SHRP2 Advancements in Rapid Tunnel Imaging and Nondestructive Testing

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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
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)
The National Tunnel Inspection Standard (NTIS) requirements lead 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 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
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

LASER DATA DEPICTING 200M OF TUNNEL LINING

TUNNEL LINING

ANOMALY

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 ft²/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
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**
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 – Visual vs IR Views with Areas of Concern in IR view
Chesapeake Tunnel IR and Visual Scans – “Wrapped” Image Scans at Tunnel Transition
Chesapeake Tunnel IR and Visual Scans of Wall

Visual Image

IR Image
Area of Concern

Construction Joint
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