Updated Analysis of Static and Seismic Stability

Berms P2-12 and P2-13

Cargill Salt Ponds

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Andrew Barrett; and Cole Bales

September 11, 2024

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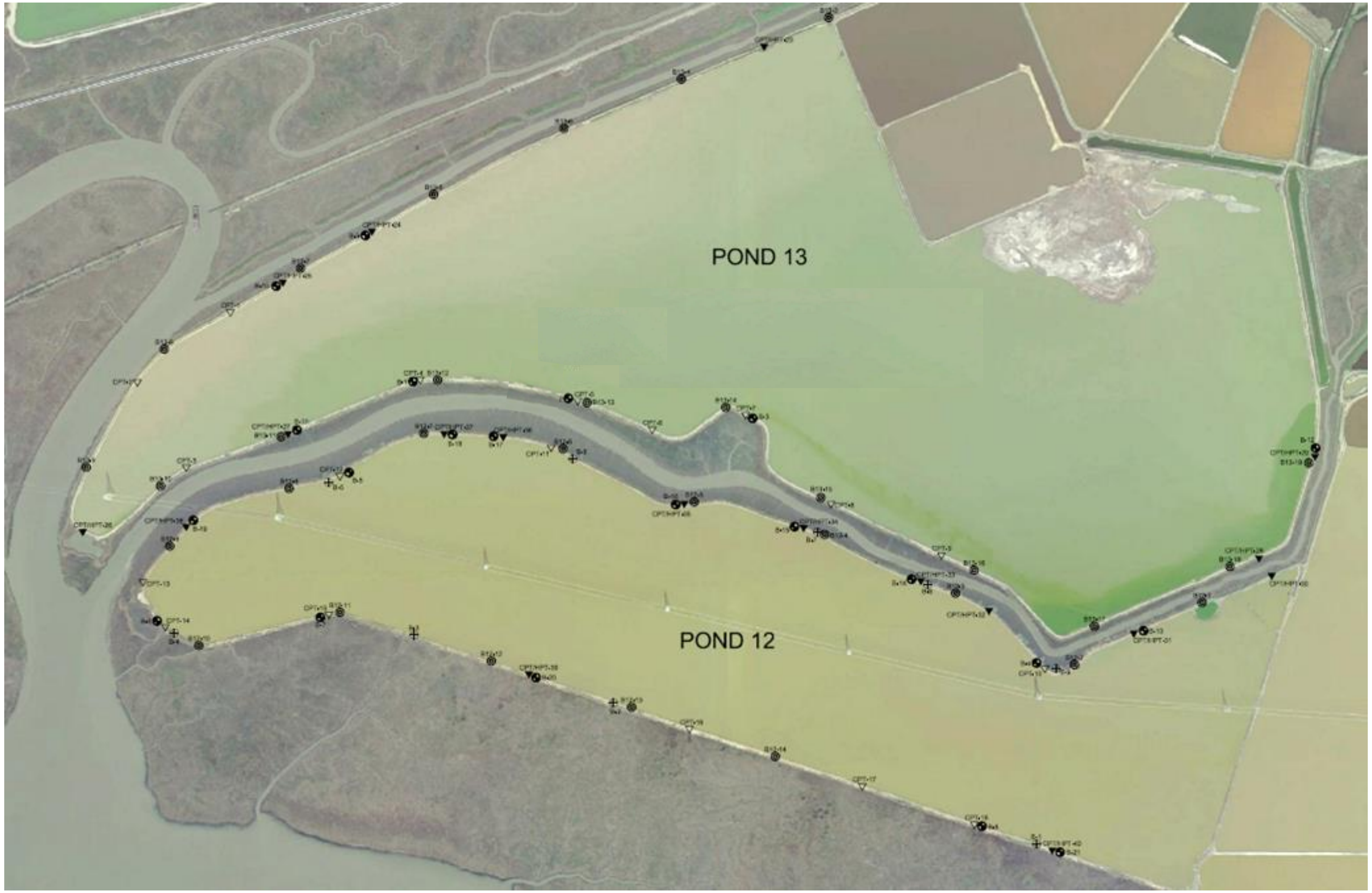
Recap of Previous Berm Stability Analysis Presentation



- 24 borings to depths of 11 to 16 feet
- 2 borings at NE corner to depths of over 80 feet
- 43 cone penetration tests (CPTs), many with hydraulic profiling tool

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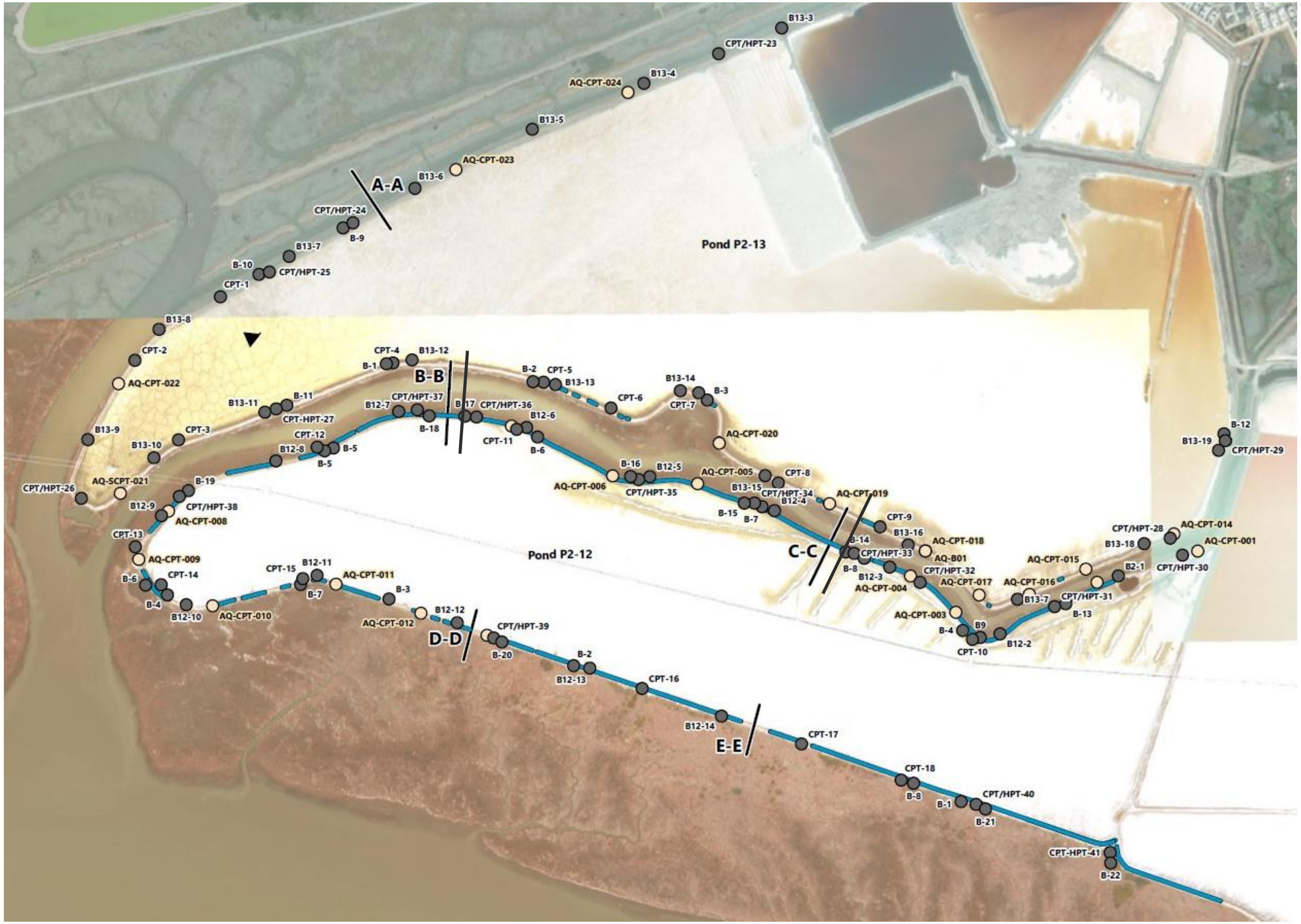
Recap of Previous Berm Stability Analysis Presentation

- Analyses performed using pre-existing subsurface data, collected by others.
- Technical memorandum dated July 31, 2023 to BCDC.
- Sufficient levels of berm stability were indicated.
- Findings were presented to ECRB in Fall of 2023.
- ECRB expressed numerous comments.
- Geotechnical Work Plan was submitted to BCDC on Dec. 29, 2023, and approved on January 8, 2024.

2024 Geotechnical Field and Laboratory Program

- Field investigations performed during first sufficient dry window: April 29 to May 3, 2024.
- 24 CPTs, two of which were seismic cones, to as much as 100 ft BGS
  - Refusal encountered at 64-65 feet
- One deep boring to 104.5 feet BGS
- 3 hand-pushed undisturbed sample cores (Shelby tubes)
- Laboratory tests: Strength tests, Plasticity (Atterberg limits), Grain size, Moisture Content

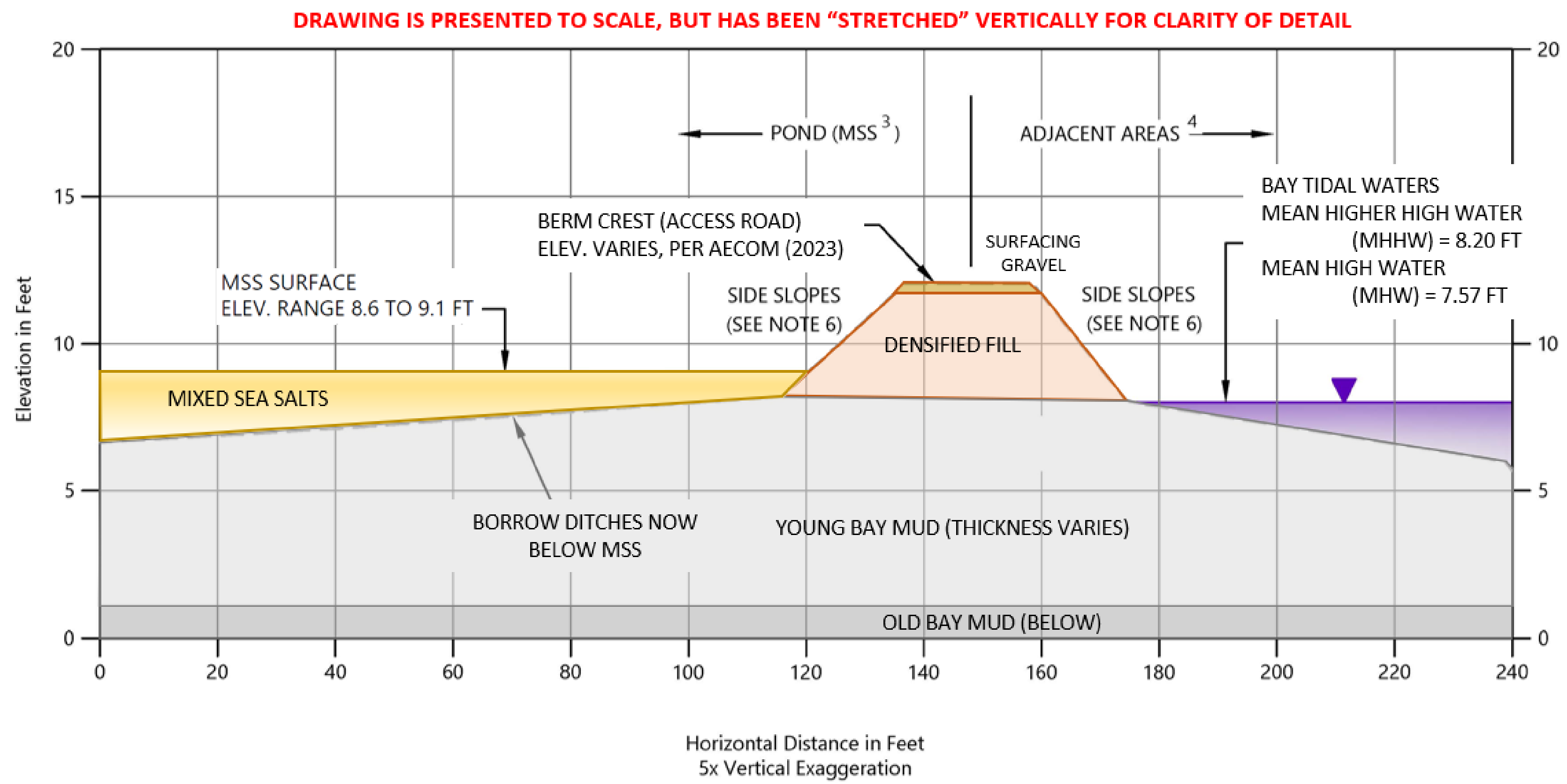
2024 Geotechnical Program



- Critical cross-sections noted
- Areas keyed in the recent past (last 5 years) indicated in blue.

Berm Cross-Sections Developed for Analysis

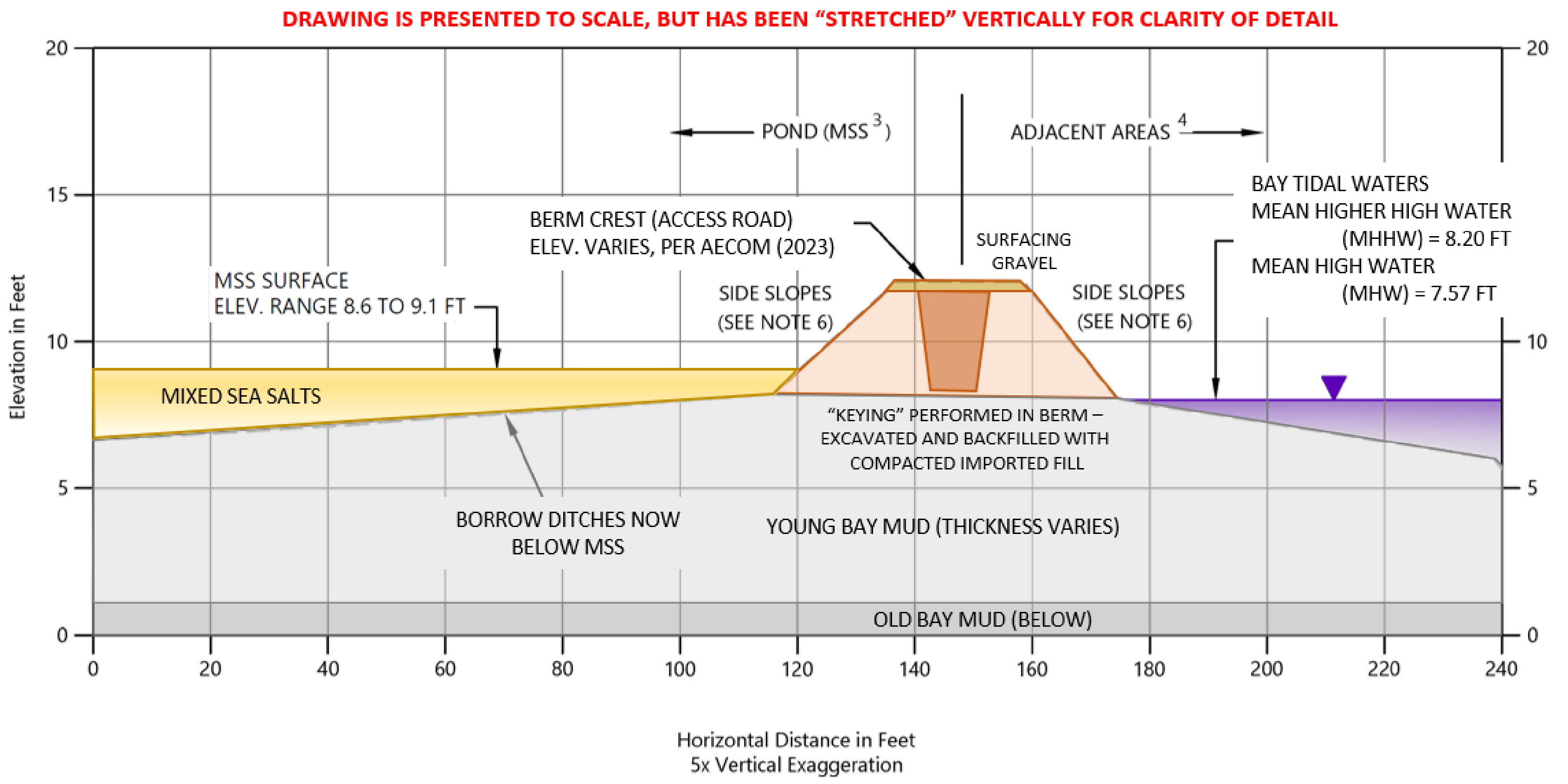
Generalized Berm Cross Section



NOTES:

1. Horizontal datum: California state plane, Zone III, North American Datum of 1983 (NAD83), U.S. survey feet
2. Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)
3. MSS = Mixed Sea Salts
4. Adjacent areas include San Francisco Bay waters, marshlands, Plummer Creek, and related tributary creeks
5. MHH = Mean Higher High Water
6. Berm side slopes range from 2H:1V to 2.5H:1V

Generalized Berm Cross Section with Keyed Interior



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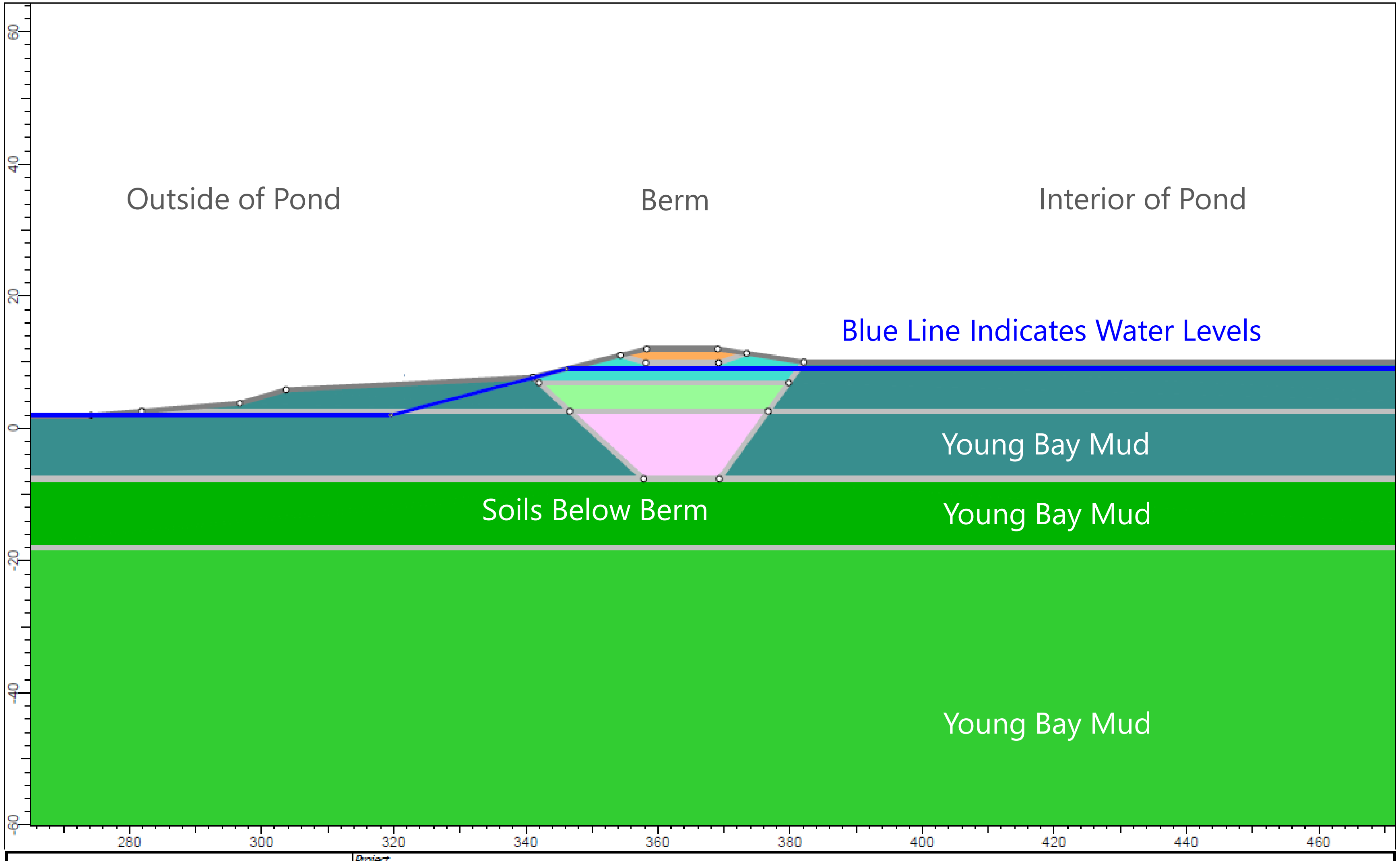
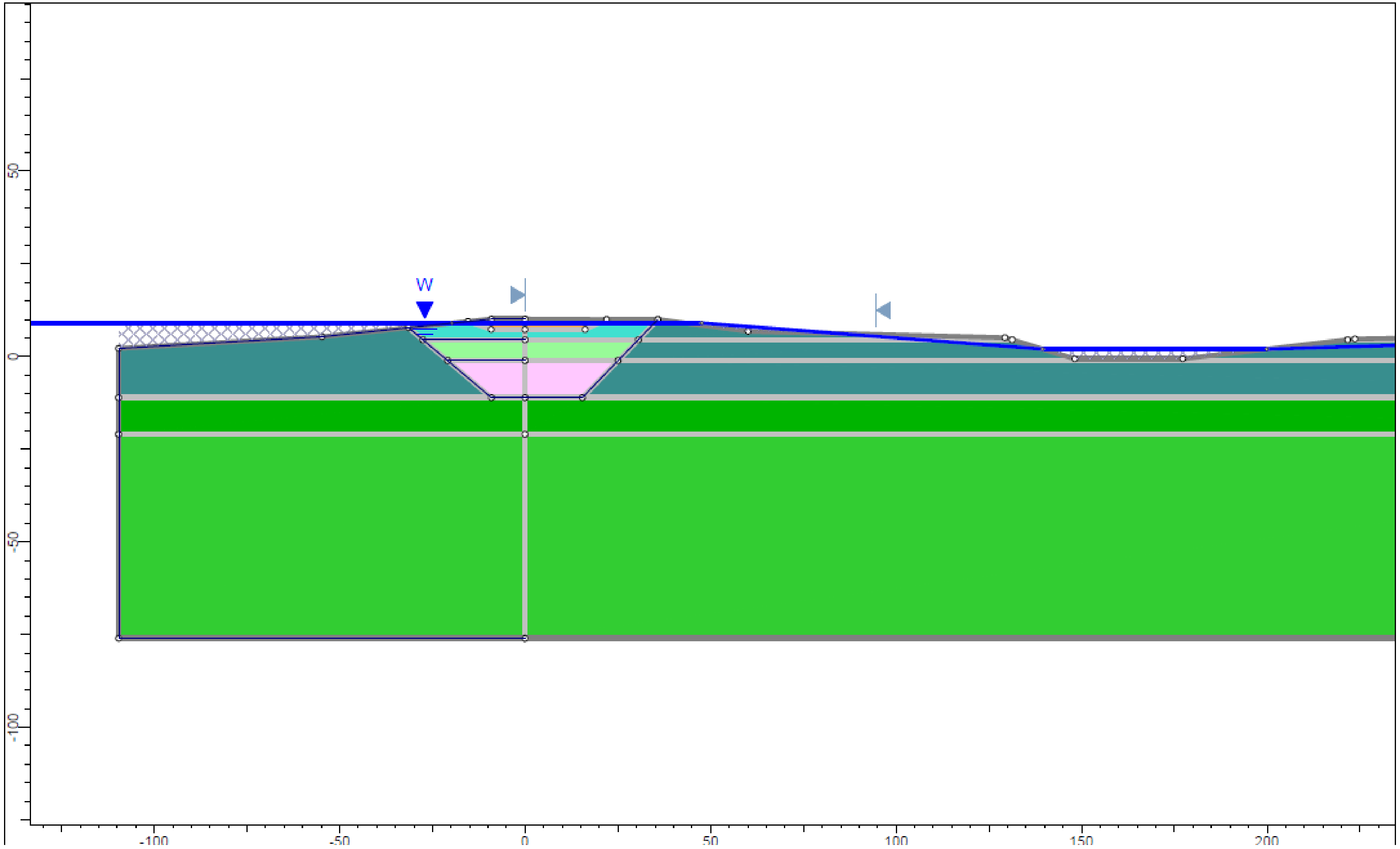
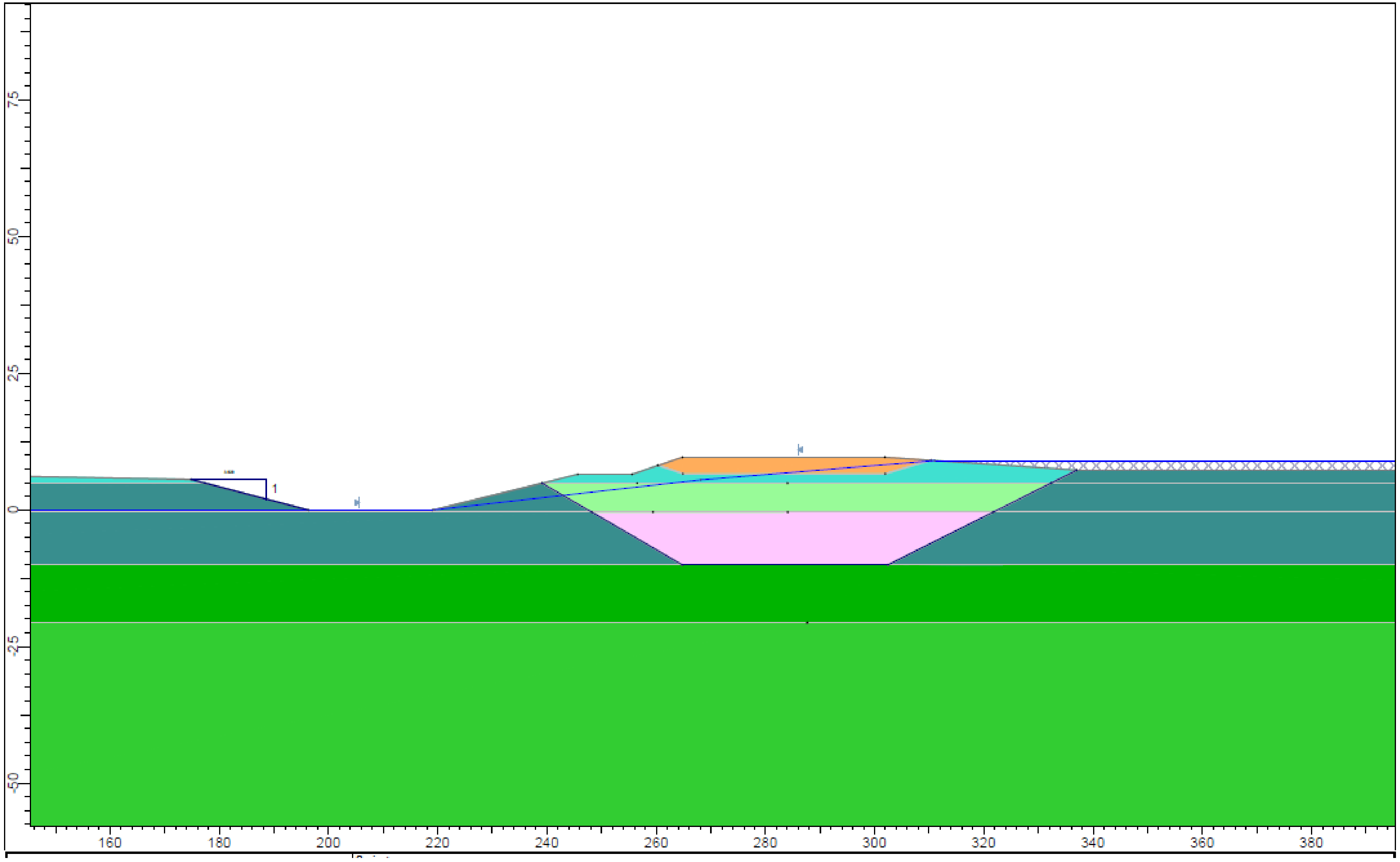
Selected Cross-Sections for Analysis: Location A-A'



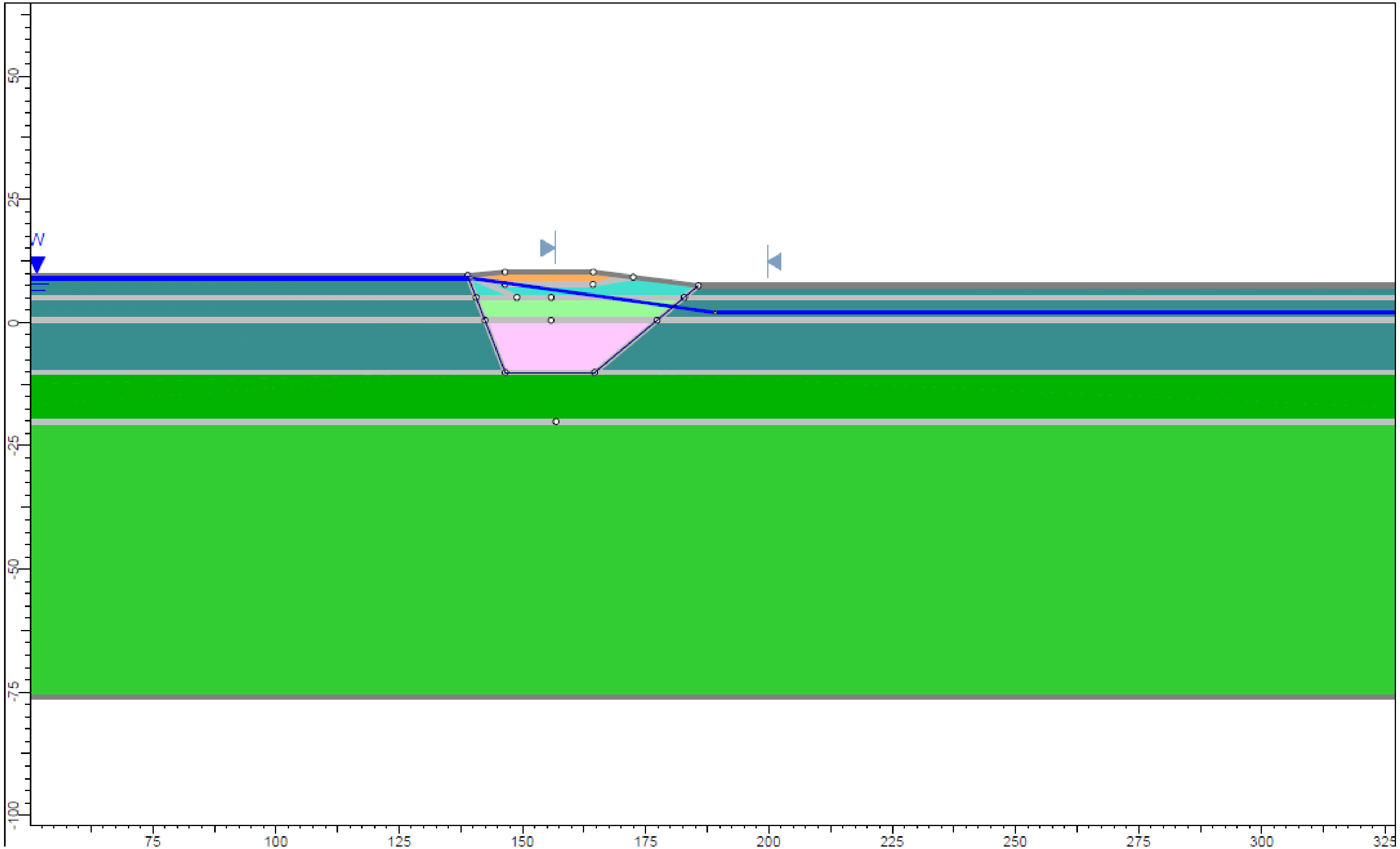
Selected Cross-Sections for Analysis: Location B-B′



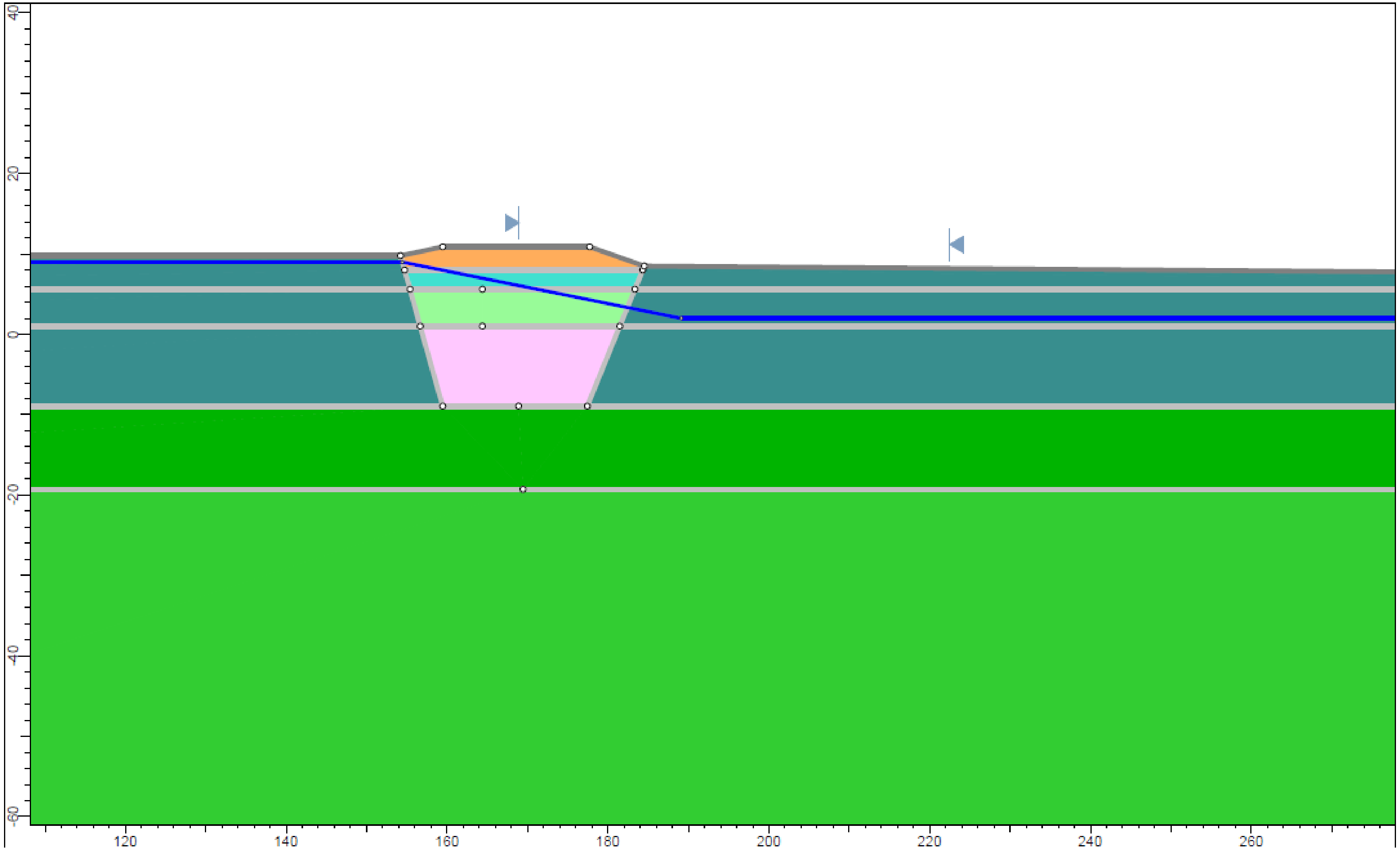
Selected Cross-Sections for Analysis: Location C-C′



Selected Cross-Sections for Analysis: Location D-D′



Selected Cross-Sections for Analysis: Location E-E'



Analysis of CPT Data to Derive Strength Properties for Young Bay Mud (YBM)

Geotechnical Properties used in 2023 Analysis

Summary of Undrained[1] Soil Properties Used for Analyses

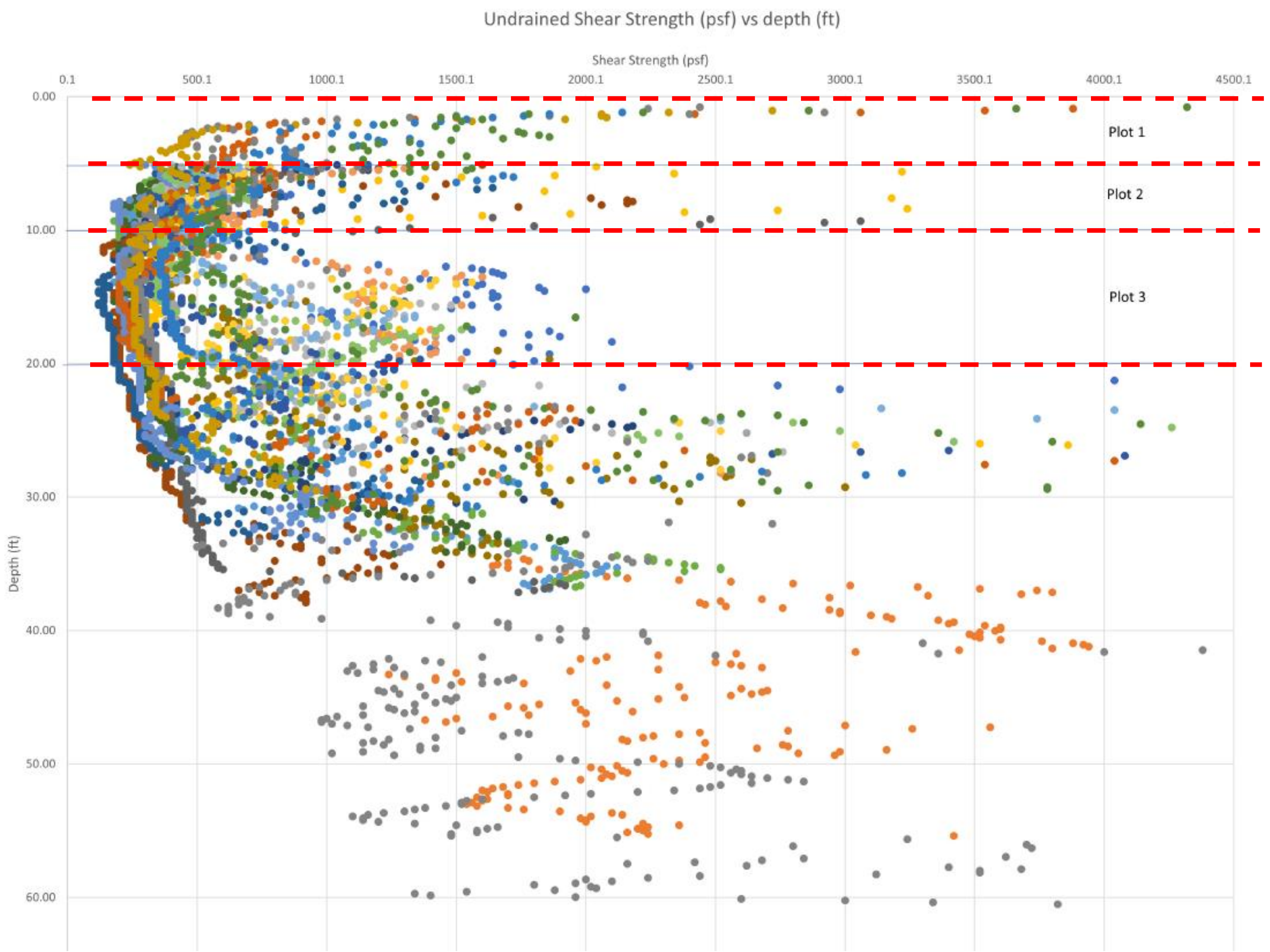
Soil Units	Unit Weight (lbs/ft³)	Cohesion, top of unit (psf[2])	Cohesion increase with depth (psf per ft)	Cohesion, base of unit (psf)
Densified Berm Fill	115	700	12	1,250
Young Bay Mud (YBM)	105	300	8	1,000
Old Bay Mud (OBM)	115	1,500	12	4,000

Notes:

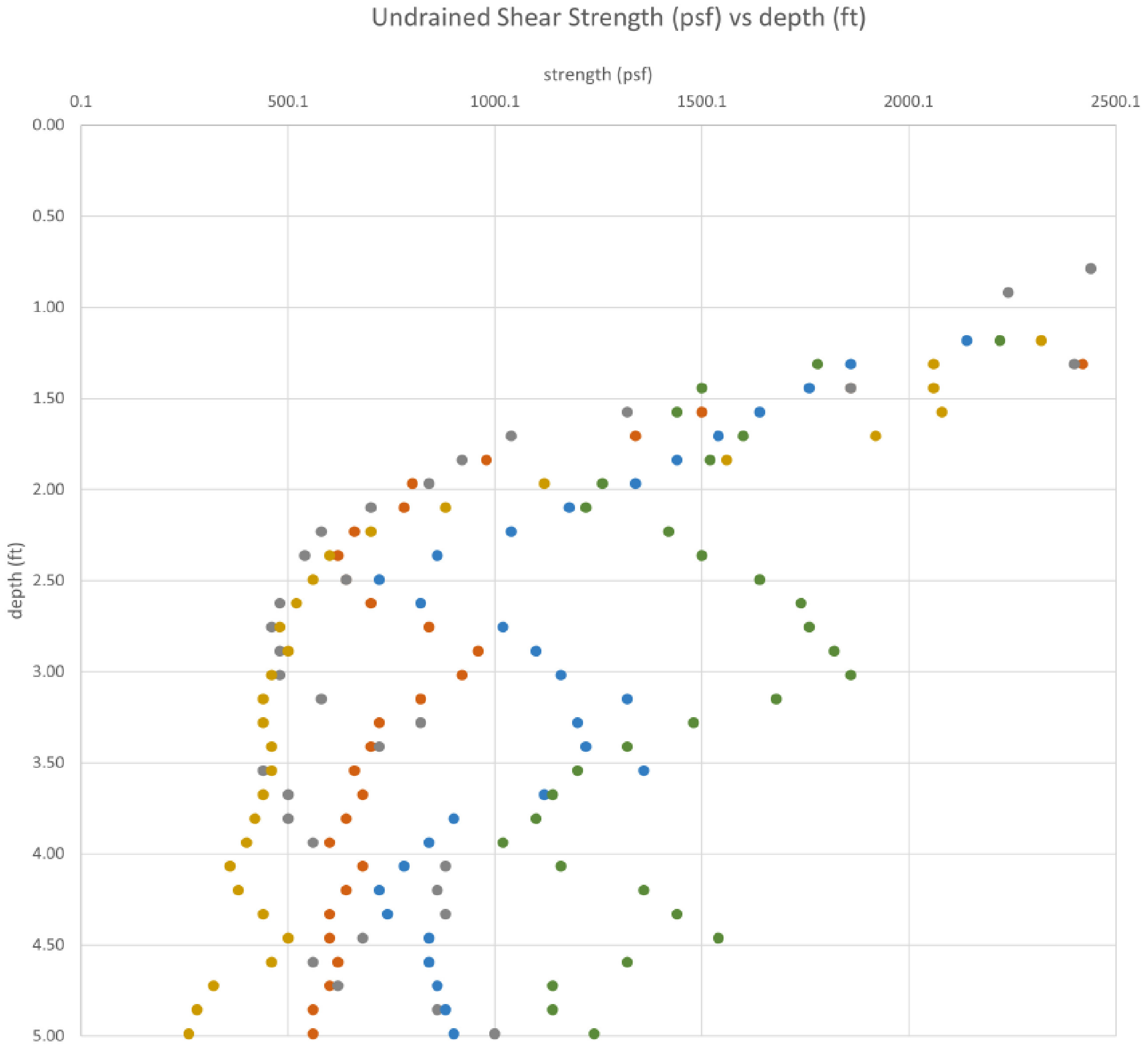
1. Undrained properties are most appropriate for the soil types encountered at this Site, as discussed in text.
2. psf = Pounds of force per square foot

Compilation of 2024 CPT Data

- Suggests separate below-surface layers with distinct strength properties
- Frequency-distribution plots used to select appropriate strength parameters for analysis

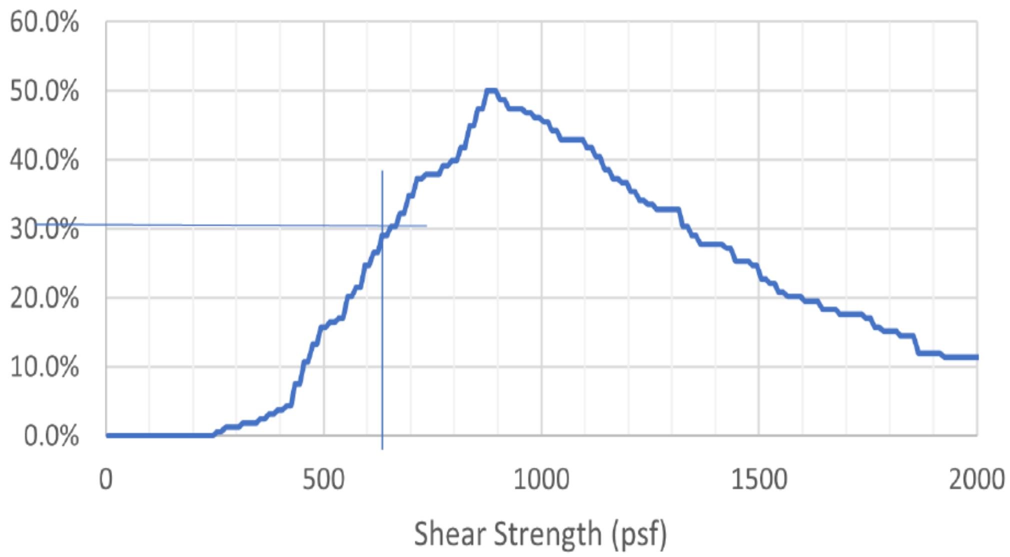


Upper five feet below ground surface



Includes Densified Berm Fill and uppermost YBM

Selection of appropriate strength at the 30-percentile level



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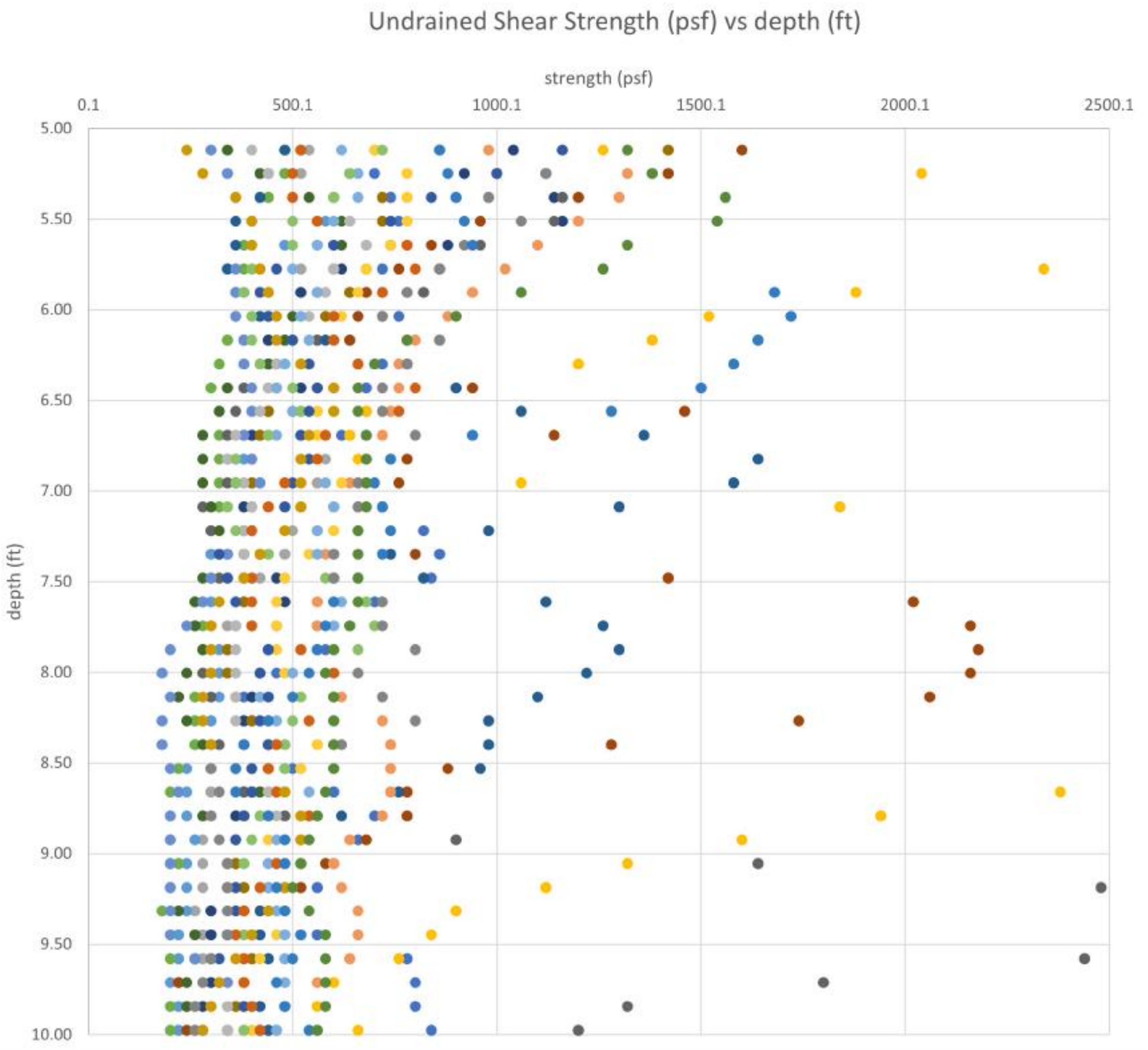
5 to 10 feet below ground surface



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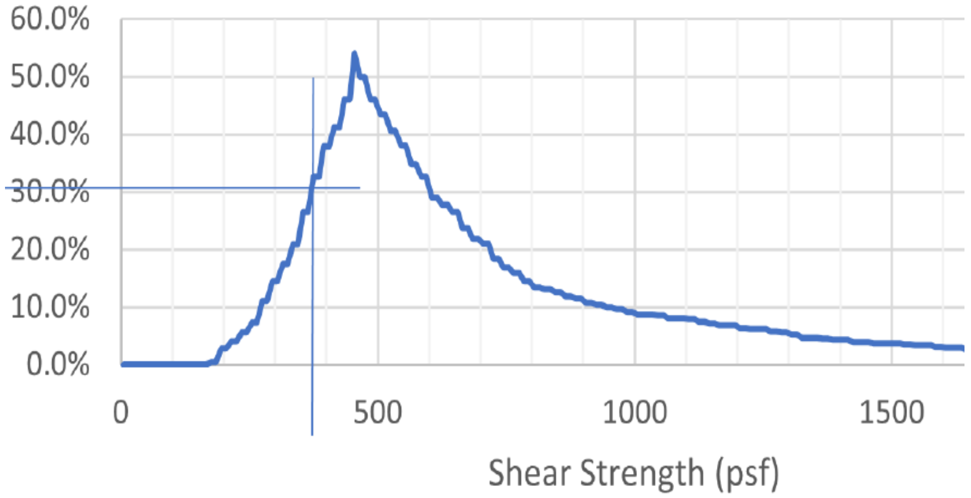

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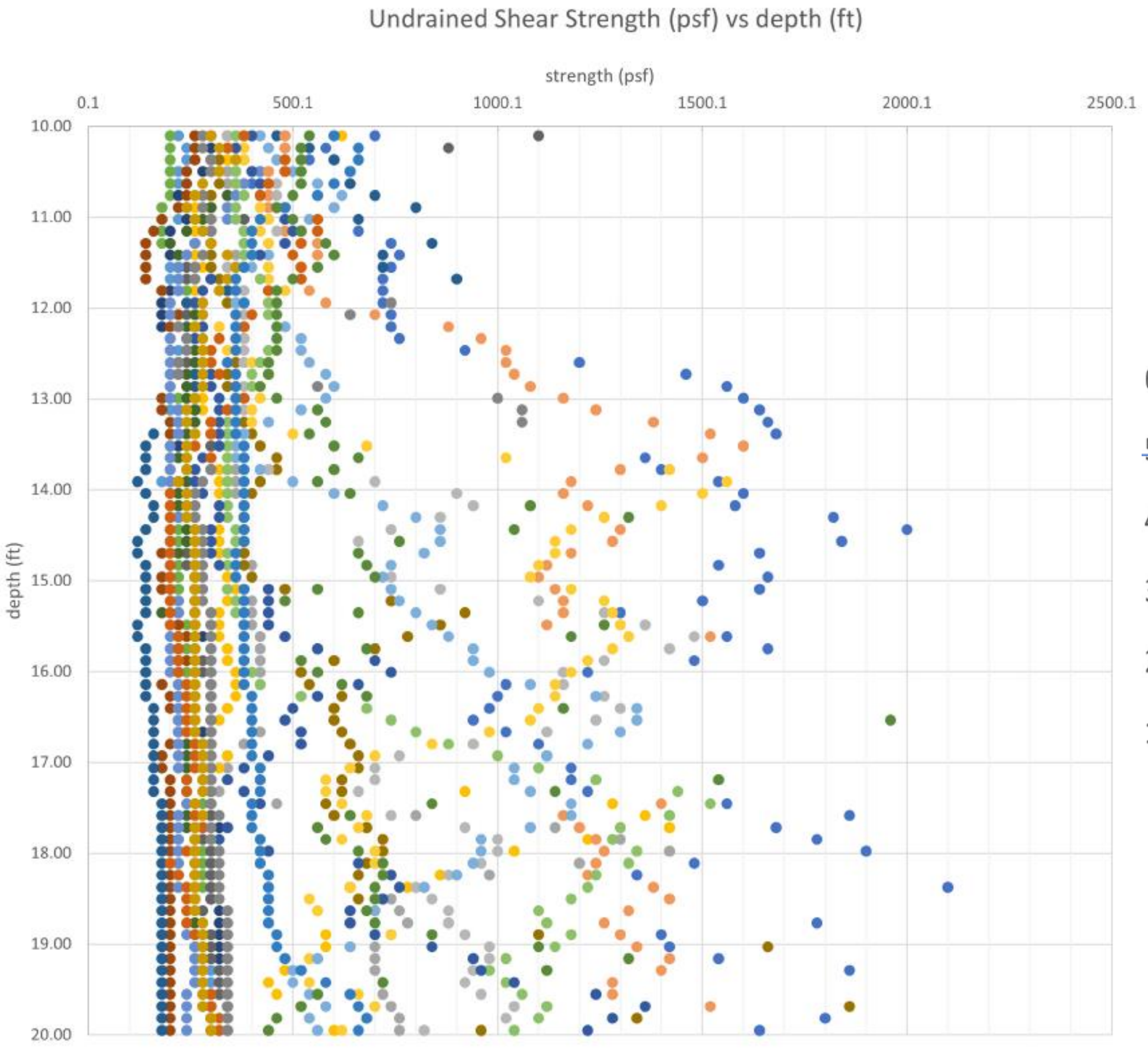
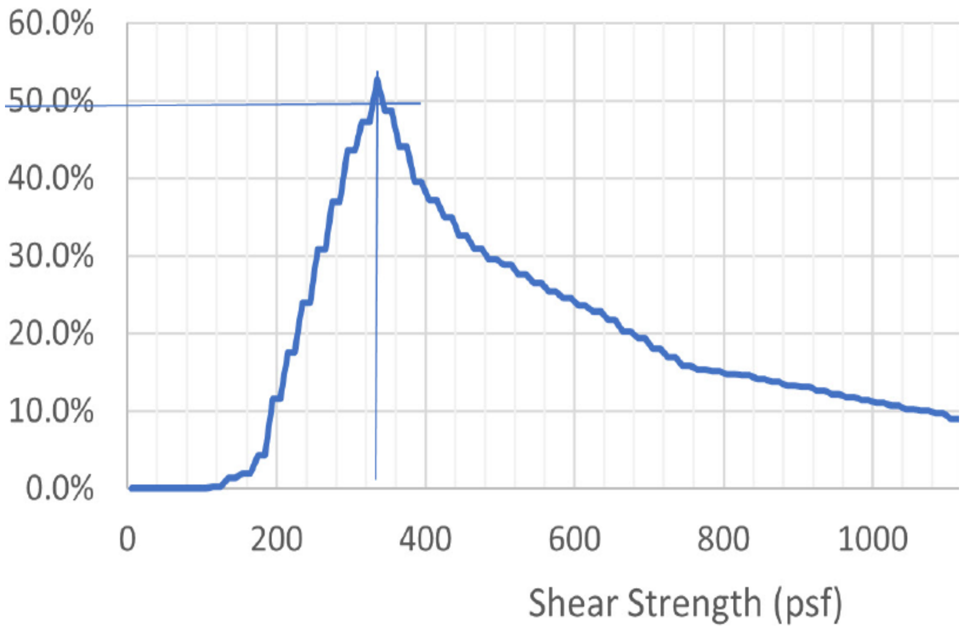
Plot Three: 10 to 20 feet below ground surface



Selection of appropriate strength at the **50-percentile** level



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Geotechnical Engineering Properties (2024 update)

Soil Units	Unit Weight (lbs/ft^3)	Cohesion, top of unit (psf^2)	Cohesion increase with depth (psf per ft)	Cohesion, base of unit (psf)
Densified Berm Fill	115	1250	-	-
Young Bay Mud (YBM), 0-5 ft BGS	105	675	-	-
YBM, 5-10 ft BGS	105	375	-	-
YBM, 10-20 ft BGM, and outside berm footprint	105	275	7.5	350
YBM, 20 ft BGS and below	105	375	12.5	500
Old Bay Mud (OBM)	115	1,500	18	4,000

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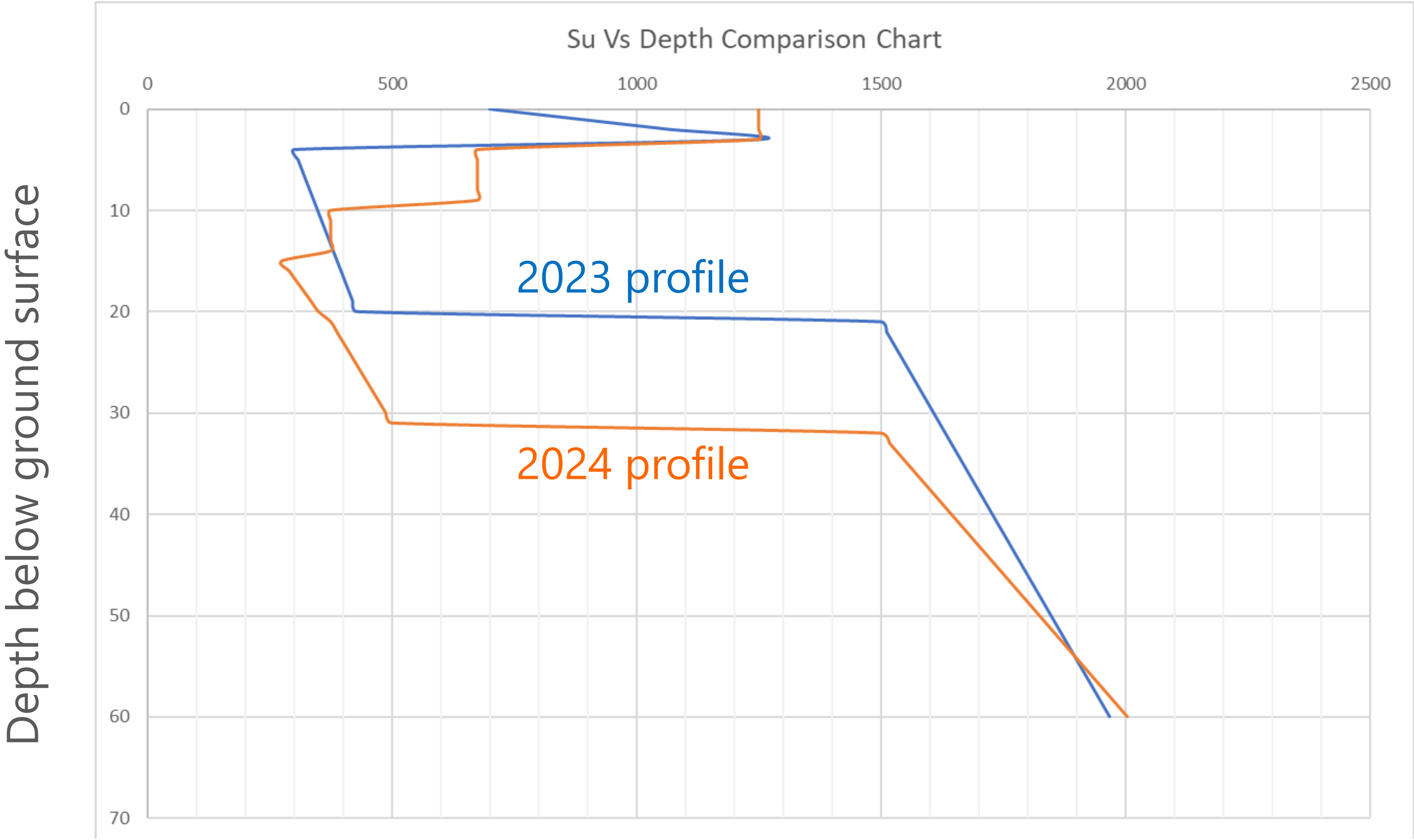
Comparison of 2023 vs 2024 Strength Profiles



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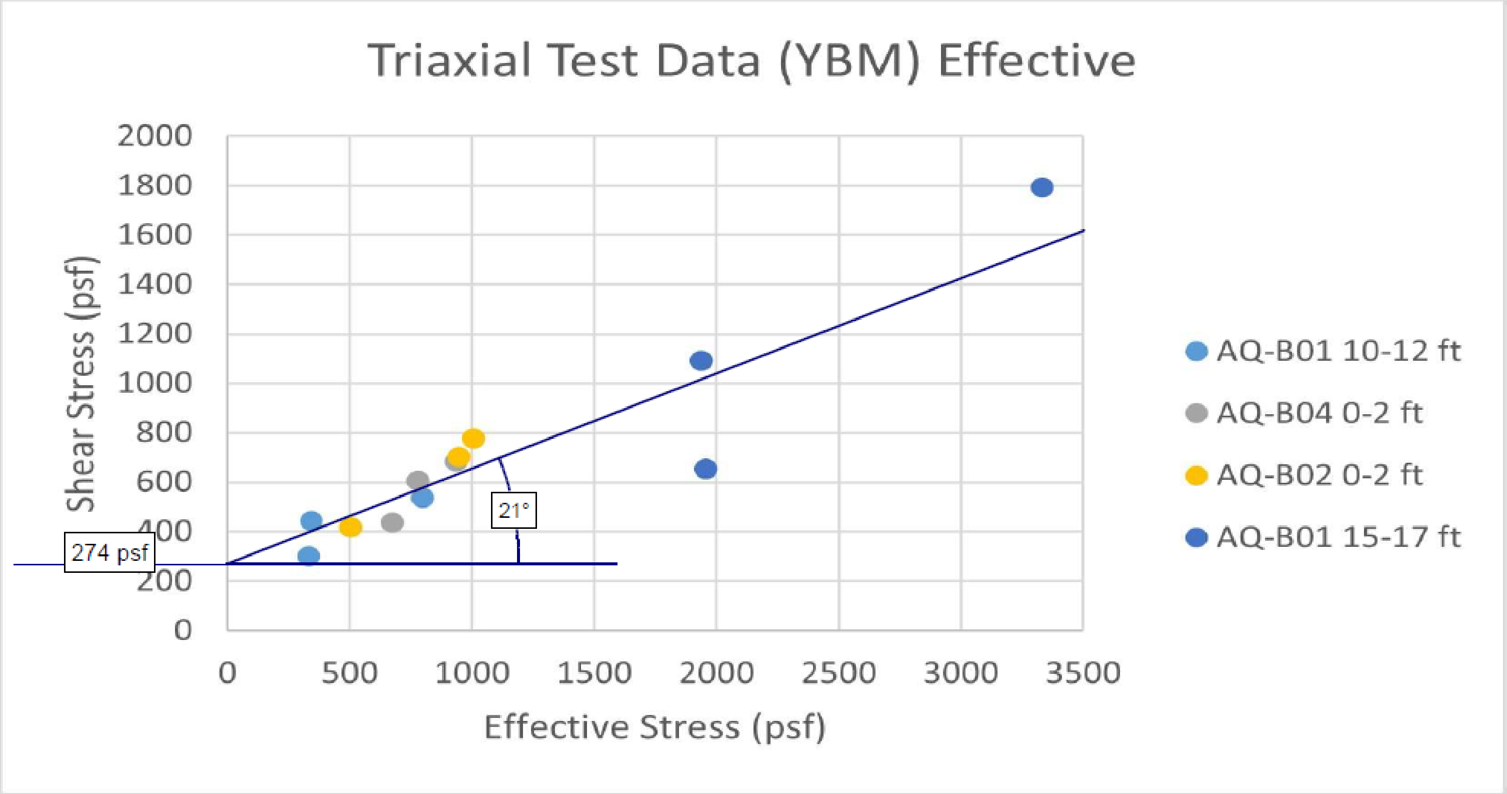
Results of Triaxial Strength Testing

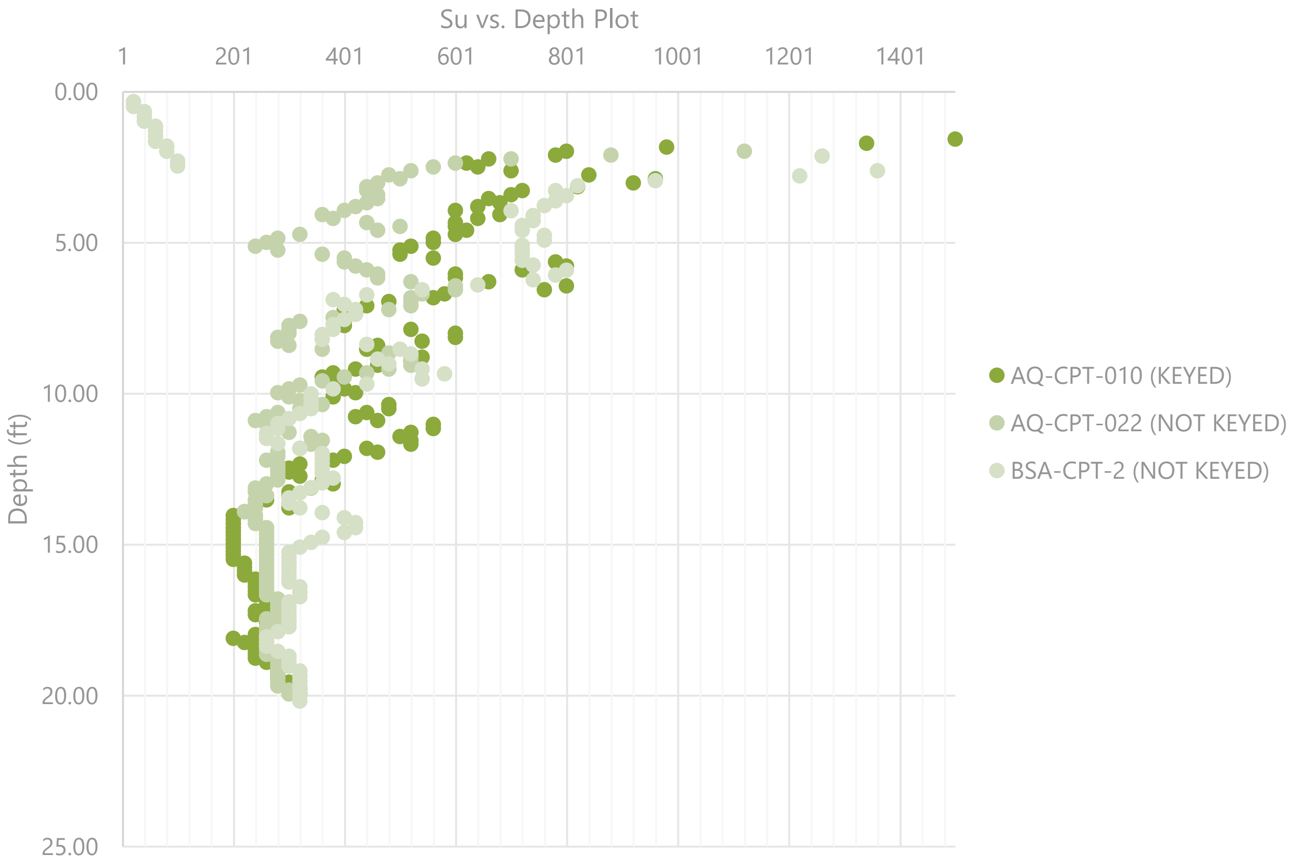
- “Best-fit” strength envelope defined
- Cohesion and “phi” angle
- Used as strength parameters for YBM in slope stability analyses



Effects of Keying

Effects of Berm Keying

- Cargill addresses potential indicators of seepage by performing keying.
- Plot shows example of representative conditions.
- Some soil strength benefits observed between 0-10 feet, suggesting equivalent level of benefits for reducing seepage potential.
- Keying does not create strength reductions nor preferential failure planes.
- No significant strengthening effect below 10 feet.



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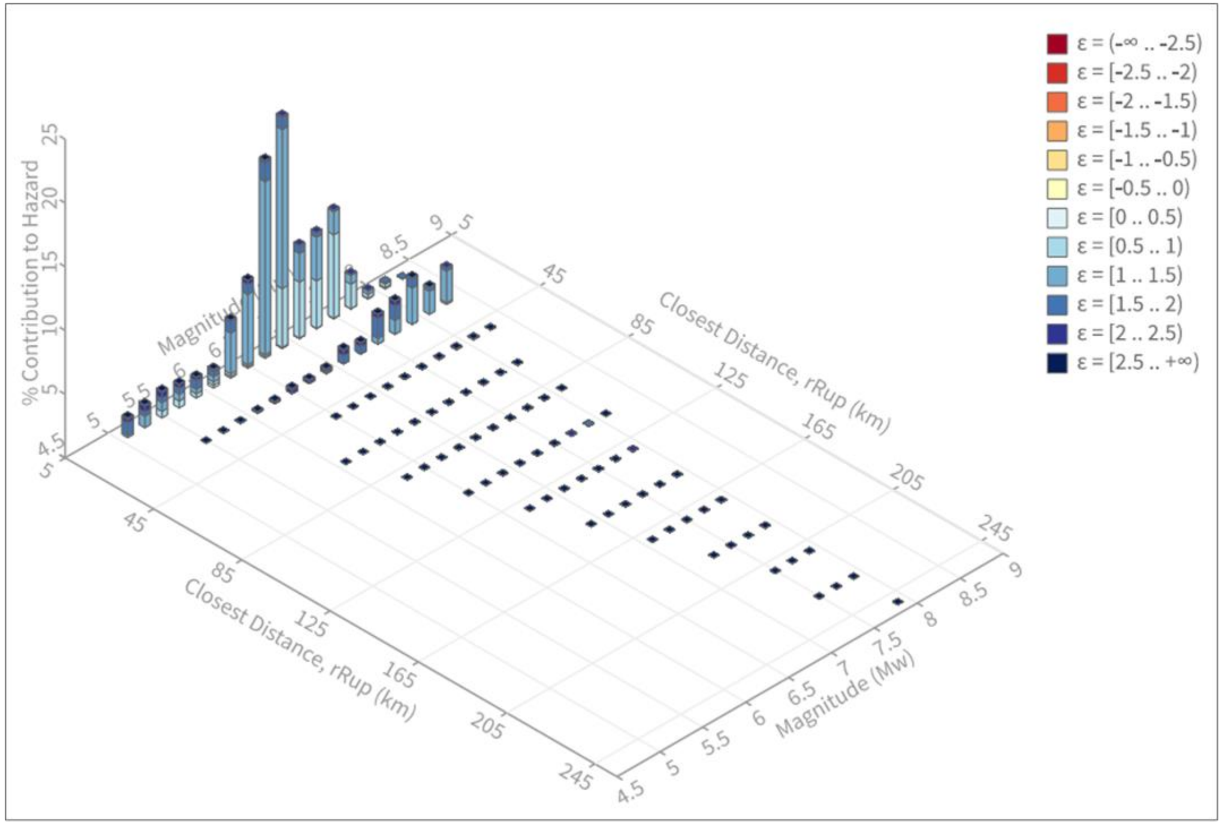
“Design-Level” Seismic Events

Seismic Effects: Peak Ground Acceleration

- Determine peak ground accelerations (PGAs) corresponding to two return periods at the Site.
- “Base PGA” determined from USGS compilation of historic events and fault zones.
- “Modified PGA” determined from site conditions and Site Class “E” (soft deposits).
- 475-year earthquake: PGA = 0.9 x 0.55 g = **0.5 g**
- 50-year earthquake: PGA = 1.6 x 0.21 g = **0.34 g**



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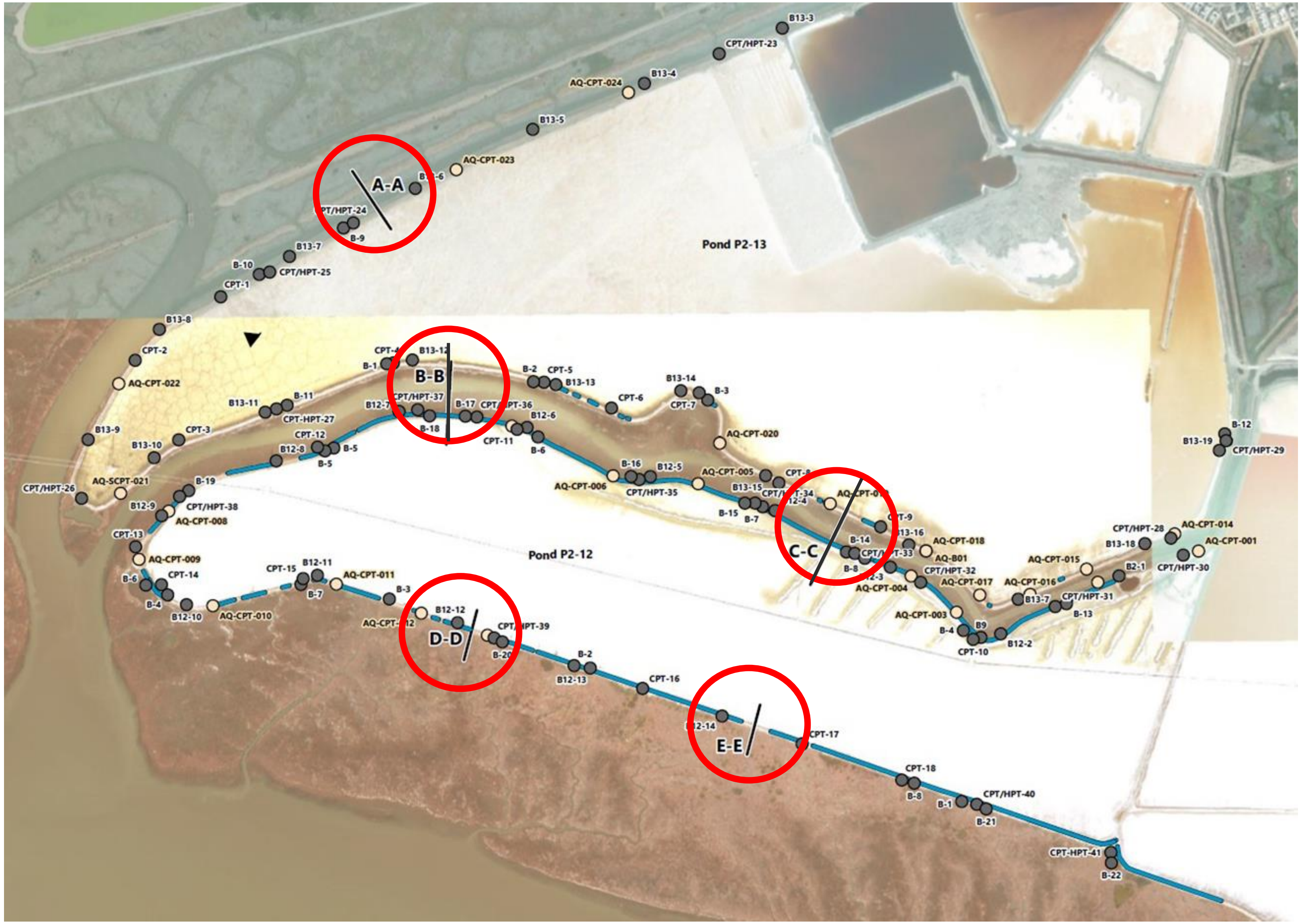
Cross Sections and Stability Analysis

Representative Cross Sections



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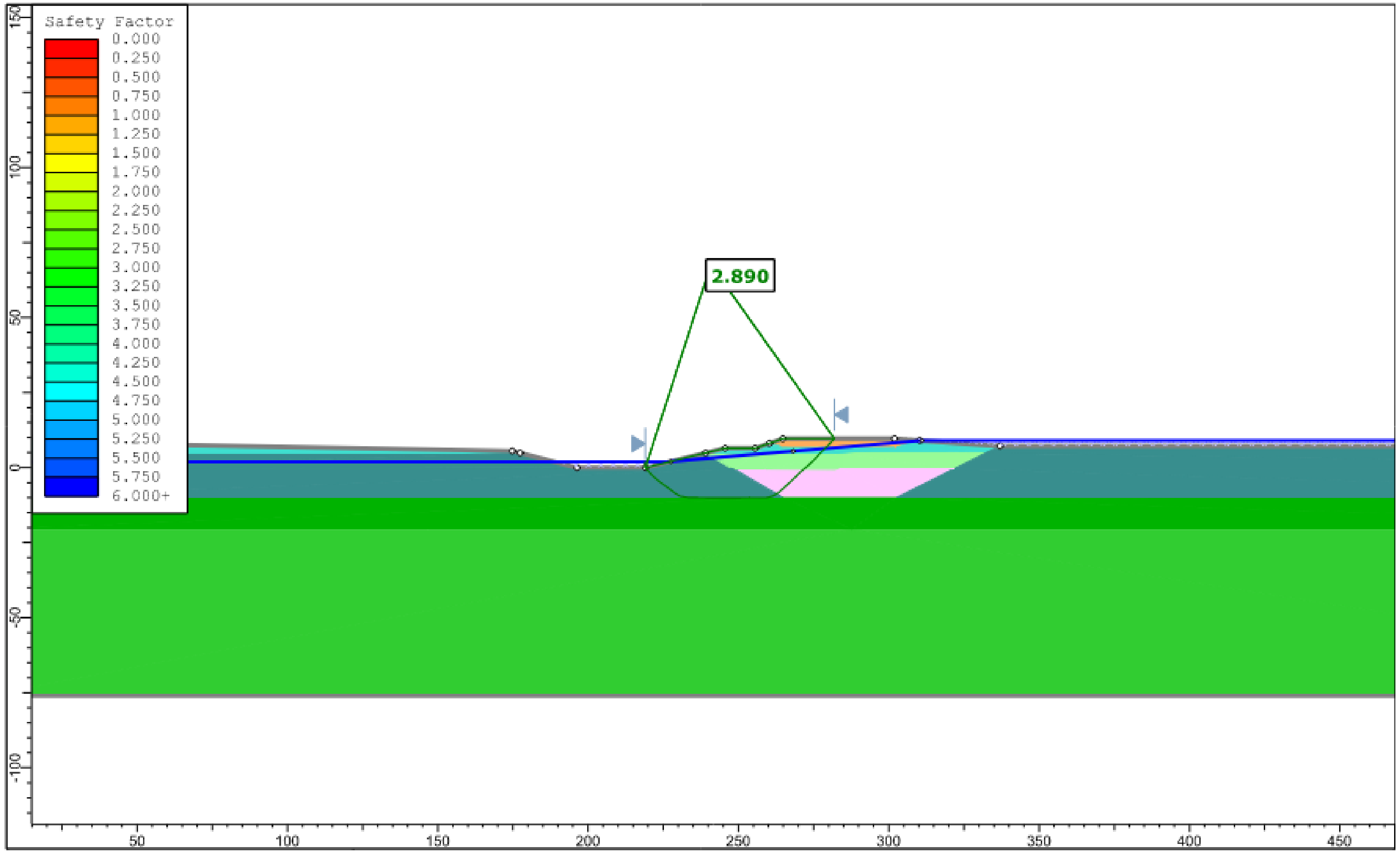
Factor of Safety (FOS) Analysis

- FOS is a comparison between destabilizing forces attempting to cause failure, to the stabilizing forces that resist failure.
- A FOS of 1.0 indicates equal balance between destabilizing and stabilizing forces.
- Geotechnical engineering practice recommends specific target FOS for different conditions.
  - Normal "static" conditions should have FOS greater than 1.5.
  - Short-term seismic loading conditions (earthquakes) should have FOS greater than 1.1.
  - FOS values below these numbers suggest deformation is occurring.

Typical stability result: "Normal" (Static) Conditions



Section C-C′ in static conditions

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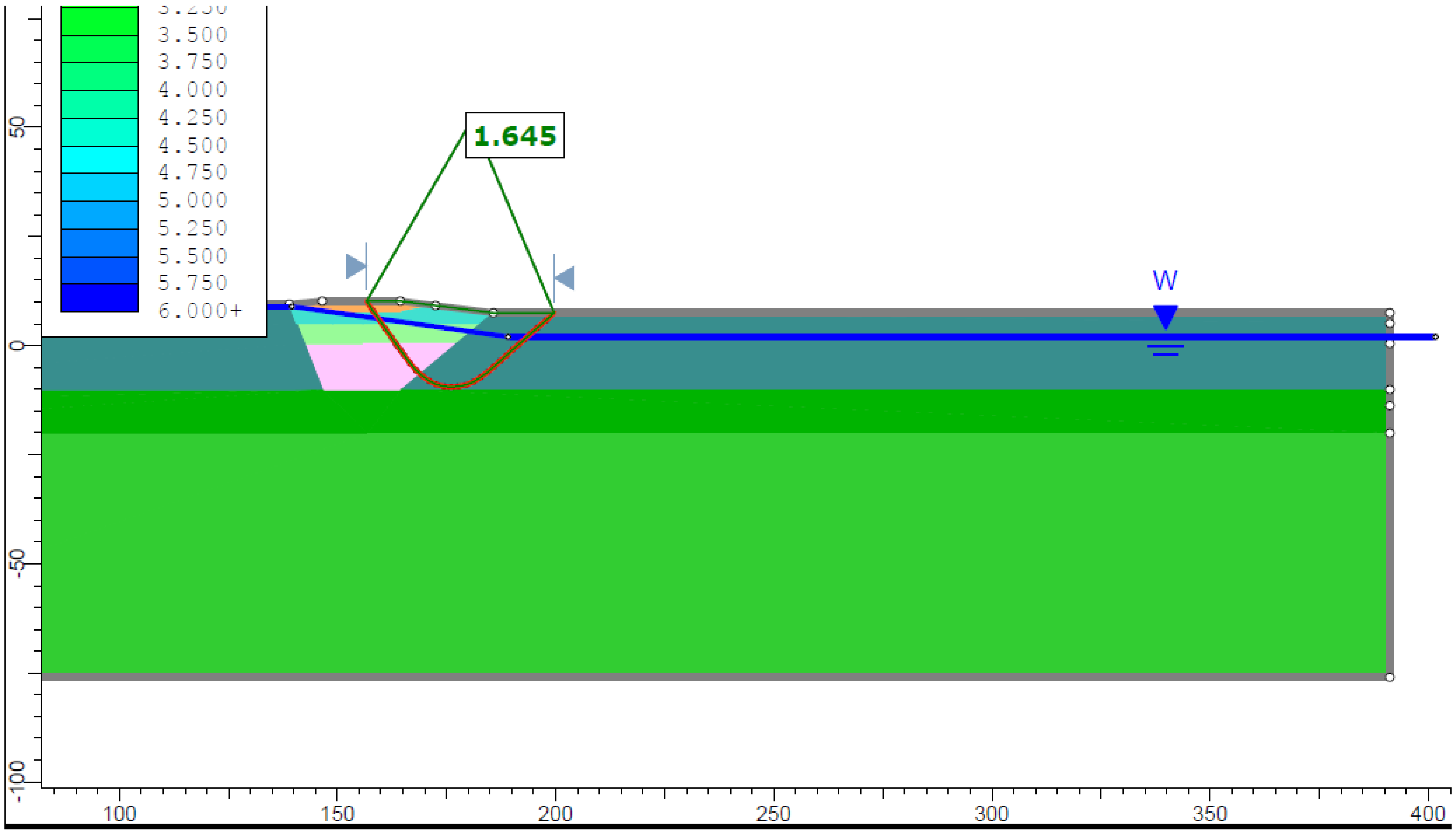
Seismic Stability: 50-year quake



Section D-D′; low tide; OLE

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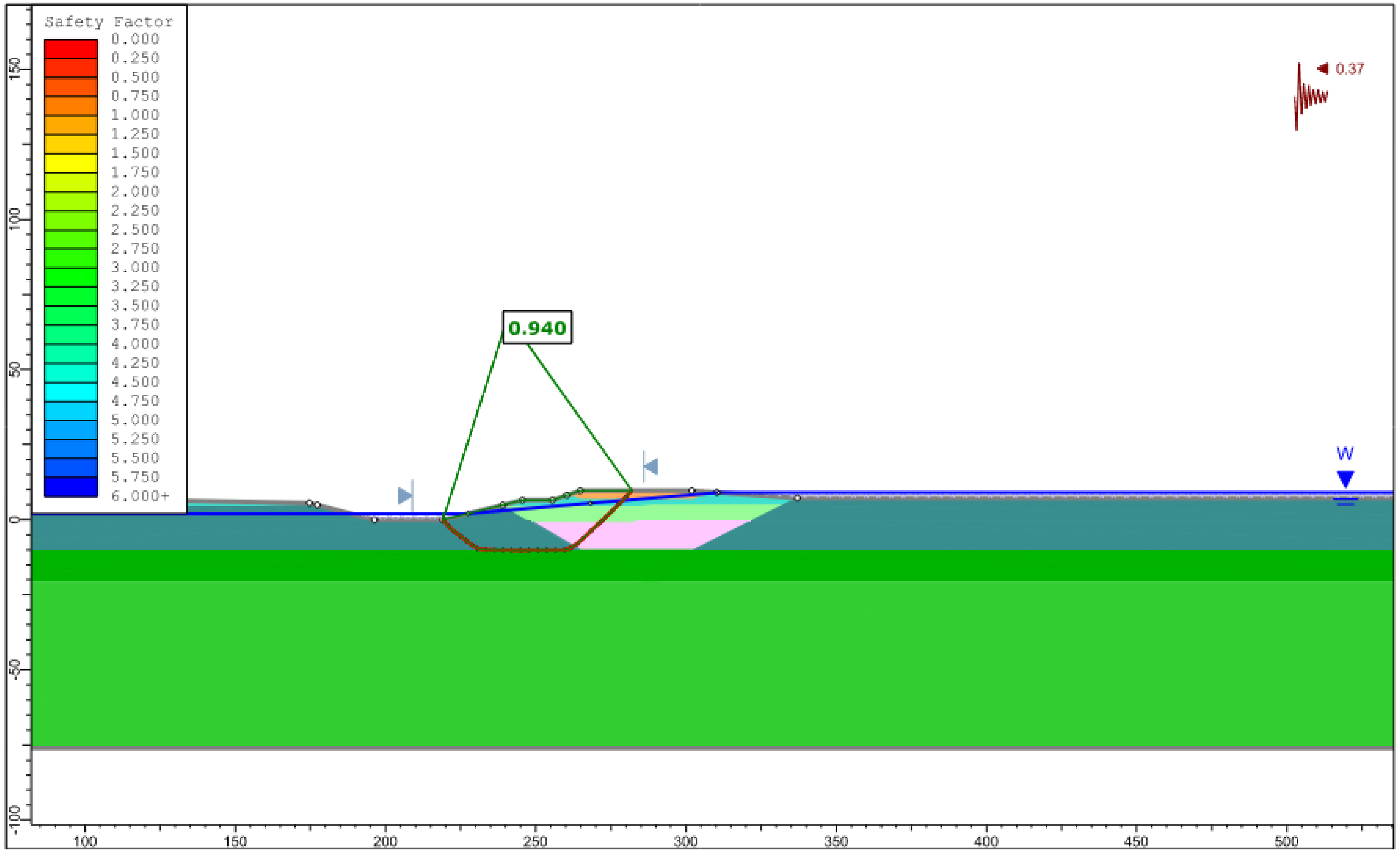
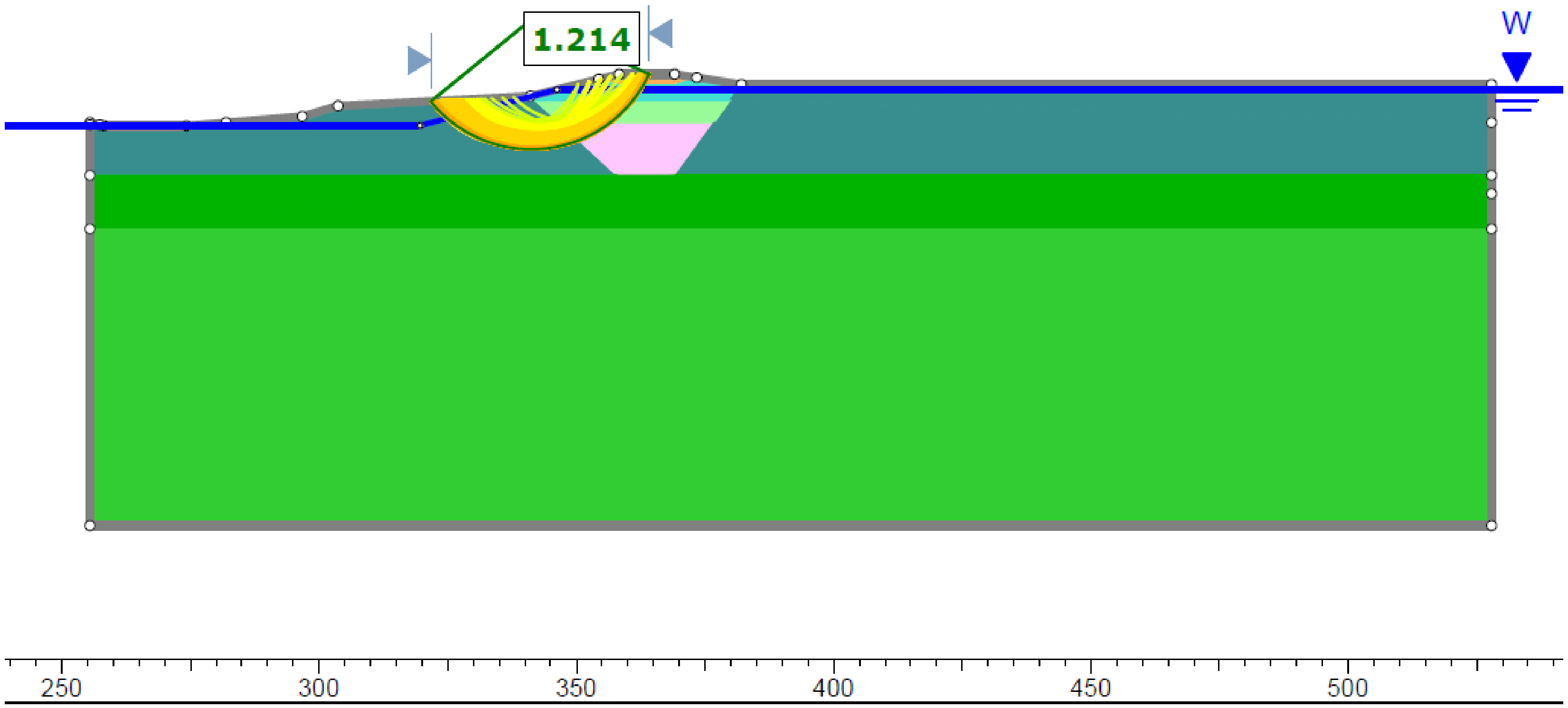
Seismic Stability: 50-year quake



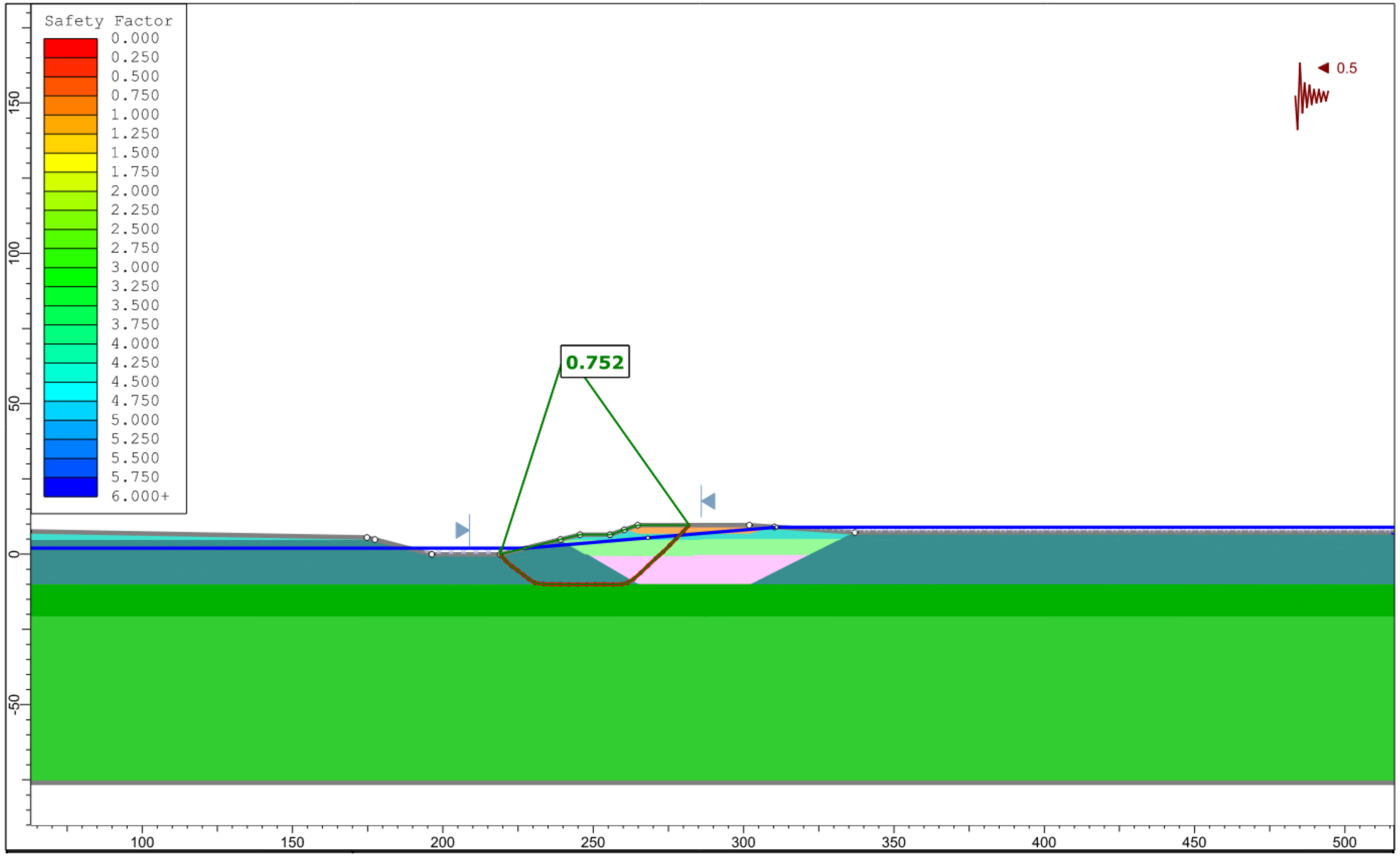
Section C-C"; low tide; OLE

Seismic Stability: 475-year quake



Section A-A′, low tide, CLE

Seismic Stability: 475-year quake



Section C-C′, low tide, CLE

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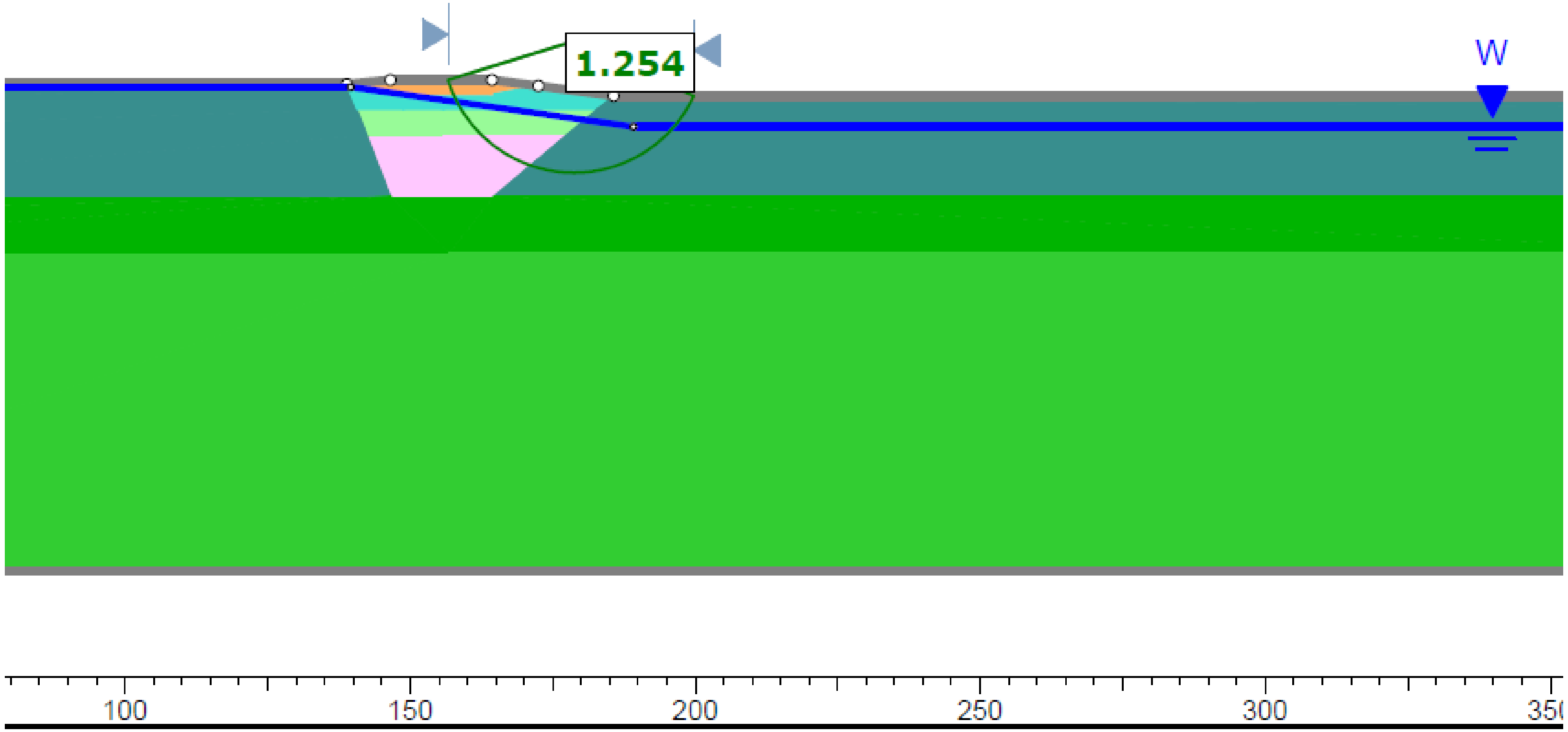
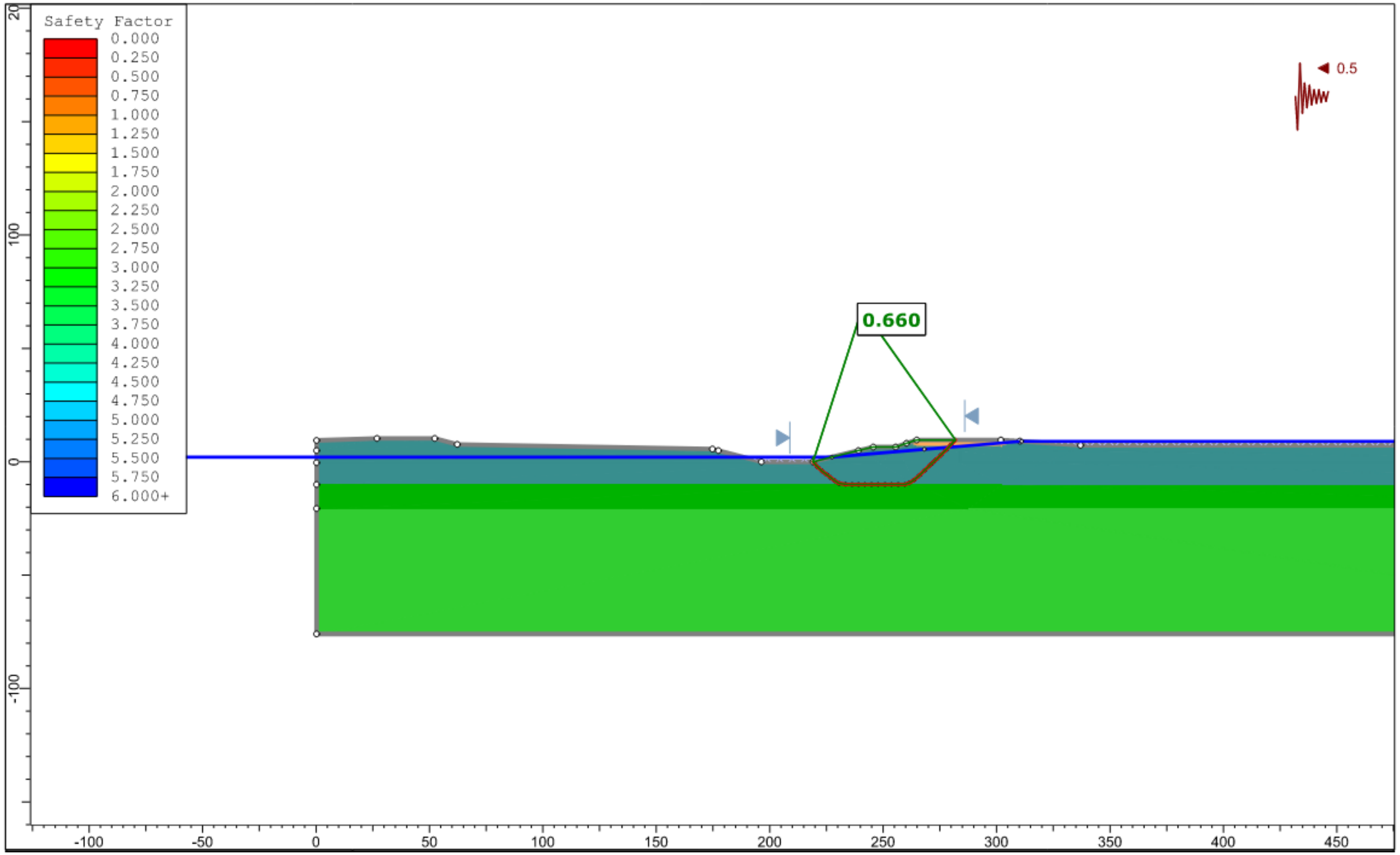
Seismic Stability: 475-year quake



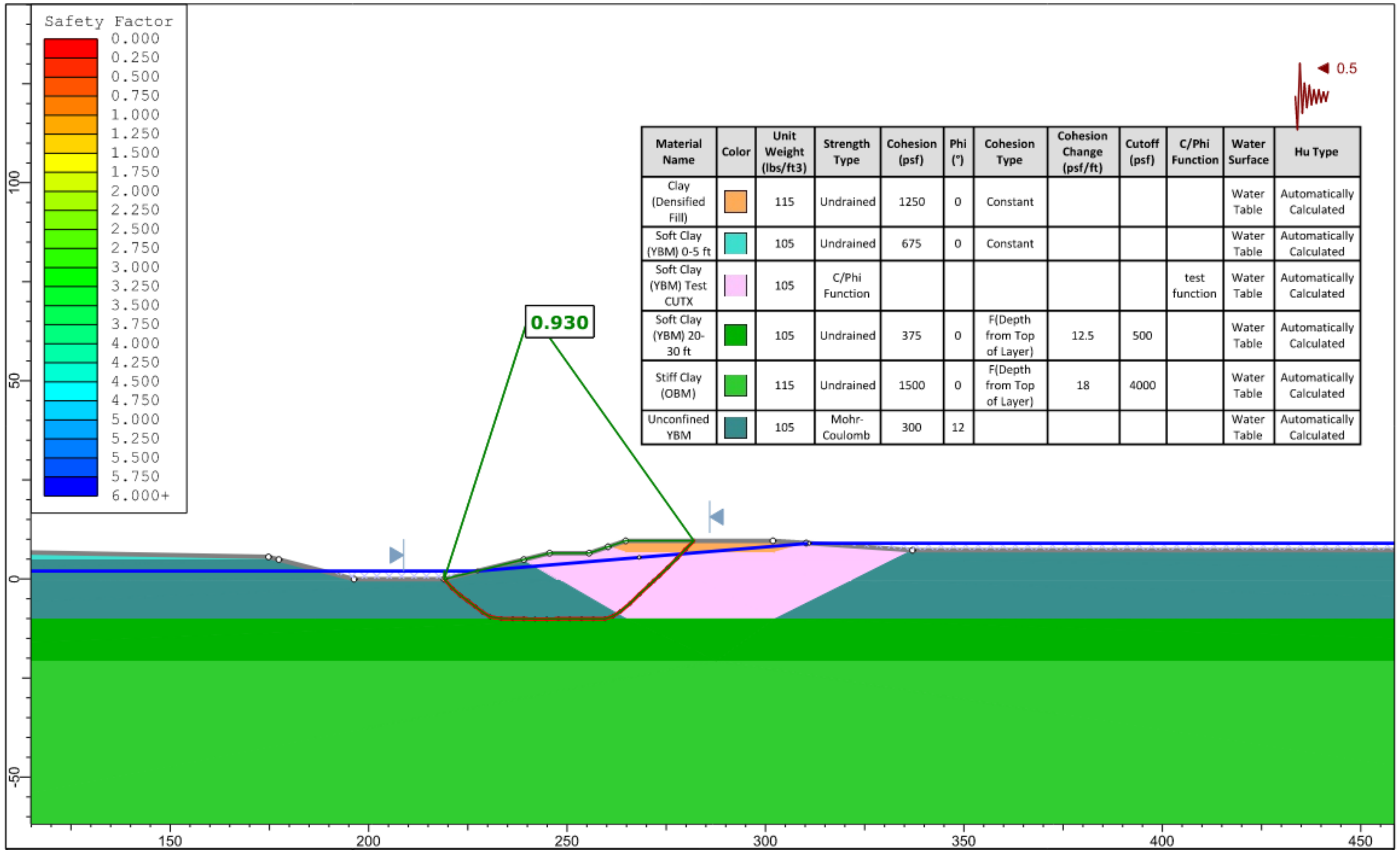
Section D-D′, low tide, CLE

Seismic Stability: 475-year quake (using Su ratio – strength gain vs depth)



Section C-C’, low tide, CLE

Seismic Stability for 475-year quake (using triaxial strength testing results)



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (°)	Cohesion Type	Cohesion Change (psf/ft)	Cutoff (psf)	C/Phi Function	Water Surface	Hu Type
Clay (Densified Fill)		115	Undrained	1250	0	Constant				Water Table	Automatically Calculated
Soft Clay (YBM) 0-5 ft		105	Undrained	675	0	Constant				Water Table	Automatically Calculated
Soft Clay (YBM) Test CUTX		105	C/Phi Function						test function	Water Table	Automatically Calculated
Soft Clay (YBM) 20-30 ft		105	Undrained	375	0	F(Depth from Top of Layer)	12.5	500		Water Table	Automatically Calculated
Stiff Clay (OBM)		115	Undrained	1500	0	F(Depth from Top of Layer)	18	4000		Water Table	Automatically Calculated
Unconfined YBM		105	Mohr-Coulomb	300	12					Water Table	Automatically Calculated

Section C-C', low tide, CLE

Summary of Analysis Results

Cross Section	Pond Water Level[1]	Bay/Slough Water Level[1]	Static FOS[2]	Seismic FOS[2]; OLE (50-Year Event)	Seismic FOS[2]; CLE (475-Year Event)
A-A′	9 feet	Flood (11 feet)	>2.5	1.8	2.0
		High tide (7 feet)		1.9	1.9
		Low tide (2 feet)		1.8	1.1
B-B′	9 feet	Flood (11 feet)	>2.5	>1.7	0.9
		High tide (7 feet)		1.9	0.9
		Low tide (2 feet)		1.1	0.6
C-C′	9 feet	Flood (11 feet)	>2.5	>1.7	0.8
		High tide (7 feet)		1.8	0.8
		Low tide (2 feet)		0.9	0.6
D-D′	9 feet	Flood (11 feet)	>2.5	>1.7	1.4
		High tide (7 feet)		1.8	1.4
		Low tide (2 feet)		1.6	1.1
E-E′	9 feet	Flood (11 feet)	>2.5	>1.7	>1.7
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Deformation Analysis

Deformation Analysis

- Commonly used to understand implications of apparent low factors of safety
- Uses “sliding block” formulas
- Seismic forces push back-and-forth in quick succession.
- Weight of berm, and friction underneath, helps to resist seismic forces.
- Analysis estimates total accumulated amount of movement along “slip surface” during the quake.

Deformation Analysis

- Calculated for location and scenario that resulted in lowest FOS: Cross section C-C', during 475-year quake, at low tide.
- Total deformation estimated at 2 to 9 inches (best estimate is 5 inches) for this "worst case".
- Deformation can be envisioned as movement along the "critical slip surface" (settlement at crest, horizontal movement near toe).
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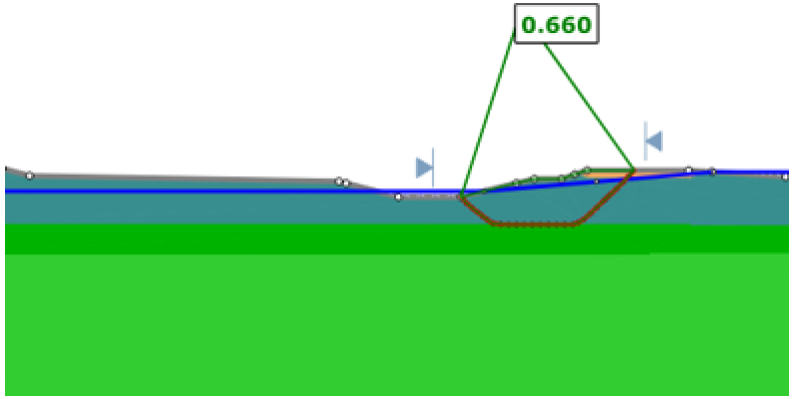
- This projected deformation would not constitute a breach or failure of the berm.



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Summary of Findings

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- Site-specific geotechnical investigations were performed in 2024, consistent with the BCDC-approved December 2023 Geotechnical Work Plan.
- 2024 findings allow for confirmation and refinement of soil properties, particularly in Young Bay Mud.
- Static stability factors of safety significantly exceed targeted values.
- Seismic stability factors of safety are generally at or above targeted values with some exceptions.
  - Cross-section C-C′ is "worst-case"; seismic factor of safety is indicated as below targeted values.
- Deformation analysis was performed, indicating that a limited amount of displacement (2 to 9 inches) could occur.
- Based on the 2024 findings and geotechnical analysis, the berms demonstrate sufficient stability under static and seismic conditions (no failure or breach).