Lessons from Poplar Creek, VA: The Deepest Precast Box Culvert in the U.S.

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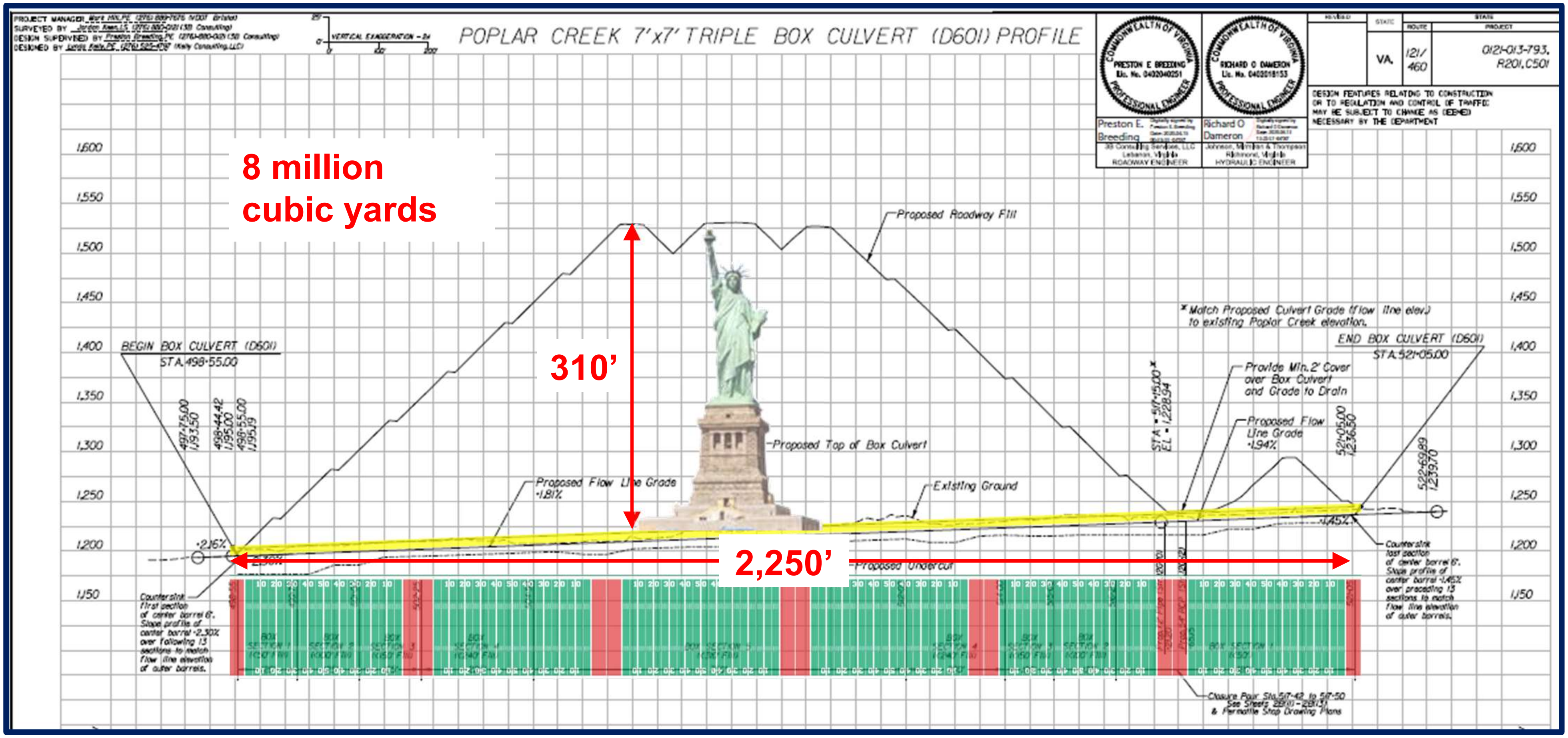
Why this matters



Today's Roadmap

- Project in a Nutshell
- Design & Construction Challenges
- Field-Monitoring Data
- Interpreting Field Data through Soil-Structure Interaction Models
- Next Steps & Acknowledgements
- Discussion

01

Project Overview

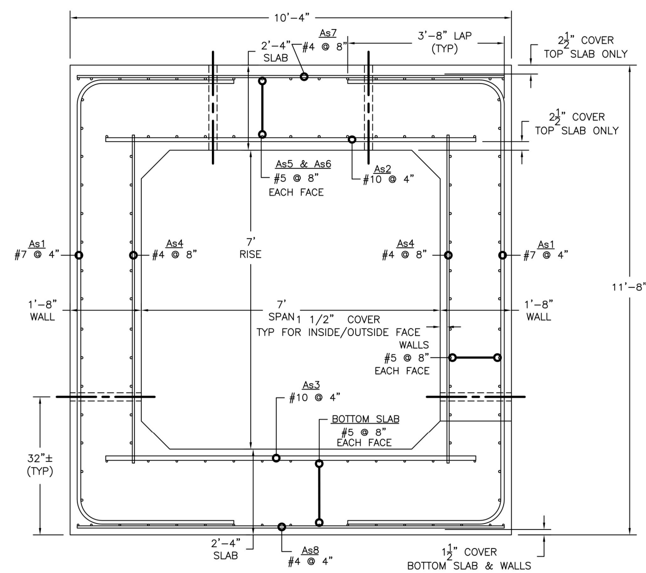
Poplar Creek Culvert

- Route 121-460, ADHS Corridor Q
- Precast concrete triple box culvert
- 2,250 linear feet long
- Total 1,146 precast box sections (~382 boxes per barrel)

Our scope is to conduct a retrospective review of design practices and field measurements to develop design recommendations.

Design Concept & Constraints

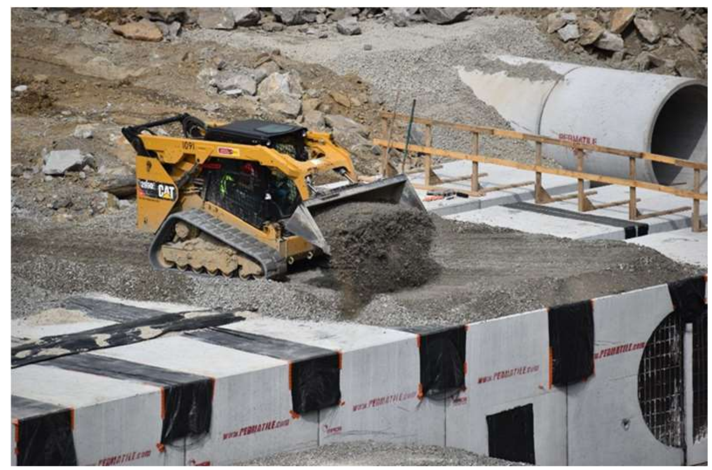
- Precast box under embankment: cost effective and re-use of cut material
- "Special Design" due to the large cover
- Triple box function: (normal hydraulic flow, 100-yr storm excess, redundancy)
- +10,000 psi concrete and ASTM A1035 MMFX 100,000 psi yield strength



Site and Subsurface Conditions

- Subsurface profile: ±30 ft of alluvium over McClure Sandstone, with interbedded shale layers and occasional coal seams.
- Fill material: Blasted shot-rock aggregate. Particle sizes up to ≈ 36 in.
- Placement: 48 in lifts; fill spread by dozers and "kneaded" by repeated passes of off-road haul trucks – no vibratory rollers.

Construction



Embankment Today

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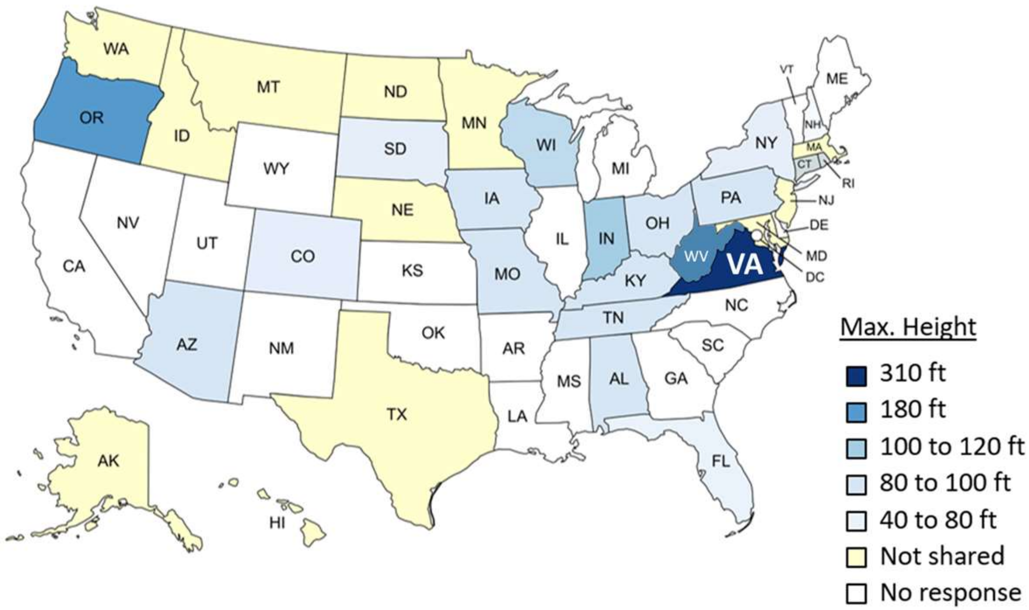
Challenges

Do any DOT’s have deep buried culverts?



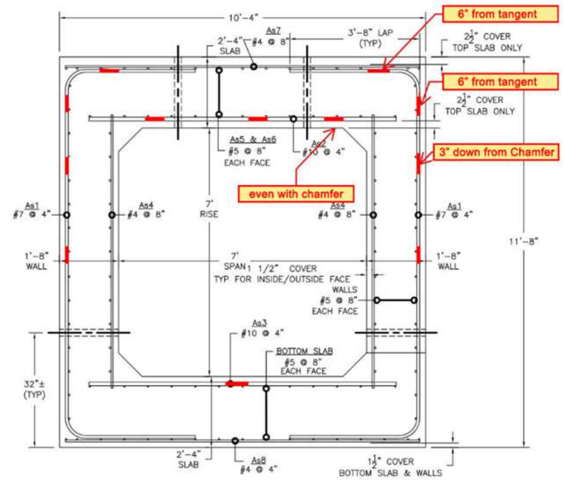
<u>36 states responded</u>

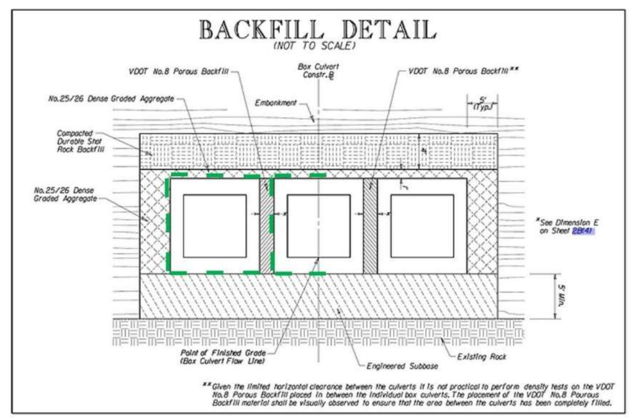
- 70% have fill heights > 35 ft
- 50% cited insufficient guidance in design codes, leading many to avoid such projects due to uncertainties.
- Many reported maintenance and durability issues
- 45% report considering earth pressure as purely geostatic ($\gamma \times H$)

Soil-Structure Uncertainties

Unknown	Why It Matters
Deep-burial stress distribution	Sets design loads. Get it wrong – cracking, costly over-build, or worse.
Shot-rock properties (36 in "max")	Controls the analysis; hard to measure uniformly; compaction.
Post-construction settlement	Controls timeline for paving highway; differential settlement of boxes; long-term serviceability.
Internal force paths, detailing, and materials	Dictates rebar layout, wall thickness, corrosion protection and durability.
Limits of current SSI models	Constrains confidence; need for shot-rock constitutive models; uncertainty about 3-D effects; nonlinear FE.
Lack of precedent & code guidance	Few comparable cases; commercial tools unvalidated.

Instrumentation Plan – 240 ft and 310 ft





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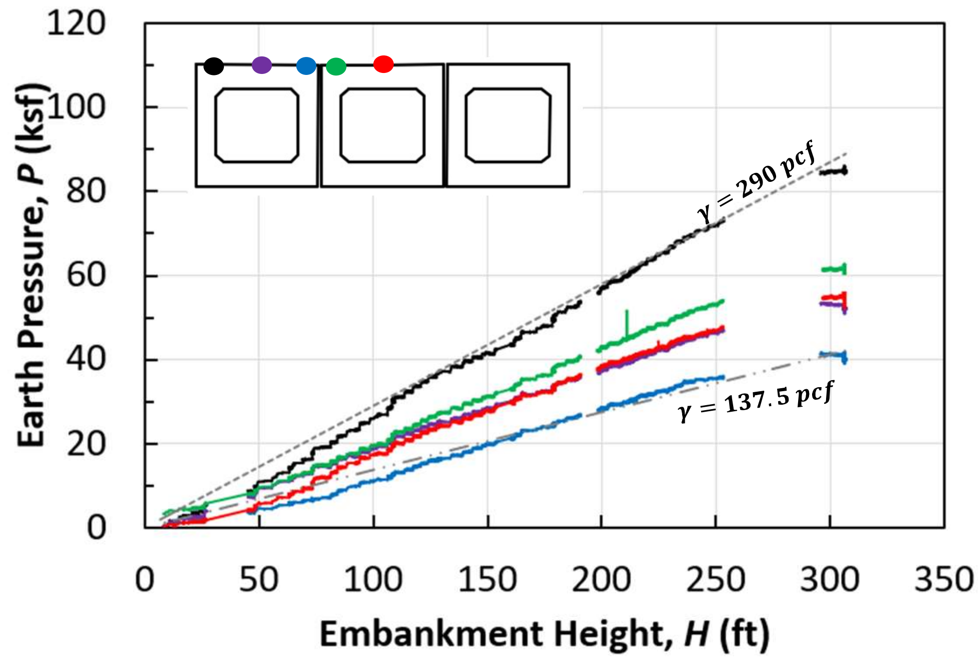
Field Measurements

Pressure Results – 240 and 310 ft Sections

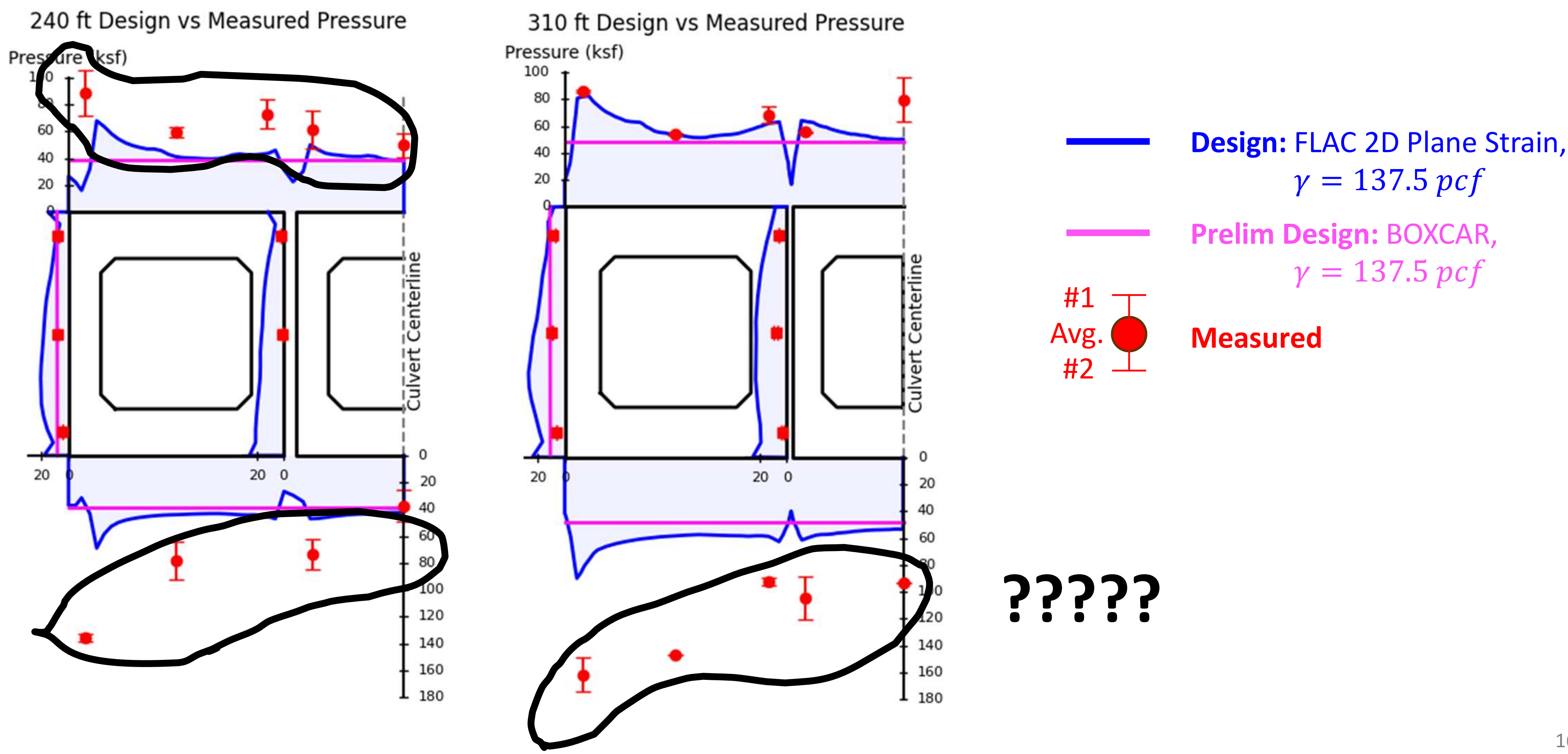
- Pressures continue to rise after 240 ft filling has completed?

240 ft Top Pressures

310 ft Top Pressures



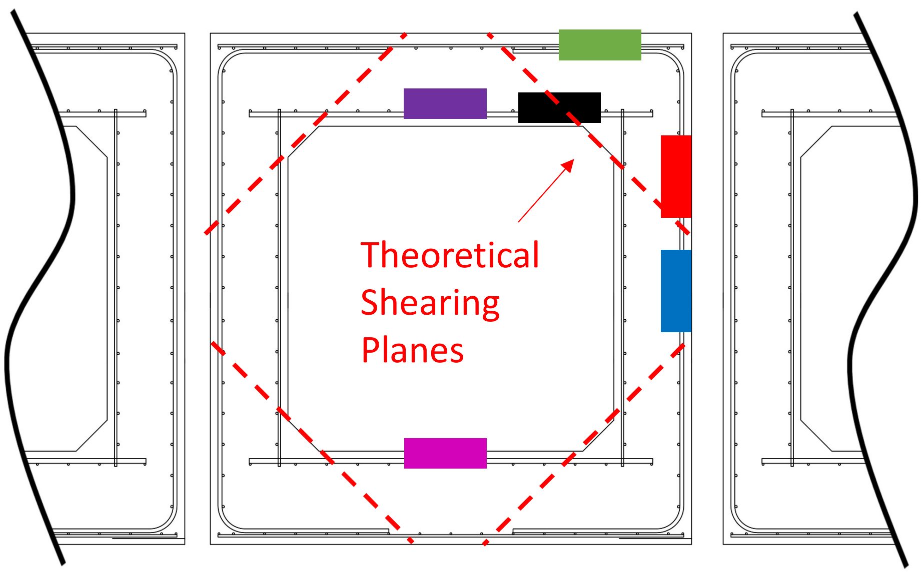
Pressure at 240 ft. and 310 ft. Sections

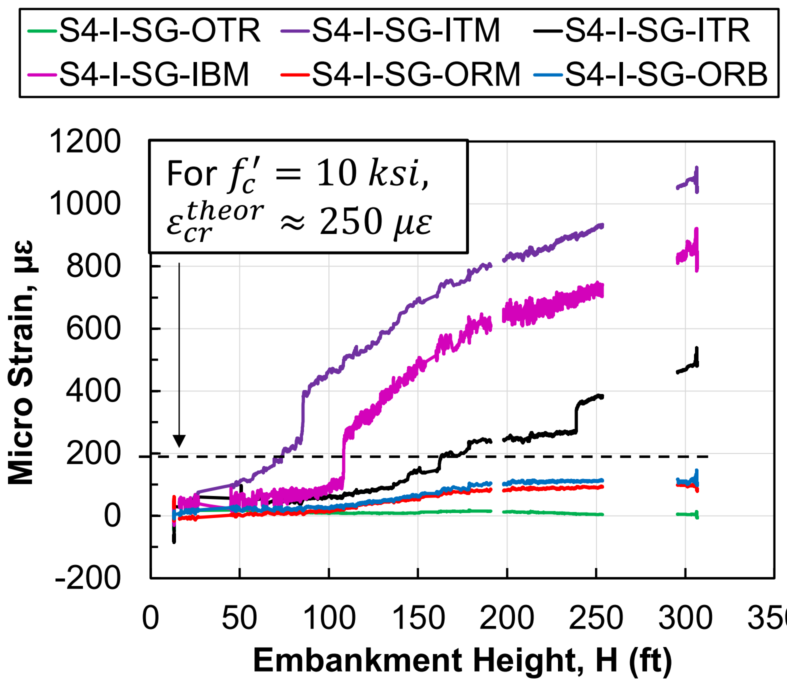


Concrete Strain Highlights – 310 ft section

- Measured strains are reasonable, suggest complex load path
- Provide a valuable basis for FE back-estimation of soil pressures under deep fill

Strain Gauge Locations





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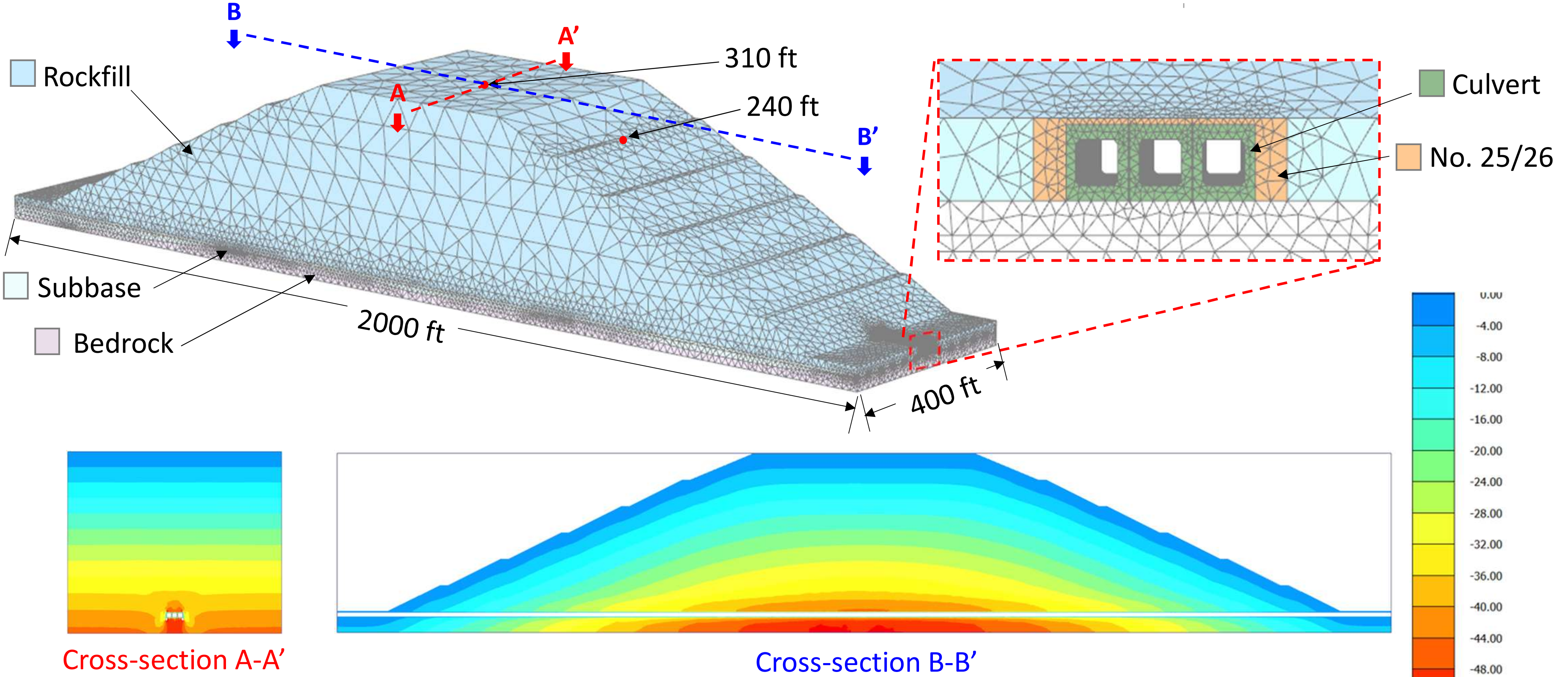
Modeling

3D Culvert and Embankment Model

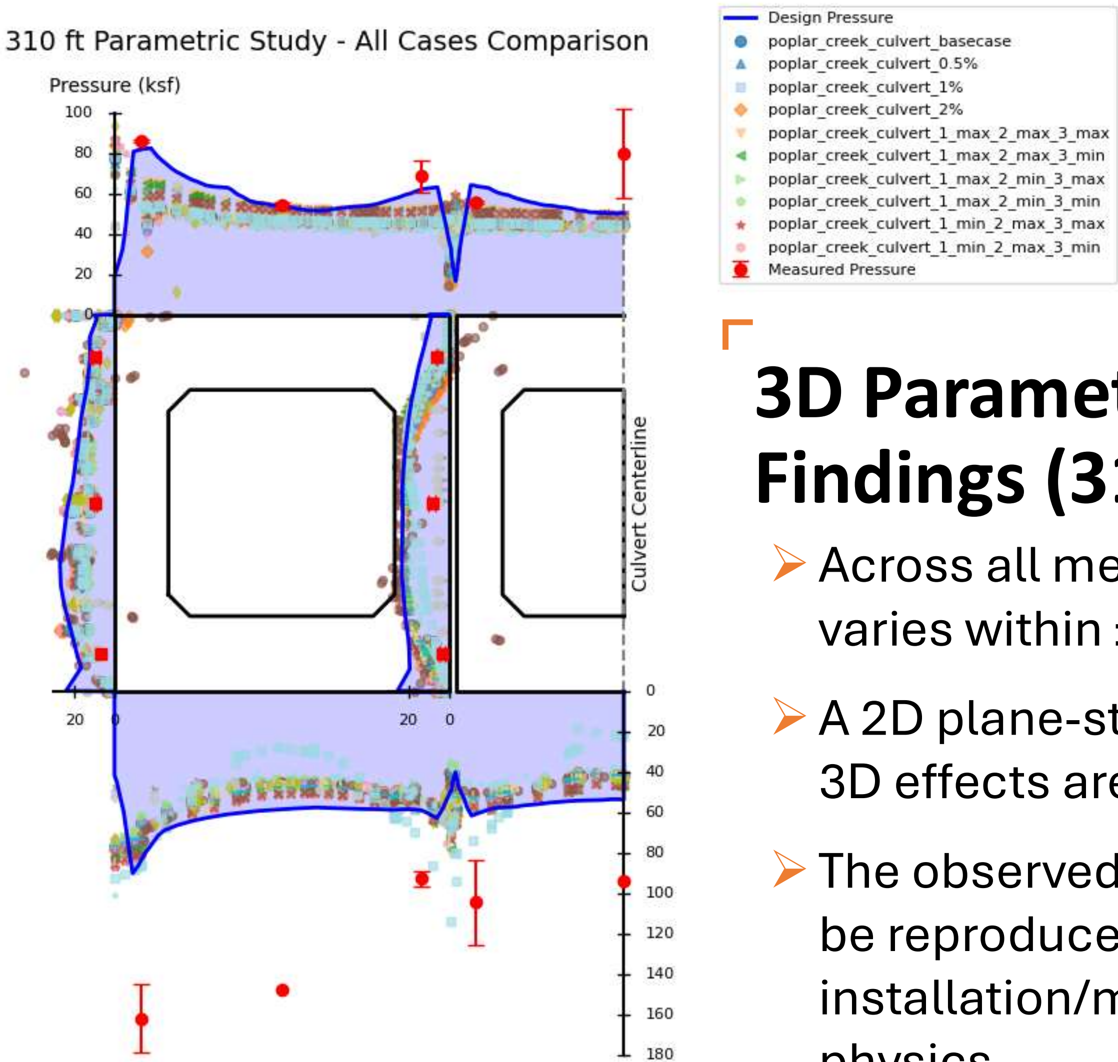
Goal: Assess 3D effects on fill-culvert interaction to verify pressure readings

- FE Software PLAXIS 3D
- Base model: Hardening soil model ("equivalent" to design constitutive model and assumed input values), monolithic culvert structure, actual bedrock elevation, no valley, straight alignment
- Baseline model for parametric analyses:
  - Subbase material properties
  - Shot rock strength, stiffness, density
  - Bedrock elevation
  - Valley topography
  - Culvert alignment
  - Soil-culvert interface
  - Secondary consolidation

3D Culvert and Embankment Model



Effective vertical stress, σ'$_{zz}$ (ksf)



3D Parametric Study: Key Findings (310-ft embankment)

- Across all mechanisms tested, crown pressure varies within ±10% of baseline.
- A 2D plane-strain model is sufficient for design; 3D effects are second-order.
- The observed pressure irregularities could not be reproduced numerically → most likely installation/measurement artifacts rather than physics.

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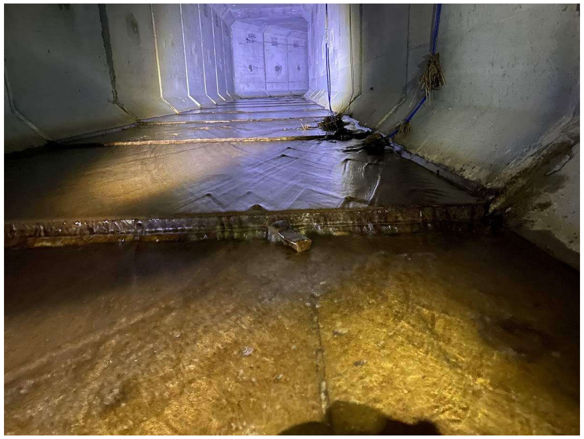
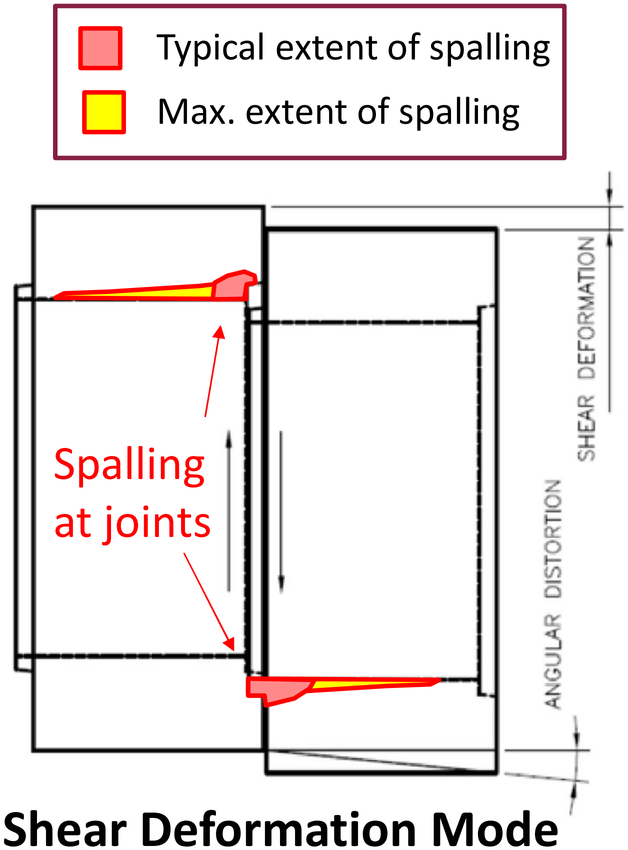
Culvert Performance

Culvert Inspection - Joint Distress

- **Flexural cracking** in top and bottom slab
- **Shear cracks** in vertical sidewalls of select barrels
- **Joint distress at many interfaces**, consistent with shear transfer & differential movement between adjacent boxes





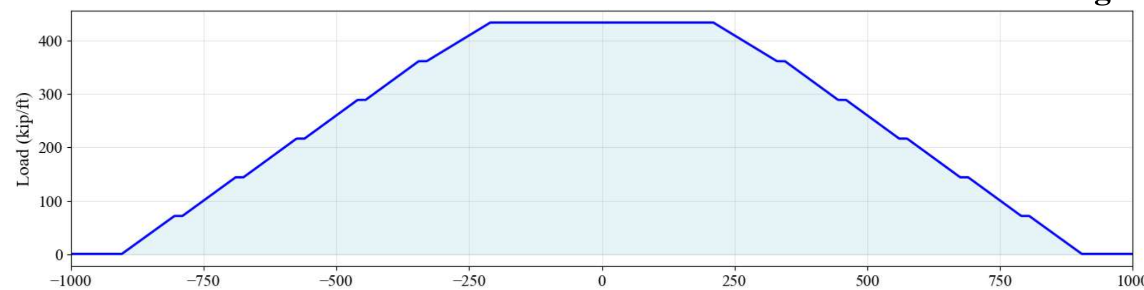
Shear Deformation Mode

Joint Distress Locations

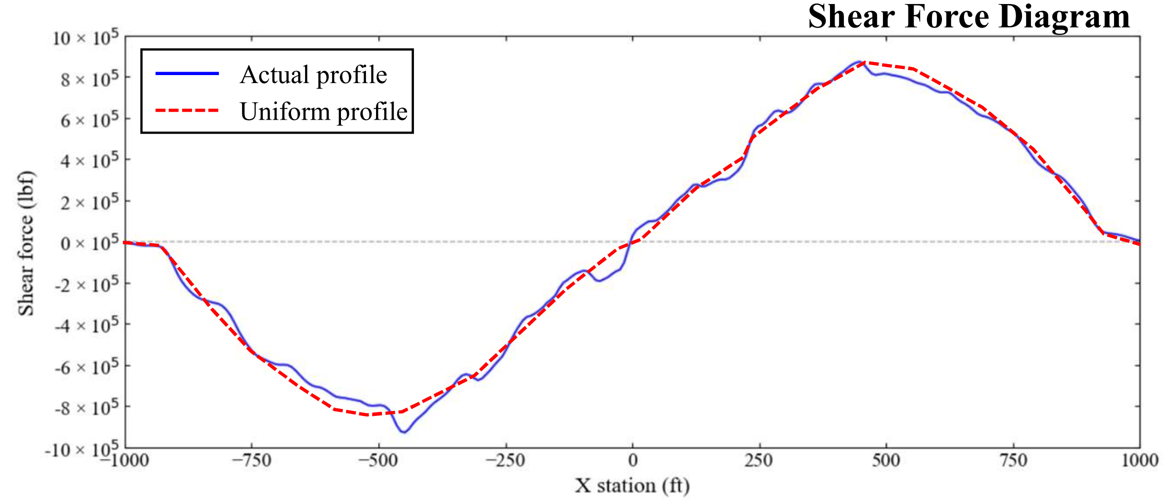
- Joint distress concentrated in the mid-slope zones along the embankment side slopes – not at the crest or toe.

- Nonlinear 3D FEA using the as-built undercut profile predicts peaks in longitudinal shear, |V(x)|, at consistently x-stations.

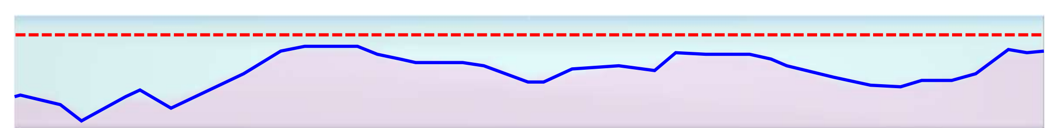
Shot Rock Surcharge



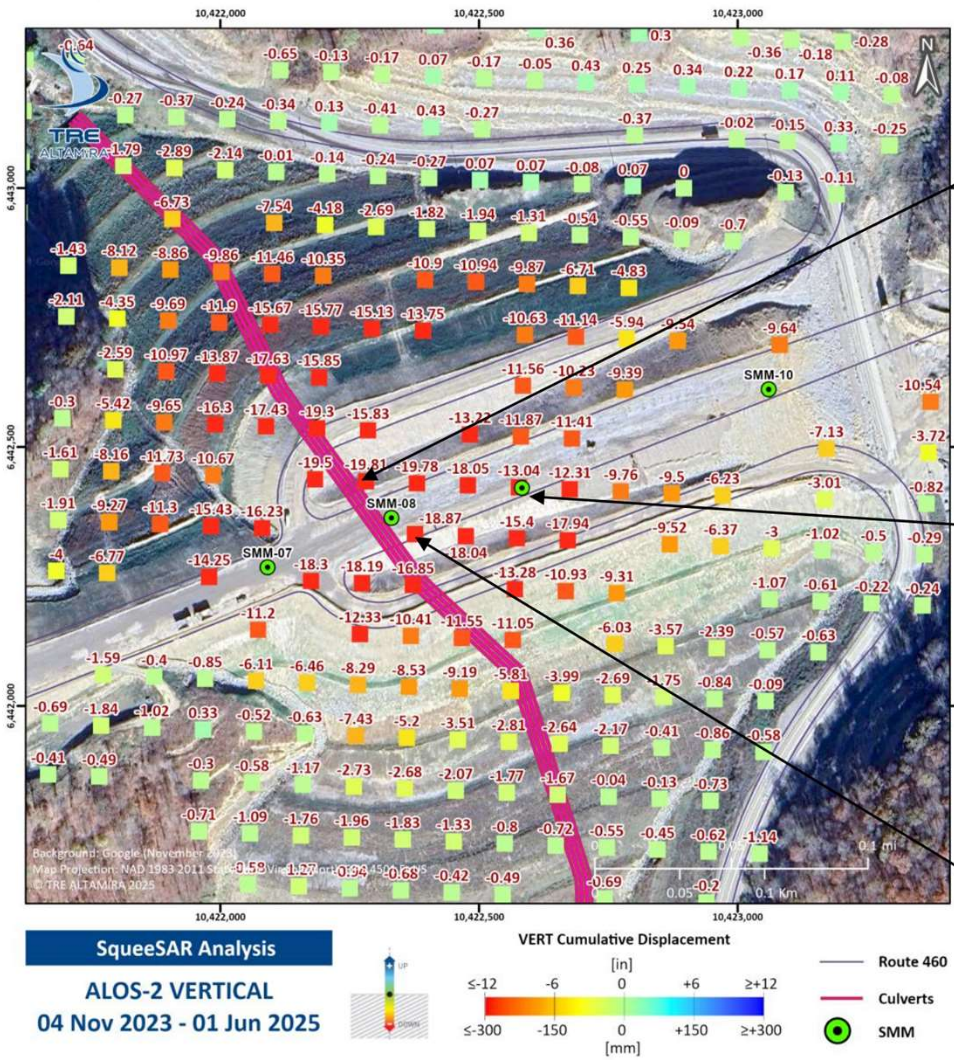
Shear Force Diagram

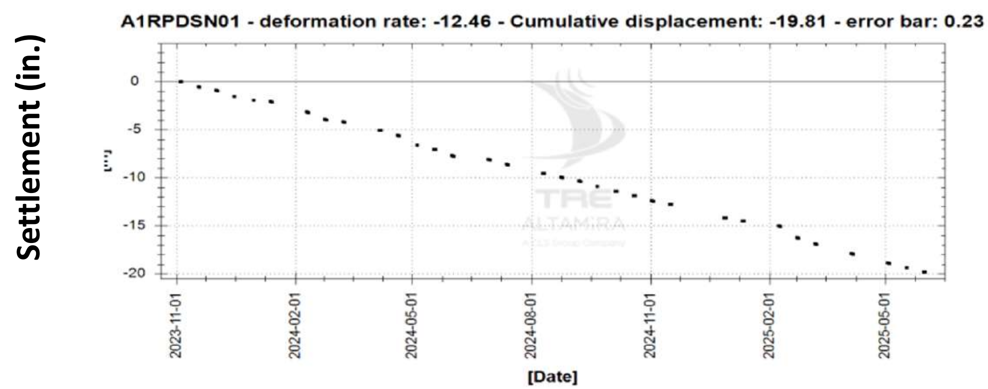


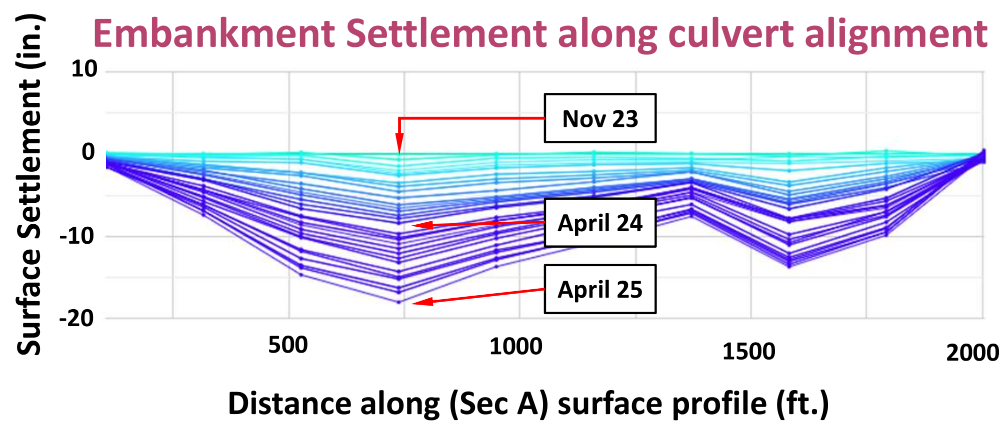
Bedrock profile



InSAR Embankment Settlement







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Synthesis

Summary and Next Steps

- **Sensor Readings:** Problems with earth pressure sensor data interpretation related to installation. Higher degree of confidence in strain data.
- **Analysis:** Models cannot reproduce the irregular pressure patterns at 240 ft & 310 ft → readings are likely impacted by instrumentation/installation artifacts.
- **Performance:** Structrally, the culverts are generally behaving well. Embankment settlement continues and is being monitored → long term behavior?
- **Critical issue**: Culvert joint details are the weak link → maintenance issue. Research to develop structural box culvert joints is needed.
  - Ongoing: explicit culvert-to-culvert interface modeling.
  - Pending: results of the post-construction deformation survey.
  - Evaluate redesign alternatives: (1) improved precast joint details, (2) cast-in-place culvert with expansion joints, (3) local soil reinforcement to promote composite action.

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Thank you!

Feel free to contact us – we welcome your feedback and expertise!

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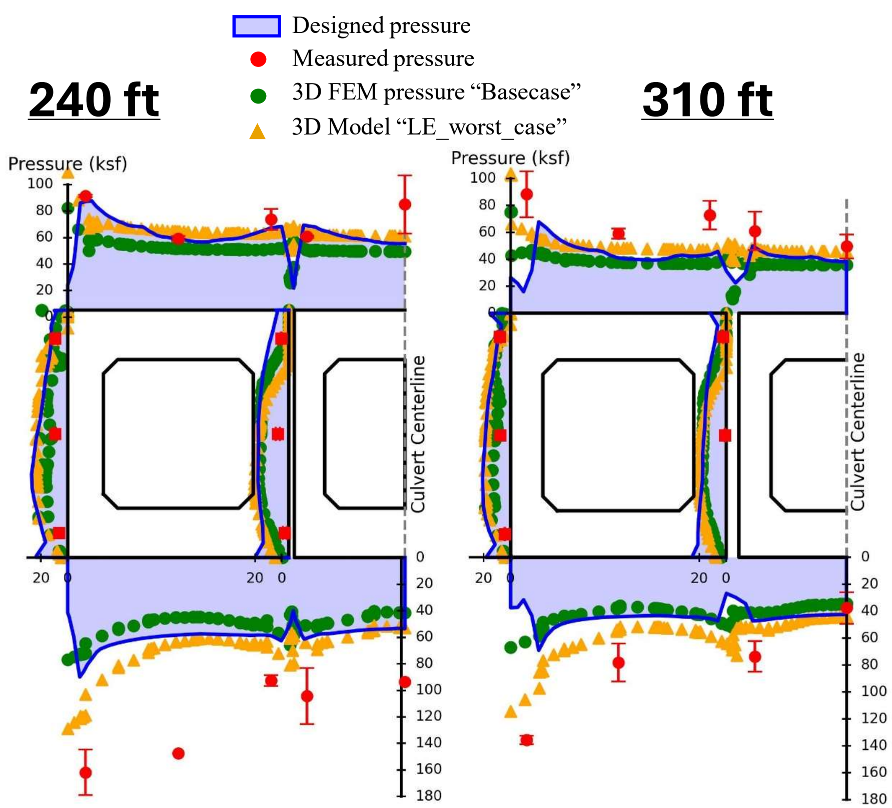
Linear-Elastic Shot Rock: Upper-Bound



- Modeled shot rock as linear elastic with upper-bound stiffness and an unrealistically high unit weight → **deliberate worst-case**
- **Use case:**
  - Conservative preliminary analysis for member sizing.
  - Final design should use measured/typical unit weight and nonlinear, stress-dependent modulus.