

Damage to the 9-ft Tunnel at Mud Mountain Dam



Northwest Regional Technical Forum
August 7, 2008

Presented by: CENWS-EC-TB-HH
Douglas D. Knapp, PE



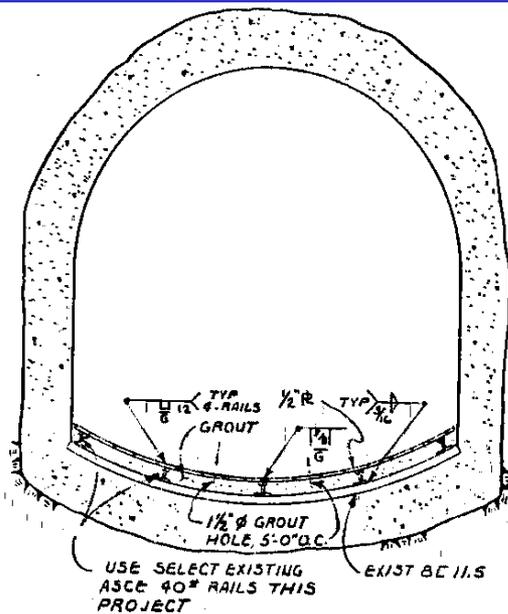
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Presentation Overview

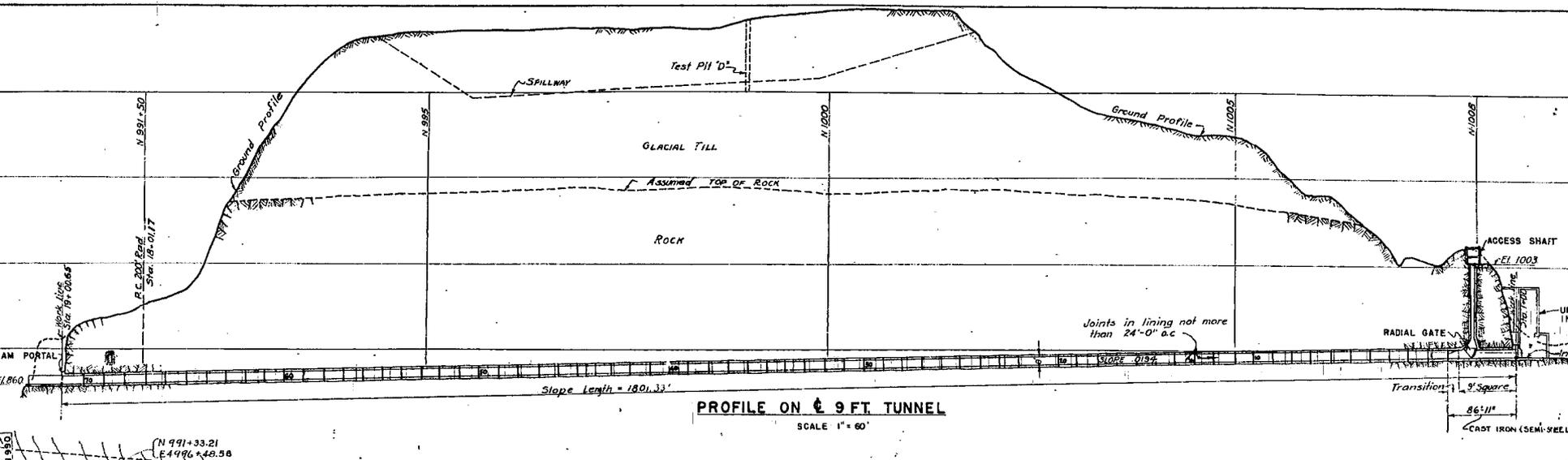
- Background
- Current Condition
- Technical Analysis
- Long-term solutions
- Questions



The Original 9-foot Tunnel

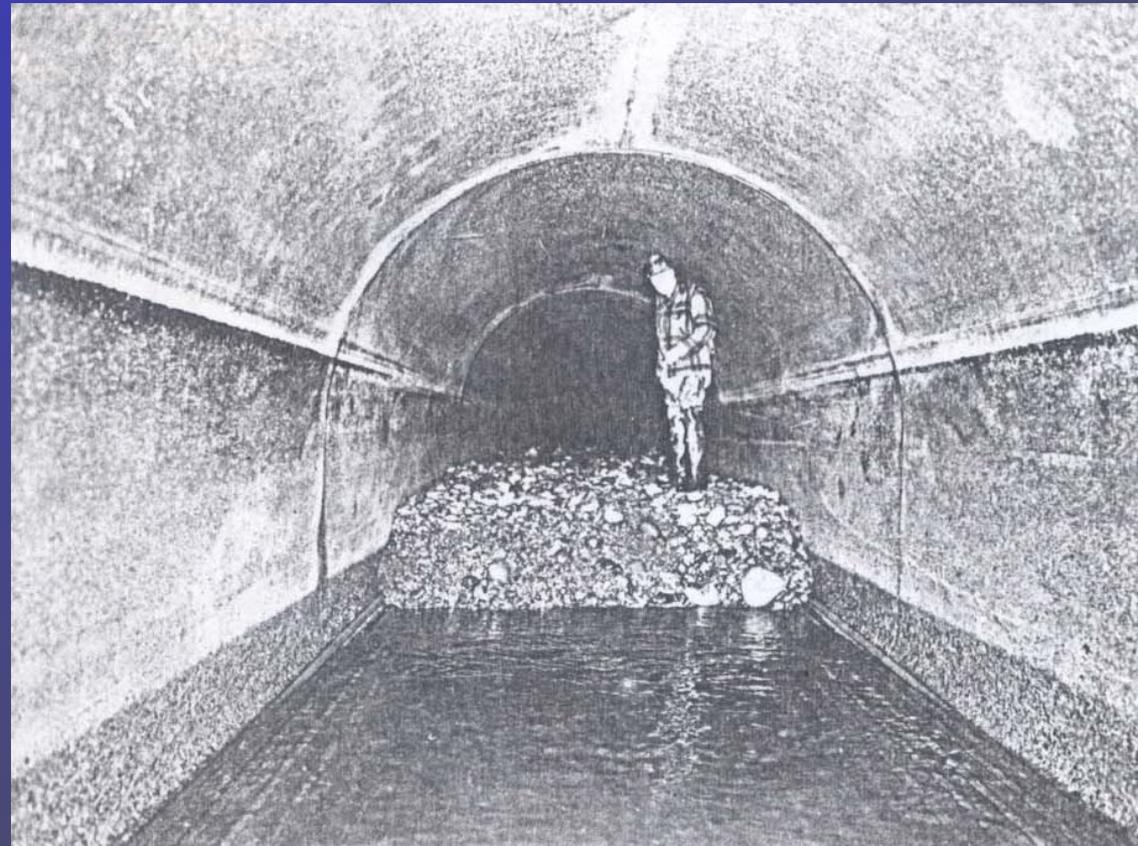


- Project officially completed in June 1953
- Length = 1800'
- Top radius = 4.5'
- Bottom Radius = 9'



The Original 9-foot Tunnel

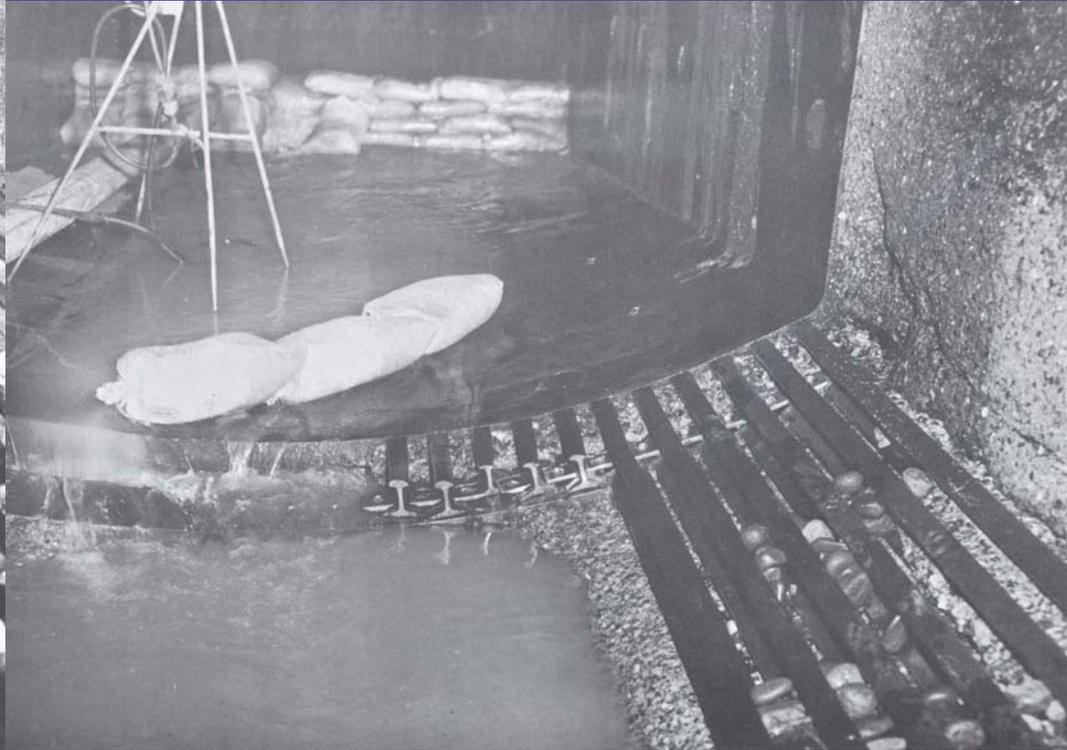
- Average annual sediment load = $\frac{1}{2}$ million cubic yards
- Rail-grout system designed to handle sediment abrasion



Historic Damage to the 9' Tunnel



- Periodic Inspection No. 1 (1968)
- Damage due to abrasion starting at the rail interface



M M Dam #4626 Upstream View of the Upstream End of 9 foot Tunnel at Transition from Liner to Rails.
Note Cavitation at Junction of Liner and Rails

Historic Damage to the 9' Tunnel



M M Dam #4873 - View of Nine Foot Tunnel Test Section Showing 1/2" X 3" Flat Bars Welded to Rails Before

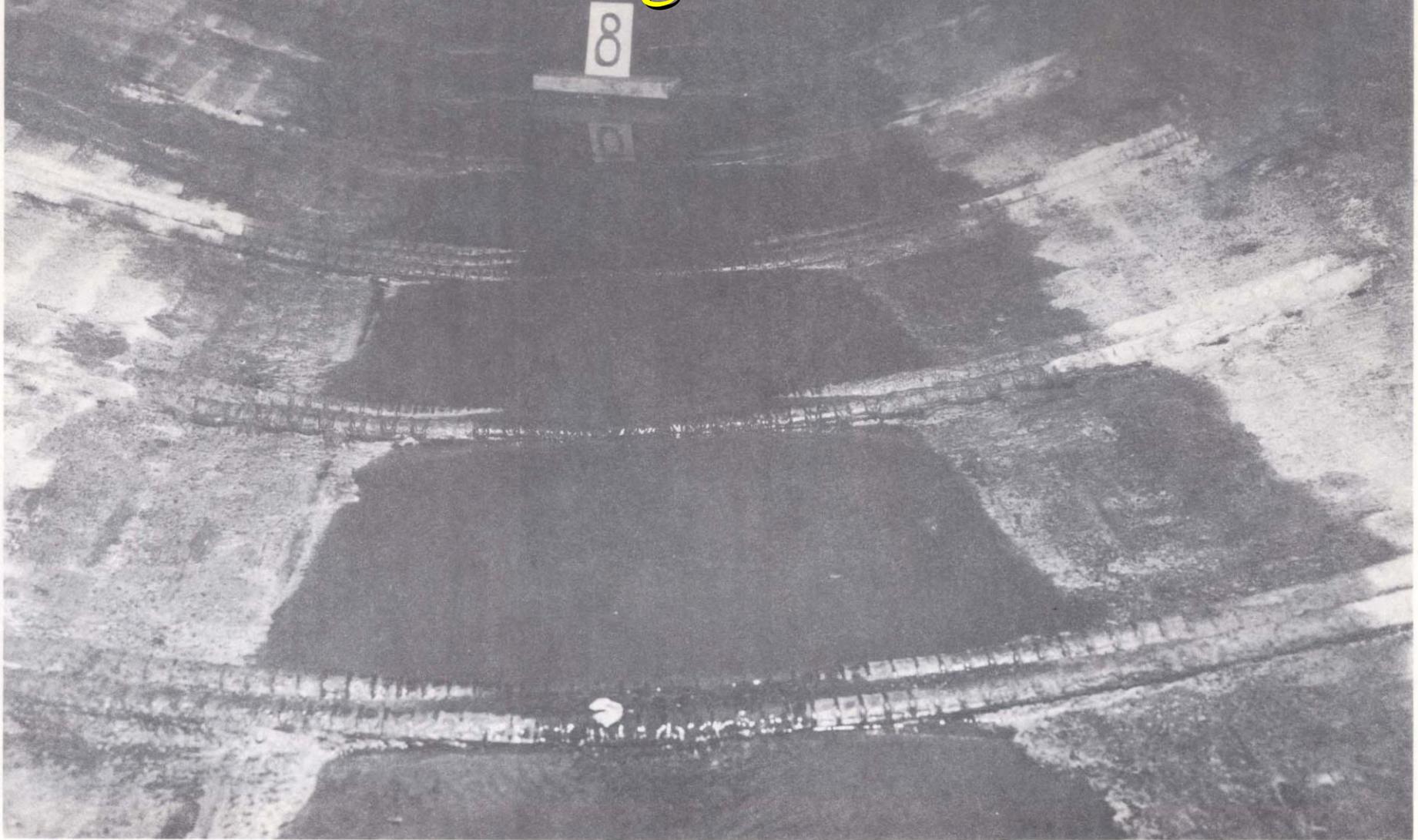
Exposure to Abrasion - 8 Jan 1971

Historic Damage to the 9' Tunnel



M M Dam #4955 - View of Nine Foot Tunnel Test Section Showing #11 Reinforcing Bars Welded to Rails After Exposure to Abrasion - 8 Sept 1971

Historic Damage to the 9' Tunnel



M M Dam #4870 - View of Nine Foot Tunnel Test Section Showing #11 Reinforcing Bars Welded to Rails Before Exposure to Abrasion - 8 Jan 1971

Historic Damage to the 9' Tunnel



M M Dam #4962 - View of Nine Foot Tunnel Test Section Showing 1/2" X 3" Flat Bars Welded to Rails After Exposure to Abrasion - 8 Sept. 1971

Historic Damage to the 9' Tunnel



Photo 9 Condition of floor of 9-foot tunnel, July 1981, prior to repair performed in September 1981.

Historic Damage to the 9' Tunnel



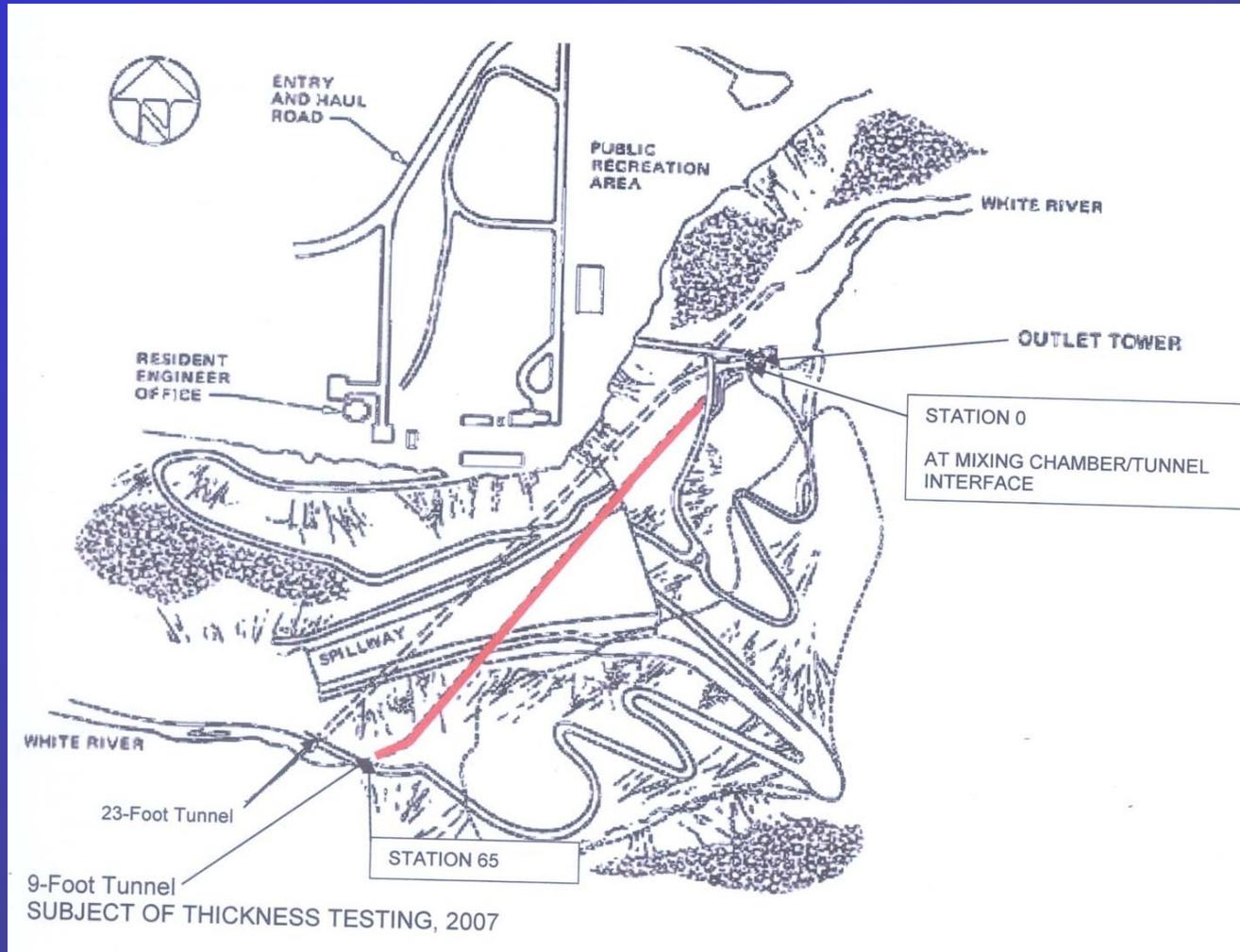
Photo 11 Condition of floor of 9-foot tunnel, May 1982. Section where concrete was placed between rails during the repair of Sept. 1981.

Historic Damage to the 9' Tunnel

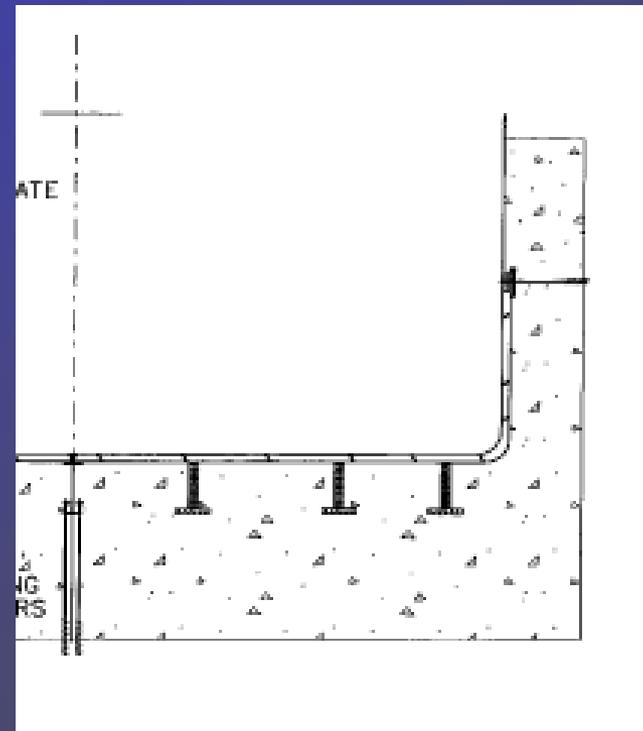
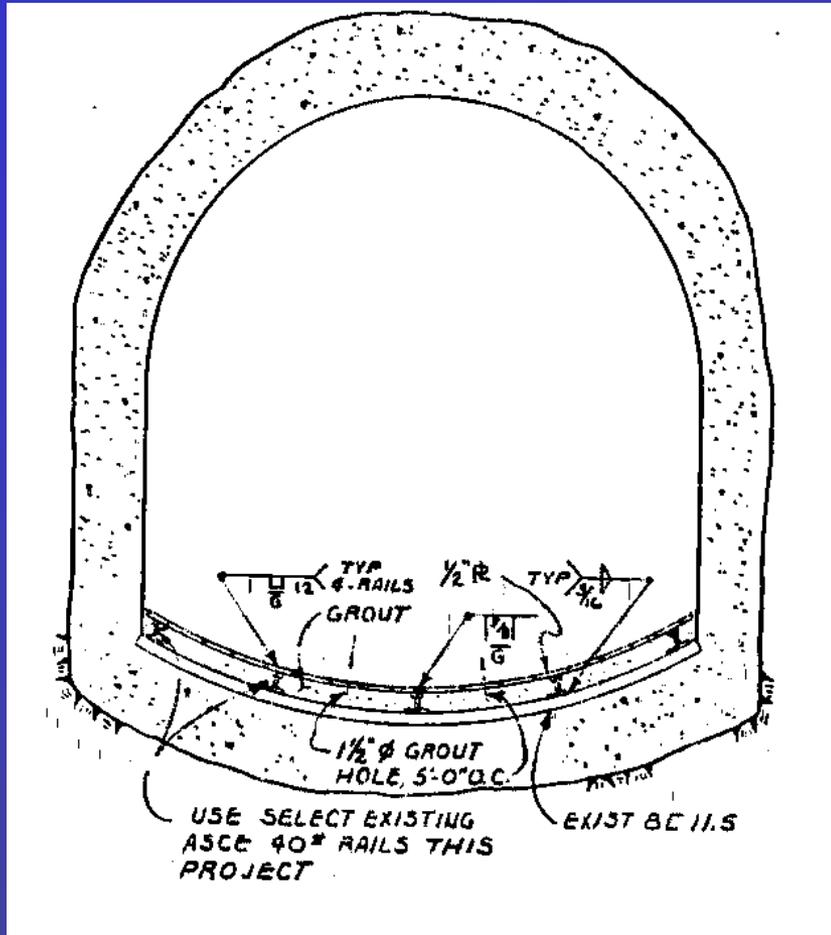


Photo 10 Condition of floor of 9-foot tunnel, May 1982. Section where grout was placed between rails during the repair of Sept. 1981.

1995 Modifications



1995 Tunnel Modification



Wall Abrasion Control (2001)



2006 Inspection



PHOTO 21 – View of Downstream Bedload that Passed thru 9-Foot Tunnel

New Intake

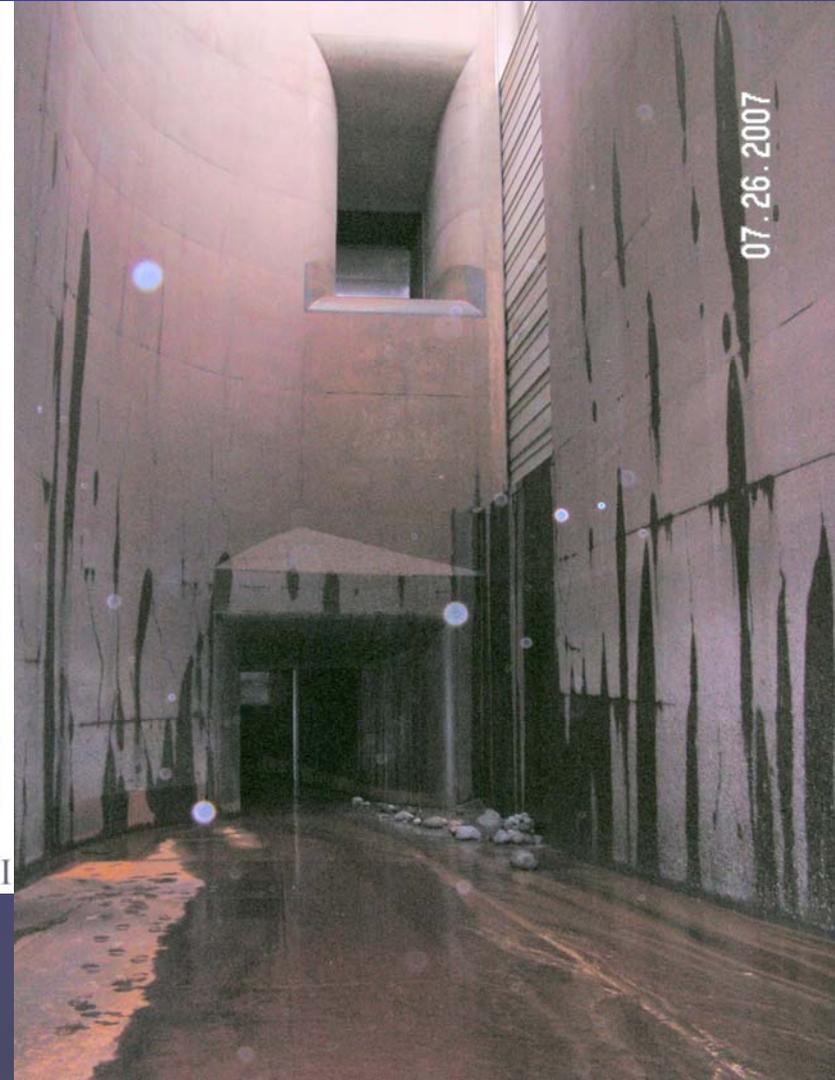


PHOTO 20 – Typical 9-Foot Tunnel Bedload, ~ 4 feet deep during the PI



AUG 2006: Periodic Inspection

- First hole found 08/15/2006
- Five total holes found with UT testing
- Holes Patched with Belzona in September



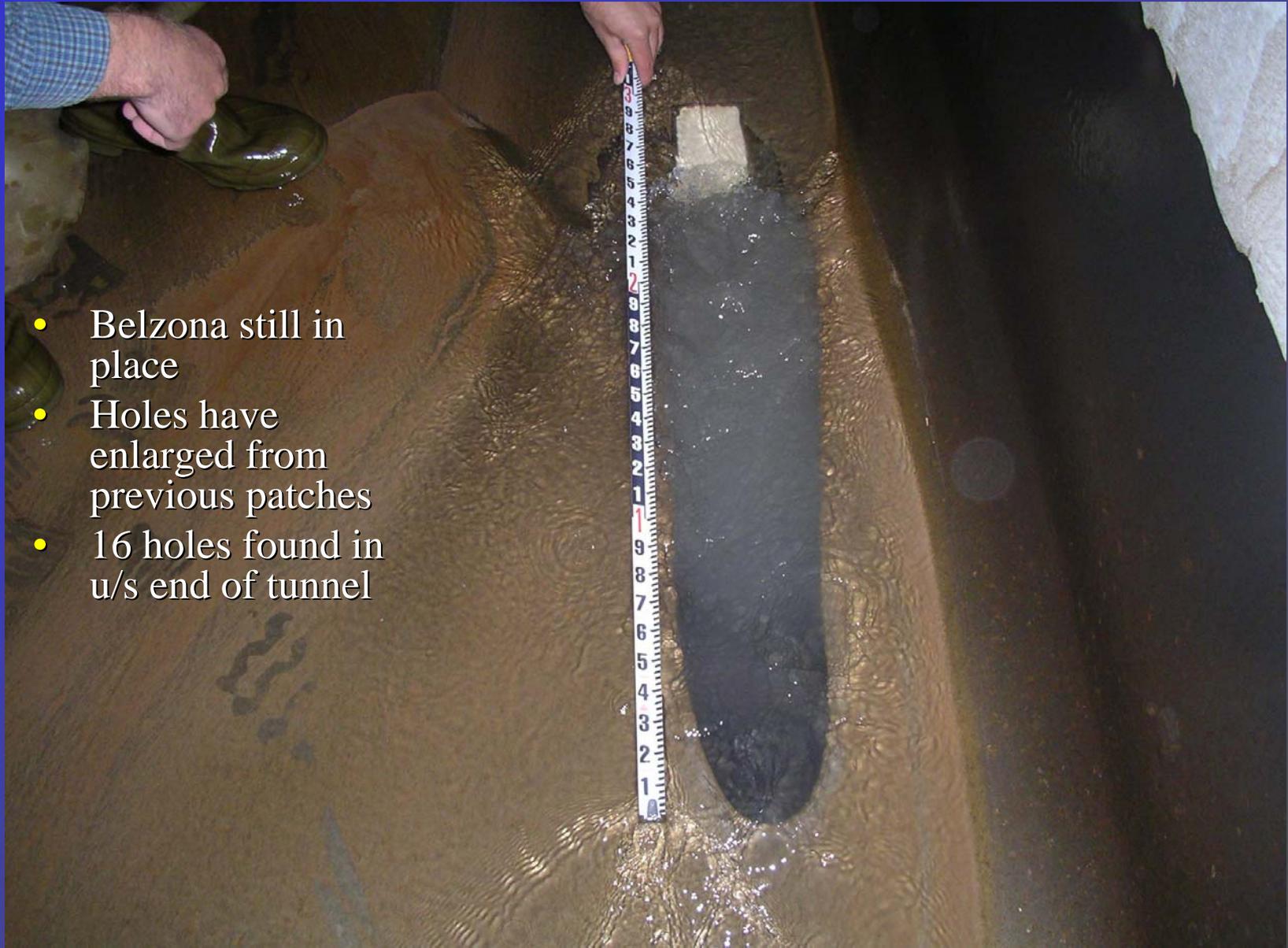
2006: Periodic Inspection

- Holes formed on (or just d/s) inside bend of tunnel
- Also typically occur just d/s of plate weld/seam



8/15/2006

2007: 9' Tunnel Inspection



- Belzona still in place
- Holes have enlarged from previous patches
- 16 holes found in u/s end of tunnel



2007: 9' Tunnel Inspection

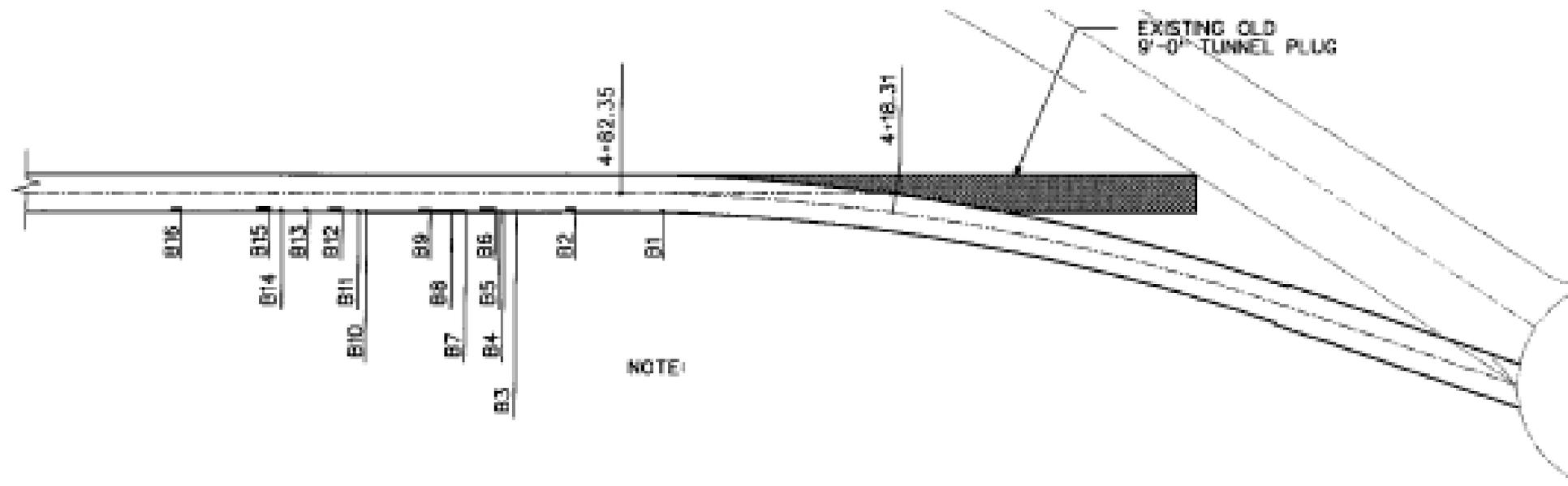
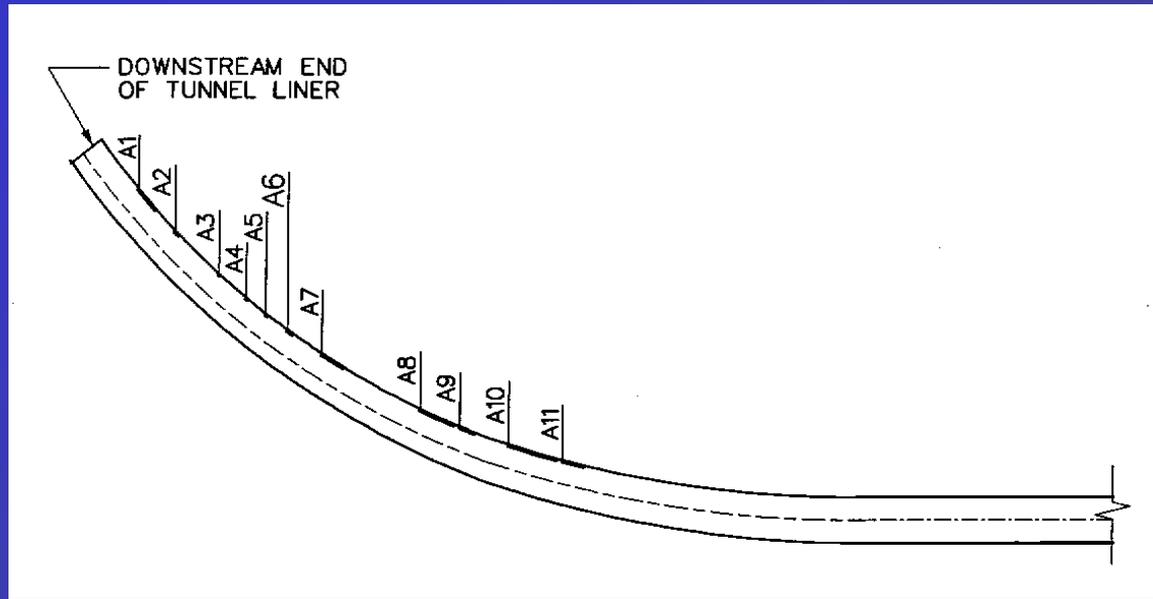
- d/s stoplog placed and 11 additional holes found
- Holes much larger than u/s
- NDT of tunnel takes place in October



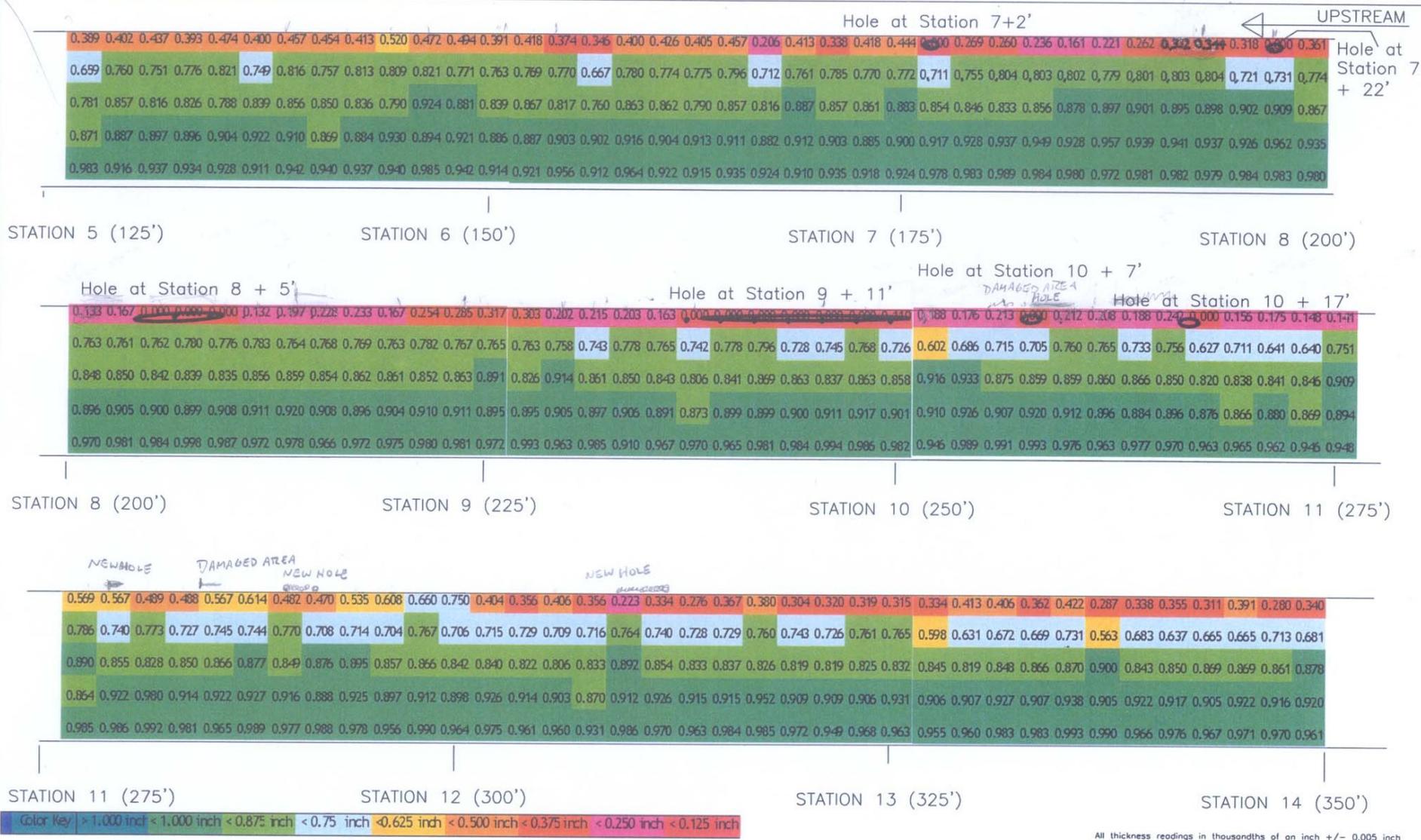
2007: 9' Tunnel Inspection



2007: 9' Tunnel Inspection



2007: NDT



All thickness readings in thousandths of an inch +/- 0.005 inch
 All thickness readings on a 2'x2' grid based on tunnel centerline

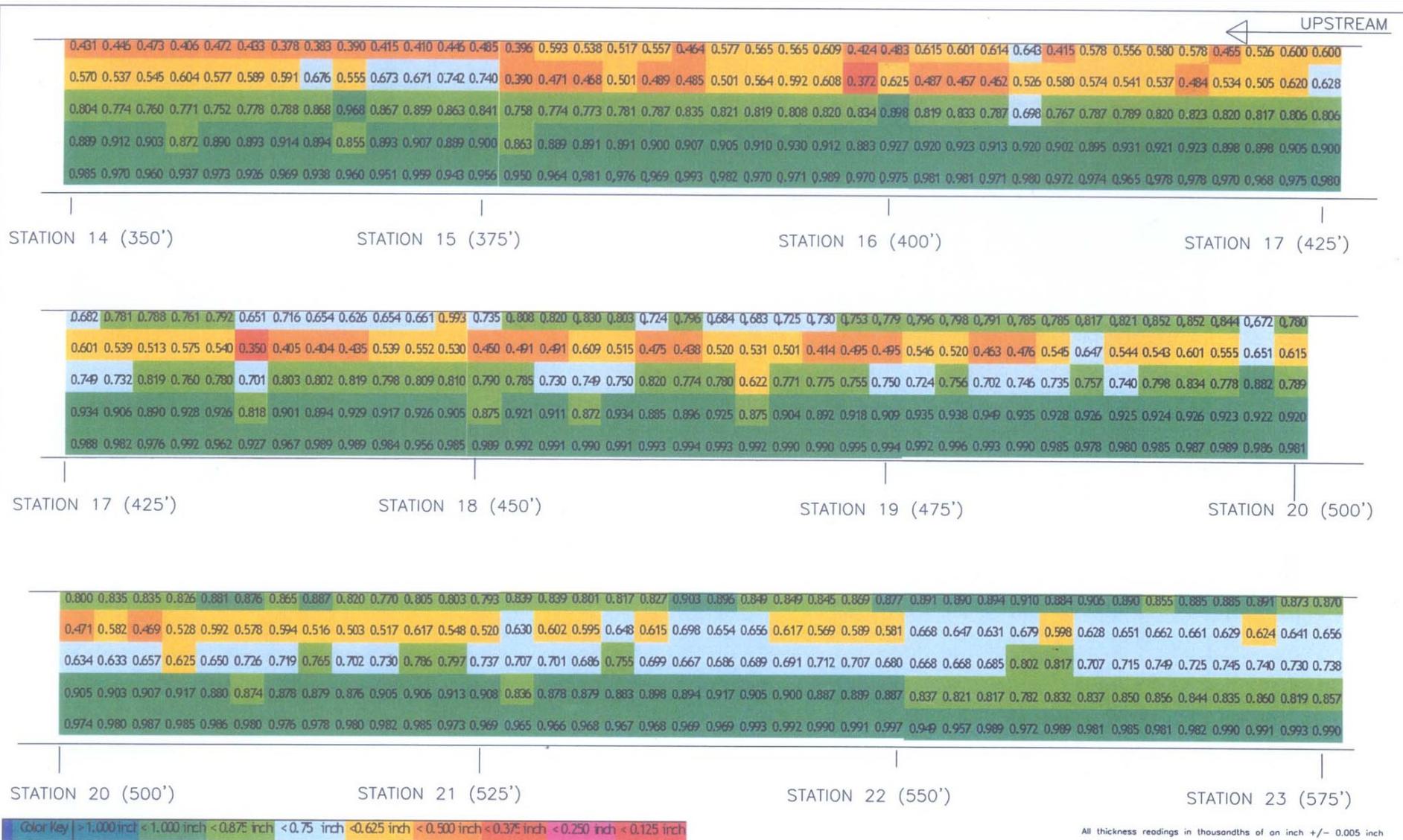
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 SEATTLE, WASHINGTON 98134-2385

9-FOOT TUNNEL STEEL THICKNESS TESTING
 MUD MOUNTAIN DAM, WASHINGTON
 CONTRACT NO. W912DW-07-P-0825

INSPECTION DATE: 10/08/2007
 DRAWING NUMBER: 129920 REV. 0 Page: 2
 CAD DRAFTSMAN: Emery E. Roberts

CALIBER INSPECTION
 7820 South 212th, Suite 110
 KENT, WA 98032
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 Tel.: 206-764-8123
 Fax: 206-764-8124

2007: NDT



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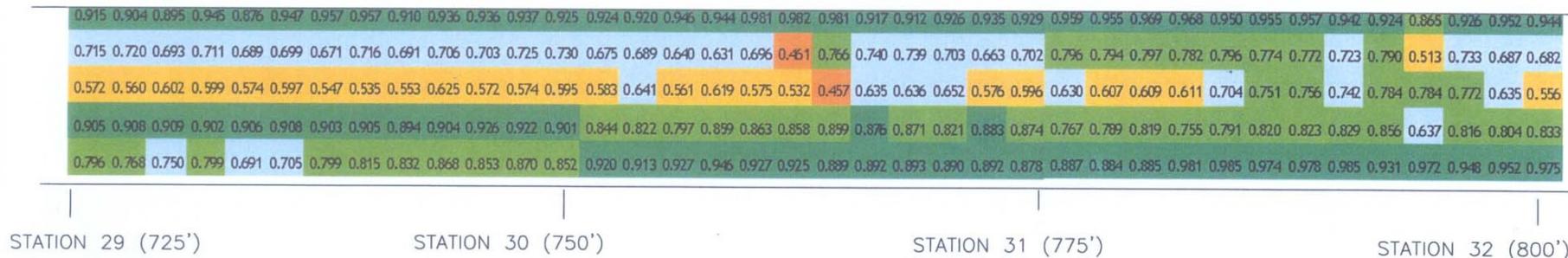
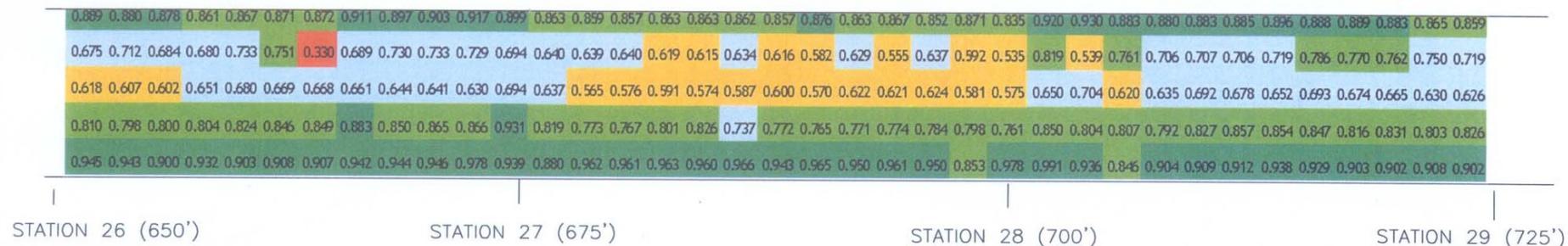
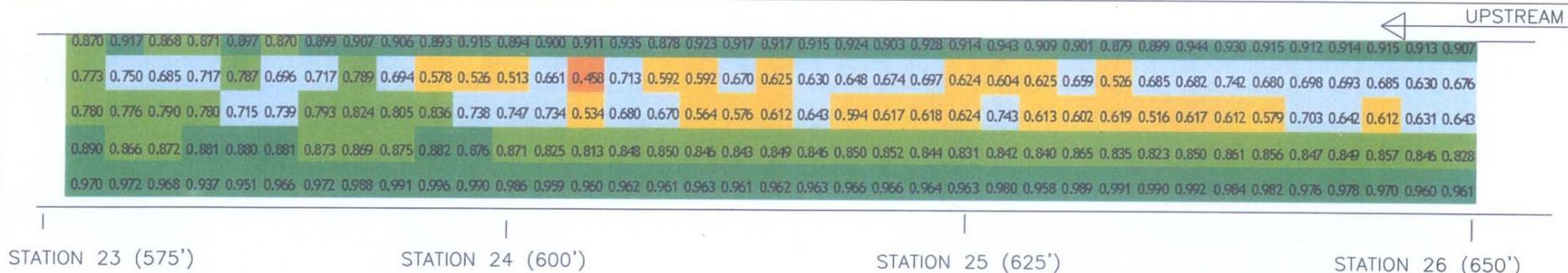
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Color Key: ≥ 1.000 inch < 1.000 inch < 0.875 inch < 0.75 inch < 0.625 inch < 0.500 inch < 0.375 inch < 0.250 inch < 0.125 inch

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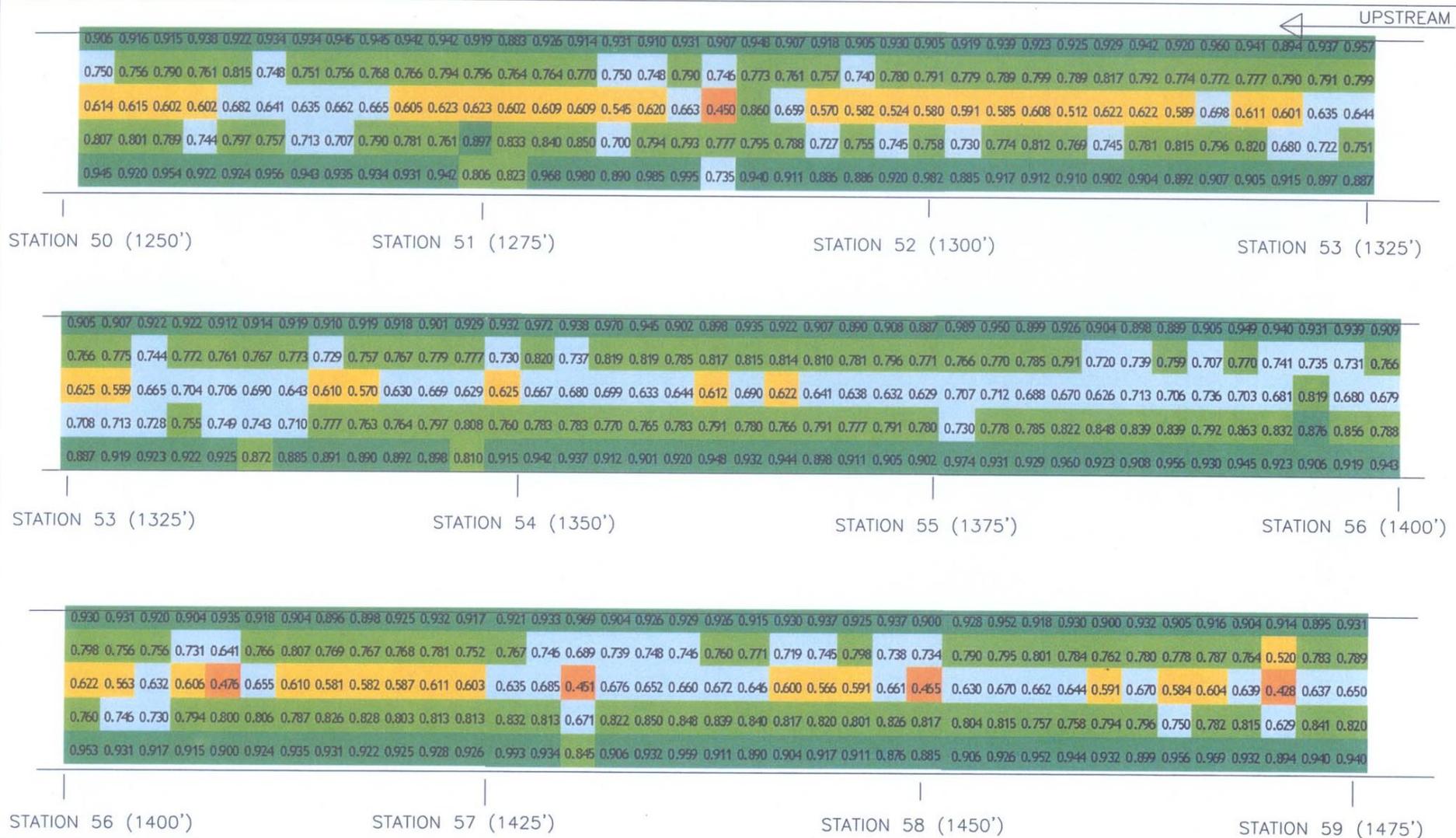
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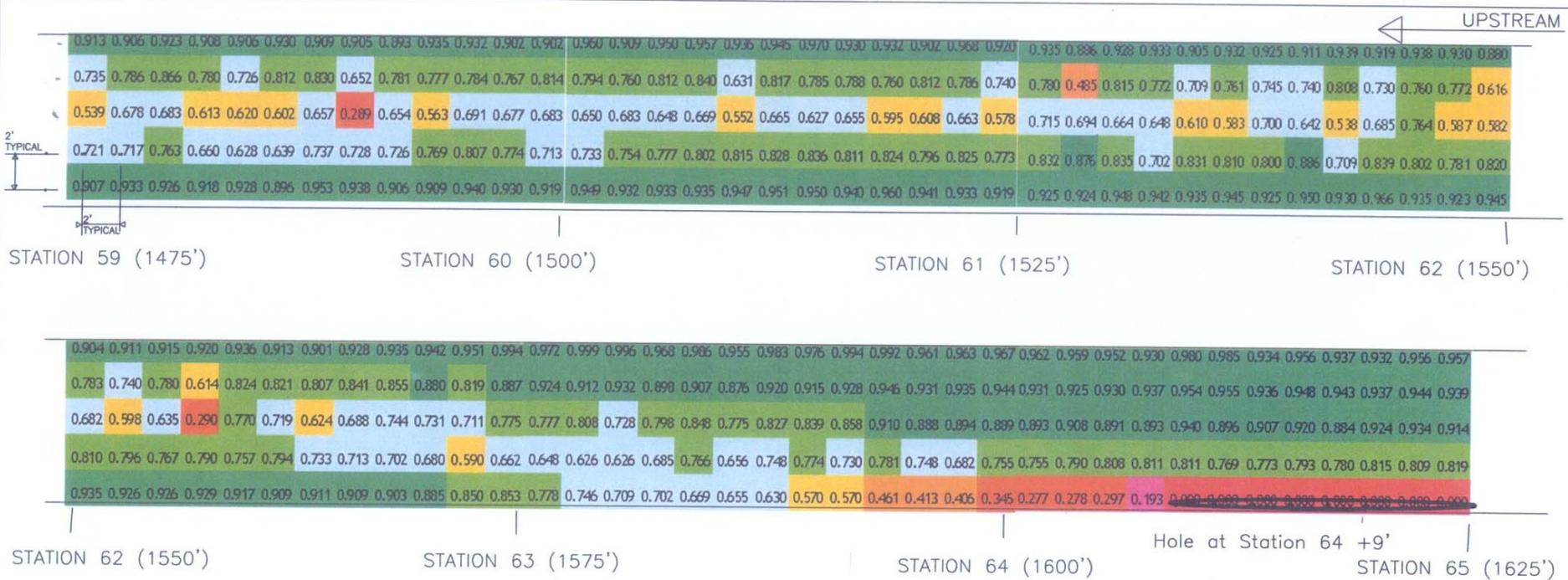
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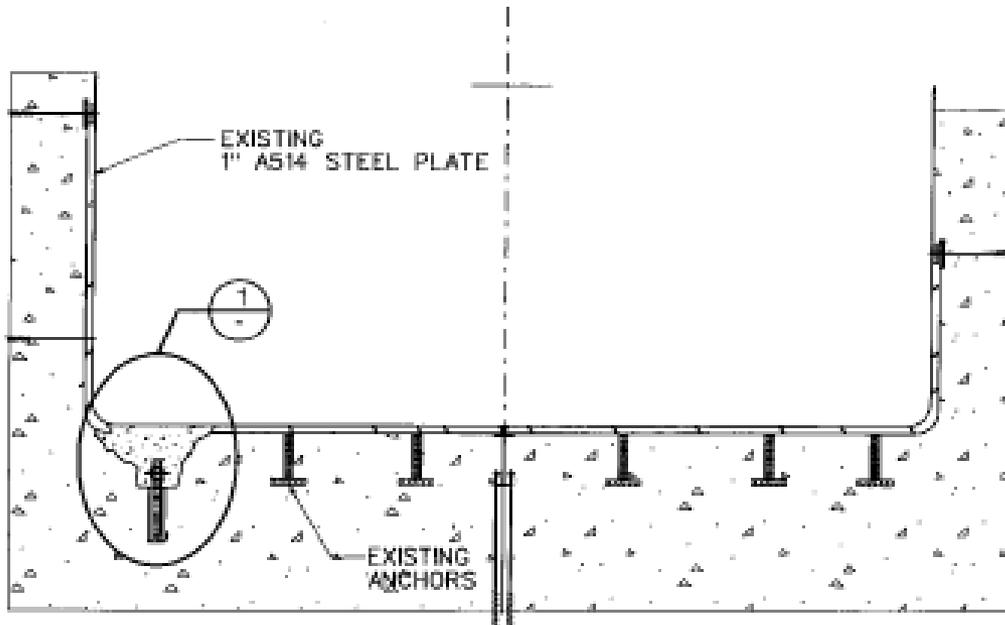
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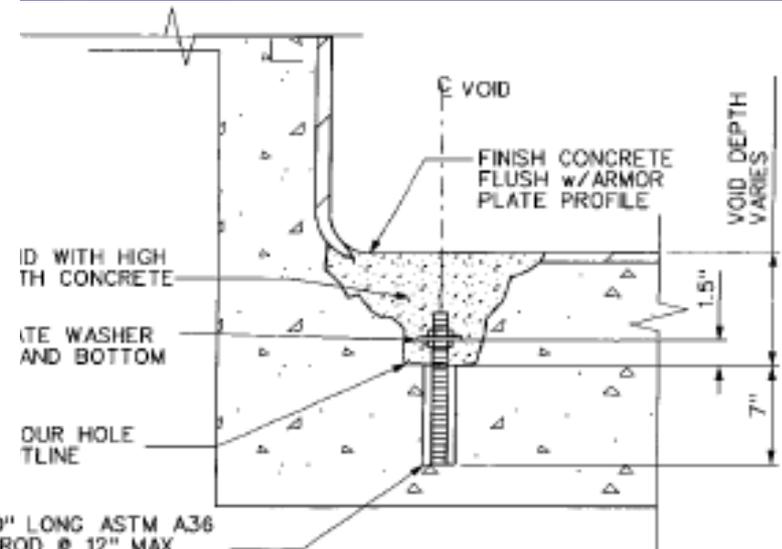
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2007: 9' Tunnel Repair



TYPICAL TUNNEL SECTION AT DAMAGED LINER

SCALE: 3/4" = 1'-0"



**1" DIA. x 10" LONG ASTM A36
THREADED ROD @ 12" MAX
ANCHOR w/EPOXY ADHESIVE
PER MANUF. RECOMMENDATION

TYPICAL REPAIR DETAIL FOR
VOIDS GREATER THAN 4" WIDE x 5" DEEP

SCALE: N.T.S.

** NO ANCHORS REQUIRED FOR VOIDS
LESS THAN 5" DEEP

1



2007: 9' Tunnel Repair



10/6/2007



10/9/2007

2007: 9' Tunnel Repair



FEB 2008: 9' Tunnel Inspection

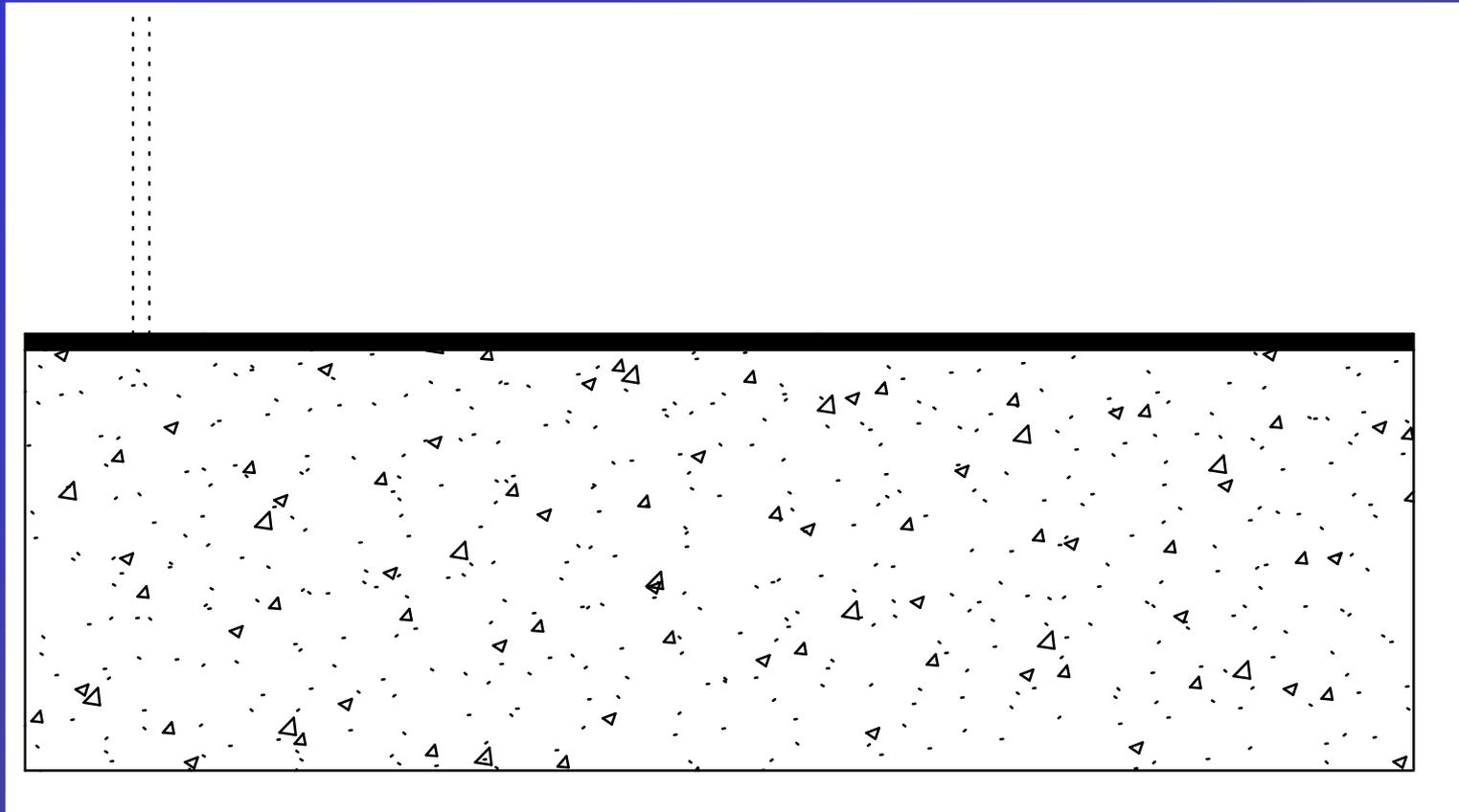


Hole Formation Theories

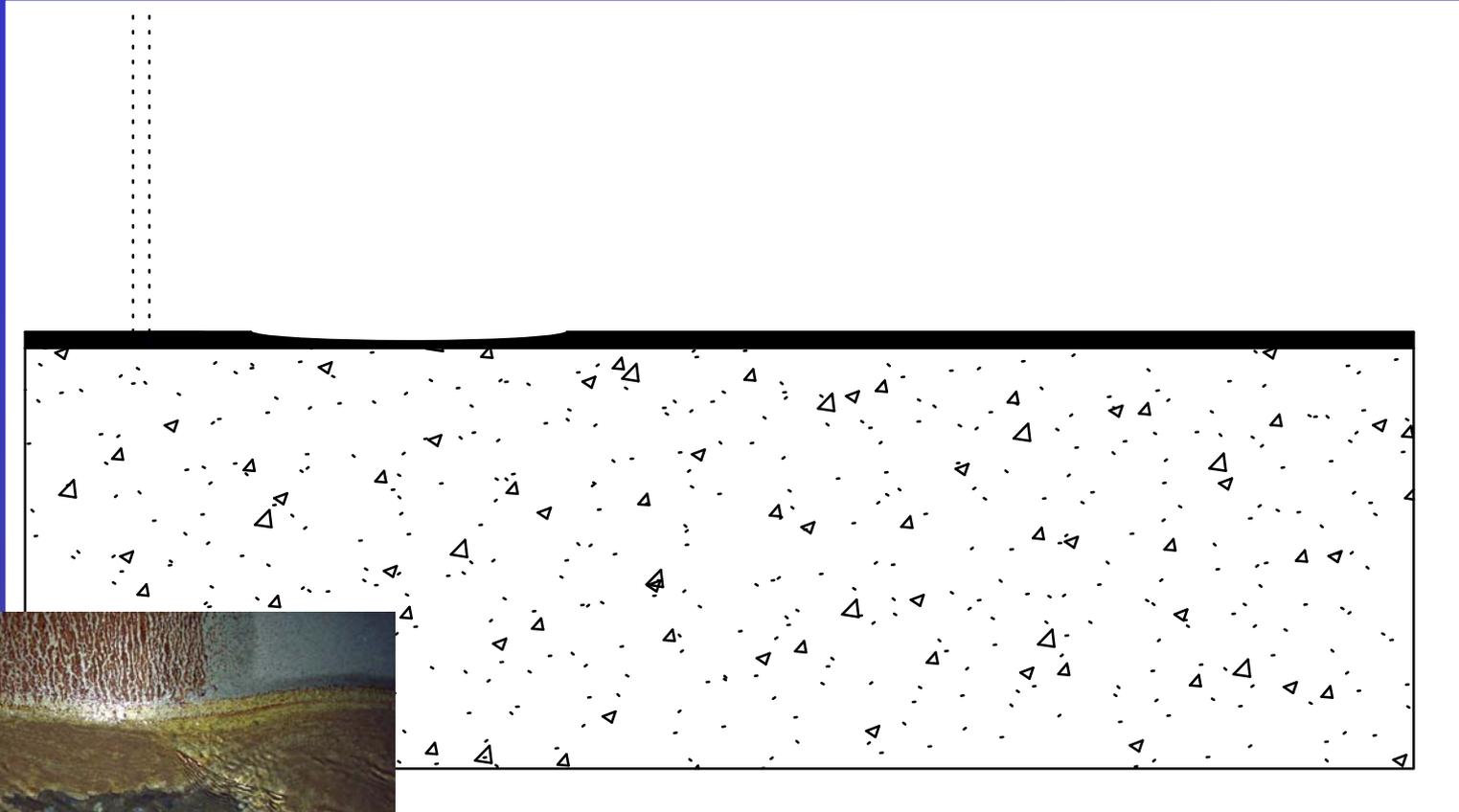
- Forces forming holes
 - Abrasion / Erosion
 - Low Pressures / Plucking
 - Cavitation
- Source of problem
 - Disturbance from old tunnel plug
 - Undulations in plates from heat welds
 - Small flow disturbance at seams
 - Curvature of tunnel



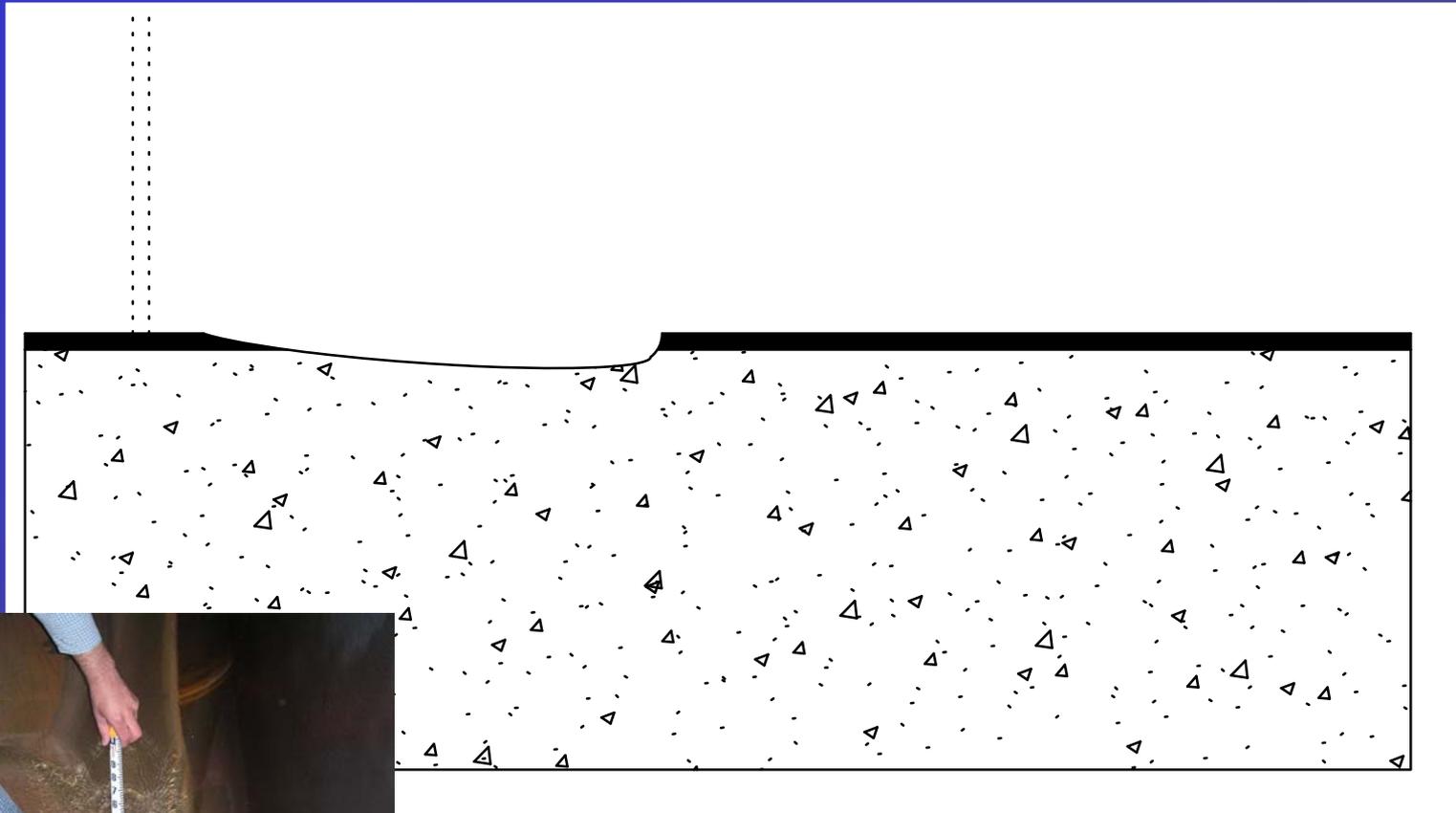
Hole Formation



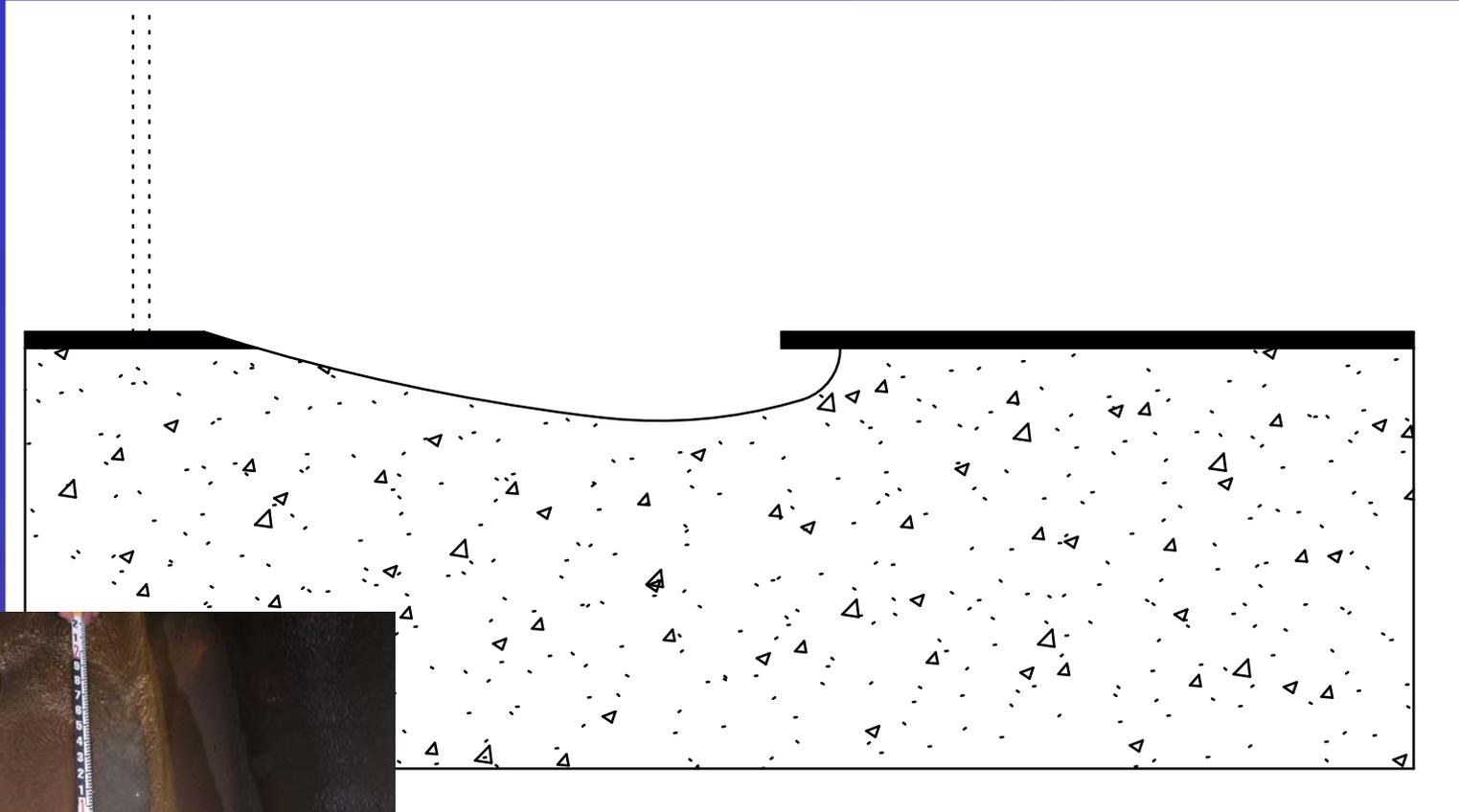
Stage 1



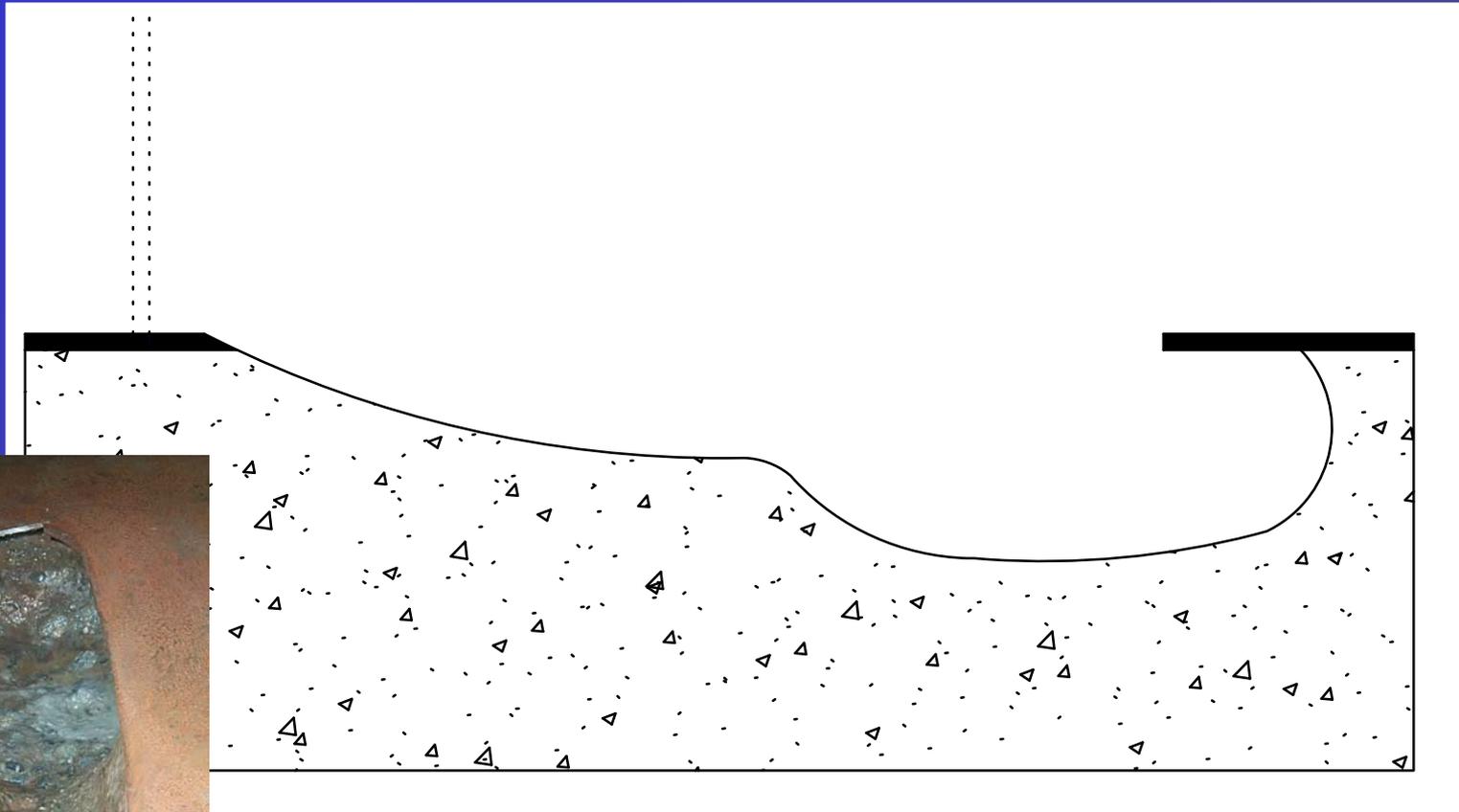
Stage 2



Stage 3



Stage 4



10/6/2007

Risk Analysis

- Structural Risk
 - Loss of steel liner
 - Loss of concrete
 - Damage at radial gate
- Geological Risk
 - Exposed bedrock
 - Pillar reinforcing bolts
 - Large scour
 - Piping
 - Tunnel collapse
- Water Management Risk
 - Sediment transport
 - Damage to the 23' tunnel
 - Damage to the trashrack
 - Loss of flood control storage



Operational Restriction

- October 2007 to February 2008
 - Max pool elevation = 950'
 - Additional hole formation
 - Lost ~75% of patch material
- February 2008 to June 2008
 - Max pool elevation = 920'
 - Average elevation during this time = 905'
 - Very little sediment transport
 - <5% increase in damage
- June 2008 to Present
 - Max pool elevation = 930'
 - Pool elevations near 930' for extended time
 - Expect that large amounts of sediment transported
 - Increased damage = 15% to 20%



Future Repair Options

- Current Plan
 - Fill holes with high-strength concrete
 - Cover with Belzona
 - Leave one hole open for monitoring
 - Continue operational restrictions
- Expect ~10 years of life left in liner
- Long Term Solutions
 - Continue regular temporary fixes
 - Replace steel liner
 - Tunnel Redesign / Realignment



Questions



10/19/20

Timeline for the 9' Tunnel

- JUN 1953: Project Officially Completed
- MAR 1968: Periodic Inspection No. 1 – Damage at liner/rail transition (Abrasion not Cavitation)
- 1968 to 1993: Rails and grout replaced regularly
- 1995: Intake Tower Replacement
 - Upstream bend
 - Tunnel lined with 1” steel
 - Cross-section shape modification
- 2001: Belzona repairs
- AUG 2006: Holes found at the u/s end of the 9' Tunnel
- SEP 2006: UT Test for u/s 600'
- OCT 2006: u/s holes patched with Belzona
- AUG 2007: Patches in moderate condition, new holes formed at upstream end, and previously unnoticed holes at d/s end discovered
- OCT 2007: Non-destructive test conducted
- NOV 2007: Anchor bolts placed and holes patched with concrete/steel fiber mix
- NOV 2007: 9' Tunnel opened for flood season with operational restrictions
- FEB 2008: Holes resurveyed (Operational limits increased)
- APR 2008: Periodic hole inspection
- JUN 2008: Periodic hole inspection
- JUL 2008: Periodic hole inspection
- AUG 2008: Close tunnel for summer



