VDOT
Virginia Department of Transportation

LESSONS LEARNED FROM LARGE HIGHWAY PROJECTS – THE IMPORTANCE OF THE GEOTECHNICAL ENGINEER

GeoVirginia, 2018

David P. Shiells, P.E.

4/17/18

Central Artery Project, Boston

Central Artery Project, Boston

“The Big Dig”

- Total Project Cost - $14.6 billion
- Initial cost estimate - $6 billion
- 15 year duration (1991 to 2007)
- 200,000 vehicles per day
- Challenging ground conditions
- Innovative construction techniques

Central Artery Project, Boston

What Do We Remember ?

Central Artery Project, Boston

What Do We Remember ?

- Cost overruns
- Schedule delays
- Leaks
- Fatal collapse
- Lawsuits

Photo Credit: NY Times

"Accident in Boston's Big Dig Kills Woman in Car", NY Times, July 12, 2006

"Boston's Big Dig Buried in Cost Overruns", Wash. Post, April 12, 2000

"State, Contractors Settle Suit over Big Dig Failures", NPR, Jan. 23, 2008

"Big Dig Springs Big Leaks, Boston Herald", Oct. 15, 2015

Central Artery Project, Boston

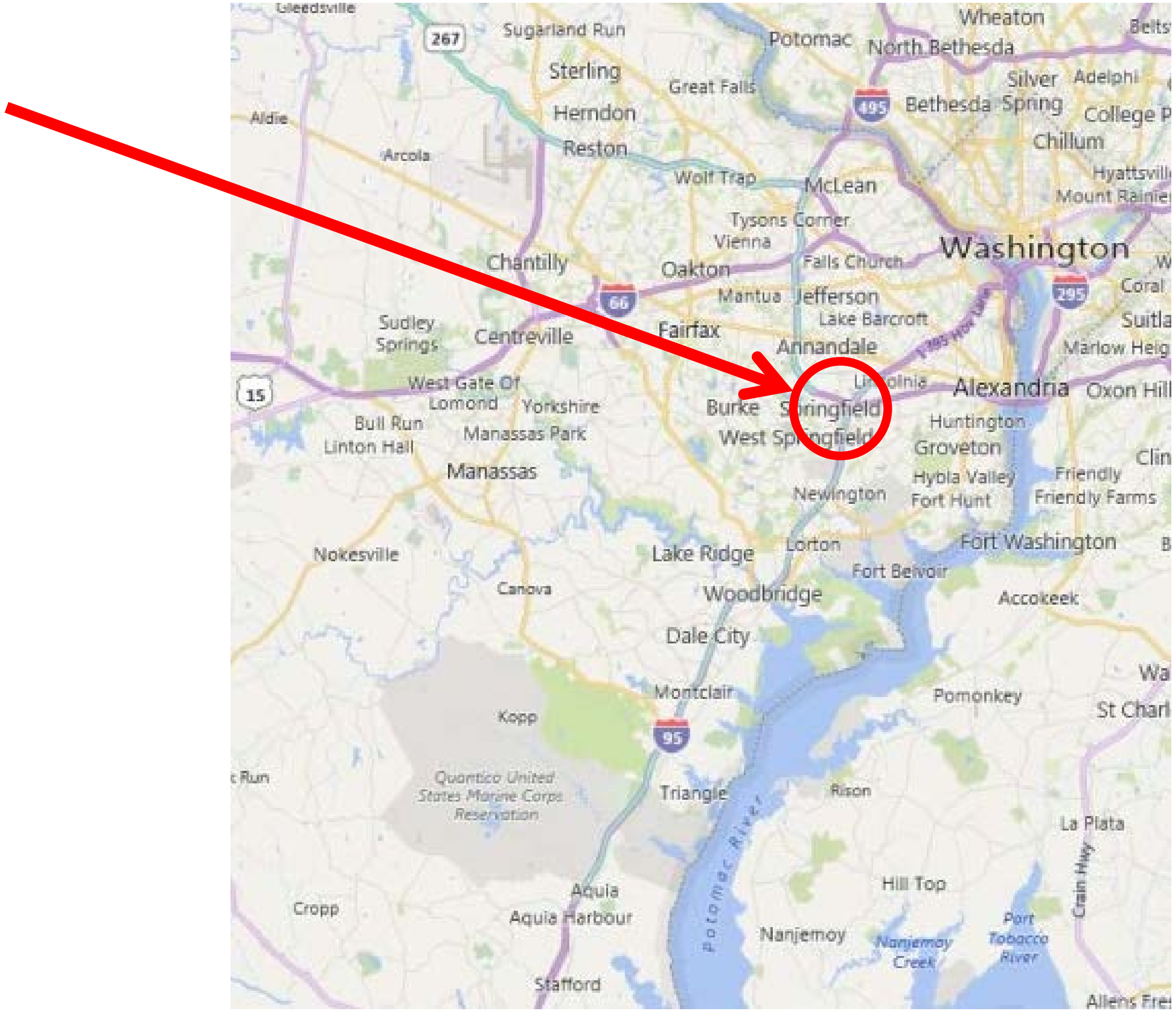
What Should We Remember ?

- Incredibly difficult construction
- Excavations 120 feet below ground
- Widest cable stay bridge in world
- Most extensive use of immersed tube tunnels in U.S.
- First jacked vehicle tunnels in U.S.
- First use of deep soil mixing on east coast
- 5 miles of slurry walls
- 16 million cy excavation
- Largest geotech. program in N. America

Mega Projects in Northern Virginia

Springfield Interchange

- $750 million



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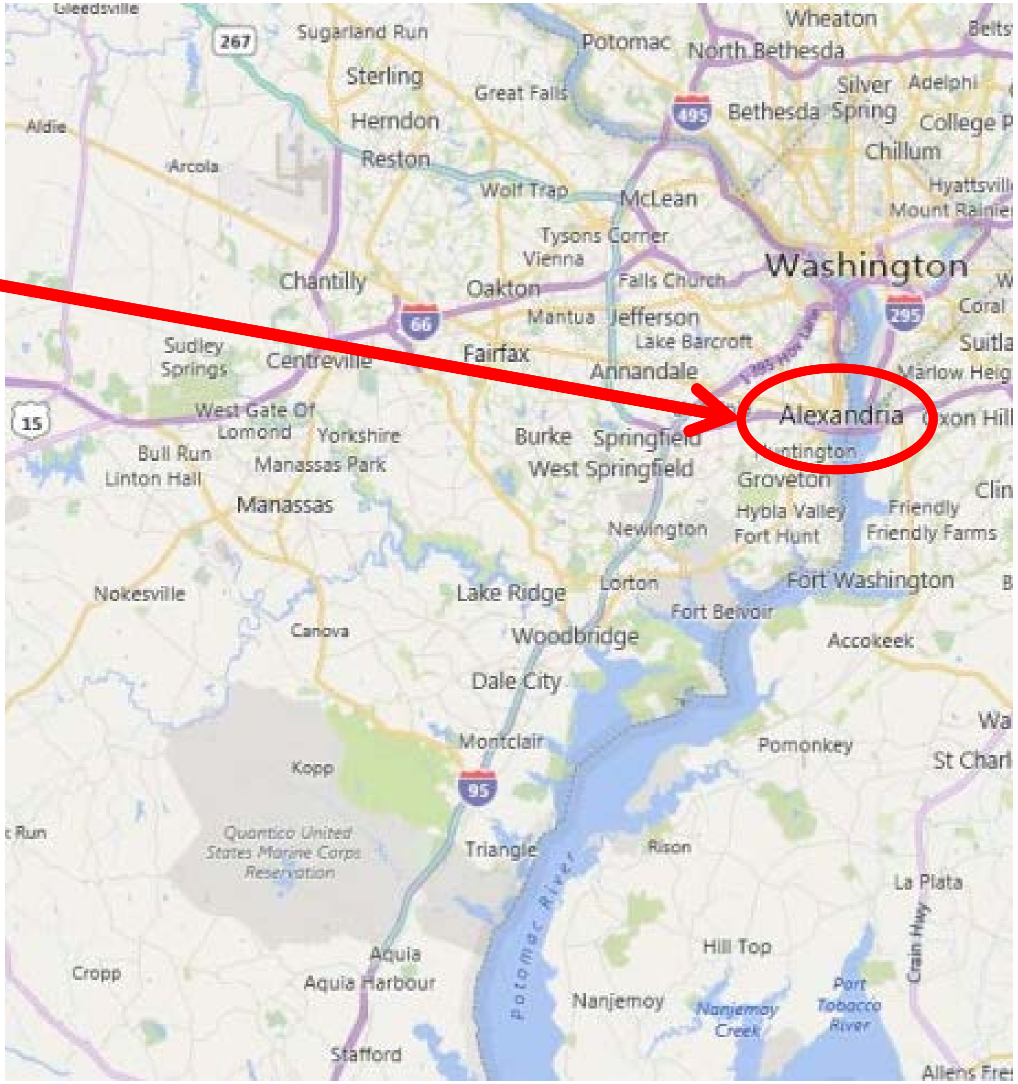
Woodrow Wilson Bridge

- $2.5 billion



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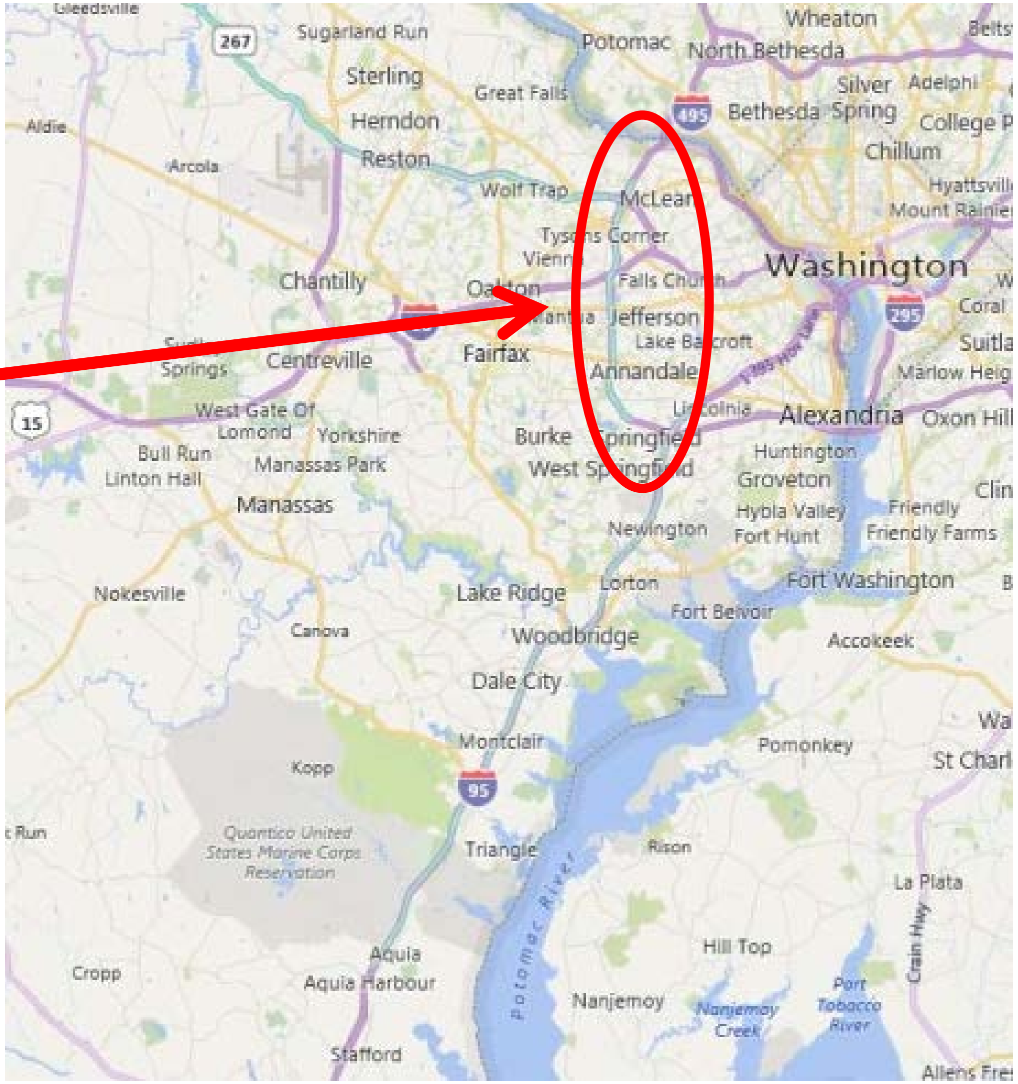
I-495 Express Lanes

- $1.3 billion



Mega Projects in Northern Virginia

Springfield Interchange

- **$750 million**

Woodrow Wilson Bridge

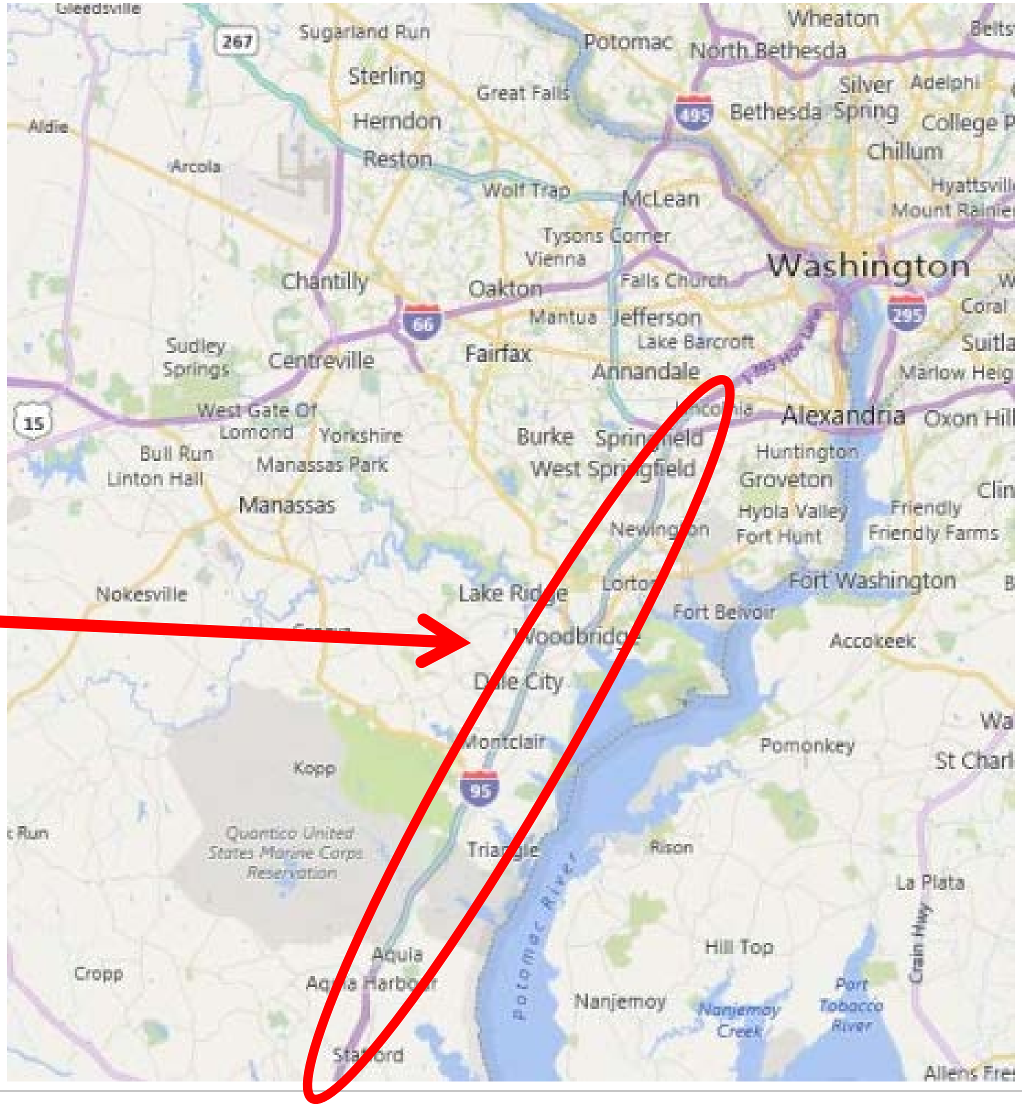
- **$2.5 billion**

I-495 Express Lanes

- **$1.3 billion**

I-95/I-395 Express Lanes

- **$925 million**



Mega Projects in Northern Virginia

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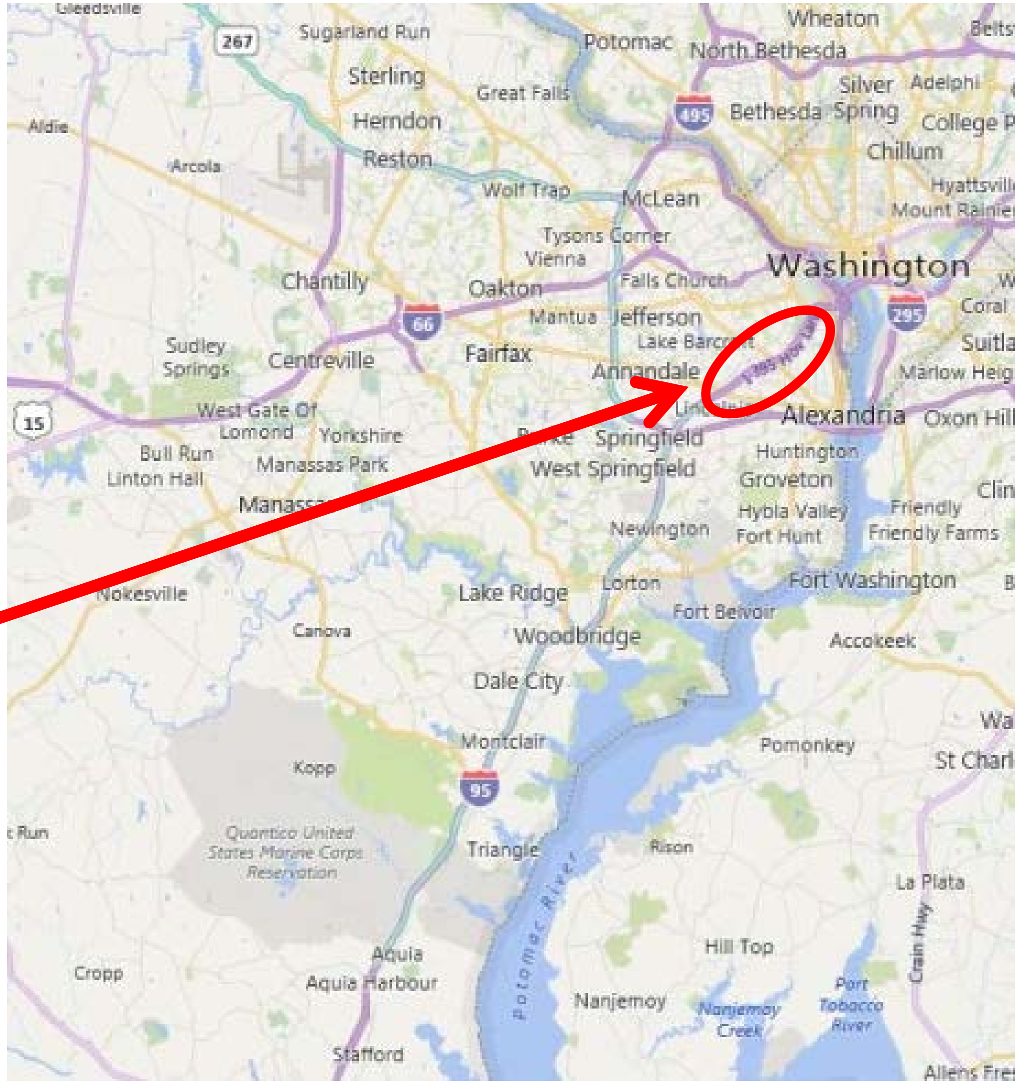
I-95/I-395 Express Lanes

- $925 million

I-395 Express Lanes

- $500 million



Mega Projects in Northern Virginia

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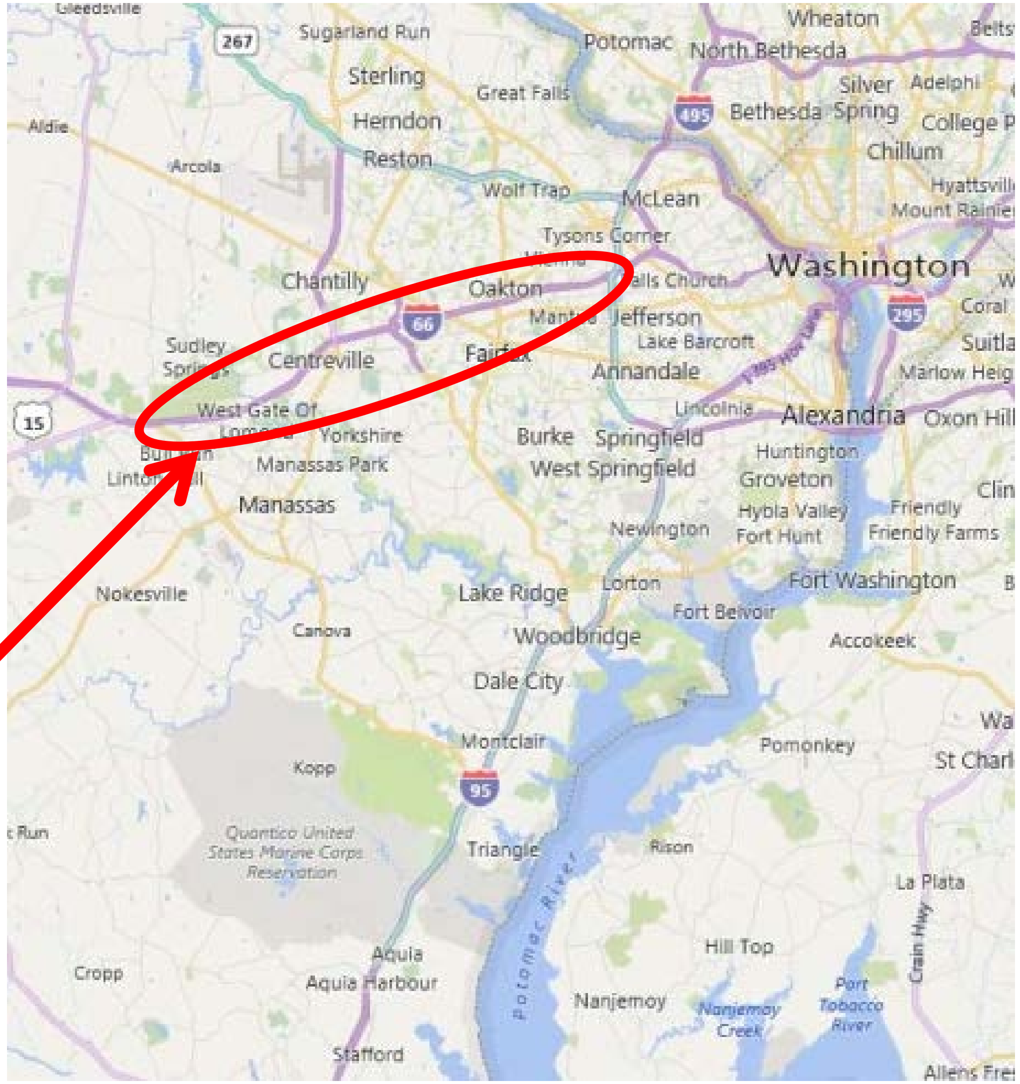
I-66 Outside the Beltway

- $2.3 billion



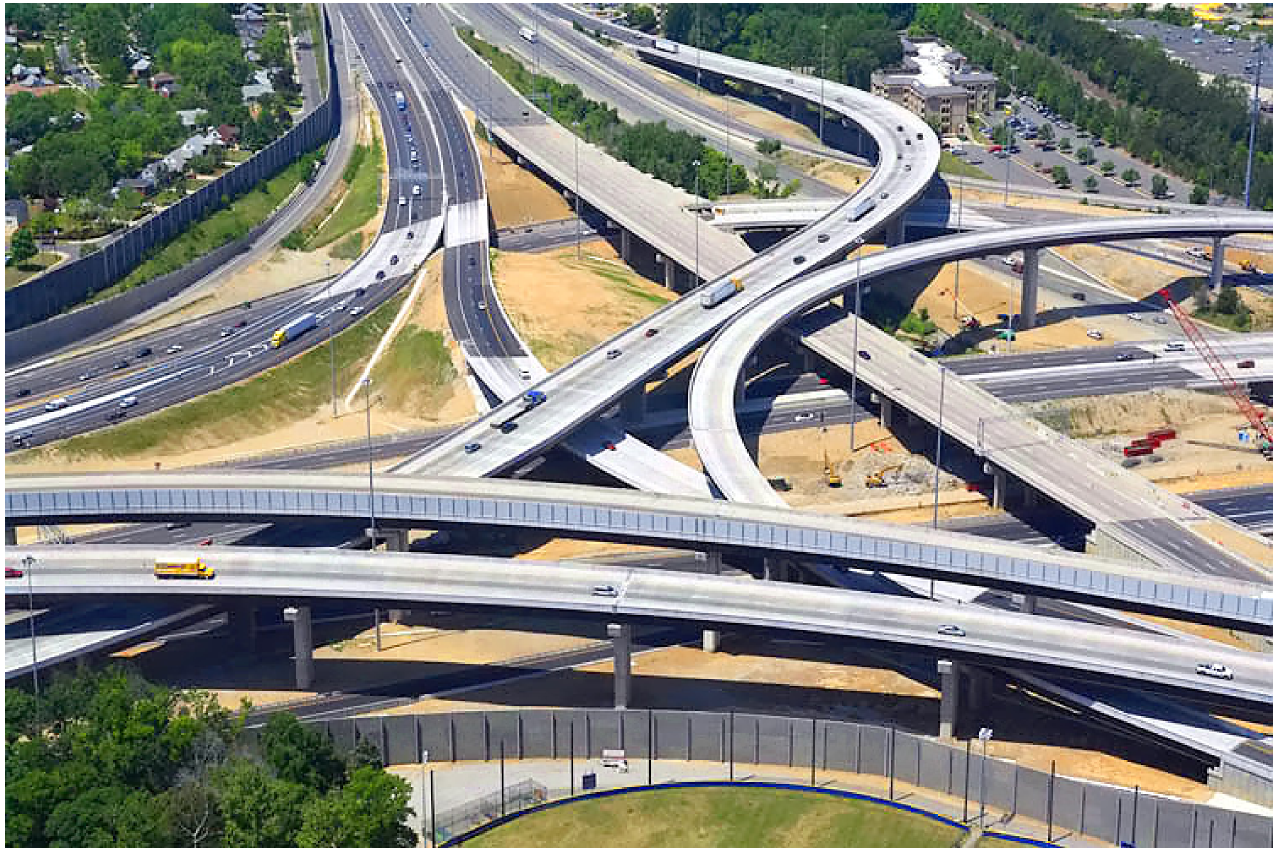
Mega Projects in Northern Virginia

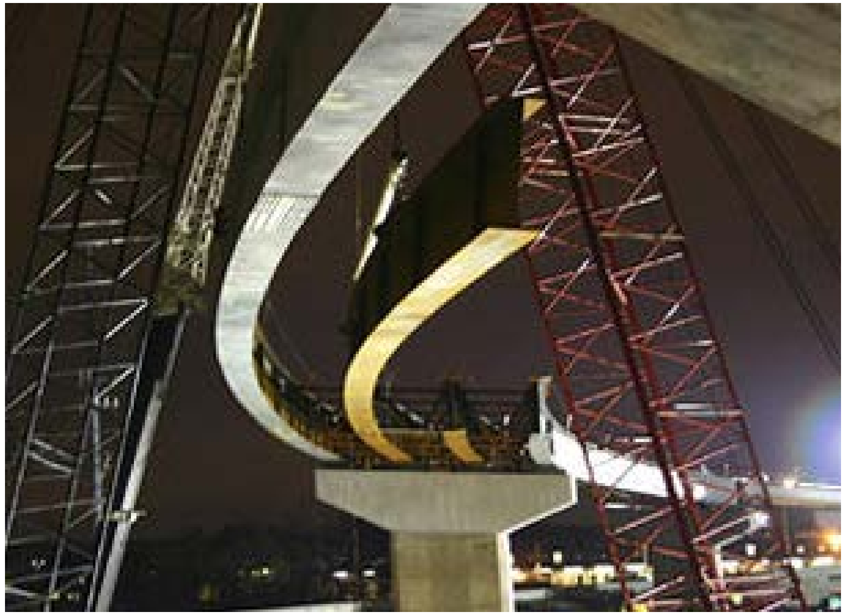
Springfield Interchange

- First “Mega Project”
- Design-Bid-Build
- 7 phases (1999 to 2007)
- 430,000 vehicles per day
- 52 bridges
- 24 lanes at widest point

Springfield Interchange

Complex Construction





Springfield Interchange

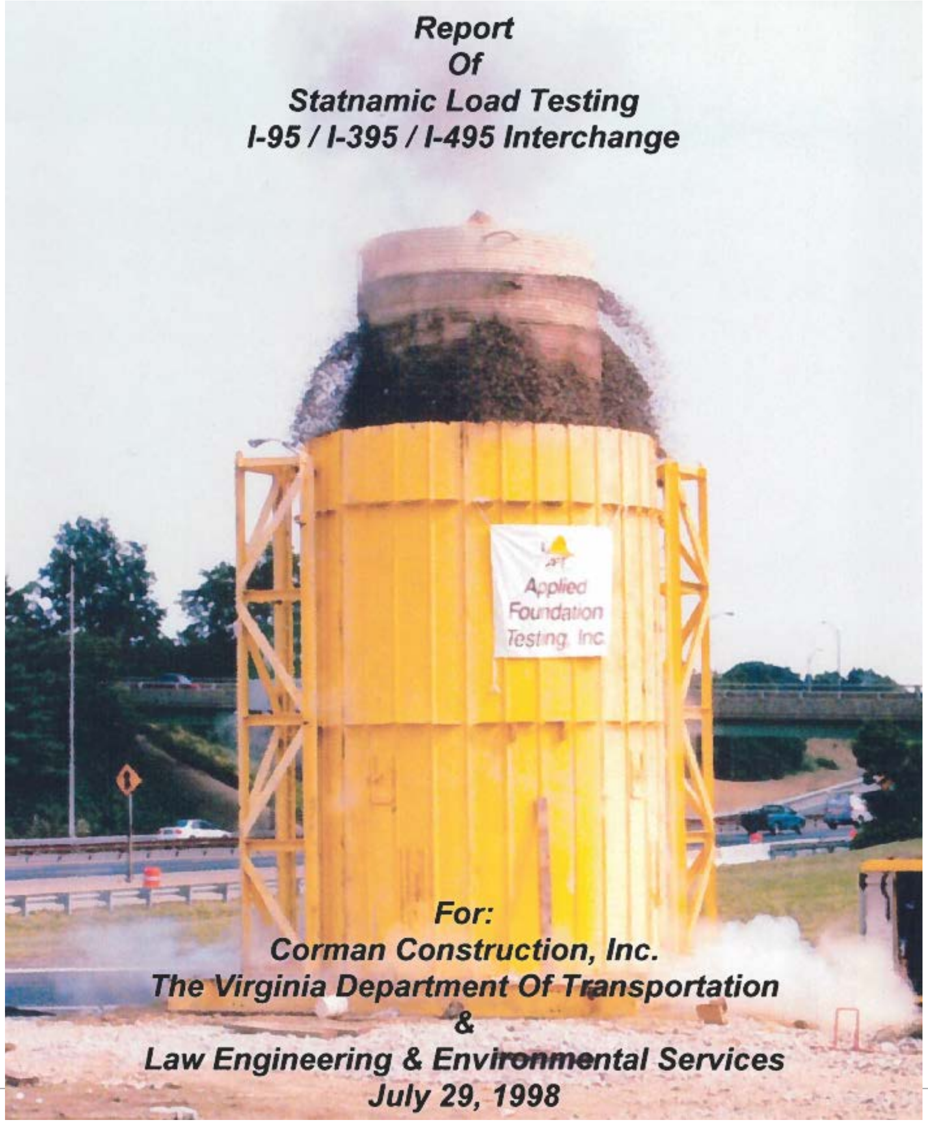
Geotechnical Program

- Consultant and In-house design
- Large diameter drilled shafts
- Drilled shaft test program
- Drilled shaft trial installations
- Potomac clays
- Bank run sand/gravel for MSE backfill
- On-site testing laboratory

Springfield Interchange

Drilled Shaft Load Test Program

- Four test shaft locations
- 5' dia. drilled shafts
- Founded in IGM and granite
- Polymer slurry
- Osterberg load cells
- Statnamic testing
- Lateral tests for deflection
- Estimated cost savings of 25%



Springfield Interchange

Potomac Clays

- I-95 NB and SB bridge over CSX rail
- Very flat slopes at east abutment
- Proposal to shorten bridge
- Potomac clay at east abutments
- Slope failure (1960s)
- New design retained longer spans

Springfield Interchange

On-Site Soils as MSE Backfill

- Bank run sand and gravel
- Variability – pockets of plastic clays

Springfield Interchange

Lessons Learned

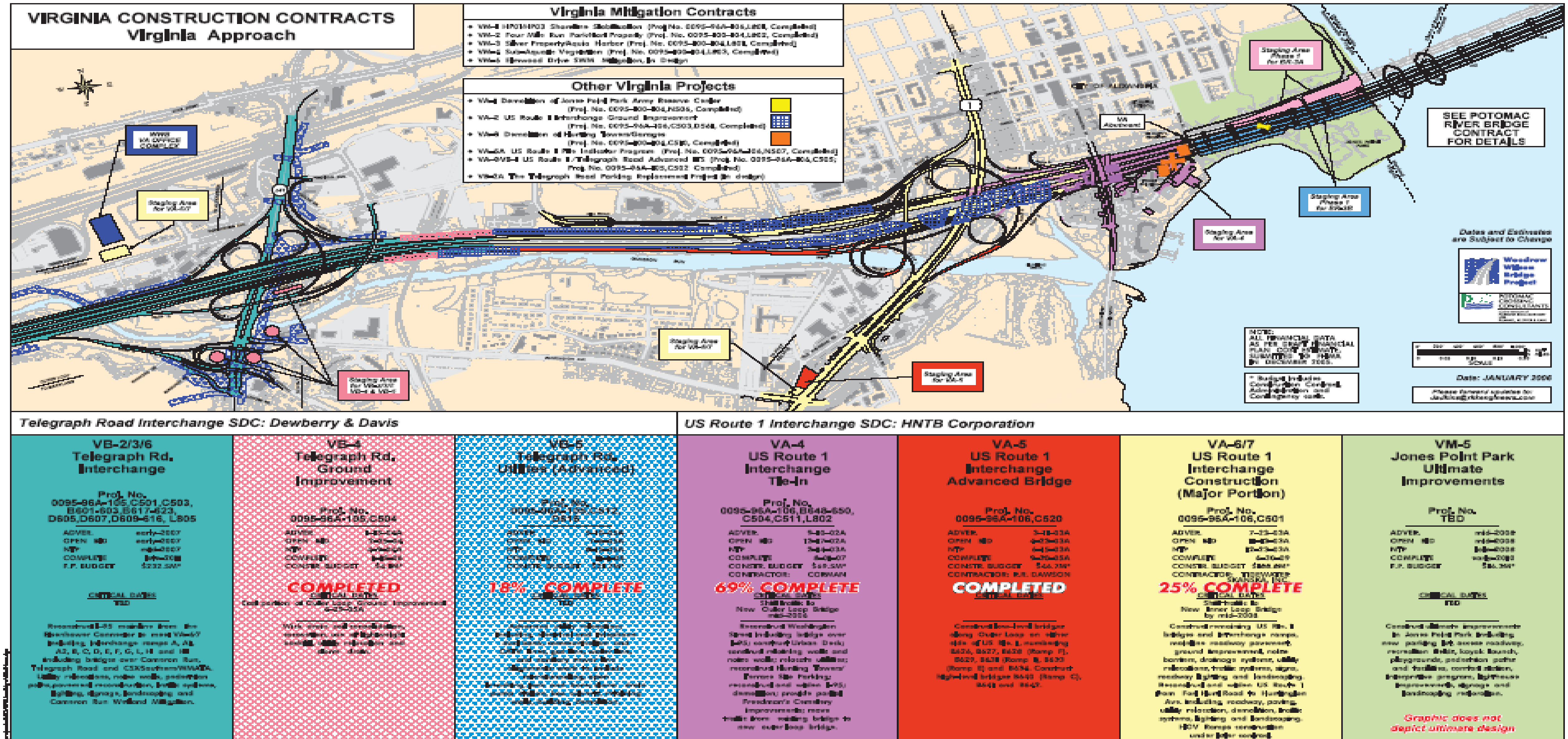
- Local geotechnical experience very important
- Experienced personnel required for drilled shaft inspections
- Inspector training (drilled shafts)
- Screening of on-site sand/gravel
- On-site laboratory was very efficient

Mega Projects in Northern Virginia

Woodrow Wilson Bridge

- $2.5 billion
- Design-Bid-Build
- 43 Contracts (2000 to 2012)
- 4 Interchanges (VA/MD)
- Main bridge
- 7.5 miles
- 220,000 vehicles per day

Woodrow Wilson Bridge – Virginia Interchanges

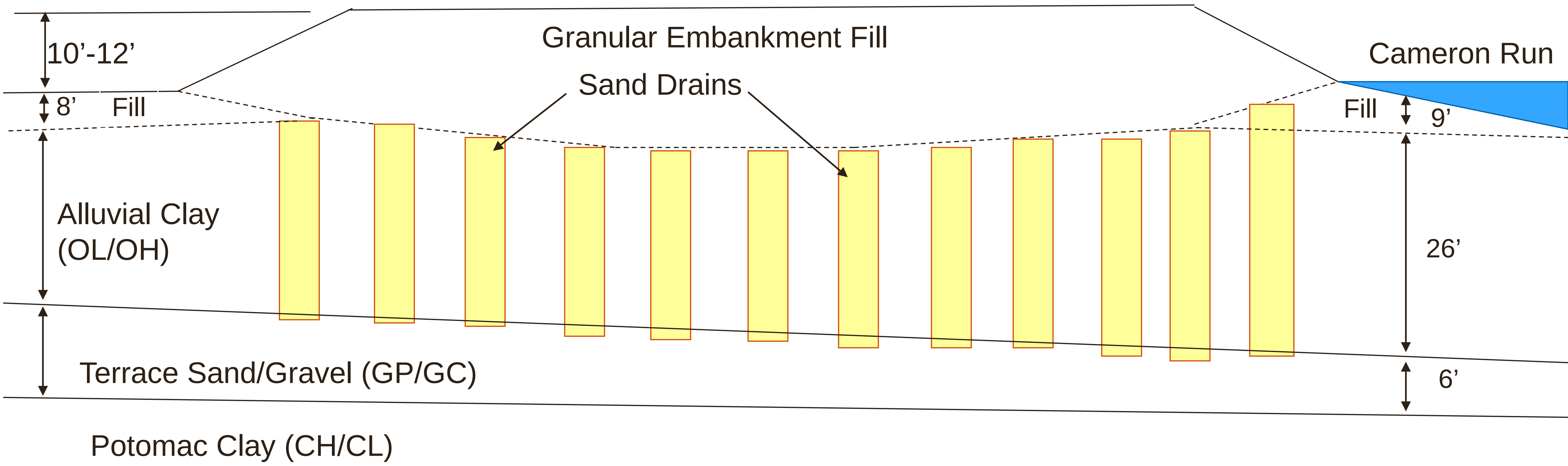


Original I-95/Route 1 Interchange

New I-95/Route 1 Interchange

I-95/Route 1 Interchange

Original Construction



Virginia Interchanges

Original 1960s Construction

- Muck-out (<15’)
- Sand drains/surcharge (>15’)
- Stability berms
- 12 to 14 months/stage
- 3 stages
- Settlements up to 5’
- Precast piles

Virginia Interchanges

Geotechnical Program

- Consultant and In-house design
- Test embankments
- Deep soil mixing (wet and dry)
- PV drains and surcharge
- Pile supported embankment
- Lightweight fills (LDCF and EPS)
- Densified aggregate piers
- Compaction grouting
- Trenchless crossings
- On-site testing laboratory

Virginia Interchanges

Geotechnical Challenges

- Widen 10’-14’ high embankment
- 10’-40’ of very soft alluvial soils
- High ground water (tidal fluctuations)
- Variable treatments of exist. embankments
- Protection of existing piles/bridges
- Protection of existing utilities/extensions
- Maintenance of traffic
- Schedule (complete GI in less than 4 years)

Virginia Interchanges

Technical Considerations

- Settlement of thick organic clays
- Differential settlements
- Long term creep settlements
- Stability of embankments/retaining walls
- Lateral squeeze
- Downdrag
- Constructability
- Vibrations/noise

Virginia Interchanges

Non-Technical Considerations

- Schedule
- Cost
- Maintenance of traffic
- Utilities
- Life cycle costs
- Risks
- Contractor availability
- Will it work ?

Virginia Interchanges

Lessons Learned

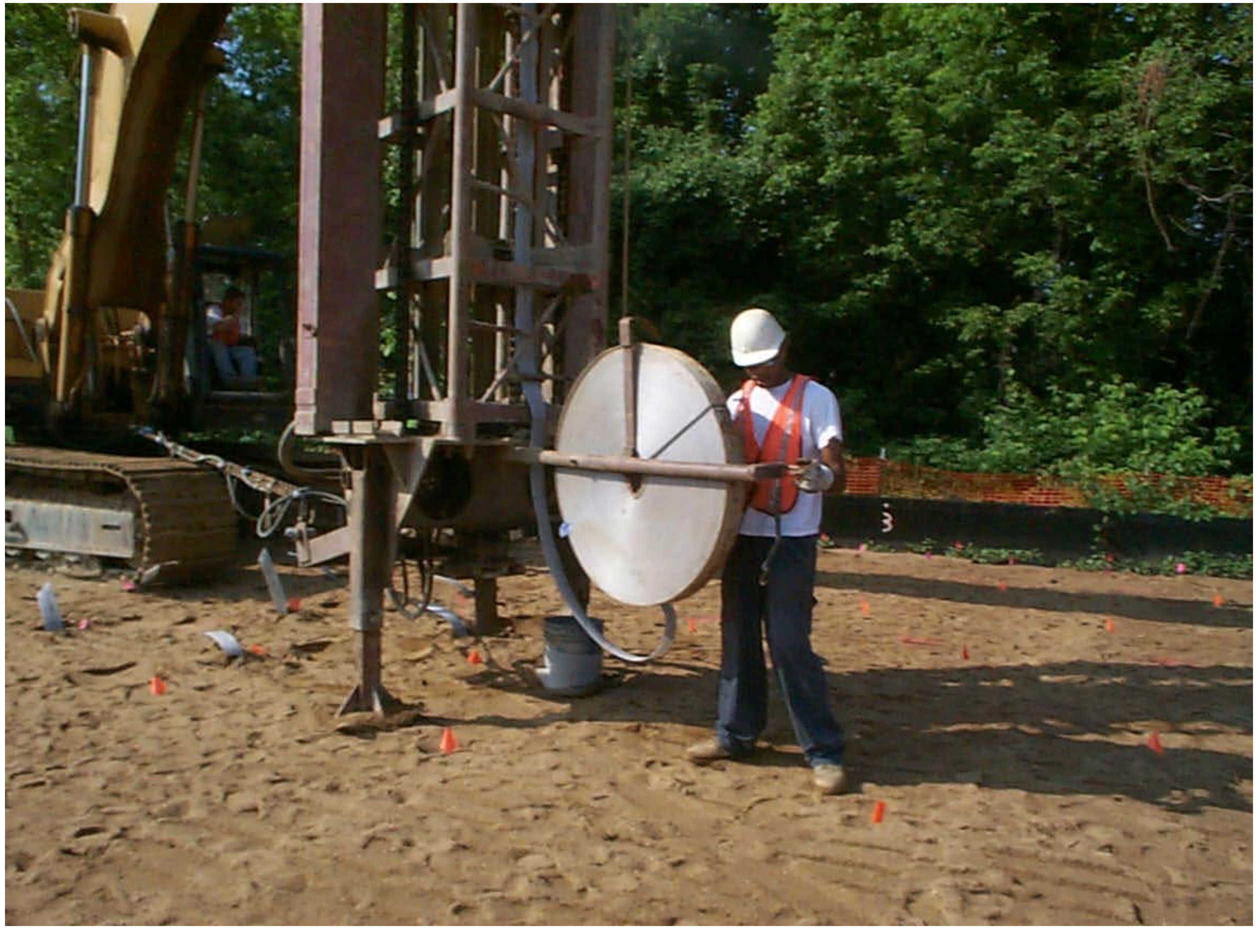
- Advance site characterization
- Consultation with technical experts
- Interviews with specialty contractors
- Test embankments
- Decision tables (schedule, cost risk, constructability, other)
- Interim milestones (incentives/disincentives)

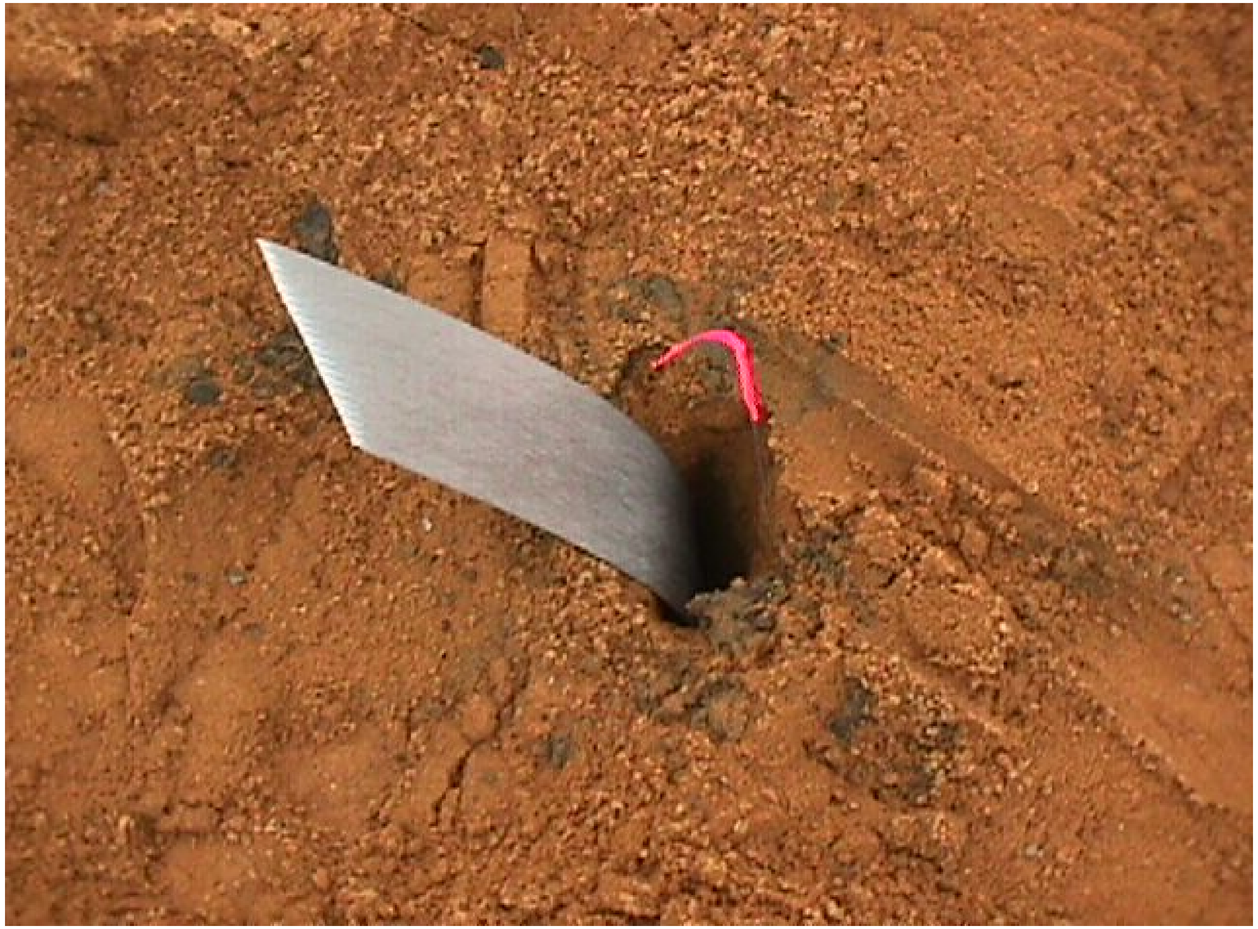
Virginia Interchanges

Geotechnical Solutions

- Remove and replace
- Staged construction/surcharge
- Prefabricated vertical drains (PVDs)
- Lightweight fills
- Deep soil stabilization/mixing
- Column supported embankments
- Bridge/structure

Pre-fabricated Vertical Drains





Virginia Interchanges

Pre-Fabricated Vertical Drains (PVDs)

- Inexpensive ($0.50/lf)
- Typically 10,000-15,000 lf/day
- Predrilling through fills
- 2’ sand drainage blanket
- Subgrade separator geosynthetic
- Limited rate of fill placement
- Staged construction
- Settlement period
- Surcharge
- Monitoring/instrumentation

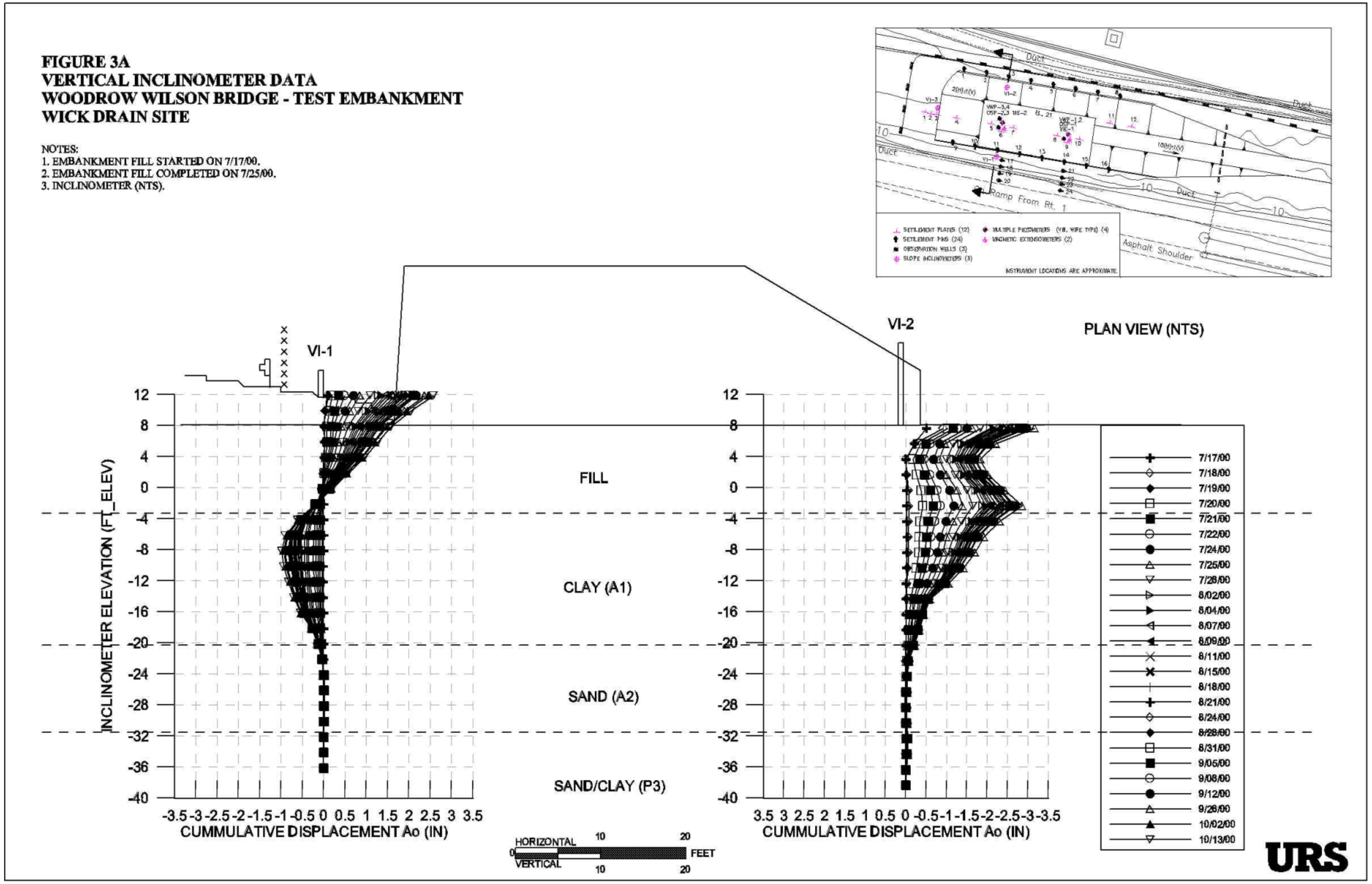
Virginia Interchanges

PVD Test Embankment

- 5’ spacing instead of 4’
- 6-month consolidation stages
- Confirmed longitudinal “joint”

- Estimated savings of $650,000
- Contractual “Lessons Learned” (pre-drilling; pay quantities; production rates; constructability)

PVD Test Embankment



Virginia Interchanges

PVDs – Lessons Learned

- Downdrag on exist. structures
- Lateral squeeze
- Stability of surcharge slopes
- Monitoring/instrumentation
- 2'-3' settlements
- Max loading 2'/week
- Long. joint in ex. pavement

Route 1 Interchange

Deep Soil Mixing - “Wet” Mix Method

- **Heavy/large equipment; batch plant**
- **Multiple/single augers**
- **Constant rotation (40 rpm)**
- **Slower (2.5’/min. insertion; 5’/min. withdrawal)**
- **Injection on insertion or withdrawal**
- **Dosage 250 to 750 lbs/cy**
- **UC strength 120 to 250 psi**
- **Settlements typically 1”-2”**
- **Spoils?**
- **Surcharge?**

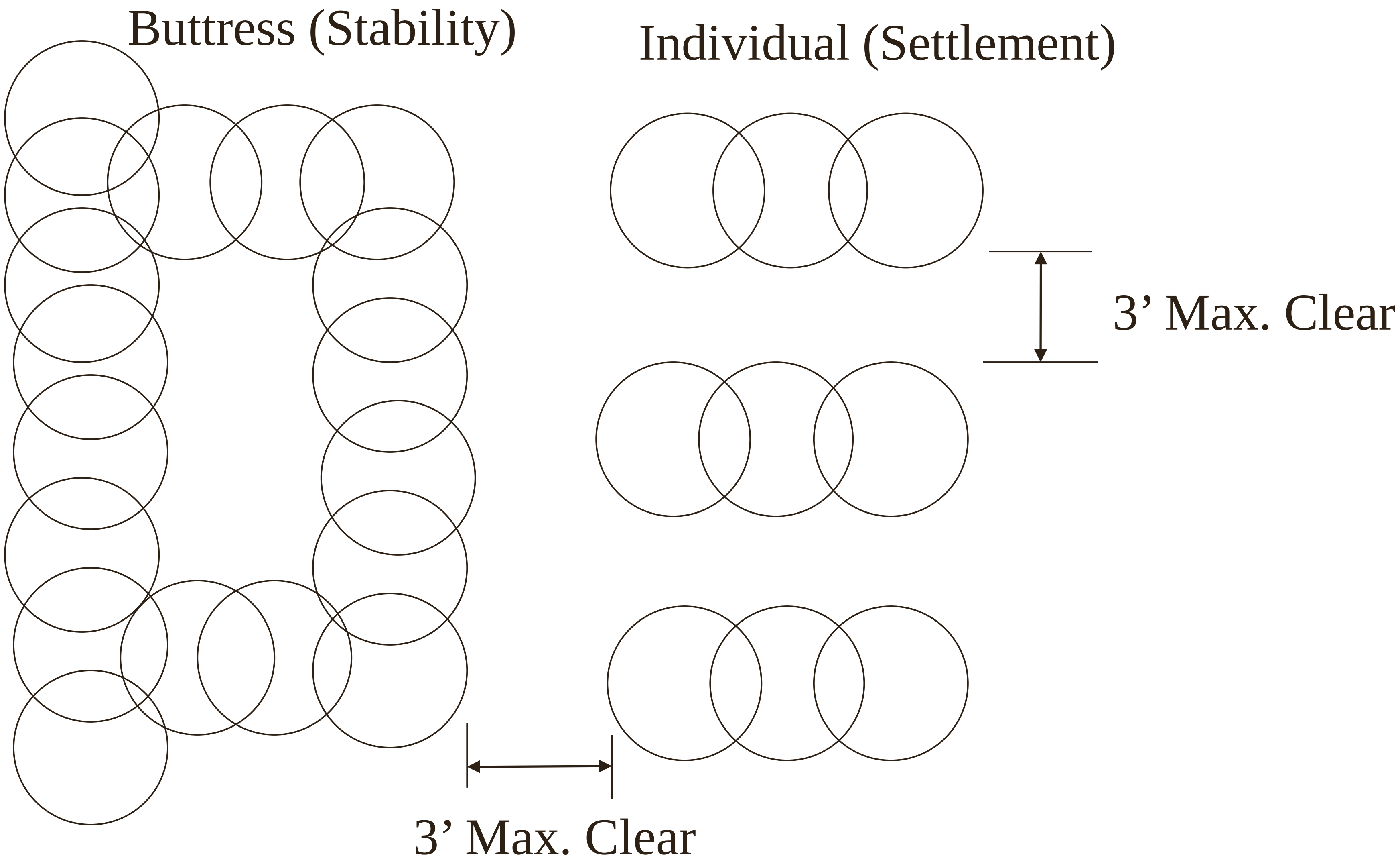
Deep Soil Mixing

Test Embankment

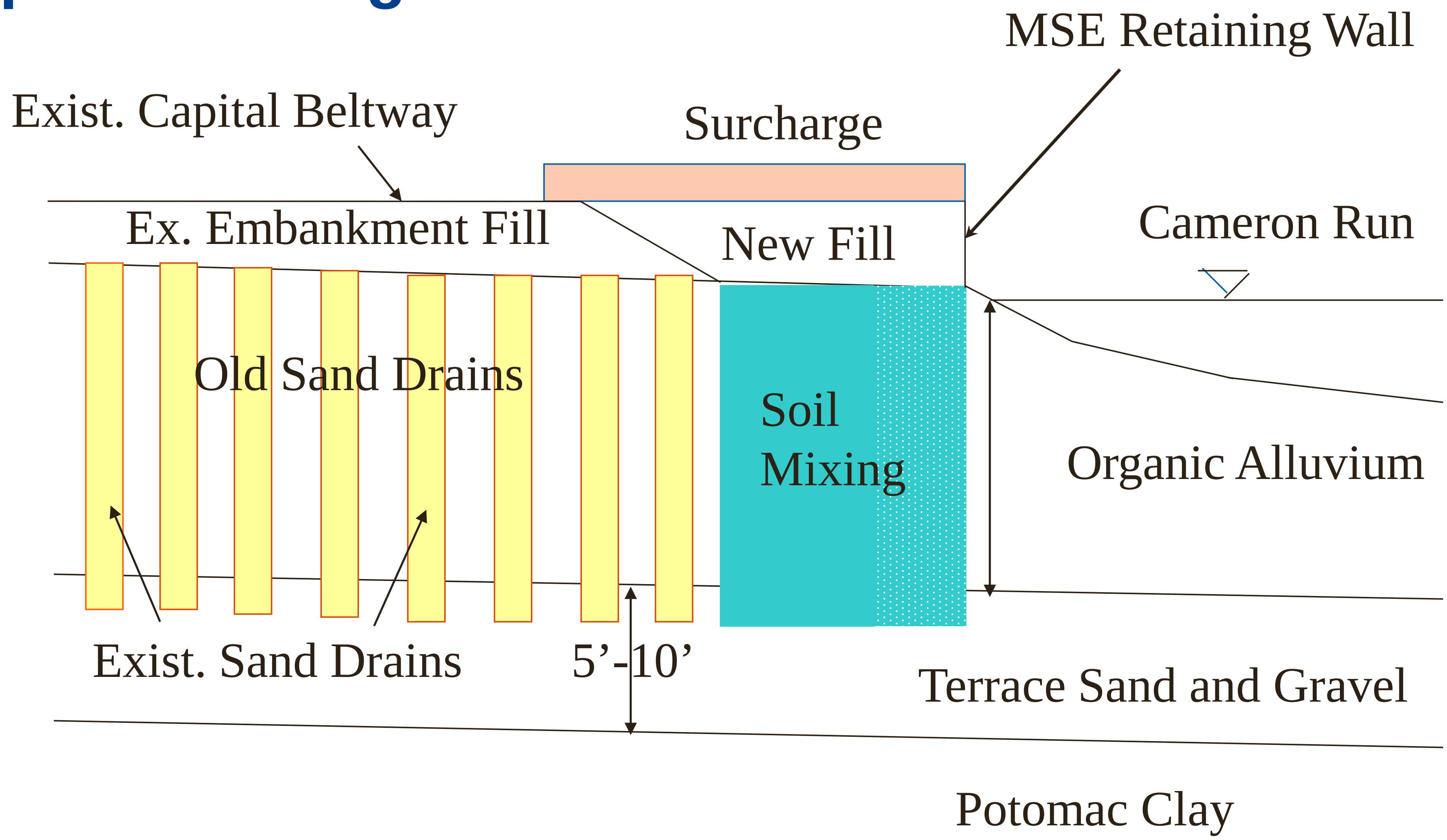
- “Wet” and “Dry” mix columns
- “Wet” mix panels
- 2’ construction platform
- Batch plant requirements

- Contractual “Lessons Learned” (acceptance criteria; mix design criteria; production rates; constructability; control of spoils)

Deep Soil Mixing



Deep Soil Mixing



Route 1 Interchange

Deep Soil Mixing - Construction

- Trial installations
- 2 rigs; 4 shifts
- Inspectors full-time on each rig
- Coring/curing/transportation of test samples by Contractor; testing by Owner
- On-site laboratory
- Daily review of test results

Route 1 Interchange

Deep Soil Mixing – Lessons Learned

- Support of equipment
- Variability of organics
- Variability of top of Terrace
- Lag between mixing and results
- Obstructions
- Tracking across fresh columns
- Equipment damage
- Pressures on piles

Deep Soil Mixing

Acceptance of Soil Cement Elements

- Continuous records of dosage/penetration rates
- Coring of elements (diameter, location, speed, plumb)
- Field inspection/pocket penetrometer
- Unconfined compression testing
- Strength average >160 psi; min. 100 psi
- Penetration into Terrace sand/gravel
- Engineering judgement

Deep Soil Mixing

Mixing Records (Tabular)

- Depth
- Time
- Speed (up/down)
- Rotation (revs/min)
- Rotation (revs/ft)
- Injection (#1, #2, #3)
- Energy Index

Zero = +6.3
TOC = +4.3
BOC = -35.

Installation Records

PAGE 1

Project Name: #4 Production (Night)

Element # : 84-180 84-180-C2 Rig # : 4 12"N 11 / 7 / 2002

Mixing System Design Data	Depth (ft)	Slurry Injection Volume (gal/ft)		Speed (ft/min)	
		Down	Up	Down	Up
1st Layer	2.0	0.0	0.0	-----	-----
2nd Layer	60.0	17.4	0.0	3.0	5.0
3rd Layer	-----	-----	-----	-----	-----
4th Layer	-----	-----	-----	-----	-----

Depth (ft)	Time (mm:ss)	Speed (ft/min)	Rotation (rpm)	Slurry Injection Volume (gal)			Energy Index	
				Column1	Column2	Column3		
0.0	0:00							
2.0	1:29	1.3	19					*
3.0	0:44	1.3	19	20.7	21.0	21.1	71	
6.0	2:16	1.3	22	50.7	50.7	50.7	65	
9.0	1:03	2.8	39	48.2	47.9	48.1	11	
12.0	1:02	2.9	38	54.3	54.2	54.5	14	
15.0	1:03	2.8	38	52.8	52.8	52.8	15	
18.0	1:02	2.9	38	51.0	51.0	51.0	13	
21.0	1:02	2.9	38	53.0	53.0	52.9	12	
24.0	1:02	2.9	38	52.5	52.4	52.4	14	
27.0	1:06	2.7	38	52.8	52.8	52.8	20	
30.0	1:41	1.7	38	67.9	67.0	65.6	22	
33.0	1:03	2.8	38	52.1	52.1	52.2	23	
36.0	1:05	2.7	38	52.6	52.6	52.5	30	
39.0	1:02	2.9	38	52.1	52.1	52.2	37	
41.7	1:33	1.7	30	62.2	61.8	62.1	74	
39.0	1:06	2.4	32	3.1	3.0	3.0		
36.0	0:38	4.7	37	0.0	0.0	0.0		
33.0	0:55	3.2	26	0.0	0.0	0.0		
30.0	1:08	2.6	19	0.0	0.0	0.0		
27.0	0:56	3.2	32	0.0	0.0	0.0		
24.0	0:39	4.6	38	0.0	0.0	0.0		
21.0	0:38	4.7	38	0.0	0.0	0.0		
18.0	0:36	5.0	38	0.0	0.0	0.0		
15.0	0:36	5.0	38	0.0	0.0	0.0		
12.0	0:37	4.8	38	0.0	0.0	0.0		
9.0	0:37	4.8	38	0.0	0.0	0.0		
6.0	0:37	4.8	39	0.0	0.0	0.0		
3.0	0:37	4.8	39	0.0	0.0	0.0		
2.0	0:12	5.0	39	0.0	0.0	0.0		
0.0	0:27	4.4	39					*
Total	28:32	------	------	726.0	724.4	723.9	-----	
Used	------	------	------	748.3	748.7	746.8	-----	

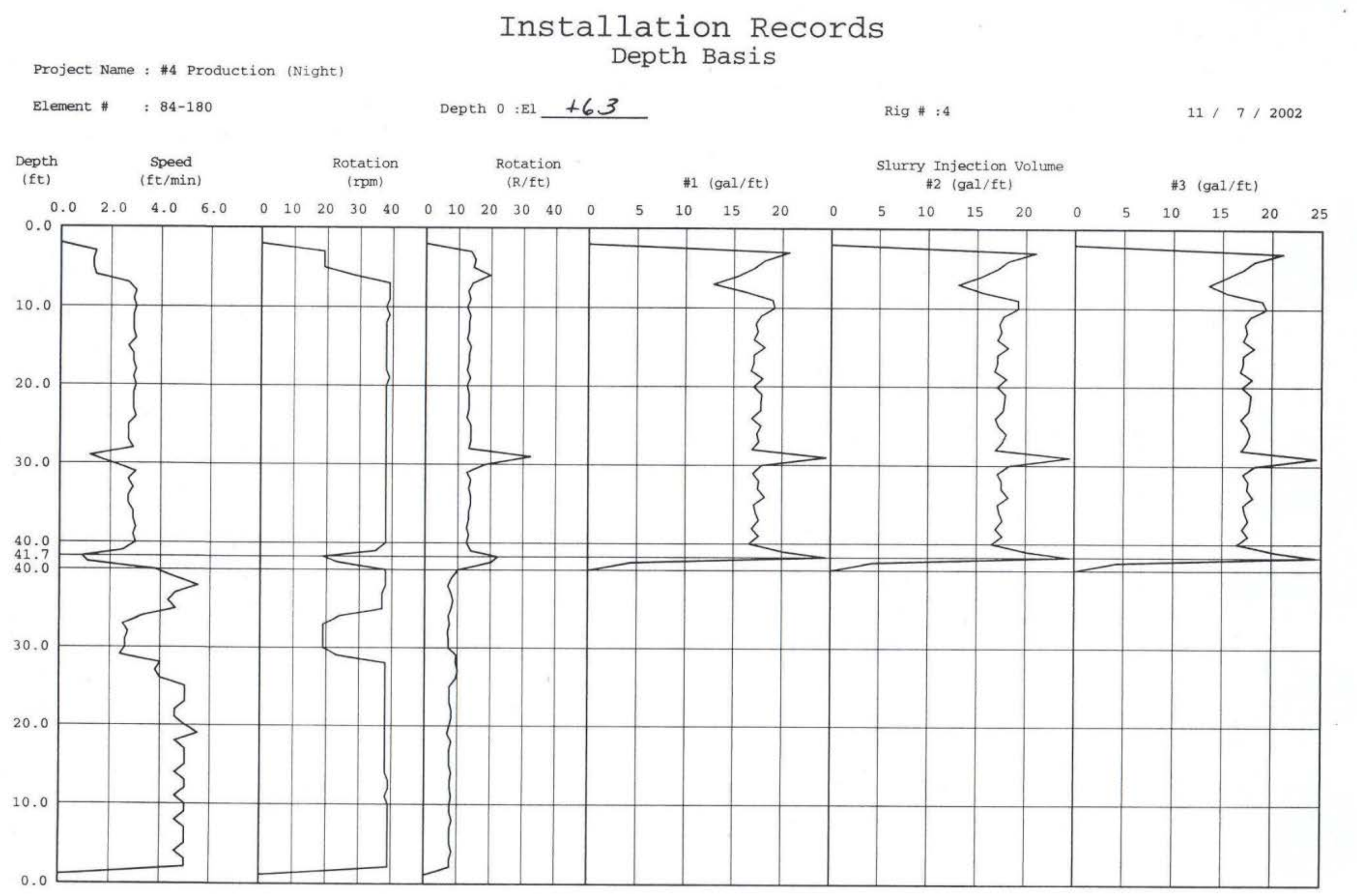
* Non-Injection Depth
** Bottom Mixing Depth
*** Refusal Criteria Start Depth

ELEMENT TERMINATION DEPTH
INSTRUCTED BY VDOT/PCC INSPECTOR

Deep Soil Mixing

Mixing Records (Graph)

- Depth
- Speed (up/down)
- Rotation (revs/min)
- Rotation (revs/ft)
- Injection (#1, #2, #3)



Deep Soil Mixing

Contractor's Responsibility

- Coring of elements

VDOT's Responsibility

- Selection and testing

Low Density Cementitious Fill (LDCF)

Properties

- Cement, fly ash, water and foaming agent
- 20-30 pcf
- 40 psi comp. strength at 28 days

Low Density Cementitious Fill (LDCF)

Lessons Learned

- **Flexibility**

Low Density Cementitious Fill (LDCF)

Lessons Learned

- Flexibility
- Ground water

Low Density Cementitious Fill (LDCF)

Lessons Learned

- Flexibility
- Ground water
- Temp. Drainage

Low Density Cementitious Fill (LDCF)

Lessons Learned

- Flexibility
- Ground water
- Temp. Drainage
- Effect of Vibrations

Low Density Cementitious Fill (LDCF)

Lessons Learned

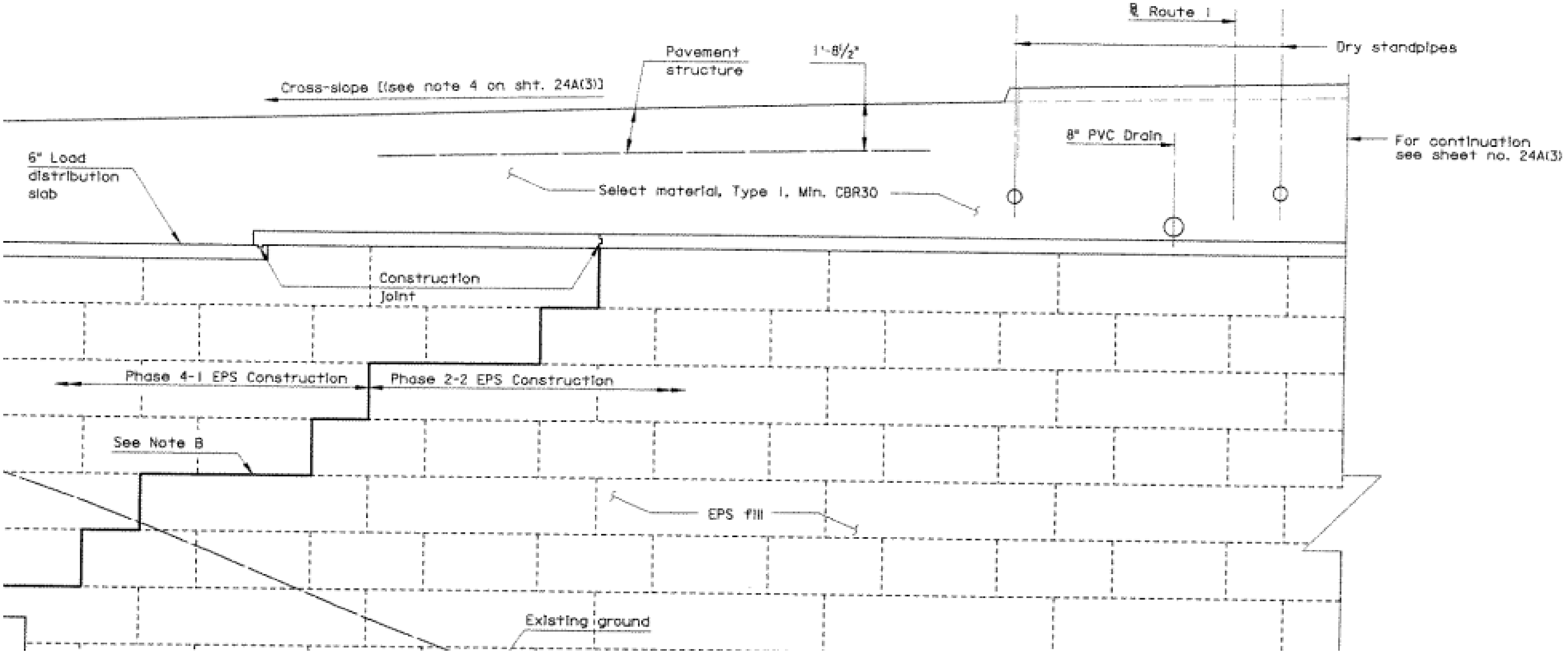
- Flexibility
- Ground water
- Temp. Drainage
- Effect of Vibrations
- Equipment damage

Expanded Polystyrene (EPS) Geofoam

Properties

- 1.5 pcf to 3 pcf
- Comp. str. >15 psi
- Flex. Str. >40 psi
- Modulus >1,015 psi
- Expensive !

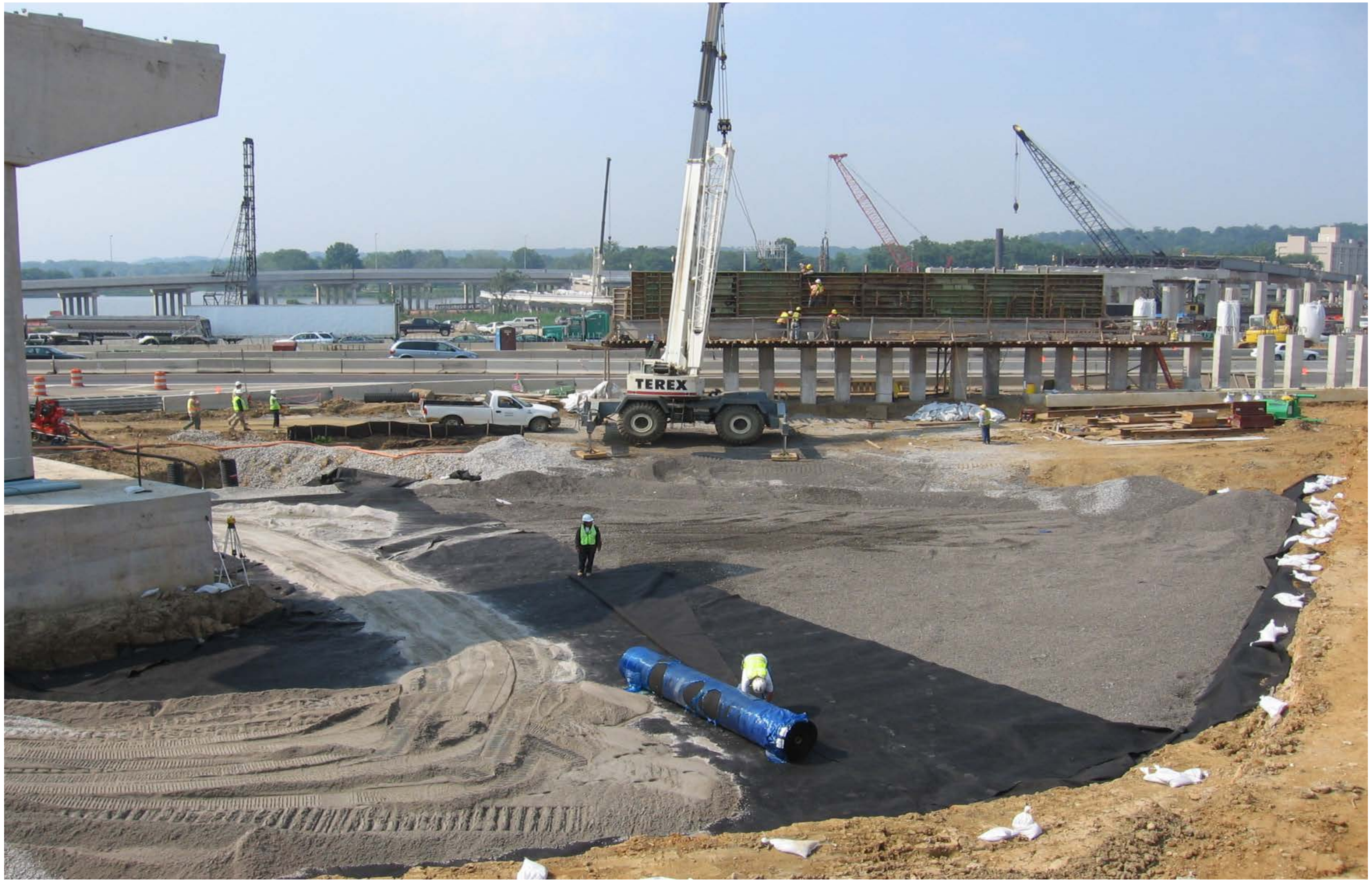
Expanded Polystyrene (EPS) Geofoam



Expanded Polystyrene (EPS) Geofoam

Leveling Pad

- Geotextile
- Stone dust



Expanded Polystyrene (EPS) Geofoam

Acceptance

- Dimensions
- Perpendicularity
- Planarity

Expanded Polystyrene (EPS) Geofoam

Acceptance

- Dimensions
- Perpendicularity
- Planarity
- Visual (each truck)

Expanded Polystyrene (EPS) Geofoam

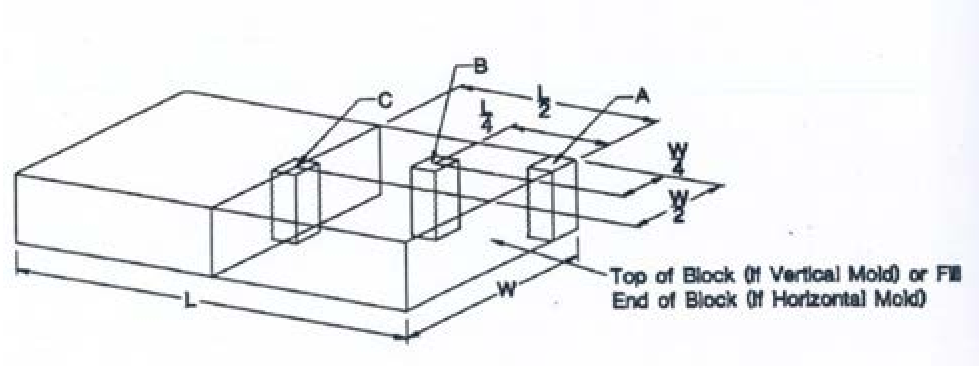
Sampling

- Large blocks
- 4’ x 4’ x 16’
- >500 lbs/block !

Expanded Polystyrene (EPS) Geofoam

Field Sampling

- Three Locations
- Comp. str. (5) 2”x2”x2”
- Flexural str. 1”x4”x12”



Expanded Polystyrene (EPS) Geofoam

Final Placement

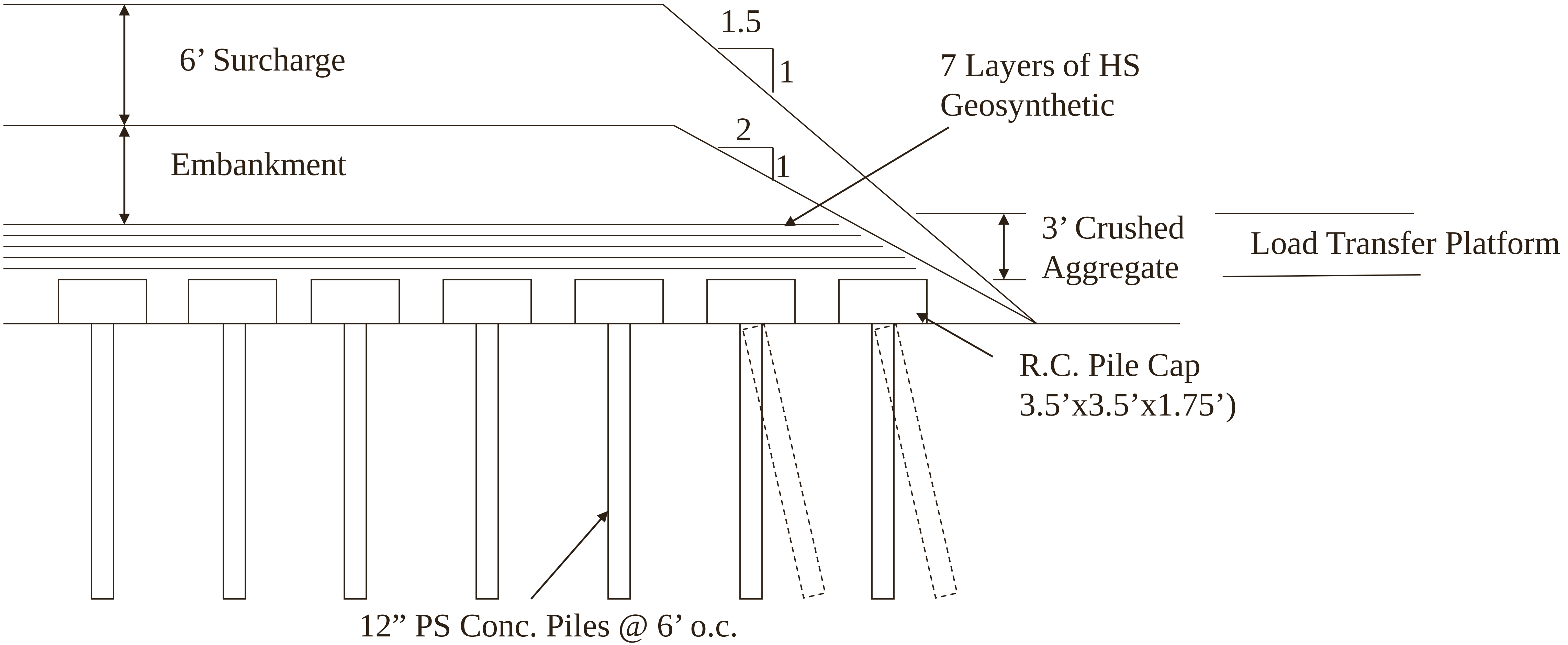
- Experienced subcontractor
- Hot wire cutting
- Accuracy

Expanded Polystyrene (EPS) Geofoam

June 25, 2006

- 10” rain in 24 hrs.
- 4.8” in 1 hr.
- >100 yr. storm

Pile Supported Embankment



Pile Supported Embankment

Layout

- **Must be accurate**

Pile Supported Embankment

Lessons Learned

- Test piles (PDA)
- 37-ton design capacity
- Spec. tip elev. *and* min. capacity
- Refusal criteria
- F-T inspection
- Noise/vibration
- Heave
- Surcharge

Geotechnical Instrumentation

Types of Instruments

- Inclinometers
- Settlement Plates
- Magnetic extensometers
- Vibrating wire piezometers
- Benchmarks; settlement plates
- Pressure cells
- Strain gauges

Geotechnical Instrumentation

Lessons Learned

- Clustered for constructability
- Time for installation in contract specs.
- Locations/types on plans
- Installation/monitoring by Owner
- Penalties (time/money) for damage
- Redundancy

Specialty Ground Improvement

Limited Number of Contractors

- Bid prices can vary significantly
- Availability
- Capacity

Materials Supply (cement, fly ash, sand, etc.)

- Availability and price

Time from design to bid/construction

- Markets changing quickly
- Cost increases
- Contractor availability

Construction Risks

- Obstructions (delays)
- Will it work ?

Summary of Lessons Learned

Expertise and Experience

- Geotechnical Engineer
- Inspectors
- Contractor
- Communication/training
- On-site laboratory

New Technologies

- Test programs are very valuable
- Trial installations
- Experience from previous projects

Evolution of Mega Projects in Northern Virginia

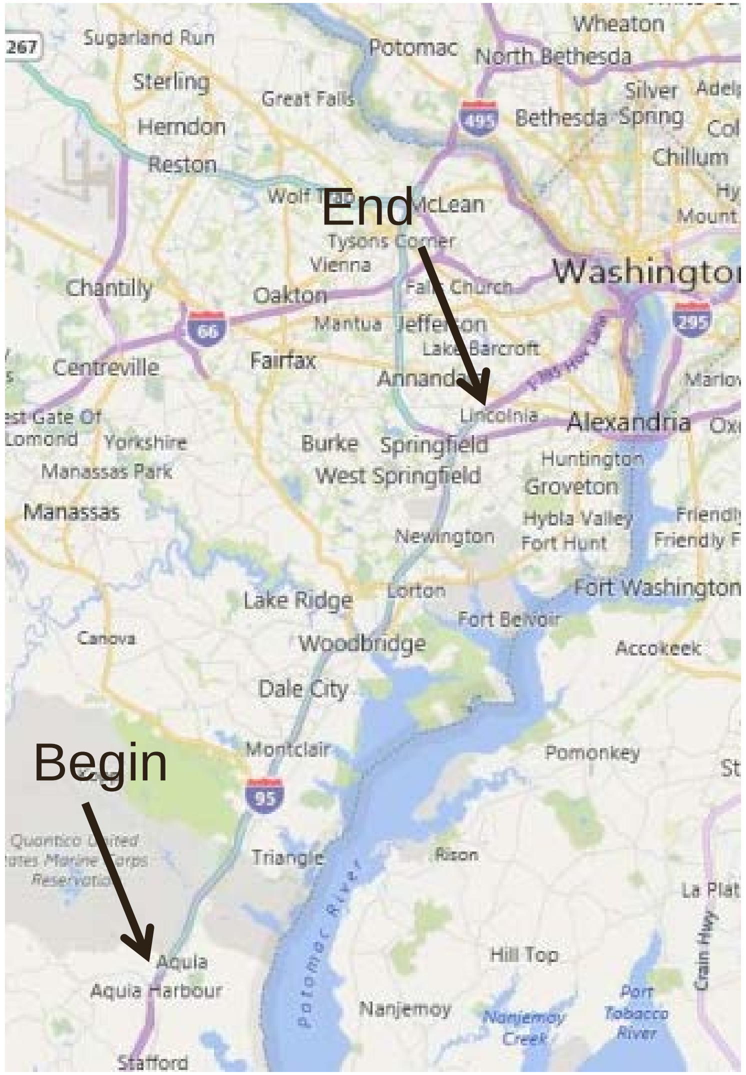
I-495 Express Lanes

- $1.3 billion
- P3/Design-Build
- 2007 to 2012
- 14 miles
- 12 interchanges
- 57 bridges

Evolution of Mega Projects in Northern Virginia

I-95/I-395 Express Lanes

- $925 million
- P3/Design-Build
- 2011 to 2014
- 29 miles total length
- 9 miles new construction
- Adding 1 reversible lane
- Interchange Improvements



Evolution of Mega Projects in Northern Virginia

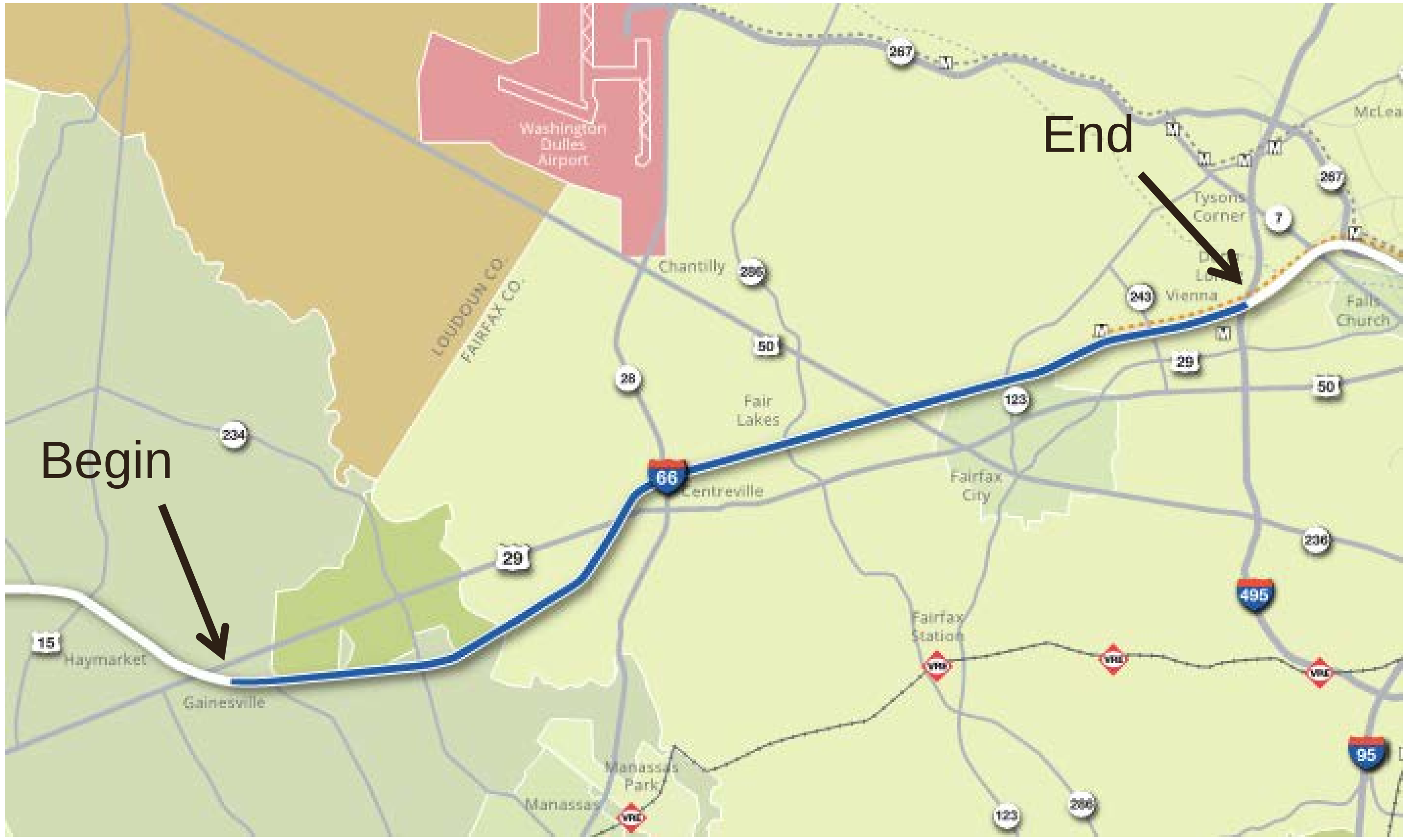
I-395 Express Lanes

- $500 million
- P3/Design-Build
- 2017 to 2020
- 15 miles
- Adding 1 reversible lane
- Interchange Improvements
- I-395 Fourth Lane SB (Duke St to Edsall Rd)

Evolution of Mega Projects in Northern Virginia

I-66 Outside the Beltway

- $2.5 billion
- P3/Design-Build
- 2017 to 2022
- 195,000 vehicles per day
- 22.5 miles
- 2 express lanes/direction
- 4,000 park & ride spaces



Design-Build Program

Geotechnical Investigations

- ***Who will maintain the final roadway?***
- **How do we characterize the site?**
- **How much investigation (prelim. vs. final)?**
- **Acceptable methods of investigation?**
- **How much testing?**

Design-Build Program

Geotechnical Design

- Minimum pavement sections
- Design parameters?
- Design methods?
- Temporary works….

Design-Build Program

Where Are We Headed ?

- Minimize risk for all parties
- D-B-B vs. D-B vs. P3
- Risks with “bad” sites
- Construction inspection

Questions?