Lessons Learned from the Geotechnical Investigation Program
DC Clean Rivers Project

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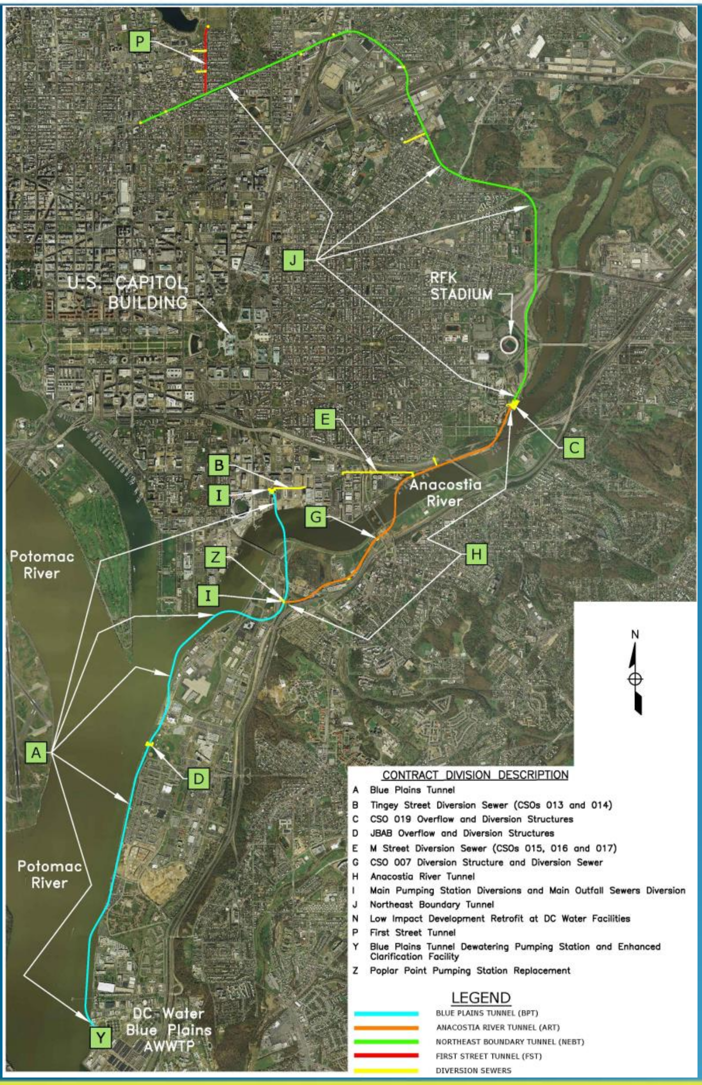
Agenda

- Project Overview
- Geologic and Hydrogeologic Setting
- Design and Construction Considerations
- Geotechnical Investigation Program
- Issues, Lessons Learned and Observations
- Other General Lessons Learned and Conclusions

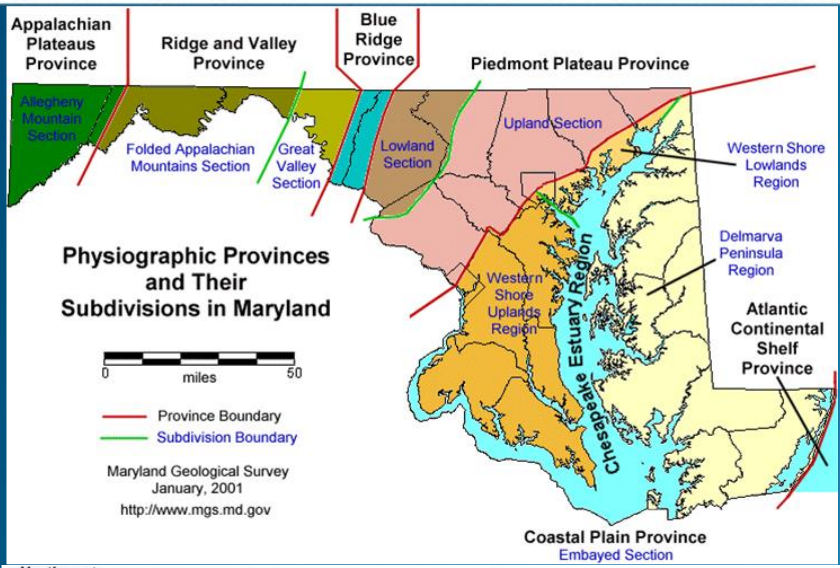
Project Overview

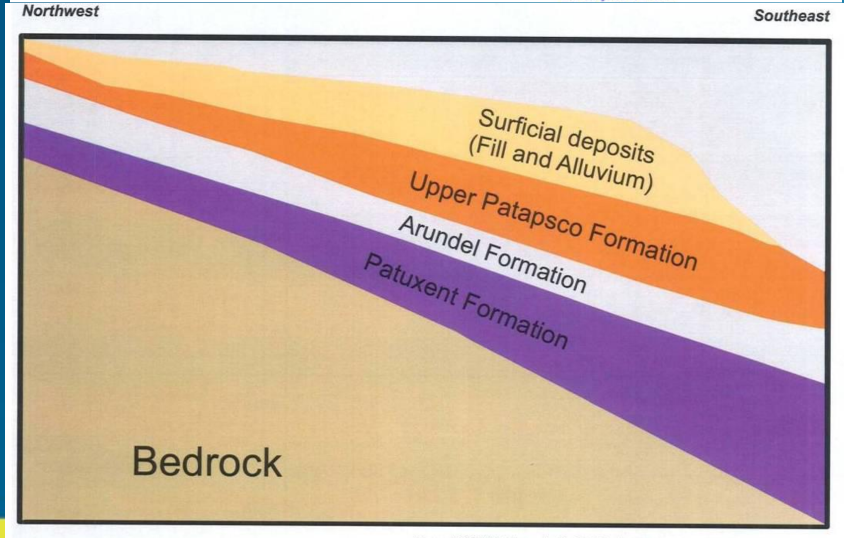
Contract Division	Description	Facilities
A	Blue Plains Tunnel (BPT)	• 24,200 LF • 23-ft diameter • 110+ ft deep • 5 shafts
H	Anacostia River Tunnel (ART)	• 12,600 LF • 23-ft diameter • ~100 ft deep • 6 shafts
J	NE Boundary Tunnel (NEBT)	• 26,700 LF • 23-ft diameter • 50 to 160 ft deep • 5 shafts
P	First Street Tunnel	• 2720 LF • 18.5-ft diameter • 60 to 140 ft deep • 4 shafts



Geologic and Hydrogeologic Setting

- Coastal Plains Sediments:
  - Fill
  - Quaternary-age Alluvium
  - Cretaceous-age Patapsco/Arundel Formation (undivided) of the Potomac Group
  - Cretaceous-age Patuxent Formation of the Potomac Group
  - Bedrock (approximate 400 ft deep)
- 3 Main Aquifer Systems:
  - Unconfined water table aquifer in the fill and alluvium sediments;
  - Confined conditions in the Potomac Group sediments;
  - Groundwater within the crystalline bedrock (gneiss and schist)





Source: USGS 2007, Patapsco Aquifer Study, Southern Maryland by David D. Drummond, August 2007

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Soil Classification System

- Similar to Washington Metropolitan Area Transportation Authority (WMATA) classification system
- Soil groups used to organize subsurface information in a manner that addresses soil behavior relevant to tunneling and other construction

Geologic Unit	Soil Group		USCS Symbol	General Soil Description
Fill	Fill		Highly variable – see Section 5.2 and site specific borings	
Alluvium	Alluvial Clay and Silt		CL, CH, ML, MH, OH, OL, PT	Clays, Silts, Organic Soils
	Alluvial Sand		SP, SP-SM, SP-SC, SM, SW, SW-SM, SW-SC, SC, SM	Clean Sand, Sand with Clay or Silt, Silty Sand, Clayey Sand,
	Alluvial Gravel		GP, GP-GM, GP-GC,GM, GW, GW-GM, GW-GC, GC, GM	Clean Gravel, Gravel with Clay or Silt, Silty Gravel, Clayey Gravel
Potomac Group	G1		CH, MH	Clays and Silts of High Plasticity
	G2		CL, ML	Clay and Silts of Low Plasticity
	G3	G3A	SM, SC, SC-SM	Silty Sand, Clayey Sand Silty/Clayey Sand
		G3B	GM, GC, GC-GM	Silty Gravel, Clayey Gravel, Silty/Clayey Gravel
	G4		SP, SP-SM, SP-SC, SW SW-SM, SW-SC	Clean Sand, Sand with Clay or Silt
	G5		GP, GP-GM, GP-GC, GW, GW-GM, GW-GC	Clean Gravel, Gravel with Clay or Silt

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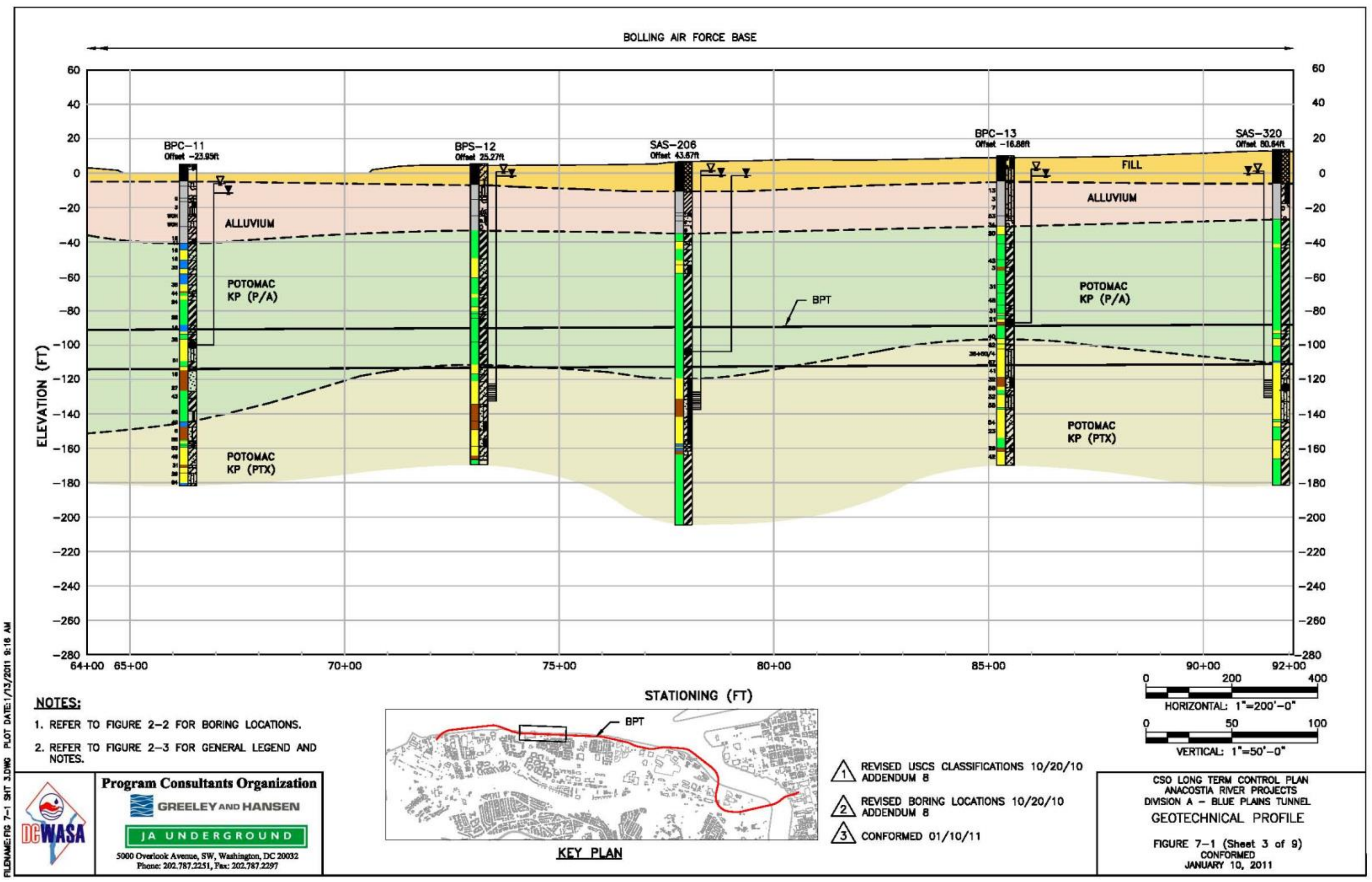
Soil Profile of Blue Plain Tunnel



Design and Construction Considerations

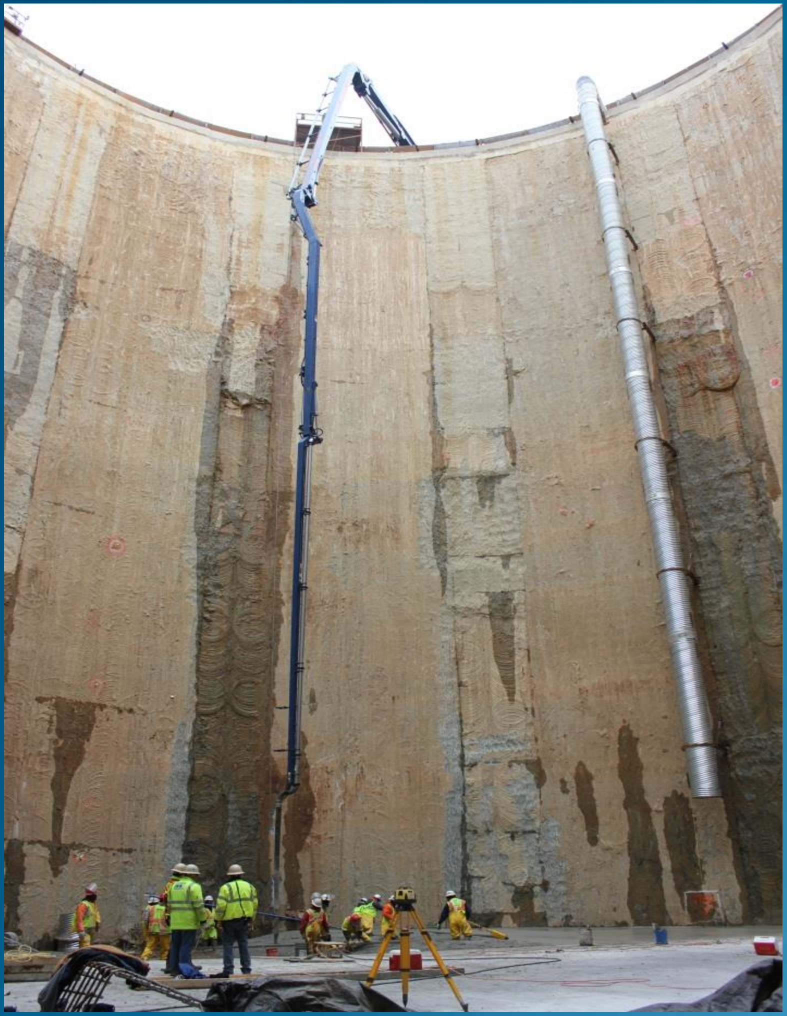
Tunnels and Microtunnels

- Liner design
- Machine selection and design
- Obstructions along the tunnel alignment
- Tunneling-induced ground settlements
- Ground improvement
- Groundwater Control

Traylor Skanska Jay Dee, JV TBM Blue Plains Tunnel

Shafts and Near Surface Structures

- **Excavation support**
- **Ground deformation**
- **Groundwater control**

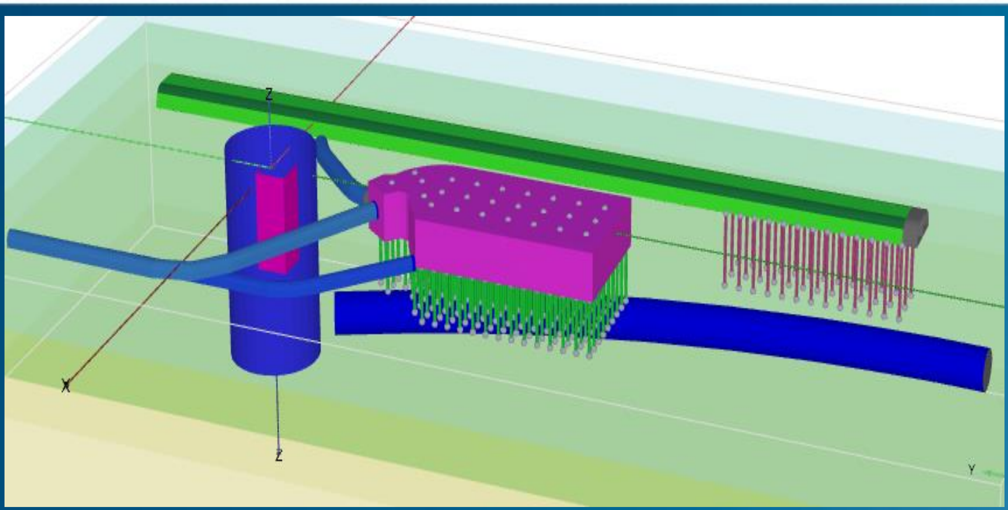


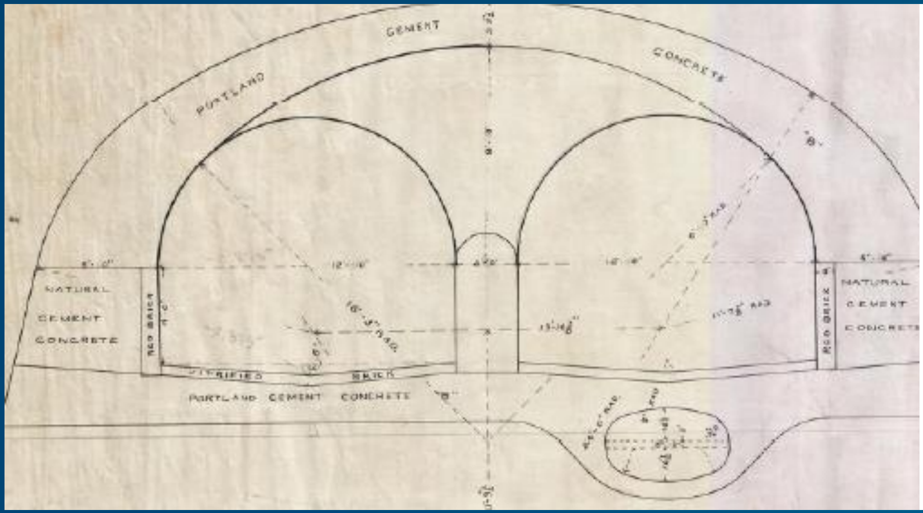
Shafts and Near Surface Structures

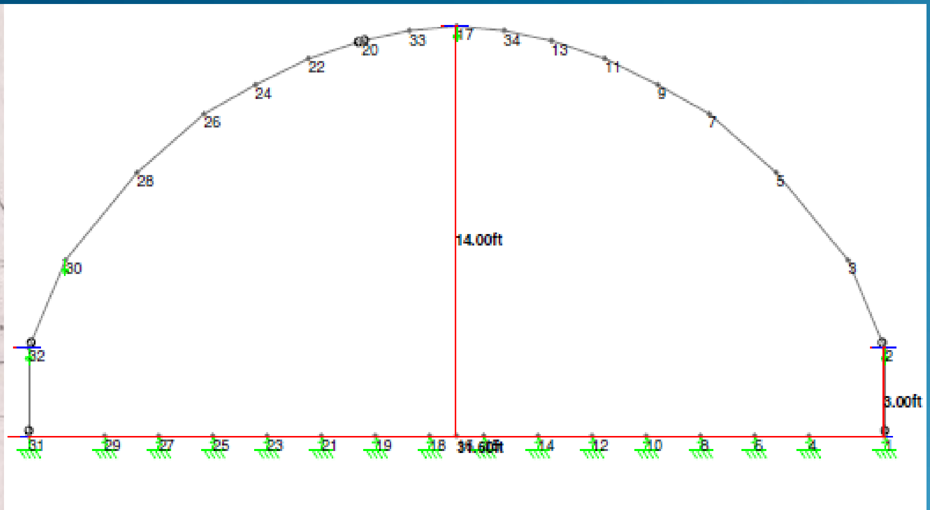
- Groundwater control
- Excavation bottom stability
- Uplift
- Break-in and break-out for TBMs (shafts only)

Protection of Structures

- Extensive analyses perform for project
- Modeling Soil Movements
- Structural Modeling for existing structures

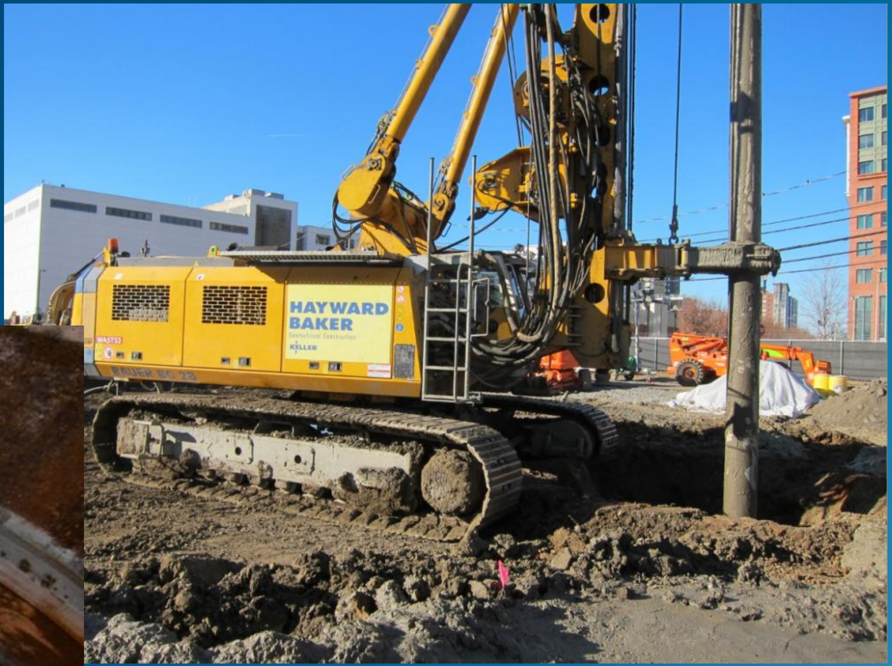






Protection of Structures

- **Mitigation measures**
  - Ground Improvement
  - Structural Rehabilitation



Design & Construction Considerations

Proposed Structure	Design								Construction											
	Foundation Bearing Capacity /Settlement	Lateral Earth and Water Pressure	Global slope Stability	Buoyancy and Uplift Resistance	Ground improvement	Liner and Wall Loads	Backfill Materials	Site Preparation And Grading	Ground Deformation	Subgrade Preparation	Obstructions	Mixed-Face Tunneling	Gas/Ventilation	Soil Disposal Or Reuse	Groundwater Control And Disposal	Soil Abrasiveness	Soil Stickiness Potential	Support of Excavation	Temporary Dewatering	Ground Improvement
Tunnels					•	•			•		•	•	•	•		•	•			•
Shafts		•		•	•	•		•	•	•	•			•	•			•	•	•
Shallow Structures	•	•	•	•	•	•	•	•	•	•	•			•	•			•	•	•
Sewers					•	•			•		•	•	•	•		•	•			•

Summary of the Geotechnical Investigation Program (Field)

- Soil Borings
  - Mud Rotary
  - Hollow Stem Auger
  - Sonic Drilling
- Soil Samples
  - Disturbed
    - Split Spoon
    - Sonic Core
  - Undisturbed:
    - Shelby Tube Sampler
    - Pitcher Sampler
    - Dension Sampler
- Rock Samples
    - Wireline Rock Core
    - Sonic Rock Core
- Field Testing
  - Pumping Test
  - Standard Penetration Test
  - Pressuremeter
  - Crosshole and Downhole Seismic Survey
  - Seismic Refraction
  - Seismic Reflection
  - Slug Test
  - Cone Penetration Test (CPT)
- Groundwater Monitoring
  - Monitoring Well
  - Vibrating Wire Piezometer

Geotechnical Investigation Program (Lab Testing)

- Laboratory Testing
  - Atterberg Limits Index Testing
  - Mineralogy (X-ray diffraction & Petrographic)
  - Soil Abrasion Test
  - Consolidation Test (ILC, CRS)
  - Strength Test (I-CUTX, K_o-CUTX)
  - Swell Test
  - Soil Corrosion
  - Groundwater Quality
  - Dissolved Gas in Water (H_2S, CH_4)
  - X-Ray Photography

Issues, Lessons and Observations

- Sonic Drilling
- Marine Survey
- X-Ray Radiography of Soil Samples
- Coefficient of Lateral Earth Pressure at Rest – K_0
- Soil Abrasion Test (SAT)

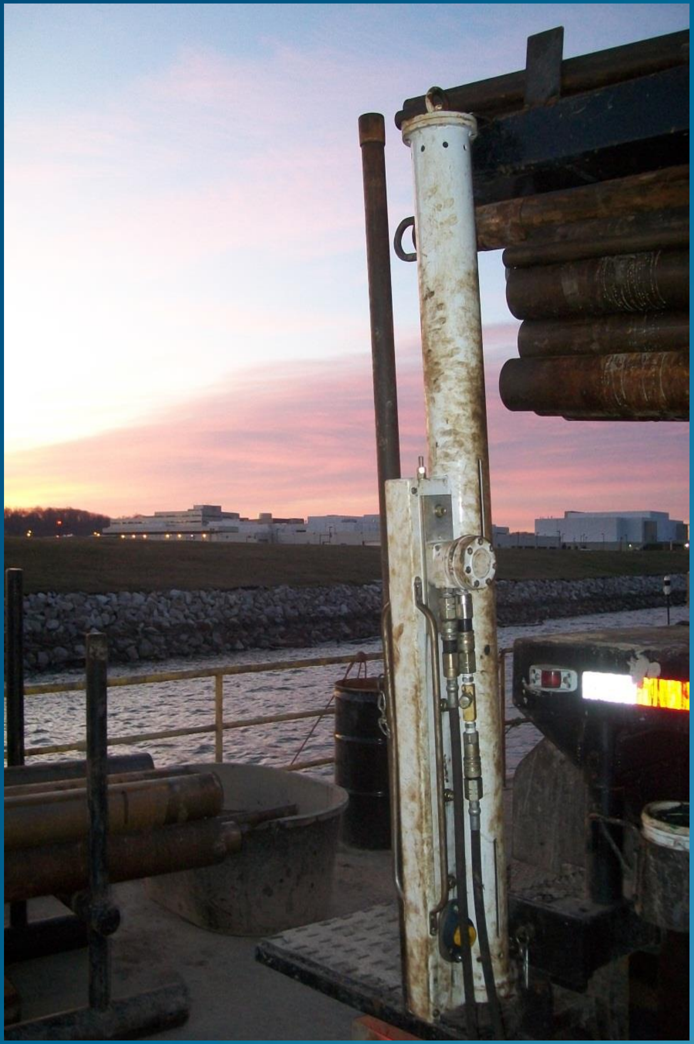
Sonic Drilling

Sonic Drilling – Great for the project

- Provides continuous coring
  - Complete soil profile for deep shafts and identify sand lenses for tunneling – Very important for preparation of the GBR
- Sonic drilling is almost twice as fast as conventional drilling
  - Sonic – ~50 to 100 ft/day
  - Convention – ~25 to 50 ft/day
- Main issue is the size of the equipment, especially support water.

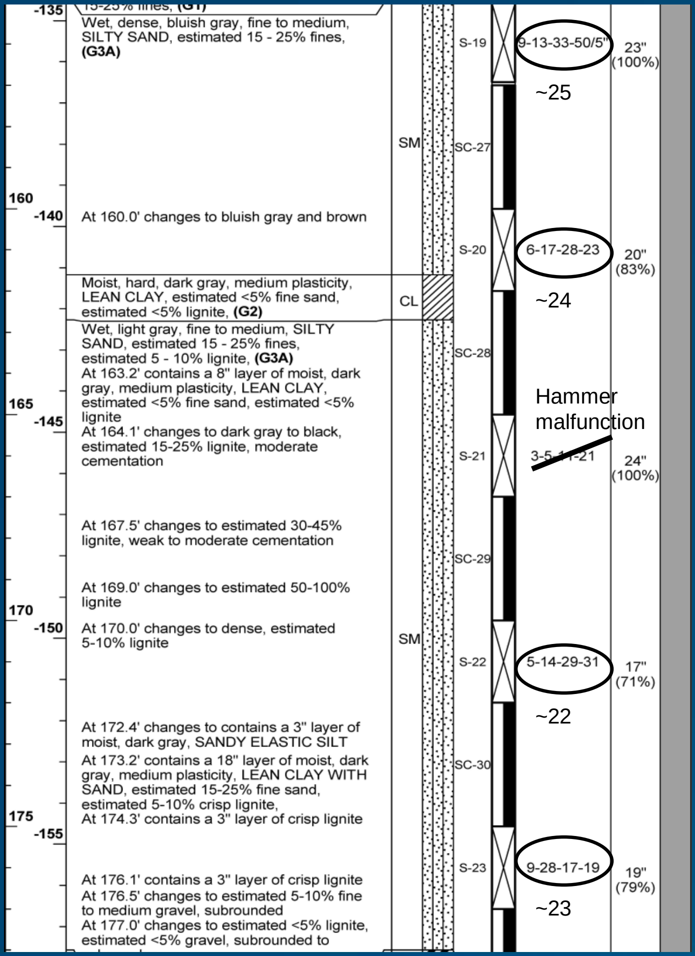
The Problem and Solution

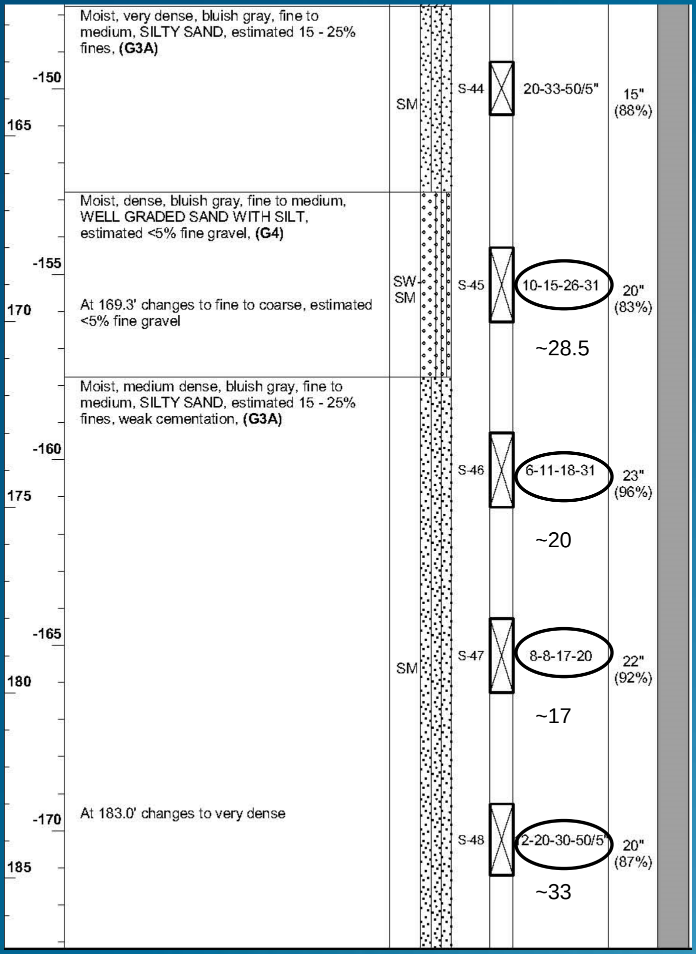
- Typical Issues:
  - Sonic drilling is typically used for continuous (disturbed) coring - no undisturbed samples and no SPT
  - (regional) Sonic drillers did not have rigs that were set-up to do both sonic drilling and undisturbed sampling/SPT
- Solutions:
  - Retrofit sonic rig to accommodate the use of automatic hammer
  - Modified the sampler (i.e. Shelby tube)
  - Result: SPTs and undisturbed Samples



Comparison of Sonic and Conventional Boring Logs

- Sonic Drilling (BPC-48)
- Mud Rotary (BPC-30)





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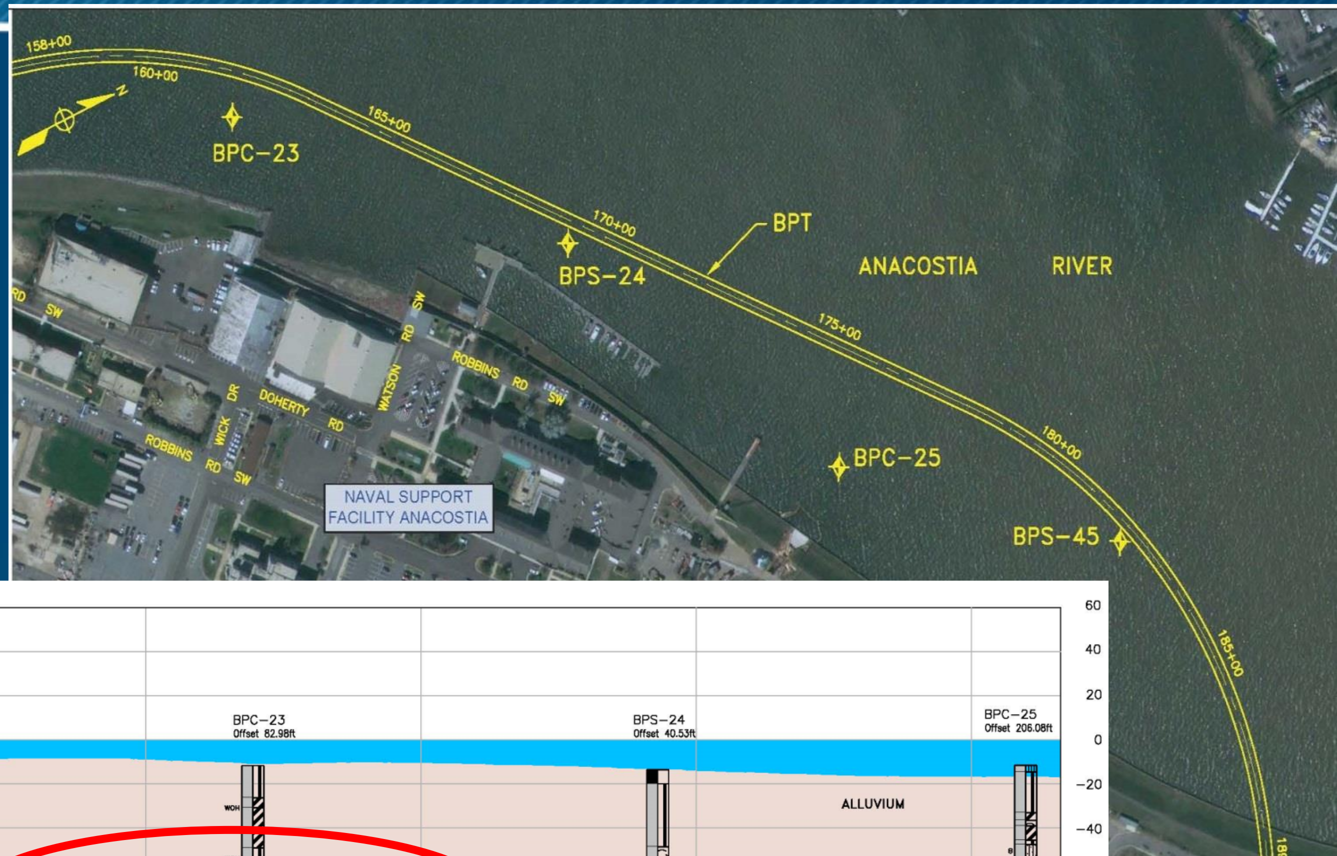
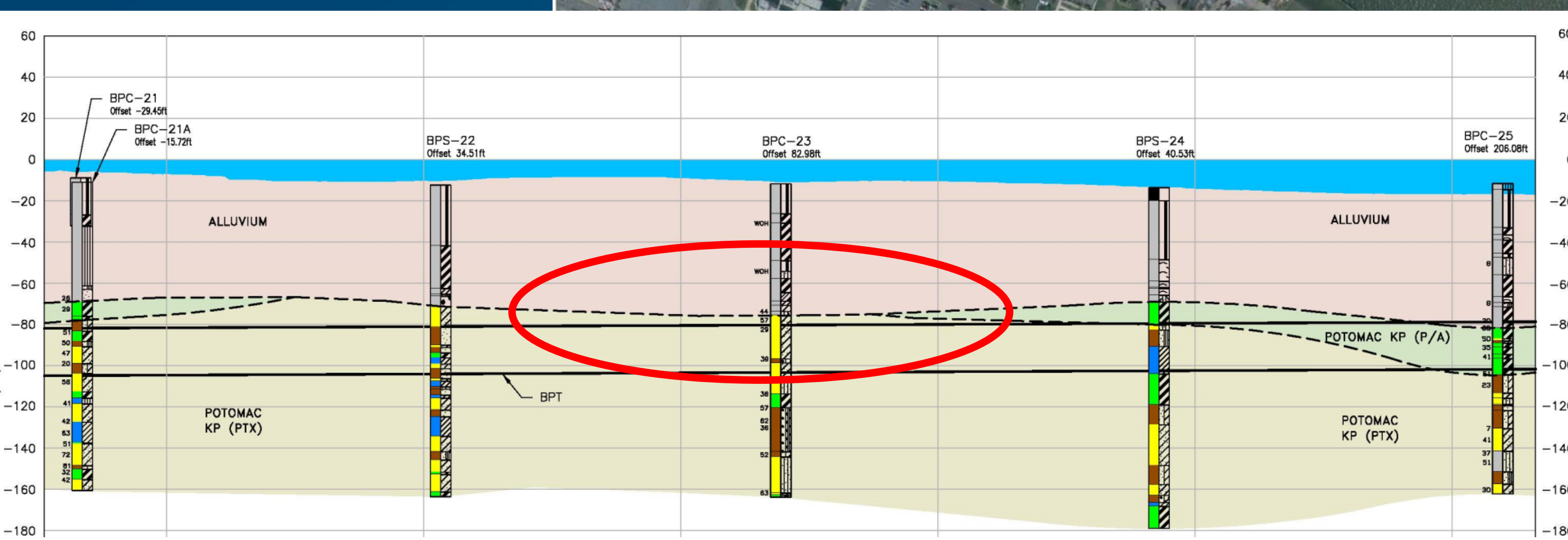
Geophysics - Marine Survey

Geophysics (Marine Surveys)

- **Goal: Better define alluvium /Potomac Contact**





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Geophysics - A tale of two surveys

- December 2009 Reflection Survey
  - Results: base of alluvium apparent; poor resolution of units w/in P/A and PTX Formations
- October 2010 Reflection Survey
  - “High resolution” survey; increased number of channels to 16 to 24 channels recorded
  - Enhanced digital processing / 3D interpretation
  - Results: base of alluvium apparent; poor resolution of units w/in P/A and PTX Formations
- Survey Comparison
  - Later survey - more sophisticated gear, more sophisticated data processing, cost about 4x more
  - Results were about the same

Lessons Learned & Observations

- Geophysical surveys were useful and cost effective for our purpose to fill the data gap between boreholes - *if the conditions are right*.
- Used other places on the project to identify possible old valleys on the alignment and reduce uncertainty during the contract preparation.
- At the end we decided not to chase the ground or have a conservative baseline condition and handled the potential for the boulders and alluvium in the crown of the tunnel in the Contract.

X-Ray Radiography of Soil Samples

X-Ray Radiography (ASTM 4452)

- X-ray radiography is extremely useful to identify soil structures and selecting good samples for strength test (i.e. locating slickensides and sand pockets)
- The key is to select a lab which has the right equipment and experience in performing X-Ray radiography
- Monitor and quality control
- Spend money to save money and reduce the number questionable results

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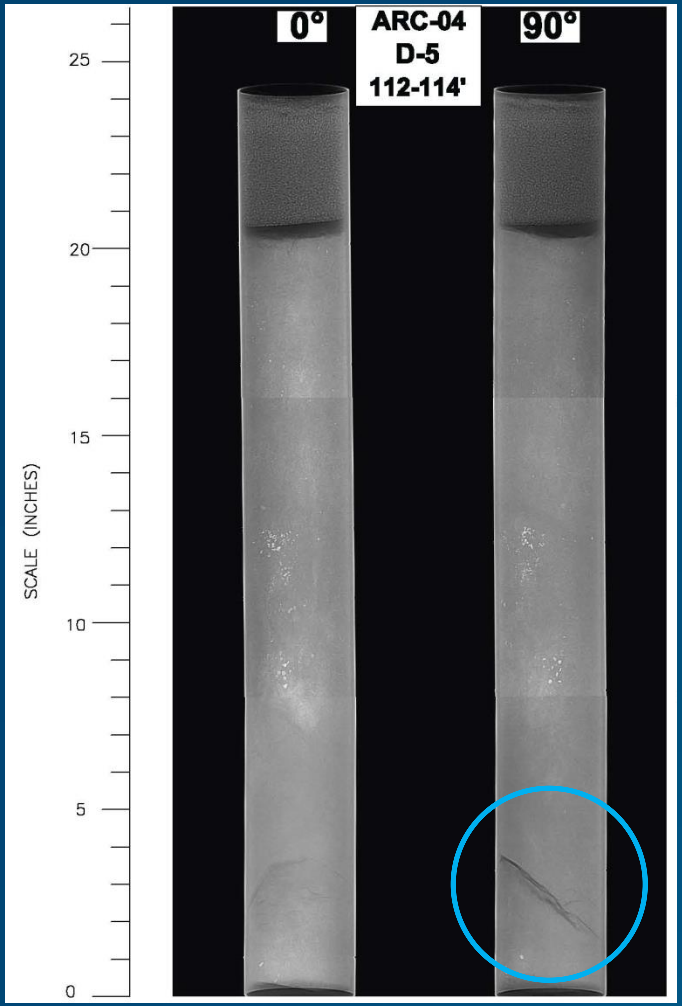
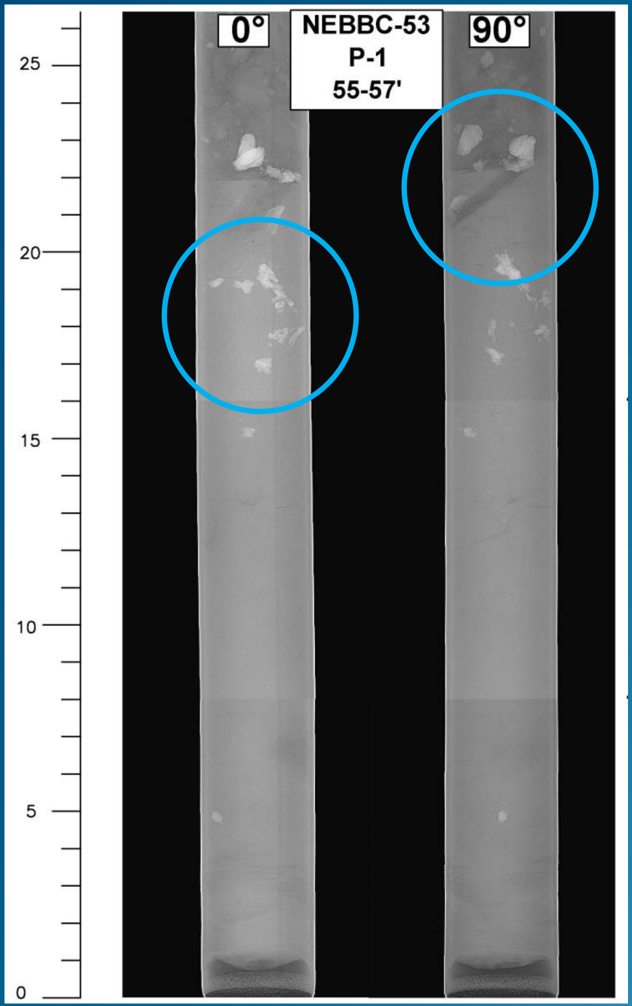
X-Ray Photos of Soil Samples (ASTM 4452)





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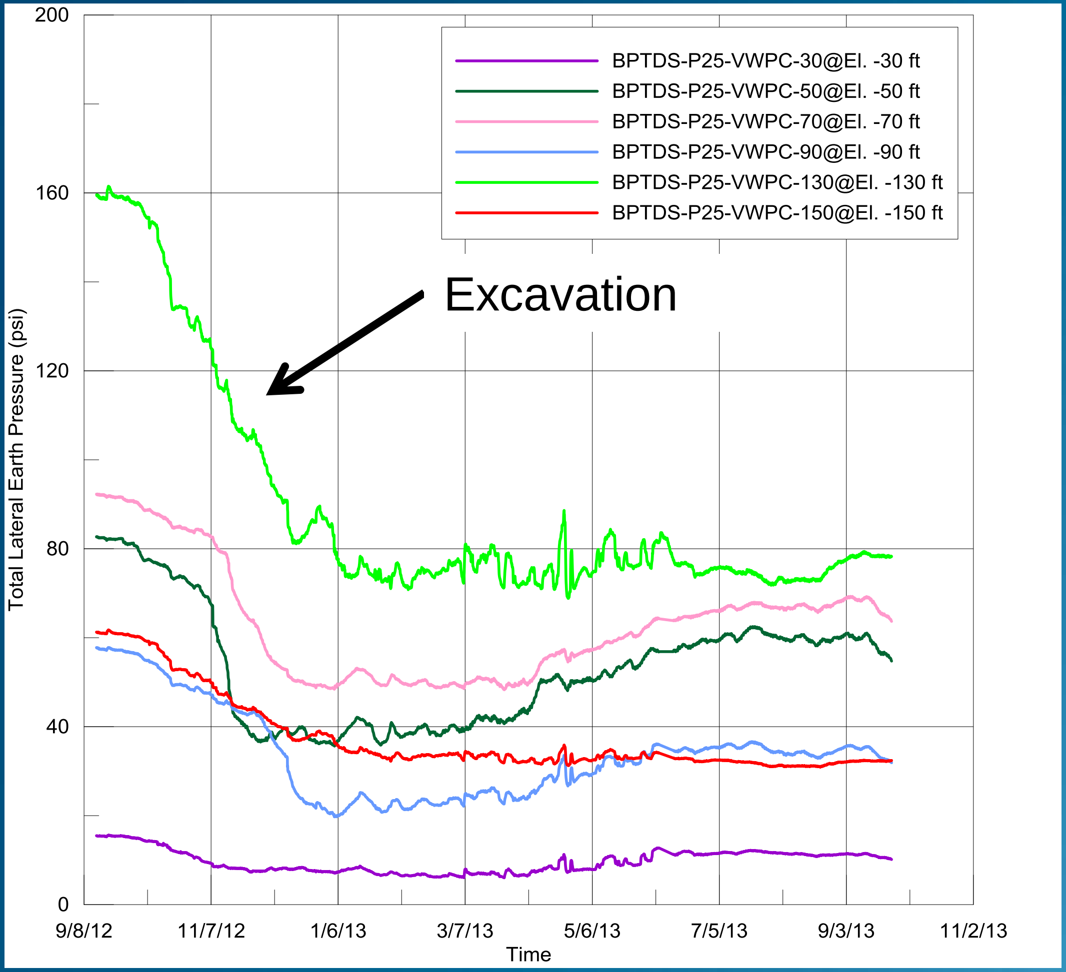
Coefficient of at Rest Lateral Earth Pressure– K_0

The Problem with K_0

- Potomac Clays are highly overconsolidated: K_o greater than 1 for the project, sometimes as high as 1.5
- K_0 values have a significant cost impact: thicker walls, thicker slabs, more rebar. Constructability issues
- Field testing for K_0 may not correlate well with empirical data – no different for this project
- We used empirical and field test data for K_o
  - Consolidation Tests (empirical relationship $(1\text{-}\sin\phi')*OCR^{\sin\phi'}$)
  - Pressuremeter Tests (direct measurement)
- Potential to measure during construction but do not know what happens over time – 100 year design life for the project

Pressure Measured during Construction



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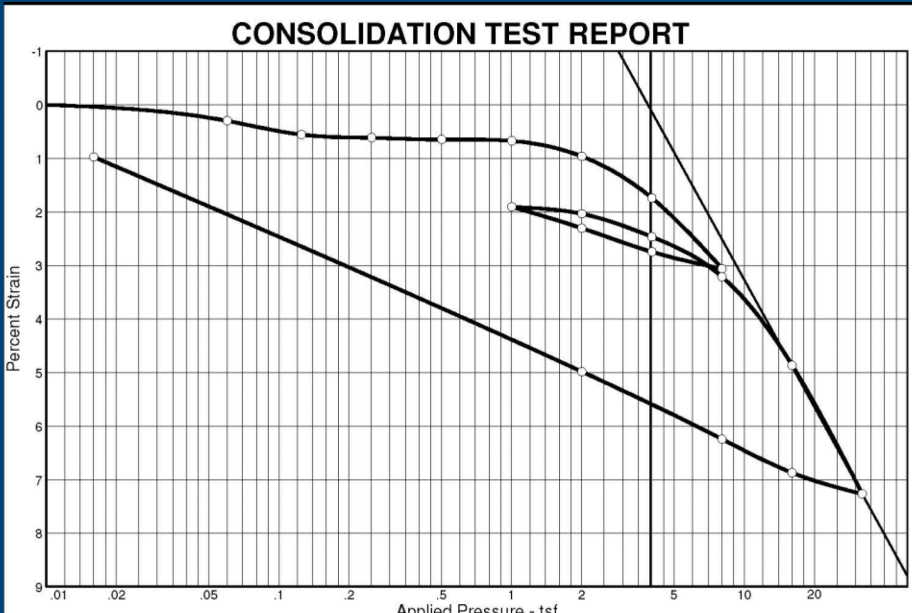
Consolidation Test (ILC vs CRS)

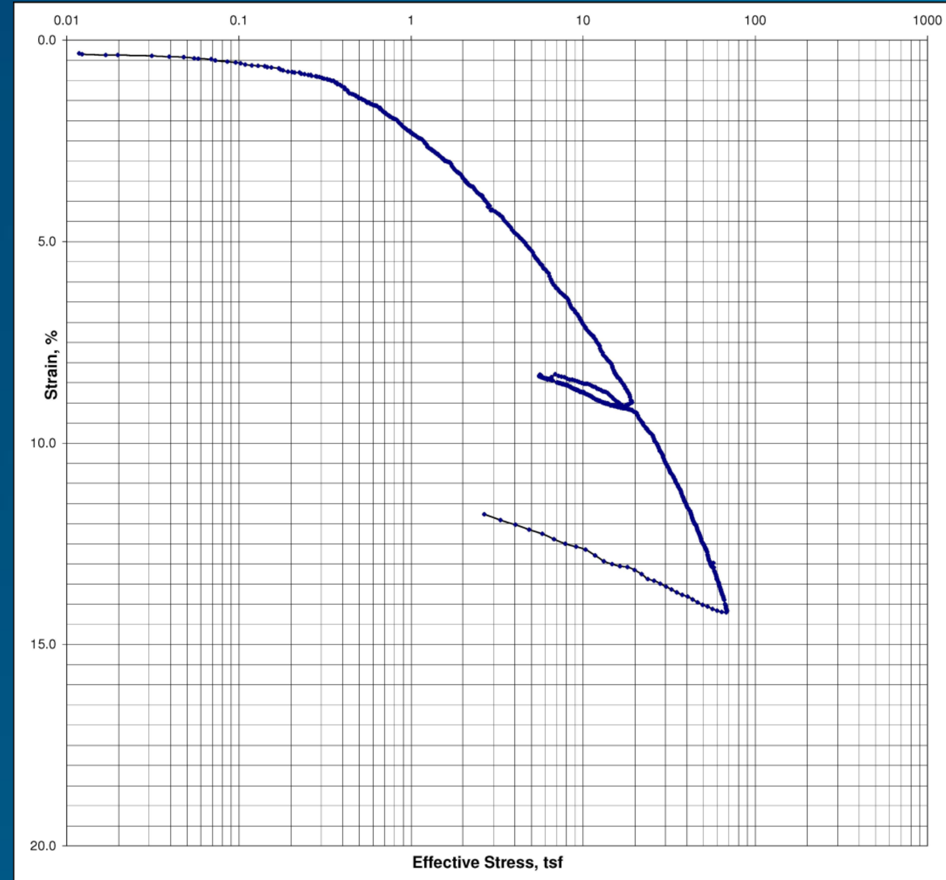
- Used Constant Rate of Strain (CRS) test over 1-D Incremental Load Consolidation (ICL) test
  - Maximum Past Pressure in Potomac greater than 30 tsf
  - ICL capacity ~30 tsf; CRS capacity of ~100tsf
  - CRS is faster and provides smoother curve
  - Permeability can be estimated by CRS
  - Down side is not a common piece of equipment
- Key test for determination of K_o
- Research is being performed to develop a piece of equipment that can estimate K_o directly

Example of ILC vs CRS



Coefficients of Consolidation and Secondary Consolidation

No.	Load (tsf)	C_v (ft.^{2}/day)	C_α	No.	Load (tsf)	C_v (ft.^{2}/day)	C_α	No.	Load (tsf)	C_v (ft.^{2}/day)	C_α
7	4.00	0.29	0.000								
8	8.00	0.22	0.002								
12	2.00	0.06	0.001								
13	4.00	0.14	0.001								
14	8.00	0.08	0.001								
15	16.00	0.02	0.003								
16	32.00	0.01	0.007								



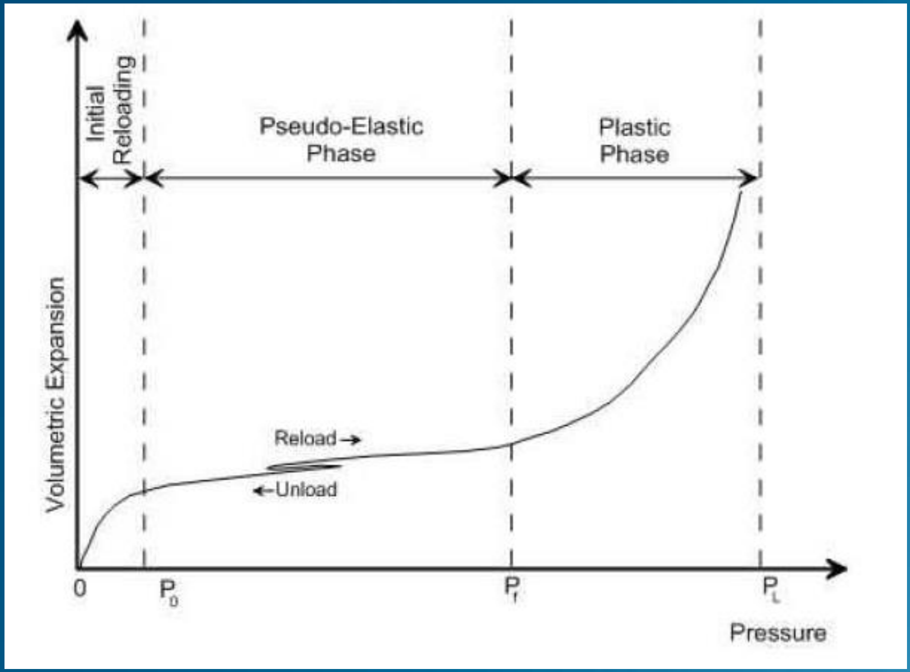
One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading(ASTMD 4186)

Settlement Curve from ILC (same sample)

Settlement Curve from CRS (same sample)

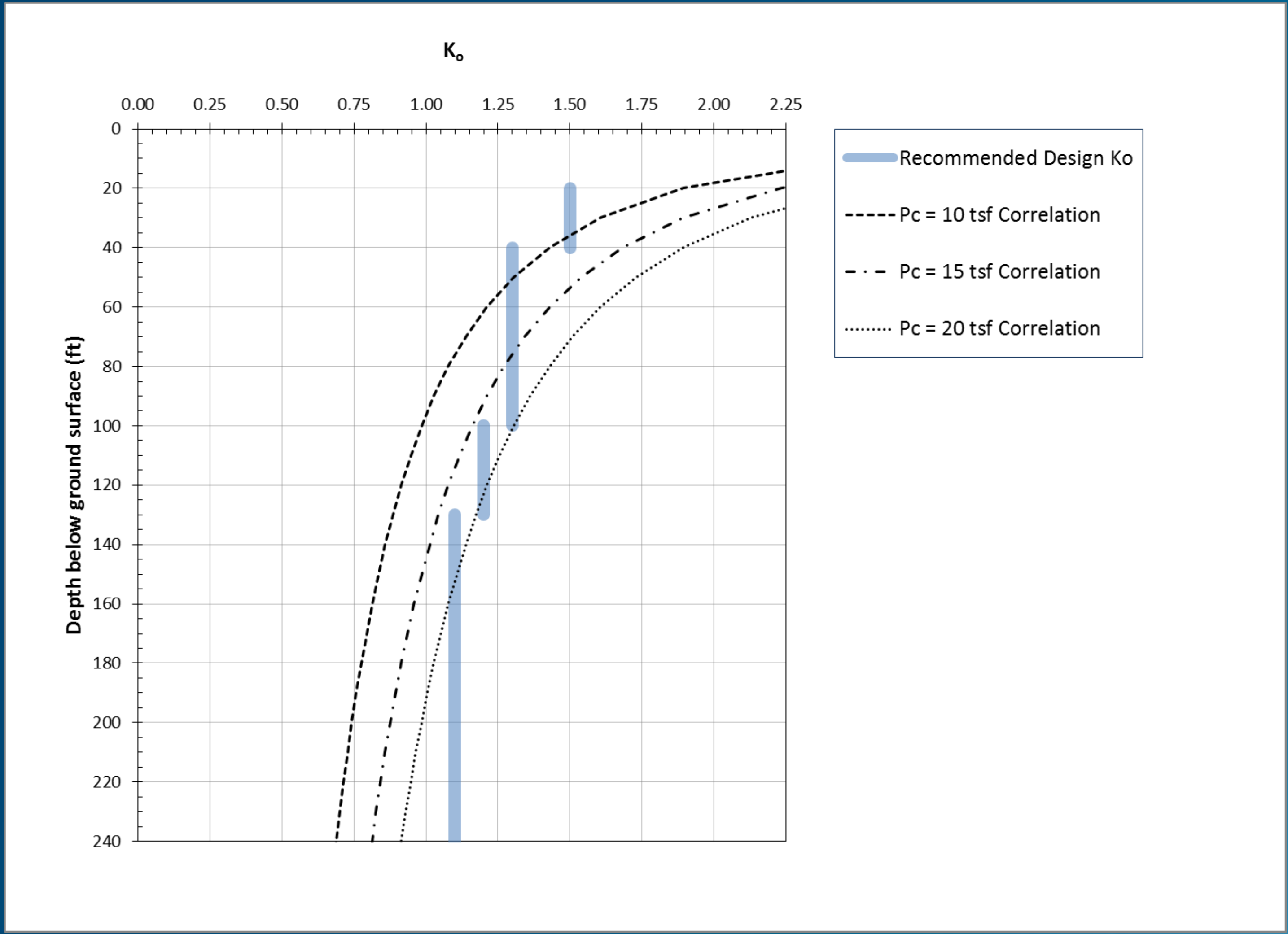
Pressuremeter (PMT)

- Modulus of Elasticity (E)
- Supplemented data for K_o
  - Correlated well with empirical relationship



Unload-Reload in Elastic Phase (BPT)

Coefficient of Lateral Earth Pressure at Rest – K_0



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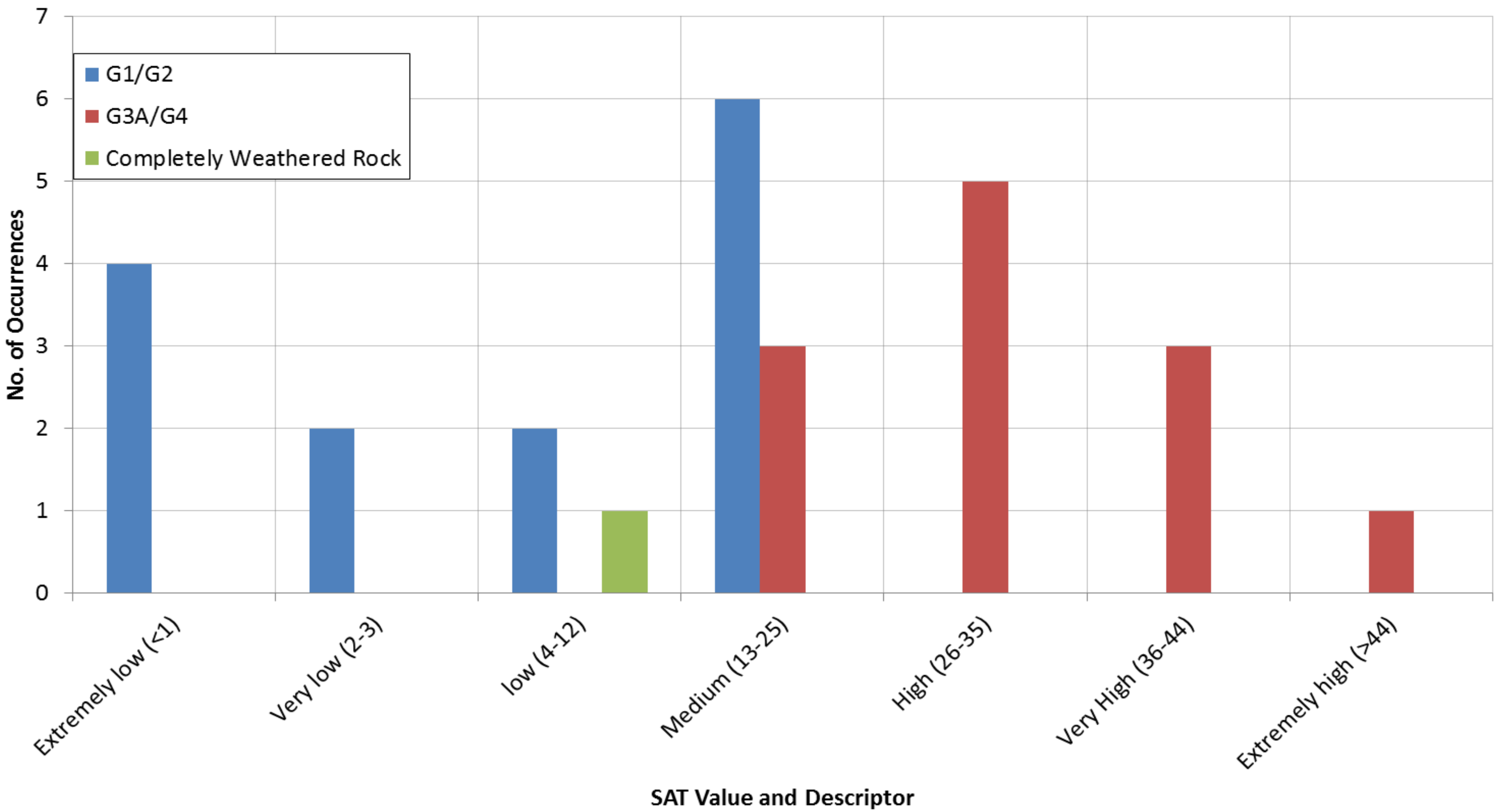
Soil Abrasion Test (SAT)

Soil Abrasion Test (SAT) – Why we care?

- Abrasive soil can wear out the cutting tools and TBM - Affects pricing and scheduling.
- The abrasiveness of soils was included in the Geotechnical Baseline Report as a soil property.
- Tunneling industry is becoming more familiar with SAT
- In addition to SAT, Petrographic and X-Ray Diffraction are recommended be performed together to determine the mineralogy of the soil.
- SAT results will become more useful as more correlations are developed.

Soil Abrasion Test (SAT) Results



Soil Abrasion Test Equipment

Test equipment used to determine Abrasion Value Cutter Steel (AVS) and Soil Abrasion Test (SAT™).

Part of a cutter ring, a 10 mm slice taken from the same ring, and two prepared AVS test pieces which are cut out of the centre of the slice.

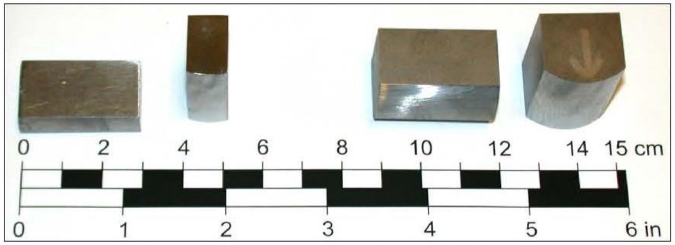


Photo showing two AVS (to the left) and two SAT™ test pieces (to the right).

Other Lessons Learned and Conclusions

- Get a good Historical Photograph person on your team (old channels, land use (UXO). Can save you lots of $$$ and better define investigation
- Sometimes you spend money to save money – X-rays and marine seismic survey
- More research is needed to determine if and how long it takes K_o to come back onto excavations final liners (tunnels and shafts). The design life for projects can be order of 100 to 200 years.

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Q&A

Questions?