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DATE	May 8, 2019
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REGARDING	Implementation Close Out of SHRP2 Product: Nondestructive Testing for Tunnel Linings (R06G)

Overview of Product Activity - Executive Summary

The R06G product, Nondestructive Testing for Tunnel Linings was intended to provide funding to state DOT's to implement one or more of the Nondestructive testing (NDT) technologies previously identified as being applicable to the rapid and accurate evaluation of tunnel lining condition. Tunnels have tended to be a part of the highway networks that are difficult to evaluate in detail and thus the evaluation of these structures is a big challenge facing state and local agencies across the country. The R06G product was expected to result in a number of states adopting NDT methods as a means to improve the accuracy and speed of tunnel liner condition rating and deterioration mapping while also increasing safety to workers and the travelling public. The NDT results from these evaluations would be expected to be used in asset management programs for long term use as well as in project-level evaluations to determine repair/replacement decisions and scopes of work. The results were also expected to be fed into the new NTIS tunnel evaluations to improve the overall accuracy and usefulness of the evaluations.

The R06G product was made available through SHRP2 in a Round 4 and Round 7. Round 4 involved 2 states, while Round 7 was a total of 4 states. It should be noted that one of the Round 7 states was also a Round 4 state (Colorado).

The list of states participating are shown below

Round 4	Round 7:
Pennsylvania Colorado	Colorado (also in Round 4) Oregon Virginia California

The award amounts per state were higher in Round 4 that in Round 7. The total awards were:

- **Round 4** – Each state was awarded $250,000.00 plus unspecified SME support of over 24 hours.
- **Round 7** – Each state was awarded $30,000.00 plus 8 hours of dedicated SME support.

The results of the NDT investigations on tunnels by the various states were mixed. Several states attempted to use Infrared Thermography (IR) to investigate the condition of tunnel liners, but most found that the cameras they were using did not have sufficient sensitivity to allow the collection of meaningful data except for water seepage identification. Colorado, however, put in some extra research effort and found that high-end cooled-element IR cameras WERE able to collect useful data. They tested a number of tunnels with these cameras and were able to locate delaminations and other issues in the shotcrete and concrete liners. The use of GPR for tunnel liners was found to be effective in condition evaluation of concrete liners, but the geometry and interferences inside tunnels from lighting systems etc. sometimes slowed down or limited the collection of GPR data. Finally, the use of high resolution optical, laser or photographic systems (LiDAR, High Resolution Video, Photogrammetry, etc.) was found to be very useful in mapping out and quantifying cracking on tunnel liners as well as documenting the presence and locations of assets inside tunnels.

One additional interesting finding was that since tunnels often consist of flat road decks inside round bores, the decks inside tunnels can also act as “bridge decks” and are subject to many of the same degradation mechanisms facing normal bridge decks. However, these decks can be evaluated with many of the techniques used for rapid bridge deck evaluation as per R06A. At least one state DOT did in fact evaluate the tunnel deck with GPR at the same time as evaluating the tunnel liner condition.

Output

- Technical Assistance
  - Technical meetings with States (how many and which ones)

    Technical assistance meetings were held with all of the Round 4 states, and most of the Round 7 states. For Round 4, the technical meetings and training occurred in a single site visit, with typically a 2 day combination of office training and presentations followed field demonstrations and additional training in the testing methods available. The SME produced the content for all of the technical training events. The actual topics covered varied somewhat between the two states depending on the specific areas of interest each state had, but generally included an overview of the NDT methods available, how they were applied, what information could be obtained from each, and some ideas about relative speed and cost for each method.

    For Round 7, the training and presentations were updated to reflect the latest results available at the time of each training event. The events for Round 7 were typically done in a single day for each state, but still included an office portion followed by a shorter field demonstration.

    In addition to the formal technical assistance training and demonstrations, there was also SME support provided to the awardees in the form of RFP review, data review and discussion, report review, recommendations about technology applicability, etc. This support gave the states much greater confidence in both the deployment of choice of the methods as well as in the results obtained.

  - Technical Working Group conference calls and webinars

    One webinar was held that covered both R06A and R06G (Tunnel NDT). This webinar was held to introduce the R06 A and G products to new states prior to the start of Round 7. The webinar presented an overview of the test methods used on bridge decks as well as a summary of the results available at that time from the work of Round 4 states. The SME provided the technical content for the webinar, as well as presenting the technical material during the webinar.

  - Knowledge transfers/Peer-exchanges

    As part of the R06G product, there were two Showcase events held. One of these was in Pennsylvania and the other in Colorado. The details of these Showcase events are available in the Showcase Reports provided with the product deliverables, and are summarized below:

    Pennsylvania Showcase Overview

A SHRP2 Showcase event to highlight the results of *Nondestructive Testing for Tunnel Linings* (R06G) was held in Pittsburgh, Pa., on Sept. 14, 2016. The event, which was hosted by the Pennsylvania Department of Transportation (PennDOT), had over 65 participants from a number of state DOTs as well as vendors and others. The event featured educational presentations in the morning on tunnel evaluation and the specific results of tests in tunnels performed recently by PennDOT. The morning presentations were followed by a site visit by all attendees to the Liberty Tunnel for demonstrations of various scanning and point-by-point NDT technologies in the tunnel itself. The afternoon featured additional presentations, including a very interesting summary of Colorado Department of Transportation (CDOT)'s new Asset Management System for tunnels.

Colorado Showcase Overview

The SHRP2 Showcase event highlighting the results of *Nondestructive Testing for Tunnel Linings* (R06G) held in Golden, Colorado, on August 8-9, 2017, was hosted by the Colorado Department of Transportation (CDOT). Nearly 80 participants attended from 13 state DOTs as well as vendors, Colorado School of Mines (CSM) students and faculty, and others. The event featured a full day of informative presentations on tunnel evaluation and the specific results of tests in tunnels performed by CDOT and Pennsylvania Department of Transportation, (PennDOT) as well as overviews of the SHRP2 program and a presentation on CDOT's new Asset Management System for tunnels. The second day was a field trip where participants were bused directly to "Tunnel 4", an off-system tunnel owned by CDOT without traffic. At the tunnel, there were demonstrations of various scanning and point-by-point NDT technologies on the tunnel liner including hand held and scanning Ground Penetrating Radar (GPR), Infrared (IR), and Impact Echo (IE). After lunch at Tunnel 4, the trip continued to the Eisenhower/Johnson tunnels on I-70 at the continental divide for guided tours of the tunnel facilities there.

- Field Activities
  - Demonstrations
    - The field activities for the R06G product primarily consisted of live demonstrations of selections of the various test methods available for evaluation of tunnel liners (and other tunnel components such as slabs and portals). The actual methods demonstrated depended on the individual states and their needs. In some cases, actual data was collected and analyzed for a portion of a specific tunnel to allow the state to see "real" data on a typical tunnel liner. This was done in Colorado, for instance, on an off-system tunnel to demonstrate the Ground Penetrating Radar (GPR), Impact Echo (IE) and Infrared (IR) methods as applied to tunnel liners.
    - Some additional field work was also conducted for Round 4 states to support their implementation activities. Part of this additional field work by the SME was to document (via video and photo) the implementation activities of the two Round 4 states. In addition, extensive technical assistance was provided where needed to allow a higher degree of confidence in the collection and interpretation of the data as well as improve the utility of the results in overall tunnel condition assessment.
- Ad hoc Activities
  - Community of Interest activities

    As part of the overall R06G effort, the SME prepared a number of presentations that were given at public events such as conferences. These included annual TRB meetings and other events. A list of the specific events attended where presentations were made is shown below:

    - Transportation Research Board (TRB), 2016
    - LIDAR mapping Forum 2016
    - American Society for Nondestructive Testing, SNT 2016
    - Transportation Research Board (TRB), 2017
    - Transportation Research Board (TRB), 2018

Outcomes

The major outcome of the R06G program was the education of state DOT's in the advantages and best use of various NDT methods in tunnel evaluations, as well as the optimization of the tunnel evaluation tools and methods. The Colorado DOT also developed a detailed asset management tool that allows the input of NDT information into maintenance decisions. A summary of the R06G work in each state along with a summary of the results and planned future efforts is presented below by Round and state.

Round 4 States

Colorado:

Colorado participated in both Round 4 and Round 7 of the R06G product, and also hosted a Showcase event. They conducted testing primarily with the IR method but also did scanning with liDAR for their R06G effort. In addition, CDOT developed a Tunnel Asset Management system using a spread-sheet based approach to allow them to integrate tunnel NDT data with other information such as element cost, expected lifetime, criticality, etc. to come up with a long-term planning tool for use in planning maintenance and replacement activities. One aspect of the asset management tool was the idea of managing tunnel assets by the element within the tunnel rather than by the overall tunnel itself. CDOT ended up with a sortable excel spread sheet that lists all their tunnel assets and informs Tunnel Asset Management Decisions, a program that uses inputs from NTIS inspection data and can also use NDT data.

As part of CDOT's overall efforts to perform effective rapid tunnel liner scanning, they first conducted several studies of how temperature affects the performance of IRT investigations on tunnel liners and how to work around the limitations that were found in the PennDOT studies previously conducted. They used thermocouples mounted on a tunnel liner as well as in the air in the tunnel to measure the temperature differential to determine the optimal conditions for IR evaluations. CDOT and their vendor, SAM, found that using a more sensitive (<20mK) IRT camera with a cooled sensor resulted in obtaining higher-quality and usable IRT data on tunnel liners, and allowed the method to work even with the smaller temperature differentials found in tunnels. They also looked into the effects that the time of day or seasonal factors in determining the best time to collect useful IRT data. Finally, they looked at the effects of air flow/powered venting had on the effectiveness of IR data collection. The LiDAR method was used to map the interior of tunnel liners, to evaluate the shape and inner surface of the tunnel liner. This information can also be used for crack mapping to establish a baseline for comparison to future evaluations to see if movement or other distortions of the liner have occurred.

The final outcome of the CDOT testing was a number of 2- and 3-D image maps of a number of tunnel liners, with the maps showing areas of apparent delamination of shotcrete, water seeps, and other issues. The data was correlated to known defects. In one location, a shotcrete failure that occurred after the testing was complete (but before the data was processed) was indeed visible in the IR data. Testing was able to be collected at 35 to 40MPH in the tunnels, which allowed the use of rolling closures rather than full lane closures.

Future Plans:

CDOT has plans to continue to use this technology in their many tunnels, as well as continuing to use the asset management system they developed. Their testing vendor, SAM, has developed a way to use virtual reality viewers to allow a vendor such as the DOT to view the tunnel IR and LiDAR data in true 3-D form, including looking around at features and anomalies, close-ups, moving through a tunnel, etc. all in an office setting using the detailed data collected.

Pennsylvania:

The Pennsylvania DOT had an on-site training and demonstration event by the SME, then conducted NDT investigations on two tunnels as part of the R06G effort, and finally hosted a Showcase event. The evaluations were conducted on the Liberty and Armstrong tunnels. The tunnels were evaluated by a number of both scanning and hand-held techniques by various vendors including Penetradar, SPACETEC/AID, and Mackin. Included in the testing program were scanning evaluations with GPR, IR, and high-speed photogrammetry as well as detailed evaluations at selected locations using IE and hammer sounding for comparison to the scanning evaluations.

The final results from the scanning were depicted in a color-coded picture of areas that showed apparent areas of moisture, delamination, voids and other issues. These were then compared to known location spots and distances of known damage with a relatively close correlation. One recurring theme from the testing was that the IR (infrared) method is difficult in tunnels due to the lack of a temperature differential in many areas.

The conclusions from the field testing included:

- GPR was effective but shallow delaminations less than an inch deep were difficult to detect. GPR cannot be used on steel liners or steel reinforcement. GPR was found to be reliable in confirming sound areas and locating moisture intrusion areas.
- The IR technology used by AID was effective at detecting moisture related defects. The LiDAR technology produced a detailed summary of locations and sizes of cracks. These techniques are not capable of detecting defect through the liner thickness.
- There is still a need for some form of physical inspection to support NDT inspections.
- Once the baseline data is completed, the follow-up scanning NDT work becomes much more cost competitive with traditional methods.
- There is a need to correlate the NDT results with the repair recommendations needed.

As part of the tunnel field work, representatives of the SME were on site to take photographs and video of the field testing as well as to take notes on testing speeds and other aspects.

Future Plans:

Pennsylvania has some plans to continue using NDT, but more likely on a program-level basis, rather than for specific inspection treatment recommendations. They understand that the costs may be prohibitive to do this every two years (in conjunction with NTIS inspections), so basic hammer sounding may be more cost effective.

Round 7 States

Colorado:

Colorado participated in both Round 4 and Round 7. Their Round 7 work was a continuation of the work done in Round 4, with additional tunnels scanned with IR and LiDAR methods. They also improved the methods of processing and presenting the large data sets created from IR and LiDAR evaluations as part of the Round 7 work.

California:

CALTRANS has a long history of using various NDT methods as part of their bridge, utility, and roadway maintenance programs. For the SHRP2 effort, they combined funding from several SHRP2 programs (R01B, R06A, R06D, and R06G) to purchase a 3-D radar multi-channel antenna GPR scanning system. This system has been mounted into a vehicle with a redundant distance tracking system to allow scanning of pavements and bridge decks for thickness, integrity, rebar, utilities, and other elements. In addition to the GPR system, CALTRANS also purchased an IE system for use on bridge decks and tunnels for project level condition evaluation. The GPR system purchased can be used currently on decks in tunnels, but will need some modification in the mounting system to allow tunnel liner evaluation.

Future Plans: CALTRANS plans on using the GPR system for high-speed program-level evaluations of concrete decks inside of tunnels, and has some plans for the future fabrication of an articulating mount to allow the system to be used for tunnel liner evaluation.

Virginia:

An investigation was carried out by Virginia DOT using subcontractors to evaluate the condition of the tunnel walls and roadway deck of the Hampton Roads Tunnels, which carry I-64 and span the Chesapeake Bay in Norfolk, Virginia. The tunnel wall evaluation was carried out using a 2-phased approach, with Phase 1 consisting of rapid scanning of the tunnel walls using high-resolution video (HRV) and Infrared Thermography (IR) while Phase 2 consisted of targeted acoustic (impact echo and hammer sounding) and ground penetrating radar (GPR) testing

on selected tunnel wall locations. In addition to the tunnel walls, the tunnel roadway deck was also evaluated using NDT by using 3D GPR (similar to tests done on bridge decks for the R06A product). The information provided by this testing was used by Virginia Department of Transportation to augment their routine inspection efforts.

The tunnel wall scans were conducted by a vehicle mounted system, with each wall surveyed using a single driving pass (two-passes per tunnel). The GPR survey of the roadway deck of both tunnels was performed in accordance with ASTM D 6087-08 using a 3D Radar step-frequency array system mounted to a vehicle in a series of 3 passes per lane at approximately 40-mph.

One interesting finding was that at the start and end portals of each tunnel, the 3D-Radar antenna picked up radio transmission interference (from external sources) severe enough that it could not be filtered out. As a result, a portion of the start and end of the tunnel deck survey was not analyzed.

The Phase 2 data was collected to validate and augment the Phase 1 tunnel wall condition evaluation. The data collection included the use of impact echo (IE), and ground coupled GPR,

The results of the nondestructive tunnel evaluations were presented as condition maps using the combination of IR, HRV ground-coupled GPR, IE to evaluate the condition of the tunnel walls; and 3D GPR to evaluate the condition of the tunnel decks.

Based on the data collection and analysis efforts carried out for this project, VADOT was able to draw the following conclusions:

- The IE correlated with the Phase 1 infrared results at 79.7% of the test locations.
- The IE correlated with the “calibrated” (and final) IR results at 86.3% of the test locations.
- The ground-coupled GPR testing carried out as part of Phase 2 was found to correlate to the IE results at 68% of the IE test locations. A majority of the IE tests that did not correlate with the GPR were “false negatives” where the IE response was indicative of “sound” concrete in an area where the GPR was detecting possible deterioration. The GPR is likely detecting precursor conditions in these areas (likely due to high chlorides that may cause future issues but are not causing cracking yet).
- Low thermal differential was the limiting variable when analyzing the IR data within the tunnel. The length, insulation, and consistent air exchange by the ventilation system, resulted in a near homogenous temperature profile within each tunnel.
- Ventilation and electrical systems create artificially cool or warm areas that were a source of a large number of false positive IR targets included in the Phase 1 results.
- Given the low thermal contrast in the tunnels, it is recommended that future evaluations include more GPR testing of the tunnel walls. GPR provides a direct measurement of the materials within the walls.
- GPR provides an objective measurement of the rebar conditions
- The HRV surveys produced a clear visual representation of the tunnel walls, which can be used to augment the routine inspections.

Future Plans:

VDOT was able to collect very useful data on the tunnel lining and has plans to use GPR for additional future inspections as well as the HRV survey data for comparison in subsequent surveys. They are unlikely to IR in future tunnel surveys due to the same issue that Pennsylvania and Oregon ran into with the limited sensitivity of lower-cost IR cameras resulting in little or no usable condition information.

Oregon:

Oregon DOT participated in the Round 7 tunnel work. For their R06G effort, they used IR and GPR on a single tunnel (Vista Ridge). They subcontracted out the work to Penetradar to conduct IR, GPR, and high-resolution video scans on the tunnel to evaluate the tunnel liner conditions. The results obtained were mixed – the IR method did not appear to provide much usable data on the tunnel liner conditions other than locating water

seeps and for areas near the portals (where air temperature contrasts were greater compared to the central tunnel areas). The GPR data, however, was used to determine condition and was also able to identify the presence and location of timber sets at the portal areas of the tunnel and also appeared to locate voids behind the tunnel liner (not verified at the time of this report). The GPR data was also used to look for debonded tiles, and did indeed identify areas of apparent delamination, but it was not clear if the delaminations were right behind the tiles or were deeper.

The GPR testing conducted was found to be most useful for locating features inside the concrete liner and for voids behind the concrete liner. It was also able to map out the geometry of the rebar mat and verify the presence and depth of the mat. The high-resolution video was less useful than expected due to lighting issues and resolution issues.

Future Plans:

Oregon DOT may use the GPR method for some future tunnel evaluations, but has no plans to use IR for further tunnel testing at this time due to the issues with sensitivity found in the tests conducted. The limitations with GPR included slow setup and calibration times for the hardware being used, and difficulty in interpreting the data. They do plan to look at more of the features identified in and behind the tunnel liner when time permits, to see how well the GPR data correlates to actual conditions found.

Other Recommendations for Future Activities and/or Programs

At the R06G Showcase events, a majority of the states who have tunnels in their inventory participated in the event. One outcome of the Showcase events was a listing of current concerns and areas of future development desired by various state entities to further the use of NDT in tunnels. The full lists can be seen in the showcase reports attached to this report, but a summary of the most common issues includes:

- Verification of the validity of the results
- Verification and research into the effectiveness of the test methods in tunnels
- Actual costs of point by point as well as scanning NDT for Tunnel Linings in various scenarios
- How to process NDT results to effect recommendations for repair
- Recognizing within the NDT results where EMERGENCY repairs might be needed
- How to correlate over time when tested areas are changing from one inspection to the next
- Relative safety of scanning NDT inspections versus traditional inspection methods
- Data assessment of the elements in the asset management software
- How to bring new technology to a DOT.
- Determination of what NDT tools work best in what situation.
- Using Traffic and Detour strategies.
- Using this info going forward for input into NTIS-required inspections and tracking of asset condition.
- Employee skills needed to accomplish in-house testing.

Similar to one important outcome from the R06A (NDT of Bridge Decks product), one of the most common concerns was for the development of standardized language for RFPs and contract documents, to make sure that the deliverables provided at the end meet the actual needs of the state agency requesting the work. This was coupled with a common concern as to the best way to select vendors for NDT services.

Benefits

The R06G product was planned to provide states with funding to implement known-effective NDT methods that had previously been researched and determined to be effective for tunnel and tunnel liner evaluations. The final results of the Round 4 and Round 7 implementation show that the effective use of NDT in tunnel evaluation is not

the same for all states and also showed the advantages and limitations of the various NDT methods used. One of the major outcomes of the product was a much better understanding of the use of the IR test method for tunnel liner evaluations. Both Oregon and Pennsylvania had issues with the IR method due to the relatively small temperature differential seen in the air inside a tunnel compared to the liner. Colorado, however, recognized these issues (from looking at the previous efforts of PennDOT) and put a significant amount of effort into determining the best way to get usable data from an IR study of a tunnel liner. The outcome of this was very encouraging, as they were able to use very high resolution, cooled IR cameras to get usable data from tunnel liners to identify potential delaminations and other issues.

One area where expectations and outcomes did not always match was in the speed of testing for tunnels. The GPR method, in particular, took longer to scan a tunnel than initially expected. This was found to be due primarily to the geometry of tunnels, as well as the presence of various assets suspended from the roofs or walls of tunnels such as signs and lighting systems. The presence of these interferences required the use of single-antenna systems that had to be aligned with each pass to test only a small portion of a tunnel liner while avoiding the various interferences present. The variability of tunnel liner diameters (such as portal versus central areas) also slowed down the GPR testing. Conversely, the IR and optical (LiDAR and Photogrammetry) tests were found to be able to be done at near-highway speeds and could be done in 1-2 passes (depending on the tunnel size). The detailed methods such as IE required lane shutdowns, of course.

Appendix A - Attendee Lists

Pennsylvania Showcase Event

I am participating as a	Last Name	First Nam	Organization/Agency	Title	Office Pho	Email Address
Partner Agency (FHWA/AASHTO/TRB)	Bush	Patricia	AASHTO	Program Manager	202624818	pbush@aashto.org
State DOT participant	Shaw	Jason	Alabama Department of Transportatoin	Maintenance Engineer	(251) 978-	shawj@dot.state.al.us
State DOT participant	Christie	Eric	ALDOT	State Bridge Maintenance Engineer	334 242-62	christiee@dot.state.al.us
Other Allegheny County DPW	Burdelsky	Mike	Allegheny County Department of Public Works	Project Manager	412-350-5	mburdelsky@alleghenycounty.us
Other County Govt.	Connors	Richard	Allegheny County Dept. of Public Works	Chief Bridge Engineer	412-350-6	richard.connors@alleghenycounty.us
Other ARA	Chesnik	Kevin	ARA	Principal Engineer	608-692-7	kchesnik@ara.com
State DOT participant	Tedrow	David	Colorado Department of Transportation	Tunnel Asset Manager Region 3	303512561	david.tedrow@state.co.us
State DOT participant	Weldon	Tyelr	Colorado Department of Transportation	Maintenance Enginner	303-512-5	tyler.weldon@state.co.us
State DOT participant	Sardinas	Alberto	FDOT District 4	Structures and Facilities Maintenance Section Manager	(954) 777-	alberto.sardinas@dot.state.fl.us
Partner Agency (FHWA/AASHTO/TRB)	Blades	Douglas	FHWA	Structural Engineer	202-366-4	douglas.blades@dot.gov
Partner Agency (FHWA/AASHTO/TRB)	Buck	Jon	FHWA	Bridge Engineer	717-221-4	jonathan.buck@dot.gov
Partner Agency (FHWA/AASHTO/TRB)	Mento	Tony	FHWA	Director of Technical Services	717-221-3	tony.mento@dot.gov
Partner Agency (FHWA/AASHTO/TRB)	Bergeson	William	FHWA-HIF/HIBS	Senior Tunnel Engineer	202-366-4	william.bergeson@dot.gov
Other Consultant	Terry	Kyle	Mackin Engineering	Structural Designer	412788047	kterry@mackinengineering.com
Other consultant	Brophy	Ed	Mackin Engineering Company	Director of Field Operations - Bridge Inspection	412 788-04	ebrophy@mackinengineering.com
Other Consultant	Mackin	Dean	Mackin Engineering Company	CEO	412-788-04	dmackin@mackinengineering.com
Other Consultant	Miller	Bradley	Mackin Engineering Company	Chief Structural Engineer - Inspections	412-788-04	bmiller@mackinengineering.com
Other consultant	Nath	Steven	Mackin Engineering Company	E.I.T.	412-788-04	snath@mackinengineering.com
Other Consultant	Stadtfeld	Wallace	Mackin Engineering Company	Senior Structural Designer	412-788-04	wstadtfeld@mackinengineering.com
State DOT participant	Williams	Dan	Maryland Transportation Authority	Chief Engineer	410-537-7	dwilliams1@mdta.state.md.us
State DOT participant	Wolfe	Brian	Maryland Transportation Authority	Bridge/Tunnel Manager	410-537-7	bwolfe3@mdta.state.md.us
State DOT participant	Parker	Paige	MassDOT	Tunnel Contracts Engineer	617308942	paige.parker@dot.state.ma.us
State DOT participant	Rigney	Joseph	MassDOT	Tunnel Engineer	857-368-9	Joseph.Rigney@dot.state.ma.us
Other MTA Bridges and Tunnels	Salah	Samir	MTA Bridges and Tunnels	Assistant Director - Bridges and Tunnels Inspections Programs	212-360-2	ssalah@mtabt.org
State DOT participant	Renman	Gregory	NJDOT	Manager	609-530-3	greg.renman@dot.nj.gov
State DOT participant	Tintle	Douglas	NJDOT	Principal Engineer	609-530-5	douglas.tintle@dot.nj.gov
Other SME	Sack	Dennis	Olson Engineering	Principal Engineer	303423121	dennis.sack@olsonengineering.com
Other State Commission	Slippey	Kenneth	PA Turnpike Commission	Sr. Engr. Project Mgr.	717 831-75	kslippey@paturnpike.com
Other Demonstration	Alongi	Anthony	Penetradar Corporation	President	(716) 731-	sales@penetradar.com
Other Demonstration	Stang	Anthony	Penetradar Corporation	Engineer	716-731-4	stang@penetradar.com
Other Demonstration	Vogt	James	Penetradar Corporation	Field Operations Manager	716-731-4	vogt@penetradar.com
State DOT participant	Carrier	Ethan	PennDOT	Bridge Asset Management	412429489	etcarrier@pa.gov
State DOT participant	Macioce	Tom	PennDOT	Chief Bridge Engineer	717783761	tmacioce@pa.gov
State DOT participant	DeVore	Ben	PennDOT 11-3	Tunnel Manager	412-292-8	bdevore@pa.gov
State DOT participant	Moses	Jonathan	PENNDOT Dist. 11-0	Asst. District Bridge Engineer	412-429-4	jmoses@pa.gov
State DOT participant	Ciesa	Chris	PennDOT District 11	Bridge Asset Management Supervisor	412-429-4	cciesa@pa.gov
State DOT participant	Lloyd	Cassie	PennDOT District 11-0	Bridge Analysis Supervisor	412-429-2	caslloyd@pa.gov
State DOT participant	Peng	Allen	PennDOT District 11-0	Civil Engineer - Bridge	412-429-4	apeng@pa.gov
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State DOT participant	Ruzzi	Lou	PennDOT District 11-0	District Bridge Engineer	412-429-4	lruzzi@pa.gov
Other Pennsylvania Turnpike Commission	Boyer	John	Pennsylvania Turnpike Commission	Engineer Project Manager 2	717-831-7	jboyer@paturnpike.com
Other Transportation Agency	Stump	James	Pennsylvania Turnpike Commission	Bridge Engineer Manager	717 831-71	jstump@paturnpike.com
Partner Agency (FHWA/AASHTO/TRB)	Kladny	Stephen	Port Authority of Allegheny County	Senior Project Engineer	(412) 566-	skladny@portauthority.org
Other Owner's agent	LaBella	James	Port Authority of Allegheny County	Project Manager	412-566-5	jlabella@portauthority.org
Other Port Authority	O'Hare	Greg	Port Authority of Allegheny County	Assistant Director	412-566-5	go'hare@portauthority.org
Other Port Authority of Allegheny County	Thiry	Bob	Port Authority of Allegheny County	Sr. Project Engineer	412-566-5	RThiry@PortAuthority.org
Other Port Authority of NY&NJ	Dagher	Camille	Port Authority Of NY & NJ	Project Manager	201-395-3	cdagher@panynj.gov
Other AID	Wittwer	Andreas	Spacetec	Dr	732648900	andreas.wittwer@spacetec.de
Other Consultant	Salamon	Mike	Stantec - Denver, CO	Senior Transportation Specialist	303-758-4	michael.salamon@stantec.com
Other Service Provider, Supporting CDOT on SHRP2	Treon	Mark	Survey and Mapping LLC	Project Manager	303-716-8	mtreon@sam.biz
State DOT participant	Ilk	Ron	Surveying And Mapping, LLC	Transportation Market Leader, Survey	303-988-5	rilk@sam.biz
State DOT participant	Paulson	Steven	Tennessee DOT	Transp spec supervisor	615887480	steven.paulson@tn.gov
State DOT participant	Tays	Jason	TN Dept of Transportation	Operations Supervisor 1	423634751	jason.tays@tn.gov
Other Teresa D. Morales, P.E.	Morales	Teresa	USFS -- Northern Region	Regional Geotechnical Engineer/Program Leader	406.329.32	teresadmorales@fs.fed.us
State DOT participant	Balakuma	Soundar	VDOT	Dr.	434293190	soundar.balakumaran@vdot.virginia.gov
State DOT participant	Godsey	Lee	Virginia Department of Transportation	Ancillary Inspection Section Manager	804786617	lee.godsey@vdot.virginia.gov
State DOT participant	Cook	Phillip	West Virginia Division of Highways	Mr	304558975	phillip.j.cook@wv.gov
State DOT participant	Park	Patrick	WVDOT	Highway Engineer	304558945	Patrick.C.Park@wv.gov
Replaceing Joshua Keyser	Orozco	Pablo				

Colorado Showcase Event

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Peer Exchange - Portland, Oregon

SHRP2 Non Destructive Testing for Bridge Decks (R06A) Peer Exchange - Portland, Oregon January 30-31, 2019			
First Name	**Last Name**	**Organization/Agency**	**Email Address**
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SHRP2 Non Destructive Testing for Bridge Decks (R06A) Peer Exchange - Portland, Oregon January 30-31, 2019			
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Appendix B - Evaluation

What were the most important ideas you learned from the showcase?

NDT Technologies/ GPR Accuracy
The benefits and limitations of the technologies
Advantages vs. Limitations of various NDT technologies.
How other DOTs are approaching these issues
The products in general
Info that each of the various NDT methods can provide.
How and when to implement different technologies.
Limitations of each technique. There is no one best technique for projects.
Current state of technologies.
How testing is not a replacement for hands on methods.
Learn to evaluate and look into utilizing these NDT technologies into new projects.
Where we are currently with NDT and where we can go with it.
Networking.
What we would get out of the NDT tools.
The different methods of NDT in tunnels, when they are best used and how they will help us in inspection in the future.
The need to condition the tunnel for the testing of NDT compatibility
The available technology for tunnel testing.
Overall I have a positive position or I support the implementation of this type of field inspections
Life expectancy of (?) using CS of elements
Utilizing technology to solve infrastructure management problems.
SHRP2 approaches & functions, GPR for tunnel linings, IRT issues in tunnels.
CDOT experience was most informative.
Targeting what you are hoping to detect with the appropriate testing device.
Introduction to the newest technology for NDT of tunnels as well as other applications.
There's a very quantitative way of analyzing a tunnel.
That there is no silver bullet for NDT, each has its own strengths and weaknesses.
Importance of good quality equipment like the cryogenically cooled IR cameras.

Are there questions or issues you wished the showcase had addressed that it didn't?

How the products relate more with the inspection aspect of tunnels.
Some additional hands-on with the smaller, more localized NDT technologies available (as opposed to truck-mounted).
The differences in thermal concerns and when to use which cameras.
Demo needed to be more organized.
Application of tools as it relates to NTIS.
Yes.
Not really.
The field lesson did not work out too well. It was too loud and couldn't see/hear the presentations of the equipment.
Opportunities for funding, to implement these technologies

A brief overview of technologies and the differences would help. Also, only heard of 2 tunnels – but it sounded like there were more.

What else could the Federal Highway Administration do to support you or your agency in learning more about SHRP2 *Nondestructive Testing for Tunnel Linings*?

The field demo could have been a lot better.
Make reports readily available./ Provide reports of the studies done.
Will need funding for the NDT equipment./ Opportunities for funding, to implement these technologies
Continue Hosting Workshops and providing presentations & publications online.
Produce a report of combined findings between Penn DOT and CDOT.
Publish results of ongoing SHRP2 projects.
More info on what other states are using to meet NTIS requirements.
The next showcase.
Email blasts, website, webinars, technology updates
Doing an excellent job.
A comparison study of a tunnel between two inspections
Nothing more at this time.
Possibly show success stories in the future (where NDT caught something hands on or inspections missed)
Have more field testing.
Sharing the reports from the study will be helpful, or an executive summary.

How might AASHTO further support you or your agency in learning more about SHRP2 *Nondestructive Testing for Tunnel Linings*?

N/A
Make reports readily available.
I would greatly appreciate the opportunity to attend the next workshop in Colorado, even if similar topics are covered. It sounds like the field portion at CDOT (in the closed tunnel) will help solidify what was discussed (Doug Tintle – NJDOT)
More info on what other states are using to meet NTIS requirements.
Email blasts, website, webinars, technology updates/ place info into publications.
Show how it will benefit and compare against current manual inspections.
Continue with similar showcases.
Provide more info online.

Please provide us with additional comments, feedback, or ideas related to this event or future SHRP2 events:

Overall a decent showcase. Could've been organized better but understandable circumstances prevented that. Not much could be done.
The large group size made the field position difficult to absorb. Multiple sessions or smaller divided groups in the field would be more beneficial if possible.
I found this event to be very worthwhile and beneficial to the attendees.
State presenters were good.
Eliminate presentations which contain redundant information to allow for greater discussions.

I am probably the wrong person to ask due to my inexperience with the technologies and tunnel inspection in general. That said, **I think it should be dumbed down for the first hour or so to give very basic details of the different agencies governing bodies, inspection requirements, basics of technologies and a handout of acronyms and subject specific definitions.**

The field testing seemed a bit disorganized as there was a lot of waiting and it was very hard to hear any of the explanations with the traffic and large groups.

Appendix C - Meeting Agendas

SHRP2 *Nondestructive Testing for Tunnel Linings* (R06G) Showcase Event
Pennsylvania DOT Tunnel Showcase
Agenda

Wednesday, September 14, 2016

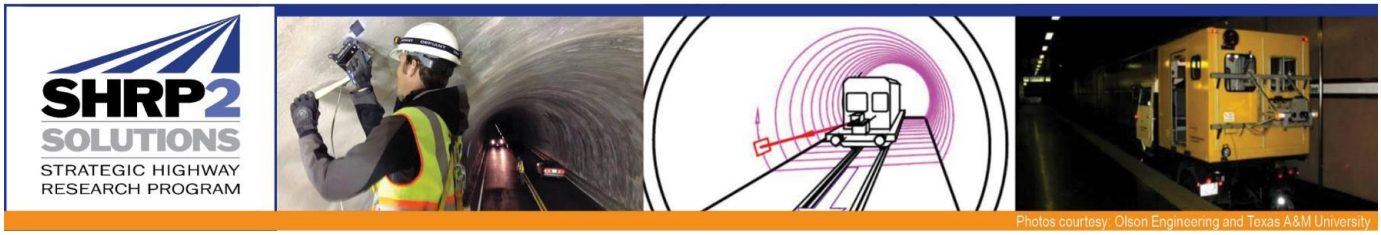
Please join us for a Showcase presentation of the latest SHRP2 Nondestructive Testing Techniques for Tunnel Linings

PLEASE NOTE THE SCHEDULE HAS CHANGED!!

Sheraton Pittsburgh Hotel at Station Square
300 W Station Square Dr, Pittsburgh, PA 15219
Haselton Room

Time	Topic	Speaker
7:30 am- 8:00 am	**Meeting Registration**	
8:00 am- 8:30 am	**Welcoming Remarks**	
	• PennDOT/T-20 • FHWA PA Division • AASHTO	Lou Ruzzi, PennDOT, District 11 Bridge Engineer Bill Bergeson, FHWA Senior Tunnel Engineer Pamela Hutton, AASHTO, SHRP2 Implementation Manager
8:30 am – 9:00 am	**Program Updates**	
	• SHRP2 Program Update • NTIS Update	Patricia Bush, AASHTO SHRP2 Product Lead Doug Blades, FHWA Structural Engineer
9:00 am – 9:30 am	**SHRP2 *Nondestructive Testing for Tunnel Linings***	
	• Background info on TRB- SHRP2 Research and Research and Deployment Overview	Dennis Sack, Olson Engineering, Sr. VP/Principal Engineer,

9:30 am – 11:00 am	**PennDOT SHRP2 Tunnel NDT Program**	
	• PennDOT Tunnel Inspection/Asset Management Overview • PennDOT NDT Field Evaluation Overview • AID Spacetec/PSPA Implementation Overview • Penetradar IRT/ACGPR/Video Implementation Overview	Lou Ruzzi, PennDOT, Dist. 11 Bridge Engineer Brad Miller, Mackin, Chief Structural Engineer Kaz Tabrizi, AID, Exec. VP, Anthony Alongi, Penetradar, President
11:00 am – 11:30 am	**Break and Board Buses**	
11:30 pm – 1:30 pm	**Move to Field Demos**	
12:00 pm – 1:00 pm	• Spacetec (LiDAR/IRT/Photography)/PSPA – AID • ACGPR/IRT – Penetradar • Photogrammetry – Tonon USA • LiDAR/IRT – SAM Engineering • Hand-held Technologies – Olson Instruments • IRT Cameras – FLIR • 3D MCGPR – 3D Radar • On-Site Wrap Up/Final Questions	All participants
1:00 pm – 2:30 pm	**Ride Buses Back to Hotel and Lunch**	
2:30 pm- 4:00 pm	**CDOT SHRP2 Tunnel NDT Program** • CDOT Tunnel Inspection/Asset Management Overview • CDOT LiDAR/IRT Scanning Evaluation Program	Tyler Weldon, CDOT, Tunnel Asset MgrRon Ilk or Mark Treon, SAM Engineering
4:00 pm – 4:30 pm	**Group Discussion**	
4:30 pm – 5:00 pm	**NDT Applications** • Extracting Value from NDT Applications – NDT Results to Asset Management to NTIS	Dennis Sack, Olson Engineering, Sr. VP/Principal Engineer
5:30 pm	**Optional Dinner at Bar Louie** **240 W Station Square Dr, Pittsburgh, PA 15219**	



SHRP2 *Nondestructive Testing for Tunnel Linings* (R06G) Showcase Event
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Agenda

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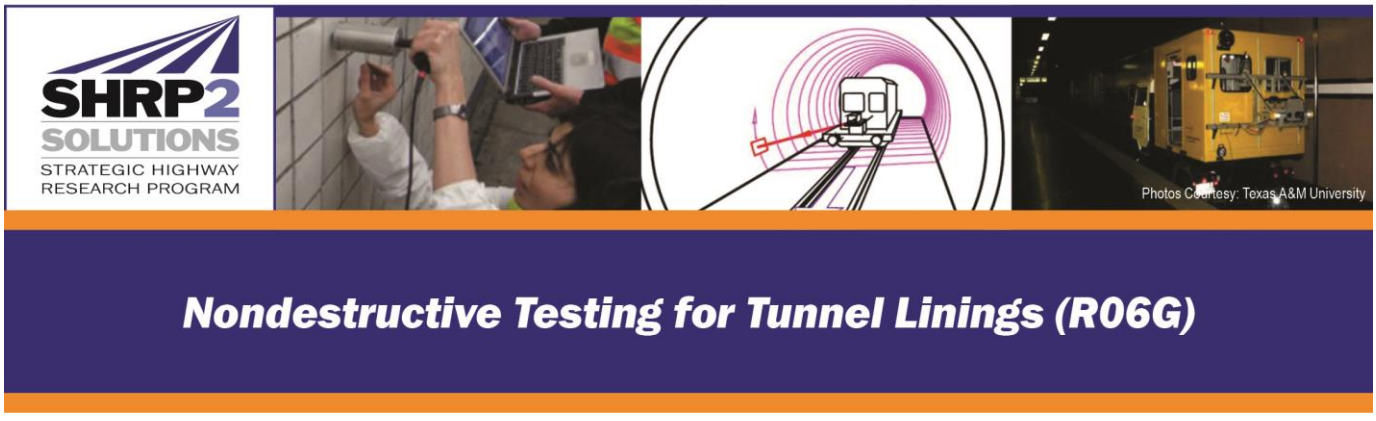

Implementation Support Meeting *Colorado Department of Transportation*		
Day One		
Length of Meeting	**AGENDA**	**Speakers**
8:30-10:30	**Meeting with Implementation Contacts**	
	1) Introductions – Day 1 • Short intro for all DOT, Olson, FHWA, and other attendees • Overview of Agenda • Introduction to SHRP2 Round 4 IAP Program 2) Problem Statement and Current Assessment Techniques for Tunnel Evaluation • Problem statement/scope of NDT application/potential benefits, etc. • DOT Discussion of state tunnel types and lining materials (what range of tunnel types the state currently has) 3) Common tunnel deterioration modes (with typical photos) 4) Overview of the SHRP2 TTI Research Product – NDToolbox for Tunnel NDT • SHRP2 Nondestructive Testing for Tunnel Linings (R06G) – NDT research efforts on tunnels overview, discussion of why NDT – beyond current methods such as sounding discussed above – can add significant value • Additional NDT methods not included in the TTI study • Discussion of mobile/hand-held options for tunnel evaluation • Discussion of the range of information that is desired/needed ***(15 minute break)***	Matt DeMarco - FHWA Larry Olson Larry Olson/DOT Personnel Dennis Sack Larry Olson/Matt DeMarco

10:30-12:00	**Meeting with Implementation Contacts (cont.)**	
	5) Nondestructive Evaluation Techniques for Tunnels (Part I – Mobile/High Speed Methods) • SPACETEC System including infrared thermography • Air-Coupled GPR • LIDAR/Laser based systems • Photogrammetry • Discussion ***(60 minute lunch break @12:00 pm)***	Dennis Sack
1:00 – 4:30	**Meeting with Implementation Contacts (cont.)**	
	6) Nondestructive Evaluation Techniques for Tunnels (Part 2 – Hand-Held/Low Speed) • Impact Echo and Hammer Sounding • Impulse Response • Ground Penetrating Radar (Ground Coupled) • Infrared Thermography (hand-held) • Spectral Analysis of Surface Waves ***(15 minute break)***	Larry Olson
	Demonstrations - Impact Echo, Ground Coupled GPR, Impulse Response, Infrared Thermography, Surface Waves	

Day Two		
8:30-12:00	**Meeting with Tunnel Management Section and Program or Project Development Office**	
	1) Introductions – Day 2 2) Current Practice of the State – State 3) Integrating NDT Test Results to a Tunnel Management System – Olson Eng. 4) Assist the State in Identifying Technology(ies) and in Database Development • Typical Summary of NDT data types required by DOT users (refined data, summary metrics (e.g., % spalling, % reinforcement corrosion, etc.), data presentation needs) • Candidate NDT technologies to deploy under R06G for evaluation for long-term DOT use • Deployment strategies – tiered inspection cycles based on ADT/tunnel class, use of mobile vs. hand-held, etc. • Acquisition strategies – service provider/ownership; contracting strategies for R06G vs. long-term application • Specification requirements and assistance available • Data acquisition details – what's required by the DOT to support data acquisition • Data management/access to users • User support – inspection, maintenance, asset management data access and use; decision-making criteria; asset planning 5) Other Topics - Adjourn @ noon	Larry Olson/Matt DeMarco Larry Olson/DOT Personnel Larry Olson/Matt DeMarco/DOT Personnel