SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

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

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Federal Highway Administration

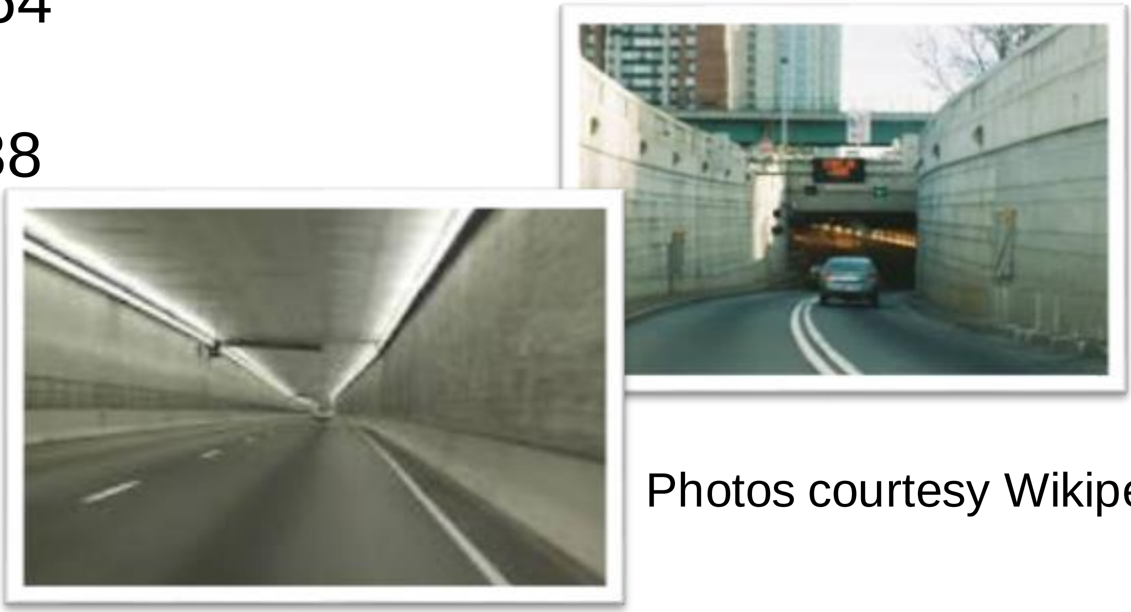
American Association of State Highway and Transportation Officials
AASHTO

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 Overview

Tunnel deterioration is a major maintenance problem for highway departments.

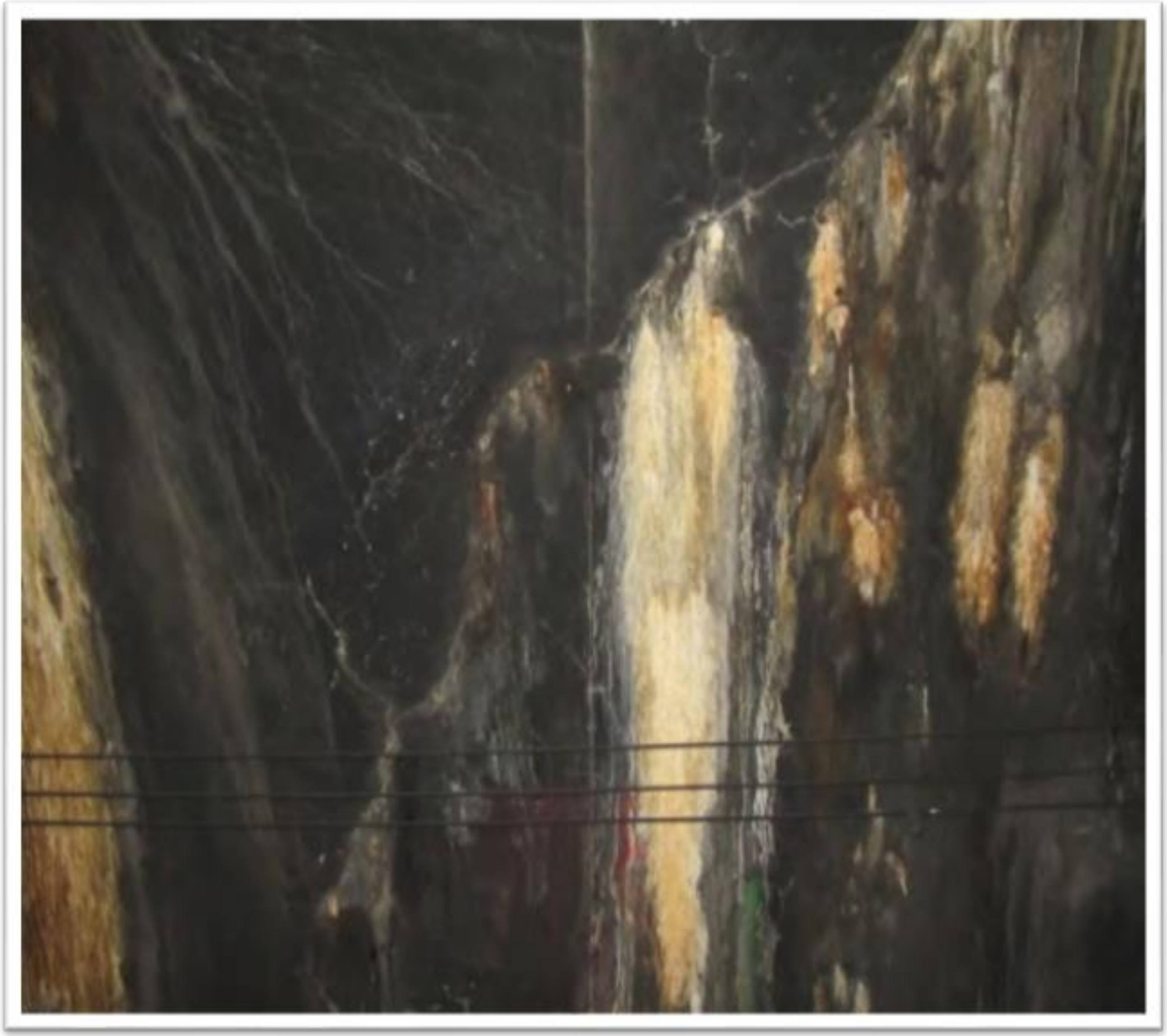
Issues for Tunnel Liners:

- 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)

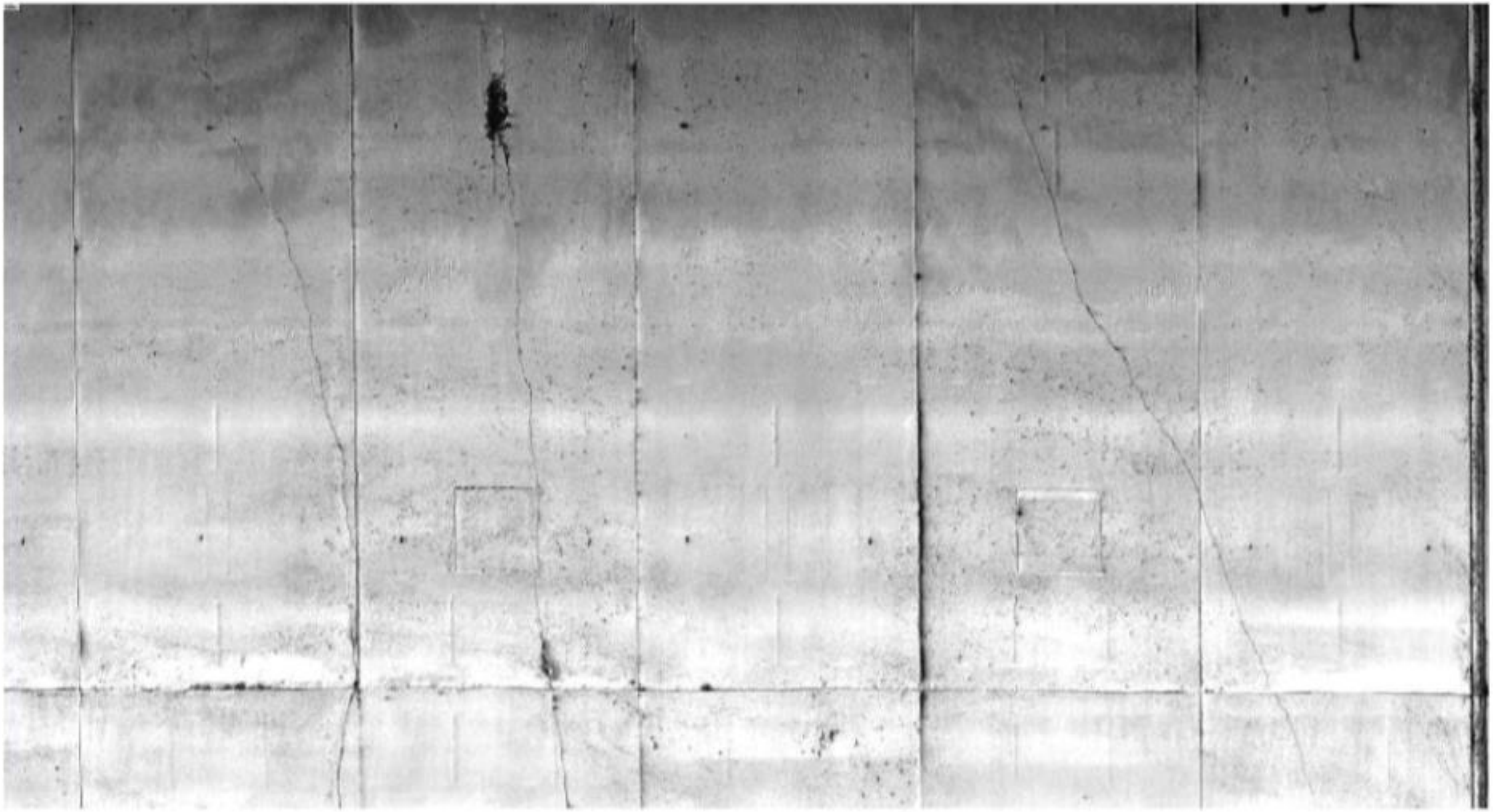
Efflorescence, Water Leakage with Cracking and Rust Staining (Rebar Corrosion)

Efflorescence/Water Leakage with Cracking and Rust Staining (Rebar Corrosion)



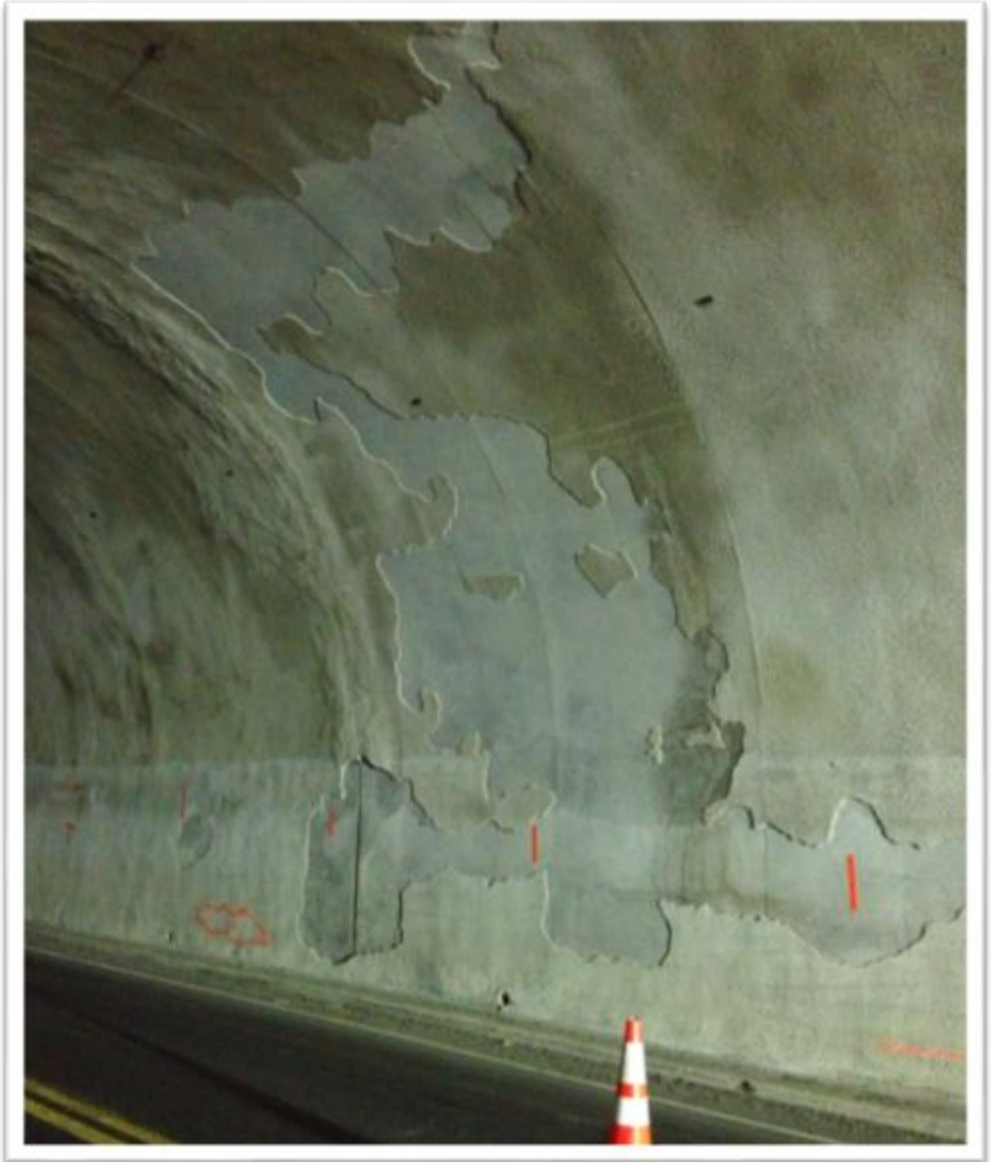
Cracking in Liner Concrete with Covered Void/Spall

Concrete Liner Cracking



Minor Moisture Intrusion and Cracking

Delamination of Shotcrete Coating

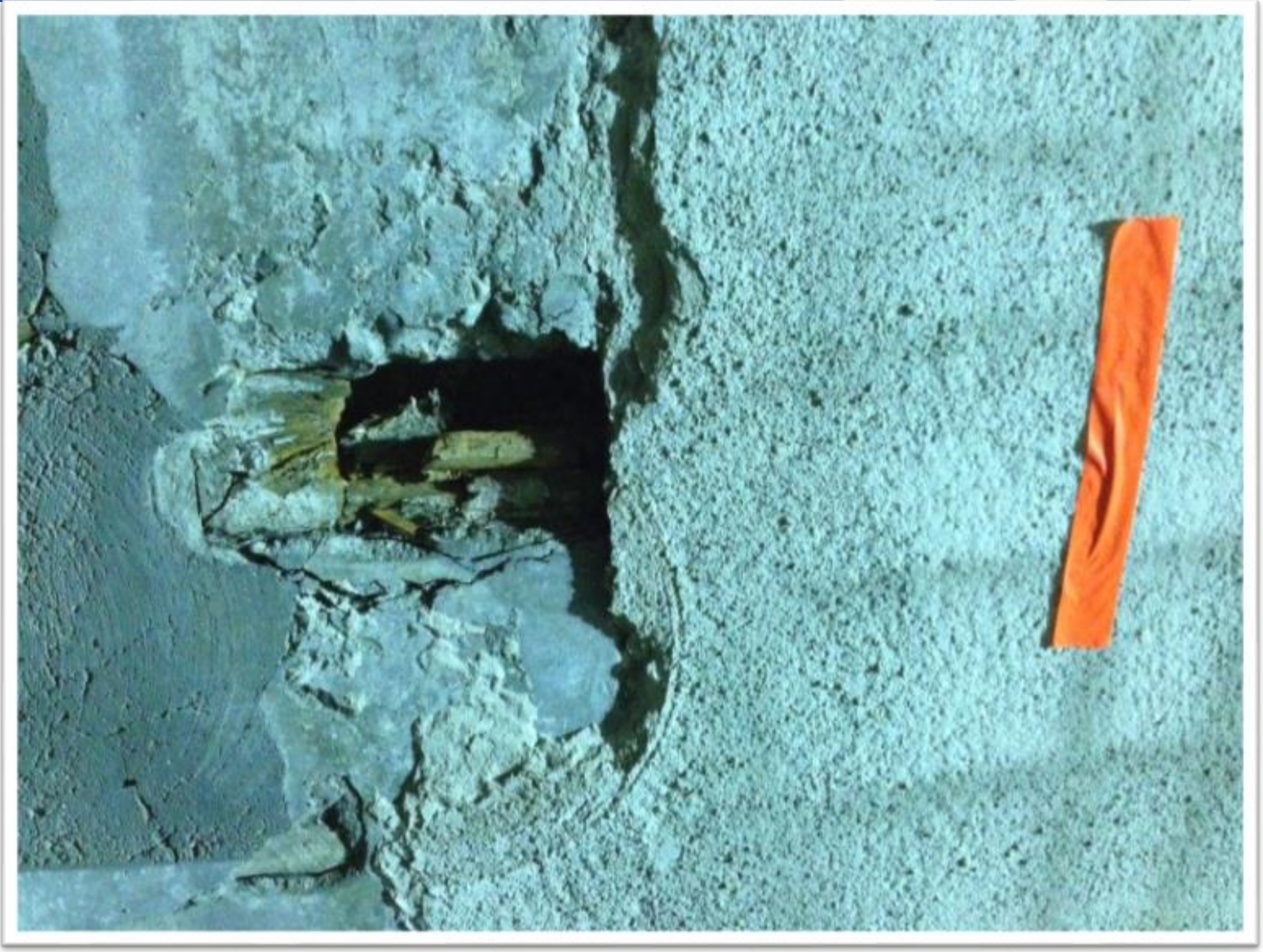


Minor Debonding of Surface Coating – Likely from Moisture

Concrete Delamination Seen in Corehole

Photogrammetry Image of Severe Liner Rebar Corrosion and Spalling

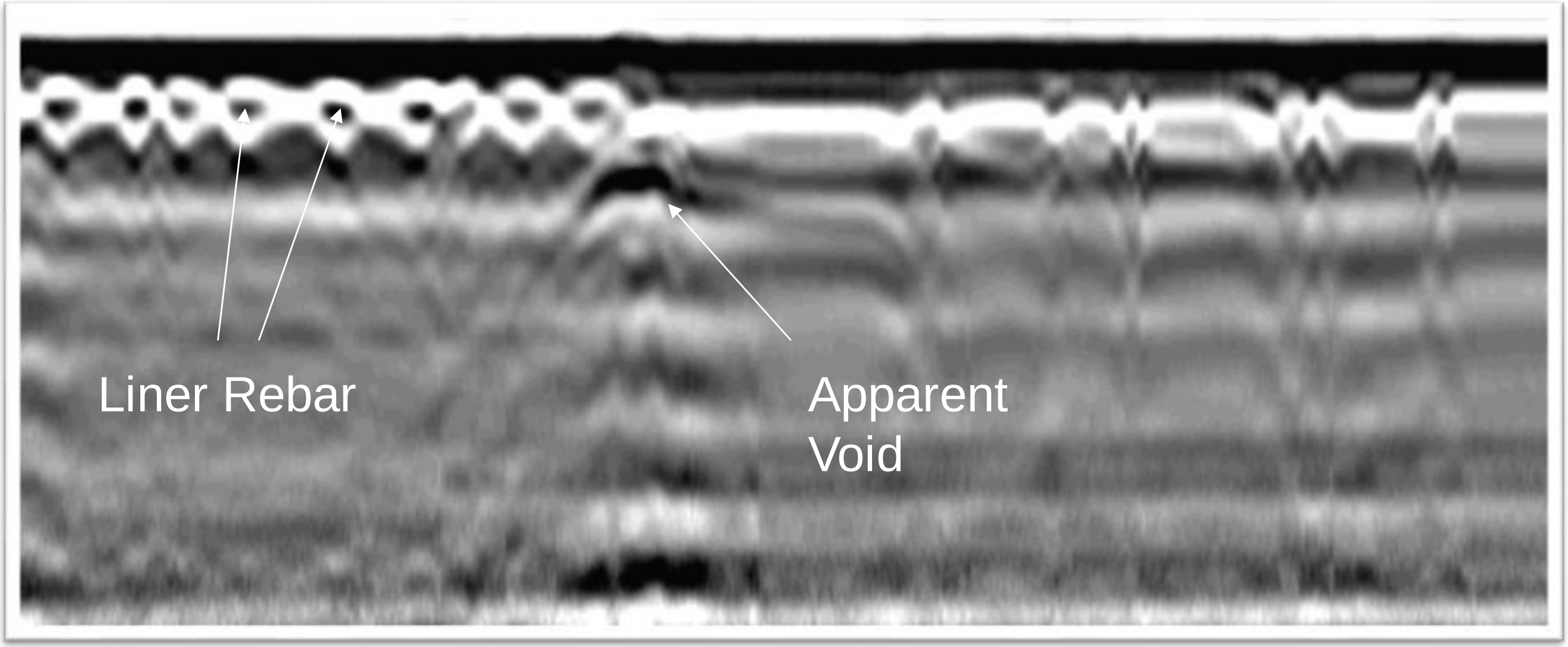
Wall Void from Embedded Timber



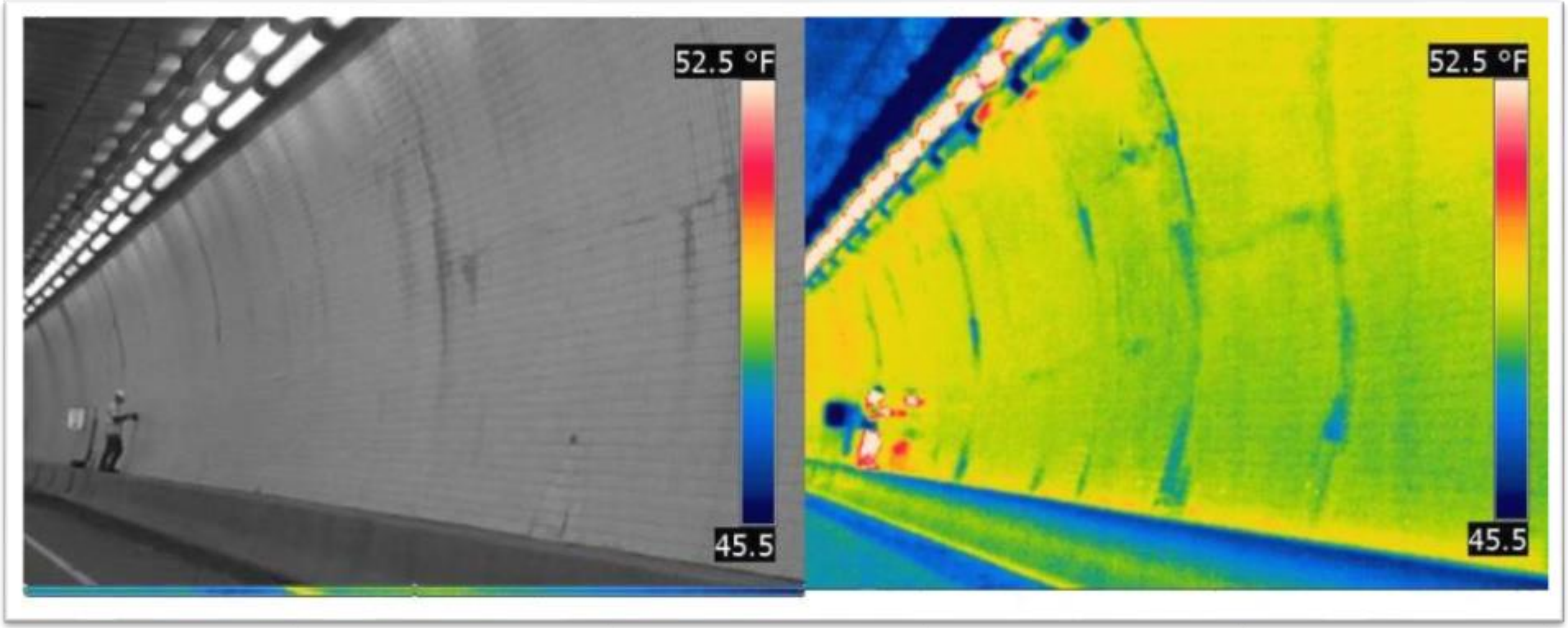
Geophones on Tunnel Crown for Void Detection Survey

Geophones Used for Shear Wave Velocity Survey to Locate Voids Above Liner

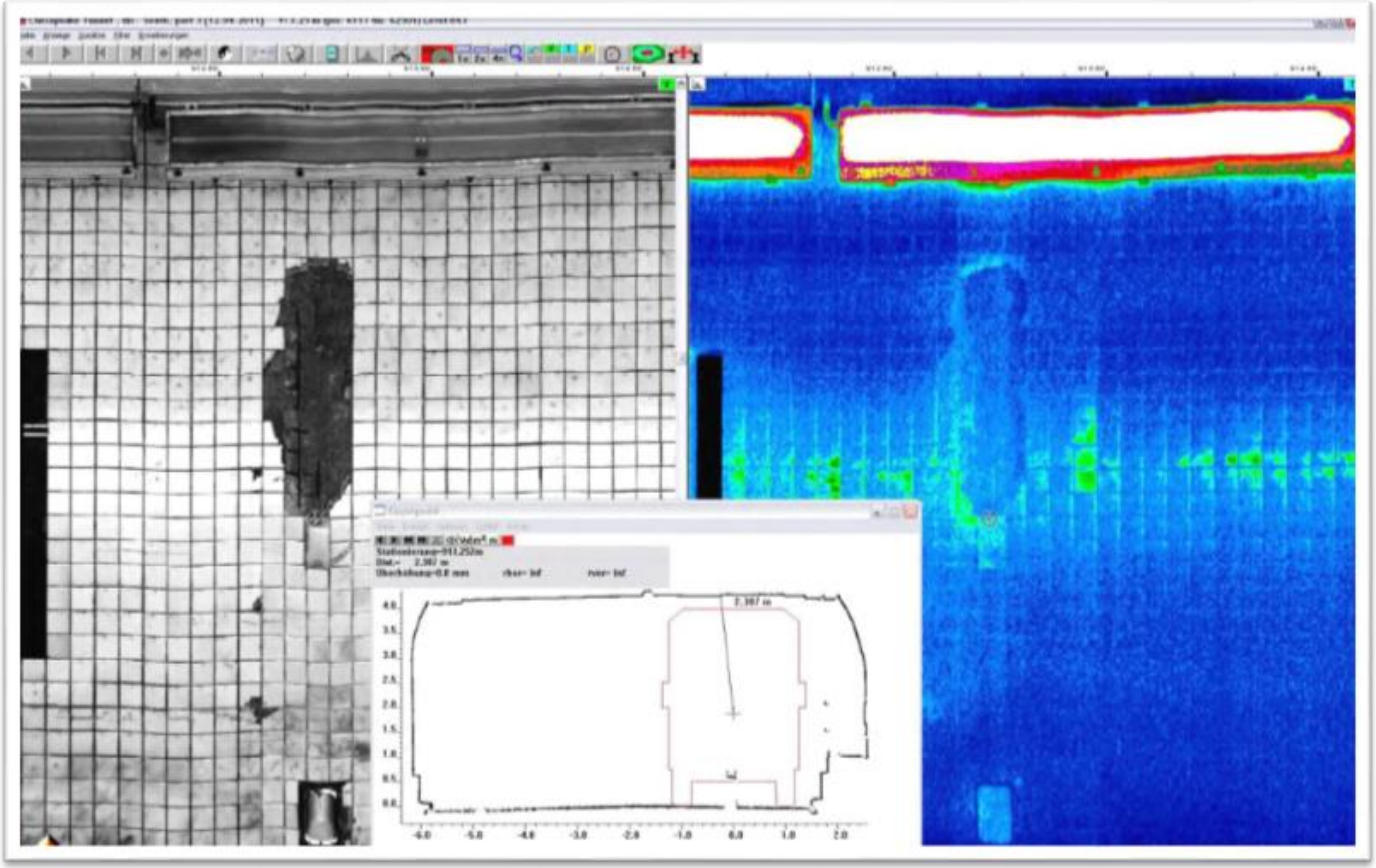
GPR Data Showing Likely Void Behind Concrete Liner (at Joint)



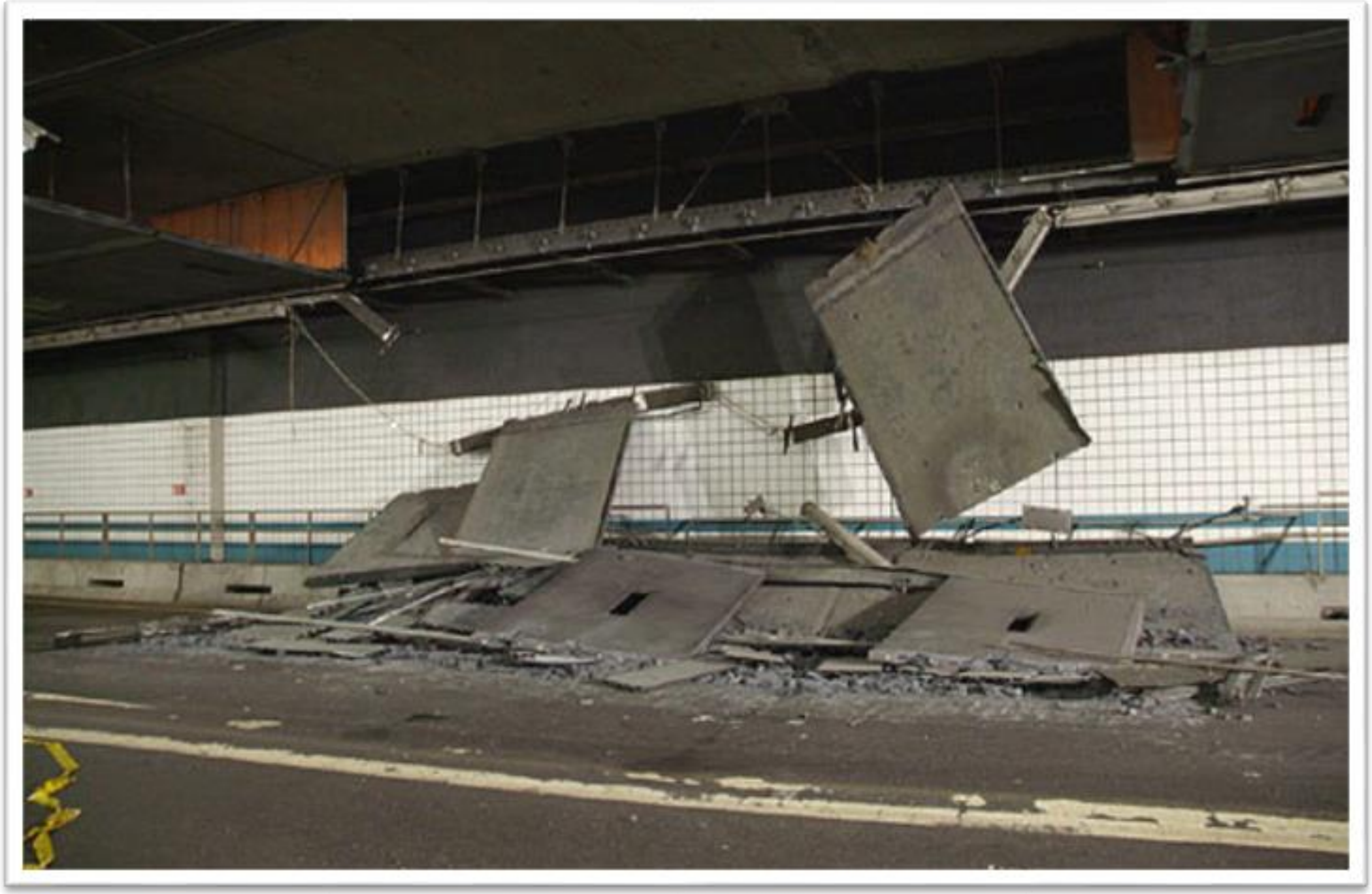
Debonded Tile on Liner (Shown with IR Scanning)



Missing Tiles (IR and Visual)

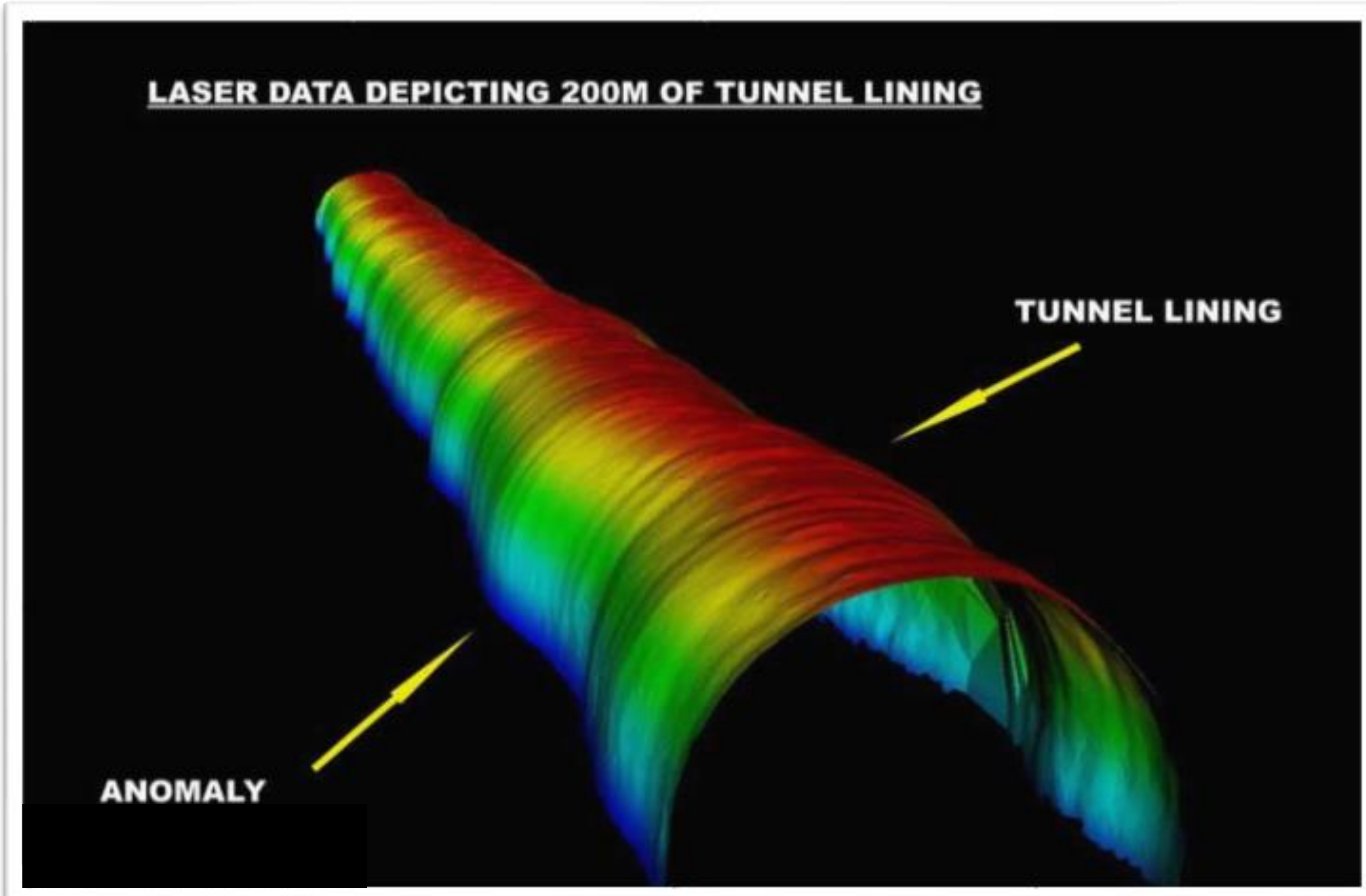


Panel Anchorage Failure



From NTSB Big Dig Failure Report

Tunnel Liner Deviations



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:

http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R06G-RR-1.pdf

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

Project Objectives

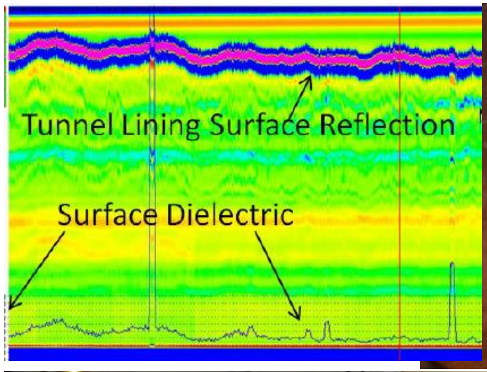
This project had **five objectives**:

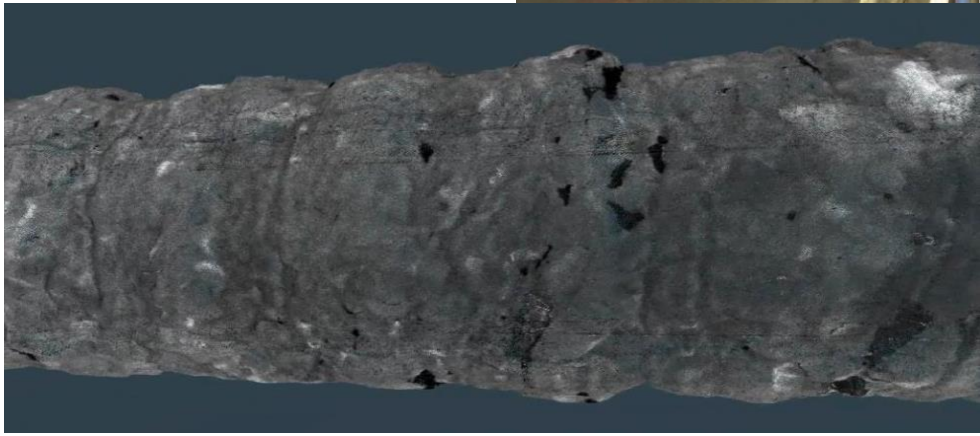
- To identify NDT relevant solutions
- To evaluate the candidate technologies
- Further develop promising technologies
- Validate technical performance
- Recommend deployment procedures

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





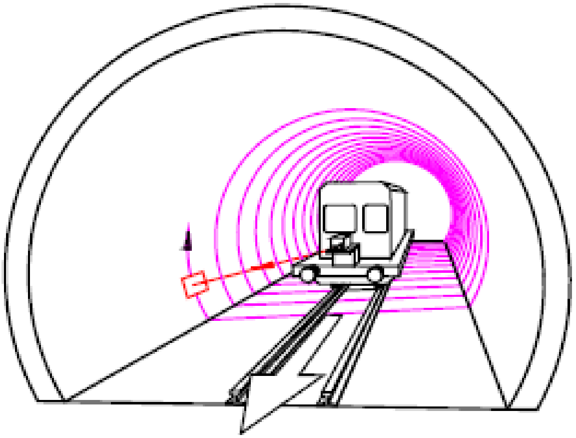
NDT Techniques included in the Original Research Study

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)

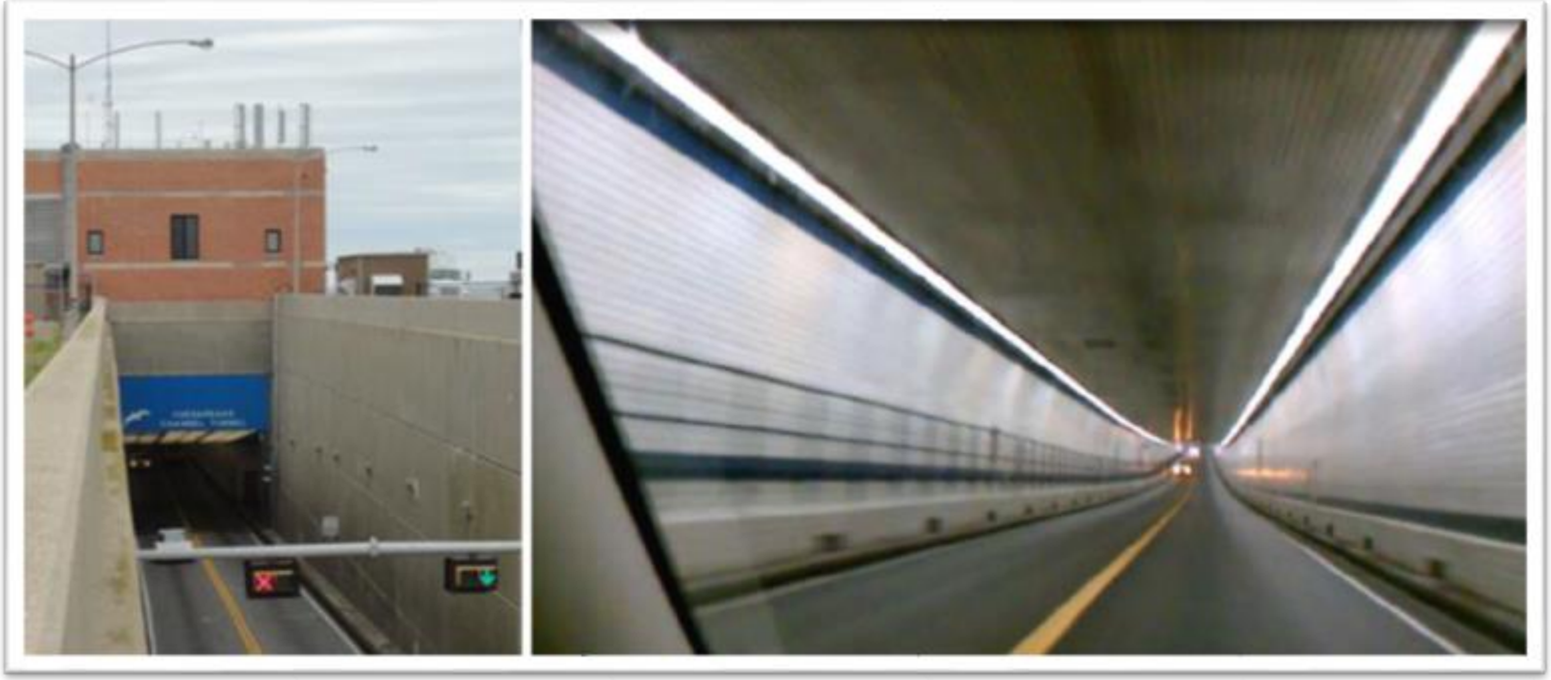
Benefits of NDT Technologies

- 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.



Field Validation Testing

Chesapeake Channel Tunnel, located east of Norfolk, Virginia: The team collected NDT data in this tunnel in September and October 2011.



Field Validation Testing *(cont.)*

Eisenhower Memorial Tunnel, located west of Denver, Colorado: The team collected NDT data in the plenum area of this tunnel.

Field Validation Testing *(cont.)*

Hanging Lake Tunnel, located on I-70 west of Denver, Colorado: The team collected NDT data in this tunnel in October 2011.

Field Validation Testing *(cont.)*

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.

Field Validation Testing *(cont.)*

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.

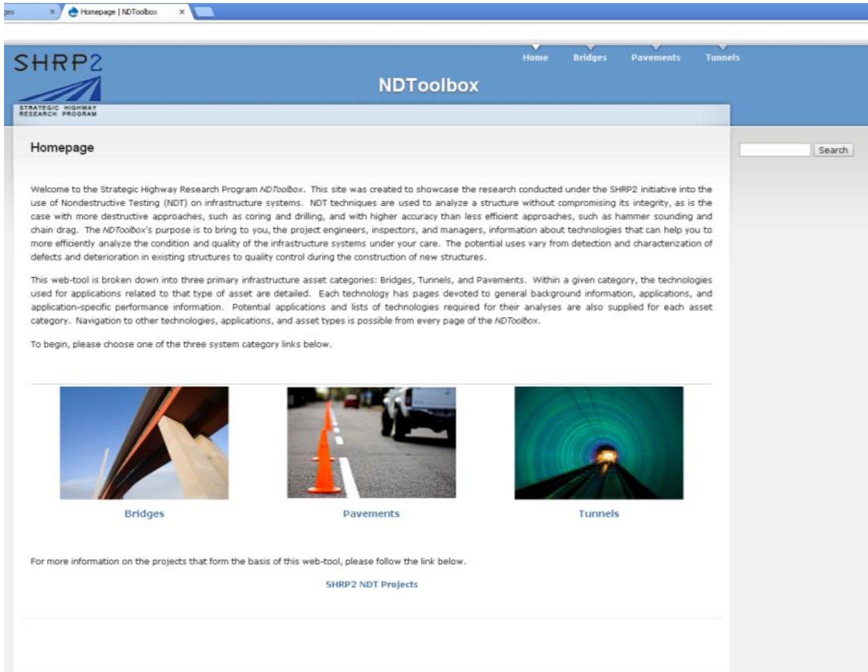
Summary of the Significant Deliverables from the Project

Summary from the Ranking of NDE Techniques

- NDToolbox - NDT Technology Electronic Repository http://www.ndtoolbox.org

NDT Ranking Table Example

Device	Accuracy	Detection Depth	Deterioration Mechanisms Detected	Tunnel Lining Types	Other Information
Air-coupled GPR	Locates defect within 1 foot of its actual location	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.	Tile debonding, delaminations, air-filled voids, water-filled voids, moisture intrusion	Concrete, tile-lined concrete, and shotcrete	This is a scanning tool that can indicate where to conduct testing with in-depth devices.
Thermography (handheld thermal camera)	Locates defect within 1 ft of its actual location	Does not measure depth, but can indicate tile debonding, delaminations up to 1 in. and voids up to 3 in.	Tile debonding, delaminations, air-filled voids, water-filled voids, moisture intrusion	Concrete, tile-lined concrete, and shotcrete	This is a scanning tool that can indicate where to conduct testing with in-depth devices.
SPACETEC scanner	Locates defect within 1 ft of its actual location	Does not measure depth, but can indicate tile debonding, possibly delaminations up to 1 in. and possibly voids up to 3 in.	Tile debonding, delaminations, air-filled voids, water-filled voids, moisture intrusion	Concrete, tile-lined concrete, and shotcrete	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.
Ground-coupled GPR	Can determine defect depth within 10% of the actual depth without reference cores—5% if cores are available	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.	Delaminations, air-filled voids, water-filled voids, moisture intrusion	Concrete, tile-lined concrete, and shotcrete	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.

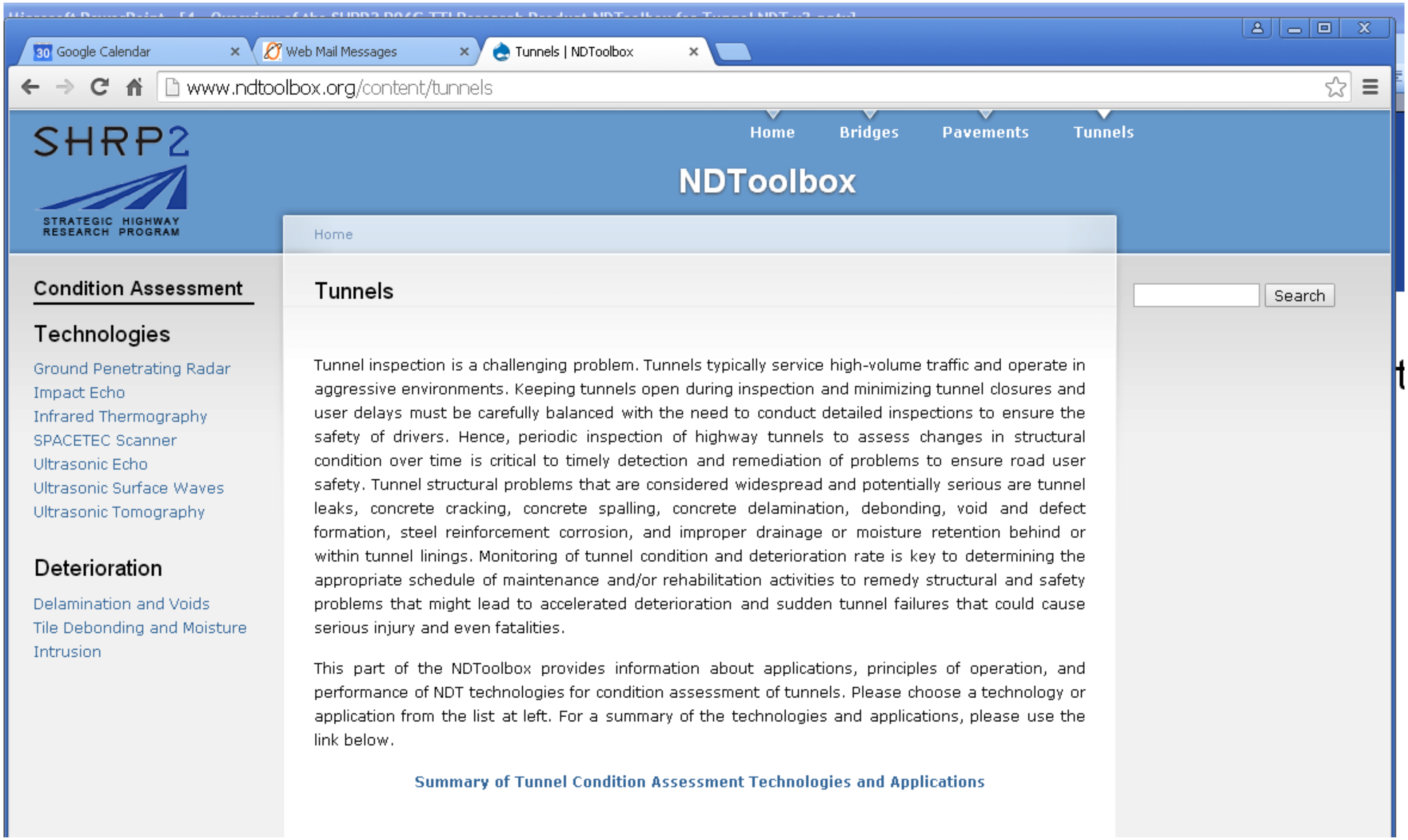


NDToolbox Home Page

NDToolbox Tunnels Page

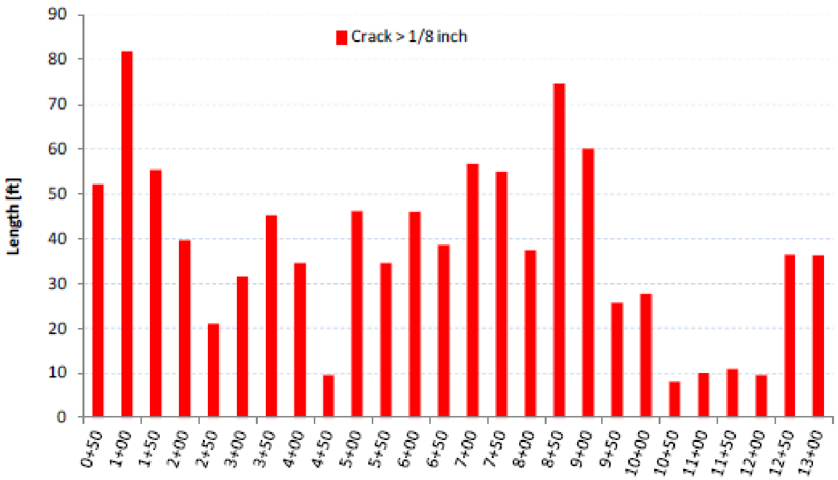
NDToolbox - NDT Technology Electronic Repository

– http://www.ndtoolbox.org



Current SHRP2 Implementation: Pennsylvania and Colorado DOT

Penetradar GPR of PennDOT Tunnel



Distribution of Cracks Greater Than 1/8", Armstrong Tunnel

- 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

R06G Implementation Phase Product Approach

- 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)

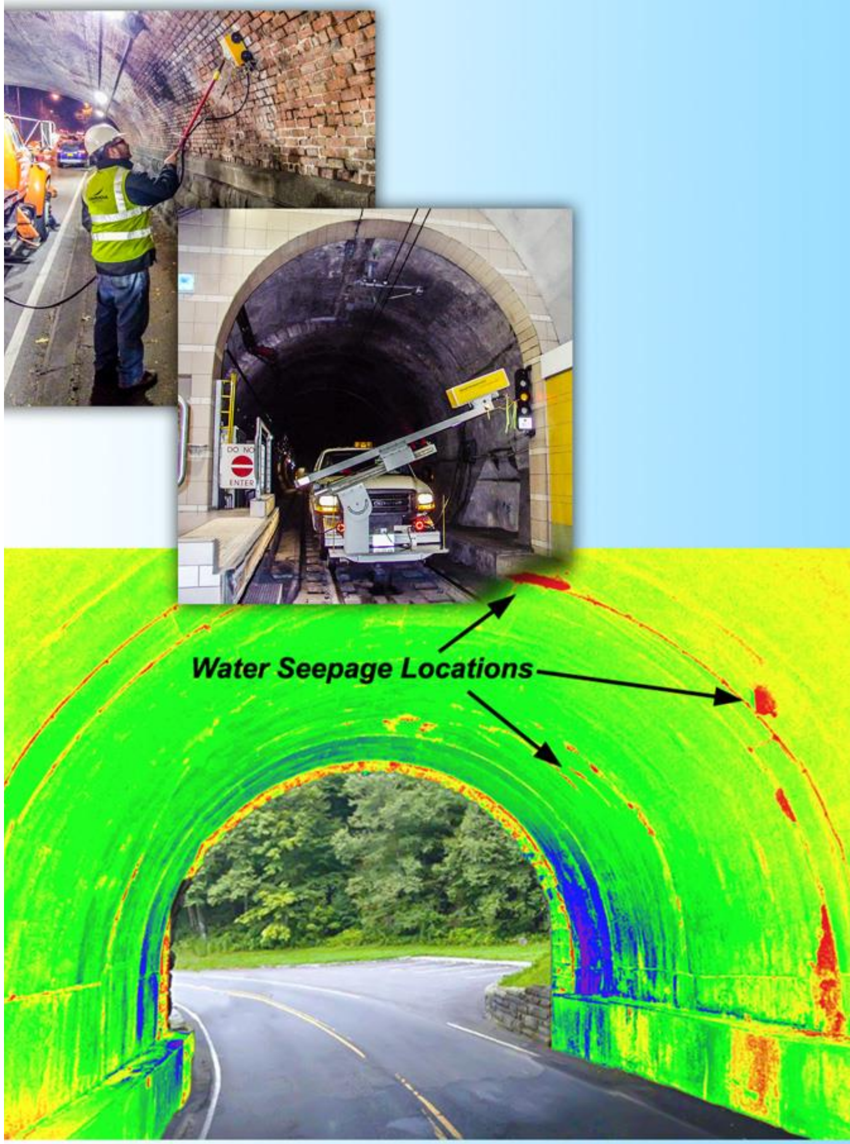
•LiDAR scanning

•Photogrammetry

Ground-coupled GPR

•Ultrasonic echo

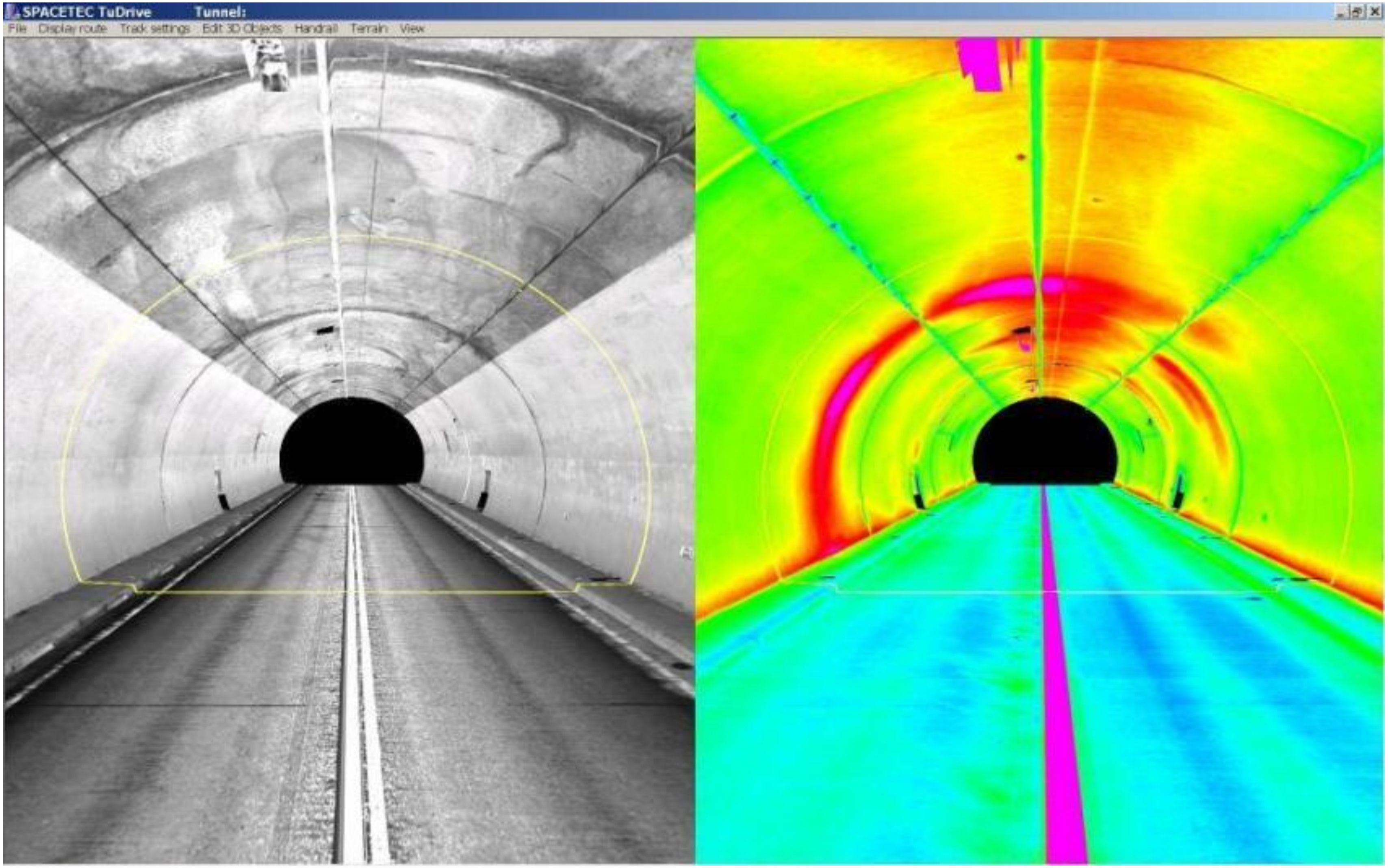
•Ultrasonic surface waves and impact echo



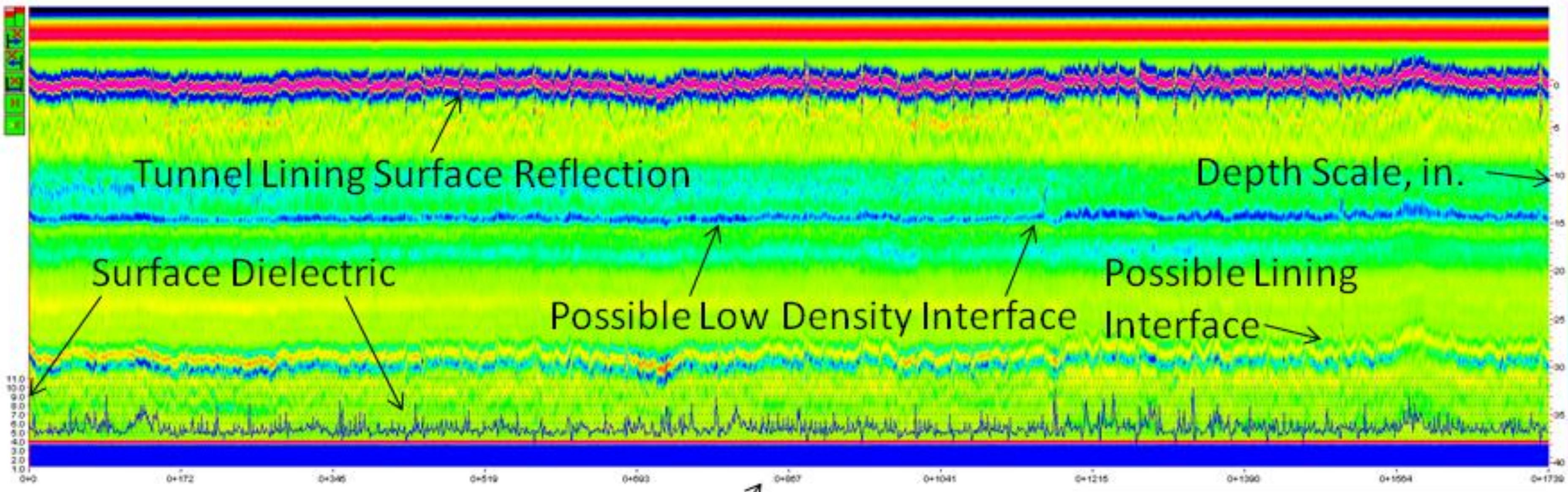
Examples of Scanning Results

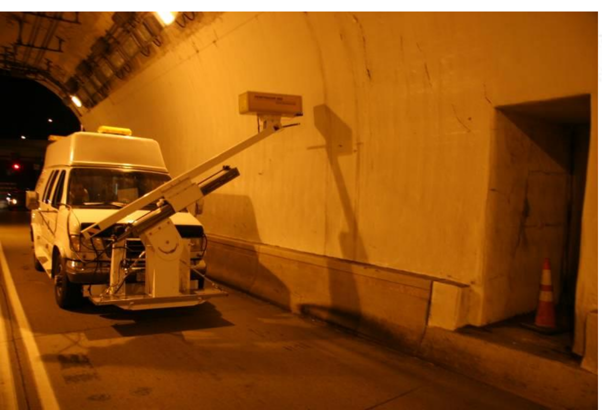
More Details for PennDOT Tests in later Presentations

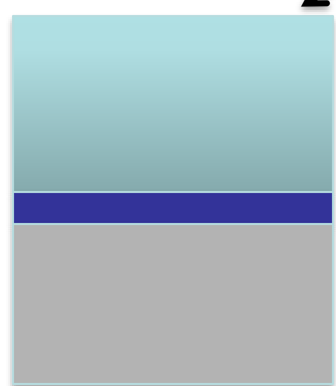
LiDAR and Infrared Scanning Examples



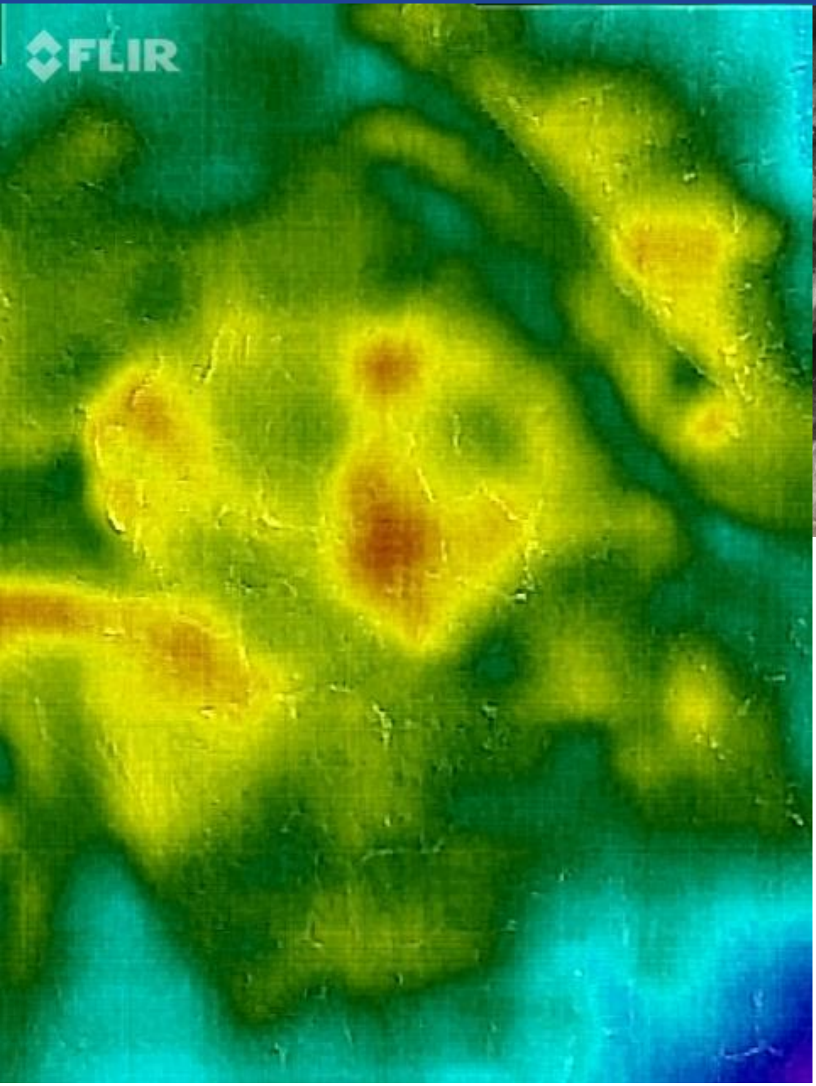
Air Coupled GPR Example



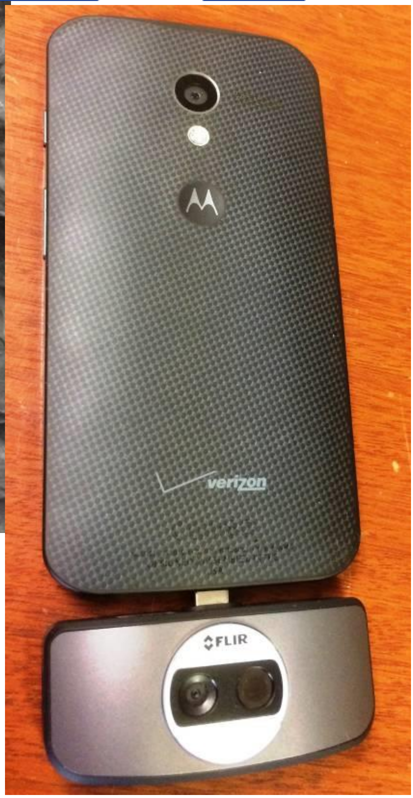




Hand-Held IR Example



Shotcrete Lined Tunnel



FLIR 1 IR Camera

IR Image of Debonded Shotcrete (debonds in red)

Live Demonstrations of Some of These Technologies This Afternoon!

Questions?