SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

SHRP2 Advancements in Rapid Tunnel Imaging and Nondestructive Testing

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Federal Highway Administration

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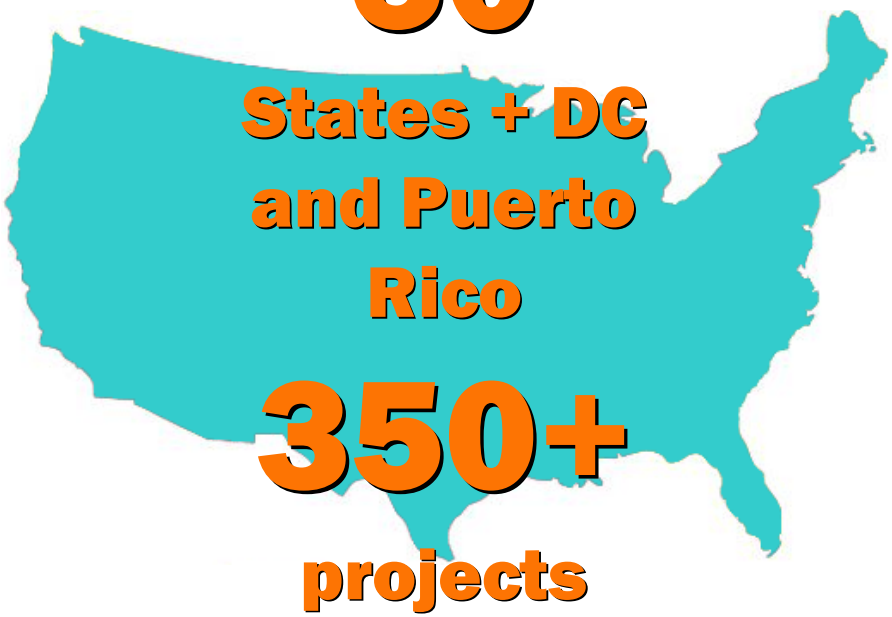
AASHTO

Overview of SHRP2 Program

- SHRP2 began in 2006, with deployment now underway
- $232M in research under SAFETEA-LU
- $171M for implementation under MAP-21 (SP&R)
- Delivered as **direct funding** and **technical assistance**
- Six IAP rounds delivered to date: **Round 7 coming in April 2016**

SHRP2 Implementation

- **SHRP2 Solutions** – **63 products** bundled into 40 implementation efforts
- **Solution Development** – processes, software, testing procedures, and specifications
- **Field Testing** – refined in the field
- **Implementation** – **350+ transportation projects**; goal to adopt as standard practice



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
  - National Park Service - 64
  - Colorado – 38

Photos courtesy Wikipedia

Tunnel Materials Used in the U.S.

- The vast majority of tunnel linings in the United States use **cast-in-place (CIP) reinforced concrete**.

- Also used:
  -CIP unreinforced concrete
  -steel/iron liner plate, or
  -shotcrete.

- The majority of tunnels are considered simple structures – few if any electro-mechanical systems elements

Source: Federal Highway Administration

Tunnel Evaluation

- New Tunnel Inspection Requirements are now in place for all DOT tunnels across the country
- Clear inspection and reporting requirements with the **National Tunnel Inspection Standard (NTIS)**

Tunnel Evaluation

- The **National Tunnel Inspection Standard (NTIS)** requirements leads to opportunities and needs for high-speed inspection methods for tunnel evaluation.

- Various methods, including **LiDAR**, have been researched and found effective for this application.

Tunnel Deterioration Overview

Tunnel deterioration is a major maintenance problem for highway departments.

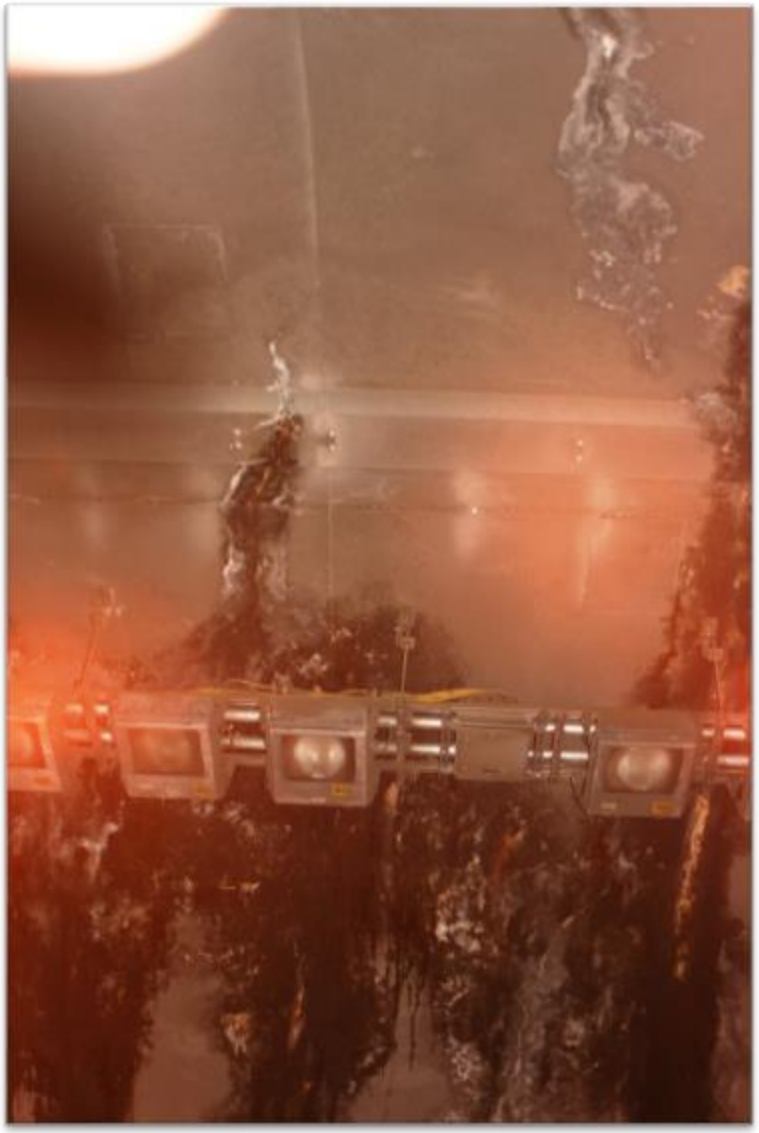
Issues for Tunnel Liners:

- Corrosion of Reinforcing Steel
- Moisture Intrusion
- Debonding/Delamination of Shotcrete and Tile
- Drainage System Failure
- Cracking of Concrete
- Deformations and Bulges

Tunnel Deterioration Overview

Other Issues:

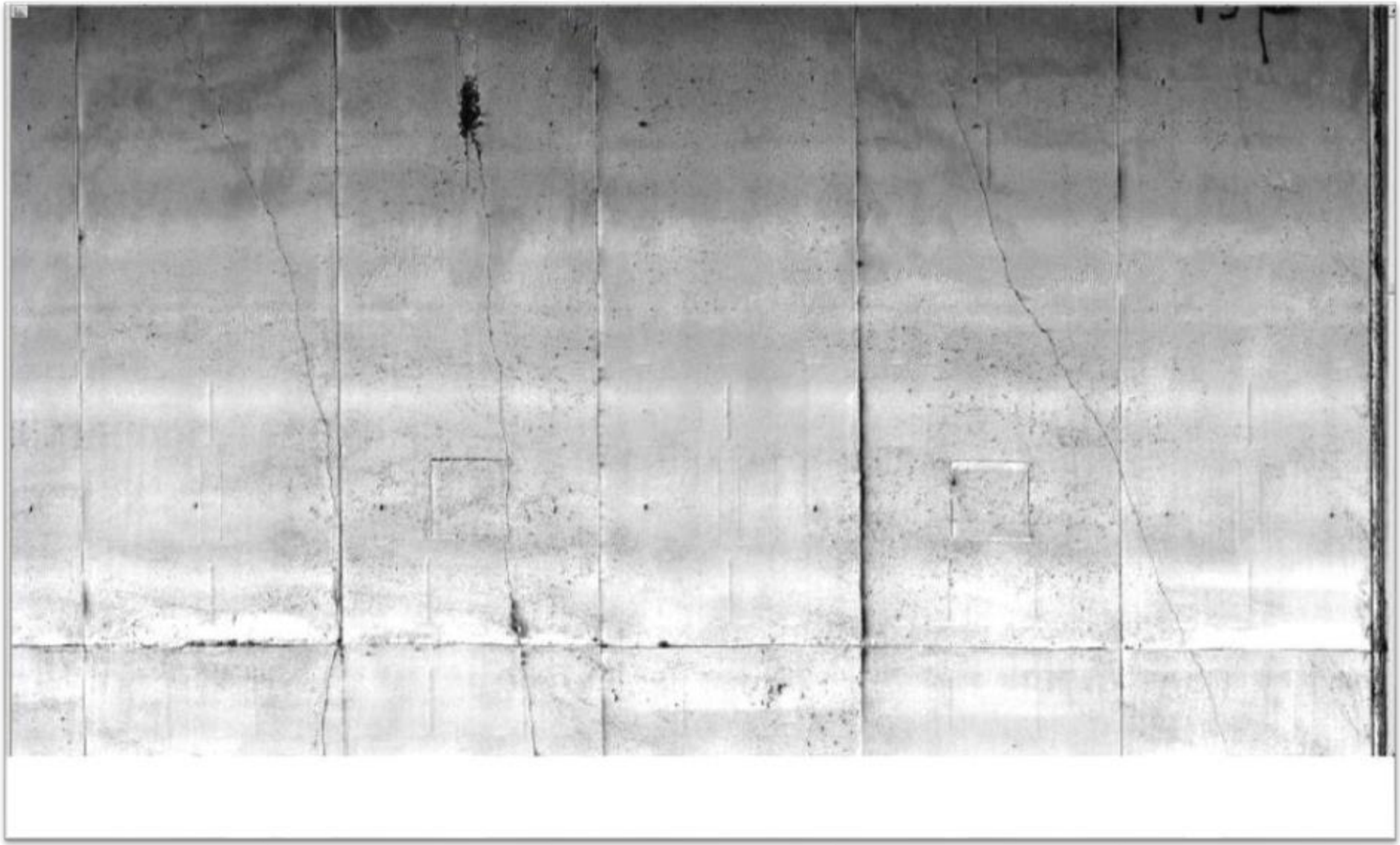
- Ice Build-up
- Corrosion of Fixtures and Signage
- Normal Roadway Surface and Subsurface Issues



Efflorescence, Water Leakage (Mineral Deposits from Water Flow)

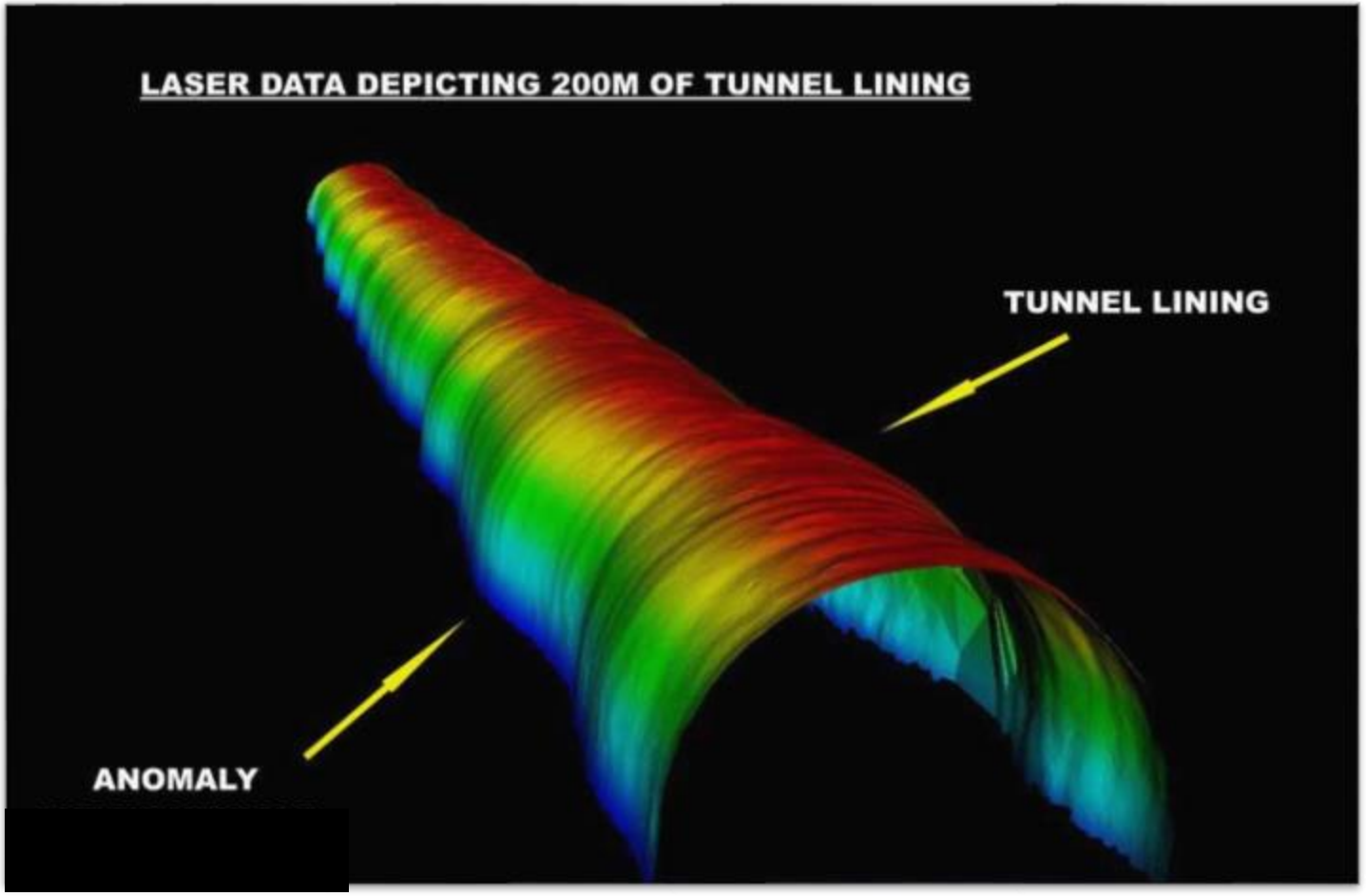
Cracking in Liner Concrete with Covered Void/Spall

Concrete Liner Cracking



Cracking/Spalling of Shotcrete

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

Tunnel Assets: Where? What Condition?

Current Practice for Assessment of Tunnels

An overview on:

- Visual Inspection
- Hammer Sounding

Current State of Practice – Visual Inspection

- Visual inspection is the most basic inspection method used for tunnel evaluation.
- Visual inspection is used as the “First Line” inspection technique – to find gross problems that have begun to have a visible manifestation.
- Usually requires lighting and a manlift.

Visual Inspection: Performance

- Speed of inspection can be very fast, if there are no problems seen.
- Full mapping of issues can be **very time consuming and hazardous.**
- Requires a moderate amount of **training** and experience to be most effective.
- **Low-cost** equipment – Good lighting and cameras are the most common tools needed.
- Relatively **inexpensive** test, but normally requires traffic control and a manlift.

Visual Inspection: Limitations

- Tests can be **subjective**. The results may be significantly different if performed by 2 different people.
- The **application and effectiveness are limited** to issues that are visible at the tunnel surface:
  - Moisture Flows and Staining
  - Efflorescence
  - Cracking Open at Surface
  - Spalls/Missing Tiles
  - Major Deformations
  - Visible Rust and Rust Staining

Visual Inspection: Limitations *(Cont.)*

- Cannot locate debonding or delaminations.
- Cannot inspect behind surface treatments – tile, epoxy coatings, etc.
- Unless extensive and detailed photos are taken and well-documented (time consuming), it can be difficult to do a year-to-year comparison.

State of Practice – Hammer Sounding

- The **most common** basic inspection methods used for detection of delamination in liner concrete, tile, shotcrete and other surface treatments.
- Used to detect regions **where the impact sound changes** from a clear ringing sound (well-bonded material) to a somewhat mute and hollow, drummy sound (delamination).
- **Easy to use** and requires **minimum training.**
- **Low-cost** equipment.
- Average speed of testing is about 800 ft^2/hr.

Sounding: Physical Principal

- The **operator** impacts the wall or surface material while listening to the sound the impact makes.
- A **clear ringing sound** represents sound concrete or well bonded tiles/shotcrete while **a mute/hollow sound** represents a delaminated or debonded area.
- The hollow sound is a result of flexural vibrations of the delaminated area, creating a drum-like effect.

Sounding: Limitations

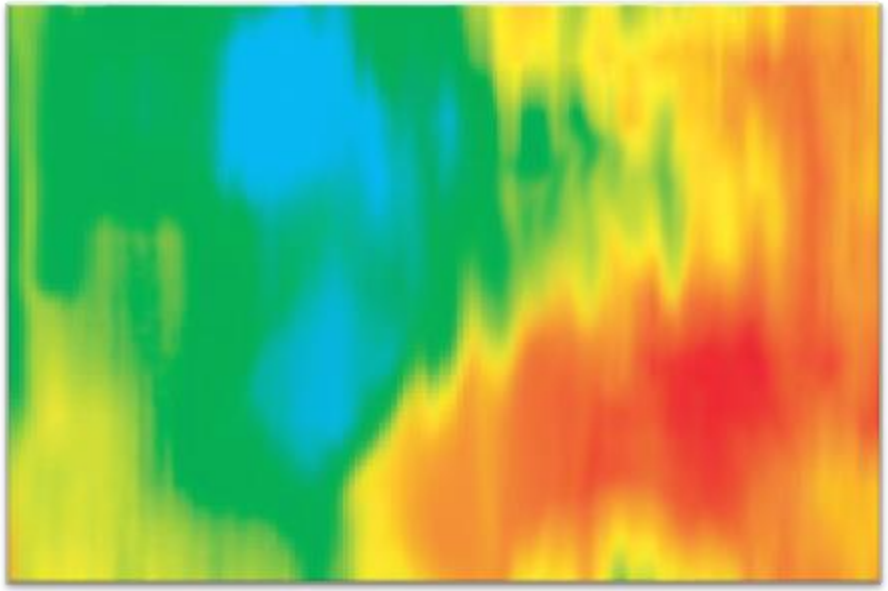
- Is highly dependent on the **operator's skill and hearing**, making the method subjective. The results may be significantly different if performed by 2 different persons.
- Initial (partial) delaminations often not detected.
- Only detects delaminations or debonds up to ~3 inches deep.
- Not easy to produce an accurate paper copy of the delamination map.
- Tunnel acoustics can make sounding more difficult.

Core from bridge deck showing delamination due to corrosion of rebar at 3.5 inches – not detected by sounding

High-Speed Assessment Techniques for Tunnels

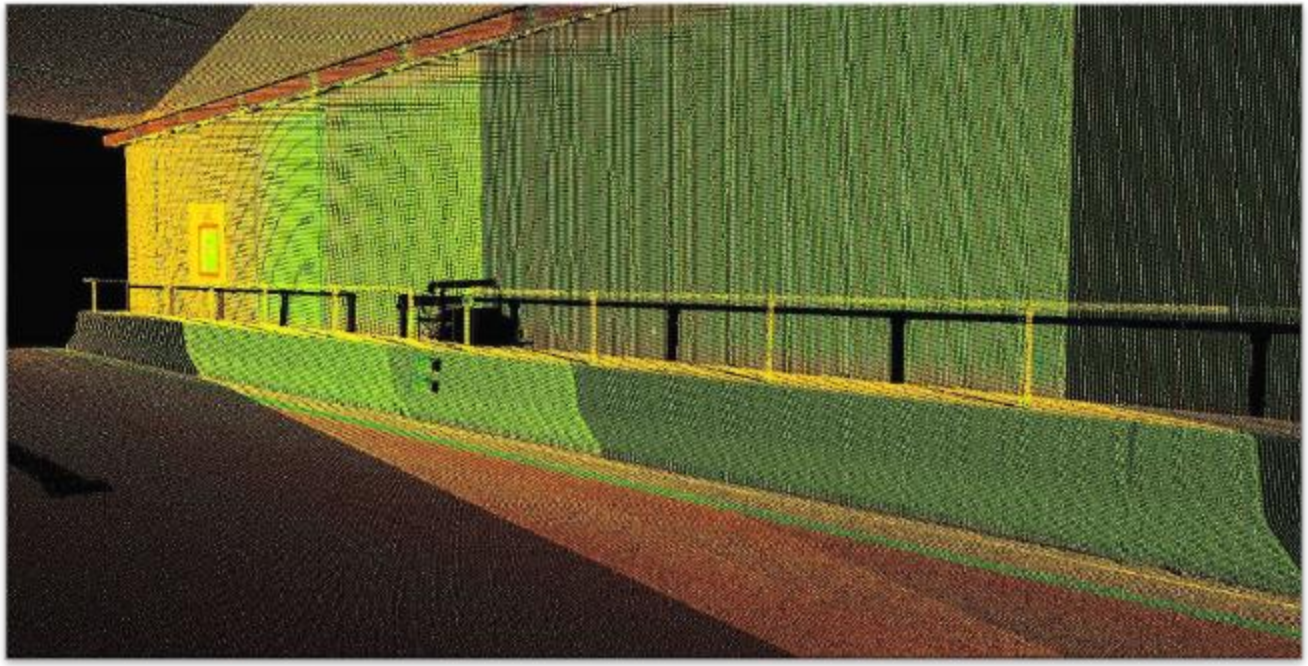
An overview on:

- LiDAR
- Infrared
- Air-Coupled Ground Penetrating Radar



Features of Mobile Scanning

- High-speed investigation methods
- Conducted from inside a vehicle
- Often still requires short traffic breaks or slowdowns
- Generally provide “overview” information about current tunnel condition and assets
- Used for initial “fast” surveys and for comparison surveys
- Less detail and depth range



Courtesy of CDOT and Stantec

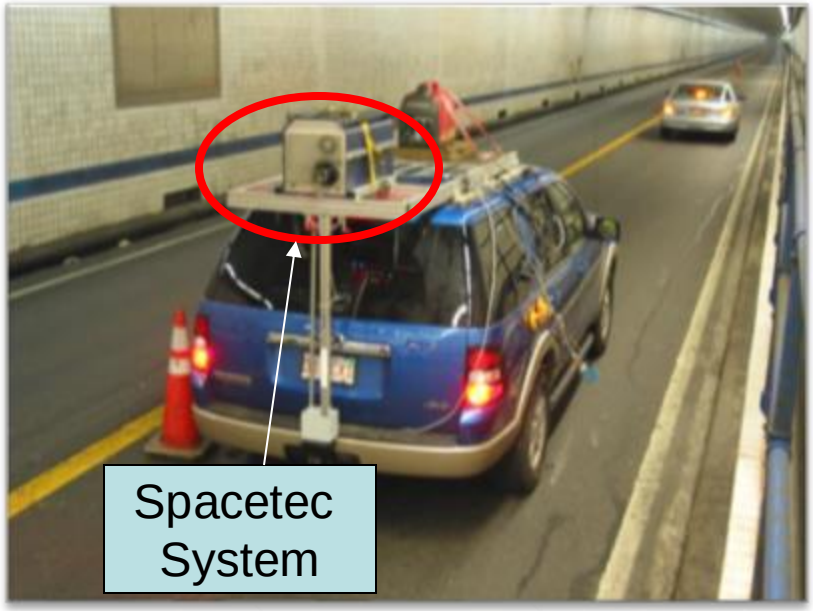
Features of Mobile Scanning

- **High-Speed NDE Methods used typically to identify:**
  - Delamination/debonding of tiles/liners/shallow concrete
  - Deformations/deviations
  - Voids
  - Moisture
  - Cracking
  - Rebar presence, depth, and geometry
  - Rebar corrosion
  - Other issues behind (more limited)/within tunnel lining
- Methods also **assess assets present/missing** in tunnel

SPACETEC System

Combined Laser Mapping and IR Scanning System

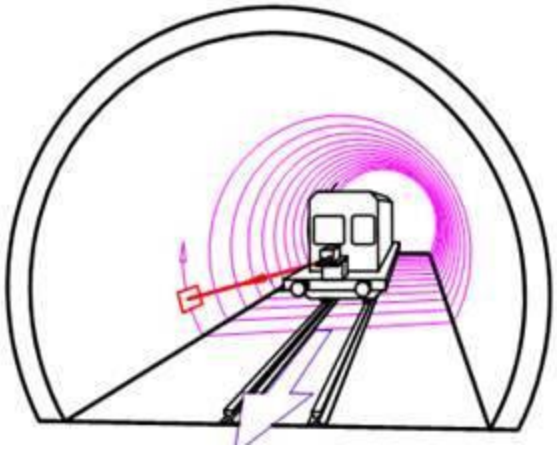
- High speed system combining IR with Laser **(LIDAR)** mapping technologies
- Includes distance tracking and visual spectrum camera for comparison
- Vehicle-mounted system
- Laser Mapping
  - Internal tunnel asset location and mapping
  - Tunnel wall movements and deviations
  - Comparison to baselines
  - For periodic inspection program



SPACETEC Typical Testing Rates

- Up to 100 km/hr (62 MPH) for “coarse” measurements
- Down to 2 km/hr (1.2 MPH) for very detailed investigations
- Typical measurement speeds of 5 km/hr (3 MPH) for balanced scanning – very good detail and more reasonable testing rates

Laser and IR Scanning

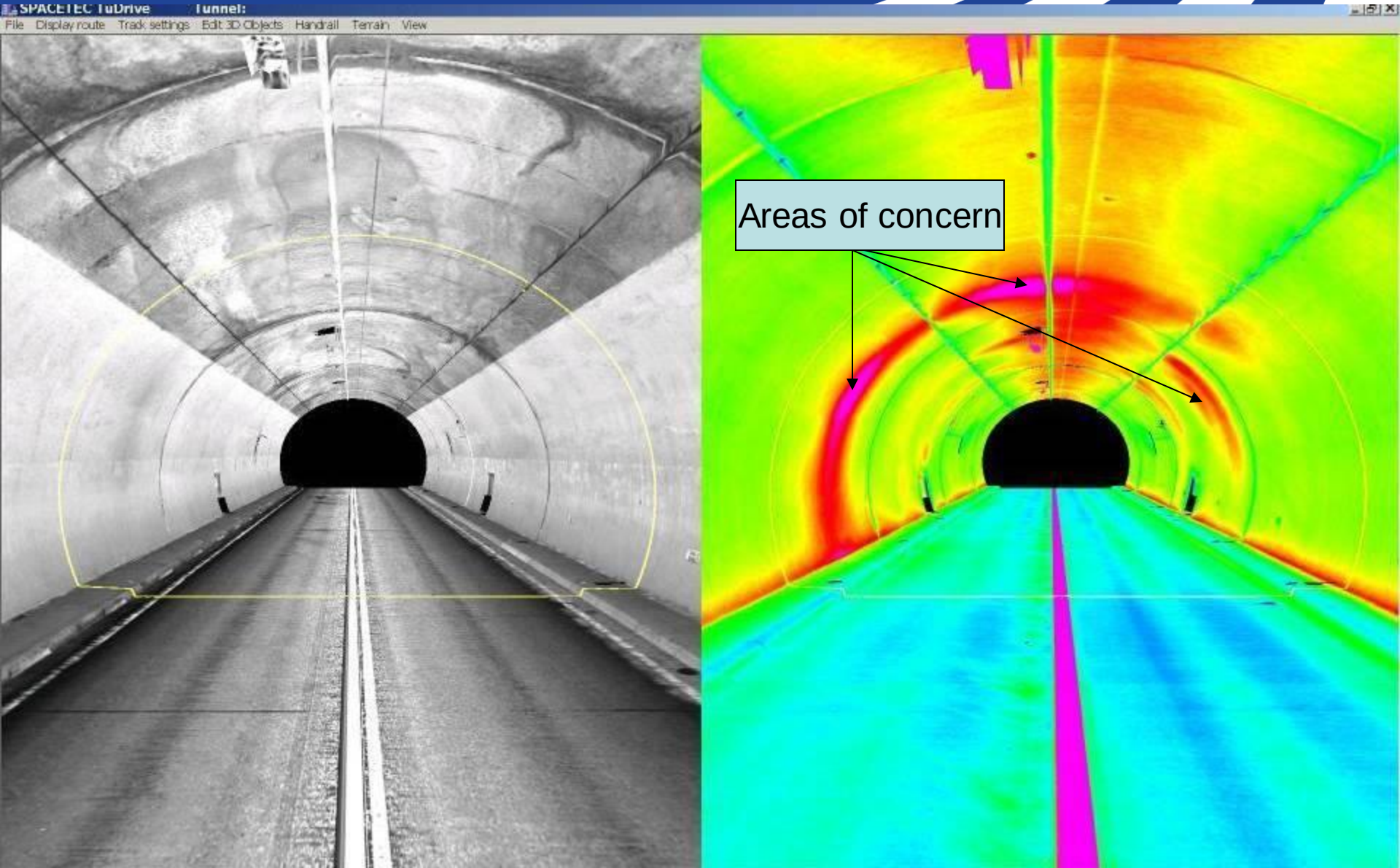


Applications

- New tunnel or post-rehabilitation initial condition and asset survey
- Periodic inspection of tunnels for early damage identification and repair planning
- Location of wall and liner movement and deviations
- Checking tunnel clearances (especially if new uses/large loads are planned)
- Slower-speed, detailed scanning can provide for crack mapping, tile debonding, and other IR applications

SPACETEC System Implementation

SPACETEC System – Visual vs IR Views with Areas of Concern in IR view

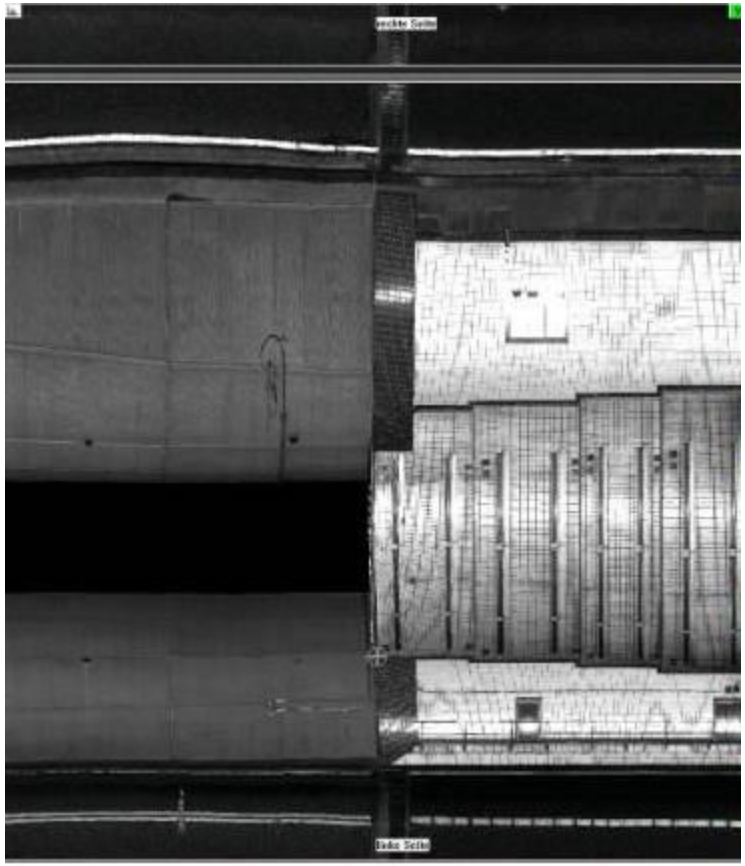


Visual Close-up View for Crack Mapping

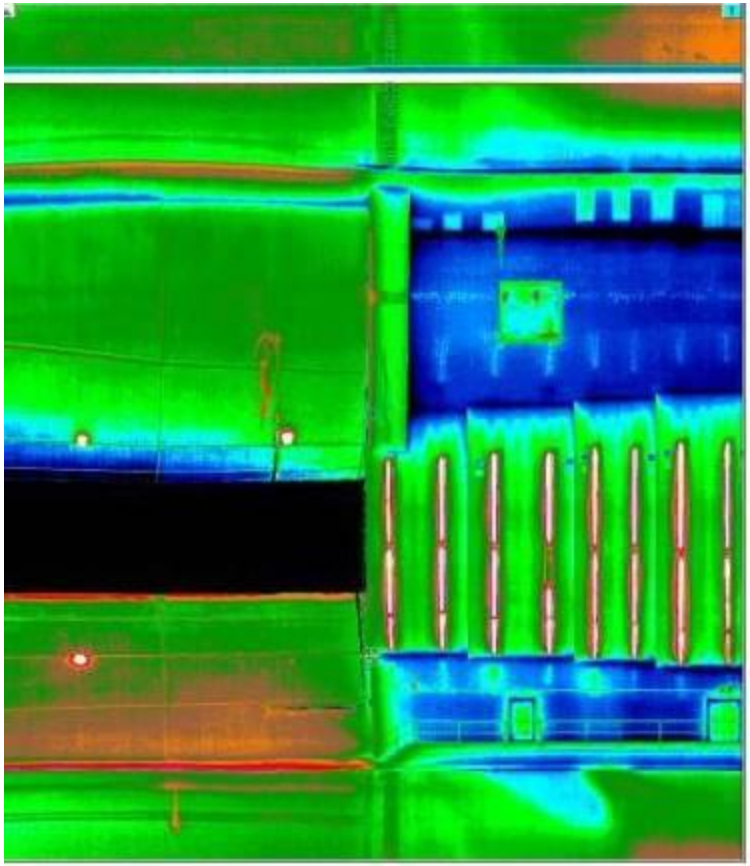
SPACETEC IR Examples

Chesapeake Tunnel IR and Visual Scans – "Wrapped" Image Scans at Tunnel Transition

Visual Image



IR Image



Pavement

Wall

Crown

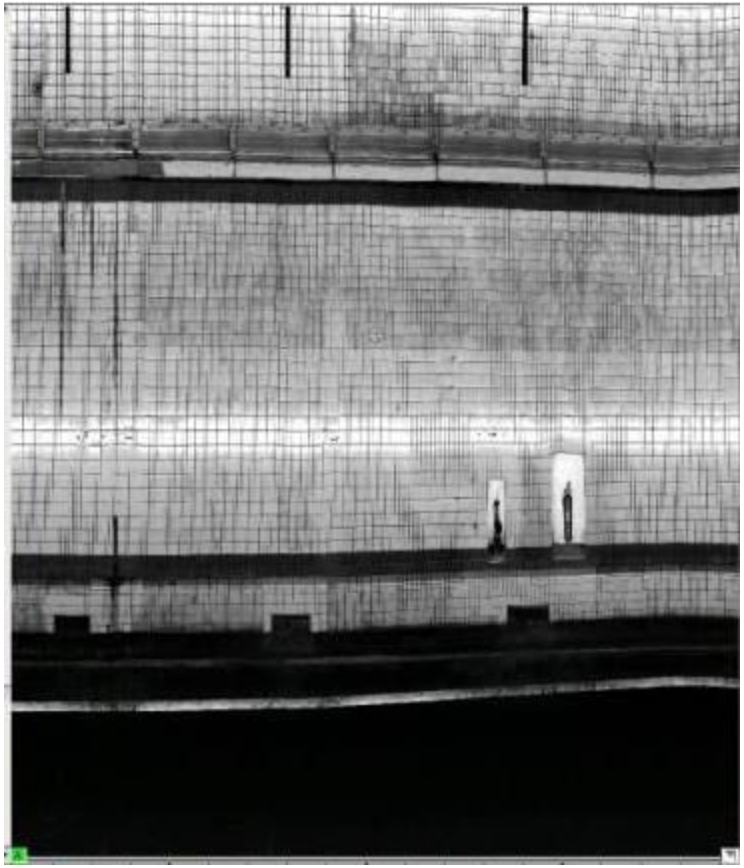
Wall

Pavement

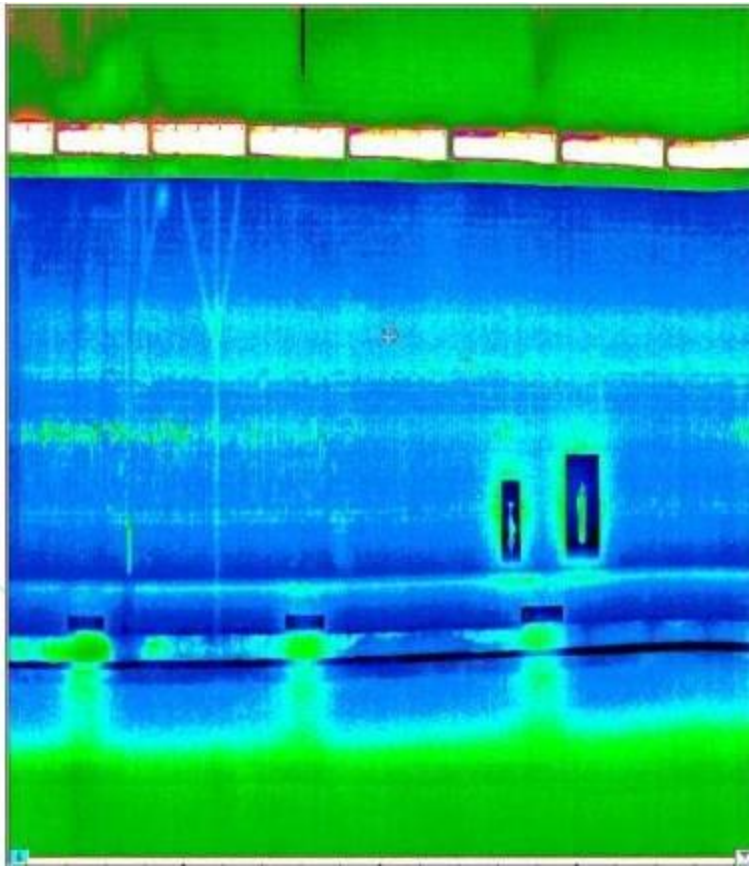
SPACETEC IR Data Showing Sound Tile

Chesapeake Tunnel IR and Visual Scans of Wall

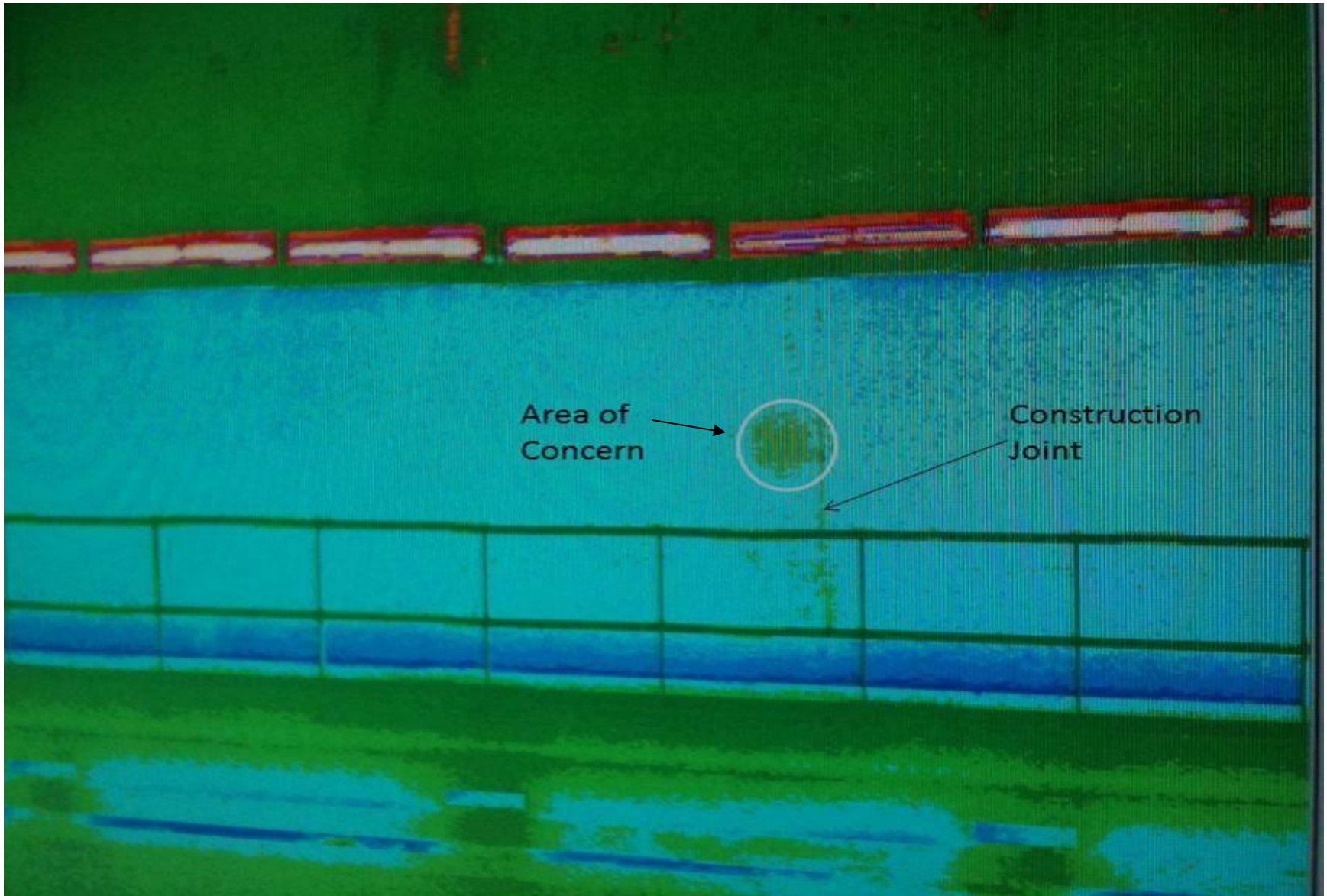
Visual Image



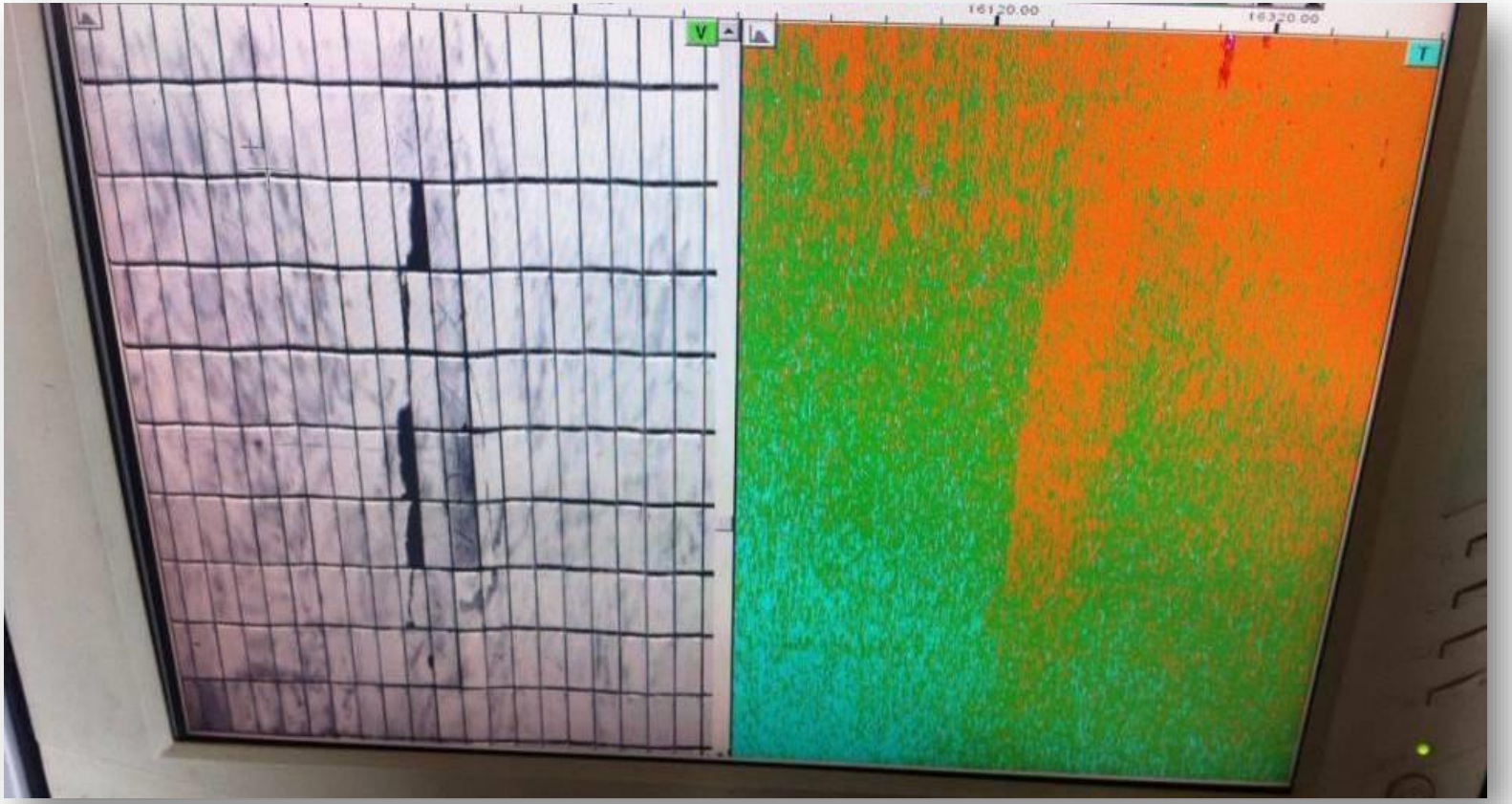
IR Image



SPACETEC IR
Data Example



SPACETEC IR Example – Debonded Tile



Current SHRP2 Implementation: Pennsylvania DOT

- Initial training on NDE methods completed
- Field testing of two tunnels completed using various scanning methods, including LiDAR, IR and GPR
- Testing reports due shortly for review

For More SHRP2 Information:

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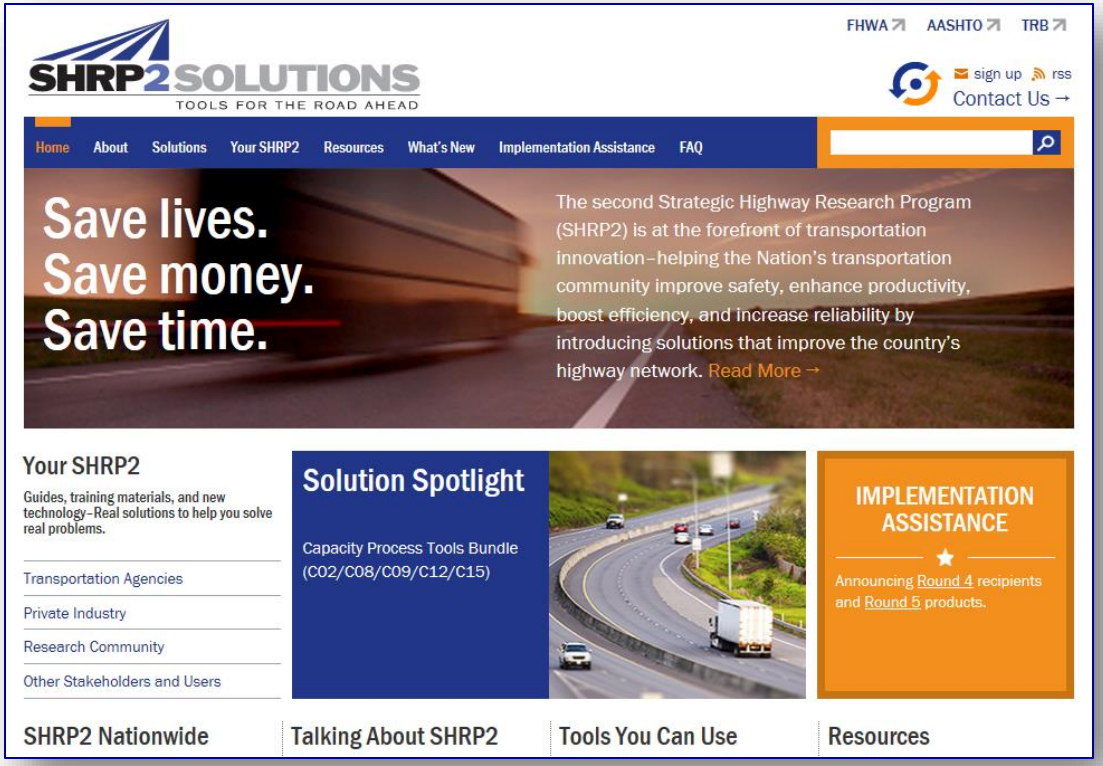

SHRP2 Websites:

https://www.fhwa.dot.gov/goshrp2

http://shrp2.transportation.org

SHRP2 Deployment Goal

***Routine use* of NDT for…**

Improved lining characterization

Asset management decision making

Control of rehabilitation options