Non-Destructive Evaluation (NDE) Technologies for Evaluating Asphalt Pavement – Virtual User-Group Peer Exchange (Post SHRP2 R06D)

Meeting Summary Report
September 28-29, 2021

PURPOSE

This Peer Exchange for Non-Destructive Evaluations (NDE) Technologies for Evaluating Asphalt Pavement is a follow-on event to the SHRP2 Advanced Methods to Identify Pavement Delamination (R06D) Peer Exchange that occurred August 2018. R06D was developed through the second Strategic Highway Research Program (SHRP2) and focused on ground penetrating radar (GPR) systems along with mechanical wave impact echo (IE) and spectral analysis of surface waves (SASW) systems with the intent to identify pavement delamination that occurs in layers of asphalt pavement. In particular, R06d focused on the stripping and debonding (two main delamination failure modes). The purpose of this Peer Exchange was to:

- Share information focused on Asphalt Pavements and use of NDE technologies by looking at GPR and IE/SASW experiences and advancements since the SHRP2 R06D Research & Peer Exchange to identify pavement delamination and moisture segregation held August 1-3, 2018
- Provide an opportunity to share other NDE benefits/uses of, or in combination with other technologies
- Provide a recap of the SHRP2 R06D Research & Peer Exchange held in August 2018
- Share state agency experiences and challenges in using NDE technology for evaluating asphalt pavement, with emphasis on identifying delamination and moisture segregation
    - as well as sharing other benefits/uses of, or
    - in combination with other technologies
- Identify vendor technology advancements in equipment and software for evaluating asphalt pavements since August 2018
- Identify gaps hindering advancement and implementation
    - including system improvements, and
    - research needed to fill those gaps
- Discuss strategies to continue advancement efforts

State Department of Transportation representatives, academia, and vendors were given the opportunity to express current and future needs to help support future research and implementation efforts for NDE technology. The agenda included a recap of the August 2018 SHRP2 Research and Peer Exchange, updates from state DOTs about current NDE uses and implementation of technologies for asphalt pavements, updates from vendors regarding advancements in NDE technologies and future needs of NDE including identification of gaps, strategies to continue advance efforts, and action items for moving forward. See Appendix A for the Peer Exchange agenda. A web site for providing the files associated to this Peer Exchange can be found at: R06D Virtual Peer Exchange | QES Pavements

Attendance was taken from the MS Teams Meeting participants list (see Appendix B). The webinar attendance was generally 50 to 70 individuals at any given time over the course of two days. Attendees included 8 from FHWA, 45 from state DOTs, 3 from the Ontario Ministry of Transportation, 10 vendors, 4 consultants, and 9 academia attendees.

DAY ONE - September 28, 2021 Team's Meeting 11:00 to 4:00 PM EST

INTRODUCTION

Dennis Morian (QES) welcomed the group and opened the meeting

Dennis explained that this meeting is a follow-on to the August 2018 SHRP2 R06D Peer Exchange. A lot has happened since 2018 with vendor developments and state use of the technology. This meeting has multiple participants (state agencies, vendors, academia, and FHWA) and will open discussion to help determine the path forward for using the technology.

Dennis introduced FHWA participants – Steve Cooper (FHWA lead), Monica Jurado, Tom Yu, and Hoda Azari.

Dennis introduced the Presenters for the Peer Exchange. Presenters included presentations from Michael Heitzman (Subject Matter Expert – SME for the SHRP2 R06D) who provided the history of past R06D efforts including the results of the August 2018 Peer Exchange followed by presentations from six states and five vendors.

Steve Cooper (FHWA Research Center) welcomed the group and explained his role with the implementation of SHRP2 products and the FHWA's support for this follow-on meeting. Steve noted that he is also presently involved in an effort that involves looking at best practices for resurfacing existing composite pavements, to include how agencies were evaluating these pavements and what was made clear to him was agencies definitely had a need for NDE technologies that could provide them with information of the existing pavement, or at least help to direct them to potential problem areas so they could take cores more strategically.

Monica Jurado commented that the FHWA's equipment loan program is active and some of the equipment that will be discussed at the Peer Exchange is available from the Mobile Asphalt and Mobile Concrete Technology Center.

PRESENTATIONS

Please see PowerPoint slide presentations located here: R06D Virtual Peer Exchange | QES Pavements

Session 1: Recap of SHRP2 R06D Research & Peer Exchange – Michael Heitzman, 3D Radar)

Mike Heitzman provided a brief overview of the R06D study and implementation efforts that culminated with a Peer Exchange in August 2018.

SHRP2 developed the objective and scope for this project in 2007. NCAT led a team of researchers for the initial 30-month effort to examine existing and developing NDT systems. The implementation effort was started in 2016 to have DOTs evaluate the selected NDT systems for "proof of concept" implementation.

The goal of the R06D study was to find a testing system that could achieve the following three attributes:

1. Must detect layer delamination (both debonding and stripping) in asphalt, including over existing concrete pavements.
2. Should operate at a reasonable traveling speed to permit the collection of field measurements without the need for a lane closure.
3. Should be capable of measuring across the entire lane width in a single pass to greatly reduce the field exposure and collection time.

After examining several technologies, GPR, IE, and SASW ranked as the highest NDTs to move forward. 3D-Radar's GPR system and Olson Engineering's IE/SASW system were selected as the systems with the highest potential to achieve the SHRP2 goals.

To keep these technologies in perspective, the 3D-Radar system does operate at traveling speed. The Olson IE/SASW system was selected because it operated at a significantly higher speed than the single test PSPA system. PSPA can perform a test in 3-5 minutes while Olson's system performs a test every one second. 3D Radar has the ability to test full-lane width in a single pass and it is a moving test.

For this study, asphalt delamination included both debonding between layers and stripping distress within a layer. In some cases, the distress occurs across the entire pavement and in other cases it is isolated to small areas, often along the edge of the pavement.

Investigations using cores are common but provide limited data. The SHRP2 R06D project was an attempt to find a detection system that collects greater field information and provides more definitive field data and coverage overall.

The initial R06D study evaluated FWD, LWD, infrared, GPR, SASW, and IE for the potential to meet the study goals. Seed money was provided to selected vendors to promote the development of hardware and software. Each technology was evaluated for its potential to meet the goals. The 3D Radar and IE SASW systems were upgraded and validated, examined in the field and demonstrated to interested agencies.

Test sections were built on the NCAT Test Track with specific delamination distress features in seven of 10 25-ft test sections. Both debonding and stripping were simulated at two-layer depths (2 and 5 inches). Debonding was achieved by spreading a thin layer of asphalt plant baghouse fines between the lifts. Stripping was simulated by placing coarse RAP between the constructed layers. The 3D-Radar GPR measurements clearly identified the layer stripping but could not identify debonding between layers unless the debonded zone was saturated with water. Simulated stripping is generally easier to detect than actual stripping due to control conditions. 3D-Radar created a related analysis software tool called Examiner, and it was available prior to SHRP2 R06D.

The final 3D-Radar GPR prototype system for the SHRP2 R06D study mostly satisfied the testing requirements. The stepped frequency antenna array system has significant advantages over conventional single frequency systems and is capable of full-lane width, high speed collection of field measurements.
The R06D research team concluded that the 3D-Radar GPR system was a valuable NDT technology for project level investigations to identify the location and extent of delamination damage and has potential to be a network level tool.

IE measurements correctly identified the debonding between the pavement and 5-inch asphalt overlay in NCAT test section No. 1 and measured the full pavement depth in the control section. For clarity, IE only measures in the vertical direction, so the visual display is a simple plan view of the pavement showing the depth to the distress or bottom of the pavement (when the materials are completely bonded).

The SASW measurements clearly identified the debonding at the 0.4 to 0.5 foot depth slice as a change in wave velocity. The visual display of SASW is a series of horizontal slices through the pavement.

The final rolling IE/SASW rolling meter system prototype for the SHRP2 R06D project has significant advantages over manual single test IE/SASW systems and is capable of full-lane width, low speed collection of field measurements. The R06D research team concluded that the IE/SASW rolling meter system was a valuable NDT technology for project level investigations to identify the location and extent of delamination damage. Further, it was the only technology to detect debonding between layers.

After SHRP2 R06D research, FHWA and AASHTO initiated an Implementation Assistance Program (IAP). Several states participated in the program to further evaluate 3D GPR and IE technologies which were identified by R06D research as most promising technologies for detecting debonding/stripping. Summaries of experience from individual R06D Implementation states (TX, NM, MN, KY, FL, CA) can be found at this link: http://shrp2.transportation.org/Documents/Renewal/R06D/R06D%20MN%20Peer%20Exchange%20Report%204.1.19.pdf.

The following R06D implementation summary was taken from the August 2018 Peer Exchange report.

- Equipment calibration assures precision and accuracy – critical when pavement layer thickness is a key survey output.
- Equipment verification assures proper field operation – it is important to know that the NDT system is operating correctly before days of field survey are performed.
- Testing protocols guide measurement quality for different roadway features – the survey parameters need to encompass the target concerns. As an example, this is particularly important when the NDT is used for PC pavement and the concern is the condition of load transfer dowel bars.
- Recording test location is key to identifying distress location – using a quality GPS system will reduce data analysis problems.

- Software to automate data analysis improves the efficiency of analysis time – this is, in Michael Heitzman's opinion, the most important feature for gaining highway community use of these NDT systems. The data captures the pavement condition, but the computer needs to be trained to identify the critical locations.
- User Group – both GPR and IE/SASW have multiple highway applications. A User Group that shares NDT successes and failures is vital to improving the value of each technology.
- 3D-Radar – All agencies and consultants are using about a 2-meter wide antenna array and are working with EXAMINER software.
- Olson – At the time of the 2018 Peer Exchange, Olson was still developing user-friendly software to process the data.

Michael provided some final thoughts:

- Chicken and Egg: Vendors need agency interest before investing in system development. Agencies need implementable systems before investing in equipment – both NDT development and agency interest need to grow at the same time.
- Both technologies have strengths and weaknesses – GPR can quickly survey a pavement, identify stripped sections but heavily relies on moisture to highlight debonding distress. IE/SASW can identify debonding (not stripping), but the survey requires a lane closure.
- Both systems can be used for multiple agency evaluations – asphalt pavements, concrete pavements, and bridge decks all benefit from these NDT technologies.
- Mostly for project development, not ready for system-wide asset management – until analysis automation develops to better identify features, these technologies are ineffective for monitoring pavement condition as part of an asset management program.
- ROI is making better pavement rehab project decision to avoid construction change orders – having better pavement condition data improves the project rehab design decisions. Avoiding just one major construction change order easily pays for the NDT system.

Mike Heitzman's presentation can be found here: Implementation Strategies (qespavements.com)

Session 2 - Use of NDE Technologies for Asphalt Pavement (Uses, Experiences, and Challenges) – State Updates

Presentation 1: Minnesota Experience – Eyoab Zegeye (MnDOT)

Eyoab Zegeye's presentation covered the Application of 3D-GPR for Evaluation of Asphalt Pavements Affected by Stripping – Case Study Example. Within his presentation he covered the following:

- Stripping in AC pavements
- Evaluation of pavements affected by stripping
- A Case Study Example (TH71 Beltrami County, MN) which included and investigated:
    - Coring and geo-probing
    - Falling Weight Deflectometer (FWD)
    - 3D Ground Penetrating Radar (GPR)
        - Layer Interface
        - Quantification of Stripped Sections
- Using GPR to detect moisture susceptible pavements

- Recommendations to the group for moving forward

Eyoab Zegeye's presentation can be found here: PowerPoint Presentation (qespavements.com)

Presentation 2: Texas/New Mexico Experiences– Darlene Goehl (Texas Transportation Institute)

Darlene Goehl's presentation covered GPR use and results in both Texas and New Mexico. Three GPR technologies (1GHz, 2GHz, and 3D Radar) were used and discussed as well as a study and the development of an algorithm by Dr. Hayat from New Mexico University. Darlene discussed the following in her presentation:

- comparison criteria used between the three different GPR devices
- the locations where the GPR devices were used in both Texas and New Mexico
- the results and conclusions (for both flexible concrete pavements)
- recommendations for both TXDOT and NMDOT for moving forward

Additionally, she presented and discussed the IE/SASW technologies used in Texas and a report on Olson Engineering. And lastly, she provided the GPR systems that both NMDOT and TXDOT have.

Darlene Goehl's presentation can be found here: Microsoft PowerPoint - TTI-AccelPavConst-0-6985-CST-MT-SHRP2 (003) ts (qespavements.com)

Presentation 3: Virginia Experiences – Brian Diefenderfer (Virginia Transportation Research Council)

Brian Diefenderfer's presentation covered Virginia's Experiences with Pavement NDE Technologies (GPR and Traffic Speed Deflectometer [TSD]). Brian's presentation outline included:

- Background and NDE for pavements in Virginia
  - GPR and TSD
- GPR
  - Overview and examples
- TSD
  - Overview and national experiences
- Conclusions and outllook

Brian Diefenderfer's presentation can be found here: Slide 1 (qespavements.com)

Presentation 4: Florida Experience – Guangming Wang (FLDOT)

Guangming Wang's presentation covered GPR Applications – Florida Practices. Guangming provided an overview of the following:

- GPR Applications
  - Air-Launched GPR

    - Ground-Coupled GPR
    - PaveScan
    - Mini XT
- Challenges on GPR Applications
- Moving Forward – New GPR Technology

Guangming's presentation can be found here: STRATEGIC PLAN (qespavements.com)

Presentation 5: California Experience – Bill Owen (Caltrans)

Bill Owen's presentation covered deployment of emerging SHPR2 Technologies at the California Department of Transportation. His presentation provided:

- History of GPR at Caltrans
- Caltrans SHRP2 Implementation
- Post-SHRP2 Deployment
- Continuing Improvements
- Findings
- Moving Forward (Process Improvements and Integration with visual/thermal Imaging Systems)

Bill Owen's presentation can be found here: 6-Caltrans_WO_Peer_Xchg_9-28-21-Bill-Owen.pdf (qespavements.com)

Presentation 6: Kentucky Experience – Brad Rister (UYK) – Presentation given on Day 2, September 29, 2021

Brad Rister's presentation covered 3D Radar's GPR system including:

- Mounting the device – equipment not standard with the purchase of GPR equipment. Agency devised a frame that works well and causes no radar interference.
- What the device can do:
    - Water Bleeding Through Pavements
    - Keeneland Scan (Horse Racing Track)
    - Dowel Bars
    - Bridges
    - Forensics (Pavement Surface Distress)
- Kentucky's Findings and Conclusions for 3D Radar
    - Helped identify where water was be trapped within the water bleeding project.
    - Identified where track conditions were changing at local horse track.
    - Identified where dowel bars are in JCP, software modifications may be necessary to fully utilize.
    - Bridge deck scanning was successful with the ground coupled system. The development of processing software will greatly enhance analysis.
    - Forensic projects benefit from the 3D Radar coverage area. It takes time to process for finding delaminations.
    - Data is helping pull together pavement rehab designs

Brad Rister's presentation can be found here: PowerPoint Presentation (qespavements.com)

Session 3 – Asphalt Pavement NDE Technology Advancements (Post SHRP2 R06D) Vendor Updates

Presentation 1: 3D-Radar – Jacopo Sala

Jacopo Sala introduced the 3D-Radar System which includes data collection at highway speeds, data processing software of 3-dimensional data, technology, and product components. The 3D-Radar System allows road and pavement inspection, but with experience users have learned that they can expand into additional applications and generate more business.

Topics included in Jacopo's presentation were:

- GPR application process
- Network level surveys
- Application specific "toolboxes"
    - The analysis tools will work on the results of GPR data interpretation to allow reduced data, but still with 3-dimensional feel, additional interpretability, and simplified information without losing detail
    - First toolbox to be launched will be the "Pavement Analysis Toolbox"

Jacopo concluded by sharing the Research efforts at 3D-Radar. Efforts include:

- Improve automatic and semi-automatic interpretation and feature extraction, e.g., interface tracing feature recognition and classification
- Mechanisms for transferring and sharing of information
- Additional tools for Pavement Analysis toolbox

Jacopo Sala's presentation can be found here: PowerPoint Presentation (qespavements.com)

Presentation 2: Olson Engineering – Larry Olson

Larry Olson covered Olson Engineering's Sonic Surface Scanner (S^3) that uses the Impact Echo (IE) and Spectral Analyses of Surface Waves (SASW) technology. The S^3 is a slow rolling (1mph) scanner for delamination mapping of asphalt pavements and bridge decks. Iowa DOT has one S^3 and Indiana has two S^3 units for concrete bridge deck delamination mapping. The S^3 has six displacement transducers on two wheels lined up 6 to 9 inches apart and impacts the surface every 6 inches for IE and SASW tests.

Larry shared information on the basic IE/SASW theory and interpretation of IE/SASW test results.

IE/SASW testing was demonstrated as part of the initial SHRP2 R06D NCAT Research. Demonstrations occurred at NCAT as well as NMDOT, TXDOT, KYDOT, and CALTRANS.

The NMDOT IE/SASW scanning concluded:

- The IE testing on asphalt pavement shows poor repeatability on a point-by-point basis, however, the general data trends observed in the data appear repeatable.
- The temperature of the asphalt pavement effects both the IE and SASW testing by reducing the pavement material velocity.
- The SASW testing shows good repeatability across a wide range of temperatures from 80 to 130+ degrees F.

Software improvements for the S^3 include:

- Utilization of latest high-speed processors
- Bulk data processing techniques
- Attempting to fully automate data analysis; would make data analysis accessible to technicians
- Aiming to reduce data processing time by 10 – 100 times; what took a week could be reduced to an hour or less

Applications for the S^3 System includes:

- IE/SASW Scanning
  - Asphalt Pavements
  - Asphalt overlaid concrete bridge decks
- IE Only Scanning
  - Concrete Bridge Decks – Delamination / Condition
  - Parking Structures / Ramps – Delamination / Condition
  - Elevated Concrete Slabs – Condition / Thickness
  - Concrete Slab on Grade – Condition / Thickness

Larry Olson's presentation can be found here: Implementation Strategies (qespavements.com)

Presentation 3: GSSI – Rob Sommerfeldt - Presentation given on Day 2, September 29, 2021

Rob Sommerfeldt's presentation covered two elements, 1) What is GPR? and 2) Determining layer thicknesses, voids, sub-surface evaluations and issues, and other applications.

Rob explained GPR as:

- A GPR antenna transmits a radar signal into the pavement and measures the change (amplitude and phase) in that energy as it reflects back to the GPR receiver antenna.
- 2-way travel time is recorded as well as amplitude and phase.
- If there is a change in the pavement material, the radar signal response (Dielectric) reflects that change (interface between the two materials).

Rob illustrated these points by showing GPR scans and how the data could be interpreted depending on dielectric values, moisture, data filtering.

GSSI has found that GPR works well to:

- calculate layer thickness
- detect voids
- evaluate subsurface layering
- provide coring locations for any anomalies
- Some anomalies may be delaminations
- Anomalies provide coring locations for further evaluations

Information on GSSI's PaveScan Rolling Density Meter for determining asphalt pavement density was presented.

Rob Sommerfeldt's presentation can be found here: KTC PaveScan RDM Meeting (qespavements.com)

Presentation 4: Infrasense – Ken Maser – Presentation given on Day 2, September 29, 2021

Ken Maser's presentation covered:

- A discussion of three technologies
  - GPR
  - 3DGPR
  - TSD
- Applications for these technologies
  - Pavement Management
  - Rehabilitation Design
  - In-place Recycling and Density QA
  - Failure Investigations

Ken explained some of the differences between the three technologies:

- Traditional GPR – takes a slice of pavement
- 3D-GPR – provides another dimension (width), provides special delineation to find variances such as dowel bars, rebar
- Traffic Speed Deflectometer – deflection data is taken continuously, can combine with GPR

Ken ended his presentation with the point that combining surface and subsurface pavement data leads to the right decisions with reduced owner costs. The key take-aways from that were:

- Reduce life cycle costs by making better decisions
- Increase pavement life by addressing the right needs
- Accurate thickness data avoids costly changes during construction
- Diagnose failures to allow appropriate and economical fixes

Ken Maser's presentation can be found here: Microsoft PowerPoint - SHRP2 R06D Peer Exchange Looking Below the Surface_v2.pptx (qespavements.com)

Presentation 5: Road Scanners – Timo Saarenketo – Presentation given on Day 2, September 29, 2021

Timo Saarenketo's presentation started with discussing the modern road survey vehicle and technologies that are incorporated onto/within a vehicle named the Road Doctor Survey Van (RDSV) which includes:

- a video camera
- thermal camera
- laser scanners
- Global Positioning System (GPS)
- 360^0 camera
- 2 GHz and 400 MHz GSSI GPR radars (or with a 3D radar DXG GPR radar)
- 3D-Accelerometer encoder

He then discussed the future and use of a Road Doctor Digitizer for Digital Twin Data Collection (3D Radar for Ground Coupled GPR and GSSI's 2.5GHz Air-Coupled GPR). The presentation then was focused on moving from reactive to proactive pavement management and indicated that mapping cracks and pavement distress means that you are monitoring only how late you are with your maintenance measures. The monitoring of pavement moisture, fatigue cracking, and microcracking in both old and new pavements and illustrating what their measurements can be was presented. The monitoring of moisture and how to have a moisture damage index and drainage diagnostics was presented. Detecting debonding and delamination and their importance with determining proper milling depths was discussed. The monitoring of asphalt segregation (thermal data and 3d Radar GPR data) with the use of a thermal camera, GPS, Weather Station, PC and display with data being sent to the Cloud all deployed in the construction phase on paving equipment was then presented. And lastly, the use of coreless GPR to diagnose for internal asphalt pavement damage (or lac k there-of) using dielectrics of the whole asphalt pavement depth indicating thermal segregation, both dry cracks and wet cracks, and pavement thickness was presented.

Timo Saarenketo's presentation can be found here: PowerPoint Presentation (qespavements.com)

DAY TWO - September 29, 2021 Team's Meeting 11:00 to 4:00 PM EST

OPEN DISCUSSION – (OTHER STATE EXPERIENCE AND Q&A)

To start the conversation on other NDE experience used by states Darlene Goehl provided an overview of the NDE technologies and techniques used in Texas.

Presentation: Texas Pavement's Innovative Technologies and Techniques – Darlene Goehl (Texas Transportation Institute)

Darlene's presentation covered the NDE technologies and techniques used in Texas. Darlene discussed the benefits, limitations, and availability for the technologies:

- Ground Penetrating Radar (GPR)
  - GPR is standard practice in Texas
  - Texas owns 5 antennas
- Mobile Lidar

    - Texas owns 1 unit
    - Used for new project information, forensic evaluation of drainage problems. Better suited for asset management.
    - Limitations of Lidar is the complexity of data analysis
- Falling Weight Deflectometer (FWD)
    - FWD is standard practice in Texas
- Total Pavement Acceptance Device (TPAD)
    - Texas owns 1 device
    - Benefits: efficient forensic investigations, assess alternative M&R strategies, timely decision making and test of load transfer for concrete pavement joints.
    - Limitations: not suited for layers less than 3 inches thick and traffic control is required.
- Electrical Resistivity Tomography (ERT)
    - Benefits: Identify locations with high moisture content, identify locations with unusual subsurface conditions and allow timely decision making.
    - Limitations: Experienced personnel are needed to collect and analyze the data.
- Web Soil Survey
    - Web Soil Survey (WSS) provides soil data and information produced by the National Cooperative Soil Survey. The Survey is available at: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
- Dynamic Cone Penetrometer (DCP)
- Portable Weigh in Motion (p-WIM)
    - The p-WIM is a traffic data collection system that is used to measure traffic characteristics. System collects site specific field traffic measurements including traffic volume, vehicle classification, axle loads and vehicle weights.
    - Traffic control is required for set up but not for data collection.
    - Texas has used information from the system to recalculate Truck Factors. Texas found they were much higher than had been previously used.
    - Texas owns 5 systems.

Darlene Goehl reported that TTI has prepared one-page folios describing the technology and applications for each of these types of equipment. These folios can be found at: https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6985-P8.pdf.

CURRENT NEEDS/FUTURE NEEDS AND INDENTIFICATION OF GAPS

The objective of this discussion was to identify current and future needs of NDE technology and answer such questions as:

1. What research is needed?
2. What improvements are needed for wide-spread use?
3. Where do we go from here?
4. What support is needed to move forward?

Current Needs

Brian Prowell started the current needs discussion by asking a series of questions.

1. What indices are reliable to measure specific anomalies (thickness, presence of anomalies, moisture, moisture damage, segregation, voids?

Darlene Goehl – A way to determine indices is to look at case studies that focus on forensics. Explaining how tools were used to find solutions gives insight of what to look for and what indices to use.

Shongtao Dai – Measuring pavement thickness. Thicknesses for older pavements may not be clear because of deterioration. Second is voids; to determine if there is a void under the pavement. Image analysis for voids, what should it look like on GPR? How small of a void can GPR see? Is this based on frequency of antenna?

Timo Saarenketo – the accuracy of cores with GPR dual antenna GSSI system is 4%. Complex reflection from the bottom of asphalt may require core verification, for instance, if there is stripping at the bottom of the layer. Determining voids under the pavement can be difficult. The material below the bound pavement layers may be saturated, or not. These conditions result in different radar reflection patterns. Other companion technology is needed to support strong determination.

Shongtao Dai – Can artificial voids be constructed so we know what we are looking for?

Tom Scullion – We did that. Air voids could not be seen if less than ¾-inch thick in the lab with a 1 GHZ antenna under an 8-inch concrete slab. Trying to map the size of voids is tough. Look for negative peak in dielectric response signal. Voids are often filled with foam, and this confuses interpretation of the GPR signal, as the dielectric for the foam is similar to that of air.

Timo Saarenketo – need to filter out below the central frequency to see voids. A higher frequency is needed to see small voids. This interpretation is very labor intensive. The advantage of 3D-Radar is that a frequency sweep is done, which facilitates the signal interpretation.

Eyoab Zegeye – It is very challenging to determine voids.

2. Data collection and analysis procedures? Automation of data analysis?

Shongtao Dai – Analysis tools would be very helpful. Need software to help operating divisions get data quickly. Users want results right away.

Eyoab Zegeye – Would be helpful but some analysis will be required. Tools for routine data analysis would be useful. We also need to standardized these tools. Several agencies including MnDOT stated that they are using in-house developed algorithms to extract GPR features that relate to stripping, moisture and other pavement damages. It is important that we standardize these tools and develop nationally agreed specifications.

Timo Saarenketo – Data collection is specific to the type of GPR you are using. Scans per meter should be specified. Automated data analysis is advancing very quickly.

Ken Maser – Provided a reference regarding void detection (W.J. Steinway, J.D. Echard, and C.M. Luke. *NCHRP Report 237: Locating Voids Beneath Pavement Using Pulsed Electromagnetic Waves*. TRB, National Research Council, Washington, D.C., Nov. 1981.)

Jacopo Sala – Echo automated data analysis using forward. 3D-Radar looks at geometry when looking for voids, not only vertical direction. Better correlation results when used with thermal imaging. Exploit the density of a data set.

3. Ease of data analysis? Data analysis time? Data storage?

Tom Scullion – Automatic data processing works better on newer pavements. When pavement has many layers, it can be difficult to find the bottom of asphalt.

Ken Maser agrees. Sometimes you can't find stripping or other distresses.

Shongtao Dai – if you can determine thickness and dielectric constant at same time. Asphalt should be 4-5 inches.

Ken Maser – "Layer identification errors." Can occur without a good verification technique.

Jacopo Sala – automated not close to replacing civil engineers but can simplify analysis. Engineers still needs to make decisions. Some things are more likely to be automated. Do the easy things first. Easy things include dielectric mapping, and surveys of things closer to the surface which are more recognizable.

4. Calibration of equipment and QC/QA of data?

Tom Scullion - TX uses GPR and FWD. GPR is calibrated every six months. FWDs are calibrated. Track with time to determine when recalibration is needed.

Ken Maser – haven't felt need to calibrate equipment. Collect calibration data on metal plate/direct coupling.

Shongtao Dai – Using high density polyethylene (HDPE) for DPS to check dielectric constant. Not frequency dependent.

Dennis Morian asked how frequently do you need to check? Every day checks?

Shongtao Dai – every day.

Kyle Hoegh – do consistency check every day on asphalt, but not HDPE.

Timo Saarenketo – One calibration per year for GPR systems used in QC/QA road surveys (typically prior to the May to September testing season) is necessary for good quality data. Timo

and his company have seen five companies doing QC/QA road surveys in another road authority (about 10-15 years ago), three with broken GPR equipment being used in routinely but not working correctly, thus showing the importance of annual calibrations. Roadscanners periodically sends their GPR antenna or central units to the manufacturer's factory to be repaired when the quality of the signal or stability is not as good as it is supposed to be.

Tom Scullion – TX DOT has five tests. Antenna over metal plate looks at variance. Long term test over two hours. Tom can share information.

From chat: Here is the Texas Report showing system performance tests that Timo Saarenketo and Tom Scullion discussed performing to verify that the GPR equipment is functioning properly (section 2.4 pg. 41): https://static.tti.tamu.edu/tti.tamu.edu/documents/1233-1.pdf

From chat: Here is the DPS **AASHTO PP 98-20 (2021)** we put together using those performance measures as a starting point but specifically for surface dielectric measurement that Shongtao Dai mentioned: https://www.techstreet.com/standards/aashto-pp-98-20?product_id=2110486

5. Level of experience needed to use?

Various participants commented that a state agency needs to invest in dedicated staff and equipment to make GPR technology successful. While tools are being developed to simplify the use of GPR, it takes years of experience to interpret GPR scans correctly.

6. Ease of software and hardware upgrades?

Timo Saarenketo – There is software compatible with almost every GPR system.

Dennis Morian – There are different levels of sophistication in hardware and software. Limitations may be tied to type of system?

Timo Saarenketo agrees. Future project plans may be dependent on the type of system being used.

Bill Owen – Software is easier than hardware. How do agencies budget for future upgrades? Need advance planning to be able to acquire new or equipment modifications.

Dennis Morian – do you need to justify the value of an upgrade?

Bill Owen – California goes through cost benefit analysis and compares this with a no action alternative. It is important to demonstrate a benefit which makes it easier to adopt more widely and to make GPR used more widely by designers/materials personnel. California is beginning to see the cost benefits in divisions.

Future Needs

Brian Prowell started the future needs discussion with a series of questions:

1. What steps do we need to follow to properly advance GPR & IE/SASW?

Bill Owen – There is a good parallel with the FHWA Every Day Counts (EDC) initiative. In the geotechnical field Geotechnical Tools for Foundations was developed. Something similar to this would bring NDE technology to agencies that would otherwise not get it.

Shongtao Dai – Need more group meetings to share information on a regular basis.

Dale Peabody seconds FHWA EDC potential.

Jacopo Sala – Vendors need field experience and test sites that states can provide. Feedback is needed.

Glenn Engstrom – MN keeps moving forward with initiatives. MNDOT has budget and people. They try to create a team and show others what's going on. It also takes a marketing effort.

Mike Heitzman – There is value in User Groups to establish tasks that need to be addressed moving forward. It is important to hear from Users to establish a standard set of parameters if data is going to be incorporated into pavement management specifications. This would help vendors know what products will be helpful to agencies.

Eyoab Zegeye – A user Group would be very beneficial. User Groups help to build confidence with using the technology. Step-by-step process.

Dennis Morian – the follow up needs to develop user training?

Eyoab Zegeye – Exactly. How can technology be applied more effectively. User Groups need to hear the needs of operating divisions.

2. Are there any additional objectives that should be focused on? If so, what?

Shongtao Dai – stripping detection. Need to use more than just GPR technology. His team is able to help districts with spring load restrictions using 3-D GPR and Traffic Speed Deflectometer data.

Bradley Rister – Don't forget to think outside of the wheel paths, our experience with stripping has not always been in the wheel path, but at the joints and or in the lane center between wheel paths.

Tom Scullion – Use technologies in pavement rehabilitation work. He described a change order example valued at $1 million which demonstrates the benefits of using NDE. TX does a lot of in-place recycling and need thicknesses that do not need to be super accurate. This helps to know where to sample to get representative thickness information to control recycling operations.

Ken Maser – Perhaps share stories of successes or cost/benefit. Publish?

3. What support/program is needed to fill gaps identified above?

4. Who needs to provide support, training, human or financial resources to continue advancing these technologies forward?

Various participants commented that the FHWA should be involved. Perhaps EDC could move this effort forward as well as a pooled fund study. Additionally, state agencies need to supply some level of support as well.

Participants identified the need to continue NDE User Group exchanges.

Shongtao Dai – MNDOT is currently working on a pooled fund study for DPS, which is using GPR to measure in-place density.

Steve Cooper – When finishing SHRP 2, MnDOT started a pool fund for DPS. It takes a while to get pool fund studies officially started. MN was not in position to do a pool fund for R06D at that time. It would take at least a year to one get started for the R06D topic. In the interim, FHWA may be able to support one more virtual User Group meeting, possibly in the late summer/early fall timeframe of 2022.

Robert Hinman – Need to look at NDE holistically. Use all the tools in the toolbox. Having multiple tools to make assessment beneficial. How to integrate data? Training to help new GPR users get up to speed.

Timo Saarenketo – Finland is using NDE technologies. Their project PEHKO 2015-2025 used NDE technologies to change their reactive pavement maintenance routines to proactive ones in order to cut down life cycle costs (LCC) of the pavements. This approach (using NDE technologies for advancing an understanding of this objective) calculated annual paving costs (LCC) already going down 30-38% from the initial costs in 2015-2016 when they started the project. It enables them to better know what to do and where.

Post Peer Exchange – Timo has provided the following additional comment on an award and for three references concerning the project.

The project has received an award from the International Road Federation (IRF) Global Road Achievement Award (GRAA) in 2018.

1. Saarenketo, T. 2017. What New Technologies can Provide to Intelligent Road Asset Management. Proceedings of the 29th International Baltic Road Conference, 28-30 August 2017, Tallin.

2. Saarenketo, T., Munro, R, and Matintupa, A. 2019. PEHKO Project, Implementing recommendations for rural road asset management in Finland. Proceedings of the International Symposium on Cold Regions, ISCORD 2019. Oulu, Finland June 17-19.

3. Tapio R., Lehtinen, J., Ylinampa, J. and Saarenketo, T. (2016). ”PEHKO Project 2015-2025, increasing the productivity of paved road management in Finland” Proceeding of EAPA Conference, Prague 2016. Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.144

They have stopped talking about technologies and concentrating on research/forensics and moved to a balanced approach. It is important to know how to get people to commit to this work. It is

necessary to sell this system to decision makers. It is important for agencies to know how you change practices so you don't get delamination.

One suggestion was a Sunday TRB Workshop in 2023. There is a need to identify committees that might support a workshop. It is too late to plan for 2022.

Mike Heitzman – There is more potential for virtual webinars, such as this, versus face-to-face. More people can attend.

Larry Olson – There is a lot of cross-over between bridge decks and roads. This might be a way to get more people involved. NCHRP may be an avenue? Supportive of the pooled fund idea.

Tom Yu – It will be difficult to merge pavement and bridge GPR initiatives.

STRATEGIES TO CONTINUE ADVANCEMENT EFFORTS

From the previous discussion it was apparent that there is significant interest among the participants in continuing the activities of the R06D Peer Exchange Group as an "NDE for Pavements". Several approaches were discussed for continuing support for the R06D NDE technologies through further peer exchange activities. It was also mentioned that ongoing support by the FHWA will be important to achieve these objectives.

The discussion of mechanisms available to continue the Peer Exchange Group efforts included:

- Activities that parallel the FHWA Every Day Counts (EDC) initiative
- Improve communications at the 2022 TRB
- A 2023 TRB workshop on NDE
    - There is a need to identify sponsoring committee(s)
- Transportation Pool Fund Study
- Additional virtual meetings- these seem to increase participation as a result of ease of participation
- Potential NCHRP efforts
- User Groups, that include international users (3D Radar might assist in identifying users)

The establishment of User Groups to identify tasks which need to be accomplished to continue forward progress with NDE. User Group objectives discussed include to build confidence in using the technologies, cooperate with the operational users to identify needed products, and develop step-by-step procedures for users.

It was suggested that individual areas for application of NDE technologies should be identified including:

- Planning
- Design
- Construction
- Quality Assurance

Several tasks were identified as being needed to continue moving the NDE technologies forward. These tasks include:

- Equipment calibration, methods, and renewal frequency
- Development of standards for the various NDE applications
- Development of automated data processing/analysis tools for various NDE applications
- Compilation of experience and guidance for the use of combined NDE technologies
- User training for the various NDE applications. This should include
    - The basics of GPR technology
    - Data analysis methods and use of tools

A couple activities were identified in the near term to continue the momentum from this meeting. Shongtao Dai indicated that MnDOT would lead an effort, working with other lead

agencies/contractors, to develop a draft pooled fund workplan identifying the activities to advance NDE technologies focused on asphalt pavements. Minnesota has continued to work with the NDE technologies since the expiration of the R06D activities. Volunteers were solicited to assist in the effort.

Steve Cooper indicated that FHWA could assist with collaboration efforts during the interim till MN DOT could get a new pool fund going, possibly sponsoring another virtual Peer Exchange meeting in the late summer/early fall timeframe in 2022.

ACTION ITEMS FOR MOVING FORWARD

The following action items were discussed:

- Become more involved with and collaborate with TRB.
- Host another User Meeting. Expand to (additional) International Users. Jacopo could help facilitate this by reaching out to customers in other parts of the world.
- A virtual meeting would be more likely to get strong participation, but a meeting in-person has value too.
- Maintain the focus on asphalt pavement applications (Tom Yu, Glenn Engstrom, and Jeff Brunner)
- MnDOT agreed to develop a scope work/work plan for a potential pool fund study focusing on improving collaboration and conducting priority research efforts to advance NDE for asphalt pavements technology. FHWA (Steve Cooper) agreed to assist MnDOT in reviewing the pool fund proposal when drafted. Other states are encouraged to contact MnDOT if they are willing to contribute to the work plan development?

Appendix A: Peer Exchange Agenda

Agenda

Non-Destructive Evaluation (NDE) Technologies for Evaluating Asphalt Pavement - Virtual User-Group Peer Exchange (Post SHRP2 R06D)

Dates: September 28 – 29, 2021

Location: MS Teams (hosted virtually by FHWA)

Peer Exchange Logistics and Technical Support: QES

Facilitator: Dennis Morian (QES)

Peer Exchange Purpose:

Share information focused on Asphalt Pavements and use of NDE technologies (Post SHRP2 R06D GPR and IE/SASW) and their advancements, to identify asphalt pavement delamination and moisture segregation, but also provide an opportunity to share other benefits/uses of, or in combination with other technologies.

Peer Exchange Objectives:

- Provide a Summary Recap of the SHRP2 R06D Research & Peer Exchange held in August 2018
- Provide State Agency experiences and challenges with using NDE technology for evaluating asphalt pavement, with emphasis on identifying delamination and moisture segregation, as well as sharing other benefits/uses of, or in combination with other technologies
- Provide vendor technology advancements in equipment and software for evaluating asphalt pavements since August 2018
- Work with stakeholders to identify gaps hindering advancement and implementation, including system improvements, and research needed to fill those gaps
- Discuss strategies to continue advancement efforts

Day 1: September 28, 2021 (All times Eastern)

11:00 am	**Welcome and Opening Comments**	Dennis Morian (QES)
11:05 am	**Welcome from FHWA**	Cooper & Jurado (FHWA)
11:10 am	**Introductions (Name, Organization, Position)**	Dennis Morian (QES)
11: 25am	**Recap of SHRP2 R06D Research & Peer Exchange (Held August 2018)**	Michael Heitzman (3D Radar)

11:50 am	**Use of NDE Technologies for Asphalt Pavement (Uses, Experiences, and Challenges) – State Updates** (30 minutes each)	
		Minnesota– Eyoab Zegeye (MNDOT)
		Texas/New Mexico – Darlene Goehl (TTI)
		Virginia – Brian Diefenderfer (Virginia Transportation Research Council - VDOT)
1:20 pm	**Lunch** Break	
1:50 pm	**Use of NDE Technologies for Asphalt Pavement** (**Uses, Experiences, and Challenges) – State Updates** (**Cont'd.)** (30 minutes each)	
		Florida – Guangming Wang (FDOT)
		California – Bill Owen (Caltrans)
2:50 pm	**Asphalt Pavement NDE Technology Advancements (Post SHRP2 R06D) – Vendor Updates** (30 minutes each)	
		3D-Radar – Jacopo Sala
		Olson Engineering – Larry Olson
3:50 pm	**Day 1 Wrap-up**	Dennis Morian (QES)
4:00 pm	**Adjourn for Day 1**	

Day 2: September 29, 2021 (All times Eastern)

11:00 am	**Day 1 Recap**	Dennis Morian (QES)
11:05 am	**Asphalt Pavement NDE Technology Advancements (Post SHRP2 R06D) – Vendor Updates (Cont'd.)** (30 minutes each)	
		GSSI – Rob Sommerfeldt
		Infrasense – Ken Maser
		Road Scanners – Timo Saarenketo
12:35 pm	**Use of NDE Technologies for Asphalt Pavement (Uses, Experiences, and Challenges) – State Updates (Cont'd.)** (30 minutes)	
		Kentucky – Brad Rister (UKY)
1:05 pm	**Open Discussion (Other State Experiences and Q&A)**	All
1:30 pm	**Lunch** Break (Day 2 Morning Technical Session Adjourns)	

2:00 pm	**Future Needs and Identification of Gaps**	Brian Prowell (AMS/QES)
	(Current and future needs, where do we go from here, what needs to happen next, what research is needed, etc.)	
3:00 pm	**Strategies to Continue Advancement Efforts**	Dennis Morian (QES)
3:30 pm	**Action Items for Moving Forward**	Dennis Morian (QES)
4:00 pm	**Adjourn for Day 2**	

Appendix B: Workshop Participants

Name	Affiliation	Role
Cooper, Steve	FHWA	Lead
Yu, Tom	FHWA	Attendee
Kliethermes, Kevin	FHWA	Attendee
Azari, Hoda	FHWA	Attendee
Melgoza, Luis	FHWA	Attendee
Hinman, Robert	FHWA	Attendee
Jurado, Monica	FHWA	Attendee
Sivaneswaian, Nadarajah	FHWA	Attendee
Morian, Dennis	QES	FHWA Contract Support
Koser, Steve	QES	FHWA Contract Support
Uhlmeyer, Jeff	QES	FHWA Contract Support
Prowell, Brian	AMS/QES	FHWA Contract Support
Giessel, Richard	AK DOT	Agency
Wheeler, Mark	ID DOT	Agency
Wielenga, Craig	ID DOT	Agency
McCarty, Ed	MD DOT	Agency
Peabody, Dale	ME DOT	Agency
Bradbury, Richard	ME DOT	Agency
Hoegh, Kyle	MN DOT	Agency
Turgeon, Curt	MN DOT	Agency
Brunner, Jeff	MN DOT	Agency
Engstrom, Glenn	MN DOT	Agency
Teshale, Eyoab Zegeye	MN DOT	Agency
Dai, Shongtao	MN DOT	Agency

Mahmoud, Enad	TX DOT	Agency
Gonzalez, Juan	TX DOT	Agency
Flores, Roberto	TX DOT	Agency
Armstead, William C.	AL DOT	Agency
Frazier, Brad	KY DOT	Agency
Schwiers, Ogechi	NJ DOT	Agency
Blight, Robert	NJ DOT	Agency
Reed, Ty	PA DOT	Agency
Rubin, Jacquae	MD DOT	Agency
Guangming, Wang	FL DOT	Agency
Holland, Joe	CA DOT	Agency
Owen, Bill	CA DOT	Agency
Holikatti, Sri	CA DOT	Agency
Rizvi, Rais	NM DOT	Agency
Montoya, Kelly	NM DOT	Agency
Armendariz, Armando	NM DOT	Agency
Landefeld, Craig	OH DOT	Agency
Schofield, Kim	WA DOT	Agency
Carlson, Kyler	WA DOT	Agency
Weston, Jim	WA DOT	Agency
Diefenderfer, Brian	VA DOT	Agency
Kane, Thomas	NY DOT	Agency
Walker, Jacob	GA DOT	Agency
Martin, John	GA DOT	Agency
Schmitt, Jeffrey	Iowa DOT	Agency
Brakke, Chris	Iowa DOT	Agency

Rea, Robert	NE DOT	Agency
Paye, Barry	WI DOT	Agency
Su, Mert	AR DOT	Agency
Nantung, Tommy	IN DOT	Agency
Harris, Dwaine	IN DOT	Agency
Morrison, Clark	NC DOT	Agency
Buyuan, Kyle	HI DOT	Agency
Lee, Stephen	Ontario Ministry of Transportation	Agency
Gumisiriza, Gideon	Ontario Ministry of Transportation	Agency
Wang, Zach	Ontario Ministry of Transportation	Agency
Sommerfeld, Robert	GSSI	Vendor
Martin, Kent	GSSI	Vendor
Sala, Jacopo	3D Radar	Vendor
Olson, Larry	Olson Engineering	Vendor
Miller, Pat	Olson Engineering	Vendor
Maser, Ken	Infrasense	Vendor
Annan, Peter	Sensors and Software	Vendor
Heitzman, Michael	3D Radar	Vendor
Khazanovich, Lev	University of Pittsburgh	Academia
Goehl, Darlene	TTI	Academia
Wilson, Bryan	TTI	Academia
Sebesta, Steve	TTI	Academia
Leiva, Fabricio	Auburn	Academia
Musselman, Jim	Auburn	Academia
Rister, Brad	University of Kentucky	Academia
Scullion, Tom	TTI	Academia

Name	Affiliation	Role
Nazarian, Soheil	UTEP	Academia
Celaya, Manuel	Aidpe	Vendor
Saarenketo, Timo	Roadscanners	Vendor

Appendix C: GPR Reflection Patterns (TTI)

ReflectionPatterns.pdf

Acronyms and Abbreviations

- 3D is the abbreviation for three-dimensional
- AC is the abbreviation for asphalt concrete
- DMI is the abbreviation for distance-measuring instrument
- GHz is the abbreviation for gigahertz
- GPR is the abbreviation for ground-penetrating radar
- GPS is the abbreviation for global positioning system
- Hz is the abbreviation for hertz
- IE is the abbreviation for impact echo
- MHz is the abbreviation for megahertz
- mph is the abbreviation for miles per hour
- NDT is the abbreviation for non-destructive testing
- NDE is the abbreviation for non-destructive evaluation
- SASW is the abbreviation for spectral analysis of surface waves
- SHRP2 is the abbreviation for second Strategic Highway Research Program
- User Guidelines refers to Nondestructive Testing to Identify Delaminations between HMA Layers