2020 MID-ATLANTIC QUALITY ASSURANCE WORKSHOP – WILLIAMSBURG, VIRGINIA

Micropile Supported Slab for Sinkhole Mitigation on S.R. 422

Frank P. Namatka, P.E.
Chief Geotechnical Engineer

February 12, 2020

Gannett Fleming

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ISO 9001:2015 CERTIFIED

Micropile Supported Slab for Sinkhole Mitigation on S.R. 422

- Site Location
- Site Geology
- Sinkhole History
- Available Geotechnical Data
- 2019 Repair Strategy
- Design Details
- Micropile Inspection
- Load Testing
- Construction

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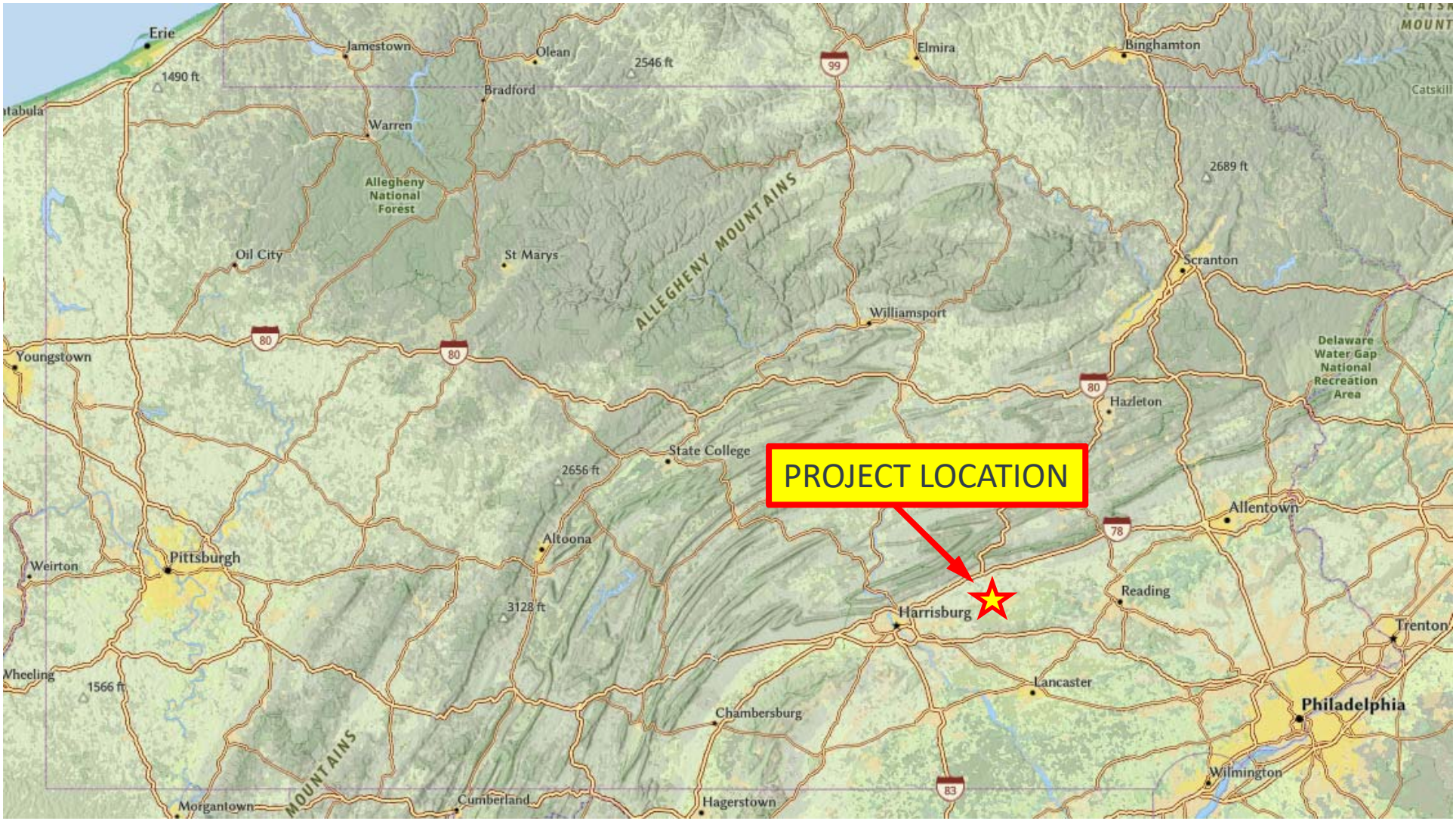
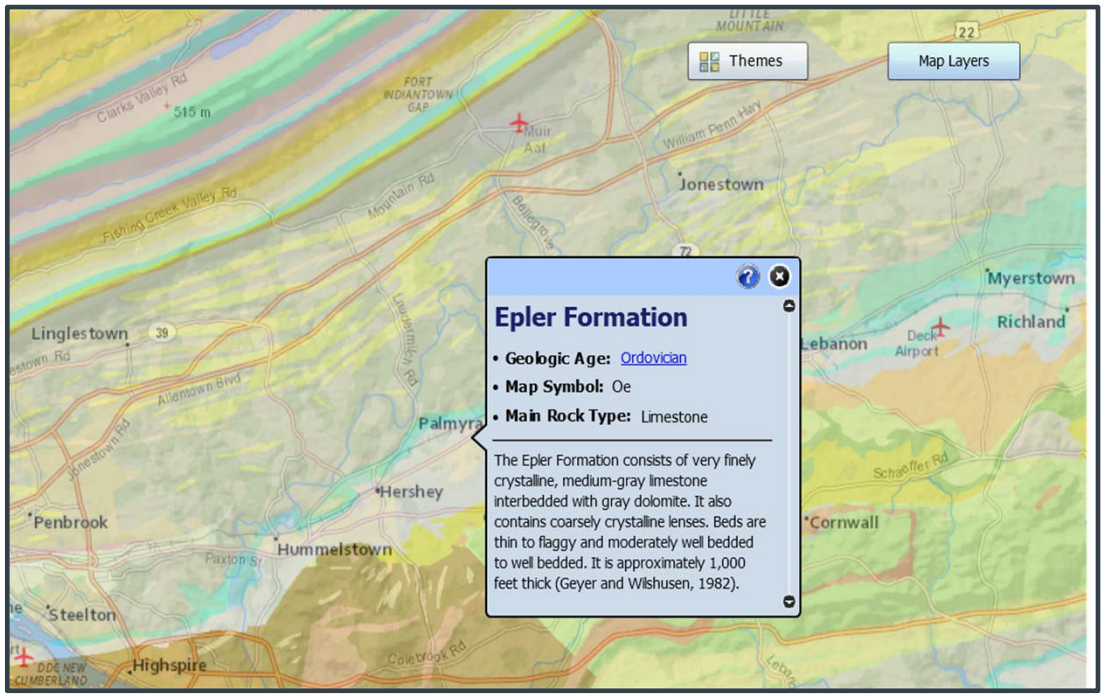

PROJECT LOCATION
Erie
Jamestown
Olean
2546 ft
Elmira
Binghamton
1490 ft
Bradford
Warren
Allegheny National Forest
ALLEGHENY MOUNTAINS
2689 ft
Oil City
St Marys
Scranton
Williamsport
Youngstown
80
99
Delaware Water Gap National Recreation Area
Hazleton
State College
2656 ft
Allentown
Altoona
Pittsburgh
Weirton
78
Reading
3128 ft
Harrisburg
Trenton
Lancaster
Philadelphia
Chambersburg
1566 ft
Wilmington
Morgantown
Cumberland
Hagerstown
83

Site Location

Site Geology

- Epler Formation – (“*Engineering Characteristics of the Rocks of Pennsylvania*”):
  - Limestone interbedded with dolomite
  - Common Characteristics
    - Bedrock pinnacles
    - Sinkholes and caves
    - Cavernous areas



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Site History

- Long history of sinkhole activity at site
- 1950's – Sinkholes documented
- 1979 – Sinkhole closed center lane
- 1982 – Sinkholes along shoulder
- 1992 – Sinkhole at S. Green Street Int.
  (Repair: concrete and aggregate)
- 1993 – Sinkholes adjacent to SR 422
- 2009 – Sinkholes closed SR 422
  (Repair: concrete and aggregate)
- 2014 – Sinkholes closed SR 422
  (Repair: Land bridge)
- 2017 – Sinkholes in shoulder
  (Repair: Sinkhole Safety Net)
- 2019 – Sinkholes closed SR 422

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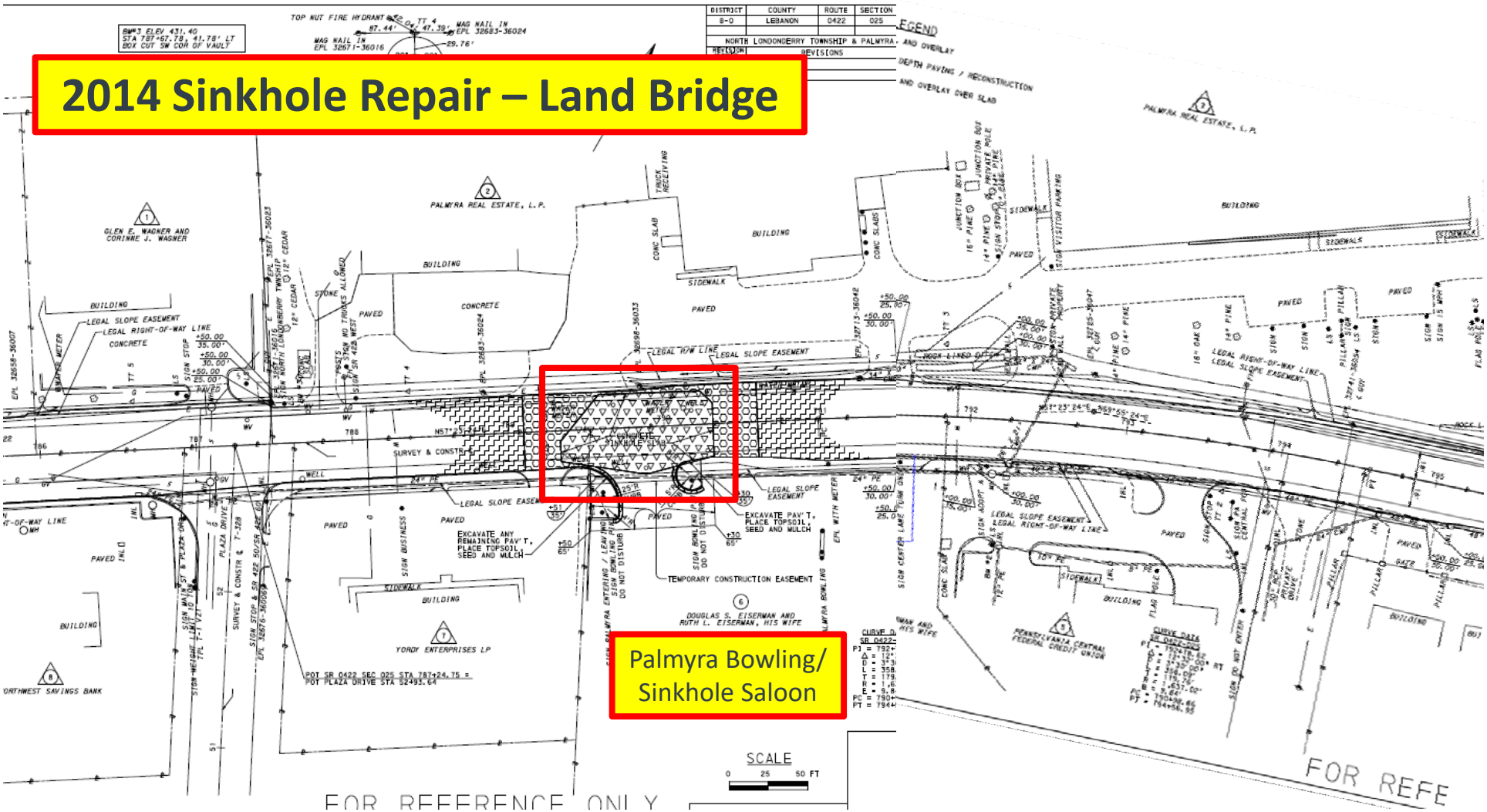
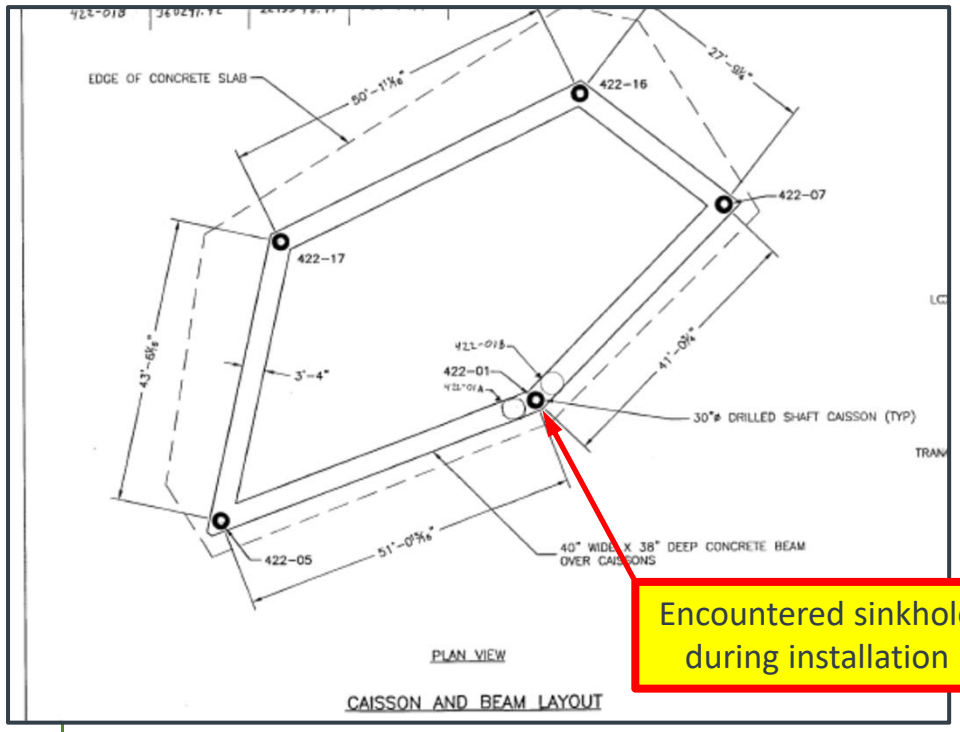
2014 Sinkhole Repair – Land Bridge



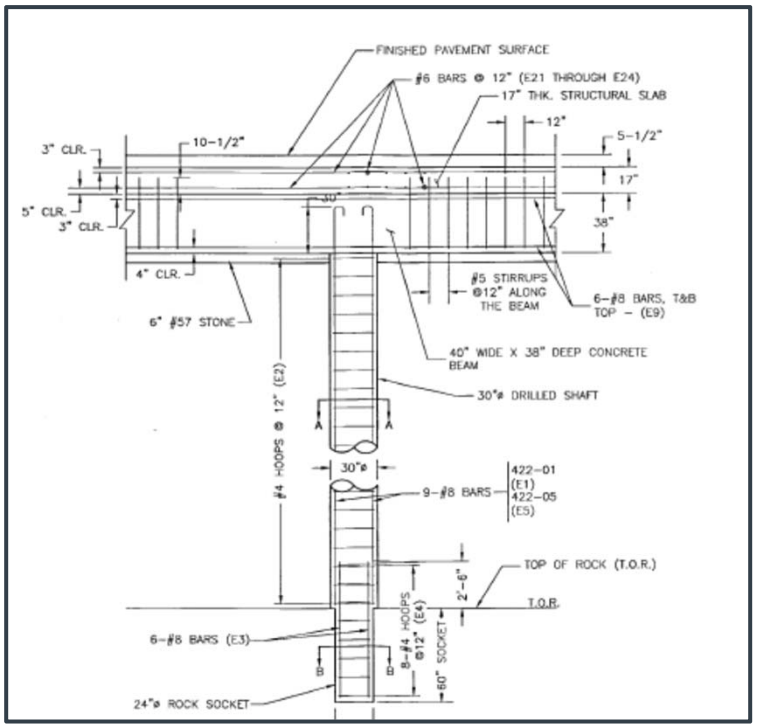
2014 Sinkhole Repair – Land Bridge

- Concrete Slab with Edge Beams



Encountered sinkhole during installation

- Drilled Shaft Supports

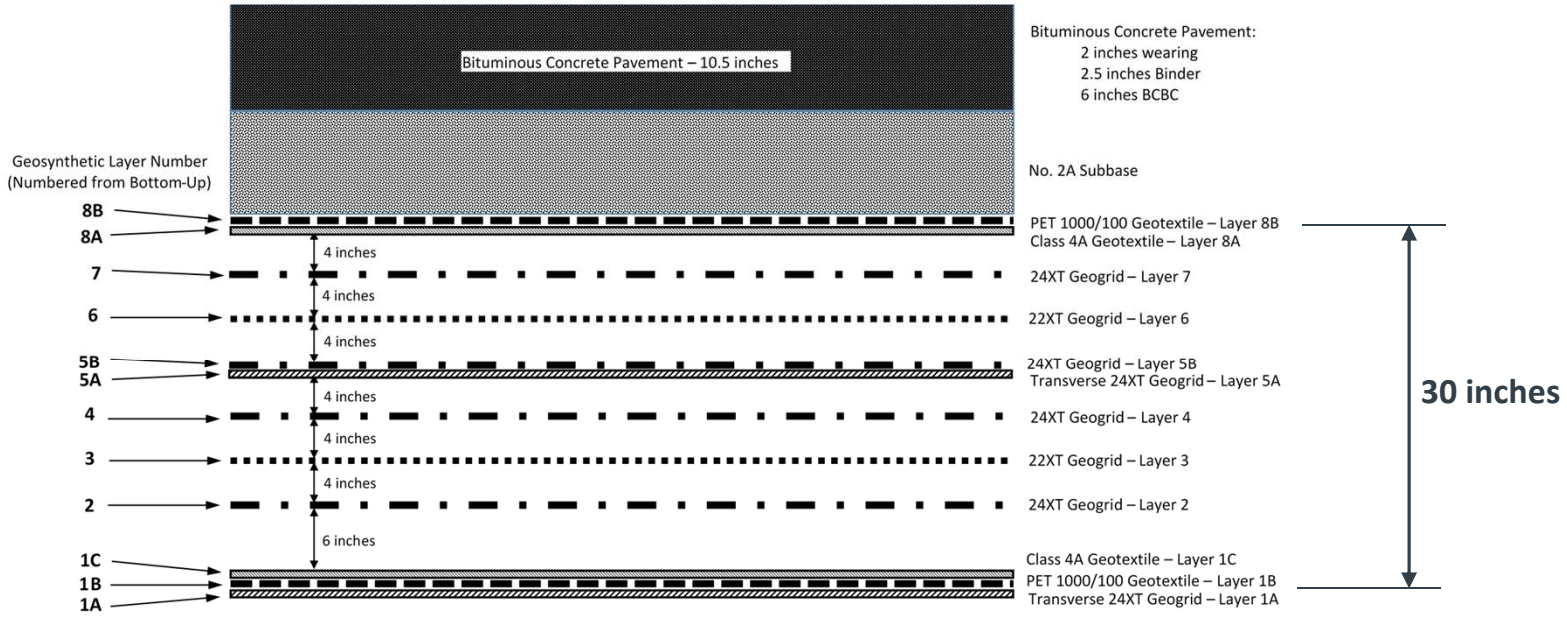


2017 Sinkhole Repair – Safety Net (i.e., layers of geosynthetics)

- PennDOT considered many conceptual designs:
  - "Buried Bridge", similar to 2014 repair
  - Structural Concrete Slab
  - Unreinforced Concrete Slab
- PennDOT not comfortable with closing SR 422 for long duration. Developed Sinkhole Safety Net concept
- Intention is to mitigate and minimize the impact of future sinkholes
- ***Not intended*** to prevent future sinkhole events
- Provides means to better manage future events


Quarry Pit Elev.
–52 ft
Approximate Limits
of Quarry
Quarry Inflow Zone
N
= Sinkhole Location
= 2017 Event
SR422
Palmyra, PA, USA

2017 Sinkhole Repair – Safety Net Typical Section



Typical Section – Flexible Sinkhole Safety Net – Roadway
(N.T.S.)

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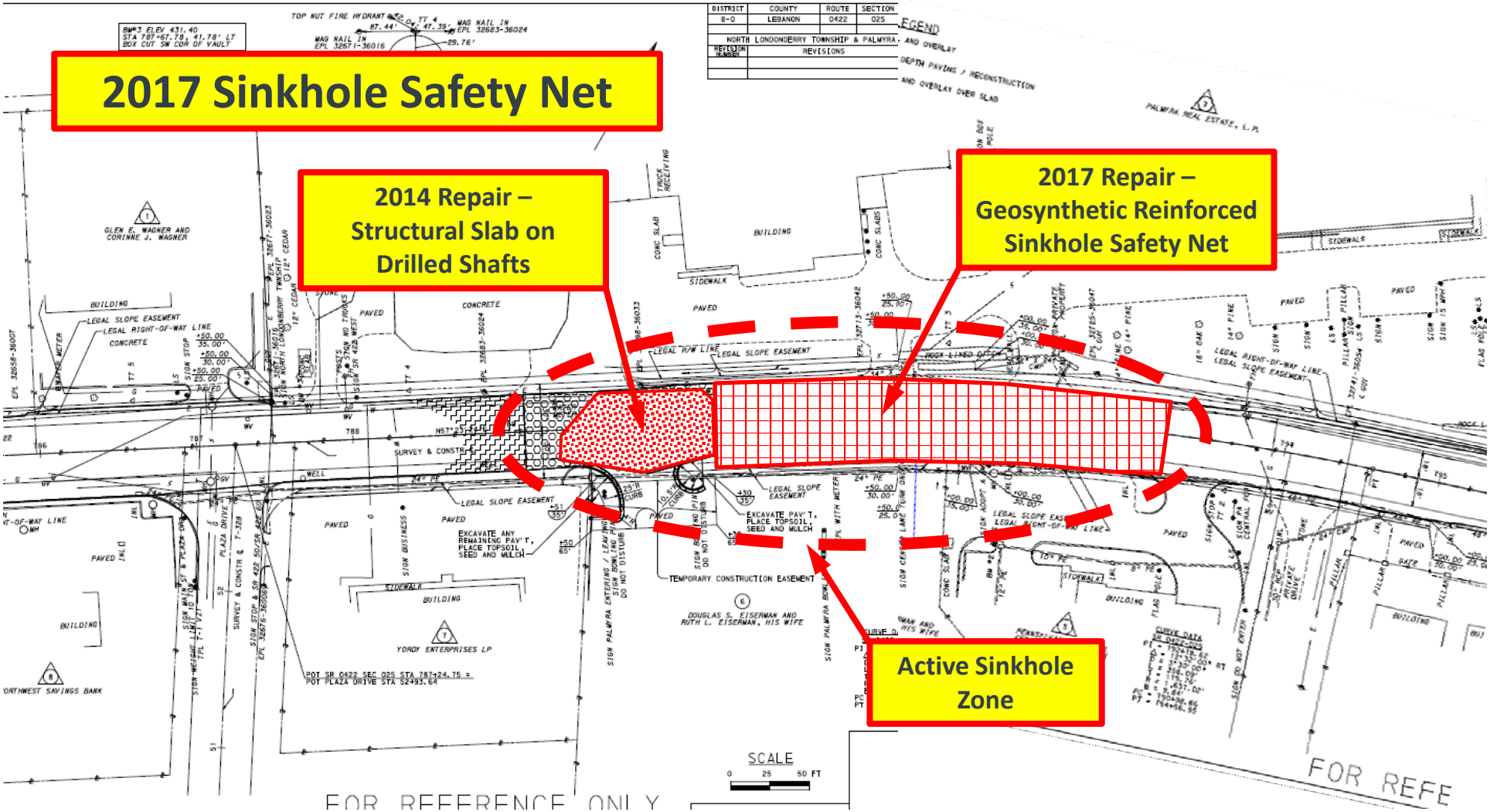
2017 Sinkhole Safety Net
2014 Repair – Structural Slab on Drilled Shafts
2017 Repair – Geosynthetic Reinforced Sinkhole Safety Net
Active Sinkhole Zone
LEGEND
DISTRICT
COUNTY
ROUTE
SECTION
8-0
LEBANON
0422
025
NORTH LONDONDERRY TOWNSHIP & PALMYRA
REVISIONS
SCALE
0 25 50 FT
FOR REFERENCE ONLY

2017 Sinkhole Repair - Safety Net Construction

Excavation for Safety Net (2014 Land Bridge Exposed)

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2019 Sinkhole Repair

- Depression in westbound lane of S.R. 422
- Steadily increased in depth
- PennDOT forced to close the roadway in June 2019
- Gannett Fleming, Inc. contacted by PennDOT to assist in a “long-term” repair solution
- “Safety Net” was good, but required immediate maintenance when depressions formed

2019 Sinkhole Repair - Timeline

- S.R. 422 closed in early June 2019
  - Occurred within 2017 Safety Net Repair (adjacent to 2014 Land Bridge)
- PennDOT contacts Gannett Fleming on July 2, 2019
- PennDOT and Gannett Fleming meet on July 3, 2019 to discuss the issue and develop a repair strategy
- PennDOT and Gannett Fleming work through the July 4th holiday and following weekend to assess the site conditions and develop solutions to repair the road
- Within 5 days, the project team determined that the safest solution for the traveling public was a structural concrete slab supported by micropiles

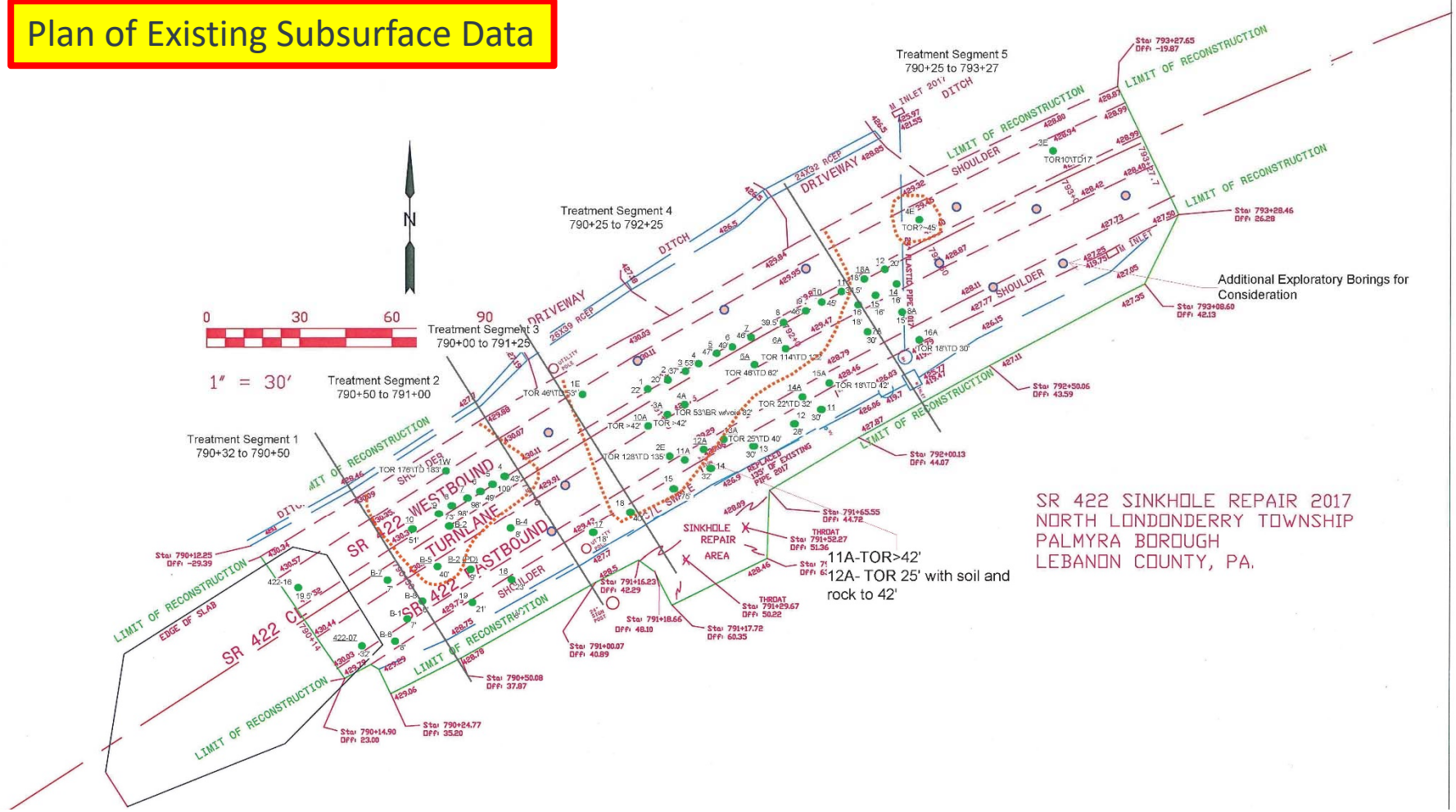
2019 Sinkhole Repair - Timeline (Cont'd.)

- Proposed repair is a "robust" design
  - Micropile supported structural slab
    - Provides redundancy
    - Ease of installation
    - Low likelihood of catastrophic failure if future sinkhole develops
      - Design to account for unsupported pile length and 1 pile/row being "lost"
- Final Plans delivered on July 17, 2019
- Micropile construction started August 7, 2019
- Micropile construction completed September 13, 2019
- Construction completed/road re-opened November 2019

Design of Micropiles – Geotechnical Data

- Sinkhole repair needed ASAP…no time for exploration
- Historic data available
  - Quality and reliability was a concern
  - Most of the data was not linked to common baseline
    - Exact locations of data was unknown
- Air track borings – 1960's through 2019
- Electrical resistivity survey (geophysical technique)
  - Limited value due to location/quality of data

Plan of Existing Subsurface Data



2019 Sinkhole Repair – Micropile Basics

- What are they?
  - Small diameter (≤9 5/8" O.D.), drilled and grouted pile, with steel reinforcement
- How do they obtain capacity?
  - Grout-to-ground bond (typically in rock)
- How are they constructed?
  - Multiple ways to construct, but typically….
  - Drill a cased borehole using percussion drilling methods to design depth (Duplex drilling)
  - Tremie grout hole
  - Place steel reinforcement with centralizers

2019 Sinkhole Repair – Micropile Design

- Micropiles are in compression and founded in rock
- Design per AASHTO and PennDOT LRFD design standards
- Design must account for:
  - Geotechnical Bond Resistance
  - Structural Resistance of cased portion of micropile
  - Structural Resistance of uncased portion of micropile
- Typically, either Geotechnical or Uncased Resistance control design!

2019 Sinkhole Repair – Micropile Resistance

- What is factored axial resistance to compression loads?
  - Geotechnical Resistance, **Q_r = 363 Kips**
  - Structural Resistance, Cased Length, **Q_{cc} = 701 Kips**
  - Structural Resistance, Uncased Length, **Q_{cu} = 327 kips**

Uncased Structural Resistance Controls Design

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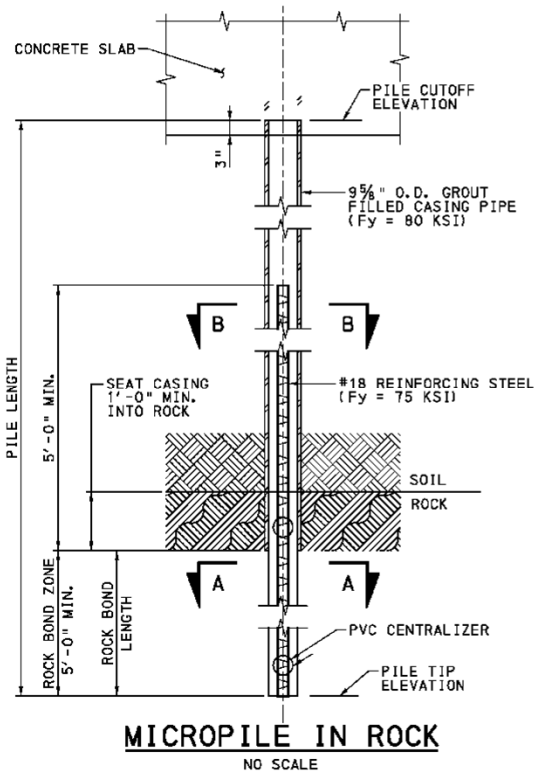
2019 Sinkhole Repair – Micropile Design Summary

- Bond Zone:
  - 5′ of continuous limestone bedrock
  - Install micropile casing 1′ into bedrock (i.e., 6′ of bedrock required)
    - Purpose - to limit grout loss at soil/rock interface
- Materials:
  - Micropile Casing
    - API N80 Steel Casing Pipe
    - 9.625″ O.D.
    - 0.472″ Wall Thickness
    - F_y = 80 ksi
  - Micropile Reinforcing Bar
    - Grade 75 Rebar (F_y = 75 ksi)
    - #18 Bar (A_s = 4.00 in^2)
    - #24 Bar (A_s = 6.82 in^2) for test micropiles

2019 Sinkhole Repair – Micropile Design Summary (Cont'd.)

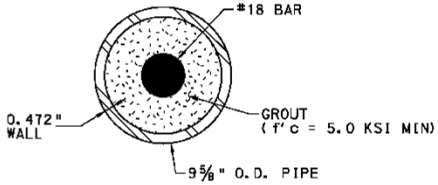
- Materials:
  - Grout
    - f'_c = 2 ksi @ 3 days
    - f'_c = 5 ksi @ 28 days
- Load Test
  - 2 Verification load tests required due to short bond length and high grout-to ground bond resistance factor
    - OK to use production piles as load test reaction piles
      - Maximum test load = 2 x design load / 2 reaction piles

2019 Sinkhole Repair – Micropile Design Details



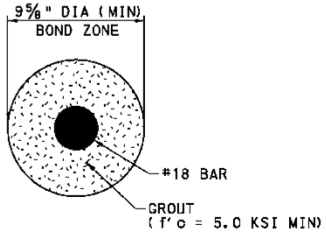
MICROPILE IN ROCK

NO SCALE



SECTION B-B

NO SCALE



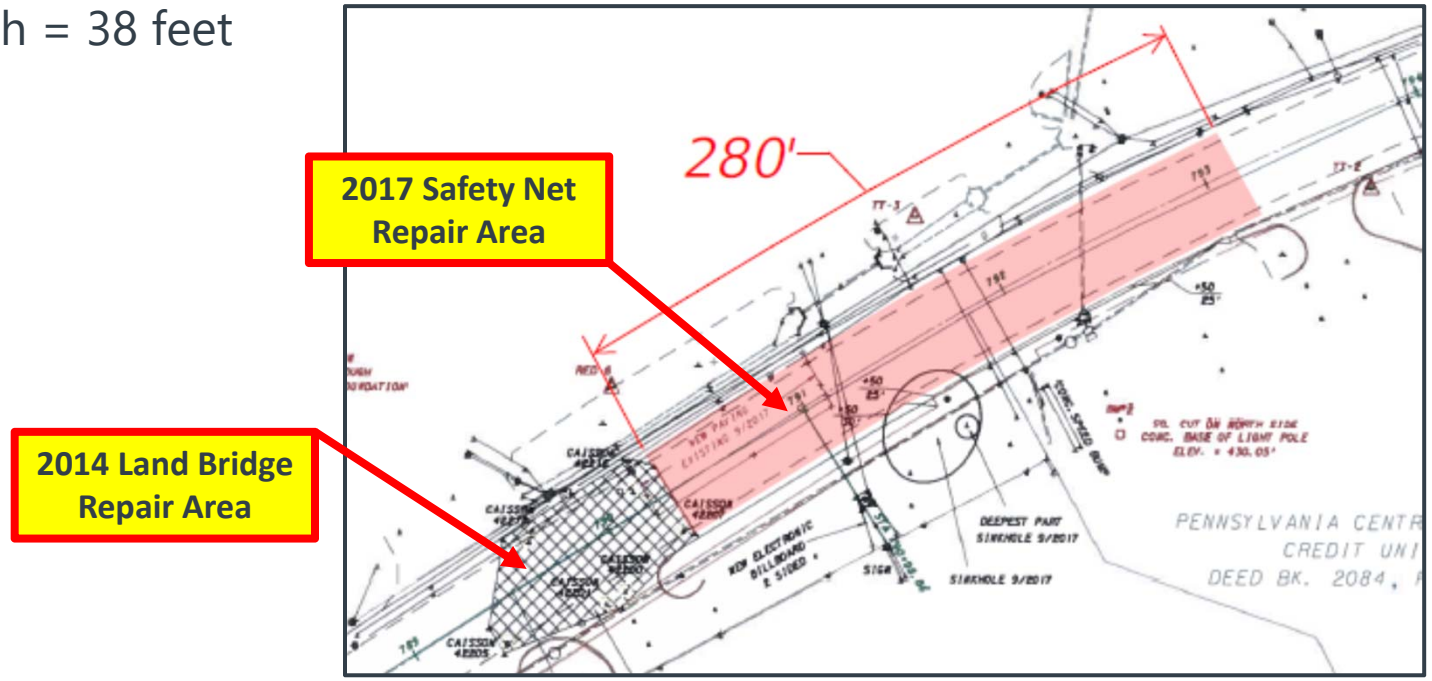
SECTION A-A

NO SCALE

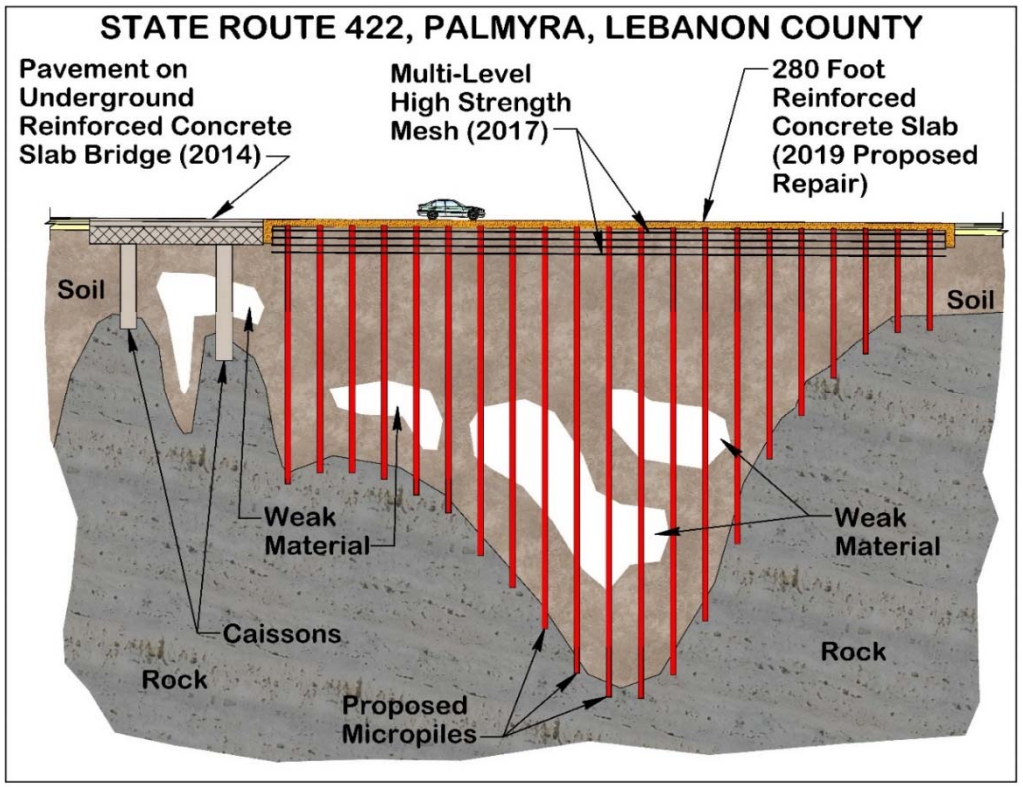
PILE LOADS (KIPS/PILE)	
ITEM	LOAD
FACTORED AXIAL COMPRESSIVE RESISTANCE, STRUCTURAL (PHI = 0.85)	327k
FACTORED AXIAL COMPRESSIVE RESISTANCE, GROUT TO ROCK BOND (PHI = 0.80)	327k
FACTORED AXIAL COMPRESSIVE LOAD	327K
LIMIT STATE	STR-I
DESIGN LOAD (UNFACTORED)	220k
VERIFICATION TEST LOAD	440k

2019 Sinkhole Repair – Repair Area

- Micropile supported slab starts at 2014 land bridge
- Extend new slab 280 feet (i.e., limits of 2017 safety net repair)
- Total Width = 38 feet



2014 Through 2019 Repairs – Profile Section



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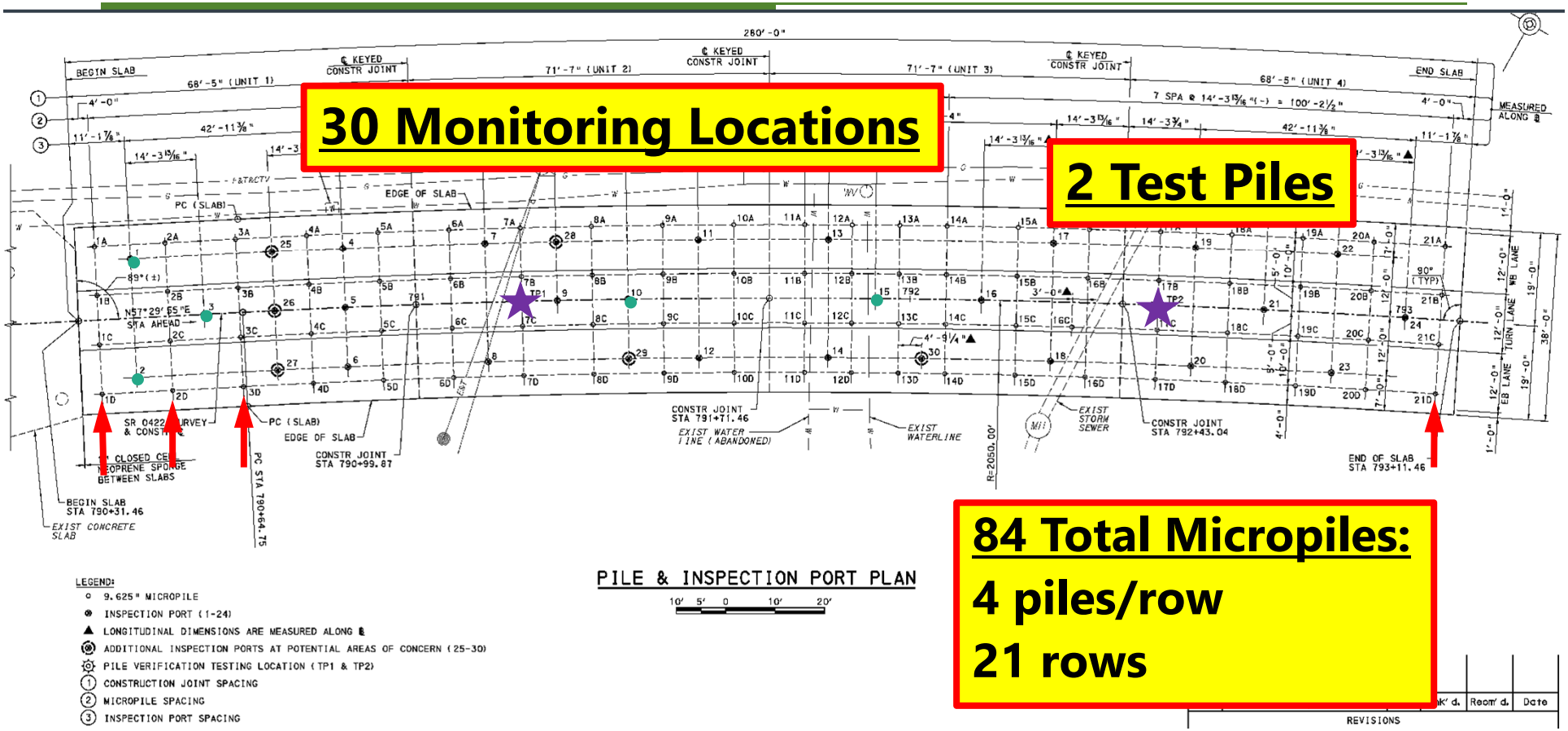
2019 Sinkhole Repair – Structural Design

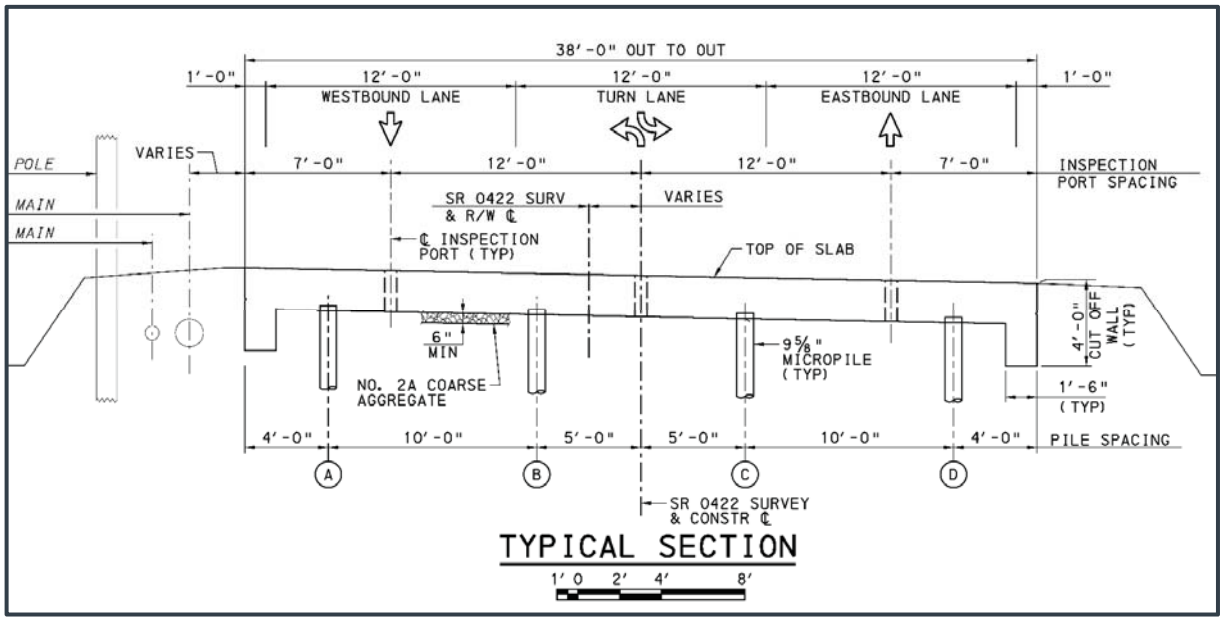
- Redundancy in design…assume the loss of 1 pile per row
- Micropile unsupported length = 25 feet
  - i.e., Micropiles will support slab if future sinkhole(s) occur provided the unsupported pile length is less than 25 feet
- Slab thickness controlled by punching shear
- Future monitoring capability provided…
  - "Manholes" provided in slab for future monitoring of ground conditions below slab
  - Provide access to fill voids
  - 45 ft. maximum spacing
  - 7" minimum diameter
  - Installed more in "problem" areas

2019 Sinkhole Repair – Structural Design



SR 422 Emergency Sinkhole Repair Project – Structural Design

- Typical Section…



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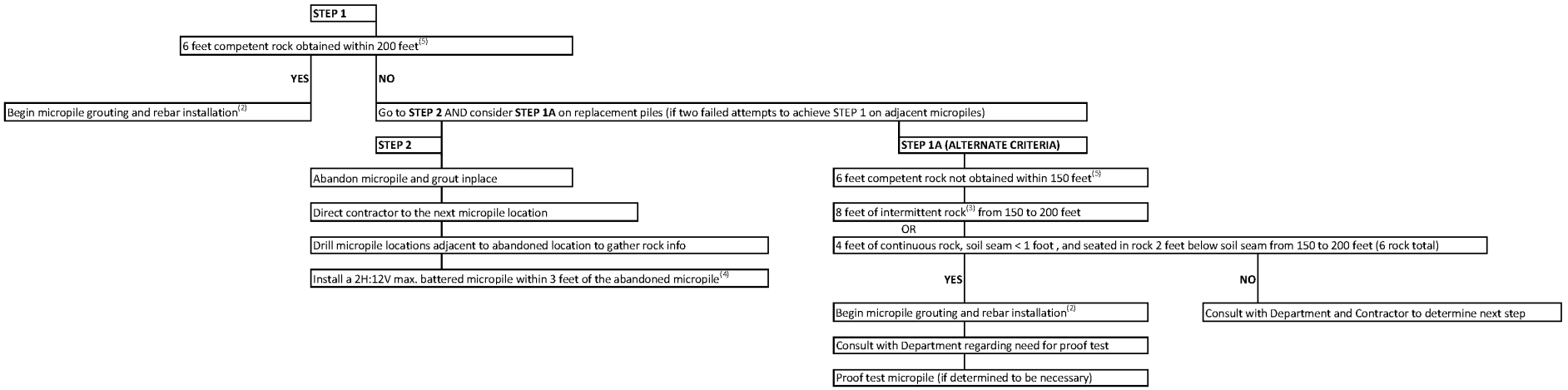
2019 Sinkhole Repair – Micropile Inspection

- GF inspected micropile installation – Developed workflow plan….

Micropile Inpection Guidance Document

Install every other pile in Rows B and D initally to determine the subsurface conditions within the work area.

The initial goal is to advance micropile hole a minimum of 6 feet into competent rock[1]. Alternate Criteria only to be considered after multiple adjacent piles do not achieve 6 feet of competent rock criteria.



Notes:

1) Competent rock is defined as 6 feet of continuous rock without soil/clay seams, voids, or highly weathered, broken rock. 1' plunge length and 5' bond zone.
2) See micropile grouting work flow chart.
3) Intermittent rock with a combined total of soil seams < 2 feet with no one soil seam > 1 foot and seated in rock (2' min). If soil seam >1 foot, reset criteria.
4) The location and direction of the battered replacement micropile shall be in the direction of the known best quality of rock.
   This will be determined on a case by case basis using previously obtained subsurface information as guidance.
   The location and direction of other previously completed vertical and battered piles will also be considered as to limit concentrated loads in any one location.
5) If open void, as evidenced by sudden tool drop > 6 inches is encountered, reset criteria.

2019 Sinkhole Repair – Micropile Inspection

- Grouting Procedure:
  - Determine theoretical volume of the drill hole
  - Verify tremie grout tube is at the bottom of the drill hole
  - Monitor and record volume of grout placed in the drill hole
  - Proceed with grouting until…
    - Full return of uncontaminated grout to the surface, or
    - 2 times the theoretical volume of grout is placed in the drill hole
  - If 2 times theoretical is placed – stop grouting and allow grout to set for 12 hours
  - After a minimum of 12 hours, measure the depth of grout in hole and redrill hole to the tip elevation
  - Proceed with grouting
  - If 2nd grouting attempt is unsuccessful, GF and Contractor to determine appropriate next steps


BOWLING


1993
3

2019 Sinkhole Repair – Grouting

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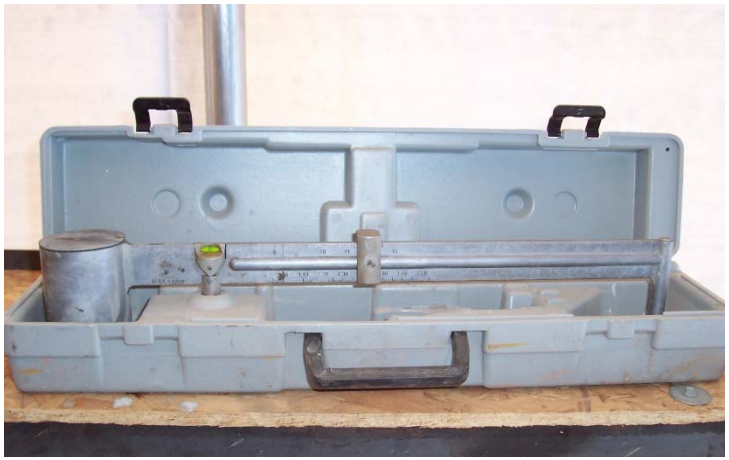
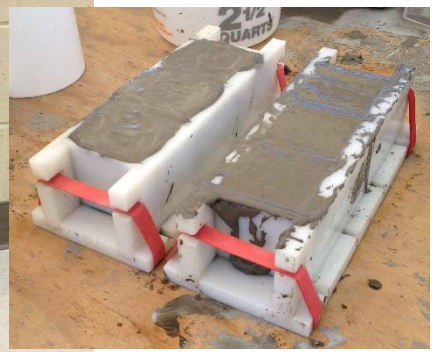
2019 Sinkhole Repair – Grout Testing

- Mud Balance (API RP-13B-1)
  - Used to determine unit weight
- Flow Cone (ASTM C939)
  - Used to determine flowability
- Compressive Strength (AASHTO T106)
  - 2-inch square cubes





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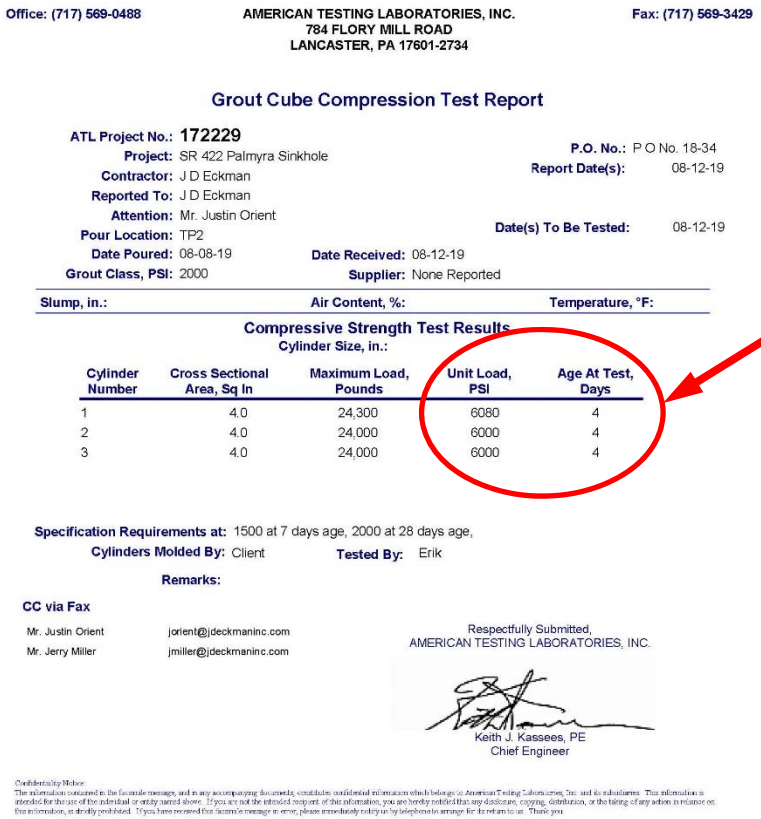
2019 Sinkhole Repair – Grout Testing (Cont'd.)



Office: (717) 569-0488

AMERICAN TESTING LABORATORIES, INC.
784 FLORY MILL ROAD
LANCASTER, PA 17601-2734

Fax: (717) 569-3429

Grout Cube Compression Test Report

ATL Project No.: 172229
Project: SR 422 Palmyra Sinkhole
Contractor: J D Eckman
Reported To: J D Eckman
Attention: Mr. Justin Orient
Pour Location: TP2
Date Poured: 08-08-19
Grout Class, PSI: 2000

P.O. No.: P O No. 18-34
Report Date(s): 08-12-19
Date(s) To Be Tested: 08-12-19
Date Received: 08-12-19
Supplier: None Reported

Slump, in.: **Air Content, %:** **Temperature, °F:**

Compressive Strength Test Results

Cylinder Size, in.:

Cylinder Number	Cross Sectional Area, Sq In	Maximum Load, Pounds	Unit Load, PSI	Age At Test, Days
1	4.0	24,300	6080	4
2	4.0	24,000	6000	4
3	4.0	24,000	6000	4

Specification Requirements at: 1500 at 7 days age, 2000 at 28 days age,
Cylinders Molded By: Client **Tested By:** Erik
Remarks:

CC via Fax

Mr. Justin Orient jorient@jdeckmaninc.com
Mr. Jerry Miller jmiller@jdeckmaninc.com

Respectfully Submitted,
AMERICAN TESTING LABORATORIES, INC.

Keith J. Kassees, PE
Chief Engineer

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Required grout compressive strength = 2,000 psi @ 3 days and 5,000 psi @ 28 days

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2019 Sinkhole Repair – Micropile Reinforcement

2019 Sinkhole Repair – Micropile Logging and Record Keeping

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ECMS No. 111832

Micropile Drilling Log

Project: SR 0422 SEC 041 - Palmyra Sinkhole
Location: Lebanon Co.
Client: PennDOT - Dist. 8-0
GF Project No: 65830
Contractor: JD Eckman - Redstone International
Inspector: C. Hallahan

Drilling Complete

Pile No.	3A	Ground Surface (GS) Elev.	427.18
Station / Offset	790+64.09	Pile Cutoff (CO) Elev.	427.63
Drilling Date	8/22/19	Bottom of Slab Elev.	427.38
Drill Rig/Drill Method	Commacchio MC1200/Duplex	Time Drilling Started	11:50 AM
Drill Rig Operator	Tyler Cottrell	Time Drilling Ended	1:30 PM

Drill Bit Type and Size	8.305" / 10.353"	Cased Length (from CO Elev.)	47.45	ft
Casing Diameter/Wall Thickness	9.625 in / 0.472 in	Plunge Length	1.0	ft
Hole Inclination	0 ° from vertical	Uncased (Bond) Length	5.0	ft
Hole Bearing	—	Total Length (from CO Elev.)	52.45	ft

Drilling Observations

427.18 Elev. (ft)	Depth from Ground Surface (ft)	Hammer: None	Hammer: Intermittent	Hammer: Steady	Soil/Rock Cuttings/Materials Description/Groudwater Observations
	0'-3.5'		X		Brown Clay & Soil cuttings — R1 Run Time = 4:24
	3.5'-8.5'		X		Brown Clay & Soil cuttings
	8.5'-13.0'		X		— R2 Run Time = 10:40
	13.0'-14.0'		X		Broken/weathered rock & soil cuttings
	14.0'-16.0'			X	Hard Rock (Dk gray limestone) — R3 Run Time = 7:15
	16.0'-18.5'		X		Brown Clay & Soil cuttings
	18.5'-23.5'		X		Brown Clay & Soil cuttings
	23.5'-26.0'		X		Broken/weathered rock & soil cuttings
	26.0'-28.0'		X		Brown Clay & soil cuttings — R4 Run Time = 4:30
	28.0'-37.0'	X			Possible void (no resistance to drill)
	37.0'-46.0'		X		Broken/weathered rock & soil cuttings
375.18	46.0'-52.0'			X	Hard Rock (Dk gray limestone) — R5 Run Time = 10:16
	EOB				R6 Run Time = 10:45

Additional Notes: Tape check @ end of drilling & casing raise = 52.0 bgs

Gannett Fleming

ECMS No. 111832

Micropile Installation & Grouting Log

Project: SR 0422 SEC 041 - Palmyra Sinkhole
Location: Lebanon Co.
Client: PennDOT - Dist. 8-0
GF Project No: 65830
Contractor: JD Eckman - Redstone International
Inspector: C. Hallahan

Install Complete

Pile No.	3A	Installer	Rocky Albright
Station / Offset	790+64.09	Time Installation Started	8/23/19 10:05 AM
Installation Date	8/23/19	Time Installation Ended	8/26/19 1:21 PM

Depth	Measurements	Elevation
+3.0 (ft)	Stick-up after raising casing	— (ft)
— (ft)	Stick-up after drilling	— (ft)
+0.45 (ft)	Stick-up after cutting	427.63 (ft)
+0.45 (ft)	Final Pile Cutoff	427.63 (ft)
+0.20 (ft)	Bottom of Slab	427.38 (ft)
0 (ft)	Ground Surface	427.18 (ft)
	Grout	
	Pile Casing	
	Cased Hole	
35.3 (ft)	Top of Bar (Bar Length = 16.7')	391.88 (ft)
	Centralizer	
	Reinforcing Steel	
46.0 (ft)	Top of Rock	381.18 (ft)
47.0 (ft)	Top of Bond Zone	380.18 (ft)
	Bottom of Pile Casing	
	Open Hole (10.353" Bit)	
52.0 (ft)	Bottom of Pile Tip	375.18 (ft)

Theoretical Grout Volume

Component	Vol/ft (ft^3/ft)		Length (ft)		Volume
A. Cased Hole	0.411	x	47.45	=	19.50 ft^3
B. Uncased Hole	0.585	x	5.0	=	2.925 ft^3
C. Rebar Volume	0.028	x	—	=	— ft^3
D.	Theoretical Grout Volume (A + B - C)			=	22.43 ft^3
E.	Theoretical Grout Volume (7.48 gal/ft^3 x D)			=	168 gal
F.	2 x Theoretical Grout Volume (2 x E)			=	336 gal

Pile Casing Length (ft)

After Drilling	After Initial Cutting	After Final Cutting
50 - 2.68	= 47.32 (Aug 23rd)	

Sounded Depths (ft)

Stage	Date	After Drilling	After Casing Raise	After Grout Set
1st Drilling	8/22/19	—	52.0' bgs	18.2' = 26-Aug-2019
Re-drill 1	26-Aug-2019	52.0 (08:52)	—	—
Re-drill 2			—	—

Grouting

Date	Time	Press (psi)	Injected Volume: ft^3	Gallons	%Theoretical
8/23/19	10:05AM	—	45.0	336.5	200%
8/26/19	1:02PM	—	24.0	180	107%

Vol. over 2x theo = 34 ft^3

Material Properties

Grout	Neat cement, min 2,000 psi @ 3 days, 5,000 psi @ 28 days
Pile Casing	9.625" OD, 8.861" ID, 0.472" wall thickness, 80 ksi steel
Reinforcing	#18, 75 ksi steel, 10' min, fully threaded, 3 centralizers (min)

Additional Notes: 26-Aug-2019 08:03: Measured depth to grout @ 18.2'. 08:11 Began re-drill (26-Aug). 09:02: Began moving off 3A after re-drill.

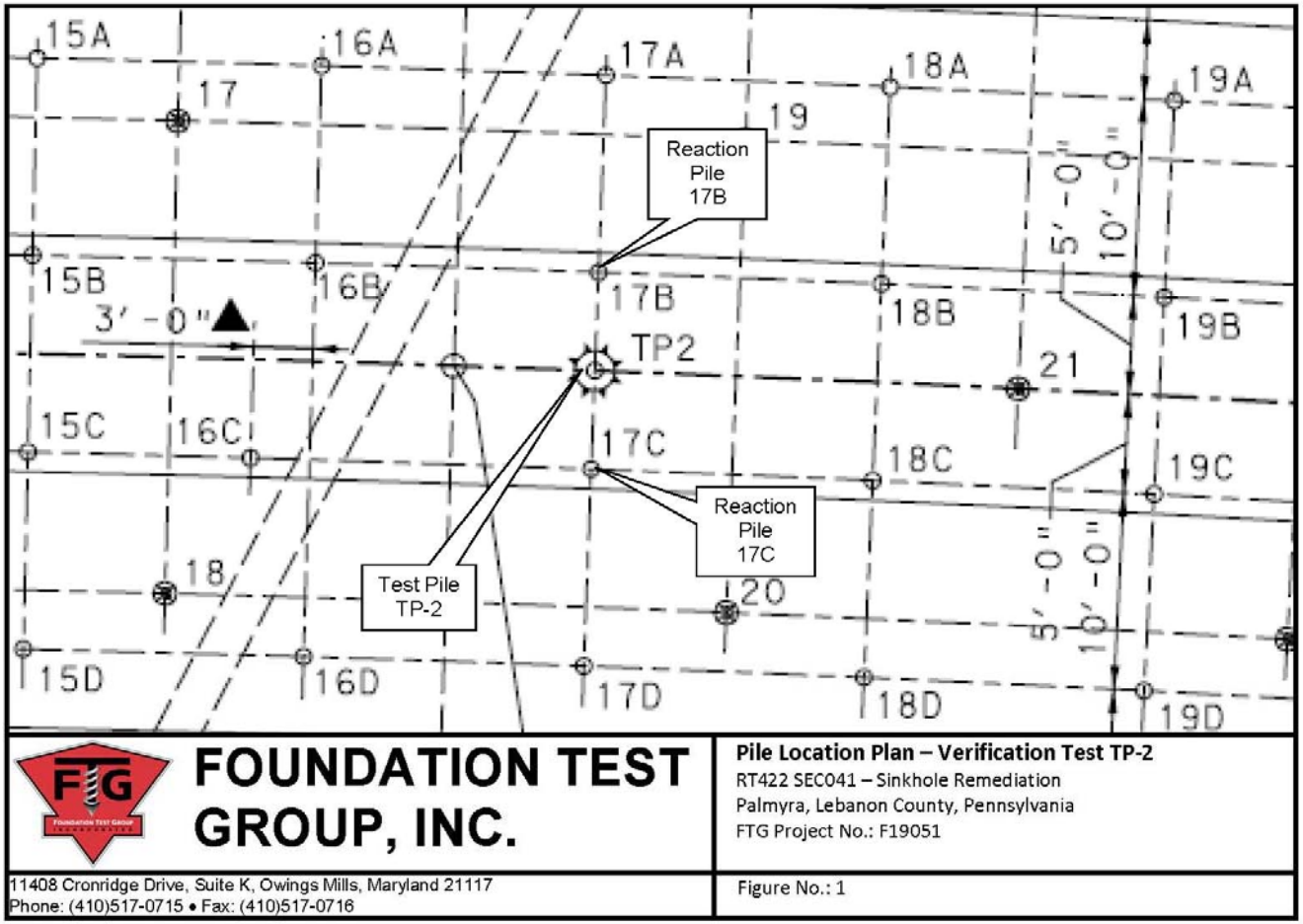
Reviewed by: _____

2019 Sinkhole Repair – Micropile Load Testing

- Why do load tests?
  - Verify design assumptions concerning bond zone strength
  - Adequacy of Contractor's installation methods
- Criteria for passing?
  - Pile must sustain the design load (i.e., service load) with no more than 0.75 inches of vertical movement
  - Failure does not occur at 2 times the design load
  - Creep rate requirements!

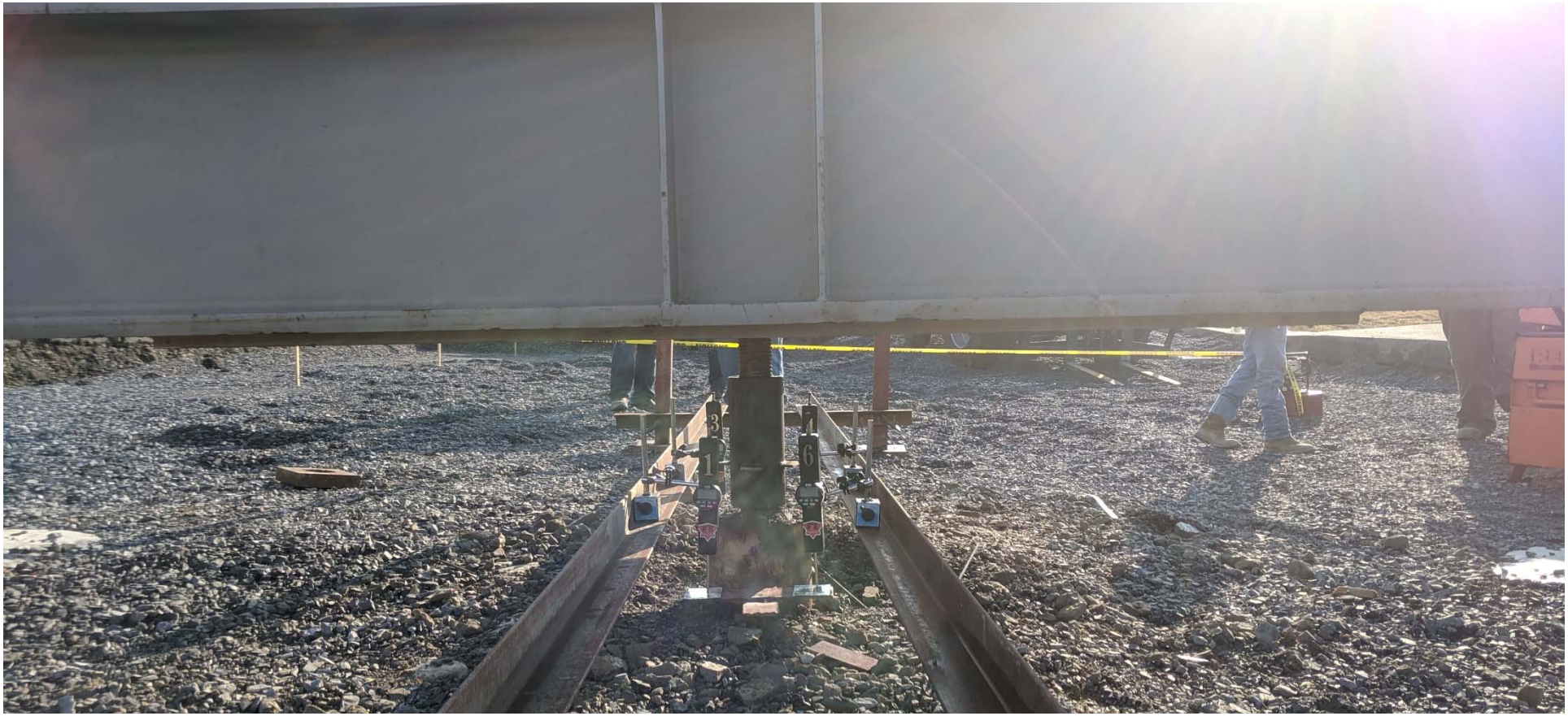
PILE LOADS (KIPS/PILE)	
ITEM	LOAD
FACTORED AXIAL COMPRESSIVE RESISTANCE, STRUCTURAL (PHI = 0.85)	327 KIPS
FACTORED AXIAL COMPRESSIVE RESISTANCE, GROUT TO ROCK BOND (PHI = 0.80)	327 KIPS
FACTORED AXIAL COMPRESSIVE LOAD	327 KIPS
LIMIT STATE	STR-I
DESIGN LOAD, DL (UNFACTORED)	220 KIPS
VERIFICATION TEST LOAD (2 X DL)	440 KIPS
PROOF TEST LOAD (1.6 X DL)	352 KIPS

Load Test Plan

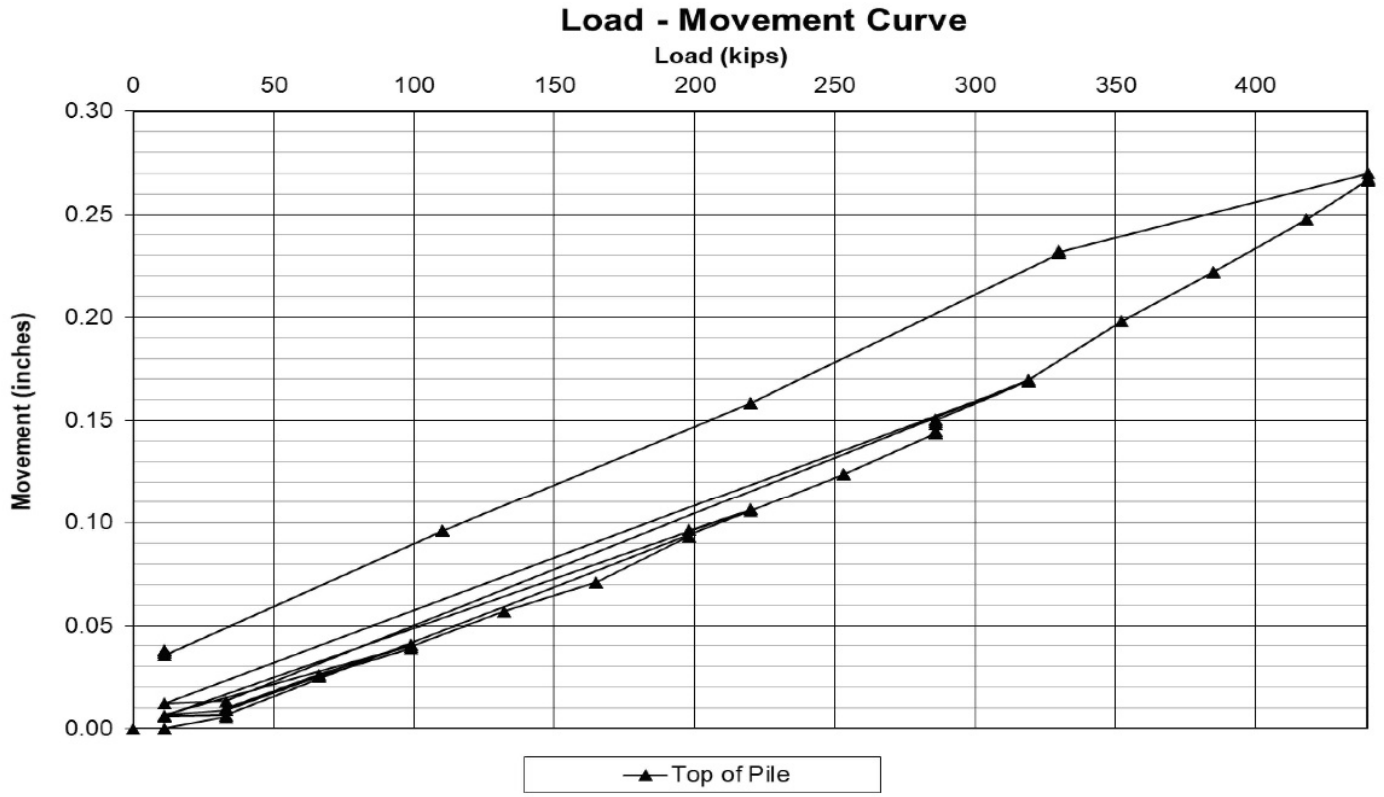


2019 Sinkhole Repair - Load Test Setup

2019 Sinkhole Repair - Load Test Gauges



2019 Sinkhole Repair - Load Test Jack and Recording Equipment

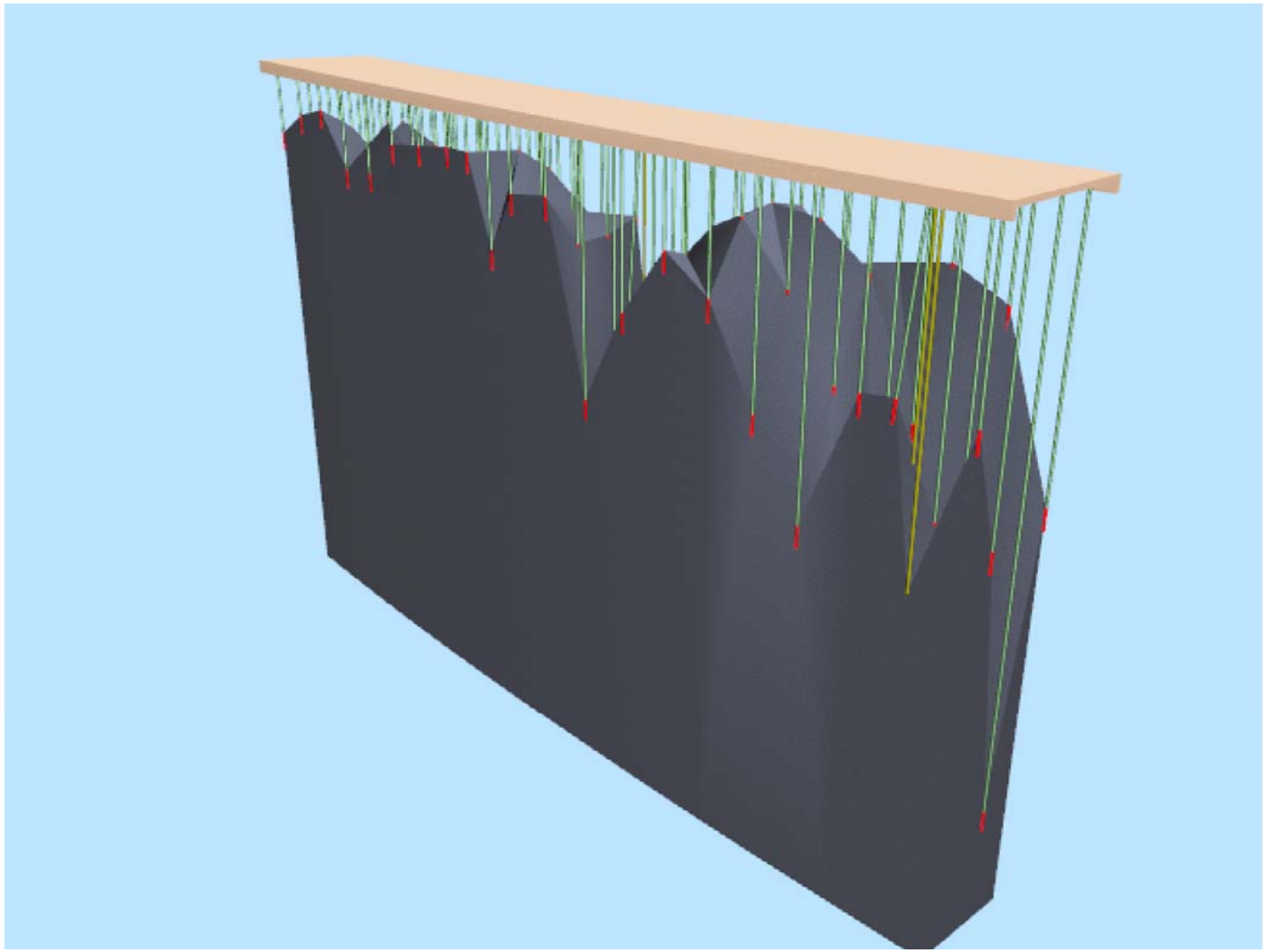


FOUNDATION TEST GROUP, INC.

11408 Cronridge Drive, Suite K, Owings Mills, Maryland 21117
Phone: (410)517-0715 • Fax: (410)517-0716

Load Movement Curve – Verification Test TP-2
RT422 SEC041 – Sinkhole Remediation
Palmyra, Lebanon County, Pennsylvania
FTG Project No.: F19051

Graph No.: 1



mised

2019 Sinkhole Repair – Completed Micropile Stats

- 89 Micropiles Installed
- (84 production piles + 2 test piles + 3 abandoned piles)
  - 86 planned (84 production + 2 test piles)
- Total Length = 4,436.5 feet (Estimated 4,957 feet)
- Minimum length = 17.5 feet
- Maximum length = 179.5 feet
- Average ~ 50 feet

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2019 Sinkhole Repair - Bottom Rebar Mat and Inspection Ports

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2019 Sinkhole Repair - Top Rebar Mat and Inspection Ports

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Excellence Delivered ***As Promised***

2019 Sinkhole Repair – Concrete Placement

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Excellence Delivered ***As Promised***

2019 Sinkhole Repair – Screeding and Finishing Concrete

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Excellence Delivered ***As Promised***

2019 Sinkhole Repair – Construction Complete!


Questions?
Thank you to the 2020 Mid-Atlantic QAW and PennDOT!