Application of a Wick Drain System for an NCDOT Bridge Project

By: Ryan P. Doyle, P.E.

Zahra Aghazadeh, PhD, P.E.

Gabriel W. Lang, P.E.

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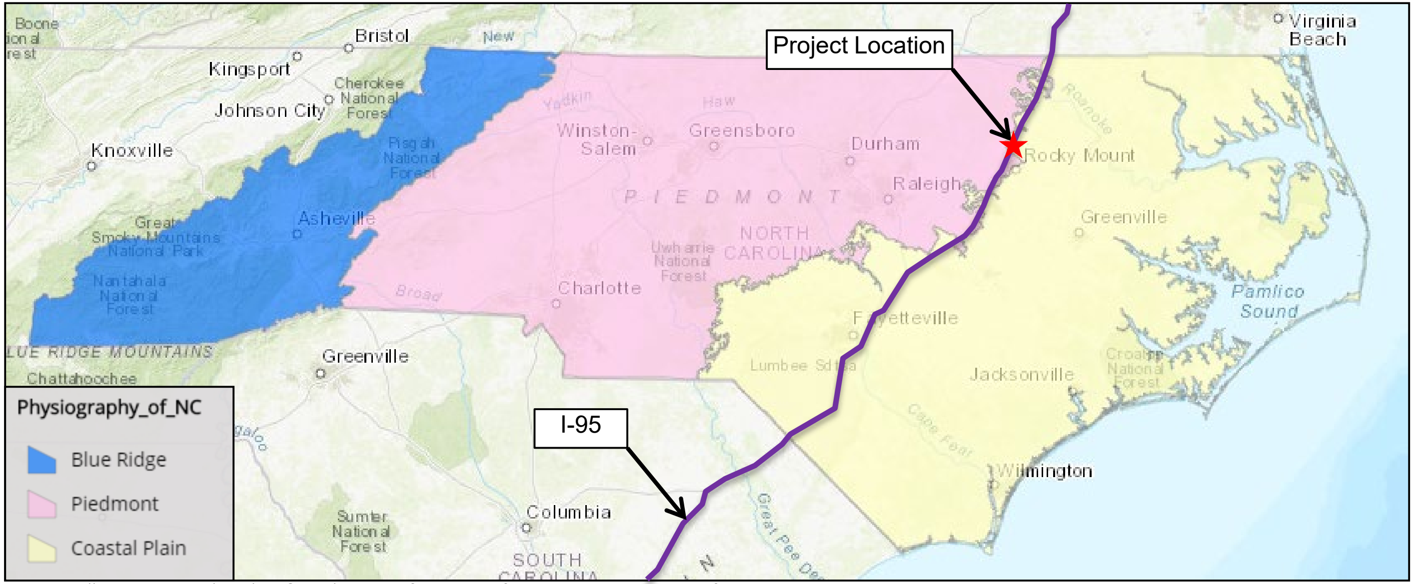
Project Background

– Located Nash County (near Rocky Mount) on the border of the Coastal Plain and Piedmont Physiographic Provinces

– Project consists of reconfiguring interchange, which includes a new bridge over I-95 with maximum embankment fill height around 34-ft



REF: https://www.arcgis.com/apps/MapSeries/index.html?appid=1316f4eb4e3349298c3bd0063ab8fb89

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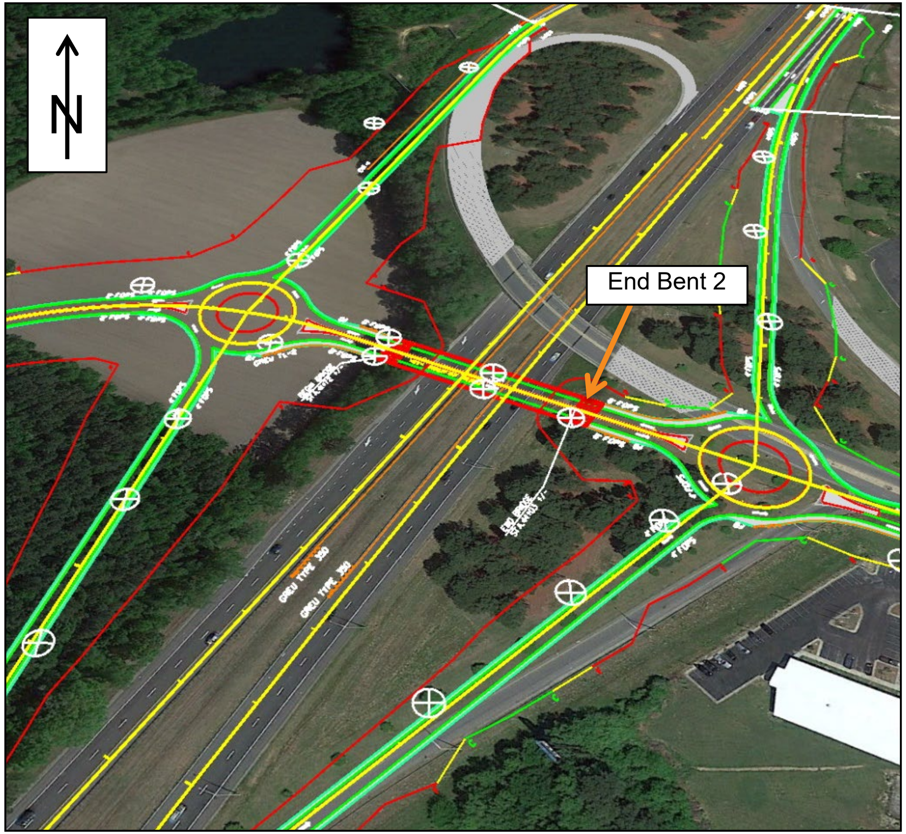
Site Investigation and Plan View

- 39 total SPT borings for new roadway and bridge structure (2 span)
- 5 SPT bridge borings:
  - 4 terminated at top of rock, and
  - 1 terminated 19.6-ft into rock (granite)
- In general, overburden consisted predominantly of Undivided Coastal Plain and Coastal Plain soils
- Yorktown Formation – clay with varying amounts of fine-grained sand; shell material commonly concentrated in lenses



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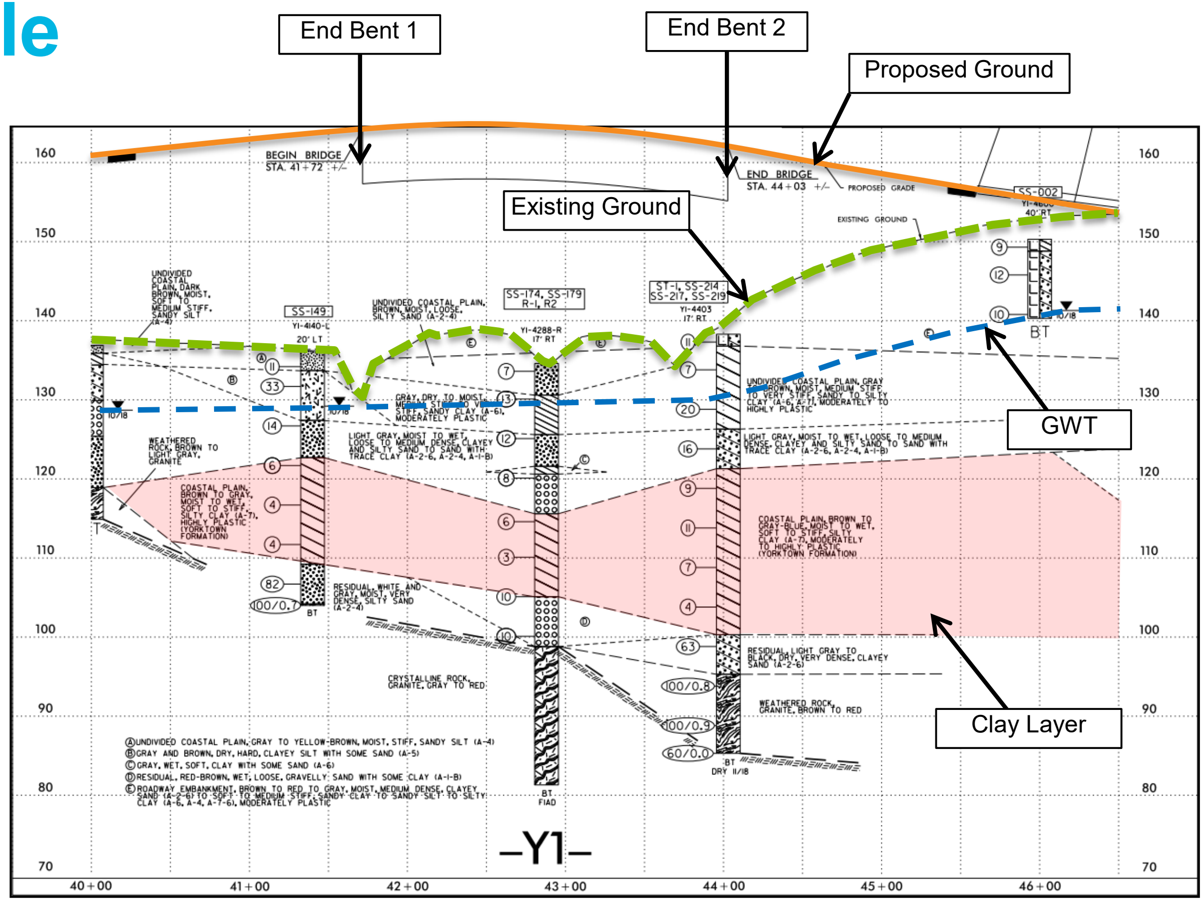
Site Photos

Subsurface Profile

- Soft to medium stiff clay starting 20 to 25-ft below existing ground surface
- Variability in soil profile throughout project in Coastal Plain soils (typical for Coastal Plain)
  - Some areas didn't encounter any clay between existing ground and top of rock



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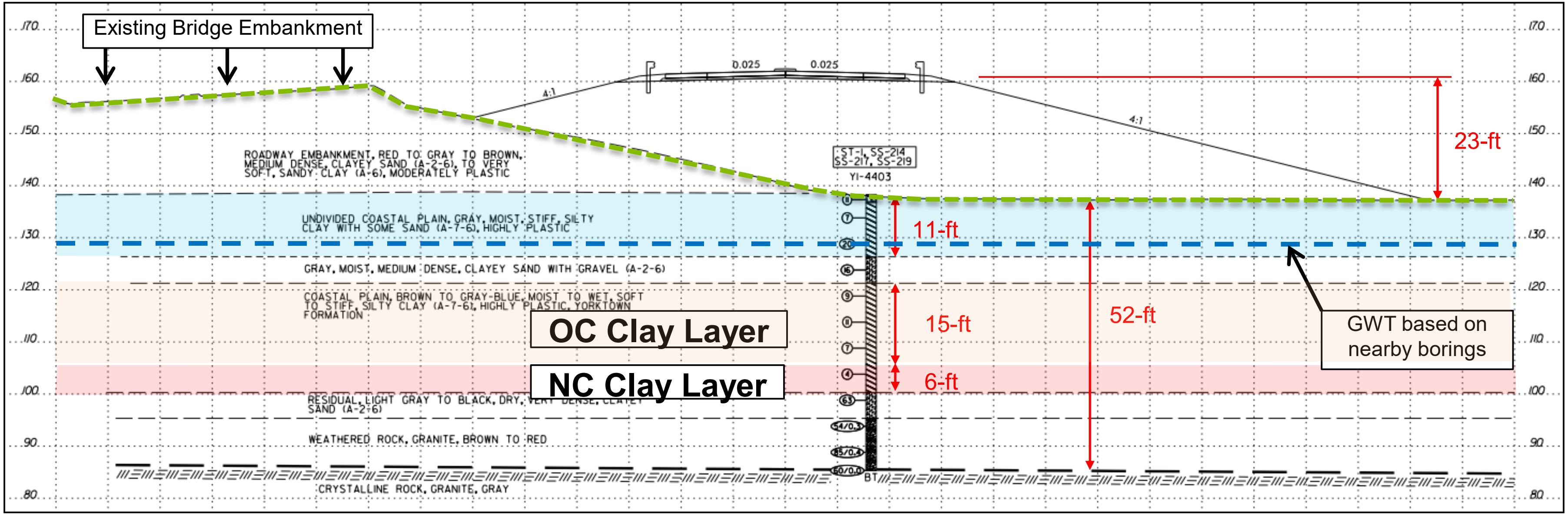
End Bent 2 Cross-Section

- Height of embankment = 20-ft
- OC Clay Thickness = 15-ft
- NC Clay Thickness = 6-ft
- GWT Elev. = 129-ft
- Depth to TOR = 52-ft



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Considerations / Challenges

– Geotechnical:
  - Long-term settlement for Roadway and Bridge
  - Differential settlement
  - Amount of time to reach appropriate consolidation
  - Presence of sand lenses
  - Downdrag on pile foundations

– Project:
  - Schedule (need to consider wait time)
  - Cost
  - Constructability

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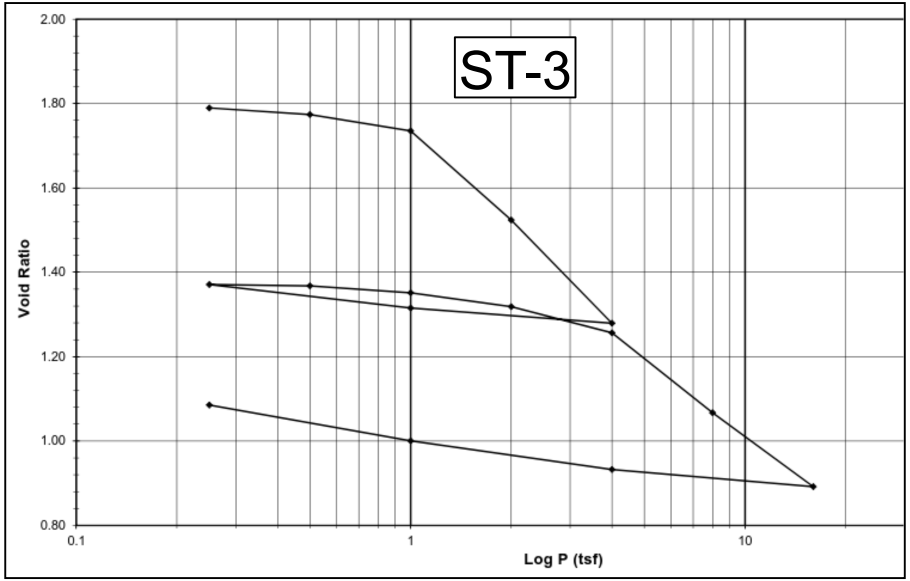
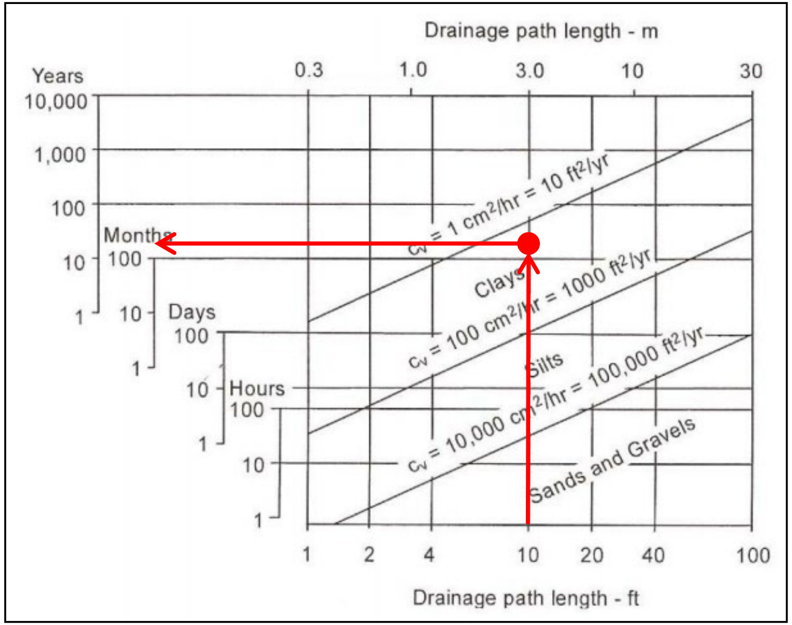
Laboratory Results

Sample	Location	Depth (ft)	Atterberg Limits	MC %	Fines %
ST-1	End Bent 2	20.0-22.0	LL= 58; PI= 39	65.8	80.94
ST-2	Ramp D	13.1-15.1	LL= 59; PI= 41	36.1	99.22
ST-3	Ramp A	20.0-22.0	LL= 59; PI= 37	67.1	94.83
SS-217	End Bent 2	23.5-25.0	LL= 66; PI= 45	49.1	84.56
SS-219	End Bent 2	33.5-35.0	LL= 70; PI= 50	68.4	85.17

Clay Characteristics

– Highly plastic
– Highly compressible
– Slow draining





REF: Figure 8-17 Drainage Time Required (Duncan and Wright, 2005) https://www.dot.ny.gov/divisions/engineering/technical-services/geotechnical-engineering-bureau/geotech-eng-repository/GDM_Ch-8_Geomechanics.pdf>

Parameter	Value
C_c	0.761
C_r	0.091
C_v	13.1 ft^2/yr

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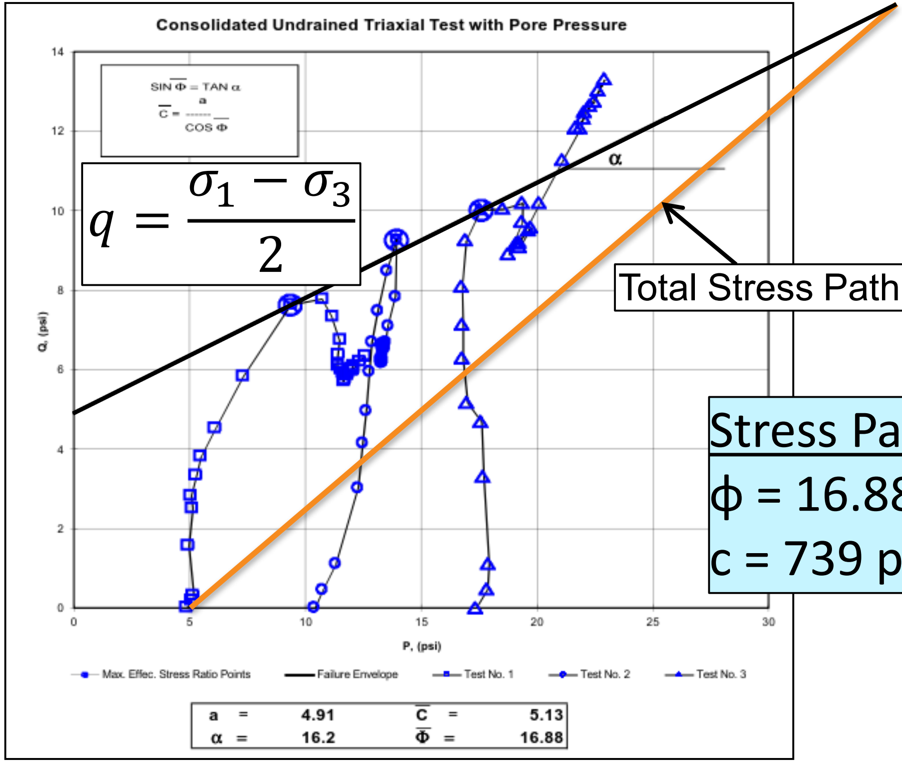
Clay Characteristics (cont.)

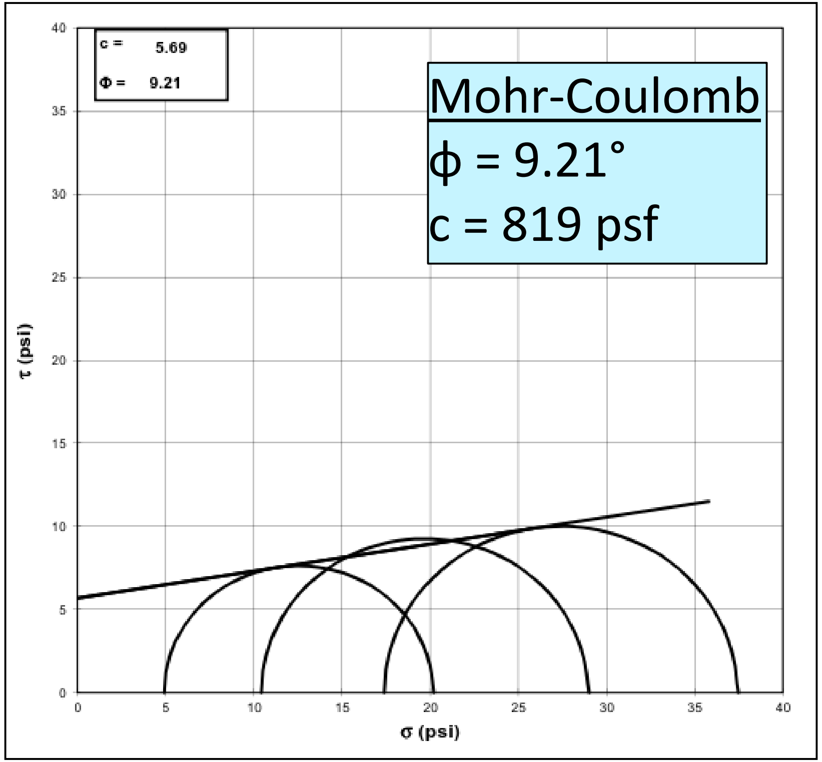


$$q = \frac{\sigma_1 - \sigma_3}{2}$$

Stress Path

ϕ = 16.88°

c = 739 psf



Mohr-Coulomb

ϕ = 9.21°

c = 819 psf

$$p = \frac{\sigma_1 + \sigma_3}{2}$$

$$p' = \frac{\sigma_1' + \sigma_3'}{2} = \frac{(\sigma_1 - u) + (\sigma_3 - u)}{2}$$

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Calculations Details: Settlement Theories

Consolidation Theory for Fine Grain Material		Elastic Settlement for Coarse Grain Material
Primary Consolidation of Soft Material	**Secondary Consolidation of Stiff Material**	**Schmertmann (1978)**
$S_c = \frac{H_0 C_c}{1+e_0} log \frac{\sigma'_{v0} + \Delta\sigma'_v}{\sigma'_{v0}}$	$S_c = \frac{H_0 C_r}{1+e_0} log \frac{\sigma'_{v0} + \Delta\sigma'_v}{\sigma'_{v0}}$	$S_c = c_1 c_2 q_n \sum \frac{I_z \Delta z}{E_s}$
S_c = Settlement of Layer H_0 = Thickness of Layer C_c = Compression Index of Layer C_r= Recompression Index of Layer E_0 =Initial Void Ratio at Layer σ'_{VO} =Effective Overburden Pressure at Layer Center $\delta\sigma'_v$= Surcharge Pressure At Layer Center (Resulting From Dewatering)		C_1=correction factor for embedment of foundation C_2=correction factor to account for creep in soil q_n =The intensity of the uniformly distributed load at the base of the foundation I_z =strain influence factor t=time in years E_s=Young's modulus of the elastic medium

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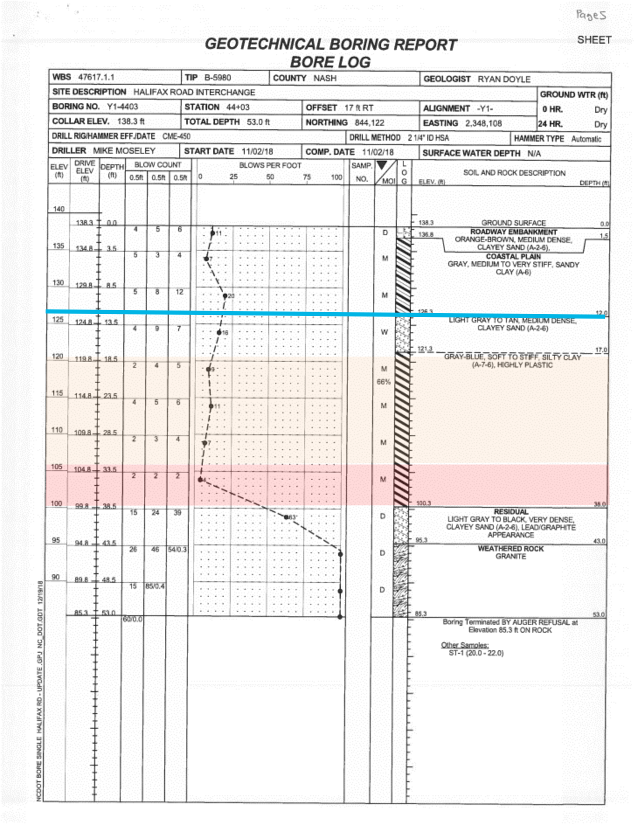
Expected Settlement and Consolidation Time Rate at Y1-4403 20-ft

Clay Layer	Consolidation Coefficients	Settlement (in)
Over Consolidated from 17 to 32-ft	C_r=0.091	2.16
Normally Consolidated from 32 to 38-ft	C_c=0.761	5.16

Applied Equation	C_v (cm^2/s)	C_v (ft^2/yr)	H_{dr} (ft)	Time (months)
$T_v = \frac{C_v t}{H_{dr}^2}$	0.00039	13.1	5	20



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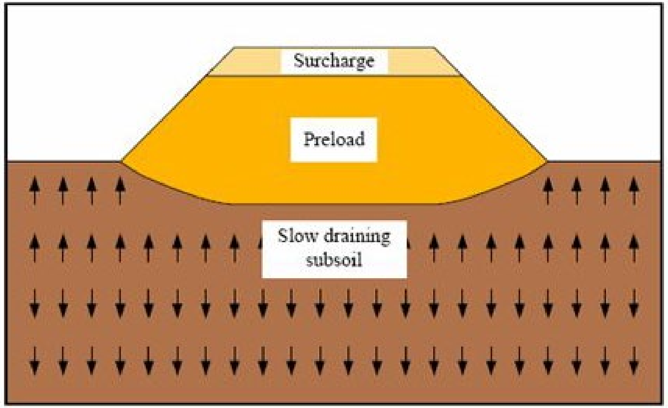
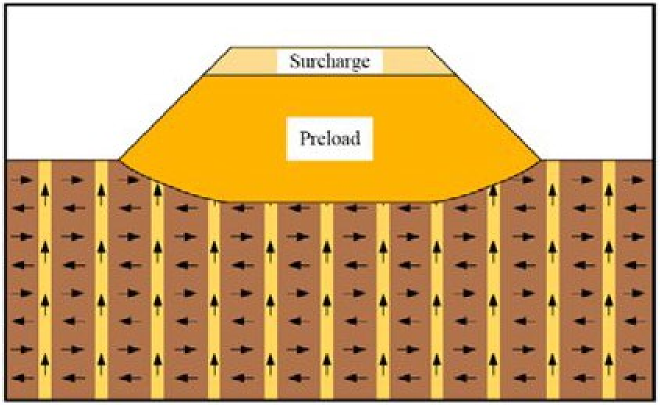
Applicable Ground Improvements by Consolidation:

- **Ground Improvement (replacement of the soil or adding sand columns)**
- **Surcharging**
- **Preloading**
- **Wick drain**

At this project: Sufficient strength, extremely slow drainage rate and high water content

Problem and Solution

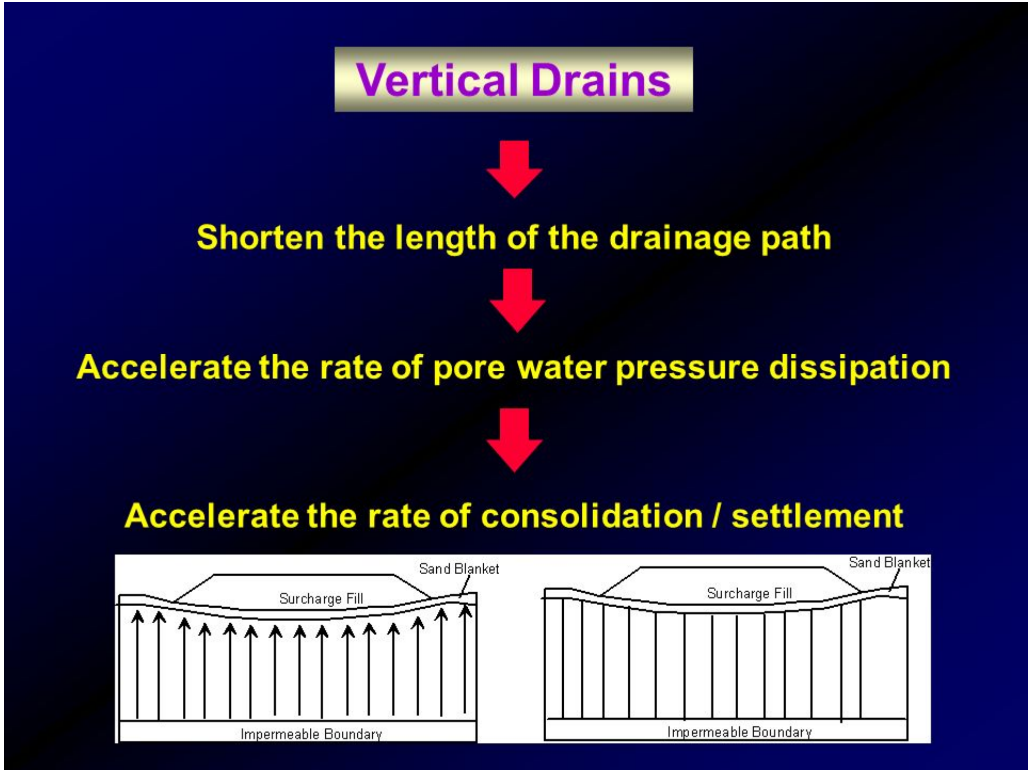




Reference: https://slideplayer.com/slide/4713675/
Dr. j.N.Jha, Professor and Head (Civil Engineering), Guru Nanak Dev Engineering College, Ludhiana, Punjab-141006

Reference: www.geomatindonesia.com

How Does Vertical Drains Work?



Reference: https://slideplayer.com/slide/10347523/

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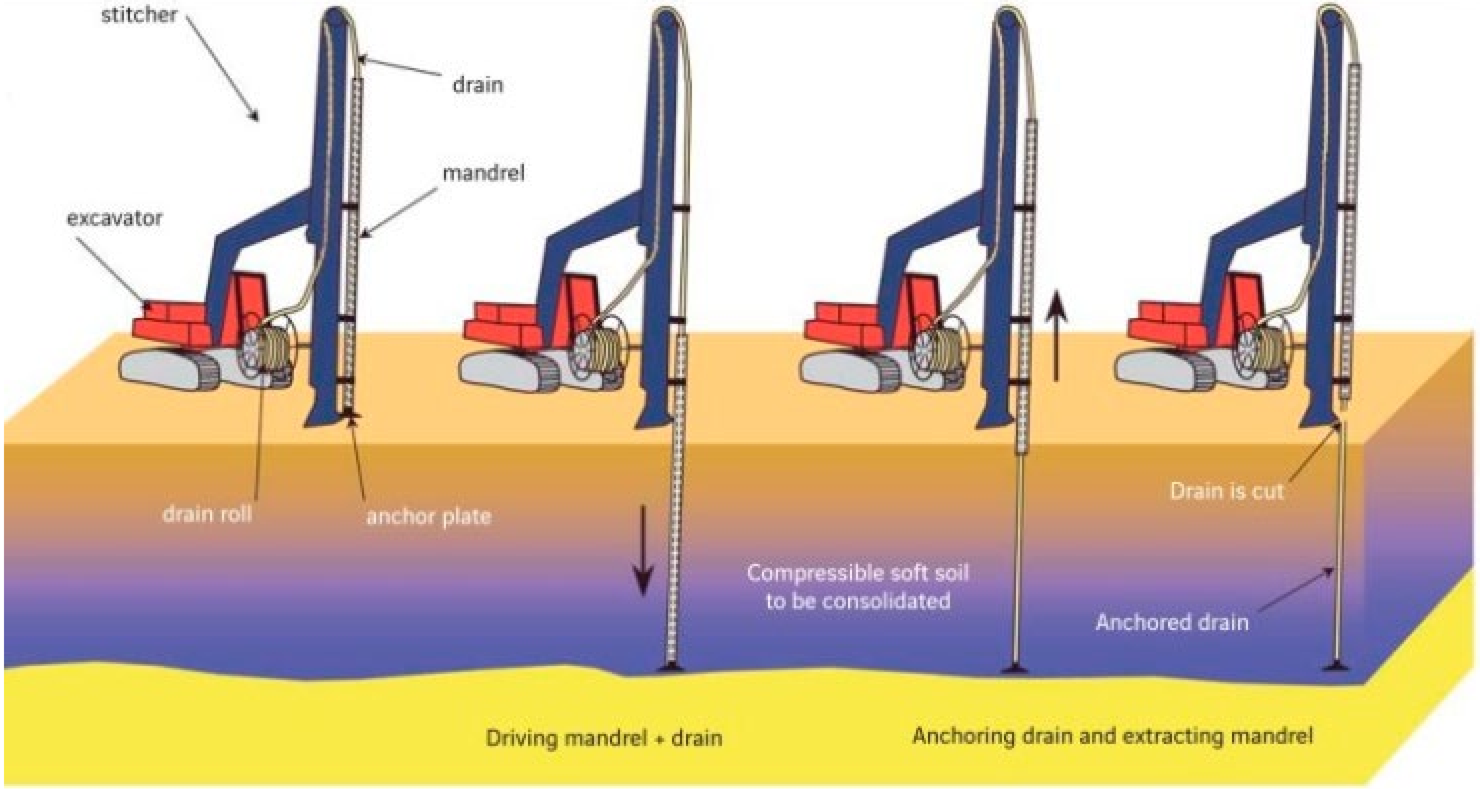
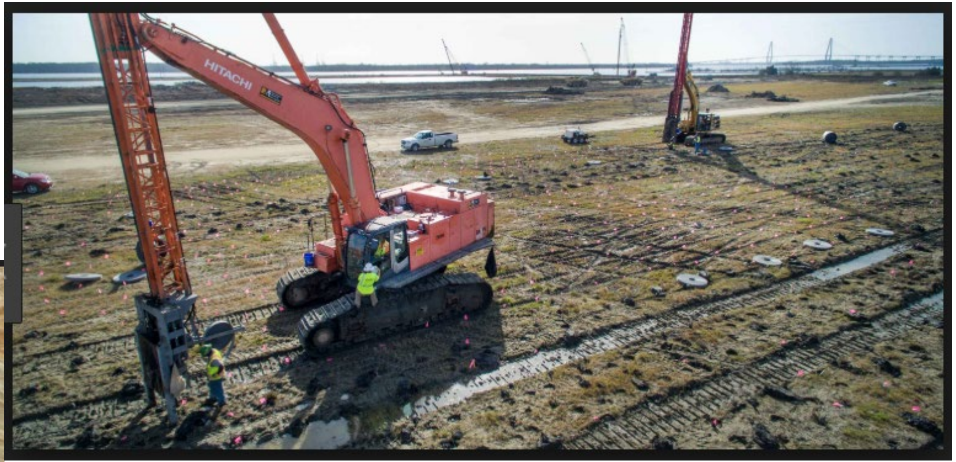
Wick Drain Installation

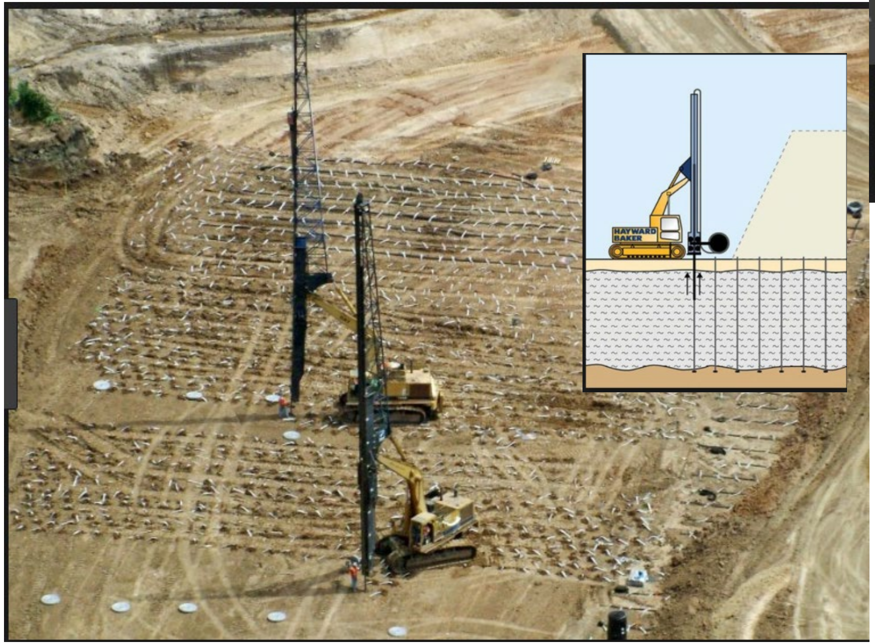


Reference: Geoengineer.org

Wick Drain Installation



Reference: Menard Group USA



Reference: Hayward Baker

Reference: stuff.co.nz

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Design with Wick Drains

Reference: NYSDOT Geotechnical Design Manual, Chapter 14

Applied Formula	Parameters
$$t = \left(\frac{D^2}{8c_h}\right)(F(n) + F_s)\ln\left(\frac{1}{1 - U_h}\right)$$ $$F(n) = \ln\left(\frac{D}{d}\right) - 0.75$$ $$T_R = \frac{F(n)\ln\left(\frac{1}{1 - U_h}\right)}{8}$$	t= time required to achieve desired average degree of consolidation U_h= average degree of consolidation to be achieved by PVD system D= diameter of cylinder of influence of the drain (drain influence zone) C_h= consolidation coefficient for horizontal drainage F(n)= drain spacing factor D= equivalent circular drain diameter F_s= factor for soil disturbance T_R= time factor for radial flow

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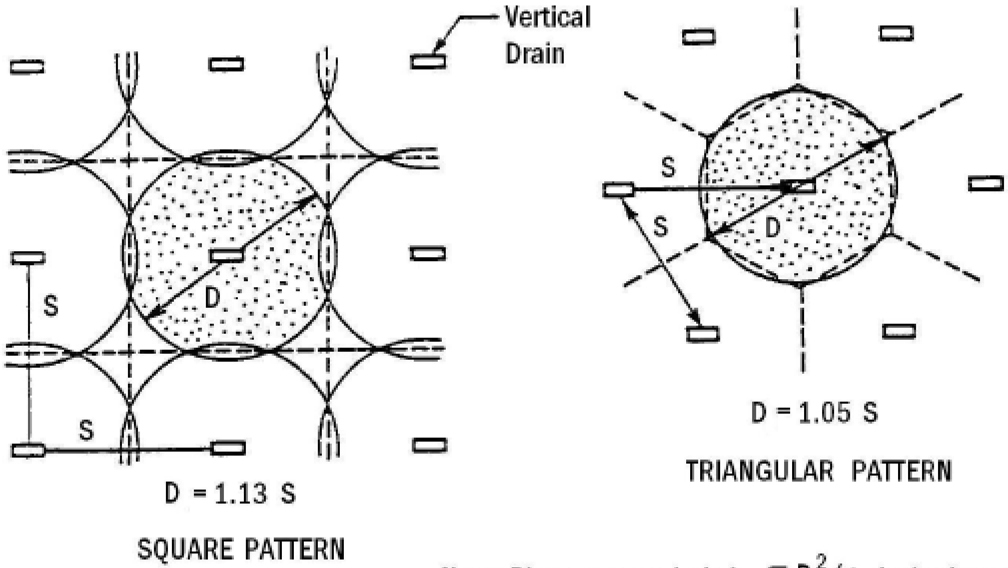
Wick Drains Installation Patterns

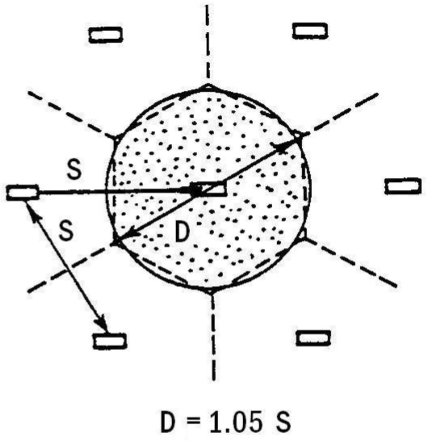


Note: Plan area per drain is $\pi D^2/4$ for both patterns

Reference: NYSDOT Geotechnical Design Manual, Chapter 14

Waiting Period by Installing of Wick Drains

Parameters	S (ft)	D=1.05 S (ft)	F(n)	Fs	t (days)	t (months)
Assuming the Soil is Sensitive Fs=2	4	4.2	2.48	2	272	9
	5	5.25	2.70	2	446	15
	6	6.3	2.88	2	667	22
Assuming the Soil is not Sensitive Fs=0	4	4.2	2.48	0	150	5
	5	5.25	2.70	0	256	9
	6	6.3	2.88	0	394	13



Reference: NYSDOT Geotechnical Design Manual, Chapter 14

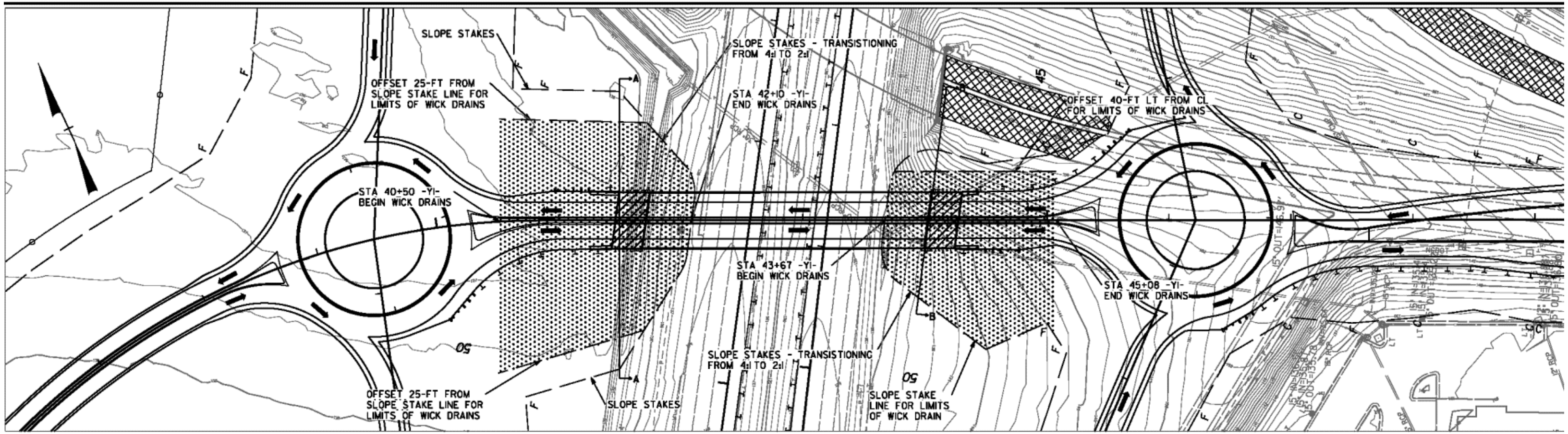
Downdrag and Consolidation after Waiting Period

Assumptions:	
d (inch)	2
C_h (cm2/s)	0.00117
U_h (%)	95%

$$U_{Total} = (1 - U_r)(1 - U_v)$$

95% radial consolidation, results in 98% total consolidation.

Final Design Plan View:

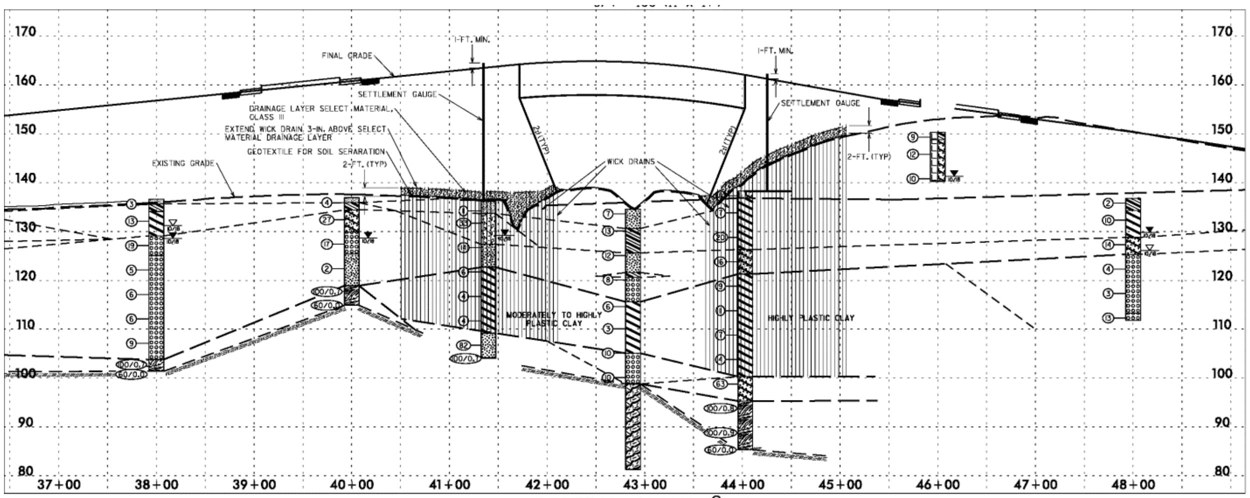


EMBANKMENT PLAN VIEW

3/4" = 100' (11" x 17")

ESTIMATED QUANTITIES	
WICK DRAINS	113,000 FT.
SELECT MATERIAL, CLASS III	2,200 CY.
GEOTEXTILE FOR SOIL SEPARATION	3,300 SY.

Final Design Profile and Cross Section View:



SECTION ALONG ℄ -Y1-

3/4″= 100′ HORIZ. (5:1 VE) (11″× 17″)

Length of embankment where wick drains will be installed = 300-ft
Depth of wick drains= 30 to 40-ft
Widest width of embankment along toe is at Bent 1 (4:1 slopes) = 280-ft
Number of wick drains at the bridge = 3,212

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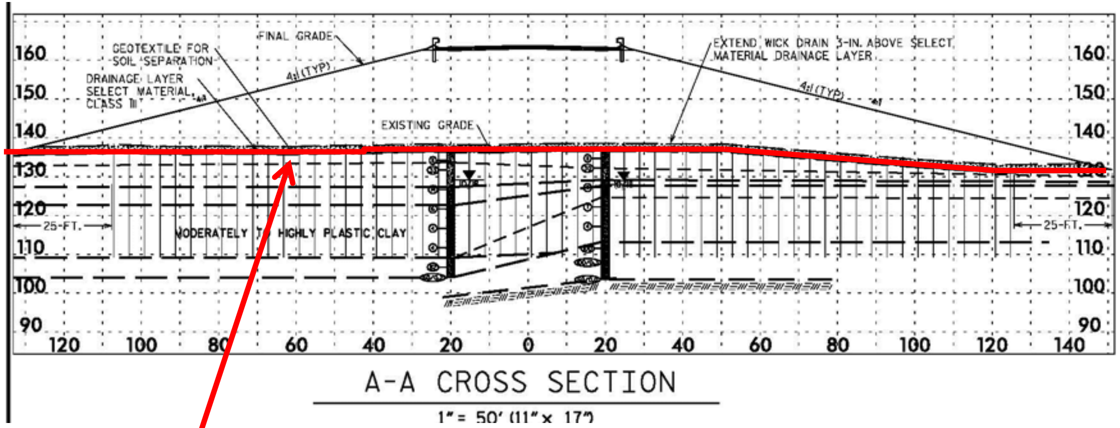
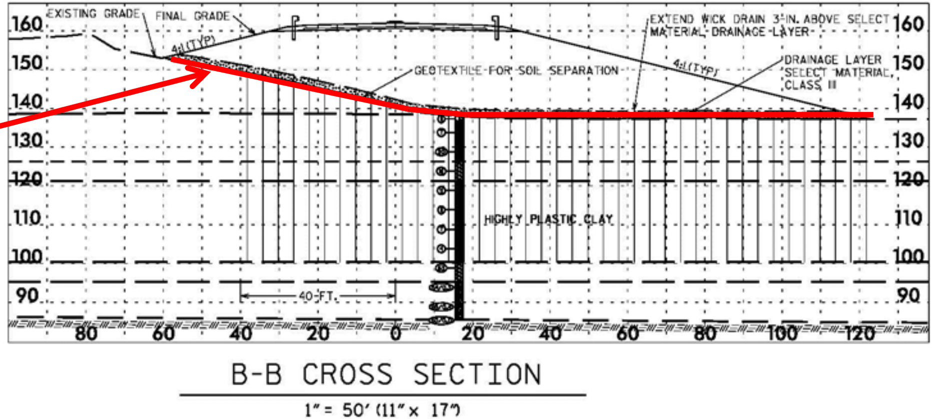
Final Design Profile and Cross Section View:





-2-ft thick drainage layer consists of select material, Class III (NCDOT Standard Specification) – granular to allow easy drainage of excess pore water pressures

- Settlement Monitoring

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Special Thanks

– NCDOT GEU
  - Jinyoung Park
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  - Dean Argenbright
– GEO^{3}T^2
– AECOM

Thank You

Any Questions?

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