consultants and vendor perspectives. Since the R06D study, the meeting noted that several state transportation agencies, including the Minnesota Department of Transportation (MNDOT), have started employing 3D-GPR to address stripping and other subsurface pavement issues in their roadways. The group reiterated the need to address the IAP recommendations through a national pool fund study. MnDOT was selected to lead and manage the pool fund study efforts, including drafting and advancing the present proposal. MnDOT recognizes the opportunities and challenges of this effort and believes they are best addressed in collaboration with other agencies and stakeholders.

Objective

The primary objective of the proposed pooled-fund project is to establish a research consortium focused on addressing the R06D and IAP recommendations. As per the IAP and R06D findings and recommendations, particular emphasis will be placed on using 3D-GPR along with Traffic Speed Deflectometer (TSD) and/or Falling Weight Deflectometer (FWD) to detect the location, distribution, and severity of stripping in full-depth and composite bituminous pavements. Recognizing that 3D-GPR and TSD may not be readily available to all participating states, the study will allocate a portion of the pool fund to hire consulting firms for 3D-GPR and TSD surveys on the projects considered in this study. This will provide a good opportunity for states to familiarize themselves with 3D-GPR applications. Furthermore, the proposed pool fund study will include 1D-GPR testing on limited projects to compare with the 3D-GPR data. The proposed investigation also recognizes that 3D-GPR alone cannot identify stripping all the time and at all subsurface moisture conditions. Hence, the proposed study will also investigate using IE/SASW, MIRA, Thermal Imaging for localized spot verifications. It is essential to clarify that the intent of this study is not to evaluate these tools but to support and validate the final deliverables of the study. The set goals are to be accomplished by:

a) Developing a methodology for rapid and automatic stripping detection based on 3D-GPR and other NDE technologies such as Falling Weight Deflectometer (FWD) and Traffic Speed Deflectometer (TSD). The development will be based on experience and needs from participants so that the developed methodology can effectively and efficiently support their pavement evaluation program.
b) Verifying and validating the developed methodology on actual projects selected by the participating agencies. The more states, the stronger the methodology
c) Providing participating agencies guidelines on data collection and analysis protocols
d) Drafting AASHTO specification.
e) Facilitating and supporting communication between experts of NDE technologies, state engineers and vendors to advance the use of GPR for inspecting pavement subsurface issues
f) Providing training and technical assistance that includes providing support for specification development and strategies for agency full implementation
g) Conducting technology promotion for the technologies

The tools (i.e., equipment, testing procedures, data processing algorithms, specifications) advanced through this project will assist state transportation agencies in rapidly and confidently detecting the extent, depth, and severity of stripping in their roads. Specific tasks within this multi-year program will be developed in cooperation with the consortium participants and in such a manner to address the needs of each participant state.

Scope of Work

The work plan will be developed based on the needs and priorities indicated by the consortium participants during the kick-off meeting. While the details and scope of the objectives will be further defined to reflect the concerns of the participants, it is anticipated that the project will include the following:

Task 1- Survey/Synthesis

This task will survey the experience of the participating states with stripping in bituminous mixtures. The survey will inquire on the types of stripping, severity, location, extent and potential causes observed by the participants. Furthermore, it will gauge the participants' expectations from this project, and the availability of resources or materials (mixtures) utilized to achieve the objective's goals. The findings of this outcome will guide the development of the testing plan for the controlled laboratory and field experiments

Task 2 - Signal Pattern Database Development

Currently, the use of GPR data to detect stripping activities in bituminous mixtures depends heavily on operators' skills and experience. The results are subjective to the operator's experience with stripping data. There is limited guideline for user to reference on what type of signal indicate potential stripping activities and severity levels. This task will involve controlled laboratory experiments and numerical simulations (theoretical modeling) in an attempt to create a database containing GPR signals that indicate potential stripping in asphalt pavement. The database will showcase on how 1D-GPR or 3D-GPR signals (A-Scan) will look like in different stripping scenarios. The followings are the proposed experiment procedures:

A. Fabricate asphalt mixture slabs that contain various defects, such as artificial induced stripped regions, moisture and other composition conditions (need inputs from other agencies). The slabs for this effort may be produced in the laboratory (e.g., 3 ft x 3 ft slabs) or extracted from field test sections (e.g., 4ft x4ft, 4 ft x 8 ft). The samples will be used for controlled laboratory testing. Ideally, the 3D-GPR will be directly employed to test and obtain typical template GPR signals. However, if the samples' small scale (dimensions) results in boundary reflections issues, testing will be conducted using handheld (small-dimension) high-frequency antennas (e.g., 2.6 GHz) to avoid or minimize the boundary issues and still extract valuable information on what is detectable and the shape of the responses.
B. Numerical simulation (theoretical modeling) will be used to validate the experimental results and expand the range of the factors considered. The tool proposed for this effort is the Finite-Difference Time-Domain (FDTD) based open source program gprMax. The program has been successfully used to simulate GSSI ground couple signals on pavements with artificial stripping. In the present study, the program would be utilized to simulate and verify 3D-GPR signals corresponding to various stripping levels and locations. See example below:

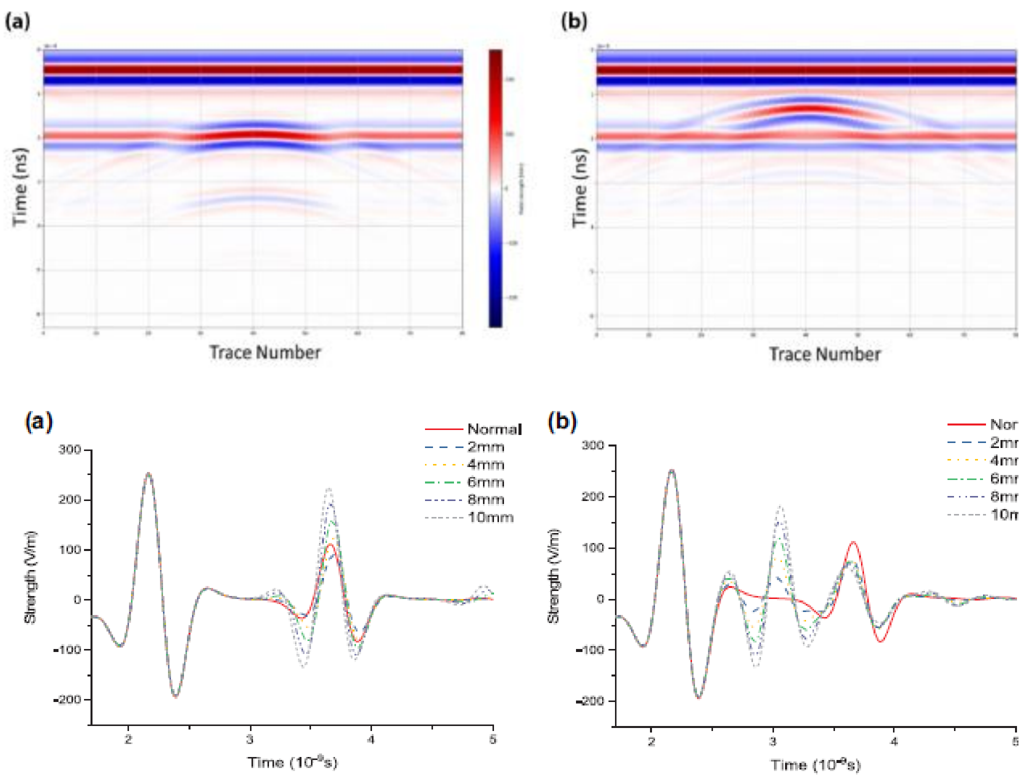

Figure 1. Pictures taken from NDT Detection of AC Stripping Damage using GPR by Ma et. al., 2019

<u>Task 3- Field experiments on controlled test sections</u>

This task will build on the lessons learned in Task 2 and will involve integrating artificially created stripped sections in pavement test sections at MnROAD test facility. The consortium will advise how best to create artificially stripped sections of different dimensions, severity levels and/or moisture conditions in the present study. Currently, some of the stripping configurations that are proposed in this study are:

1. Multiple stripped sections placed at different depths of an intact bituminous layer
2. Multiple stripped sections placed at the bottom of bituminous layers (varying thicknesses): between a bituminous and base aggregate layer and between a bituminous and concrete layer

The purpose of This task is to utilize the stripping integrated test sections to conduct frequent GPR, TSD and/or FWD, and IE/SASW testing (i.e., quarterly or semi-yearly basis). Data from these NDE technologies will be utilized to verify and calibrate the results from the numerical and laboratory experiments and for the development of standard algorithms in Task 4.

Task 4a– Development of algorithms for automatic detection of stripping

Currently, identifying stripping in the bituminous layers from GPR data is done visually by examining GPR radargram images. Hence, this process is significantly dependent on the person's experience interpreting the images, time-consuming and labor-intensive, which is difficult to be implemented by state agencies as a routine test method.

In order to gain highway agencies' interest in using GPR for the detection of stripping it is important to-develop algorithms that enable the automatic detection of stripped areas in an accurate, effective and efficient way. It is anticipated that the algorithms will incorporate both 3D-GPR and TSD/FWD measurements. The developed algorithms will be trained based on the signal databased developed on the tasks 2 and 3 to identify critical locations and quantify the level and depth of stripping. This will improve the efficiency of analysis time and reduce the cost of utilizing the technology.

Several studies have been carried out by MnDOT and others using different signal processing methods. An example of a stripping identification plot generated using the MnDOT proposed stripping algorithm is shown in Figure 2. However, comprehensive research is needed to develop more accurate and effective standard algorithms for the automatic identification of stripping.

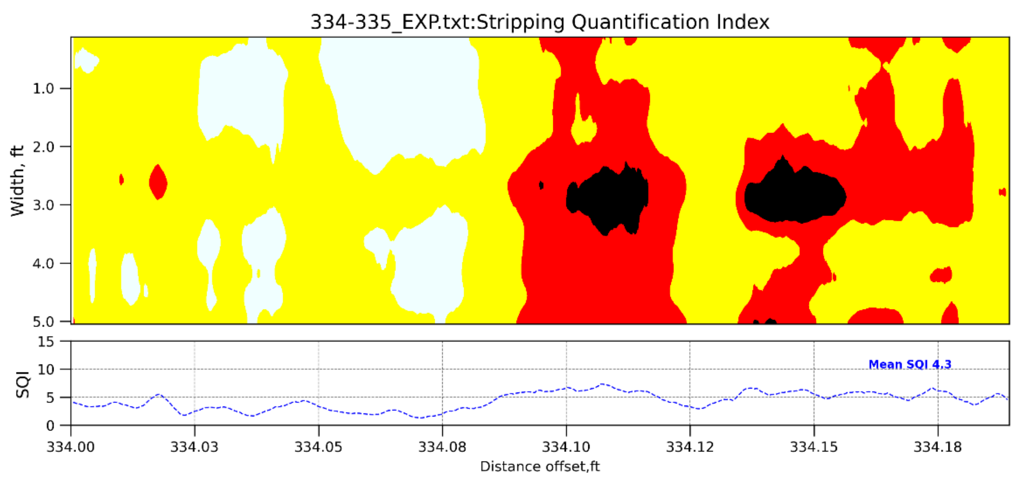

Figure 2. MnDOT proposed stripping index produced from 3D-GPR data

Task 4b– Development of algorithms for automatic detection of moisture

In a recently completed, two-years long proof of concept study, MNDOT evaluated the use of GPR to monitor the seasonal fluctuation of moisture in the unbound aggregate layers of built pavements. The study employed a single channel GSSI 350 MHz ground couple antenna operated in a push mode and three instrumented test sections with different base materials and design structures (thickness) constructed in MnROAD. This study developed an algorithm for estimating the moisture content on the base aggregate layers from the GPR data. The moisture contents and fluctuations obtained from the GPR data matched those obtained from the in-place sensors. In particular, and most importantly for the present study, the proof-of-concept study demonstrated that GPR could be used to discern and identify aggregate base materials and pavement sections likely to experience high and moisture spikes (due to material characteristics or poor drainage). These sections are also ideal candidates for stripping in the bituminous layer. At present, MnDOT is working with 3D-RADAR to transfer the lesson learned and concept from a single channel antenna to 3D-GPR for continuous full-lane coverage. This tool will provide a companion tool for predicting sections that are likely to strip based on the moisture condition in the base layer

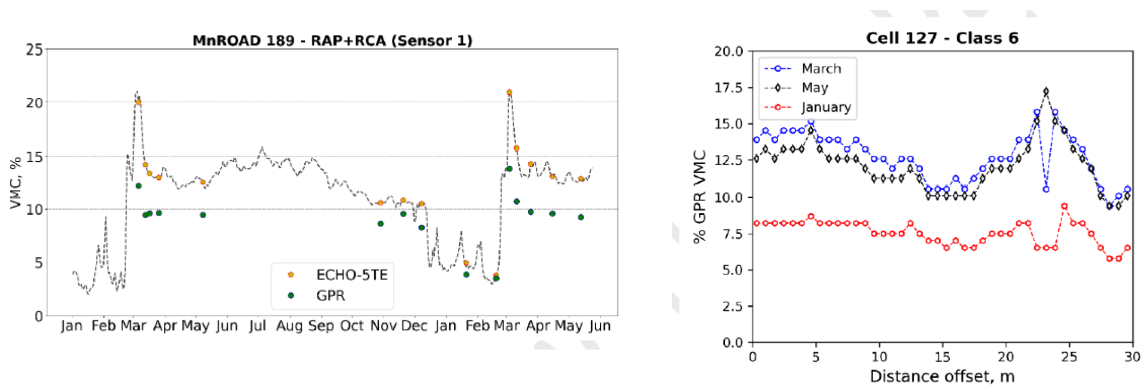

Figure 3. Pictures taken from Using GPR to Monitor Moisture Fluctuations in Base Layers of Built Pavements, Zegeye et. al., 2022

<u>Task 5 – Implementation Plans and Evaluation of Actual Roads</u>

This task will apply the developed algorithms and lessons learned on the previous tasks to evaluate ~~a~~ maximum of 2 road sections suspected of stripping issues from each of the participating agency depending on funding availability. Ideally, the evaluation of the selected road sections will be accomplished using 3D-GPR along with coring/boring data, Falling Weight Deflectometer (FWD) and Traffic Speed Deflectometer (TSD). The PFS consortium will work with the participating agencies to identify how to best analyze data from these technologies and develop an efficient implementation plan that agencies can use as a starting place. It is anticipated that 3D-GPR data collections for these roads will be carried out by participating agencies who own the equipment or by consulting firms hired by the consortium. TSD data will be contracted out to a consulting firm based on negotiated fee. Around 25% of the estimated budget is allocated for TSD and GPR testing. The NDE office of FHWA will assist with IE/SASW, PASP and MIRA testing.

Task 6 – Draft AASHTO/ASTM Specifications

Along with the standard algorithm for detecting and quantifying stripping, the other important deliverable of this study will be to develop draft AASHTO specifications for standard collection and processing of GPR data utilized for stripping evaluations.

Task 7 – Embedding the Algorithm into Commercial GPR Applications (Subcontracted to vendor(s))

The development and implementation of an algorithm in Tasks 4 and 5 may be accomplished in collaboration between the various agencies, consultants and vendors. The first version of the algorithm may be produced using popular coding languages such as PYTHON, Matlab or C++. However, once consensus is reached on the principles and concepts employed to detect stripping, the algorithm must be transferred into commercially available GPR processing software. This will standardize the process and enable agencies to use modules embedded in commercial software instead of not taking advantage of the tool due to a lack of personnel with coding abilities. If different vendors are identified for this task, care should be taken that the module incorporated in their application produce the same outcome.

Task 8 - Support and Communication

Provide a platform for communication, support and sharing information during the PFS and also at the end to identify next steps and additional research/implementation gaps that need to be addressed. This task will be essential for collecting and sharing agency concerns related to stripping and technology improvements and challenges from vendors. The task will include.

1. Semi-annual user group seminars
2. Annual face-to-face user group meetings including invitational travel
3. Quarterly conference call updates with participating agencies, vendors, and consultants
4. Quarterly conference call with the Technical Advisory Committee
5. Website establishment and maintenance

Task 9 - Training and Technical Assistance

This task aims at providing necessary training and technical assistance to participant state agencies, and it will primarily focus on hardware (i.e., 3D-GPR, FWD, TSD) and data processing software selected for the project

1. Hands-on training if needed
2. Executive level training
3. Webinar training and on-call assistance
4. Support participant agency in the development of specifications for data collection and data processing

Task 10 - Promote technology through strategic technology promotion

To successfully accomplish the objective of the project, vendors should continue to develop their equipment (hardware and software) with the goal to provide real-time stripping measurements for project and network level pavement. The vendors efforts to this end can be supported and incentivized by bringing more transportation agencies willing to include NDT technologies in their pavement assessment

1. Preparing technology promotion material
2. Technology promotion to potential vendors on the use of GPR to evaluate bituminous pavements affected by stripping
3. Technology promotion to other DOTs and local transportation agencies

Deliverables

The most important deliverables of this study will be

- Final report documenting all the work accomplished in this study
- Specification(s) for collection and processing of GPR data used to evaluate stripped roads
- Commercially available computer programs for automatic detection and quantification of stripping
- Implementation plans that agencies can duplicate
- Training documents

Proposed Budget

This project is expected to have a minimum participation of at least seven agencies. Minimum annual commitment of $25,000 per year per agency for four years within Fiscal Years 2023-2027.