PENNDOT Experience with NDT Testing on Tunnels in Pittsburgh

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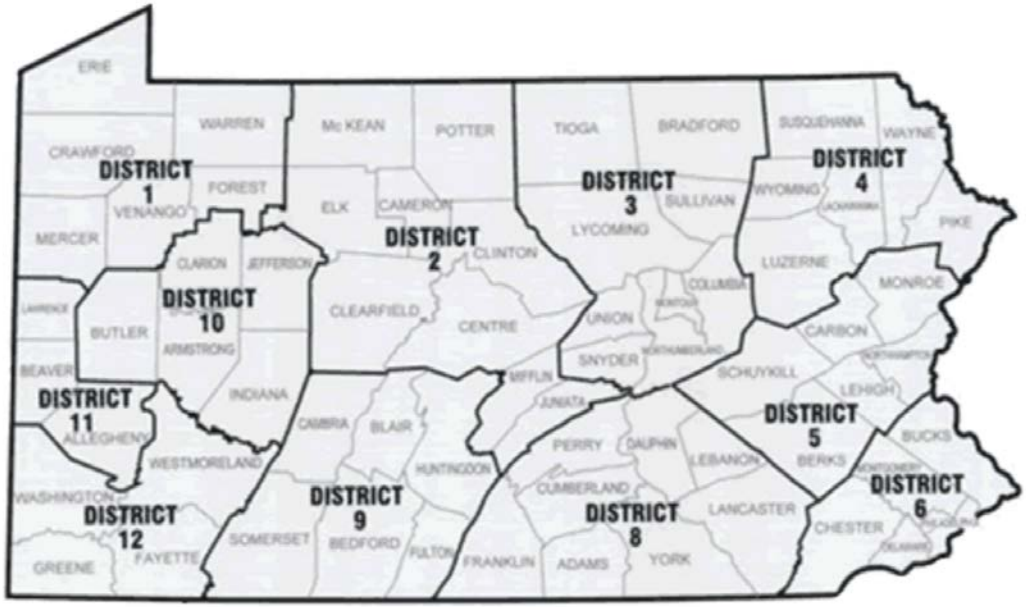
PENNDOT

- PENNDOT is divided into 11 engineering districts
- District 11 includes 3 county and 1 tunnels organization



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Tunnels in PENNDOT Dist. 11

PENNDOT District 11 owns and operates 4 tunnels and has oversight of 3 local tunnels

State-owned Tunnels

- Fort Pitt Tunnels
- Squirrel Hill Tunnels
- Liberty Tunnels
- Stowe Tunnel

Locally Owned Tunnels

- Armstrong Tunnel (Allegheny County)
- Corliss Tunnel (City of Pittsburgh)
- Wabash Tunnel (Port Authority of Allegheny County)

Busway Tunnels

- Berry Street Busway Tunnel
- Mt. Washington Tunnel

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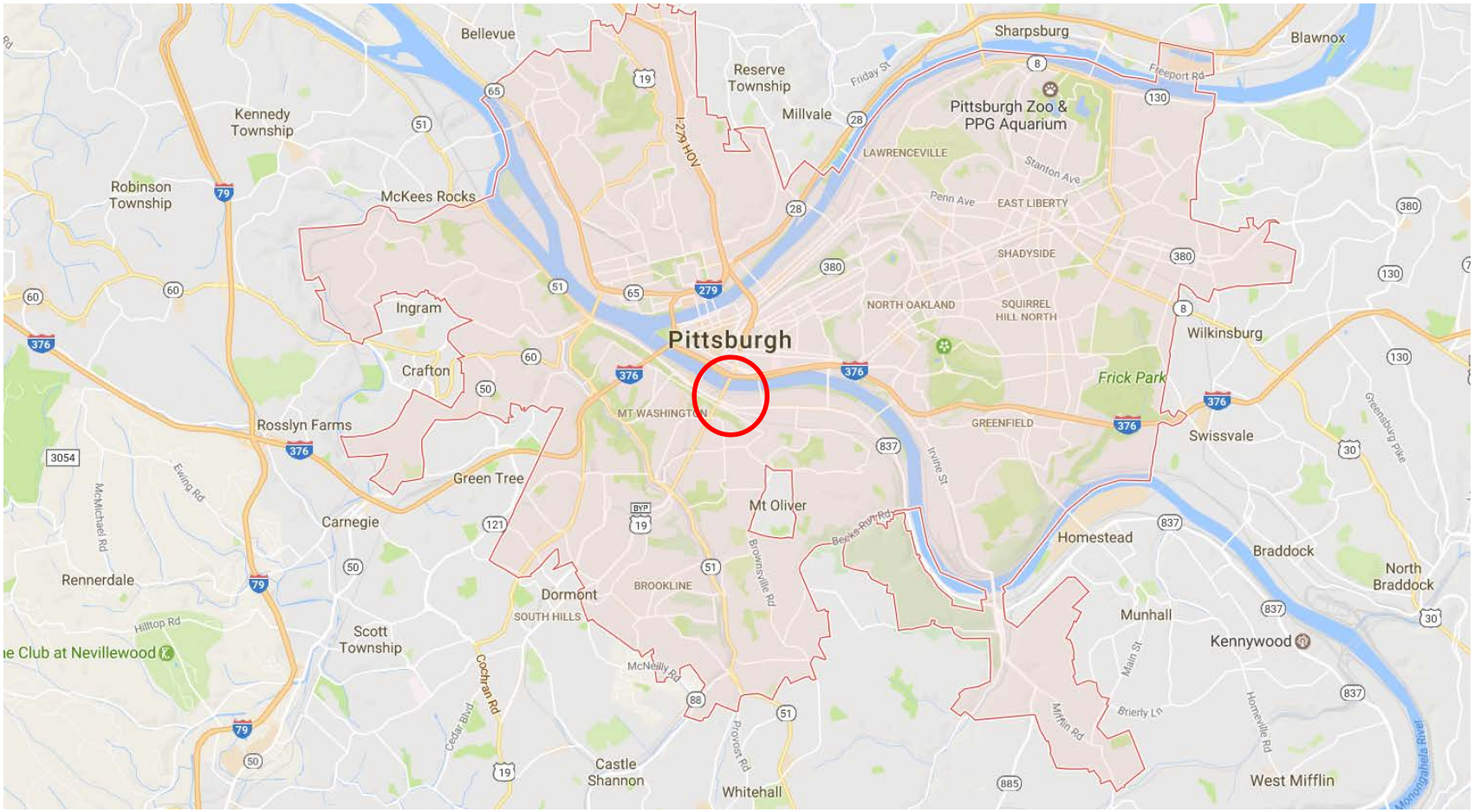
Liberty & Armstrong Tunnel NDT Testing



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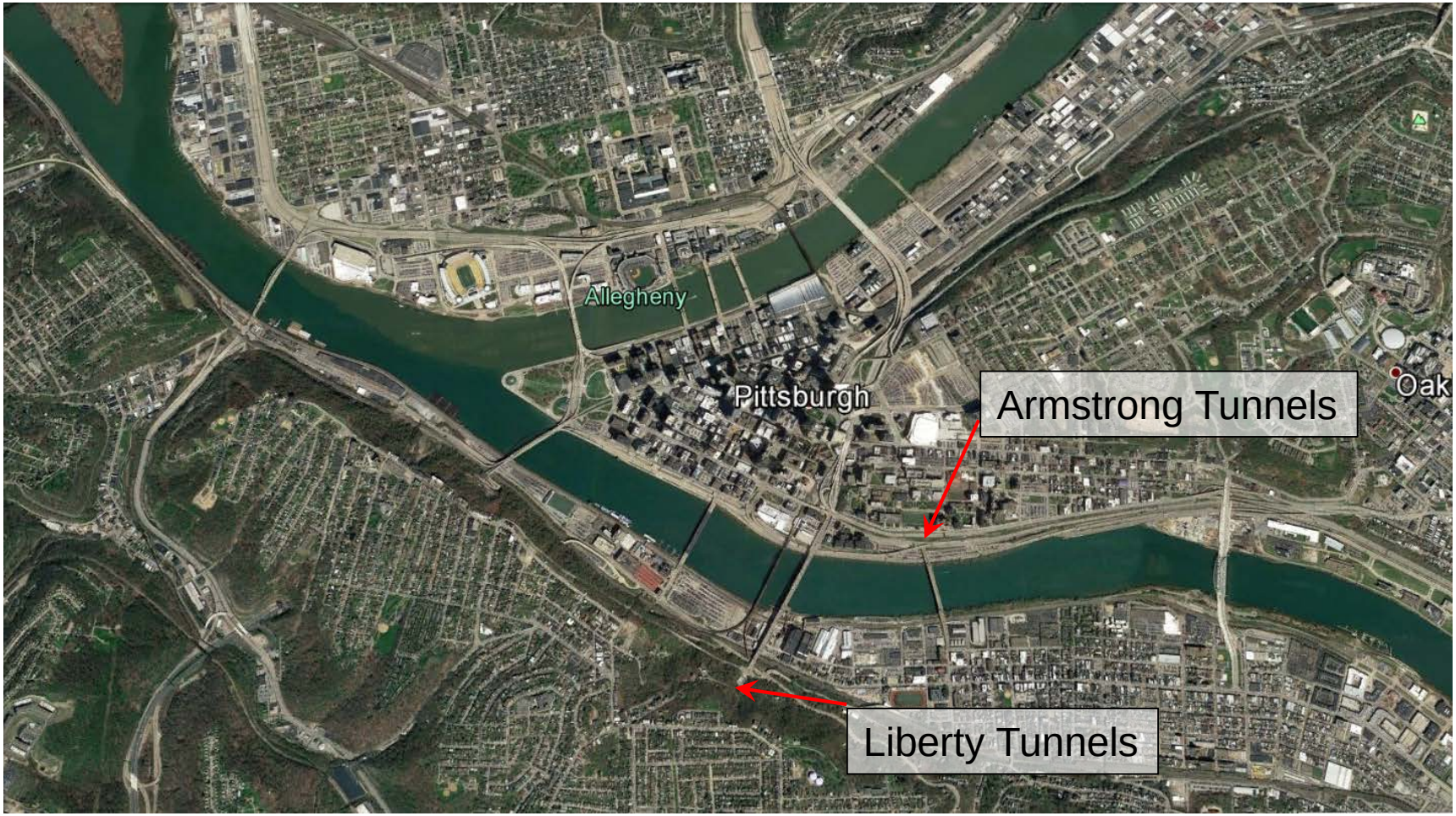
Liberty & Armstrong Tunnel NDT Testing



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Liberty Tunnels

- Cast-in-place (CIP) R/C arch built in 1926; rehabbed with synthetic fiber reinforced repairs and galvanized WWF (2011).
- 2 bores (NB & SB), 2 lanes per bore
- 5898’ long, curb-to-curb width of 23’-0” and height of 20’-9 ¼” at the arch apex.
- ADT = 17,652 vehicles/day in NB bore

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Armstrong Tunnel

- Cast-in-place (CIP) R/C arch with tile-lined walls; built in 1927, rehabilitated in 1991.
- 2 bores (NB & SB), 2 lanes per bore
- 1300’ long, curb-to-curb width of 20’-0” and height of 22’-0” at the arch apex.
- ADT = 9,230 vehicles/day in NB bore

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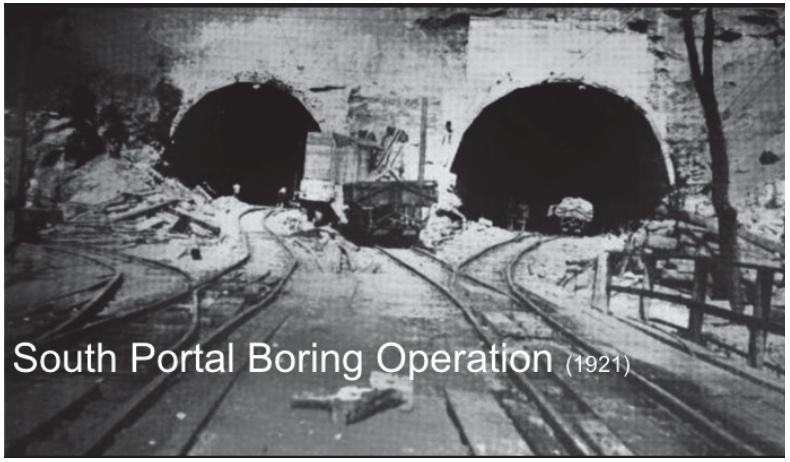
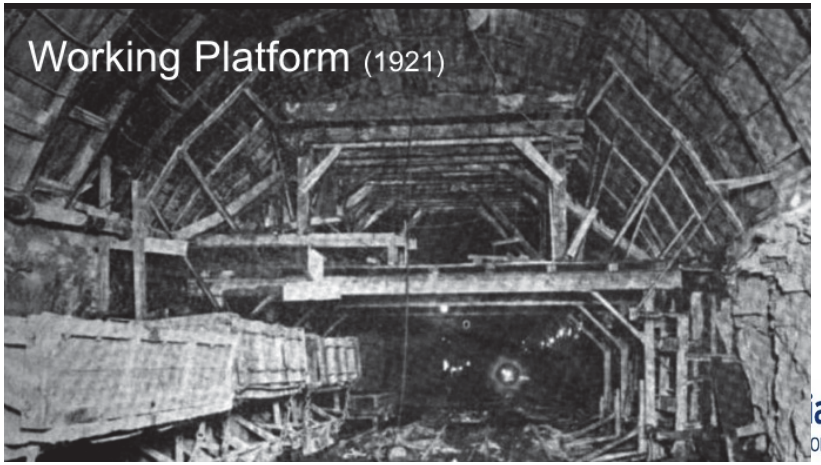
Project Background

- PENNDOT received a $250,000 grant from the FHWA to perform NDT testing under the SHRP2 R06G program
- PENNDOT used inspection consultant Mackin Engineering to facilitate the NDT testing
- Mackin managed the project, administered NDT testing contracts, and performed additional handheld NDT testing
- NDT Testing performed by Penetradar, AID, and Mackin Engineering


South Portal Boring Operation (1921)


Working Platform (1921)

NDT Testing

NDT Methods used at Liberty:

- Ground Penetrating Radar (GPR)
- Infrared Thermography (IRT)
- Impact-Echo (IE)*
- Ultrasonic Seismic Waves (USW)*
- Portable Seismic Property Analyzer (PSPA)
- Hammer sounding and coring

*The IE and USW were performed using the PSPA device

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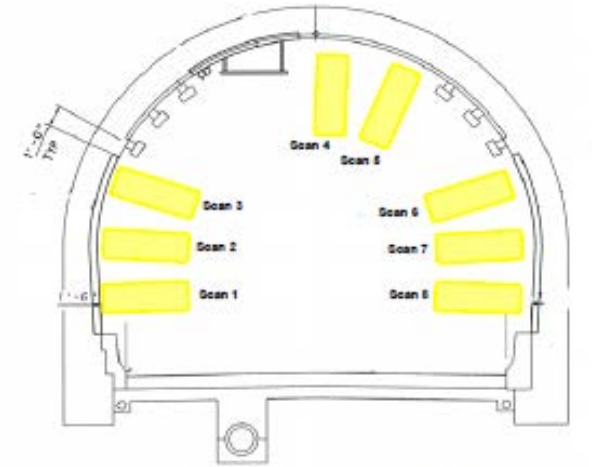
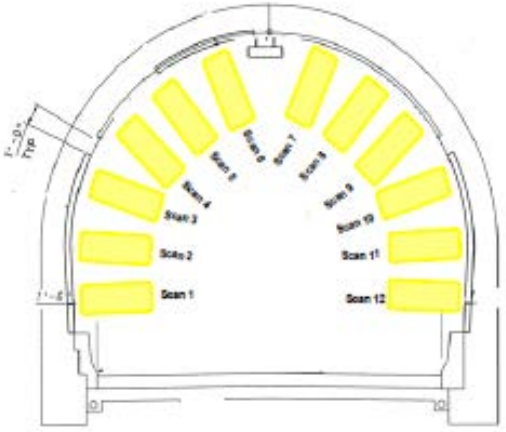
NDT Providers

Penetradar Corporation (Niagara Falls, NY)

- Performed high-speed mobile scanning using air-coupled GPR, Infrared Thermography (IRT), and video image recording
- Multiple passes required for GPR (3-6 ft widths)
- For IRT/Video, 3 passes required in each tunnel.



Liberty Tunnel - GPR Scans



Armstrong Tunnel - GPR Scans

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NDT Providers

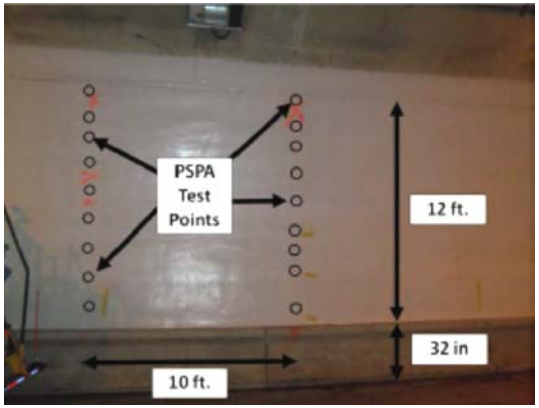
Advanced Infrastructure Design (Hamilton, NJ), which used SPACETEC (Germany)

- Performed high-speed mobile scanning using IRT, 3-D laser scanning, and video recording
  - Detects delaminated and debonded areas, spalls, cracks, efflorescence, and water infiltration. Can also detect changes in shape, bulges, etc.

Advanced Infrastructure Design

PSPA Testing:

- PSPA used to perform Impact-Echo (IE) and Ultrasonic Surface Wave (USW) analysis at “test section”.
- Test grid established to conduct PSPA testing over 200LF (10’ spacing; 9 locations vertically).
- 189 total test points – 5 hours



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Mackin Engineering

Physical Testing:

- Traditional hammer sounding was performed on the “test section” using 45-foot bucket truck
- Delam2000 – Rotary percussion tool also used to sound concrete
- Cores were taken at Station 3+475 (sound) and 3+321 (unsound)

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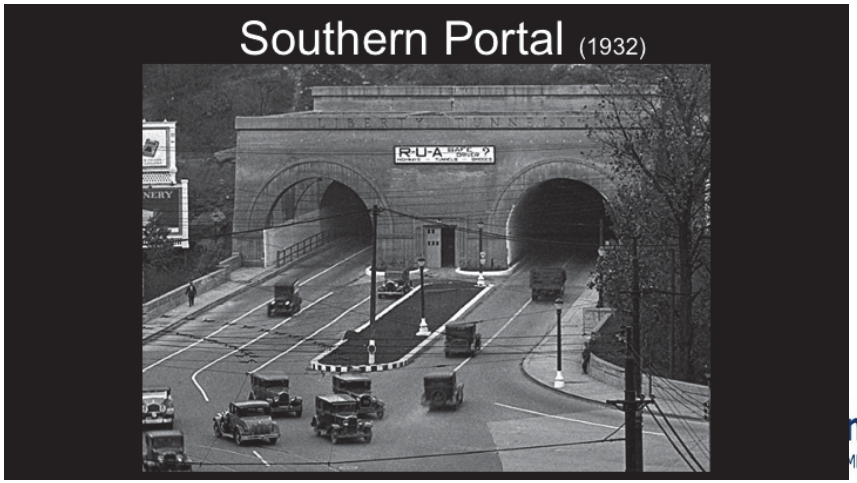
NDT Testing Schedule

Field work occurred in 2015. All work was performed overnight to minimize tunnel closure impacts to the public.

- September 21: SPACETEC (Liberty & Armstrong)
- September 22: Penetradar GPR (Liberty)
- September 23: Penetradar GPR (Liberty)
- September 24: Penetradar IRT/Video (Liberty & Armstrong)
- September 25: Penetradar GPR (Armstrong)
- November 5: Advanced Infrastructure PSPA Testing & Physical Inspection (Liberty)



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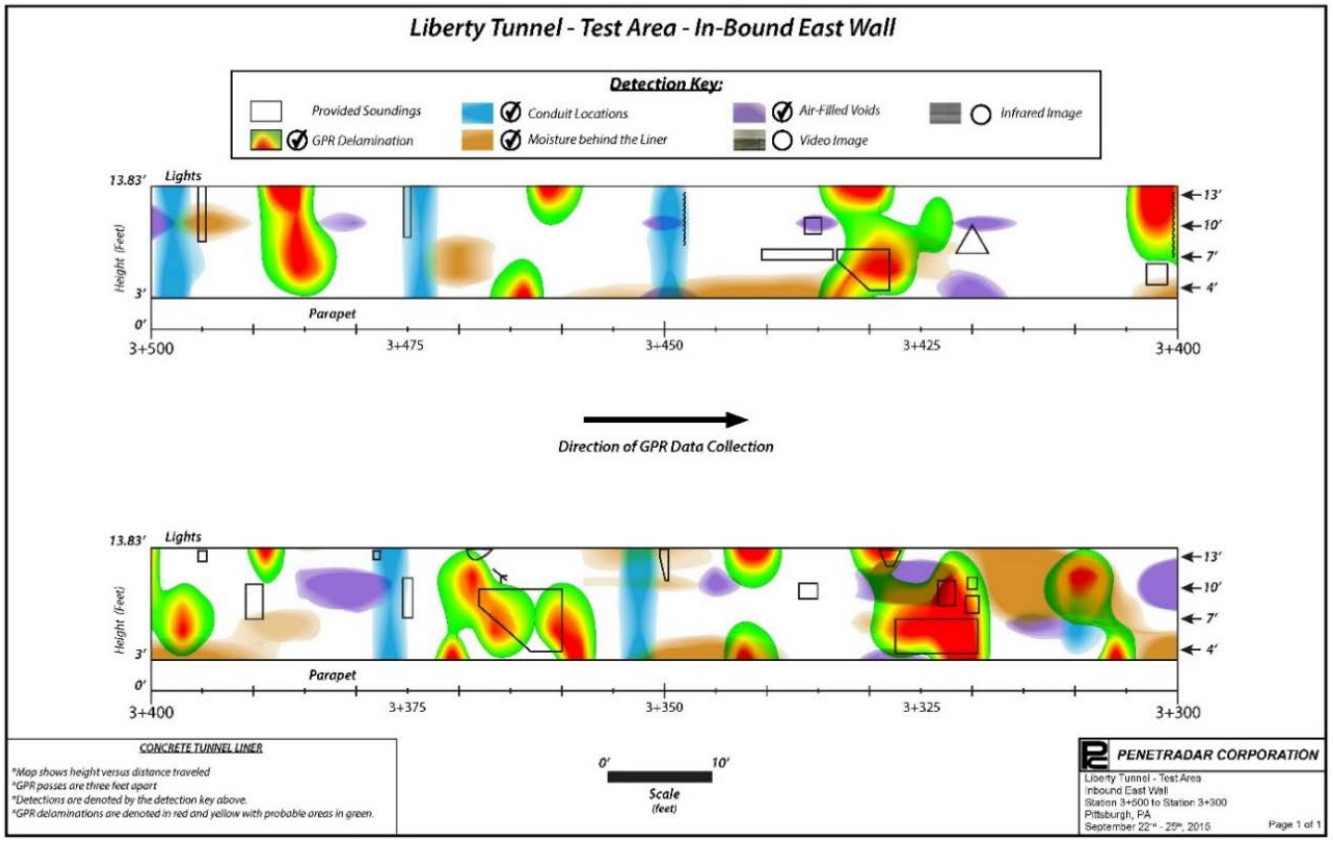
Penetradar GPR/IRT/Video

Penetradar provided interactive map to toggle on/off various defects (“test section” shown below as example).



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Penetradar GPR/IRT/Video:

Penetradar also provided table comparing GPR detections to 2014 inspection findings for the “test section”.

Delamination	*Soundings*	*GPR*
Area (%)	7.2	11.9
Area (Square Feet)	156	257
GPR Detection Percentage of Sounding Delaminations	73.2	
GPR Detection Percentage of Sound Areas	90.4	
Voids Behind the Liner	*GPR*	
	Percentage	*Area (SQFT)*
Moisture Areas or Water-Filled Voids	10.2 %	220
Air-Filled Voids	6.2 %	135

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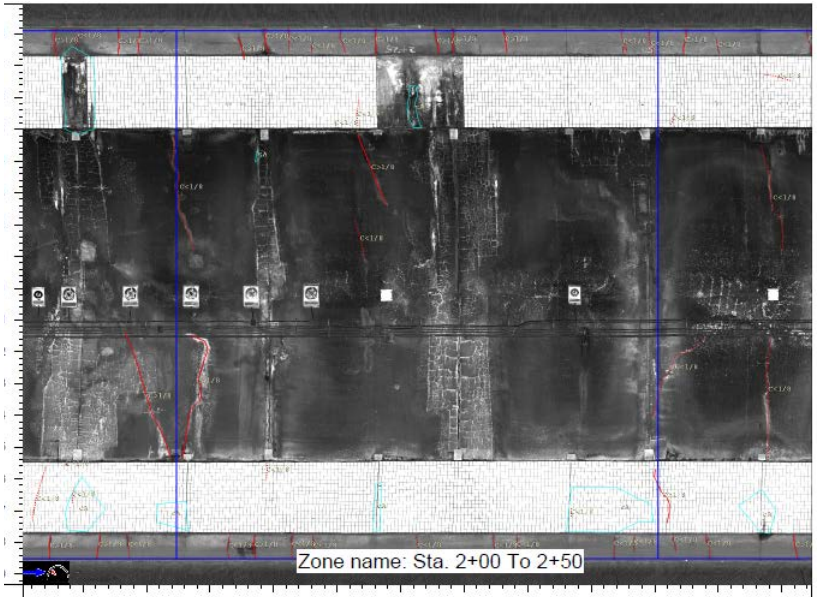
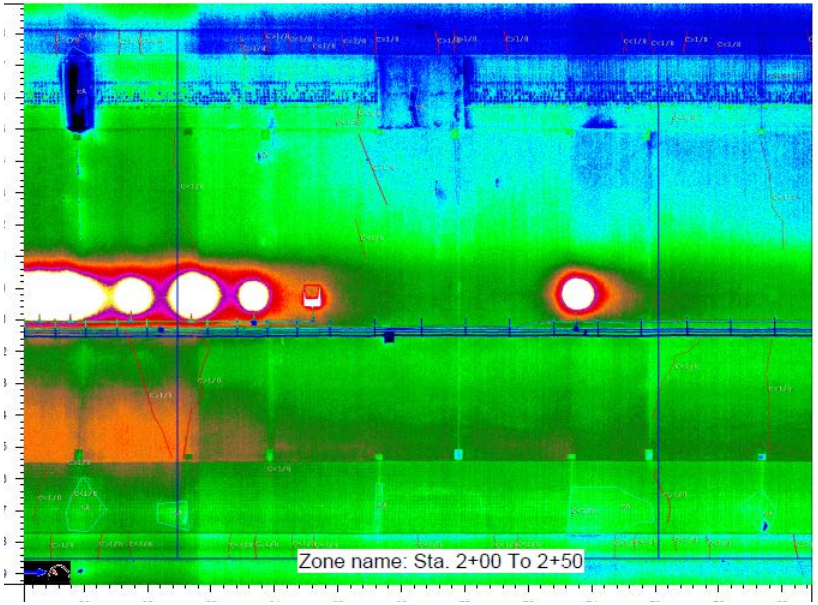
AID 3-D Laser /IRT/Video (SPACETEC)

AID provided unfolded plan views of 3-D laser and thermal images for each tunnel (typical Armstrong scans shown below).





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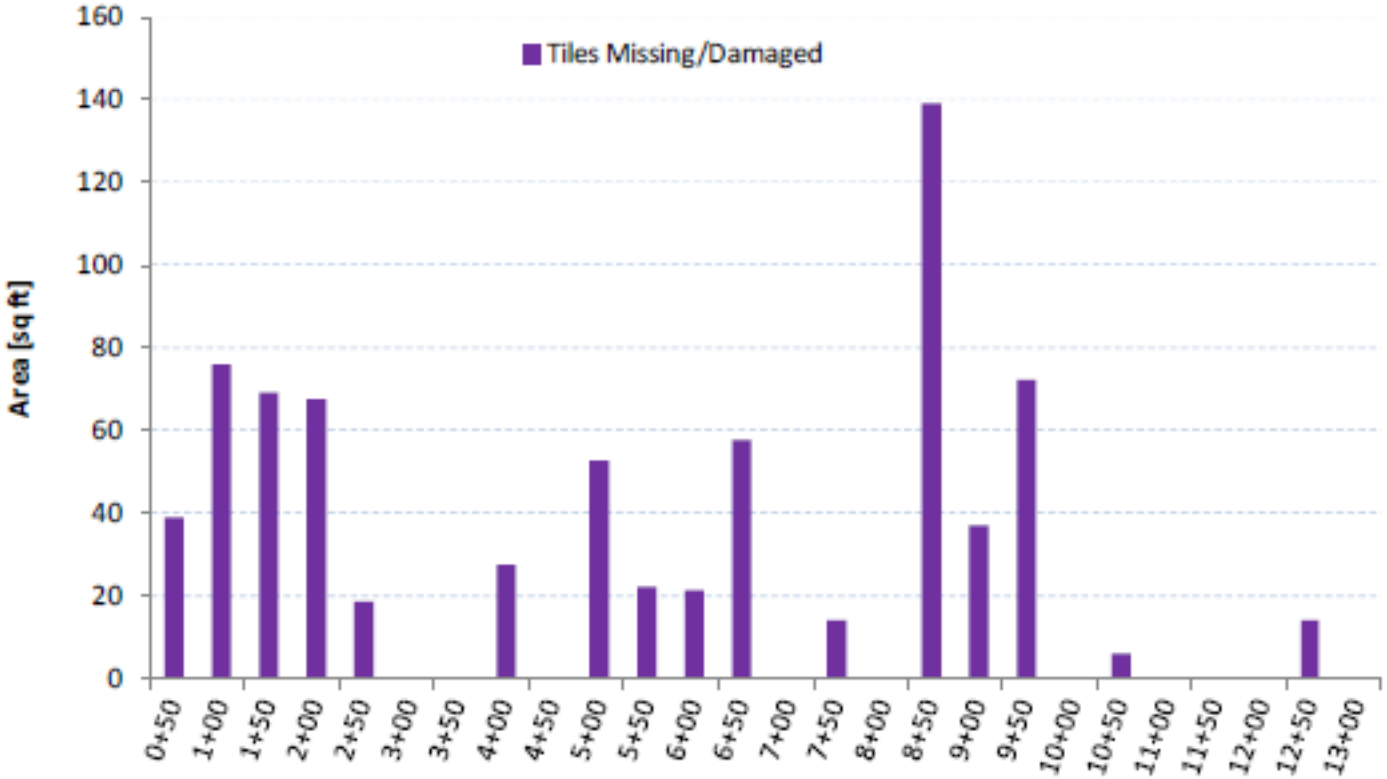
AID 3-D Laser /IRT/Video (SPACETEC)

AID also quantified various defects (cracks, warm/cold anomalies, debonded tiles) using bar charts (typical data for debonded tiles at Armstrong show below).



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Advanced Infrastructure hand-held PSPA

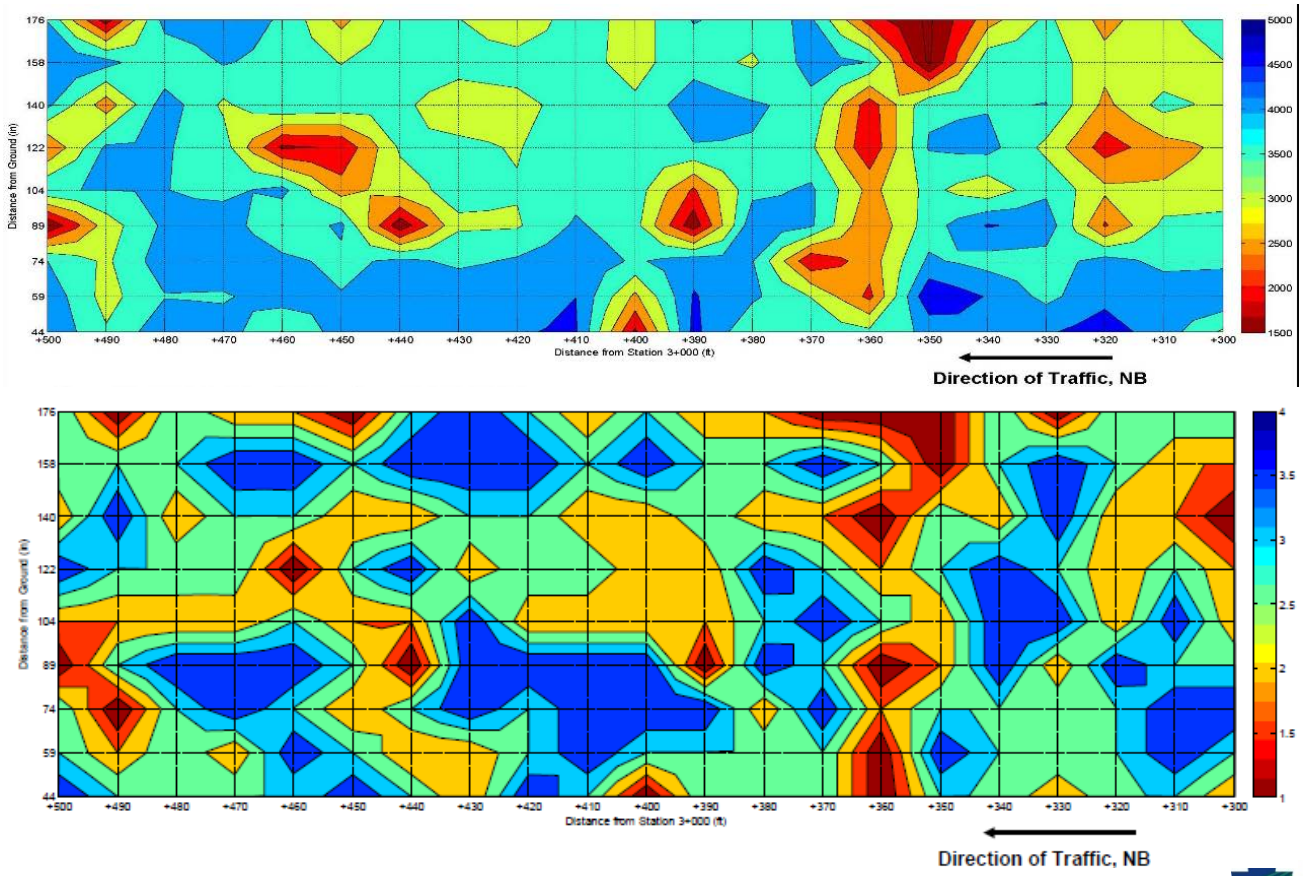
AID tabulated seismic modulus results using USW method from PSPA testing.

- Based on correlations with hammer soundings during testing, AID concluded that seismic moduli lower that 2,750 ksi were suspected as being delaminated

Distance from Ground, in	Station and Seismic Modulus (ksi)						
	3+300	3+310	3+320	3+330	3+340	3+350	3+360
176	3853	3355	2835	3617	2780	1410	2247
158	3475	3110	3170	3760	3850	1400	3993
140	3340	3677	2875	4015	3950	3925	2240
122	3103	2780	2280	3363	4183	4040	2103
104	3250	3070	3125	3880	3135	3640	2850
89	3660	3640	2427	4345	4545	3755	2525
74	3867	3865	4200	3760	3805	4080	2745
59	4427	4315	4370	3860	4465	4920	2370
44	3420	4253	4730	4445	4490	4125	3620
Average	*3599*	*3563*	*3335*	*3894*	*3911*	*3477*	*2744*
Stdev	*404*	*531*	*883*	*339*	*614*	*1229*	*656*
COV, %	*11%*	*15%*	*26%*	*9%*	*16%*	*35%*	*24%*

Advanced Infrastructure hand-held PSPA

AID also developed contour maps of seismic moduli results from USW analysis and debonding condition from IE analysis.



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Results

Comparison of NDT results and Physical Inspection results at “test section”:

- Penetradar GPR detections correlated reasonably well with hammer soundings.
- No usable data was obtained from Penetradar or SPACETEC IRT scans due to lack of temperature variation in middle of tunnel.
- PSPA testing correlated well with hammer soundings.

Conclusions

Overall:

- Penetradar was effective at detecting defects related to delaminations, moisture, and voids.
- Penetradar's combination of GPR/IRT/Video enables defects to be detected at the surface, within the liner, and behind the liner.
- Shallow delaminations (1"+/-) are difficult to detect with GPR.
- GPR cannot be used on steel liners or on tunnels with steel fiber reinforced repairs. Wire mesh fabric reinforcement should be discussed with vendor:
  - Frequency dependent
  - Antenna dependent

Conclusions

Overall:

- SPACETEC's combination of 3-D laser scanning/IRT/Video was effective at detecting cracks, tile debonding, and moisture-related defects.
- SPACETEC's combination of NDT is not capable of detecting defects through liner thickness.
- PSPA testing is effective, but only practical over small, limited areas.
- "Delam2000" good for sounding large areas fast. But difficult to delineate areas with keel/paint that are not in arms-reach.

Conclusions

Overall (general):

- Except near portals, IRT not effective for very long tunnels that are in relatively good condition. Temperature variation very important.
- IRT seems better suited for tunnels with moisture-related anomalies (evaporative cooling) and tile linings (relatively thin).
- IRT only indicates “presence” of anomaly.
- Some level of physical inspection is required regardless of NDT method.
- Still some questions regarding depth of delamination, but GPR seems best suited.

Cost

- Factors that affect cost include: tunnel dimension/geometry, type of NDT method(s), MPT requirements, data processing and report requirements, mobilization, etc.
- Penetradar (Liberty & Armstrong Inbound combined):
  - GPR (scanning & report) = $56,533 ($0.897/LF)
  - IRT (scanning & report) = $38,180 ($1.763/LF)
  - Video (scanning & report) = $26,275 ($1.213/LF)
  - Mobilization = $5,610
  - Total = $126,598

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Cost

- SPACETEC (Liberty & Armstrong Inbound combined):
  - Scanning & report = $79,412 ($10.18/LF)
  - Contingency cost for additional scanning = $6,800 per day.
  - Stand-by cost (delays, etc.) = $3,000 per day
- PSPA:
  - Total cost $14,384 (includes testing, report, mobilization, etc.) and based on 50-100 test points.
  - $143 to $286 per test point.

Cost

Other costs for scanning (Liberty):

- MPT = $16,400 ($4,100 per day)
- Equipment Truck = $2,000 ($500 per day)

Other costs for PSPA and physical inspection (Liberty):

- MPT = $4,100
- Equipment Truck = $500
- Tool Truck = $850 (for coring)
- Bucket Truck = $375 (hammer sounding)
- District 11-0 supplied lift truck for PSPA testing and performed lab testing for cores

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Cost

Compared to typical inspection of Liberty Inbound bore:

- Engineering = $37,744 (average of 2 inspections)
- Support Services = $13,600 ($6,800 per day)
- Total = $51,344

Penetradar (using 5,900LF and above unit costs):

- GPR+IRT+Video = $95,013
- MPT = $13,800 (3 days)
- Total = $108,813

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Cost

SPACETEC (using 5,900LF and $10.18/LF):

- IRT & 3-D scan & video = $60,062
- Support services = $4,600 (1 day)
- Total = $64,662

Penetradar roughly 2 times greater & SPACETEC 25% greater that traditional inspection.

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Acknowledgements

Thank You

Mackin

Olson ENGINEERING

PENETRADAR CORPORATION

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