
VDOT
Virginia Department of Transportation

GEOTECHNICAL CONSIDERATIONS FOR TUNNELING IN THE HRBT EXPANSION PROJECT

Southeastern Transportation Geotechnical Engineering Conference

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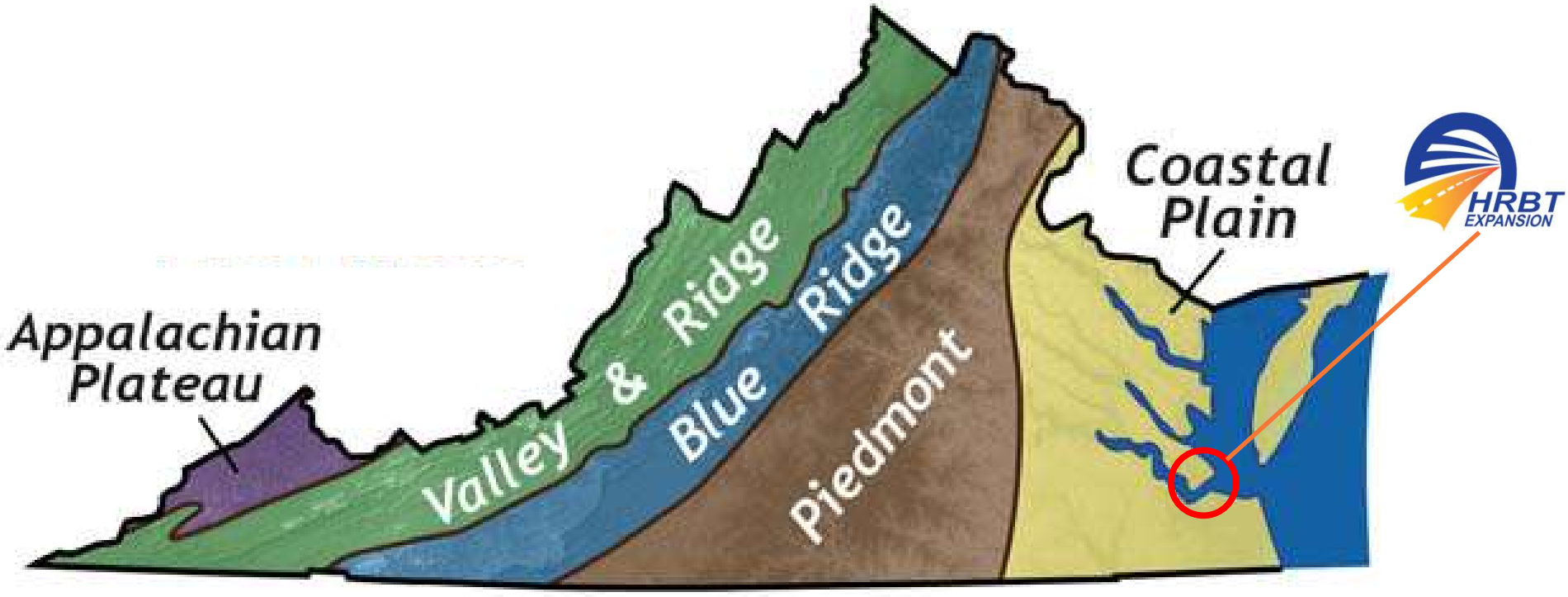
Presentation Outline

- Introduction
  - Geology
  - Project Overview
- Subsurface Conditions
- Historical Construction
- Tunnel Boring Machine
- Ground Improvement
  - Deep Mixing
  - Jet Grouting

Introduction

Geologic Provinces of Virginia



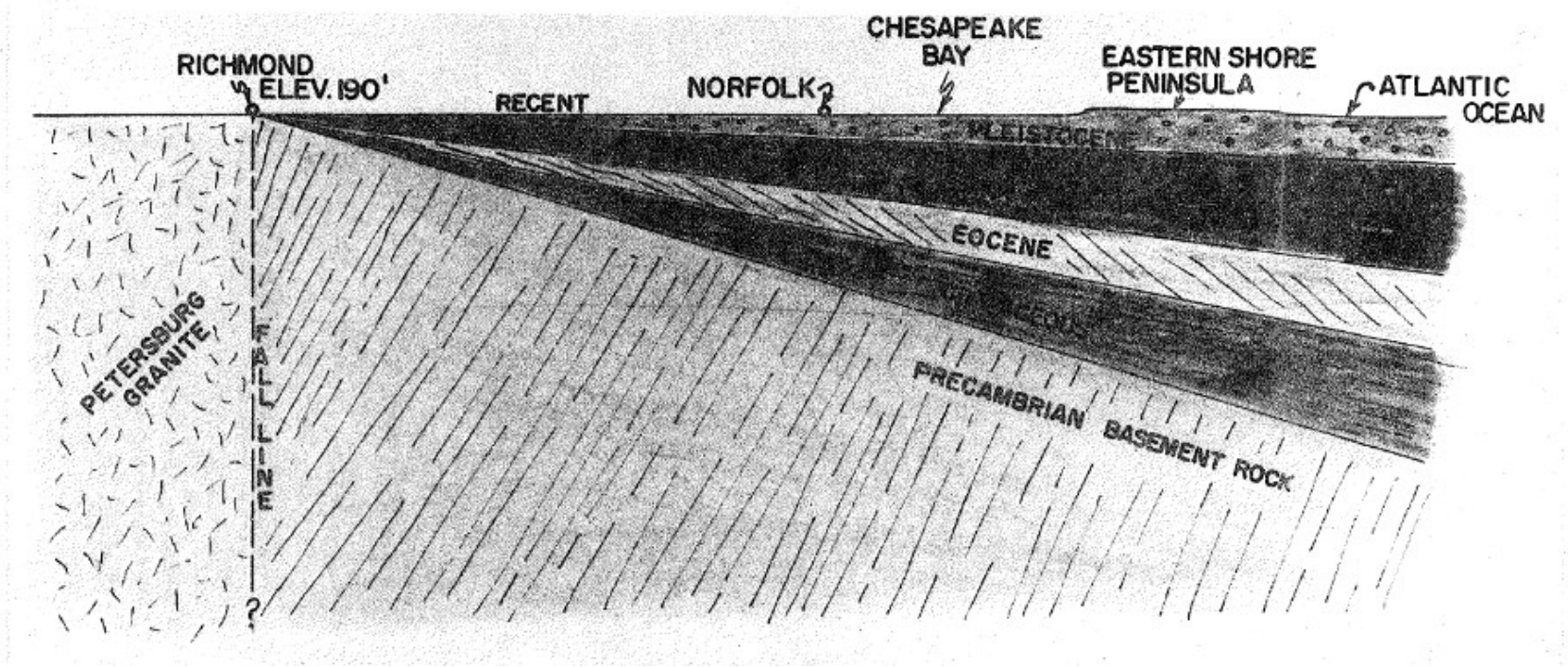
Introduction

General Geology of Virginia's Coastal Plain

- Easternmost geologic province of Virginia
- Extends from the Fall Line to the Atlantic Ocean and Chesapeake Bay
- Made up of unconsolidated or semi-consolidated marine and fluvial sediments
- Common materials: sand, silt, clay and gravel
- Sediments thickness increases eastward
- Key geotechnical features: soft and compressible soils, high ground water table, significant lateral and vertical variability over short distance.

Introduction

Geologic Cross Section at Coastal Plain

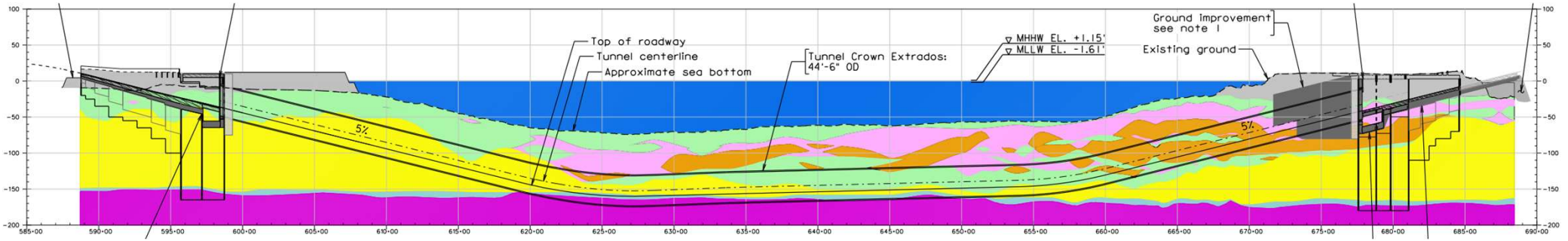


Cross Section from Richmond to Norfolk (George, 1977)

Introduction

Project Overview

Subsurface Conditions



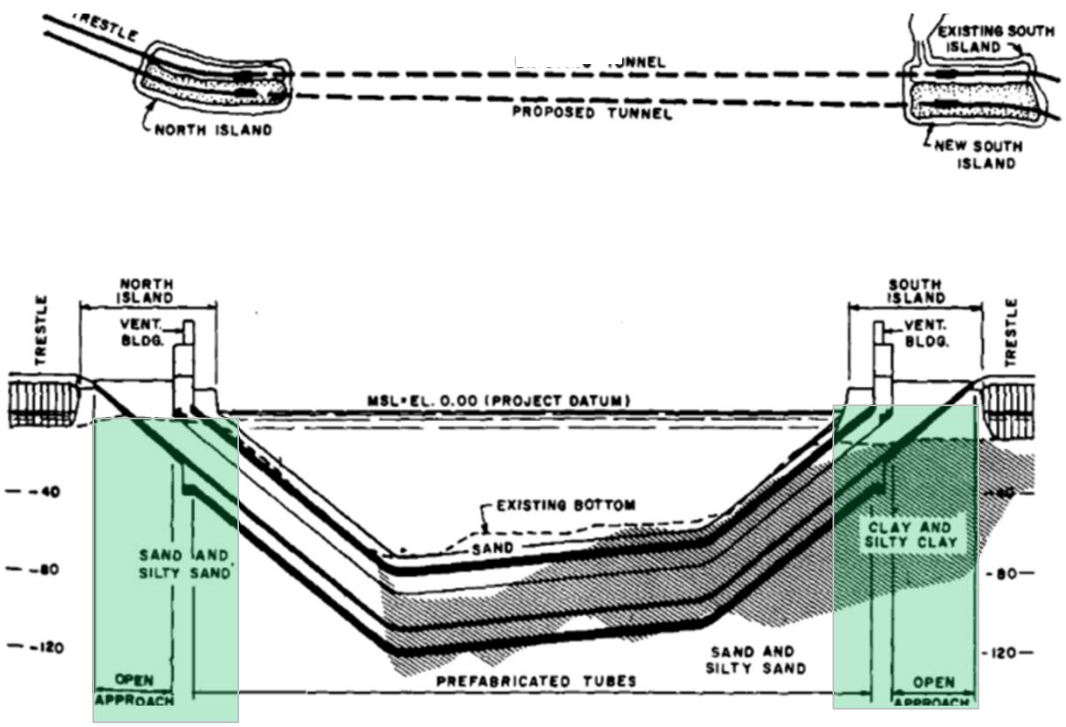
North Island

South Island

- Water
- AF, Artificial Fill
- Qc, Alluvial Marine Course
- Qf, Alluvial Marine Fine
- Qo, Alluvial Marine Organics and Plastic
- Tys, Yorktown Course
- Tyf, Yorktown Fine
- Tye, Eastover

Subsurface Conditions

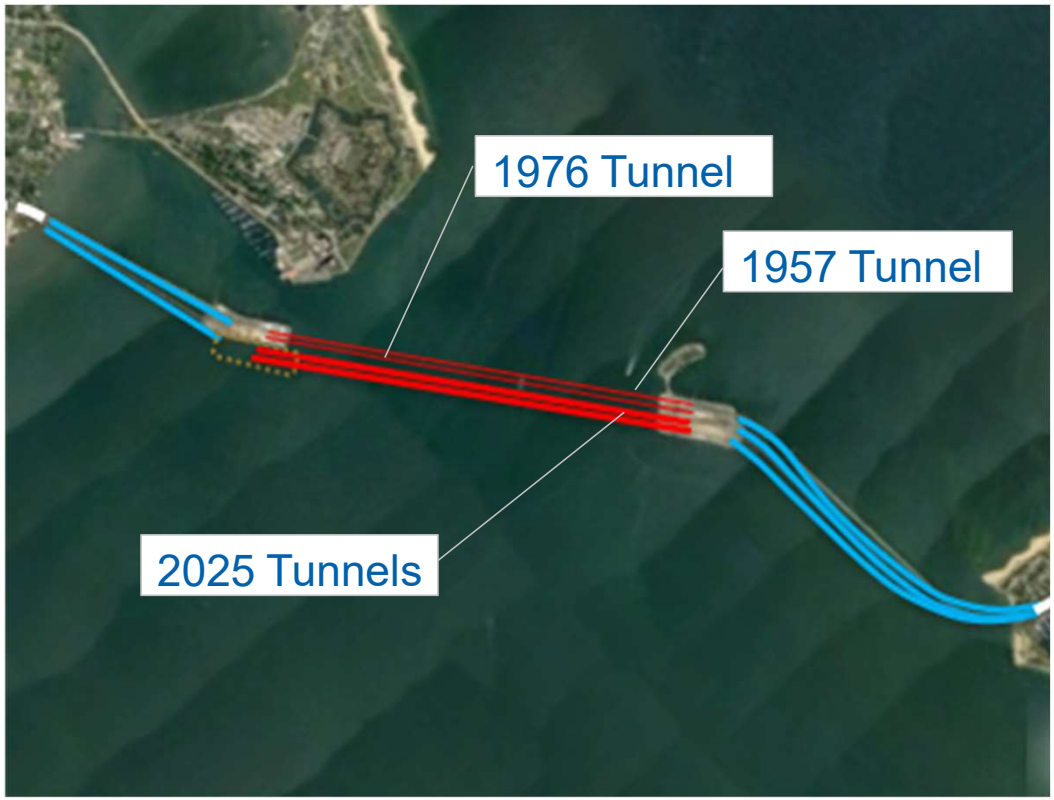
- **Soil variations at north and south islands**
  - HRBT has one “good island” and one “bad island”
  - North Island
    - Sand and Silty sand
  - South Island
    - Thick layer of clay overlies the sandy soil
    - Maximum thickness of clay layer is about 80 feet
    - Normally consolidated, partially organic and very compressible



General Plan and Profile (Rafaeli 1971)

Subsurface Conditions

- **Mitigation of soft material at HRBT south island for each tunnel**
  - 1957 - Excavation and Sand Fill
    - Clay was removed and replaced by hydraulic fill
  - 1976 - Surcharge and Sand Drains
    - Accelerate the consolidation of clay to minimize the post-construction settlement
    - Estimated maximum settlement was greater than 10 feet under the full surcharge load
  - 2025 - Cementitious ground improvement
    - Deep mixing and jet grouting



Subsurface Conditions

Geotechnical Index Properties (South Island)

	Artificial Fill	Alluvial Coarse-Grained	Alluvial Fine-Grained	Alluvial Organic	Yorktown Coarse-Grained	Yorktown Fine-Grained	Eastover Coarse-Grained
Unit Weight (pcf)	119	115	115	102	125	115	115
Moisture Content (%)	18	25	36	53	29	33	27
Liquid Limit			40	82		56	
Fines Content (%)	4	24	73	87	22	81	25
Organic Content (%)				<12			
OCR			1.5	1.4			

Historical Construction

North Island - 1957

North Island - 1955

North Island - Ongoing Construction

North Island - End of Construction in 1957

Historical Construction

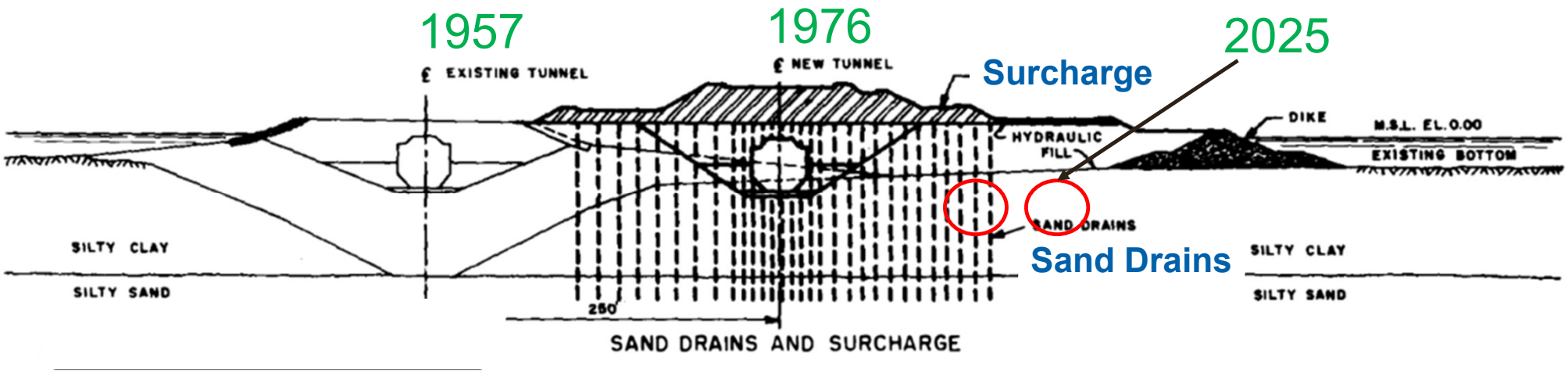
South Island - 1957

South Island - 1955

South Island - Ongoing Construction

South Island - End of Construction in 1957

Historical Construction

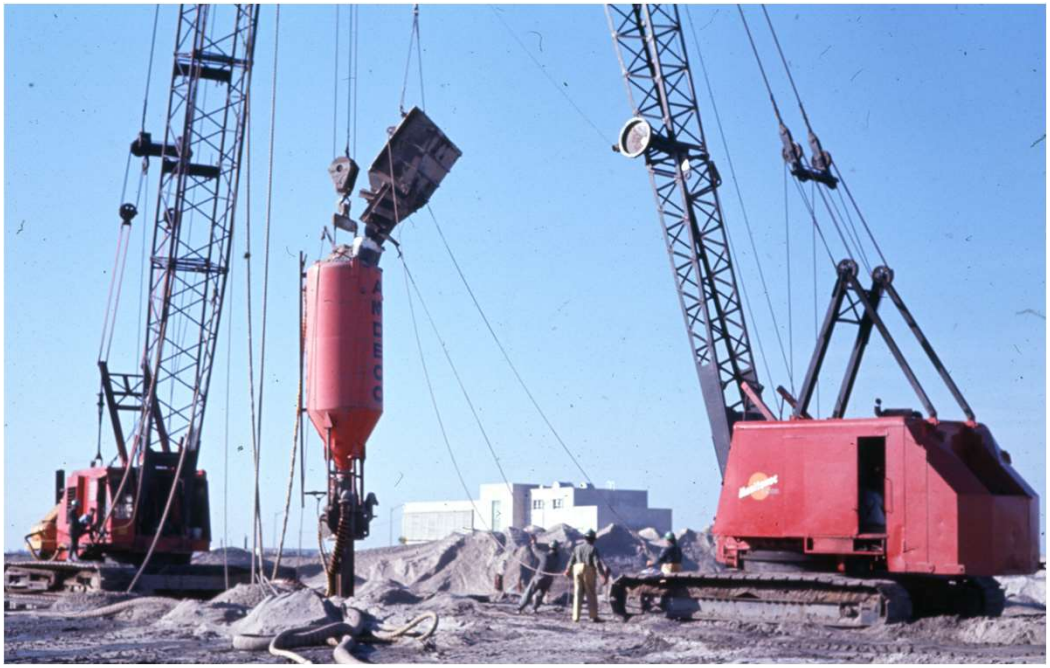


Cross-Section of South Island Expansion in 1970's

Historical Construction

South Island

Construction of South Island Expansion with Surcharge – 1970's



Sand Drain Installation on South Island Expansion – 1970s

Historical Construction

North Island

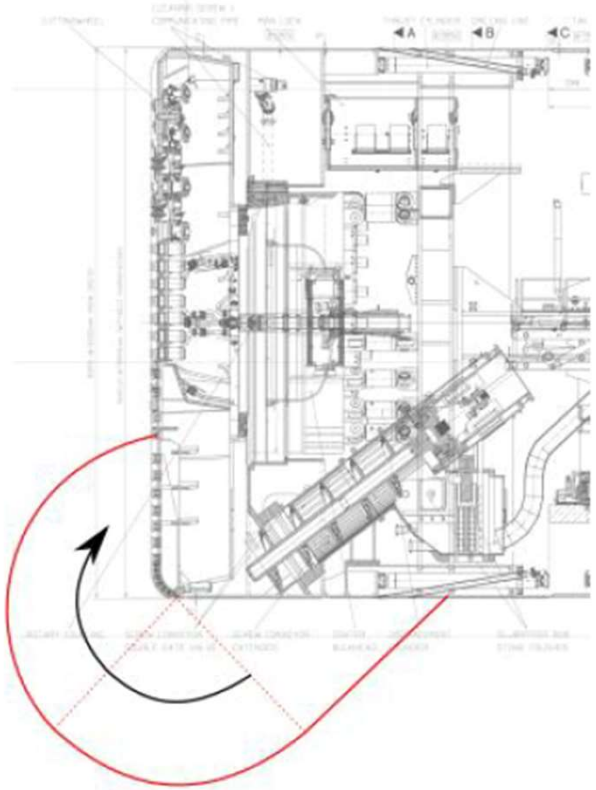
Construction of North Island Expansion with Surcharge – 1970's

Immersed Tube Tunnel Placement – 1970s

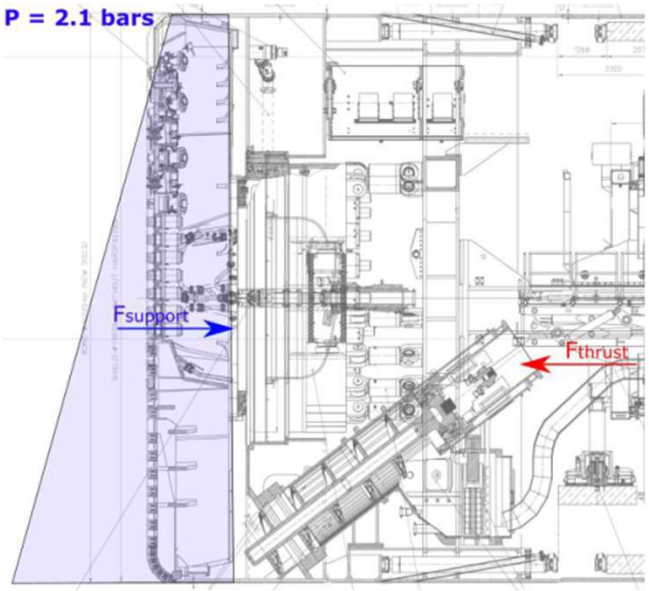
Tunnel Boring Machine (TBM) – General Information

- First bored tunnel for VDOT
- Diameter of TBM cutterhead is 46.5 feet
- 173 feet below the water surface
- 50 feet deeper than existing tunnels
- Each bored tunnel is about 1.5 miles long

Tunnel Boring Machine (TBM) – Support Requirement

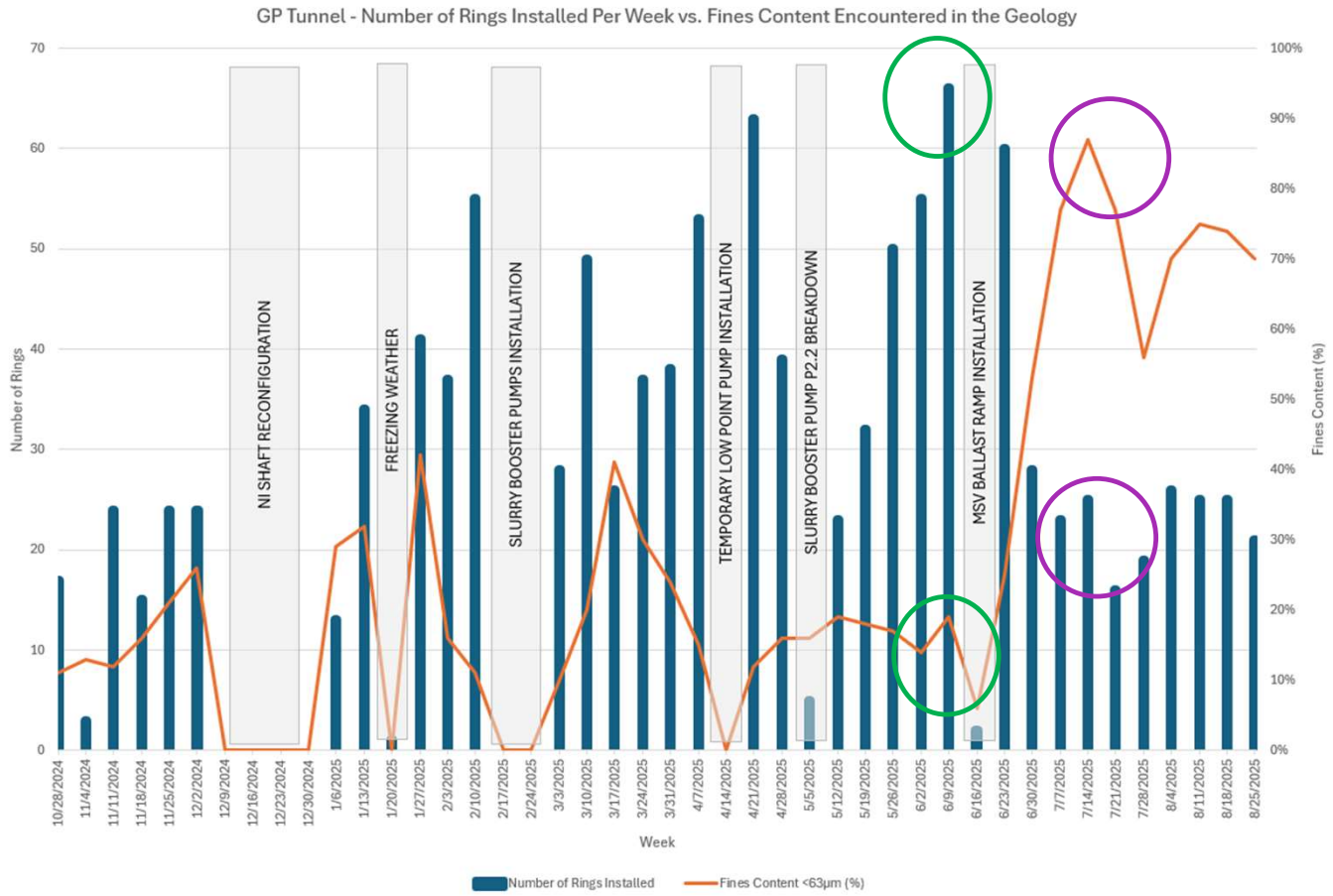


Bearing Failure



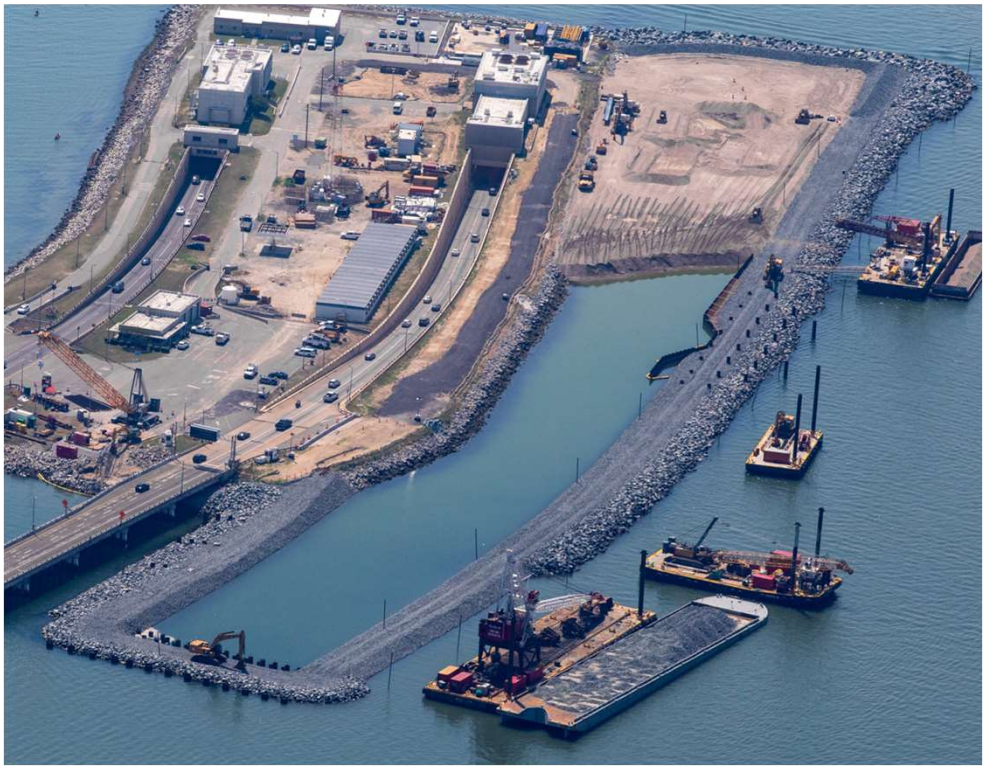
Thrust Force Eccentricity

Tunnel Boring Machine (TBM) - Production

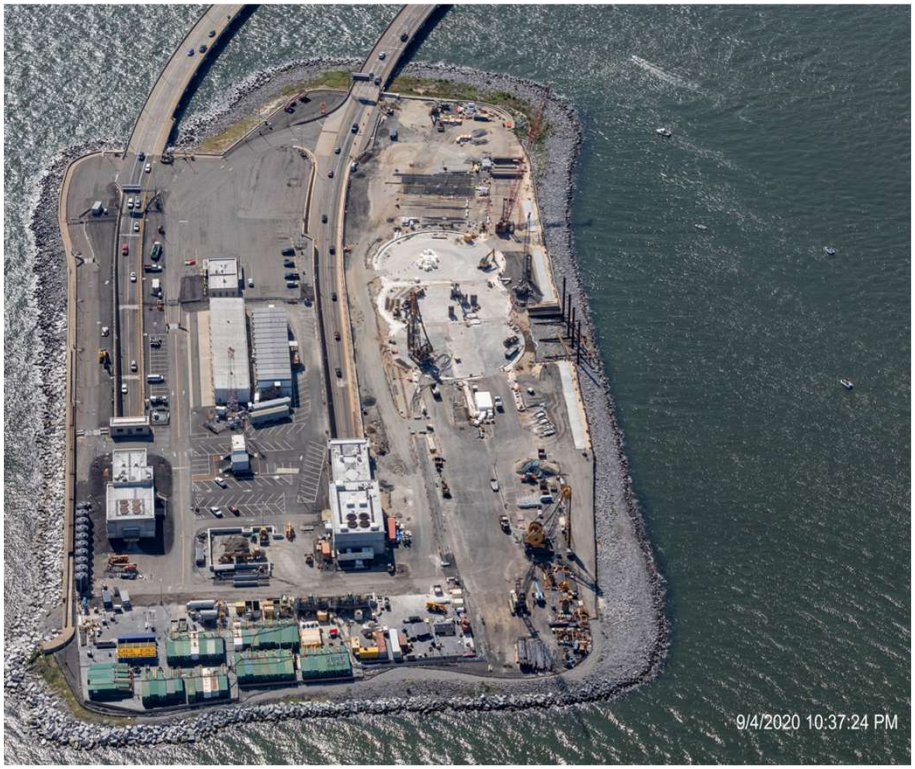


- Higher fine contents – less production (purple) – less number of rings
- Lower fine contents – higher production (green) – more number of rings

Ground Improvement

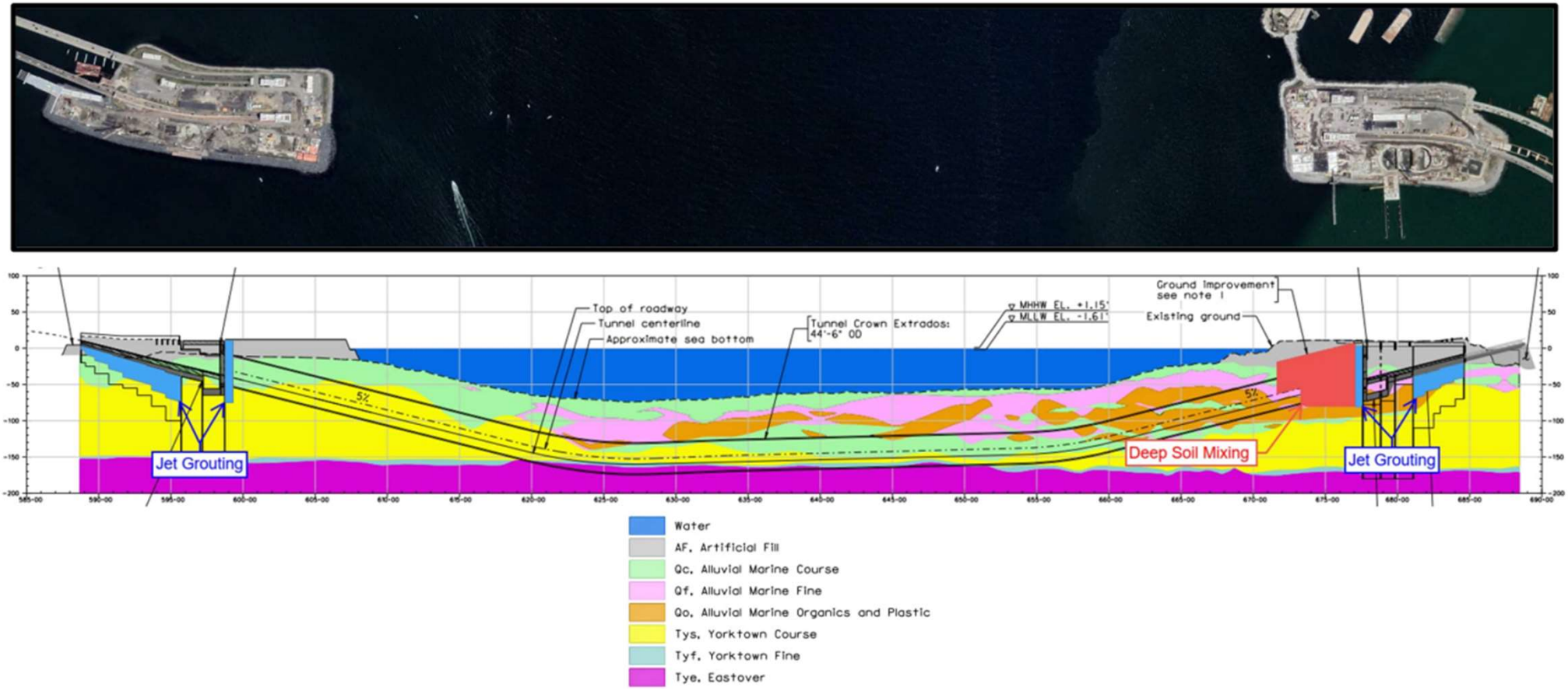


2021 North Island – Before Ground Improvement



2021 South Island – Before Ground Improvement

Ground Improvement



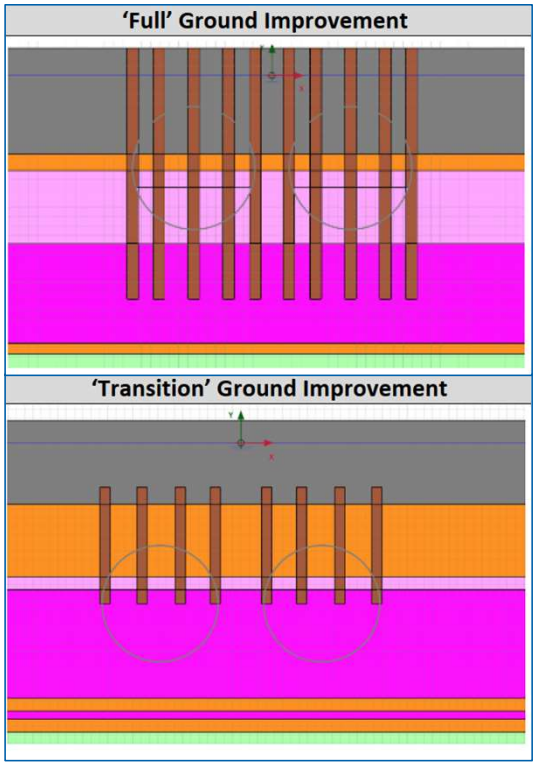
Ground Improvement

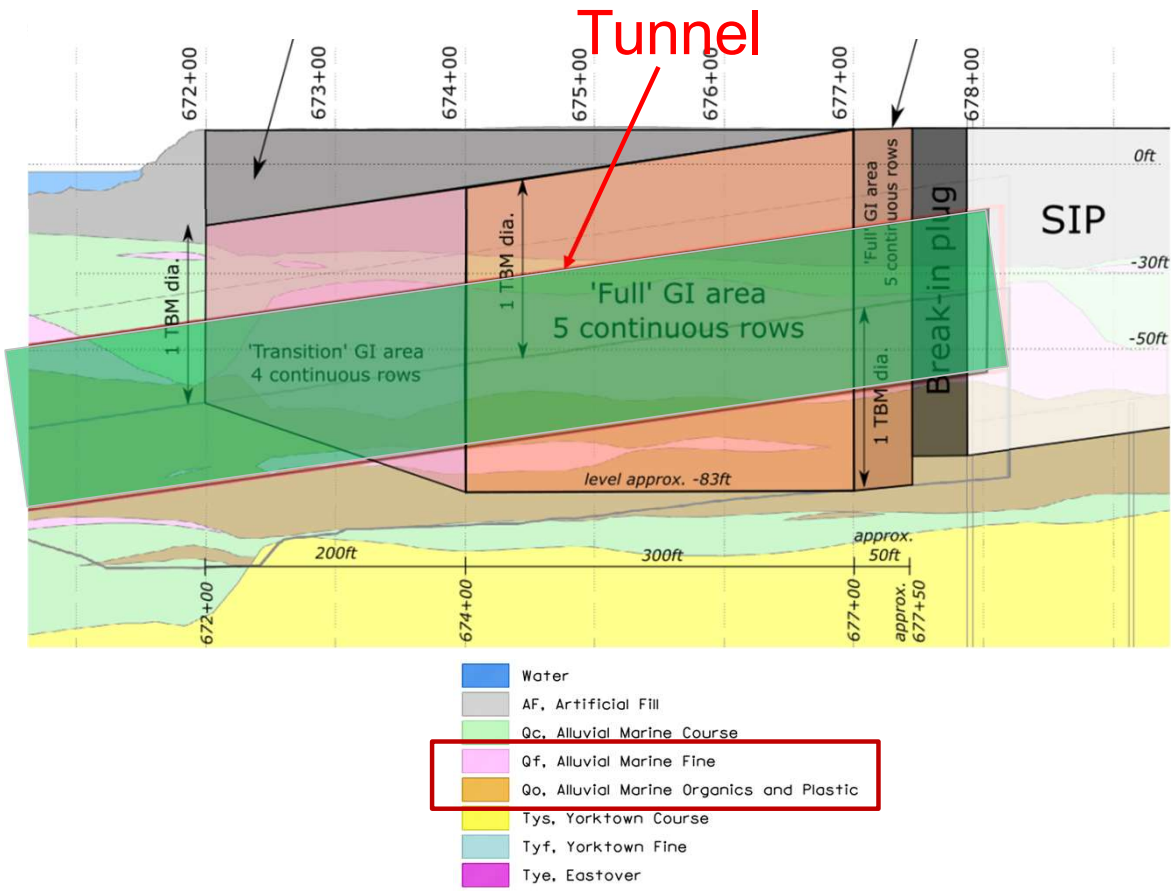
Deep Soil Mixing

❑ Tunneling Support and Stability

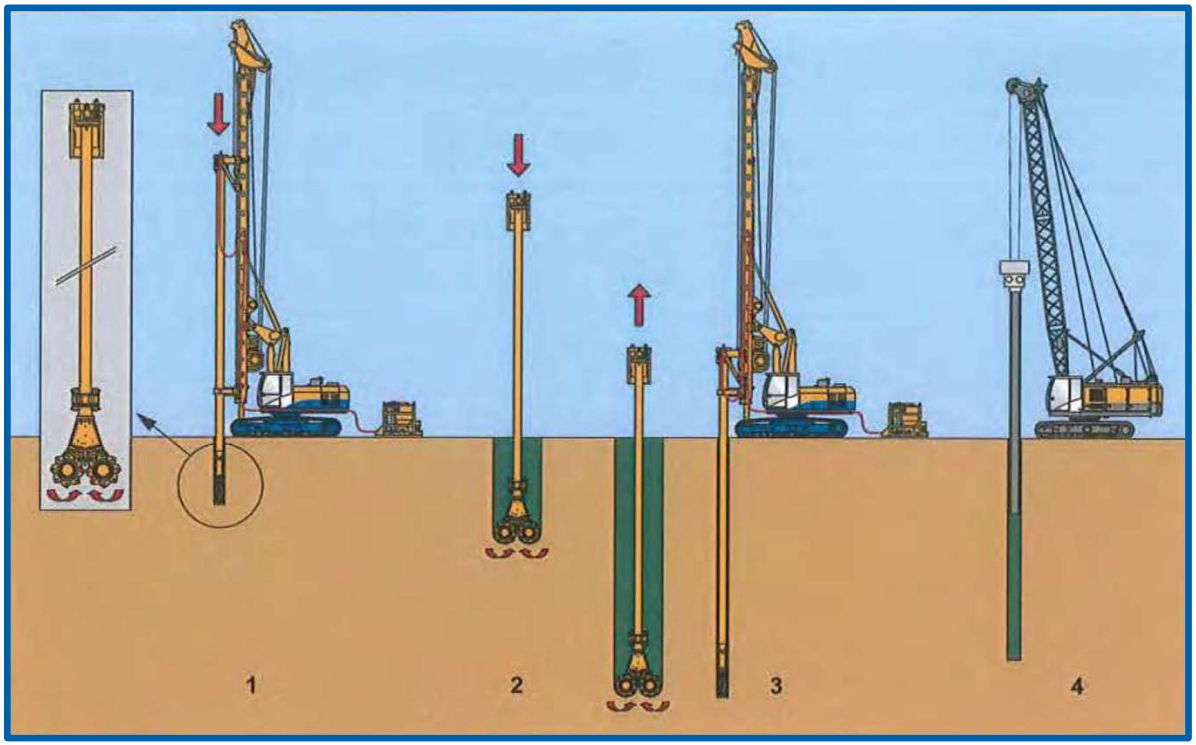
- **Short-term tunnel constructability (line and grade control)**
  - Prevents TBM tilt from uneven weight distribution
  - Maximizes thrust system by operating near allowable face pressure
- **Long-term settlement control for completed tunnel**
  - Reduced secondary compression caused by unloading effects of fine-grained deposits
  - Prevents excessive tunnel liner stresses as it transitions offshore

Deep Soil Mixing Layout





Deep Soil Mixing - Production



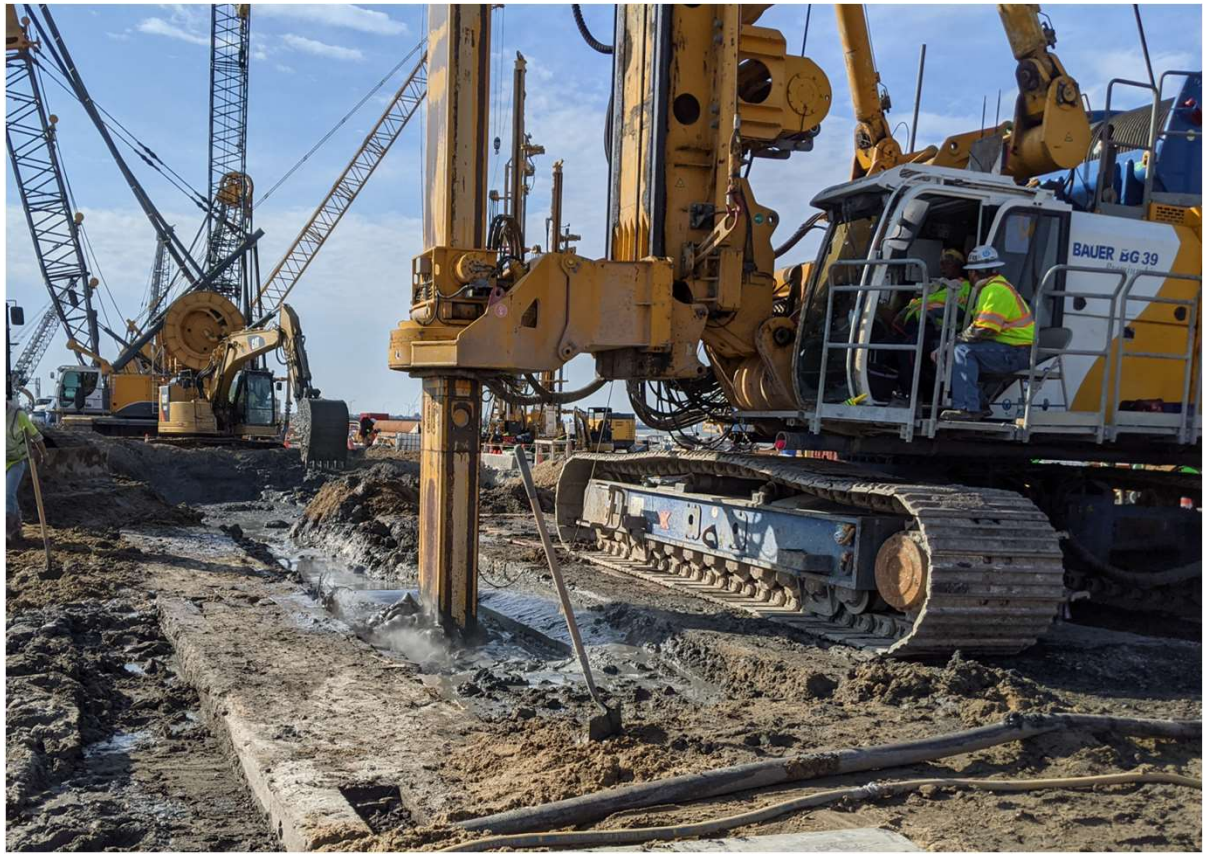
Procedure

- Top-down approach
- Tool insertion
- Mix in-situ soil with bentonite slurry to depth
- Grout Injection during tool withdrawal
- Obtain “wet grab” samples of improved ground for laboratory testing

Deep Soil Mixing - Production

Statistics

- ❑ 520 Total DSM “barrettes”
- ❑ Production from June 2021 to April 2022 (10 months)
- ❑ 32 full depth cores
- ❑ 275 compressive strength tests
- ❑ 550 sets of wet sample cylinders



Deep Soil Mixing

Performance Requirements

Test Parameter	Acceptance Criteria
Unconfined Compressive Strength (each individual element)	80% of cored sample tests must equal or exceed 145 PSI
Unconfined Compressive Strength (all elements across the CDSM site)	90% of cored sample tests must equal or exceed 145 PSI
Unconfined Compressive Strength (all elements across the CDSM site)	90% of cored sample tests shall be less than 1000 PSI
Specific Gravity	Within 3% of specified value (per mix design)
Top Elevation Tolerance	Within 4 inches of specified elevation
Bottom Elevation Tolerance	Within 4 inches of specified elevation
Vertical Alignment Tolerance	Within 1% of true vertical

- Core Recovery > 80%
- UCS for “wet grab (in-situ)” cylinders > 120 psi

Ground Improvement

Jet Grout

❑ Break-in / Break-out Blocks

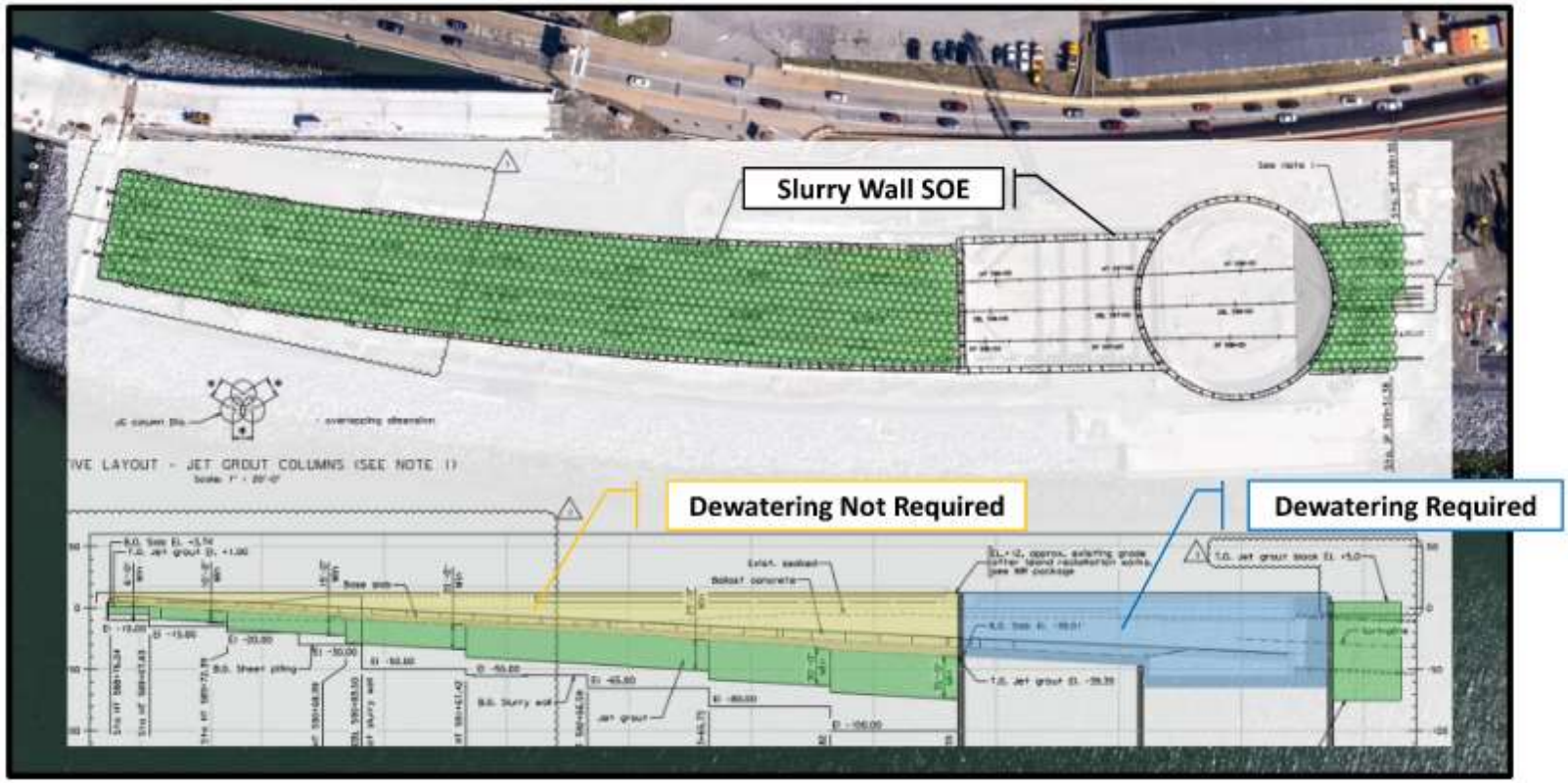
- Allows tunnel rings to be grouted before TBM builds to soil face stabilization slurry pressure
- Allows for possible “open air” interventions to visually inspect tooling damage
- Allows the TBM to build slurry pressures before excavating into the soil

❑ Approach Excavation Plug

- Provides a water cutoff barrier to reduce or eliminate dewatering
- Provides lateral stability for slurry wall SOE below excavation level

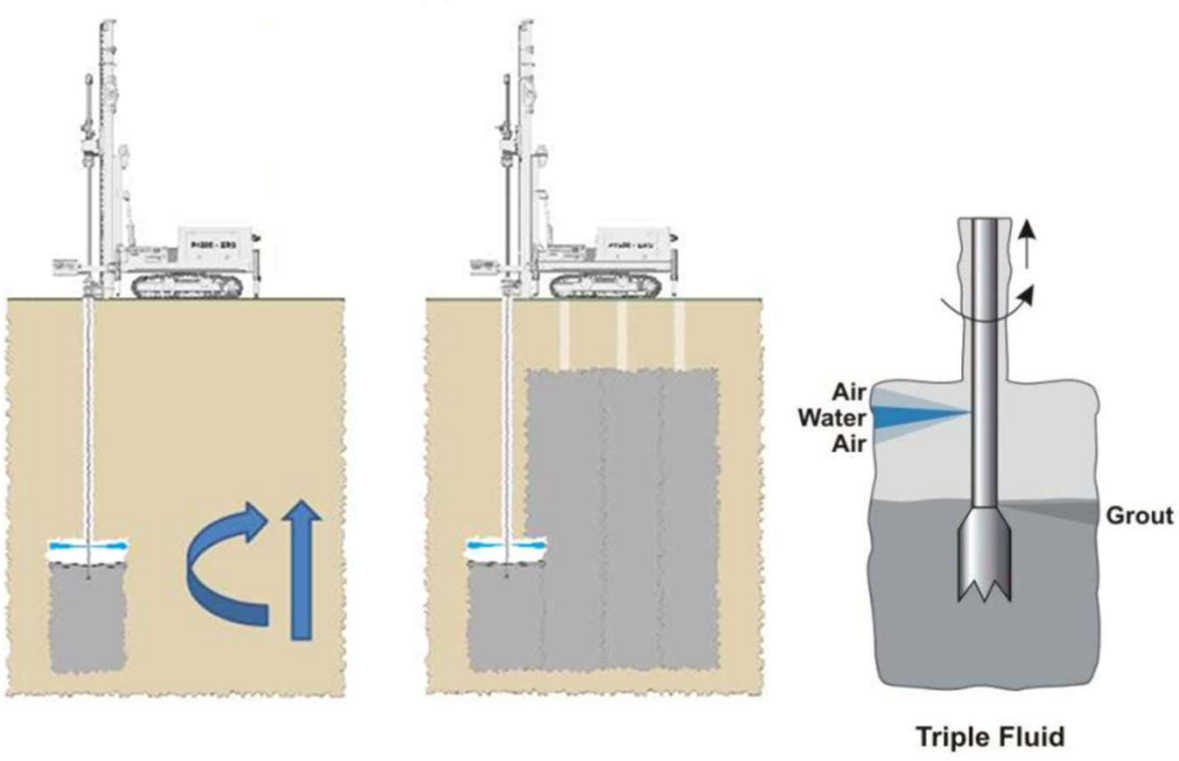
Jet Grouting

North Island



Jet Grouting - Production

Jet Grouting Triple Fluid System



- Bottom-up Installation
- Three jets are lifted and rotated
- Water and compressed air erode and remove part of soil
- Grout mixes with soil and solidifies to form a cylindrical column of treated soil (soilcrete)

Jet Grouting – Production

❑ Design Geometry

- Triangular pattern
- Overlap = 15%
- Diameter = 10 ft

❑ Design Parameters

- Cement/Water (weight) = 0.9 to 1.1

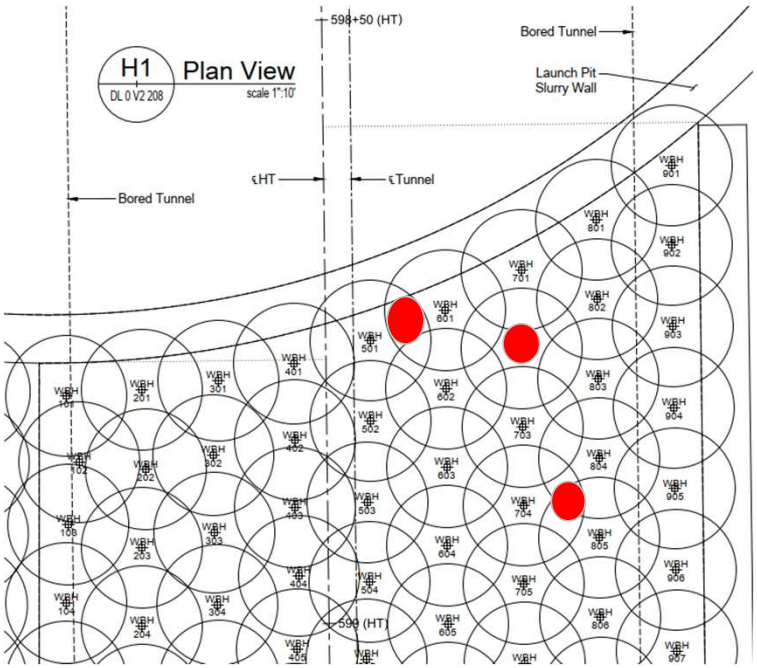
❑ Verification Testing

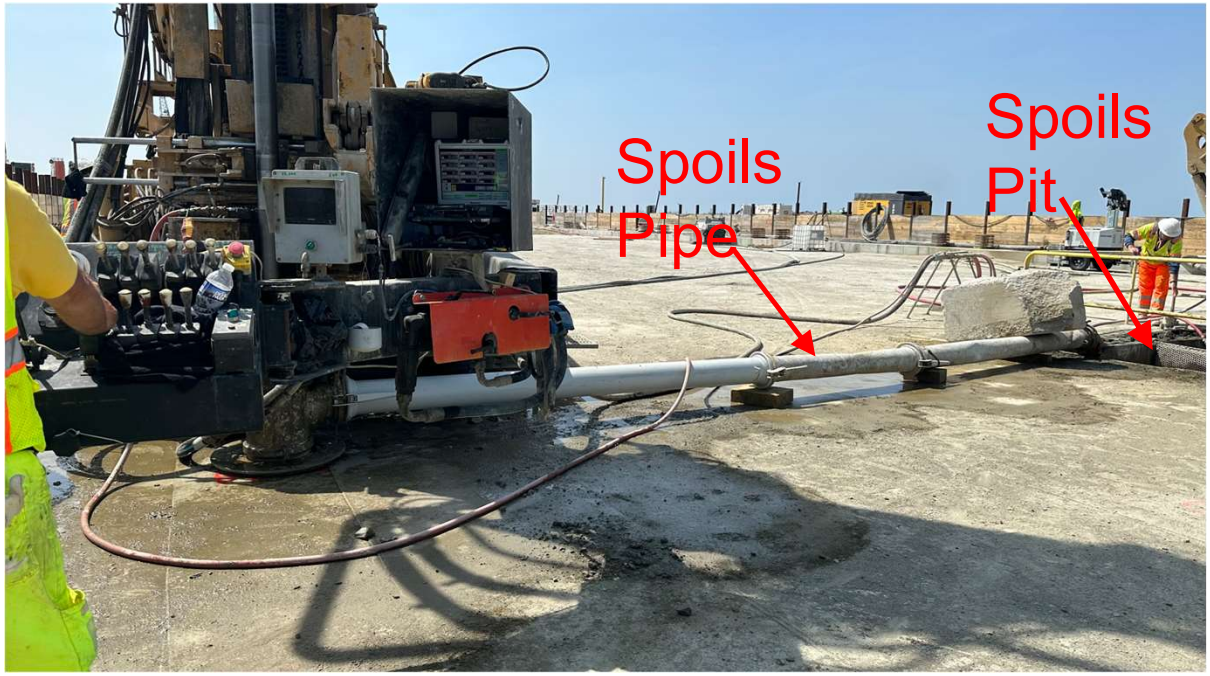
- Coring (single, double overlap, triple overlap)
- Permeability

Jet Grouting - Production

- **Sequence of Installation**
  - 24 hours before jet grouting next to installed column
- **Coring**
  - 2 cores at every 900 ft^2
  - Coring shall extend from 3 ft below the top of the column to 5 ft below the bottom of the ground improvement zone
  - Double tube core barrel
- **Structure Monitoring**
  - Monitor existing structures during jet grouting for settlement, heave, and others

Jet Grouting – Production





Jet Grouting - Production

Statistics

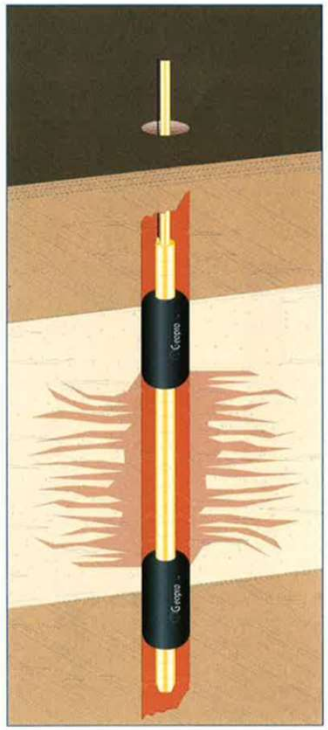
- 2,246 total jet grout columns
- Production from June 2021 to December 2023 (30 months)
- 253 full depth cores
- 400+ compressive strength tests
- 252 permeability “packer” tests

Jet Grouting

Performance Requirements

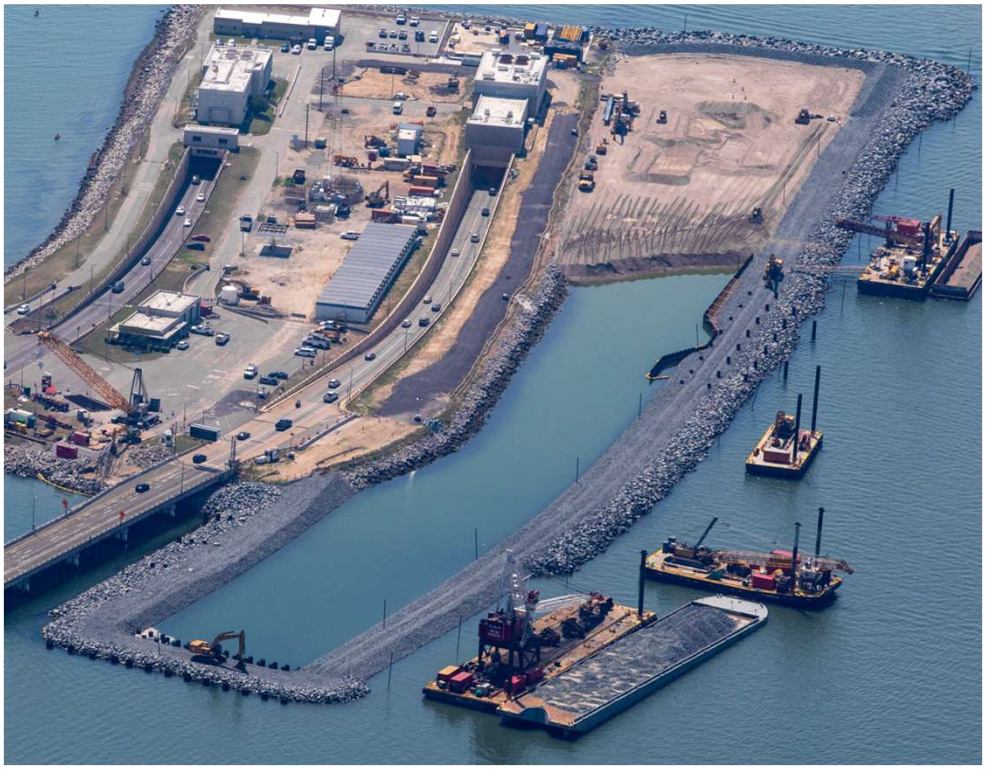
Jet Grout Function	Soil Type	Target Value		
		28 Day f 'c (psi)		*K (ft/s)
		Min	Max	Max
South Approach Structure	Granular	200	-	Upper 3.28E-08 Lower 3.28E-07
	Cohesive	200	-	Upper 3.28E-08 Lower 3.28E-07
North Approach Structure	Granular	250	-	Upper 3.28E-08 Lower 3.28E-07
	Cohesive	200	-	Upper 3.28E-08 Lower 3.28E-07
TBM Break-in / Break-out Blocks	Granular	250	1000	Upper 3.28E-08 Lower 3.28E-07
	Cohesive	200	1000	Upper 3.28E-08 Lower 3.28E-07

Permeability “Packer” Test



- Core Recovery > 85%
- Core Recovery Index (Yoshitake, et.al. 2003)

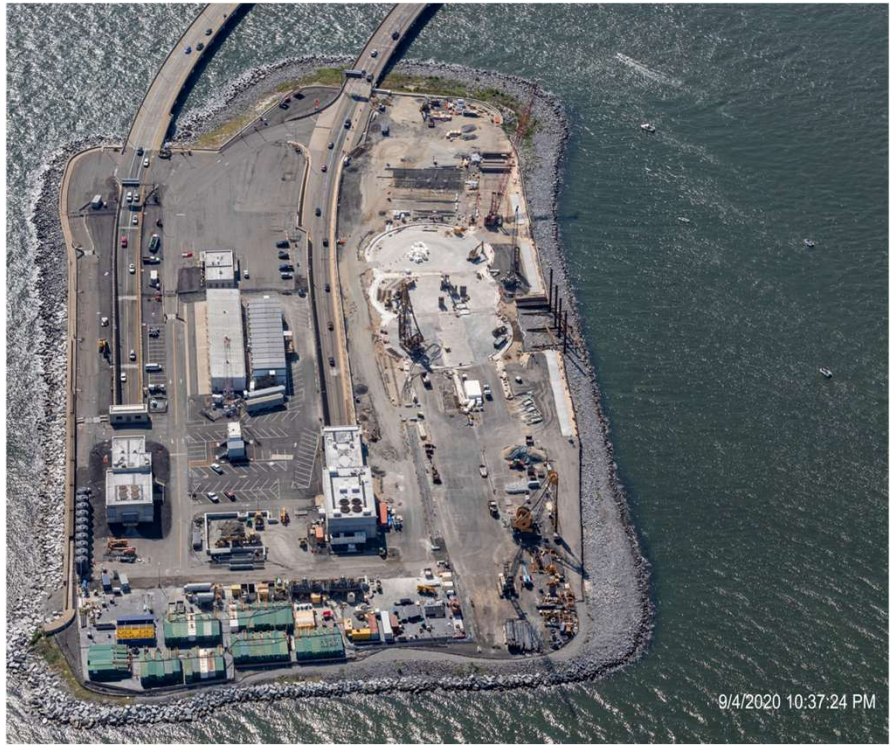
North Island – Jet Grout



2021 North Island – Before Ground Improvement

2025 North Island – After Ground Improvement

South Island – Jet Grout and Deep Soil Mixing



2021 South Island – Before Ground Improvement

2025 South Island – After Ground Improvement

Questions?