Background on the TRB-SHRP2 Research and Current Deployment Overview for Nondestructive Testing for Tunnel Linings (R06G) Implementation

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Tunnels in the United States

According to the Federal Highway Administration:

- **473+** highway tunnels in the national inventory (state and federal, including Puerto Rico) spread out across the nation

- **37 states** have at least 1 tunnel on a highway
  - California – 64
  - NPS - 64
  - Colorado – 38

Photos courtesy Wikipedia
Tunnel Evaluation

• New Tunnel Inspection Requirements are now in place for all DOT tunnels across the country with the National Tunnel Inspection Standard (NTIS)
• Clear inspection and reporting requirements, with new needs for high-speed inspection
High-Speed Mapping of Defects In or Behind Tunnel Linings (R06G)

Challenge
• Safely performing tunnel inspections in a High-traffic and confined work space

Solution
• Use proven NDT scanning technologies to evaluate tunnel linings more quickly and comprehensively.
• Results then directly coupled with an integrated Asset Management program
Background: Why Evaluate?

• Deterioration Happens –
  – Many deterioration mechanisms present
  – Many of the mechanisms are not obvious or visible during a cursory inspection
  – Some deterioration can lead to catastrophic failures

• Evaluate to identify, map out, and measure deterioration
Tunnel deterioration is a major maintenance problem for highway departments.

**Issues for Tunnel Liners:**
- Corrosion of Reinforcing Steel
- Moisture Intrusion
- Debonding/Delamination of Shotcrete and Tile
- Drainage System Failure
- Cracking of Concrete
- Deformations and Bulges
Efflorescence, Water Leakage (Mineral Deposits from Water Flow)
Efflorescence, Water Leakage with Cracking and Rust Staining (Rebar Corrosion)
Efflorescence/Water Leakage with Cracking and Rust Staining (Rebar Corrosion)
Cracking in Liner Concrete with Covered Void/Spall
Concrete Liner Cracking
Minor Moisture Intrusion and Cracking
Delamination of Shotcrete Coating
Minor Debonding of Surface Coating – Likely from Moisture
Concrete Delamination Seen in Corehole

Delamination Crack
Photogrammetry Image of Severe Liner Rebar Corrosion and Spalling
Wall Void from Embedded Timber
Geophones on Tunnel Crown for Void Detection Survey

Geophones Used for Shear Wave Velocity Survey to Locate Voids Above Liner
GPR Data Showing Likely Void Behind Concrete Liner (at Joint)
Debonded Tile on Liner (Shown with IR Scanning)
Missing Tiles (IR and Visual)
Panel Anchorage Failure

From NTSB Big Dig Failure Report
Tunnel Liner Deviations

LASER DATA DEPICTING 200M OF TUNNEL LINING

ANOMALY

TUNNEL LINING

Courtesy of CISI, Mexico
Degradation of Assets

Asset-Related Degradation Issues:

• Failing Lights/Fixtures
• Missing Assets
• Corrosion of Fixtures and Signage Supports
• Moisture in Wiring
• Plugged Drainages and Ice Buildup
Cracking, Moisture Intrusion with Rust Staining – Possible Fixture Asset Threat As Well
Initial Project Research Overview

**Research:** High-Speed Nondestructive Testing Methods for Mapping Voids, Debonding, Delaminations, Moisture, and Other Defects Behind or Within Tunnel Linings

**Available at:**

**Lead and Contributing Organizations:**
- Texas A&M Transportation Institute, College Station, Texas
- Texas A&M University, College Station, Texas
- The German Fed. Institute for Materials Research and Testing (BAM), Germany
- Roadscanners Oy, Finland
- The University of Texas at Austin

**Lead Principal Investigator, Project Director:**
Dr. Andrew Wimsatt
- Fund Amount = $1,650,000
- Project Duration: September 8, 2009 to January 31, 2013
This project had **five objectives**:

- To identify NDT relevant solutions
- To evaluate the candidate technologies
- Further develop promising technologies
- Validate technical performance
- Recommend deployment procedures
NDT Techniques included in the Original Research Study

Mobile Scanning Methods:

• Air-coupled ground-penetrating radar (GPR)
• Thermography (handheld thermal camera)
• SPACETEC scanner
• LIDAR Scanning
• Photogrammetry/Photographic
NDT Techniques included in the Original Research Study

Hand-Held or Static Technologies:

- Ground-coupled GPR
- Thermography (handheld thermal camera)
- Ultrasonic tomography (UST)
- Ultrasonic echo
- Portable seismic property analyzer (PSPA)
- Ultrasonic surface waves (USW)
- Impact Echo (IE)
Benefits of NDT Technologies

• Shorter and possibly fewer tunnel shutdowns during inspections, resulting in fewer detours.
• Safer for inspectors.
• Scanning tests provide 100% coverage.
  – LiDAR and Photogrammetry
  – Air Coupled GPR
  – Scanning Infrared
• Handheld devices to test areas in depth.
Chesapeake Channel Tunnel, located east of Norfolk, Virginia: The team collected NDT data in this tunnel in September and October 2011.
Eisenhower Memorial Tunnel, located west of Denver, Colorado: The team collected NDT data in the plenum area of this tunnel.
Hanging Lake Tunnel, located on I-70 west of Denver, Colorado: The team collected NDT data in this tunnel in October 2011.
No Name Tunnel, located on I-70 west of Denver, Colorado: The TTI team collected air-coupled GPR data in this tunnel in October 2011.
Washburn Tunnel, located under the Ship Channel east of Houston, Texas: The TTI team collected air-coupled GPR, ultrasonic tomography, and acoustic sounding data in this tunnel in September 2011.
Summary of the Significant Deliverables from the Project

Summary from the Ranking of NDE Techniques

- **NDToolbox - NDT Technology Electronic Repository**
  - [http://www.ndtoolbox.org](http://www.ndtoolbox.org)

**NDT Ranking Table Example**

<table>
<thead>
<tr>
<th>Device</th>
<th>Accuracy</th>
<th>Detection Depth</th>
<th>Deterioration Mechanisms Detected</th>
<th>Tunnel Lining Types</th>
<th>Other Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-coupled GPR</td>
<td>Locates defect within 1 ft of its actual location</td>
<td>Does not measure depth, but indicates areas of high moisture or low density (high air voids). Such areas may represent problems within or behind the tunnel lining.</td>
<td>Tile debonding, delaminations, air-filled voids, water-filled voids, moisture intrusion</td>
<td>Concrete, tile-lined concrete, and shotcrete</td>
<td>This is a scanning tool that can indicate where to conduct testing with in-depth devices.</td>
</tr>
<tr>
<td>Thermography (handheld thermal camera)</td>
<td>Locates defect within 1 ft of its actual location</td>
<td>Does not measure depth, but can indicate tile debonding, delaminations up to 1 in. and voids up to 3 in.</td>
<td>Tile debonding, delaminations, air-filled voids, water-filled voids, moisture intrusion</td>
<td>Concrete, tile-lined concrete, and shotcrete</td>
<td>This is a scanning tool that can indicate where to conduct testing with in-depth devices.</td>
</tr>
<tr>
<td>SPACETEC scanner</td>
<td>Locates defect within 1 ft of its actual location</td>
<td>Does not measure depth, but can indicate tile debonding, possibly delaminations up to 1 in. and possibly voids up to 3 in.</td>
<td>Tile debonding, delaminations, air-filled voids, water-filled voids, moisture intrusion</td>
<td>Concrete, tile-lined concrete, and shotcrete</td>
<td>This is a scanning tool that can indicate where to conduct testing with in-depth devices. Testing can only be conducted through a service contract.</td>
</tr>
<tr>
<td>Ground-coupled GPR</td>
<td>Can determine defect depth within 10% of the actual depth without reference cores — 5% if cores are available</td>
<td>Can possibly detect defects at any depth within or immediately behind tunnel linings. However, specimen testing indicates it cannot locate 1-sq-ft voids in steel plates behind tunnel linings.</td>
<td>Delaminations, air-filled voids, water-filled voids, moisture intrusion</td>
<td>Concrete, tile-lined concrete, and shotcrete</td>
<td>Experienced personnel are needed to interpret defect locations and depths from the GPR scans. Specimen testing indicates it cannot locate 1-sq-ft voids in steel plates behind tunnel linings.</td>
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Tunnels

Tunnel inspection is a challenging problem. Tunnels typically service high-volume traffic and operate in aggressive environments. Keeping tunnels open during inspection and minimizing tunnel closures and user delays must be carefully balanced with the need to conduct detailed inspections to ensure the safety of drivers. Hence, periodic inspection of highway tunnels to assess changes in structural condition over time is critical to timely detection and remediation of problems to ensure road user safety. Tunnel structural problems that are considered widespread and potentially serious are tunnel leaks, concrete cracking, concrete spalling, concrete delamination, debonding, void and defect formation, steel reinforcement corrosion, and improper drainage or moisture retention behind or within tunnel linings. Monitoring of tunnel condition and deterioration rate is key to determining the appropriate schedule of maintenance and/or rehabilitation activities to remedy structural and safety problems that might lead to accelerated deterioration and sudden tunnel failures that could cause serious injury and even fatalities.

This part of the NDT Toolbox provides information about applications, principles of operation, and performance of NDT technologies for condition assessment of tunnels. Please choose a technology or application from the list at left. For a summary of the technologies and applications, please use the link below.

Summary of Tunnel Condition Assessment Technologies and Applications
Current SHRP2 Implementation: Pennsylvania and Colorado DOT

- Initial Training on NDE Methods Completed
- Field Testing of Two PennDOT Tunnels Completed using Various Scanning Methods,
- Testing Reports Due Shortly for Review
- Tunnel-specific Asset Management programs created – and available for sharing with other states

Penetrador GPR of PennDOT Tunnel

Distribution of Cracks Greater Than 1/8”, Armstrong Tunnel
• Participate in educational programs on the use of high-speed NDT methods for evaluation of tunnels

• Learn about and apply effective Asset Management programs that uses NDT data and other sources as inputs

• Use these NDT technologies to conduct high-speed evaluations of tunnels

• Use the NDT results and other data to populate and use an effective tunnel Asset Management program
Previously Evaluated and Proven NDT Technologies

Techniques Used:

• Air-coupled ground-penetrating radar (GPR)
• Thermography (handheld or vehicle mounted thermal camera)
• LiDAR scanning
• Photogrammetry

Ground-coupled GPR
• Ultrasonic echo
• Ultrasonic surface waves and impact echo

Water Seepage Locations
Examples of Scanning Results

More Details for PennDOT Tests in later Presentations
LiDAR and Infrared Scanning Examples
Air Coupled GPR Example

- Tunnel Lining Surface Reflection
- Depth Scale, in.
- Surface Dielectric
- Possible Low Density Interface
- Possible Lining Interface
- Distance Scale, ft.

- Lining Surface
- ~14” Concrete
- ~1” Drainage Layer
- ~14” Shotcrete
Hand-Held IR Example

IR Image of Debonded Shotcrete (debonds in red)

Shotcrete Lined Tunnel

FLIR 1 IR Camera
Live Demonstrations of Some of These Technologies This Afternoon!

Questions?