

Case Study: Design and Installation of Large Diameter Open-Ended Pipe Piles for a DOT Project: Lessons Learned

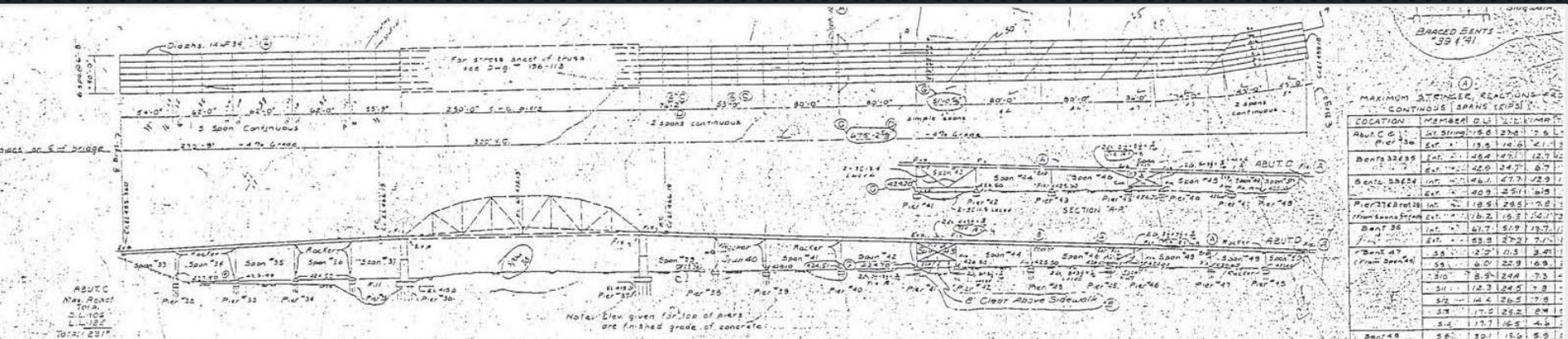
OUTLINE

- Project Overview
- Geology/Geotechnical Investigation
- Project Constraints
- The Problem
- The Solution

PROJECT OVERVIEW

- Replacement of the Original East Approach to the MLK Bridge over the Mississippi River in East St. Louis, Illinois
- Existing Structure
  - 1950s (1985 East Rehab)
  - 15 spans
  - 250' through truss span over RR
  - Multi-beam and curved girder spans





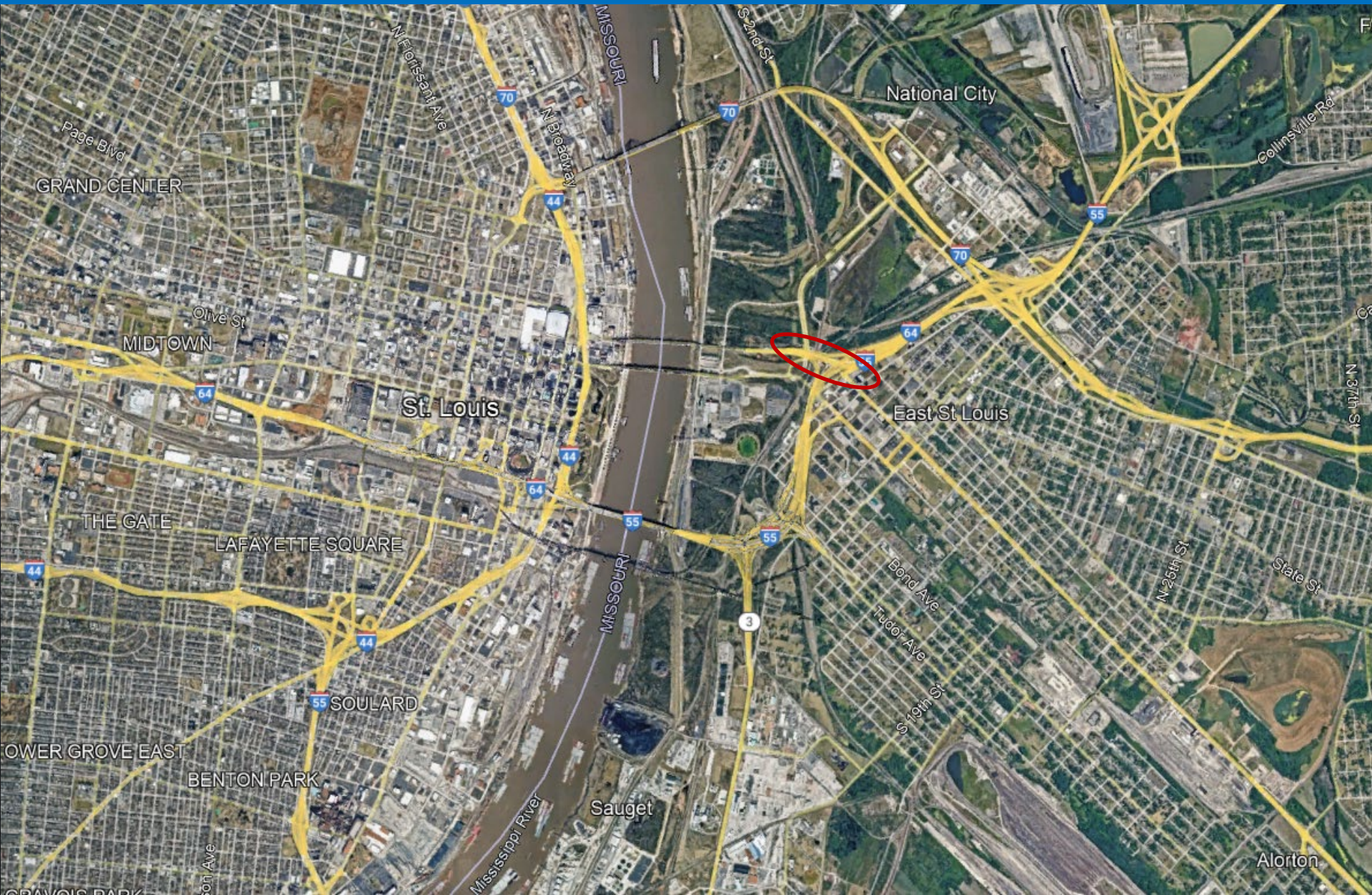
PROJECT OVERVIEW

- Proposed Structure
  - Built 2018-2020
  - 5 spans
  - Total Length ~1280 feet
  - Steel hybrid plate girder, curved at east end
  - LD OE Pipe Pile Piers
  - Stub Abutments on H-piles
  - MSE Wall with Lightweight Fill
- Design Specifications
  - Seismic Performance Zone = 2
  - 2014 AASHTO LRFD with 2015 and 2016 Interims





PROJECT OVERVIEW



PROJECT OVERVIEW



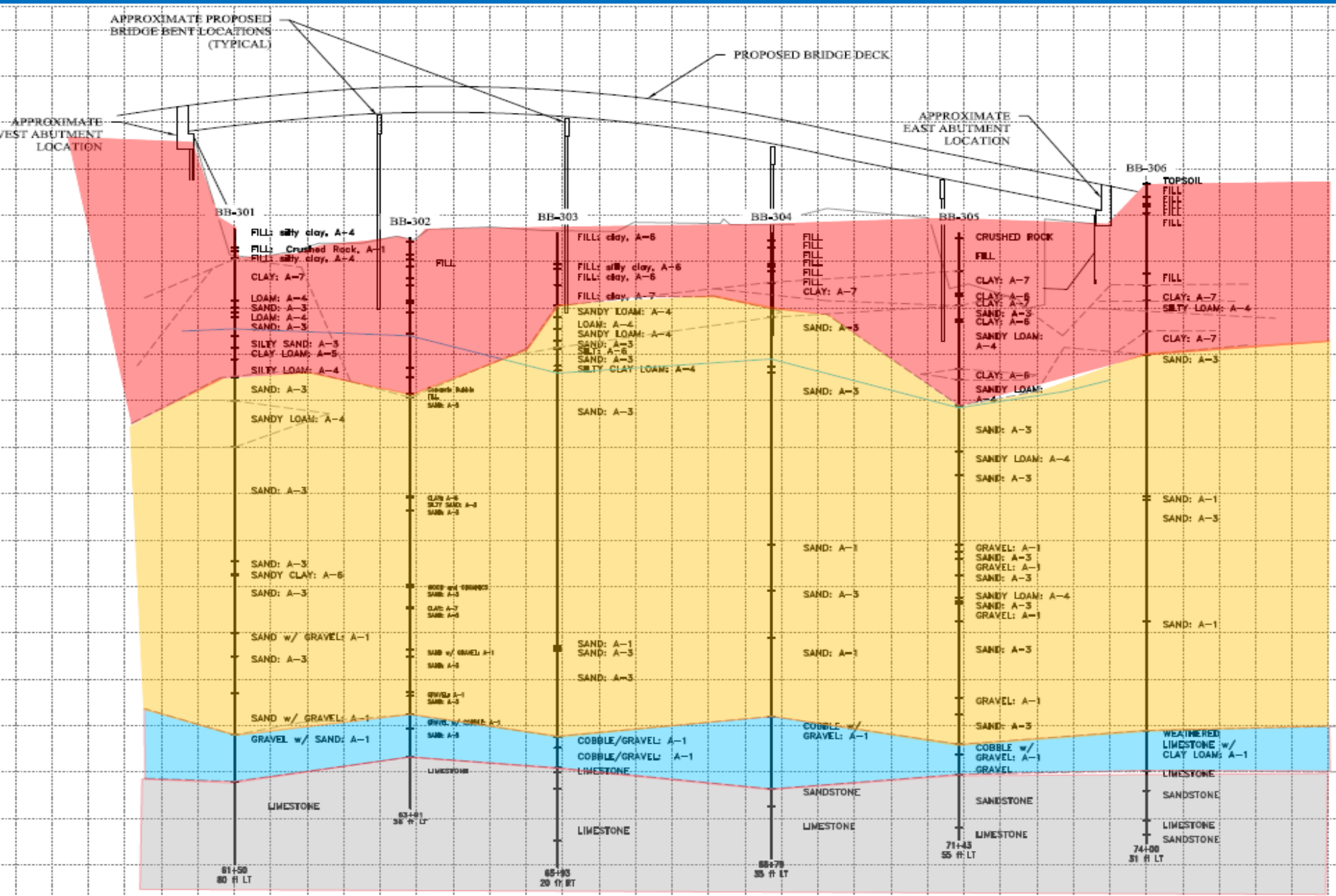
GEOLOGY

- Geology
  - "American Bottoms"
  - Fluvial Floodplain Soils
  - Typically Interbedded Silts, Clays, Sand, and Gravel
  - Bedrock ~115-120 Feet
    - Limestone
  - ~200 Years of Development
    - = Debris
      - Concrete, RR Ties, and Other Random RR Related Debris

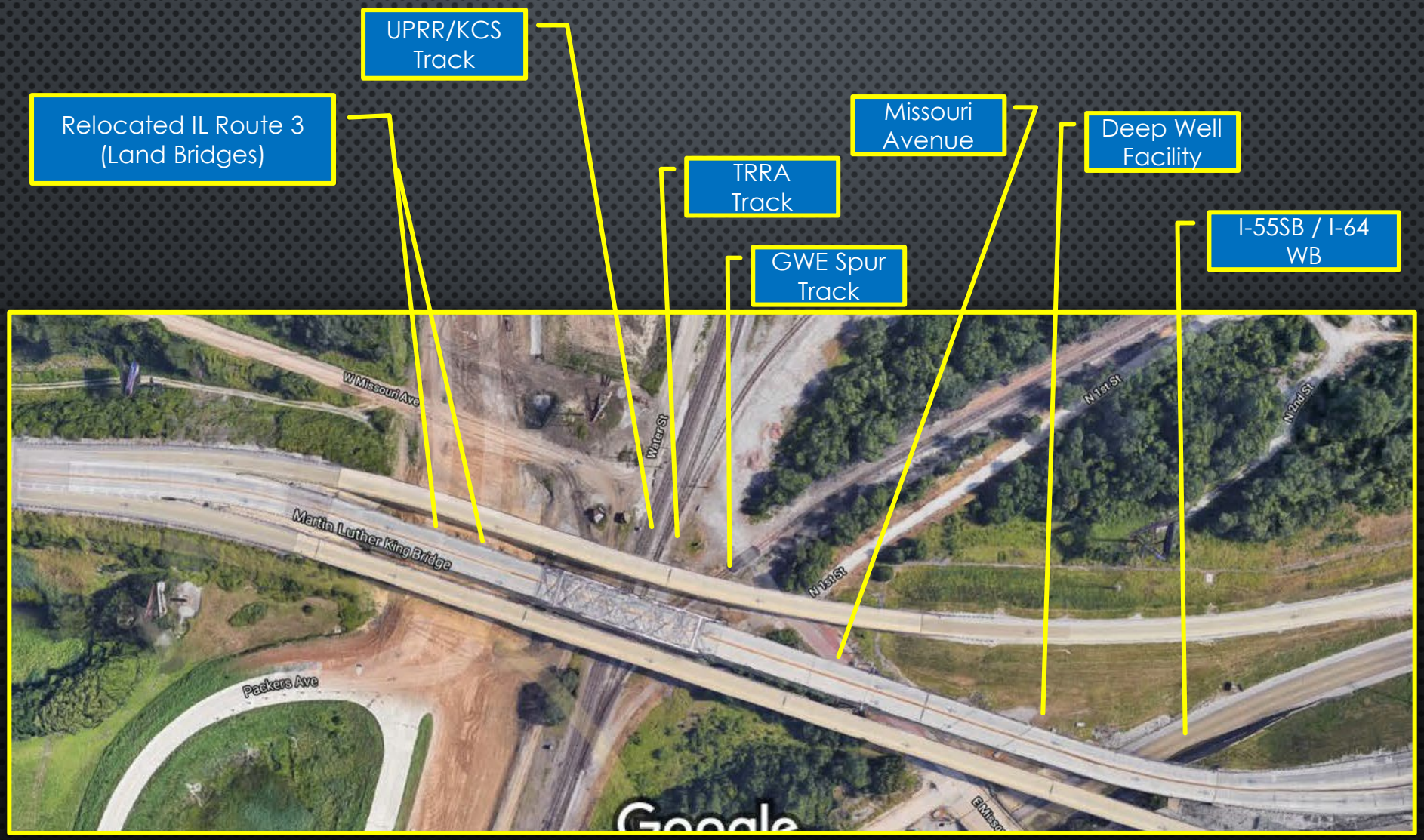


American Bottom Map

GEOTECHNICAL INVESTIGATION



GEOMETRIC CONSTRAINTS



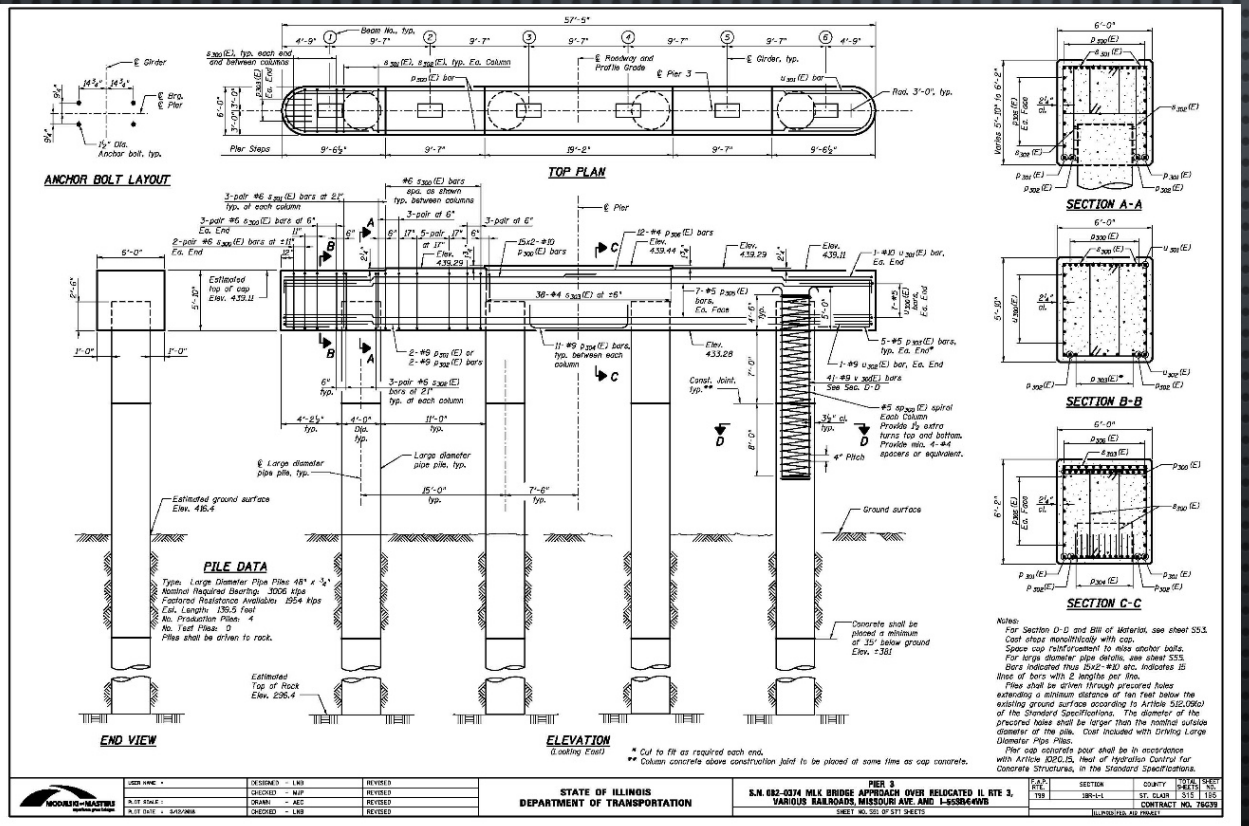
FOUNDATION SELECTION





- DRIVEN PILES – "CONVENTIONAL" AND LDOEPP
- DRILLED SHAFTS

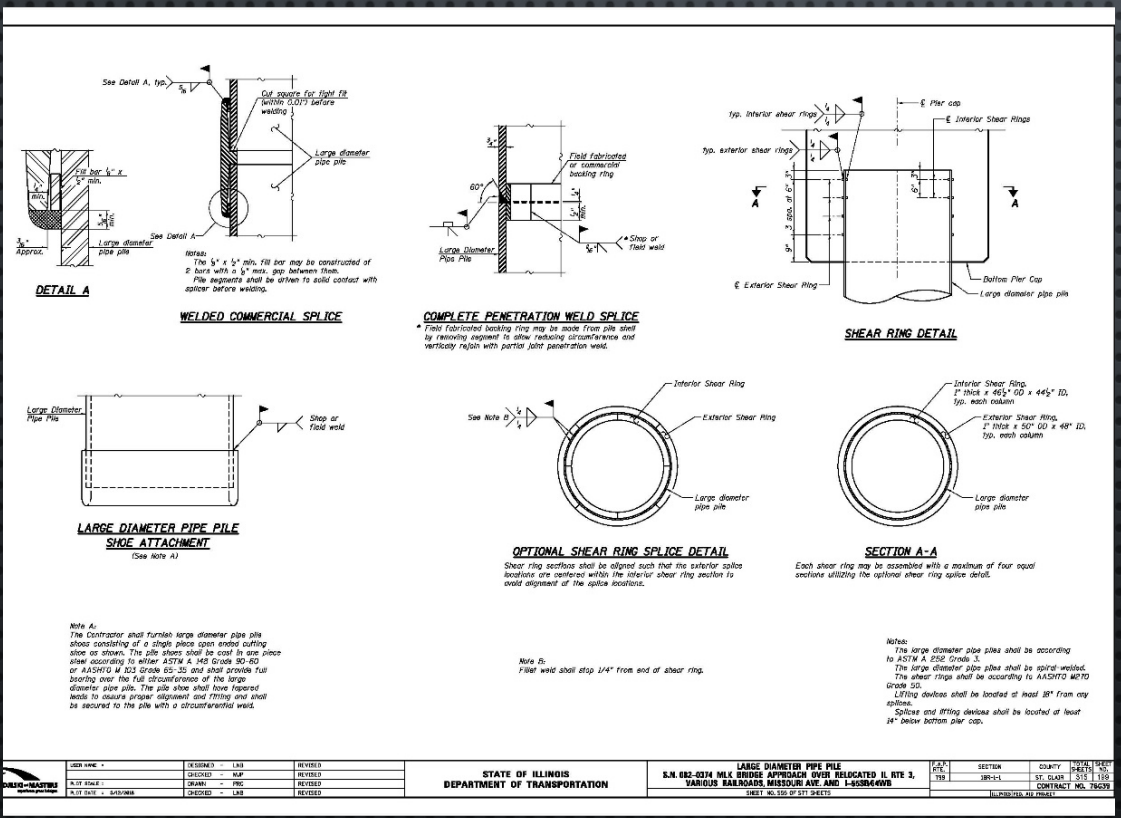
PIPE PILE DESIGN



- Pile Requirements
  - 4 piles each pier
  - 4’ diameter
  - ¾” thickness
  - Nominal Req. Bearing = 3006 kips
  - Factored Resistance Available = 1954 kips

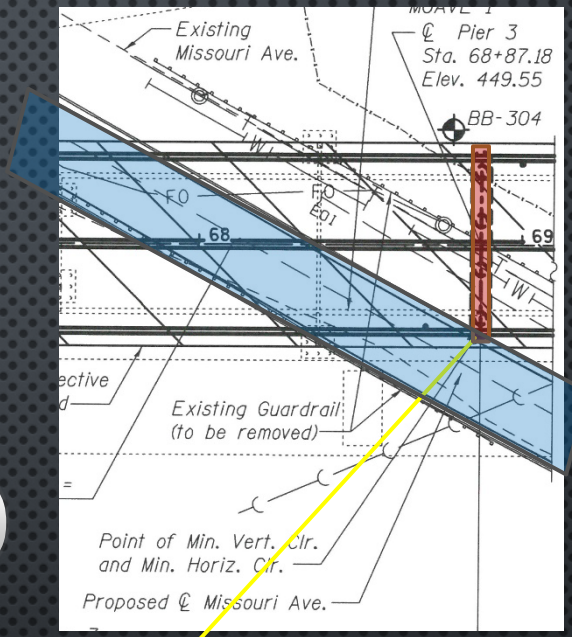
PIPE PILE DESIGN

- Pile Requirements
  - ASTM A 252 Grade 3
  - Spiral-Welded
  - Shear Rings – AASHTO M270 Grade 50
  - Pile Shoes Required



THE PROBLEM

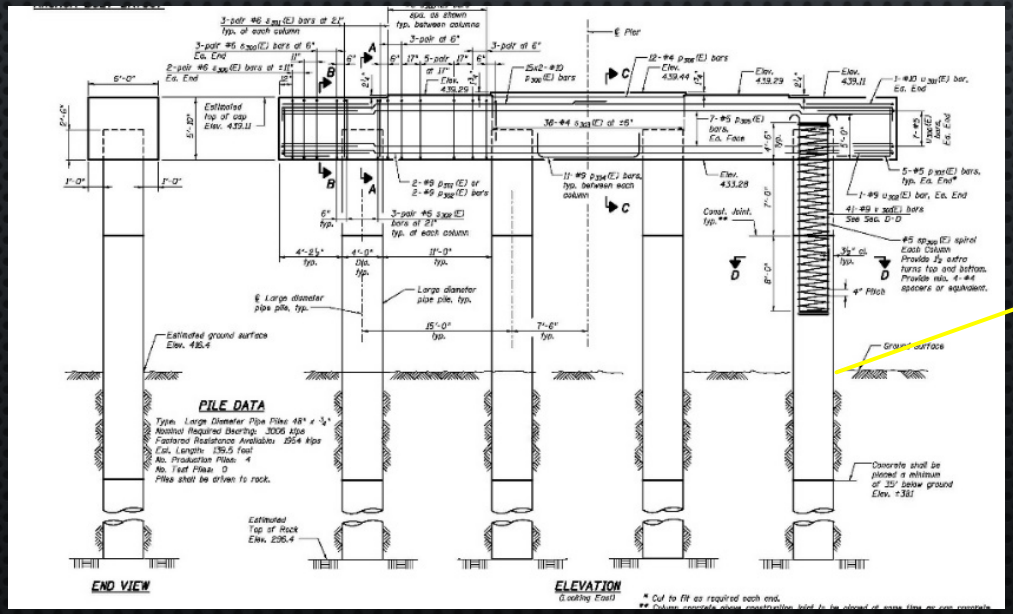
- NOVEMBER 27, 2018
- PIER 3, PILE 4
- DAMAGE INDICATED AT +/- 119 FEET
- GRL RECOMMENDATION TO UTILIZE SKIN FRICTION CAPACITY ONLY (+/- 495 KIPS)



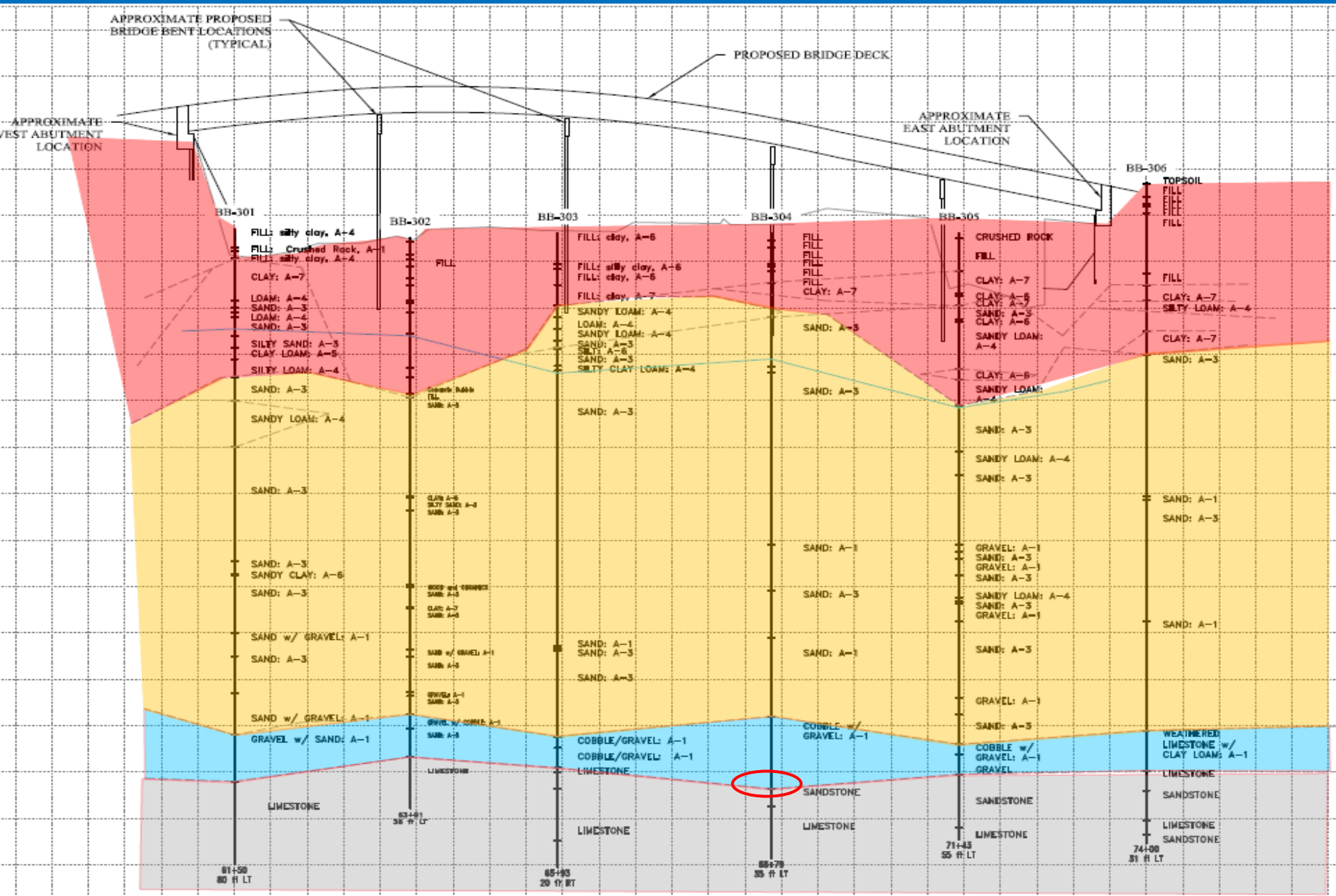
Missouri Avenue

Pier 3, Pile 4

Pile 4



THE PROBLEM


APPROXIMATE PROPOSED BRIDGE BENT LOCATIONS (TYPICAL)
PROPOSED BRIDGE DECK
APPROXIMATE WEST ABUTMENT LOCATION
APPROXIMATE EAST ABUTMENT LOCATION
BB-301
BB-302
BB-303
BB-304
BB-305
BB-306
FILL: silty clay, A-4
FILL: Crushed Rock, A-1
FILL: silty clay, A-4
CLAY: A-7
LOAM: A-4
SAND: A-3
LOAM: A-4
SAND: A-3
SILTY SAND: A-3
CLAY LOAM: A-6
SILTY LOAM: A-4
SAND: A-3
SANDY LOAM: A-4
SAND: A-3
SAND: A-3
SANDY CLAY: A-6
SAND: A-3
SAND w/ GRAVEL: A-1
SAND: A-3
SAND w/ GRAVEL: A-1
GRAVEL w/ SAND: A-1
LIMESTONE
FILL
FILL: clay, A-6
FILL: silty clay, A-6
FILL: clay, A-6
FILL: clay, A-7
SANDY LOAM: A-4
LOAM: A-4
SANDY LOAM: A-4
SAND: A-3
SILT: A-6
SAND: A-3
SILTY CLAY LOAM: A-4
SAND: A-3
SAND: A-1
SAND: A-3
SAND: A-3
COBBLE/GRAVEL: A-1
COBBLE/GRAVEL: A-1
LIMESTONE
LIMESTONE
FILL
FILL
FILL
FILL
FILL
CLAY: A-7
SAND: A-3
SAND: A-3
SAND: A-3
COBBLE w/ GRAVEL: A-1
SANDSTONE
LIMESTONE
CRUSHED ROCK
FILL
CLAY: A-7
CLAY: A-6
CLAY: A-7
SAND: A-3
CLAY: A-6
SANDY LOAM: A-4
CLAY: A-6
SANDY LOAM: A-4
SAND: A-3
SAND: A-3
SANDY LOAM: A-4
SAND: A-3
GRAVEL: A-1
SAND: A-3
GRAVEL: A-1
SAND: A-3
SANDY LOAM: A-4
SAND: A-3
GRAVEL: A-1
SAND: A-3
GRAVEL: A-1
SAND: A-3
COBBLE w/ GRAVEL: A-1
GRAVEL
LIMESTONE
SANDSTONE
LIMESTONE
TOPSOIL
FILL
FILL
FILL
FILL
FILL
CLAY: A-7
SILTY LOAM: A-4
CLAY: A-7
SAND: A-3
SAND: A-1
SAND: A-3
SAND: A-1
WEATHERED LIMESTONE w/ CLAY LOAM: A-1
LIMESTONE
SANDSTONE
LIMESTONE
SANDSTONE
61+50 80 ft LT
63+01 36 ft LT
65+93 20 ft RT
68+79 55 ft LT
71+43 55 ft LT
74+00 51 ft LT

THE PROBLEM

Illinois Department of Transportation
Division of Highways
SCI Engineering, Inc.

SOIL BORING LOG

Page 3 of 4

Date 6/6-6/8/2016

ROUTE Interstate 64 DESCRIPTION PTB 172, Item 22 - FAP 799 (MLK Drive) LOGGED BY BDG (SCI)

SECTION 1BR-1-1 LOCATION East Saint Louis, Illinois, SEC. , TWP. , RNG. , Latitude , Longitude

COUNTY Saint Clair DRILLING METHOD CME 550 w/HSA HAMMER TYPE Automatic

STRUCT. NO. 082-6003(E), 082-0374(P)
Station

BORING NO. BB-304
Station 68+79
Offset 35.0 ft LT
Ground Surface Elev. 416.0 ft

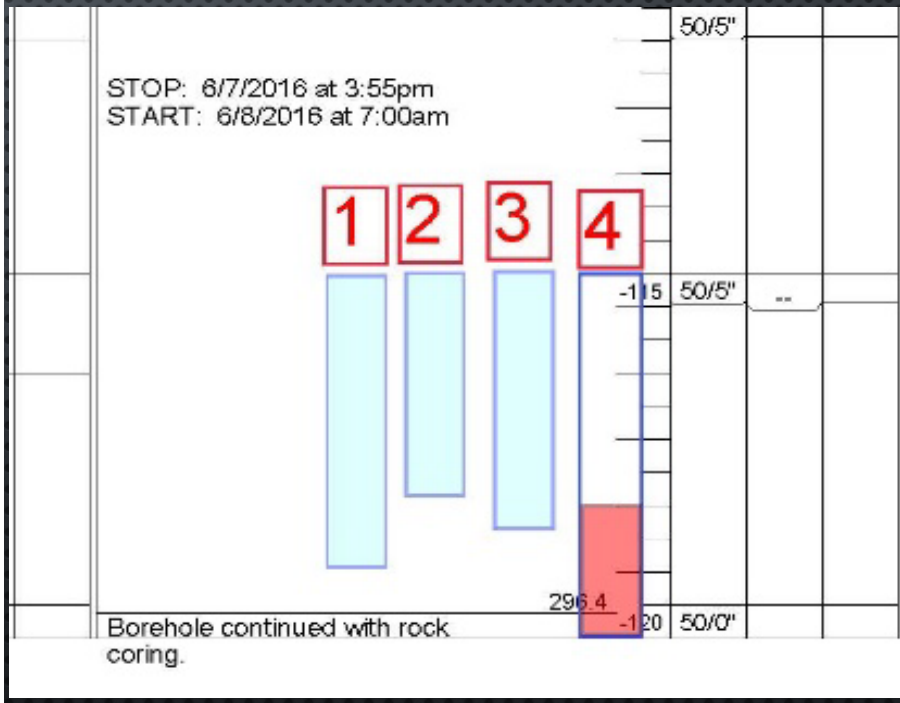
Surface Water Elev. N/A ft
Stream Bed Elev. N/A ft

Groundwater Elev.:
First Encounter 389.0 ft
Upon Completion N/A ft
After N/A Hrs. N/A ft

DEPTH (ft)	BLOWS (/6")	UCS Qu (tsf)	MOIST (%)	Description
				SAND: Gray, A-3 *(continued)*
				Rough drilling from 81.0'-82.0'
	10 13 14	N/C		
-85				
				Rough drilling from 85.5'-88.5'
329.0				
				SAND: Gray, medium to coarse, with gravel, A-1
				Advance with casing at 88.5'
-90	17 24 28	N/C		
-95	14 21 27	N/C		
-100	22			
	23 26	N/C		SAND: Gray, medium to coarse, with gravel, A-1 *(continued)*
				Intermittent hard drilling from 101.0'-104.0'
312.0				
-105	25 33 50/5"	N/C		COBBLE w/ GRAVEL: Gray and brown, A-1
-110	18 37 50/5"	N/C		Rock fragments in sample
				STOP: 6/7/2016 at 3:55pm START: 6/8/2016 at 7:00am
-115	50/5"	--		
296.4				
-120	50/0"			Borehole continued with rock coring.

1 2 3 4

The Unconfined Compressive Strength (UCS) Failure Mode is indicated by (B-Bulge, S-Shear, P-Penetrometer)
AASHTO Classifications are based on visual classifications unless otherwise noted BBS, form 137 (Rev. 8-99)



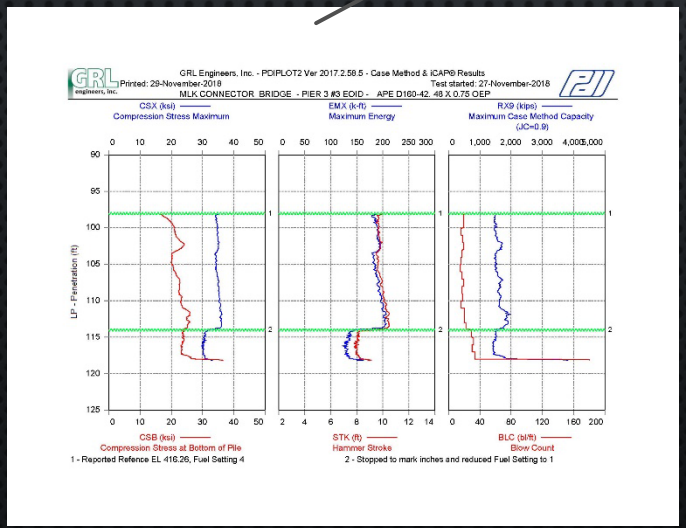
THE PROBLEM

- MW HIRES MM AND SCI – JANUARY 17, 2019
- SCI ENGAGED UNIVERSAL ENGINEERING (PDA EXPERT)
- UNIVERSAL ENGINEERING RECOMMENDS MAXIMUM ULTIMATE CAPACITY OF **1250 KIPS**
  - 750 KIPS END BEARING
  - 495 KIPS FROM SKIN FRICTION

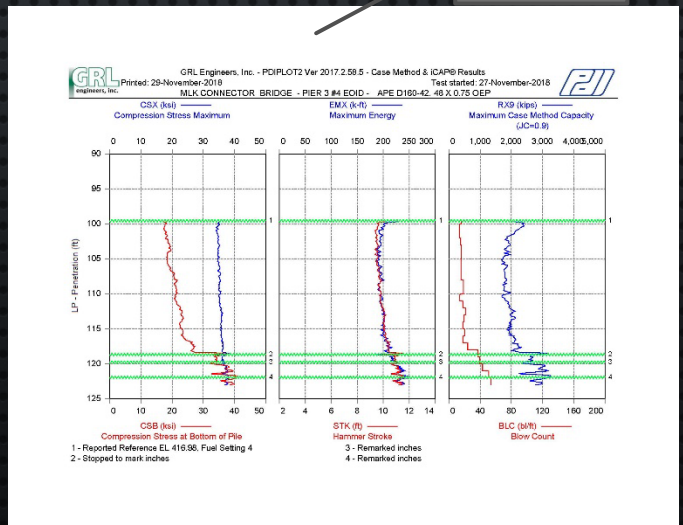
Pile Requirements

- Nominal Req. Bearing = 3006 kips
- Factored Resistance Available = 1954 kips

Pile 3



Pile 4



THE PROBLEM

- WHAT DO WE ACTUALLY NEED?

Service Load Conditions				
Nominal Required Bearing (kips)	Factored Resistance Available (kips)	Estimated Actual Ultimate Pile Bearing Capacity (kips)	Estimated Actual Factored Resistance Available (kips)	Total Original Pile Design Load (kips)
3006	1954	1250	813	1654
Extreme Event - Seismic Loading				
Nominal Required Bearing (kips)	Factored Resistance Available (kips)	Estimated Actual Ultimate Pile Bearing Capacity (kips)	Estimated Actual Factored Resistance Available (kips)	Total Original Pile Design Load (kips)
3006	3006	1250	1250	2012

THE SOLUTION

- What are our options?
  - Do Nothing (Load Test Option)
  - Grout Option
  - Drilled Shaft Option
  - Remove the Pile
  - Additional Pile Outside Original Pile

THE SOLUTION

- First – Try and figure out what happened
- Additional Investigation
  - Cut pipe pile at grade
  - Perform up to 3 additional borings inside the casing
    - 2 borings approx. 6” from edge of pile
    - 1 boring at center of pile
  - Re-assess/Determine Next Steps



THE SOLUTION



THE SOLUTION



THE SOLUTION



THE SOLUTION

- Results
  - All three borings encountered steel at a depth near 118.5 feet (116.75 feet below ground)
  - Suggests that pile buckled inward on itself evenly



The Solution

- What do we do?
  - Pull Pile
  - Drill it Out and turn it into a drilled shaft
  - Additional piles with pile cap to bolster original
  - Additional Larger Diameter Pipe Pile

THE SOLUTION

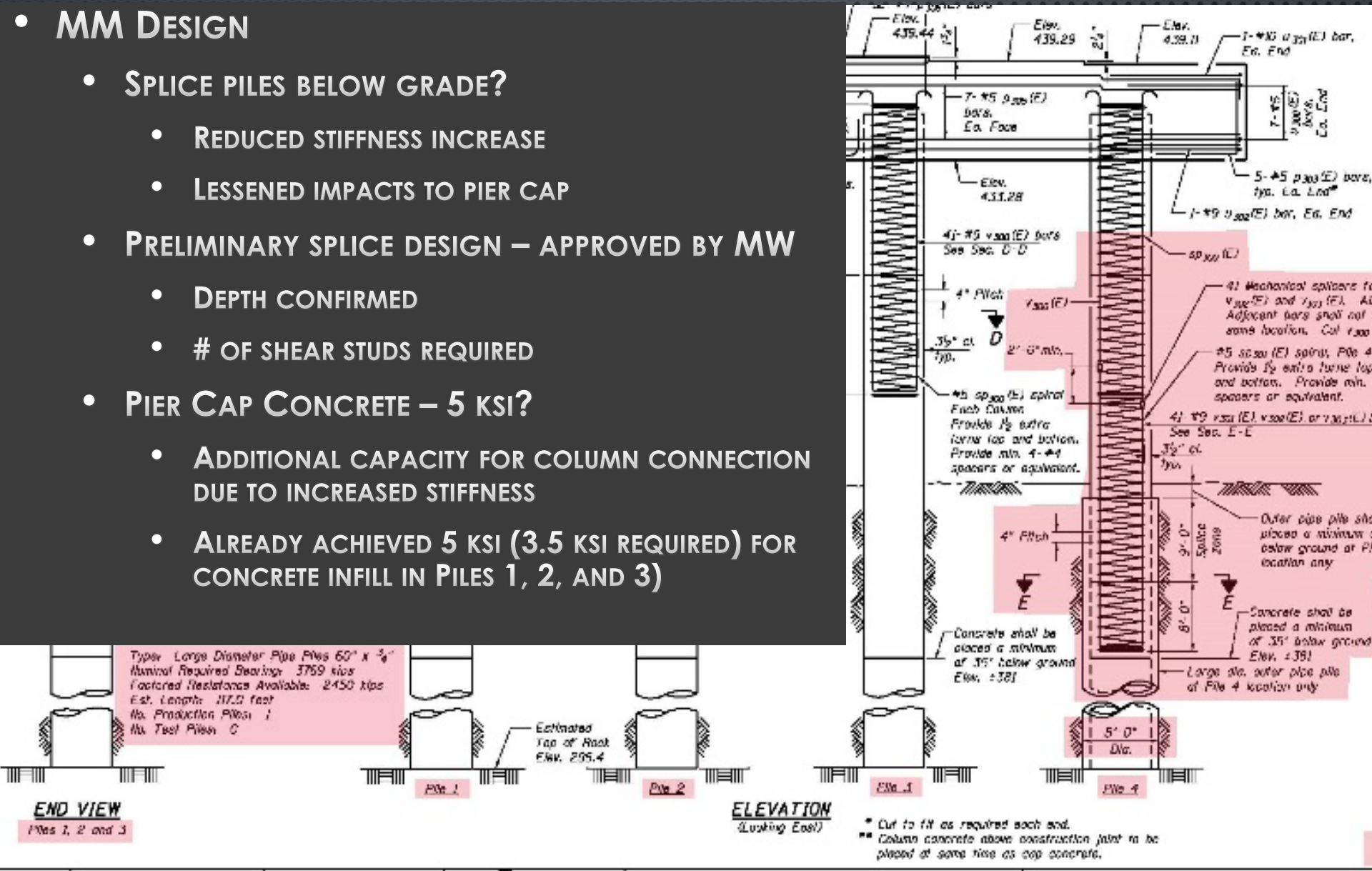
- What do we do?
  - Pull Pile
  - Drill it Out and turn it into a drilled shaft
  - Additional piles with pile cap to bolster original
  - Additional Larger Diameter Pipe Pile
    - 5-Foot Diameter

DESIGNING THE SOLUTION

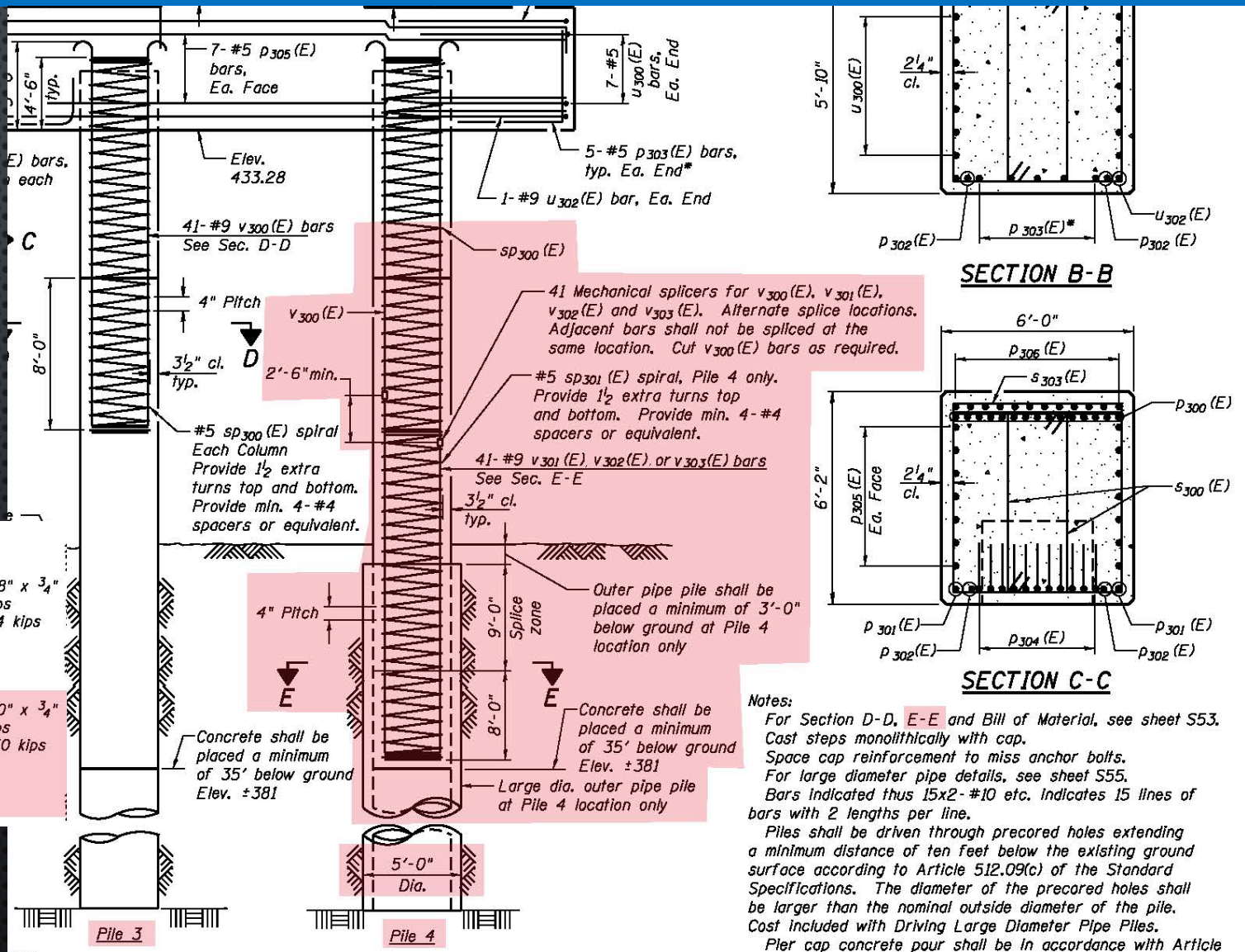
- Preferred Solution
  - 60” Diameter ¾” thick around the original 48” diameter pile
  - Pile shoe included
- Additional Considerations
  - Redesign assumes the 60” pile can achieve nominal required bearing of 3769 kips
  - MW/GRL were responsible for the driving procedure

DESIGNING THE SOLUTION

- MM Design
  - Splice piles below grade?
    - Reduced stiffness increase
    - Lessened impacts to pier cap
  - Preliminary splice design – approved by MW
    - Depth confirmed
    - # of shear studs required
  - Pier Cap Concrete – 5 ksi?
    - Additional capacity for column connection due to increased stiffness
    - Already achieved 5 ksi (3.5 ksi required) for concrete infill in Piles 1, 2, and 3)



DESIGNING THE SOLUTION



PILE DATA

Type: Large Diameter Pipe Piles 48" x $\frac{3}{4}$"
Nominal Required Bearing: 3006 kips
Factored Resistance Available: 1954 kips
Est. Length: 139.5 feet
No. Production Piles: 4
No. Test Piles: 0

Type: Large Diameter Pipe Piles 60" x $\frac{3}{4}$"
Nominal Required Bearing: 3769 kips
Factored Resistance Available: 2450 kips
Est. Length: 117.0 feet
No. Production Piles: 1
No. Test Piles: 0

* Cut to fit as required each end.
** Column concrete above construction joint to be placed at same time as cap concrete.

SECTION B-B

SECTION C-C

Notes:

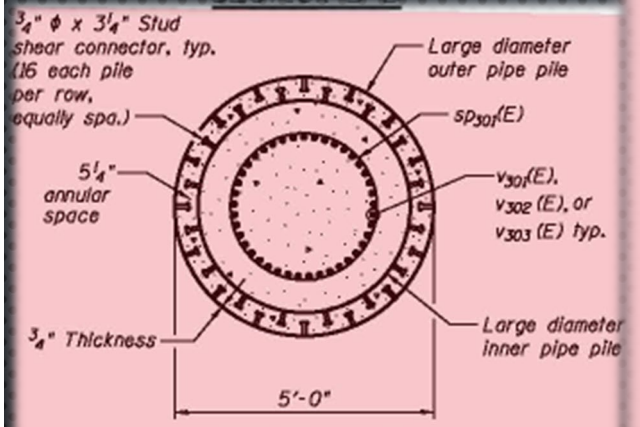
For Section D-D, E-E and Bill of Material, see sheet S53.
Cast steps monolithically with cap.
Space cap reinforcement to miss anchor bolts.
For large diameter pipe details, see sheet S55.
Bars indicated thus 15x2-#10 etc. indicates 15 lines of bars with 2 lengths per line.
Piles shall be driven through precored holes extending a minimum distance of ten feet below the existing ground surface according to Article 512.09(c) of the Standard Specifications. The diameter of the precored holes shall be larger than the nominal outside diameter of the pile. Cost included with Driving Large Diameter Pipe Piles.
Pier cap concrete pour shall be in accordance with Article 1020.15, Heat of Hydration Control for Concrete Structures; in the Standard Specifications.
All concrete for Pier 3 shall have 28 day compressive strength of at least 5,000 psi.

DESIGNING THE SOLUTION

PIER 3
BILL OF MATERIAL

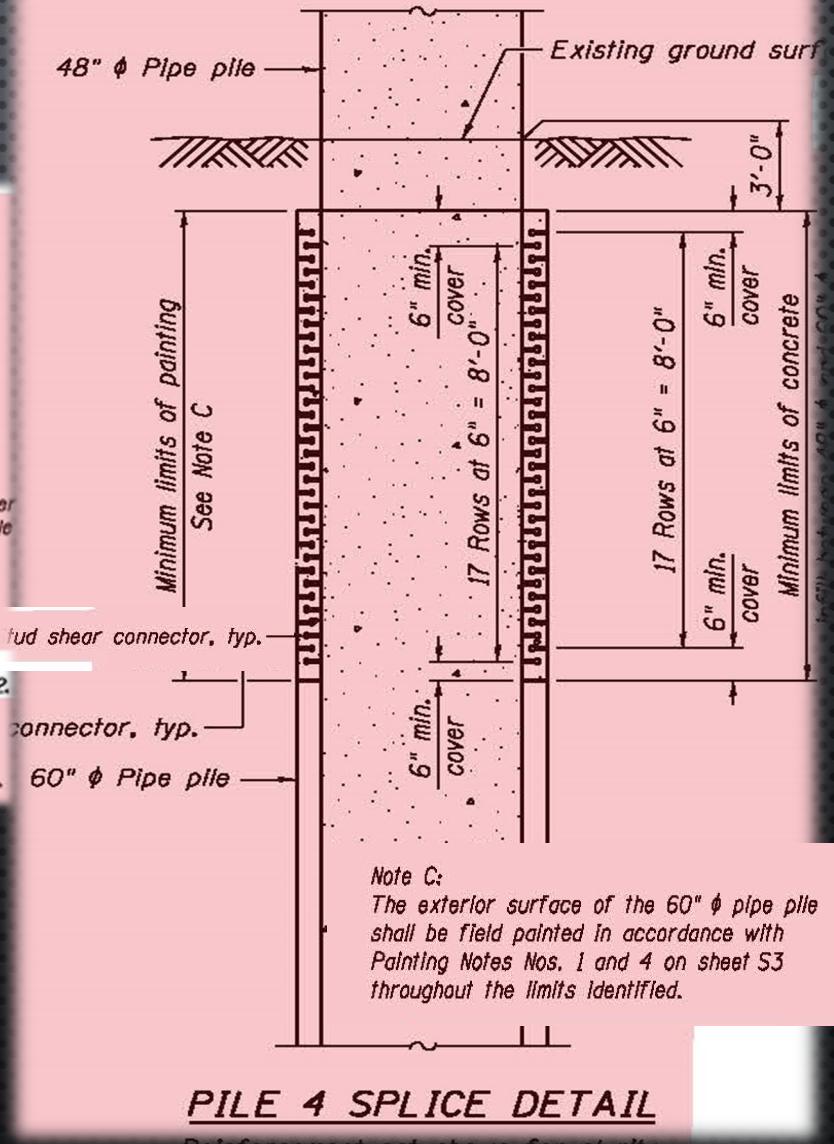
**	sp_{300} (E)	4	#5	19'-6"	
**	sp_{301} (E)	1	#5	22'-0"	
	u_{300} (E)	14	#5	14'-2"	
	u_{301} (E)	2	#10	22'-2"	
	u_{302} (E)	2	#9	19'-6"	
	v_{300} (E)	164	#9	21'-3"	
	v_{301} (E)	20	#9	22'-0"	
	v_{302} (E)	20	#9	24'-6"	
	v_{303} (E)	1	#9	27'-0"	
	Concrete Structures			Cu. Yd.	169.6
	$\frac{3}{4}$" ϕ Stud Shear Connectors			Each	544
	Reinforcement Bars, Epoxy Coated			Pound	30,270
	Mechanical Splicers			Each	41
	Furnishing Metal Large Diameter Pipe Piles, 48" x $\frac{3}{4}$"			Foot	558
	Furnishing Metal Large Diameter Pipe Piles, 60" x $\frac{3}{4}$"			Foot	117
	Driving Large Diameter Pipe Piles			Foot	675
	Pile Shoes Large Diameter Pipe			Each	5

Minimum lap for spirals = 3'-9"
** Length is height of spiral.



SECTION E-E

Notes:
For location of Section D-D, see sheets S49 thru S52.
For location of Section E-E, see sheet S51.
For splice detail, see sheet S55.
Stud shear connectors shall be granular or solid flux filled headed studs automatically end welded to pipe pile.



Note C:
The exterior surface of the 60" ϕ pipe pile shall be field painted in accordance with Painting Notes Nos. 1 and 4 on sheet S3 throughout the limits identified.

PILE 4 SPLICE DETAIL

Reinforcement not shown for clarity

INSTALLING THE SOLUTION

- April 26, 2019
- Installation of 60” diameter pile around Damaged 48” diameter pile



INSTALLING THE SOLUTION





INSTALLING THE SOLUTION





INSTALLING THE SOLUTION





INSTALLING THE SOLUTION





INSTALLING THE SOLUTION

- During installation…….
  - IDOT D-8/GRL contacted MM
  - The pile was no longer mobilizing
  - IDOT requested that MM review the pile demands
  - IDOT D-8/GRL/MW terminated driving



INSTALLING THE SOLUTION





INSTALLING THE SOLUTION



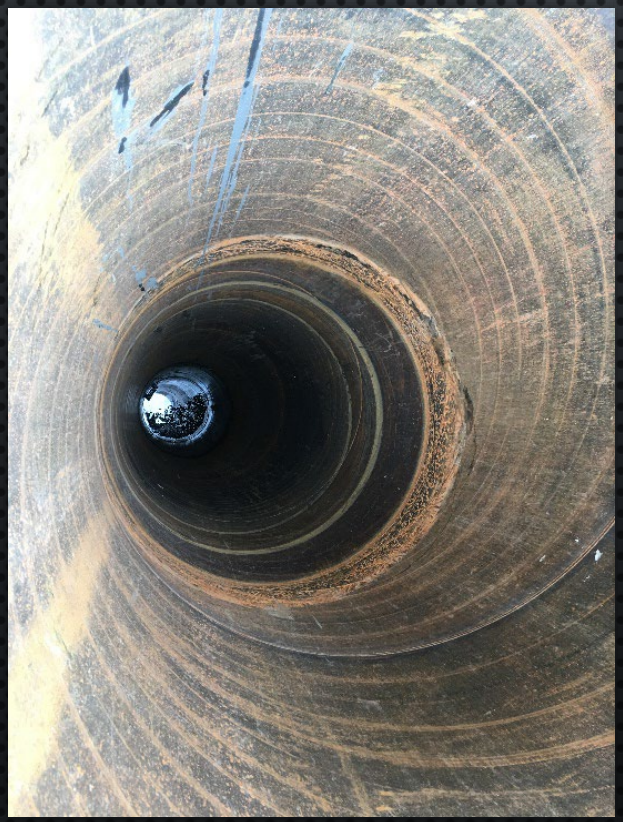


INSTALLING THE SOLUTION





INSTALLING THE SOLUTION





INSTALLING THE SOLUTION





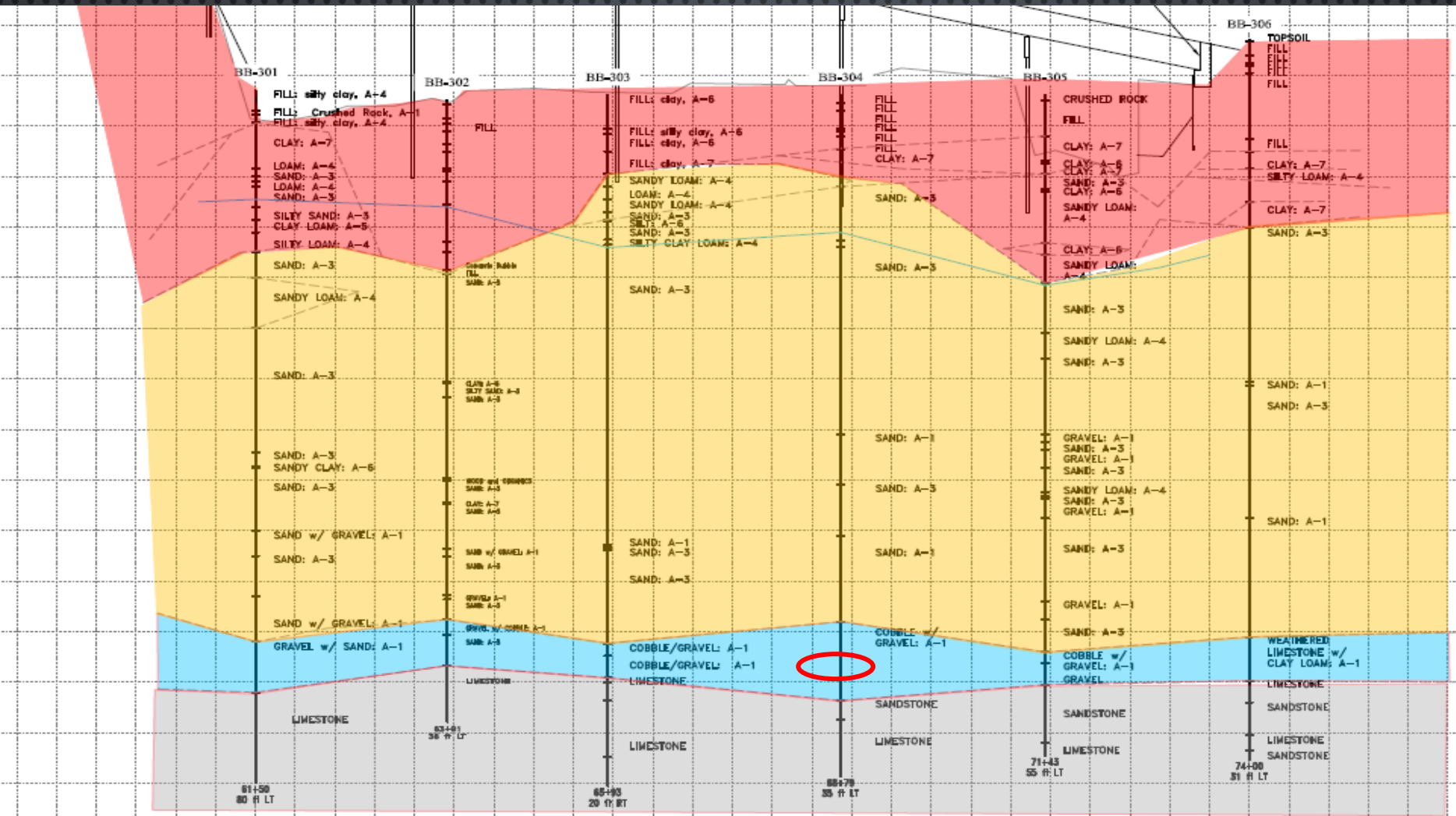
FINAL RESULTS

- During installation…….
  - IDOT D-8/GRL estimated nominal bearing capacity +/-3,600 kips
- After installation…..
  - GRL final bearing capacity = 3,733 kips
    - 1,113 kips of skin friction
    - 2,620 kips of end bearing



FINAL RESULTS

- PILE TO A FINAL DEPTH OF 115.3 FEET = A PILE TIP ELEVATION OF 299.2



FINAL RESULTS

Service Load Conditions				
IDOT Nominal Required Bearing (kips)	IDOT Factored Resistance Available (kips)	GRL Actual Ultimate Pile Bearing Capacity (kips)	GRL Actual Factored Resistance Available (kips)	MM Total Pile Design Load (kips)
3769	2450	3733	2426	1941
Extreme Event – Seismic Loading				
IDOT Nominal Required Bearing (kips)	IDOT Factored Resistance Available (kips)	GRL Actual Ultimate Pile Bearing Capacity (kips)	GRL Actual Factored Resistance Available (kips)	MM Total Pile Design Load (kips)
3769	3769	3733	3733	2747

Final Results

- Take-Aways
  - Don't crumple your foundations during installation
  - Think Outside the Traditional Analysis Box
- Questions?