LESSONS LEARNED FROM LARGE HIGHWAY PROJECTS – THE IMPORTANCE OF THE GEOTECHNICAL ENGINEER
GeoVirginia, 2018

David P. Shiells, P.E.
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

“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

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
Mega Projects in Northern Virginia

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Woodrow Wilson Bridge
- $2.5 billion
Mega Projects in Northern Virginia

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I-495 Express Lanes
• $1.3 billion
Mega Projects in Northern Virginia

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I-95/I-395 Express Lanes
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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

Image Credit: Google Earth
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
Original I-95/Route 1 Interchange
New I-95/Route 1 Interchange
I-95/Route 1 Interchange

Original Construction

- Alluvial Clay (OL/OH)
- Terrace Sand/Gravel (GP/GC)
- Potomac Clay (CH/CL)
- Granular Embankment Fill
- Sand Drains
- Fill

Cameron Run

Fill 9'

26'

6'

10'-12'

8' Fill
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)
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

Buttress (Stability)  Individual (Settlement)

3’ Max. Clear
Deep Soil Mixing

Exist. Capital Beltway

Ex. Embankment Fill

Old Sand Drains

Surcharge

New Fill

Soil Mixing

MSE Retaining Wall

Cameron Run

Organic Alluvium

Terrace Sand and Gravel

Potomac Clay
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

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<th>Rotation (rpm)</th>
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Total: 266.32
Used: 265.44

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

ELEMENT TERMINATION DEPTH
INSTRUCTED BY VDOT/POD 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
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

- 6' Surcharge
- Embankment
- 1.5
- 7 Layers of HS Geosynthetic
- 3' Crushed Aggregate
- Load Transfer Platform
- R.C. Pile Cap 3.5’x3.5’x1.75’
- 12” PS Conc. Piles @ 6’ o.c.
Pile Supported Embankment

Layout

- Must be accurate
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?