FOAMED GLASS AGGREGATE

DESIGN AND CONSTRUCTION OF AN OFF-ALIGNMENT BRIDGE, MSE WALLS, AND EMBANKMENT IN COLCHESTER VERMONT

ACEC-NH TECHNICAL EXCELLENCE CONFERENCE

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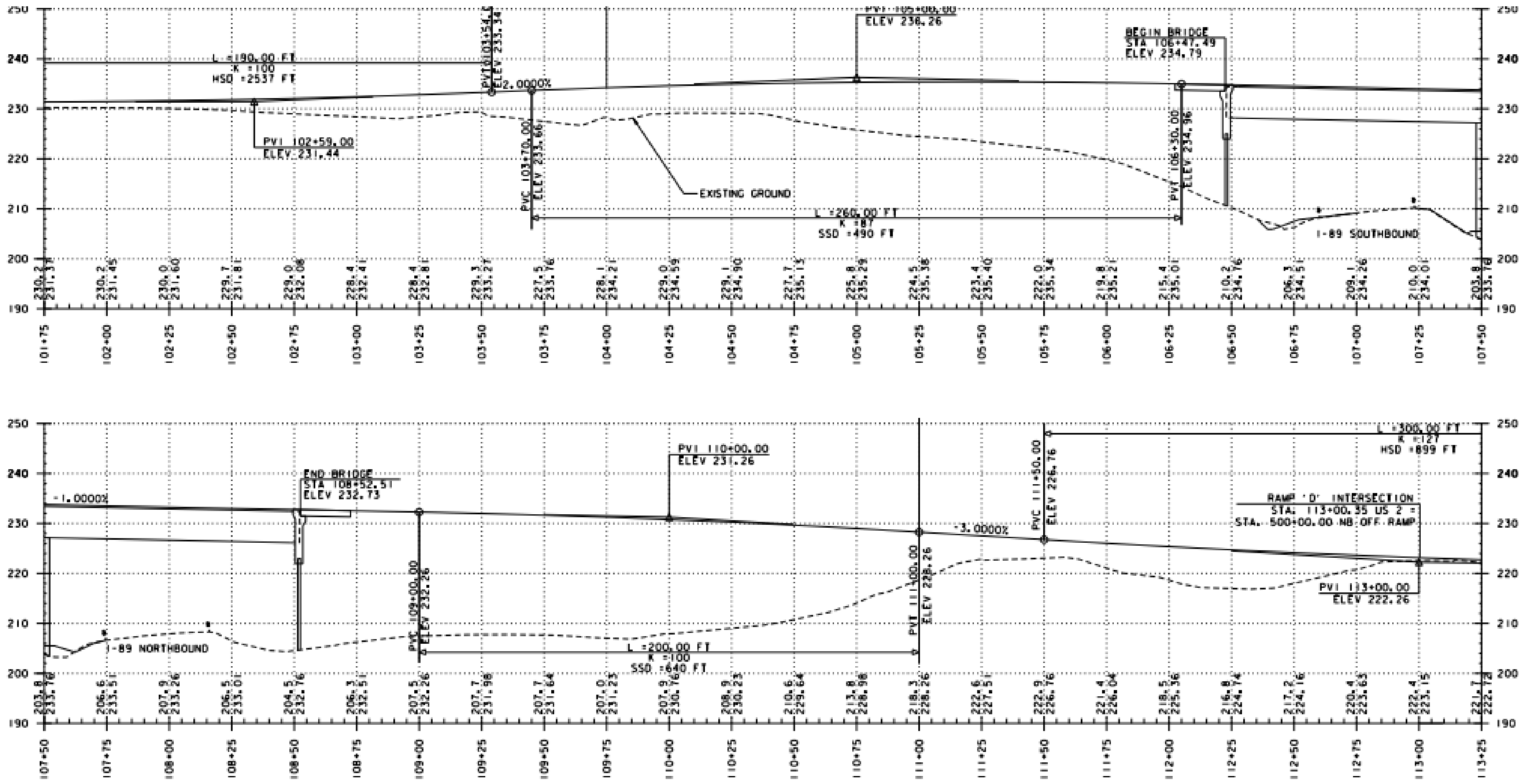
Project Features

- Bridge replacement (US 2 over I-89): ☆
  - 2-span integral abutment bridge
  - Pile-supported abutments & pier, driven to bedrock
  - Abutments supported by MSE walls on 3 sides
- New I-89 SB offramp to US 2 ★
- Reconfigure I-89 NB onramp & offramp ☆
- US 2 realignment: tall embankment fills & MSE walls ☆
- **Project Partners** VERMONT AGENCY OF TRANSPORTATION vhb

Proposed Profile on US 2

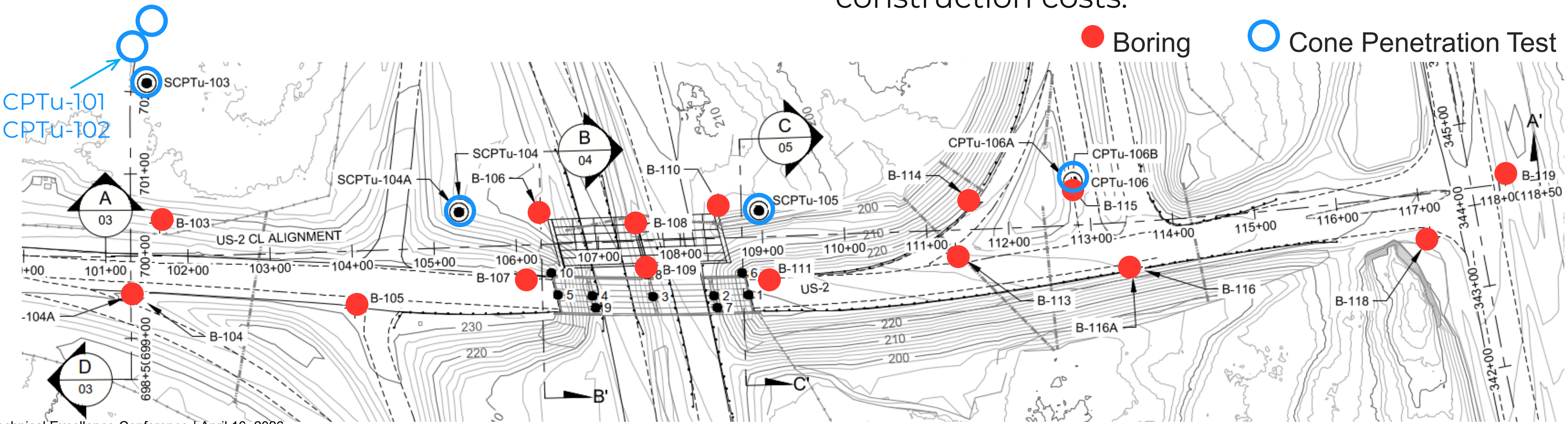
- 2 Span Integral Abutment Bridge
- Vertical H-Piles driven to bedrock



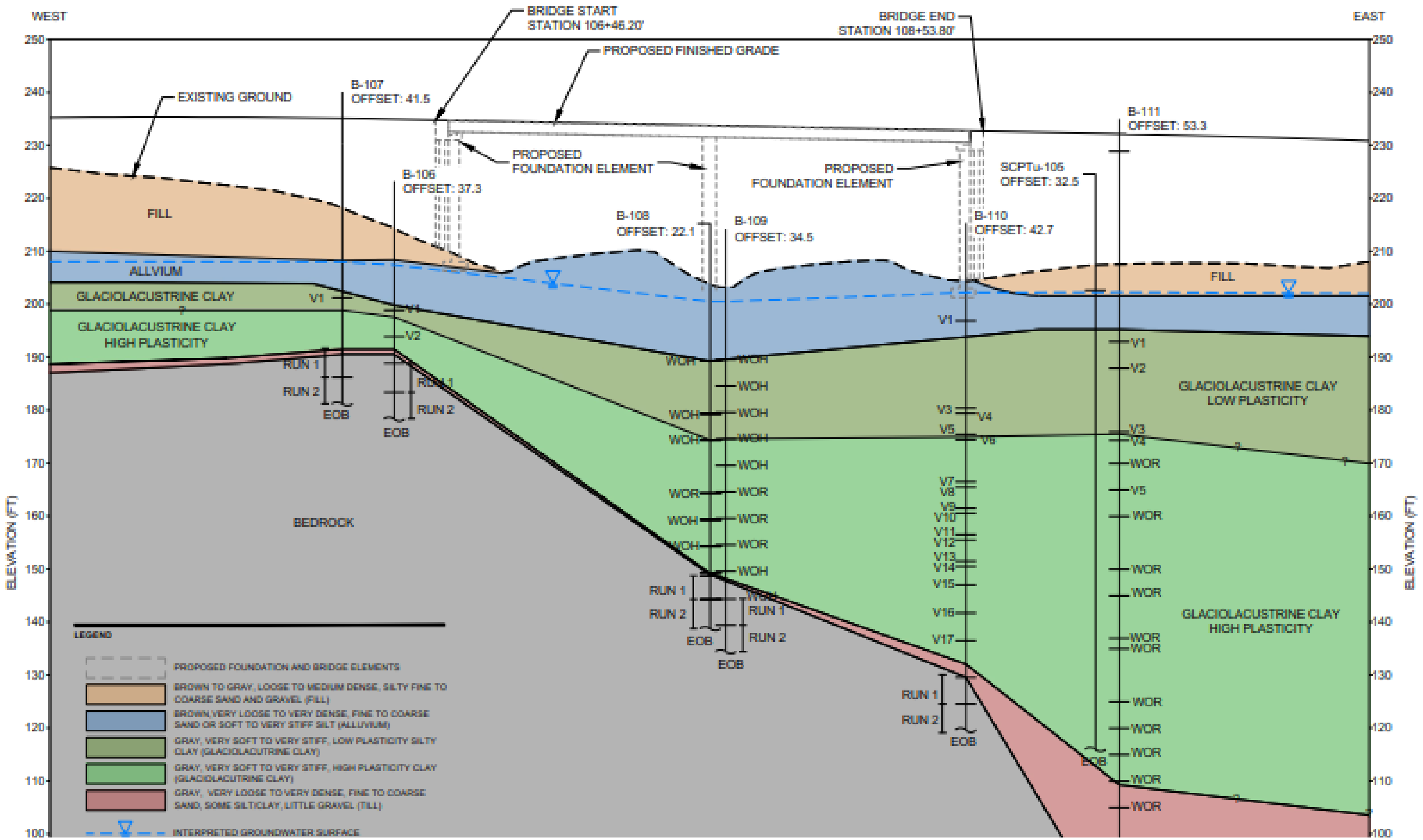
Subsurface Investigation

- 15 borings to refusal, 6 with 10 feet of rock core
  - Standard Penetration Testing (SPT)
  - Field Vane Shear Testing (VST)
  - Undisturbed Shelby tube sampling

- 4 Seismic Cone Penetration Tests (SCPT), 2 CPTs, using track-mounted drill rig
  - Measured V_s: Site Class D.
    SPT WOH/WOR: Site Class E.
  - Avoided overly conservative design and higher construction costs.

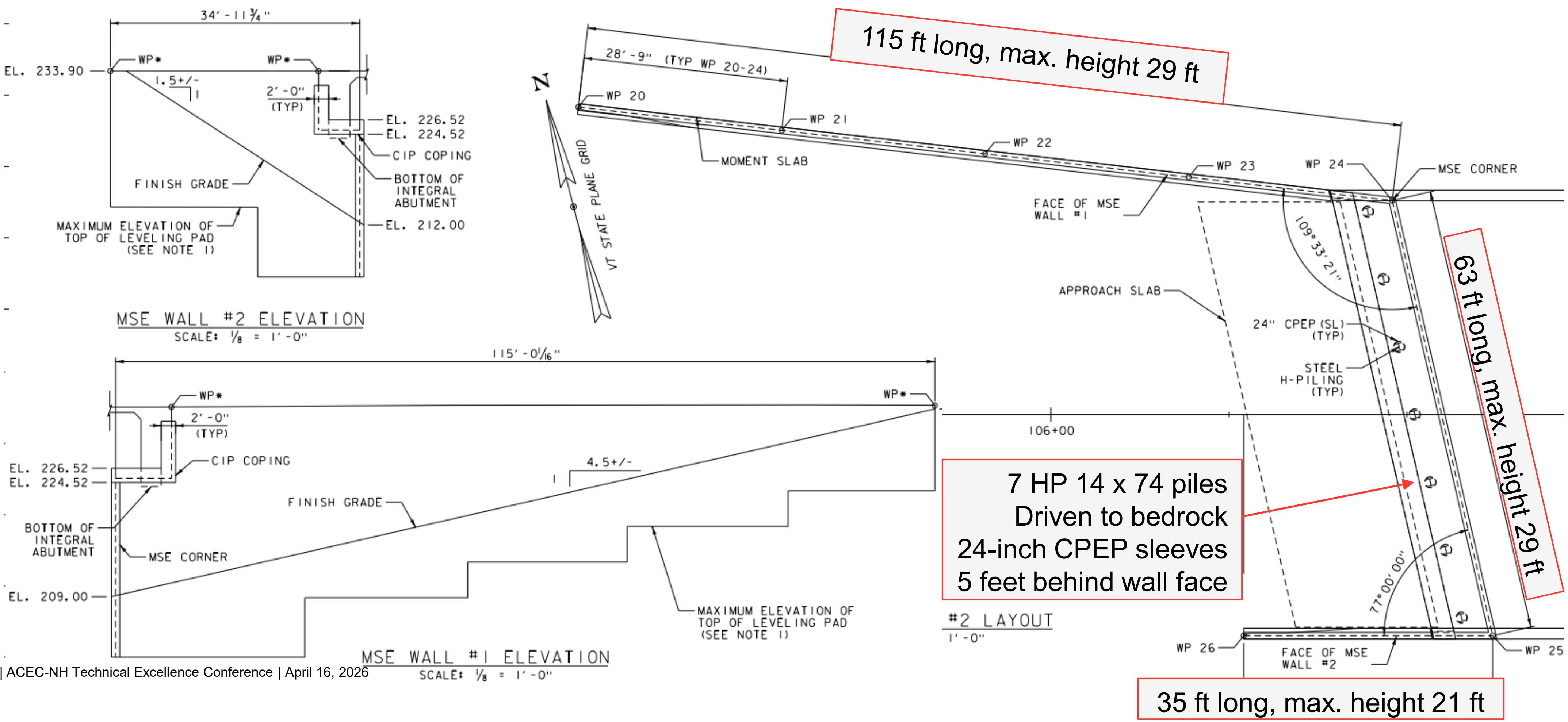


Subsurface Stratigraphy

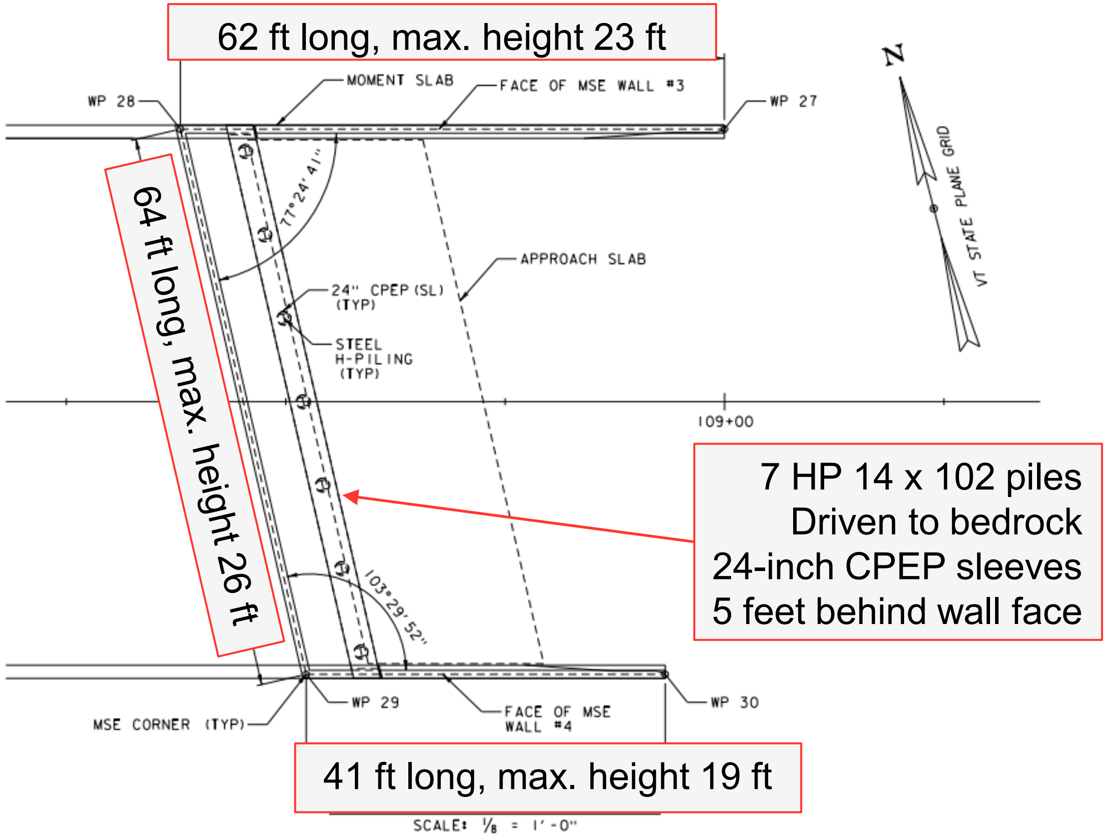


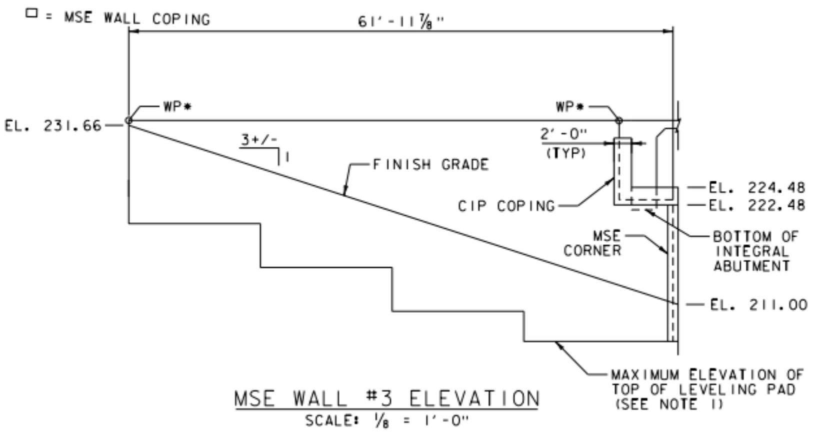
- Fill (tan): 2 ft to 34 ft
- Alluvium (blue): 2 ft to 20 ft
  fine to coarse sand
- Clay (green): 4 ft to 92 ft
  very soft to stiff,
  CL (shallow) and CH (deep)
- Till (pink): 0 ft to 20 ft
  Sand & Gravel with soft to stiff clay
- Bedrock (gray): Dolostone,
  freshly to slightly weathered,
  very to extremely strong.
- Interpreted water table shown

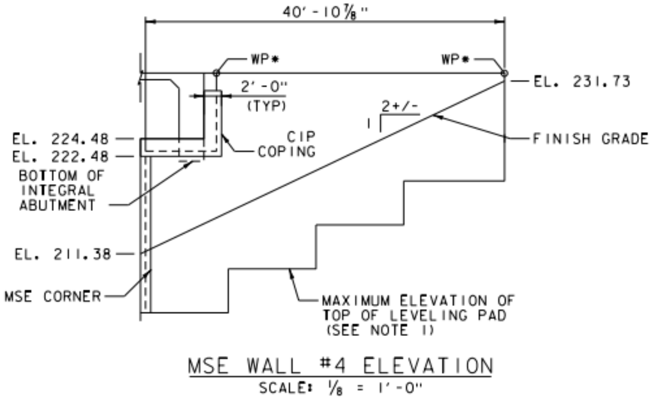
MSE Walls at Abutment 1, Wall #1 (N), Wall #2 (S)



MSE Walls at Abutment 2, Wall #3 (N), Wall #4 (S)







Abutment Foundations

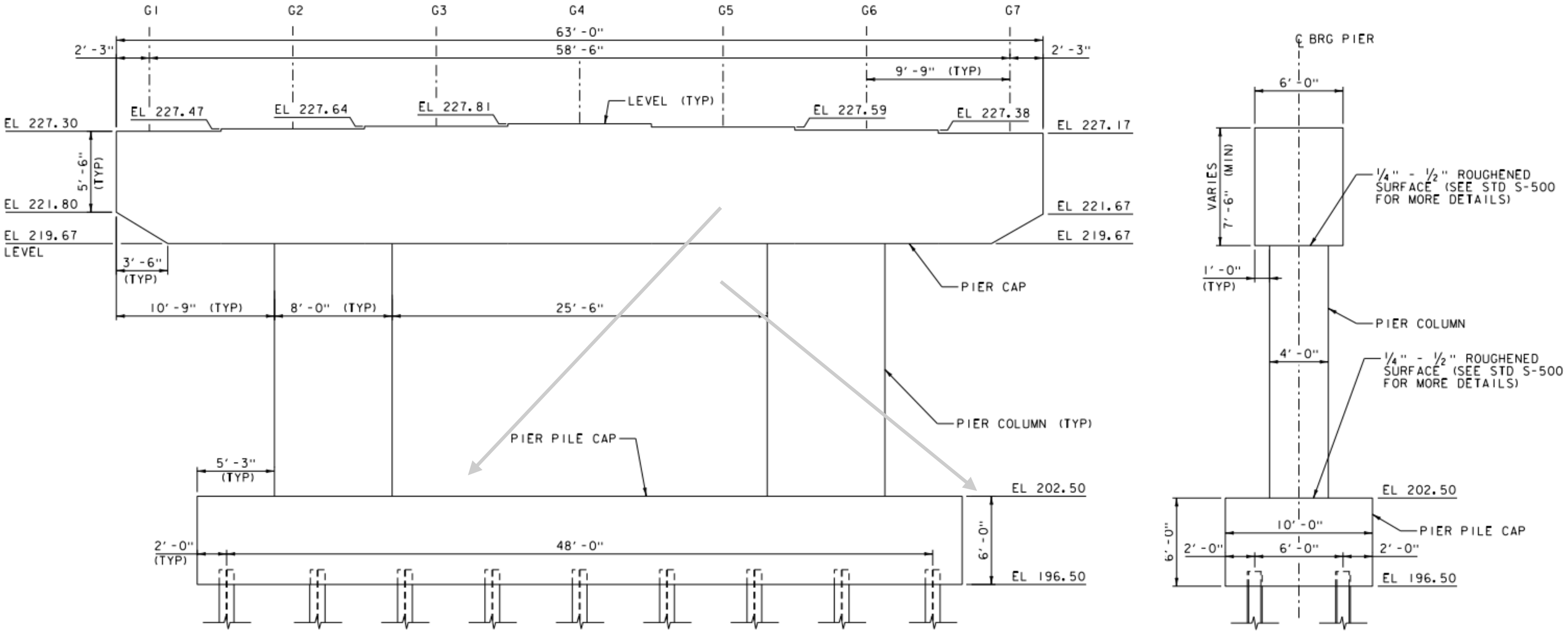
Design:

- VHB provided for center of each abutment:
- Vertical, longitudinal, transverse loading
- Lateral deflection and rotation
- Pile design:
- Design evaluated Axial, Shear, Combined axial/flexural resistance, settlement-induced Downdrag loading
- Abutment 1: 7 HP 14 x 74 piles
- Abutment 2: 7 HP **14 x 102** piles
- 3 to 15 bpi at end of driving

Recommendations:

- Piles a minimum of 5 feet behind MSEW face
- 24-inch CPEP pile sleeves through MSEW. Piles centered. Piles may be driven before or after MSEW installed
- MSEW reinforcing strips at ≤ 15º skewed to back of face panels to accommodate sleeves
- Sleeve fill: dense graded ¾” crushed stone
- Initial design: sleeves with annual backfill full height
- Concern: integral abutment displacement
- Final design: Piles with centralizer w/o backfill within 10 feet of base of abutment, then annular backfill .

Pier Foundations



- VHB provided vertical, longitudinal, transverse loads
- FB-MultiPier used to determine pile loading, downdrag not expected
- HP 14 x 89 piles, 2 rows, 9 piles/row, vertical

MSE Wall Design

AASHTO LRFD:

- Minimum strip length/ wall height ratio = 0.70 for conventional fills
- Minimum embedment = 2 feet on sloping ground
- Minimum horizontal bench = 4 feet for walls founded on slopes
- Limiting differential settlement = 1/100
- Select Backfill for MSE Walls (VTrans 704.18)

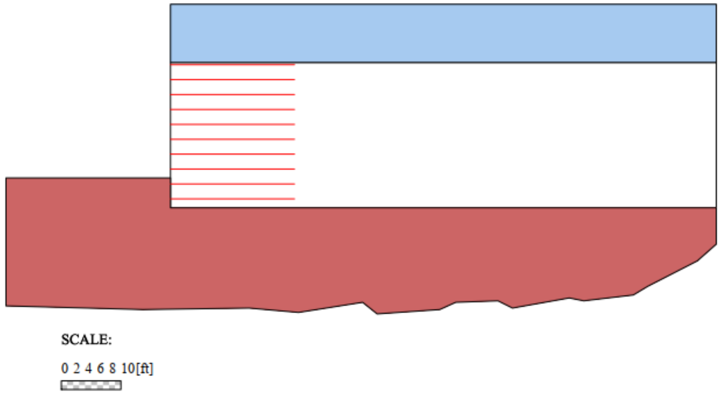
- Internal Stability – MSEW Contractor
- External Stability – WSP
  - Bearing CDR > 1
  - Sliding CDR > 1
  - Overturning CDR > 1
  - Settlement (Total and Differential)
  - Global stability (FS > 1.3)

Iterate for design

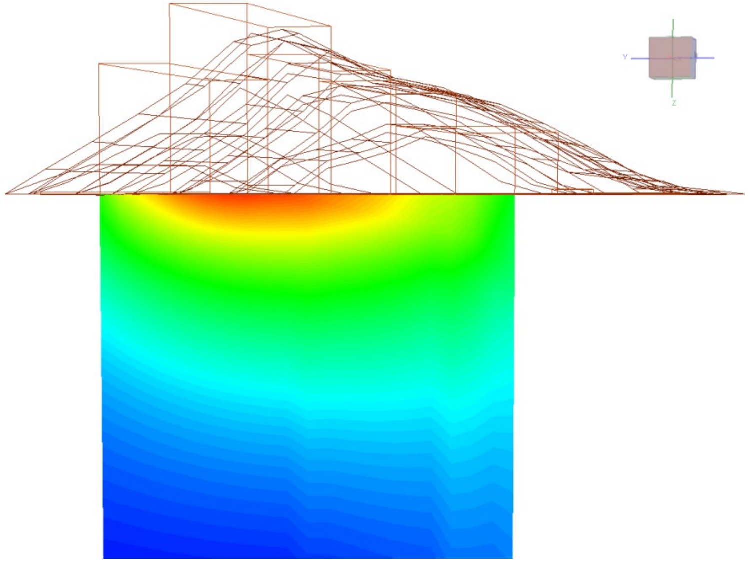
MSE Walls: Bearing / Sliding / Overturning / Global Stability

- ***MSEW+* Software (by ADAMA)**
- CDR > 1.0 for wall with strip L/H > 0.77
- **CDR < 1.0** for MSEW 1, strip L/H > 1.3 (not practical) – mitigate

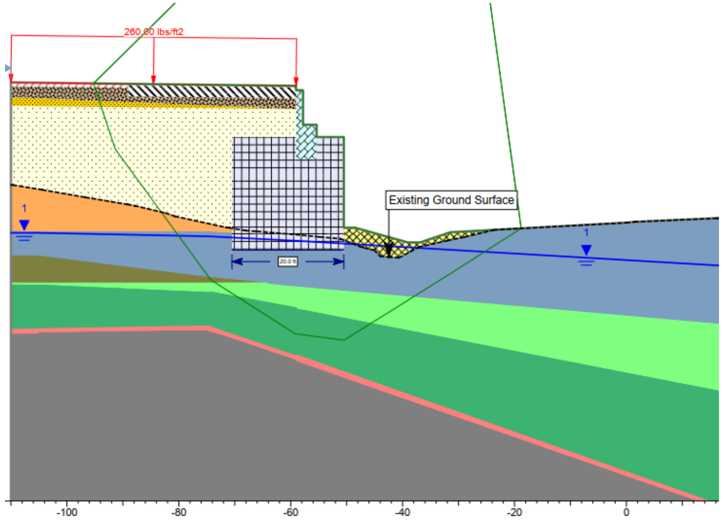
ANALYZED REINFORCEMENT LAYOUT:



- **Rocscience *Settle3***
- Soil layering and properties vary along centerline and with depth
- Differential settlement: < 1/100 at face
- Total settlement (< 4”) not a concern for panels



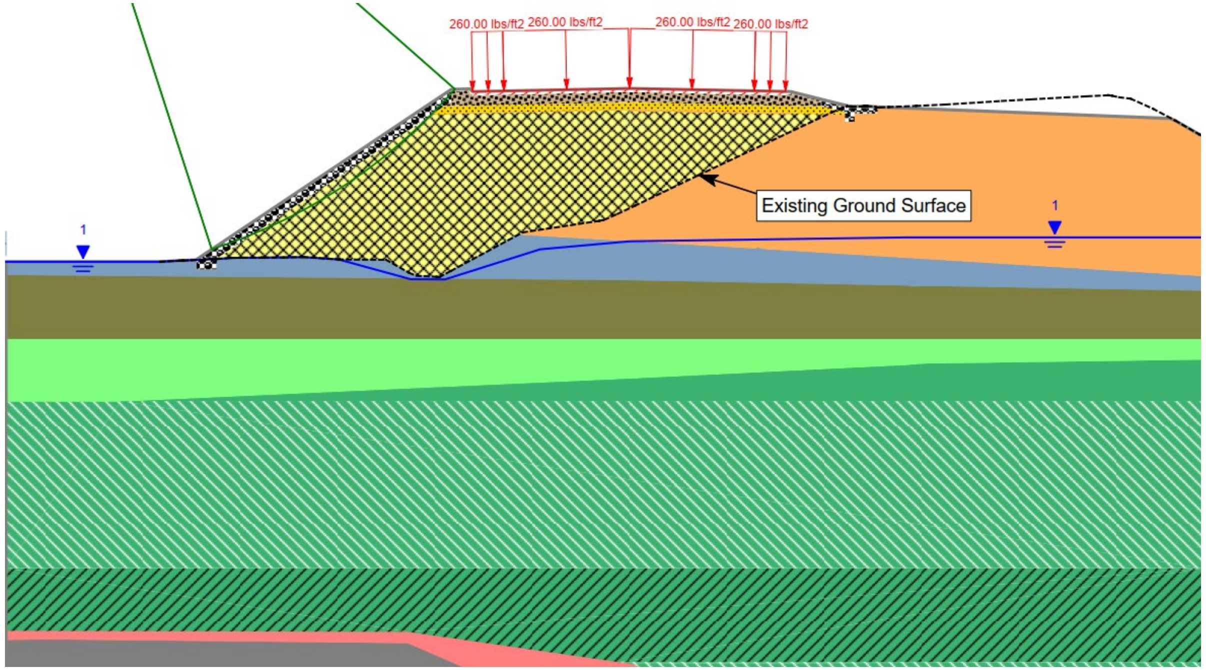
- **Rocscience *Slide 2***
- AASHTO LRFD 11.6.3.7 - Static FS ≥ 1.3
- FHWA GEC-13 - Pseudo-Static FS ≥ 1.1
- Abut. 1 MSEW, **FS < 1.3 static** - mitigate



Eastern Embankment Global Stability

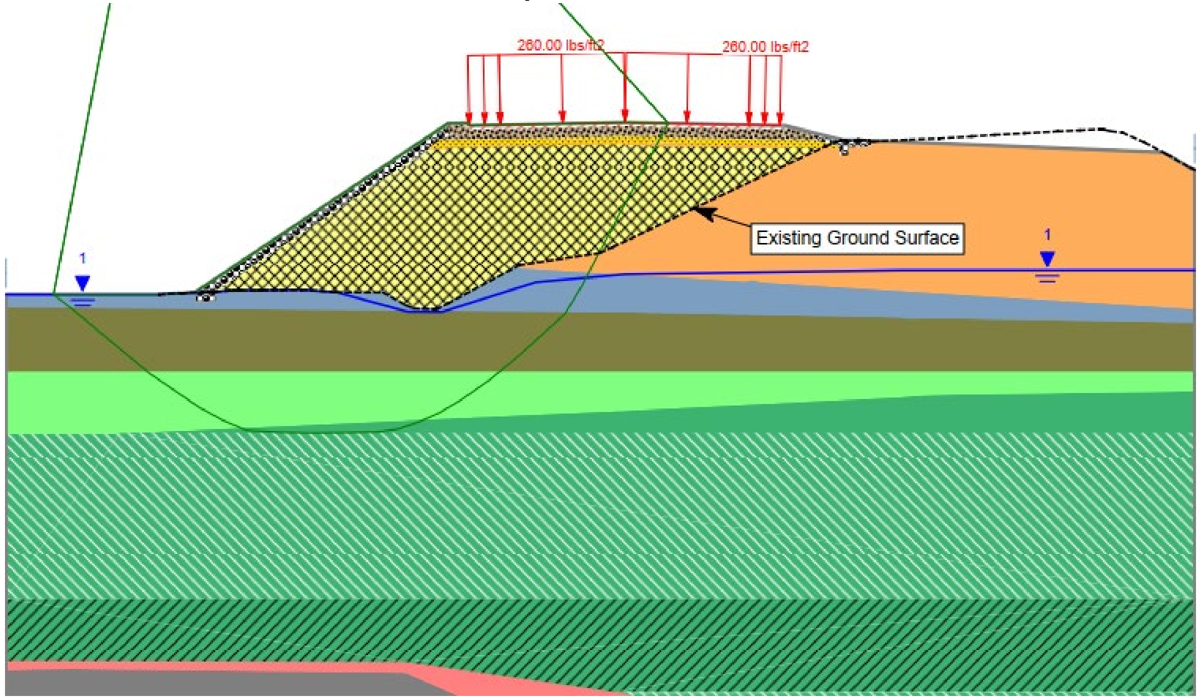
300-foot length of embankment with Granular Borrow required mitigation

Shallow FS ~ **1.0**, 1.5H:1V



Deeper FS **< 1.0**, 1.5H:1V

> 30 ft deep failure surfaces



Initial Design Findings

- Increase global stability to FS ≥ 1.3 at MSEW 1 and 300 feet of eastern embankment
- Reduce Abutment 1 MSEW loading to achieve Bearing CDR > 1.0

Alternative designs

- Would delay project and reinitiate permitting

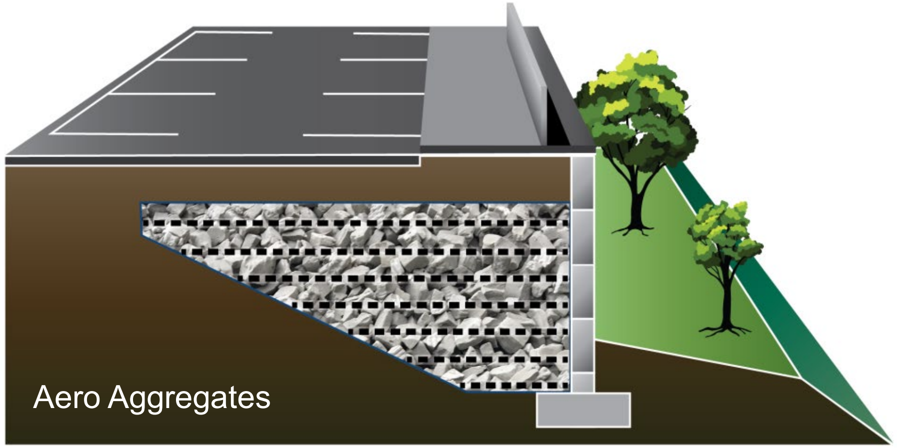
Improve subsurface material properties

- Preloading (project delays)
- Inclusions (aggregate piers, soil mixing, etc.)
- **Prefabricated Vertical Drains & Preloading***

Reduce loading

- Lightweight Fills: **Ultra-lightweight foamed glass aggregate (ULFGA)***, expanded shale, geofoam

Foamed Glass Aggregate (ULFGA)



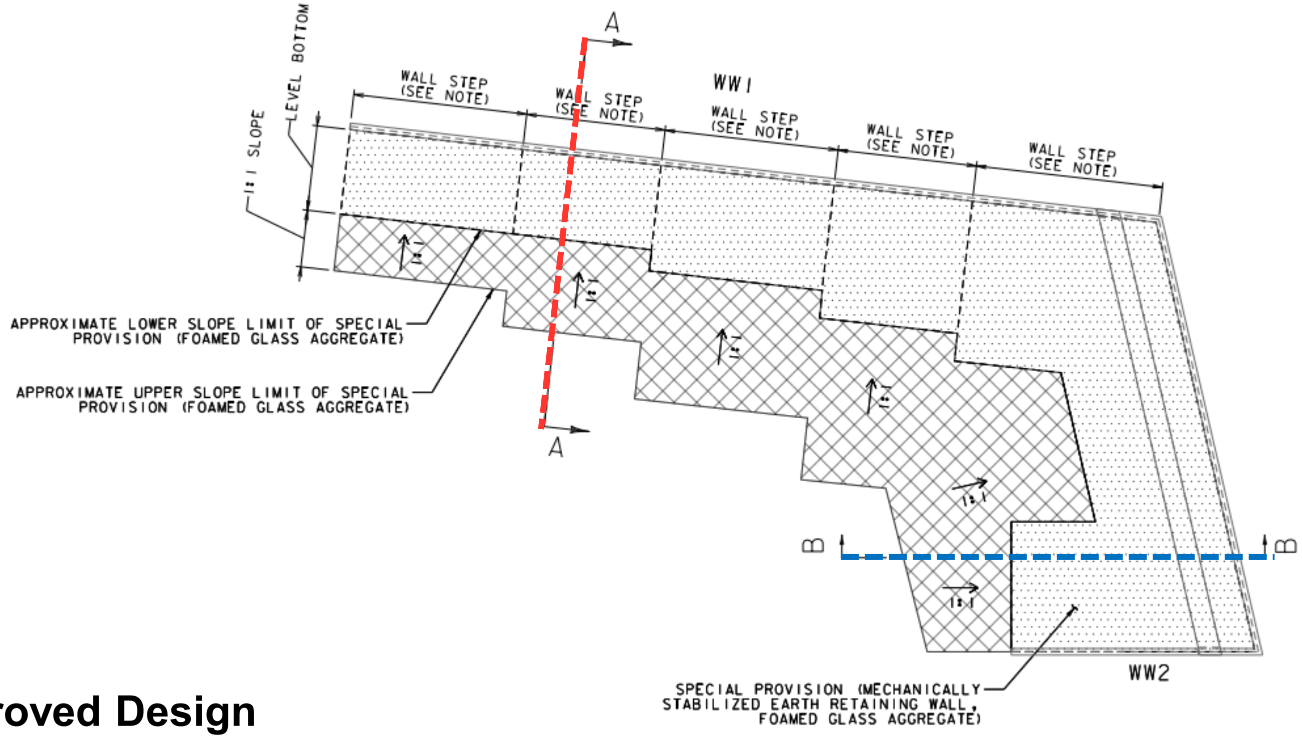
- Consulted with Reinforced Earth Company (RECO)
- Consulted with Aero Aggregates
  - ULFGA in MSEW (2020 - 4 case studies from RiDOT, PennDOT, MassPort)
  - Loux, T.A et al. (2019). "**Pullout Testing of Geogrids, Geostraps and Steel Strips Embedded in Foamed Glass Aggregate"**. Geosynthetics Conference 2019.
  - Loux, T.A. & Filshill, A.. "**A Study of the Use of Ultra-Lightweight Foamed Glass Aggregate for Retaining and MSE Wall Backfill**". Geo-Congress 2023. Passive earth pressure needed for integral abutments not included.
- ULFGA Engineering Properties – Large-Scale Direct Shear (LSDS) Tests
  - **Turner Fairbanks provided testing of Aero Aggregates Material in 2021**
  - Nicks et al. (2024). "**Strength-Deformation Characteristics of Two Different Foamed Glass Aggregates under a Static Design Load**," Geotechnical Testing Journal 47(1), 351-370.

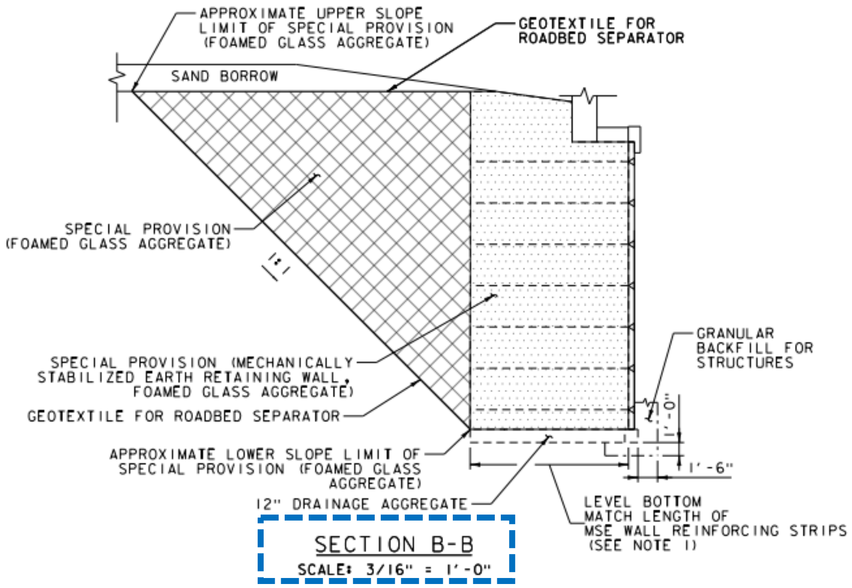
Foamed Glass Aggregate (ULFGA)

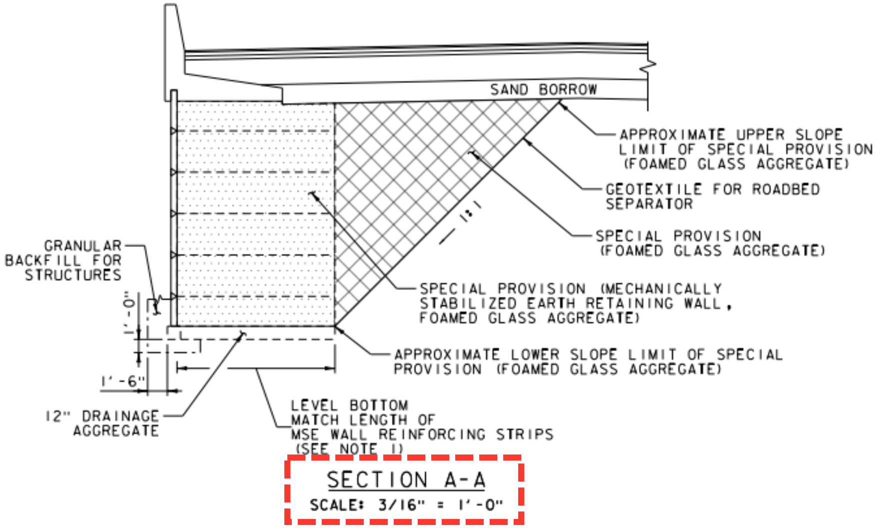
- **RECO Recommendations for MSEW**
- Aero Aggregates ULFGA
- Strip length: **L/H ≥ 0.85** & **L ≥ 12** feet
  minimize facing movement during compaction
- Unit weight: assume 20% crushing & γ_f **= 17 pcf**
- Friction angle: **ϕ = 38º** for mobilized strength
- ULFGA in driving wedge, 1:1 backslope

- **Other Considerations**
- Measured ULFGA strength: **ϕ = 45 - 55º**
- **ϕ = 45º** embankment
- **ϕ = 40º** active wedge behind MSEW
- Selected Aero Aggregates ULFGA for known:
  - Measured engineering properties
  - Compaction specifications
  - Compression behavior
  - Breadth of Transportation Research

MSE Walls ULFGA





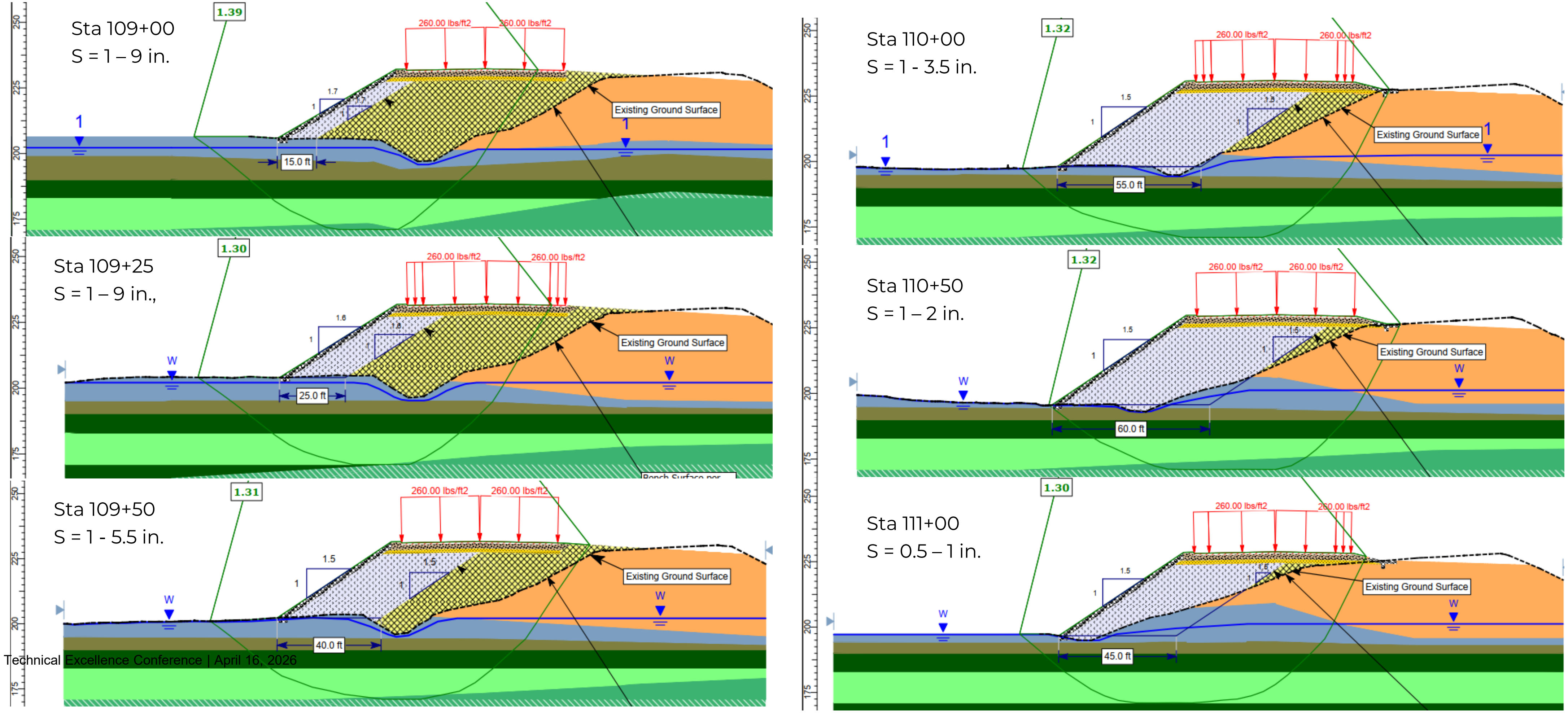


Improved Design

- Abut. 1 MSEW, FS ~ 1.4, Strip L/H = 0.95
- MSEW 1 , FS ~ 3.0 , Strip L/H = 0.85
- MSEW 2 , Strip L/H = 0.85, FS ~ 2.1

Eastern Embankment ULFGA

- Embankment: 25-30 feet tall; slopes: 1.5H:1V to 1.7H:1V
- ULFGA and Granular Borrow
- Design FS ≥ 1.3 (FS = 1.30 to 1.39 for deeper surfaces)
- Settlement reduced



ULFGA

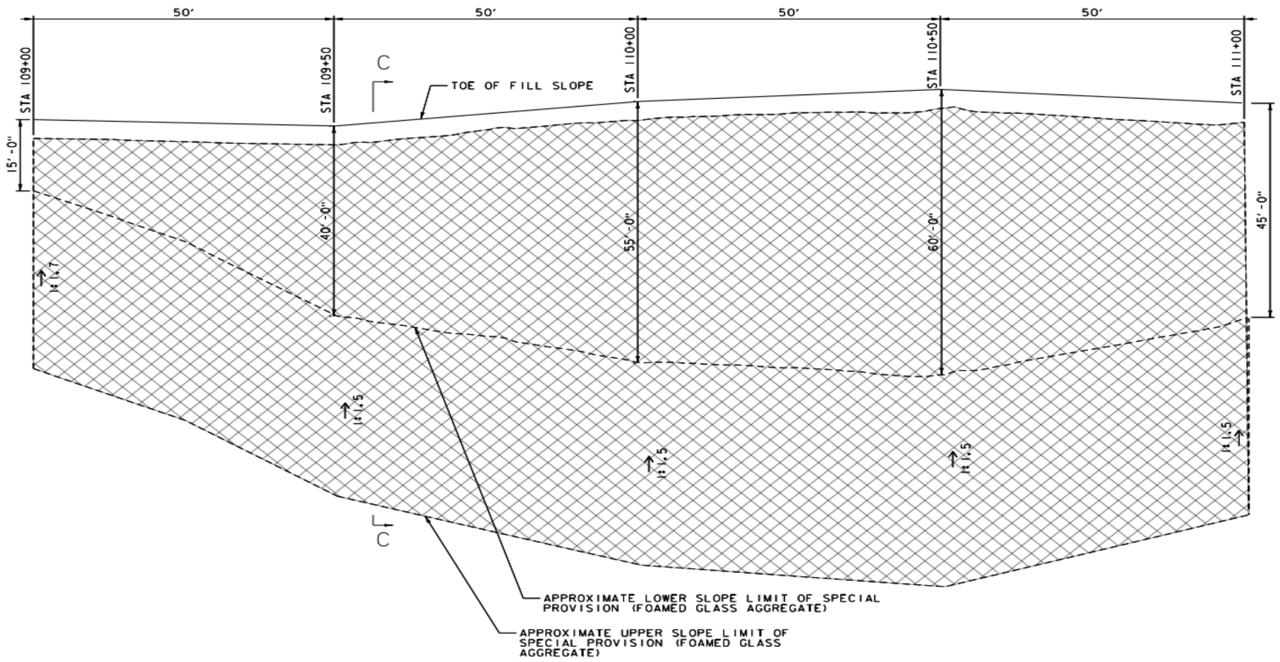
ULFGA Special Provision

- Aero Aggregates – sole source
- Material properties and compaction specified based on Aero Aggregates and Turner Fairbanks Lab Results

Value Engineering Proposal from Contractor

- Replace Aero Aggregates ULFGA with Glavel for cost savings
- Disallowed for MSEW & backslope fills
  - Nick's et al. 2024 findings
  - Glavel materials not demonstrated for MSEW
- Allowable for eastern embankment if Glavel can meet Special Provision

Eastern Embankment Plan for ULFGA



ULFGA Comparison

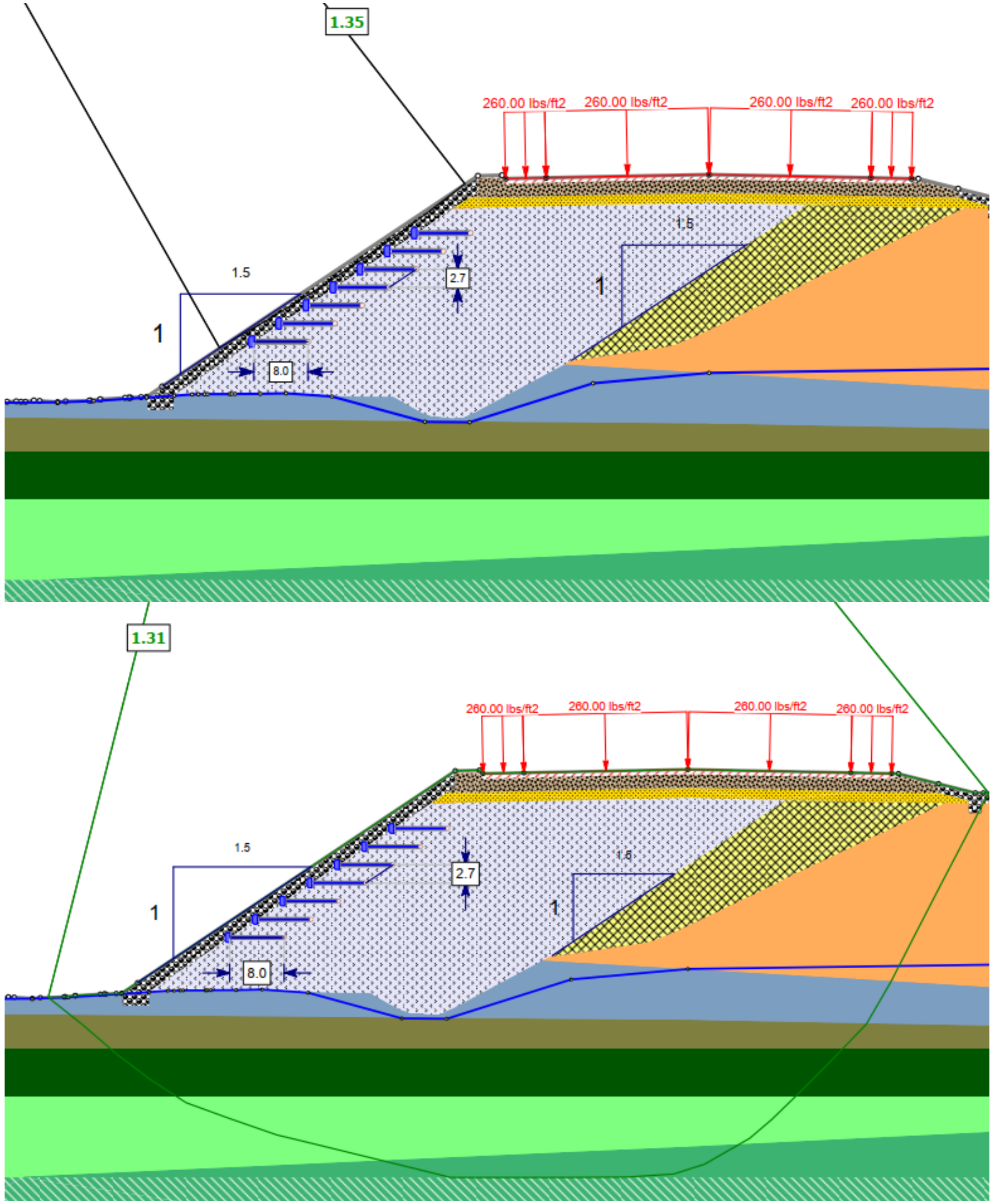
- Aero Aggregates – Design / SP
  - ϕ = 45º, γ = 18 pcf (embankment)
  - Compaction specifications provided (tracked equipment and plate compactors)

- Glavel
  - ϕ = 38º, γ = 18 pcf (lab results provided)
    WSP interpreted **ϕ at 15% strain** from ASTM D3080 as recommended by FHWA GEC 11 (MSE & RSS)
  - Did not meet SP for embankment design
  - Required redesign of the embankment
  - Compaction specifications (at the time) for plate compactors only

Refer to reference for more comparative information:
Nicks et al. (2024). "Strength-Deformation Characteristics of Two Different Foamed Glass Aggregates under a Static Design Load," Geotechnical Testing Journal 47(1), 351-370.

ULFGA Glavel Redesign

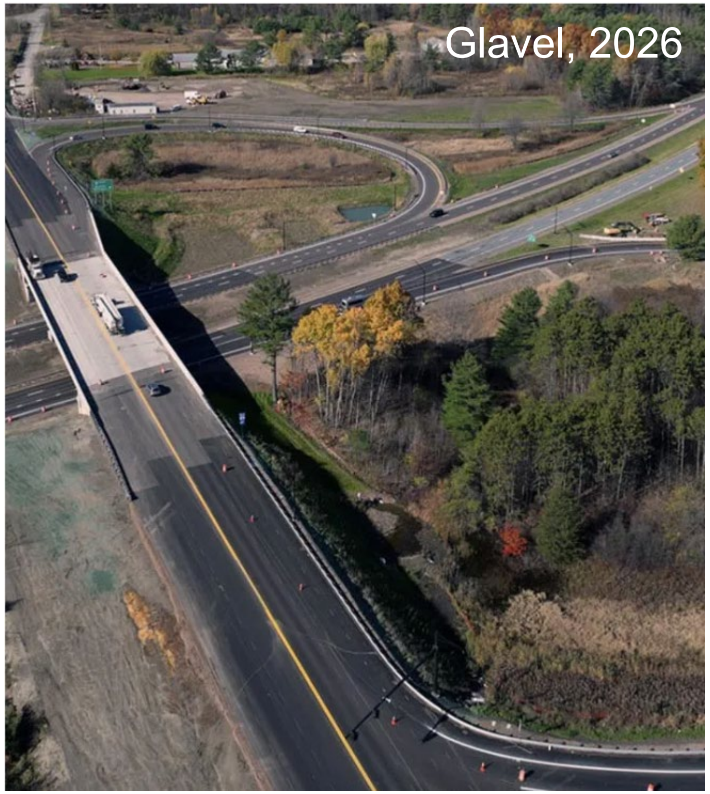
- Changes to embankment for shallow potential surface failures
  - Steep slopes (1.5H:1V to 1.7H:1)
  - Lower strength Glavel
  - No change in deep global stability
- Added to design:
  - 2-ft thick layer Type II Stone Fill at surface
  - 7 layers, 8-ft long, 32-in spacing geogrid reinforcement
- Test strip to determine compaction specs.
- Cost Savings: ~$300k



Summary

- **Piles through MSEW**
  - Piles installed first, CPEP placed, MSEW constructed
  - CPEP filled w/ ¾” crushed stone to within 10 ft of abutment – allow IAB deflections
- **ULFGA**
  - Aero Aggregates and Glavel ULFGA are <u>NOT</u> the same materials.
  - Use Engineering Judgment when selecting material properties for ULFGA depending on application (MSEW, stability, load reduction)
  - One or both ULFGA projects may not be appropriate for all applications

Construction & Post Construction



THANK YOU

Special Thanks

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Aaron Guyette & The VHB Design Team

WSP's Chris Benda & Jeff Lloyd