TECHNOLOGY DIGEST

TD-15-012
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Tunnel Lining Inspection Field Tests on Union Pacific Railroad

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Summary

Engineering students in Transportation Technology Center, Inc.'s Affiliated Laboratory Program at Texas A&M investigated the use of infrared thermography (IRT), ultrasonic tomography (UST), and ground coupled ground penetrating radar (GPR) in an effort to improve rail tunnel inspection procedures.

The testing confirmed the practicality of these nondestructive testing (NDT) methods, demonstrated their advantages, and revealed their limitations. By implementing these methods, issues involving the structural integrity of tunnels may be discovered earlier, thus increasing rail safety and reducing maintenance costs. Additionally, by using a two-step process by which defects are detected using a rapid NDT method and further explored using a more detailed NDT method, the overall track time is reduced.

The methods were tested on the concrete lined sections of the Moab Tunnel in Moab, Utah, and produced the following results:

- IRT
  - Rapid NDT method; can be used as a first step to identify locations that need further examination using a more detailed, slower NDT method; e.g., UST or GPR.
  - Only detects the shallowest of problems; detects delamination up to 2 inches deep and voids up to 4 inches deep.
  - Should be used when the ambient temperature is changing at a high rate; scans need to be taken traveling in both directions through the tunnel; heat from the sun shining through the portal alters the thermal video.
  - Detects moisture infiltrations in rock sections, the location of rock bolts, and shotcrete failures.
- GPR
  - Slower NDT method than IRT, but faster than the UST method.
  - Effective method in detecting steel; useful in determining the concrete lining construction.
  - Poor detector of delamination if the gap is not adequate to reflect the electromagnetic waves.
  - Inaccurate at detecting the depths and thickness of defects as compared to UST.
- UST
  - Best method at detecting issues within the tunnel lining; very slow and tedious procedure.
  - Scans must be made with the system oriented both horizontally and vertically to fully describe the construction reinforcement.
  - Locating defects and reinforcement is more accurate with this method than when using the GPR method.
  - Shear waves cannot pass though air voids, meaning that layered defects cannot be detected.

INTRODUCTION

The structural integrity of railroad tunnels is an important issue to the railroads. Tunnel lining issues, such as voiding, spalling, delamination, excess water infiltration, or corrosion could weaken the integrity of the lining.

Current tunnel inspection methods include a visual identification of defects and hammer sounding. While these methods are effective, they are quite time consuming, requiring an extended and costly period of track closure for a thorough inspection. Because track time in tunnels can be extremely limited, these methods may not allow for frequent, thorough tunnel inspections. Additionally, problems that occur below the surface may not be visible, and the hammer sounding methodology is somewhat limited due to the subjectivity involved with the interpretation of the results. Therefore, NDT methods have the opportunity to benefit current inspection techniques to provide information about the integrity of the concrete lining below the surface. A supplement to visual inspection is the NDT technique of pulse-echo inspection. Similar to what is done in rail flaw inspection, the inspection involves looking for reflections of sound pulses from flaws in the tunnel lining material. However, it too is a slow method and does not cover a very large surface area, resulting in a reduced likelihood of finding a defect without surface issues. Consequently, there is a need for new and improved inspection techniques.

The objectives of this research, conducted by Texas A&M engineering students participating in TTCI's Affiliated Laboratory Program, include determining which NDT methods are applicable for inspecting tunnels and providing results using the selected methods to show their strengths, limitations, and accuracy.

Applicable NDT Methods

While many NDT methods exist, few are applicable for tunnel inspections in which only one side of the lining is accessible. The number of applicable methods is further reduced because of the curvature of the tunnel lining, whether along the top or the walls themselves. The three methods chosen for testing include IRT, GPR, and UST.

IRT is a fast and easy to use methodology to detect temperature anomalies. These anomalies can represent moisture infiltration, delamination, or shallow voiding. The most useful time to use IRT is when the ambient temperature is rising or declining at a high rate. The concrete lining will change temperature at a different rate when a defect or moisture is present. The uneven cooling or heating provides the anomalies that are visible in the temperature profile. The thermal device used in this research was the FLIR® T640. It can be used for a temperature range of -40ºF to 3,632ºF and is calibrated to an accuracy within +/-2% of the reading.[1] The frame rate for the camera is 30 Hz. The device was used in conjunction with FLIR® Tools+ software for post processing.

GPR is a slow, detailed NDT methodology. It was chosen based on its usefulness and resolution in concrete[1]. The GPR emits electromagnetic radiation and receives the corresponding reflections. These reflections occur at layer interfaces because of the differences in the dielectric properties of the materials. Higher device frequencies are associated with shallower radiation penetration but higher resolution. The GSSI StructureScan Mini HR GPR device was chosen for this research. It has a frequency of 2.6 GHz, which allows it to penetrate up to 16 inches and provide high resolution results. The RADAN software was used for post processing of collected data.

Ultrasonic tomography is another relatively slow, detailed NDT methodology. The device emits ultrasonic shear waves and receives the reflections. The primary cause for the reflected waves is density change. Because shear waves cannot propagate through air, a strong reflection occurs when debonding or voiding is present.[1] The A1040 MIRA device was used in this research. It has matrix of 12 x 4 dry contact transducers. The center frequency can be set at 25, 50, or 85 kHz. The device can be used to test at a depth of 2 to 80 inches. The software in the device uses the synthetic aperture focusing technique, which allows the device to create a 2D image based on the transit time measurements. When the device is used on a grid, a 3D image can be obtained by using IDEALviewer software.

IN FIELD TESTING

The three NDT methods described above were used to inspect the concrete lined sections of the Moab Tunnel, which was built in 1962 using the drill and blast method to serve a nearby Potash mine. It is currently owned by Union Pacific. The tunnel is primarily rock with rock bolts and shotcrete, with some bare rock sections. There are four concrete sections for which the NDT methods could be evaluated. These sections of the tunnel were 23 feet high and 16 feet wide. The lining construction was unknown. Table 1 shows the length of each tunnel section and its location. Segment A begins at the east portal and Segment G terminates at the west portal.

Table 1: Moab Tunnel Segment Lengths

Segment	Total Length (ft)	Length in Curve (ft)	Lining
A	45	45	Concrete
B	263	263	Natural Rock
C	96	96	Concrete
D	2417	2417	Natural Rock
E	125	125	Concrete
F	3900	79	Natural Rock
G	215	0	Concrete
Total:	7061	3025	

The IRT was completed using the FLIR® camera's video mode. The device was mounted to a high rail truck and videos were taken at various speeds (2 to 8 mph).

Three of the videos were taken while driving from the east portal to the west portal. The last was taken while driving in the opposite direction. A 3-year temperature study revealed that the best time for using IRT is between 7:00 a.m. and 12:00 p.m.[2] The actual measurements were taken between 9:00 a.m. and 12:00 p.m.

Segment E-Grid

Based on the thermal images of the infrared camera, a grid was placed on the side wall of Segment E to facilitate more accurately locating and identifying potential flaws. Investigators chose the area based on the large temperature differential, and because it was not located on a construction joint. While other similar areas appeared in this segment, the temperature differential did not appear to be as significant. Figure 1 shows the infrared image of the scan.

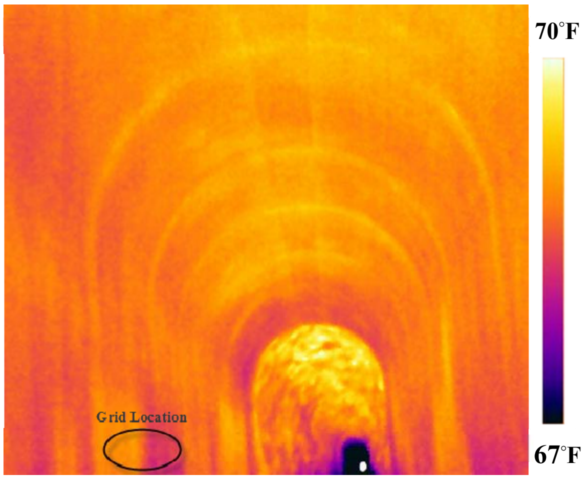

Figure 1: Infrared Image

The grid was 10 x 8 feet in size with 2-inch spacing between gridlines. Figure 2 shows an image of the custom grid.

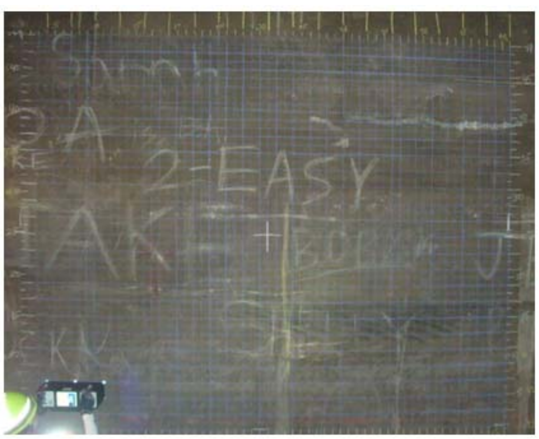

Figure 2: Grid Lines applied to Tunnel Lining Wall to assist in detailed Inspection of the Thermal Anomaly found In Figure 1.

The GPR scans were generated for each gridline in both the vertical and horizontal direction to develop a 3D scan. The GPR of the grid provided a lot of information on the construction of the tunnel lining. Because the grid was so large, many different features were identified, including rebar in both directions and the spacing of the reinforcement beams. Figure 3 shows a C-scan at a depth of 2.42 inches.

Using the scan shown in Figure 3, the spacing of the reinforcing beams was identified to be about 5 feet. Scans at deeper depths revealed two vertical rebar located between the reinforcing beams. The area that is labeled "Unknown" is believed to be rebar that was placed improperly, as it was not located at a depth consistent with the other reinforcement. Another reinforcing beam was identified just outside of the grid, which would mean that the Unknown rebar would be the second between two beams. This is consistent with the construction identified within the grid.

Horizontal rebar was identified in the C-scan at 5.71 inches. The horizontal rebars were spaced at 57 inches. The GPR was also able to locate the back wall of the concrete lining, suggesting that it must be partially debonded in this area of inspection.

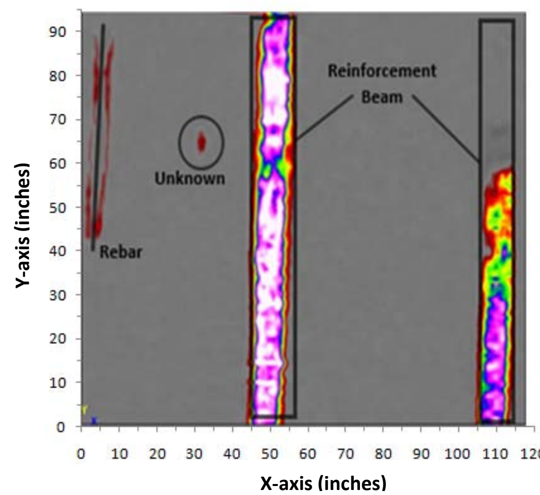

Figure 3: GPR C-Scan at 2.42 inches

The UST device was used with a step size of 2 inches in the vertical direction and 6 inches in the horizontal direction. Scans were obtained with the unit oriented both horizontally and vertically. This allowed the UST device to detect all the rebar and beams, including the Unknown bar. Figure 4 shows the data from the horizontal orientation.

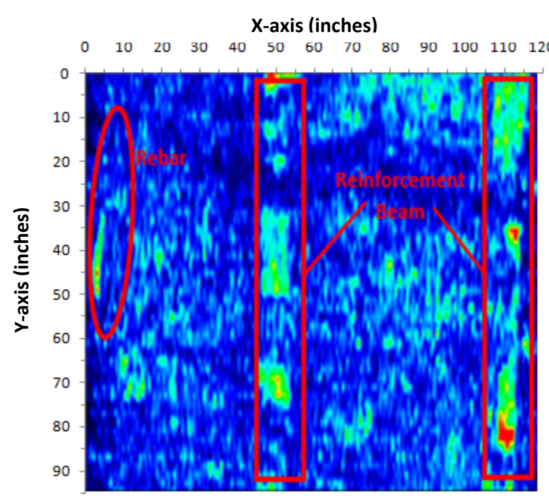

Figure 4: UST C-Scan at 3.15 inches

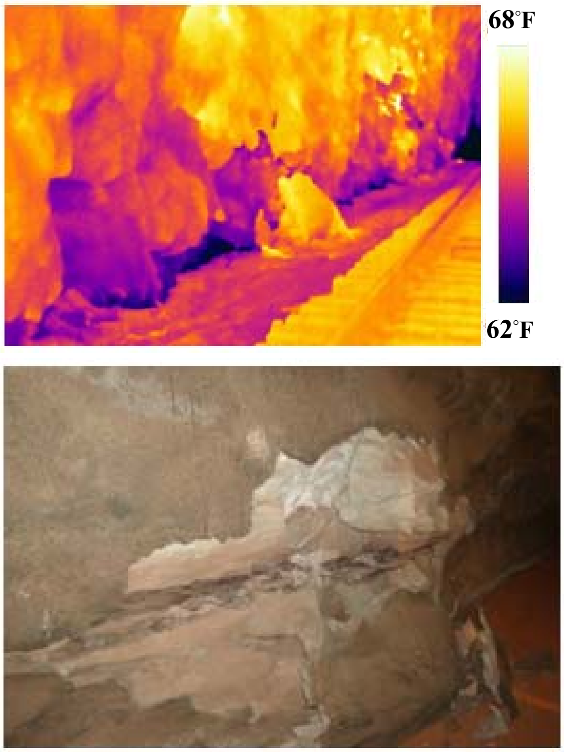

Figure 5: Shotcrete Lining Failure

The reinforcing beams and the back wall of the tunnel lining were detected in both scanning directions. The locations were consistent with those obtained using GPR. However, when the unit was oriented horizontally, it was not able to detect the horizontal rebar and when it was oriented vertically, it was unable to detect the vertical rebar. This is a consequence of the resolution of the MIRA device, the size of the reinforcement and step size of the grid.

No anomalies were discovered that would have caused the temperature variation detected with the thermal camera. The detection of the back wall seemed to correspond to the location of the temperature change, yet that difference would be too deep for the thermal camera to detect. The temperature difference was either due to environmental factors or undetected properties with the lining.

Other Results

The IRT was also able to identify a location in the tunnel where the shotcrete lining had failed. In fact, a large piece (approximately 2 feet by 5 feet) of the tunnel lining had fallen to the ground at this location. This shotcrete lining failure is visible in Figure 5.

The infrared camera was also able to detect water infiltration in the natural rock sections of the tunnel. Figure 6 is a thermal image showing a large area of water within the rock Segment F.

Finally, the infrared camera also detected rock bolts, many of which were not visible by sight.

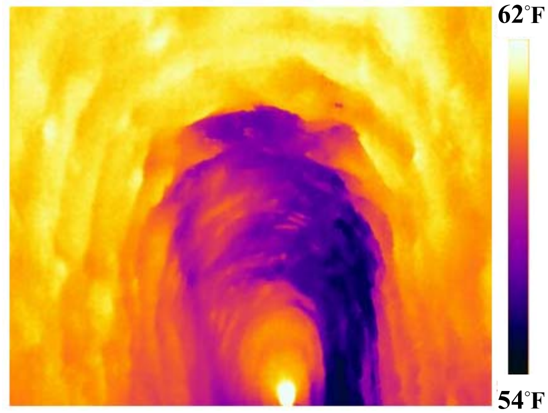

Figure 6: Water Infiltration

CONCLUSIONS

All of the methods worked appropriately and accomplished the overall objectives. The IRT method allowed for quick scanning of the Moab Tunnel and provided information for two detailed scanning locations. One of the locations had a defect that was detected with both the GPR and UST devices. Thermal imaging also proved to be useful in determining areas of water infiltration within tunnels. GPR provided detailed information about the construction of the Moab tunnel; however, it is unable to detect delamination well if the gap is not adequate to reflect the electromagnetic waves. The depths and thicknesses it detected were less accurate than those obtained using the UST device; however, the GSSI StructureScan Mini HR was easy to use and scanned faster than the MIRA device. The biggest drawback of the UST method is that it cannot pass through air voids and water filled voids. If there are any layered problems, this device will only be able to detect the one closest to the surface. It is also a very slow process to scan a large area with the device. When the device is oriented appropriately, it can detect rebar. Therefore, scanning needs to be done in both orientations to obtain a complete understanding of the construction reinforcement. Overall, these three devices provided important information about the Moab Tunnel lining that could not be determined using current investigation standards. This research shows that these methods could improve tunnel inspections and allow for more issues to be discovered earlier providing safer tunnels.

ACKNOWLEDGEMENTS

We would like to thank the Association of American Railroads for their financial support of this research, and the Union Pacific Railroad for allowing access to the Moab Tunnel and providing both vehicles and manpower. A special thanks to T. Bowley, R.L. Anderson, R. Griffin, R.E. Eller, M. Freeman, and T.A. Barlett for their time, energy, and expertise.

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