US68 Lawrence Creek Bridge

Embankment Settlement & Proposed Solutions

ACEC-KY/FHWA/KYTC Partnering Conference

Louisville, Kentucky

September 4, 2019

Project Team

Outline

- Project Background
- Geotechnical Investigation
- Bridge Evaluation
- Proposed Solutions

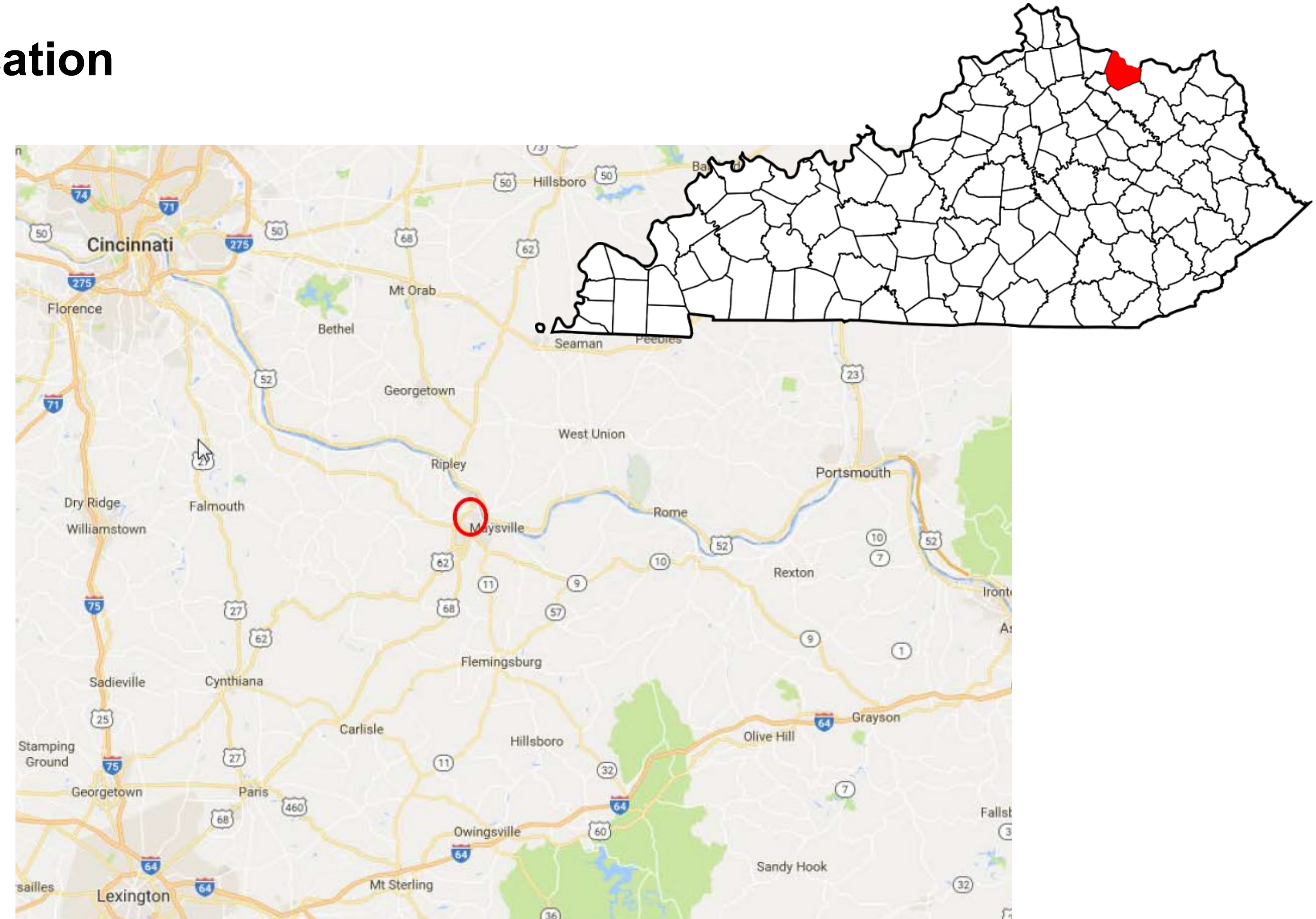
Project Background

John P. Loyd Memorial Bridge

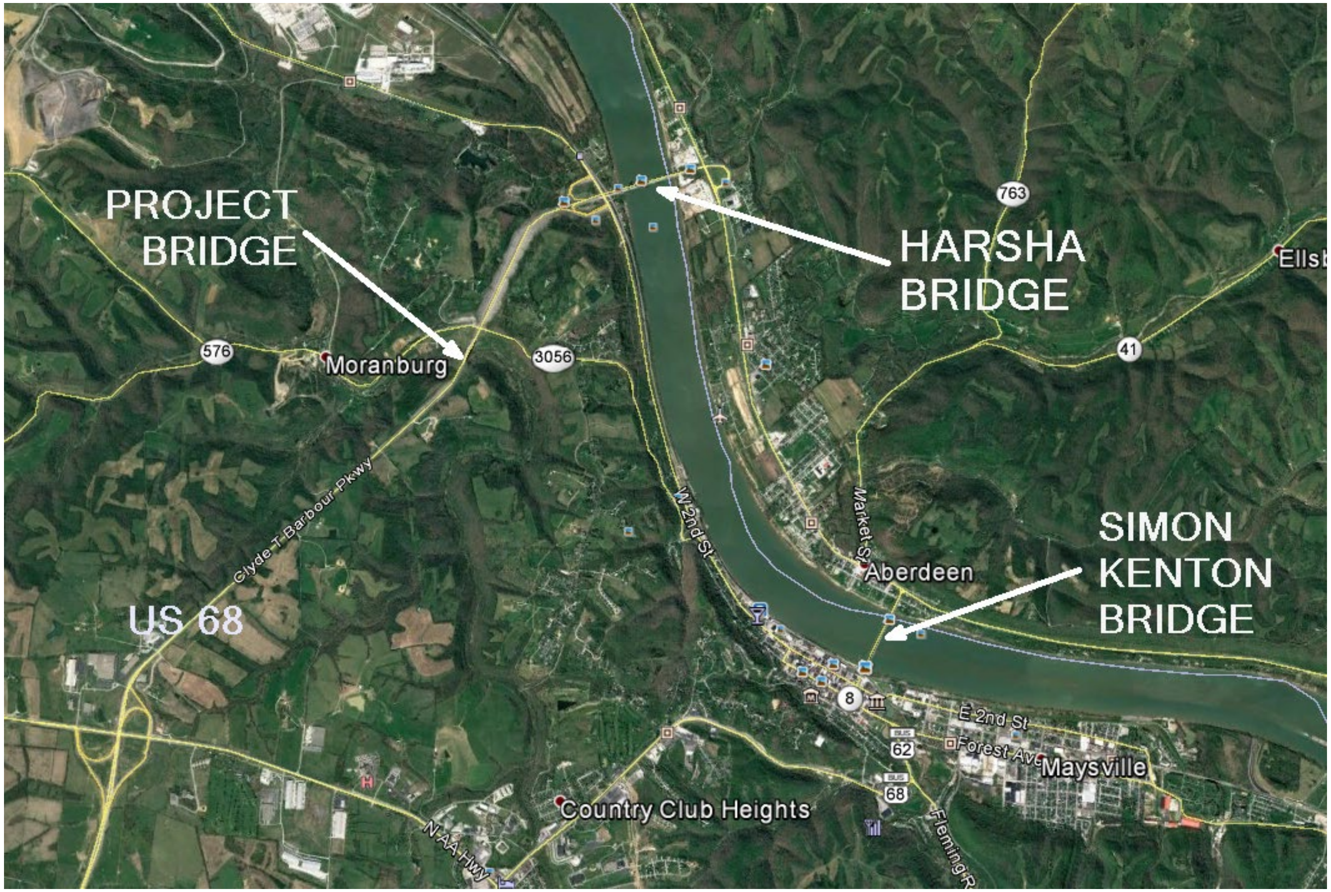
Project Data

- 766-ft Length
- ADT is 4,800
- Urban Principal Arterial
- Design 1994
- Constructed 1996-1997

Site Location



Site Location



Project Background

Ohio River Crossings in Maysville

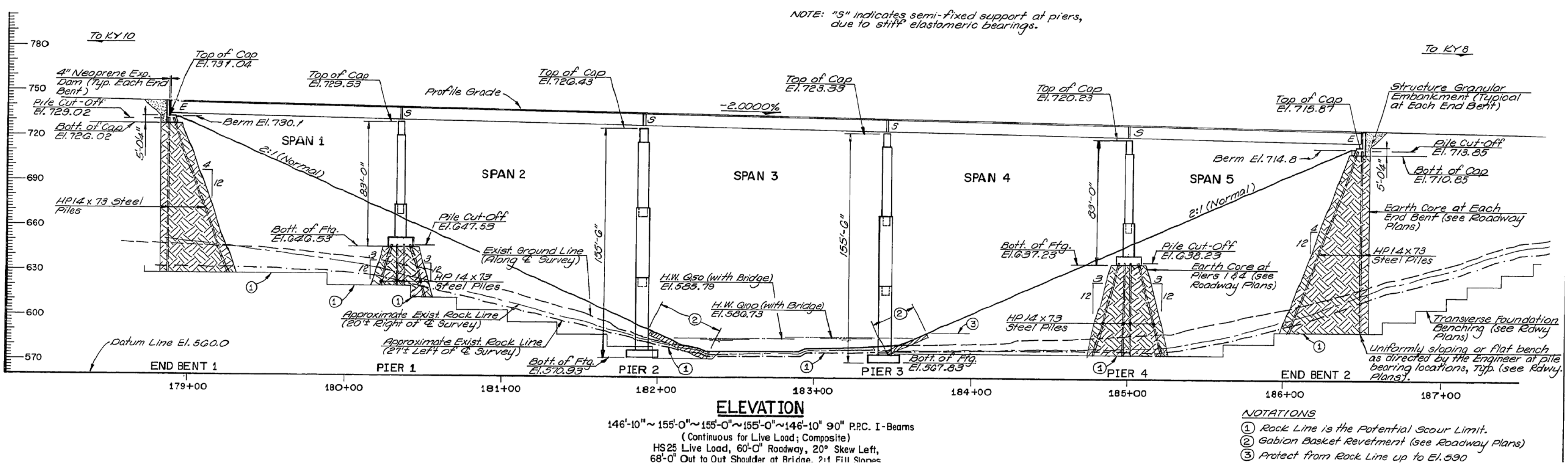
Project Background

Site Location

Project Background

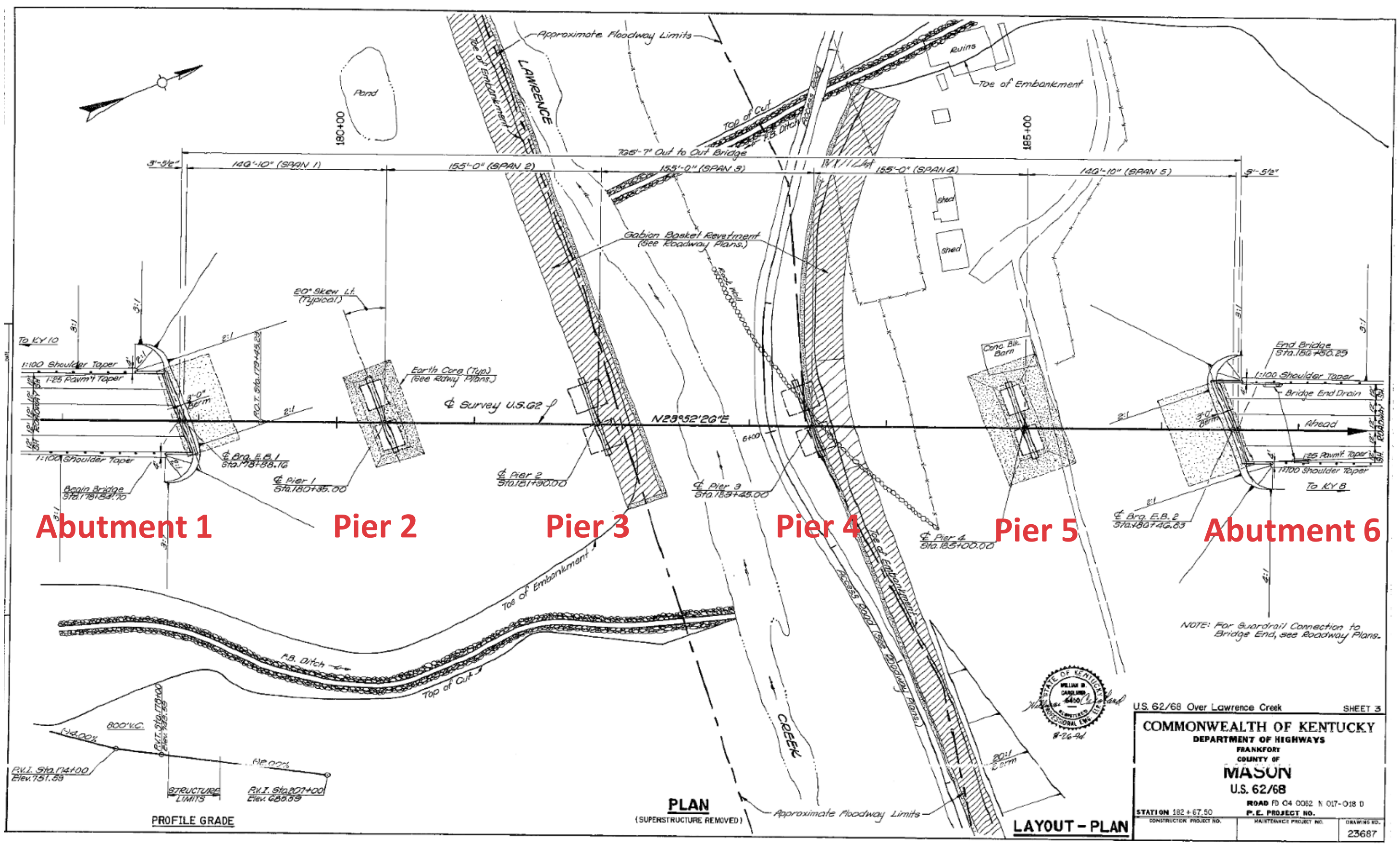
Adjacent Crossings

Bridge Elevation



Abutment 1 **Pier 2** **Pier 3** **Pier 4** **Pier 5** **Abutment 6**

Bridge Plan


Abutment 1
Pier 2
Pier 3
Pier 4
Pier 5
Abutment 6
PLAN
LAYOUT - PLAN
PROFILE GRADE
COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
MASON
U.S. 62/68
U.S. 62/68 Over Lawrence Creek
SHEET 3
Approximate Floodway Limits
LAWRENCE
CREEK
Pond
Ruins
Toe of Embankment
Top of Cut
Gabion Basket Revetment (See Roadway Plans.)
20° Skew Lt. (Typical)
Earth Core (Typ) (See Rdwy Plans.)
N23°52'26"E
NOTE: For Guardrail Connection to Bridge End, see Roadway Plans.
23687

Bridge Problems – Issues from Day 1

Project Background

Bridge Problems – July 2014

Bridge Problems – July 2014

Project Background

Bridge Problems – July 2014

Bridge Problems – 2016

Project Background

Bridge Problems – 2016

Bridge Problems – 2016

Bridge Problems – 2016

Bridge Problems – 2016

Bridge Problems – 2016

Bridge Problems – 2016

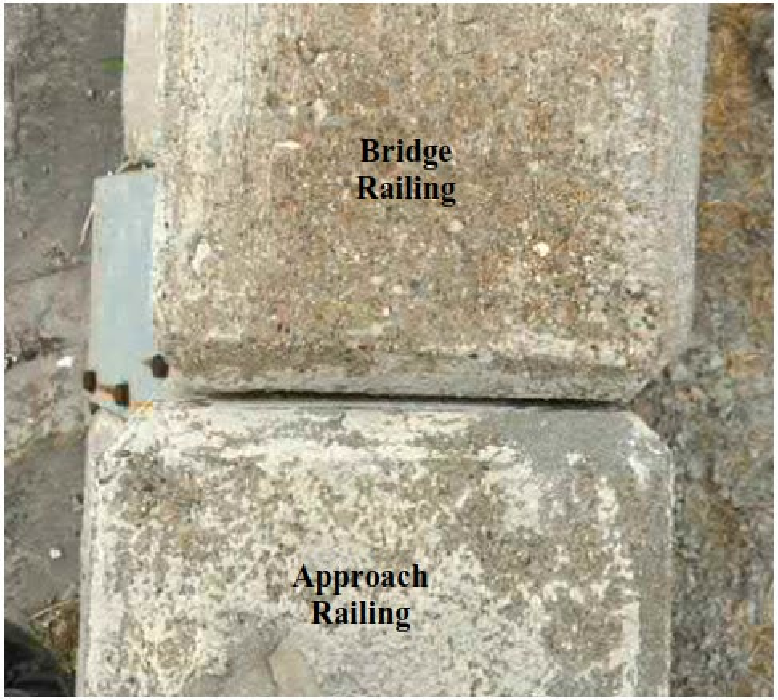


Photo 58.7-3: West railing at Abutment 6 misaligned transversely 1 inch to the west

Photo 58.7-4: East railing at Abutment 6 misaligned transversely 1½ inch to the west

Project Background

Bridge Problems – July 2016

Bridge Problems – Facts & Rumors

- **Value Engineering**
  - Apparent Minimum Design Tolerances
- **Construction Issues**
- **No As-Built Plans**
  - Including Pile Driving Records

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Proceed to Find a Solution

RFP for Design Services

- RFP -> October 2016
- NTP -> March 2017
- AECOM / Geotechnology

Scope of Work

- Review of Project Documents
- Surveying / Monitoring
- Bridge Inspection
- Geotechnical Investigation
- Structural Analysis
- Evaluation of Rehabilitation Alternatives
- Report Preparation
- Final Design

Geotechnical Investigation

Project Scope

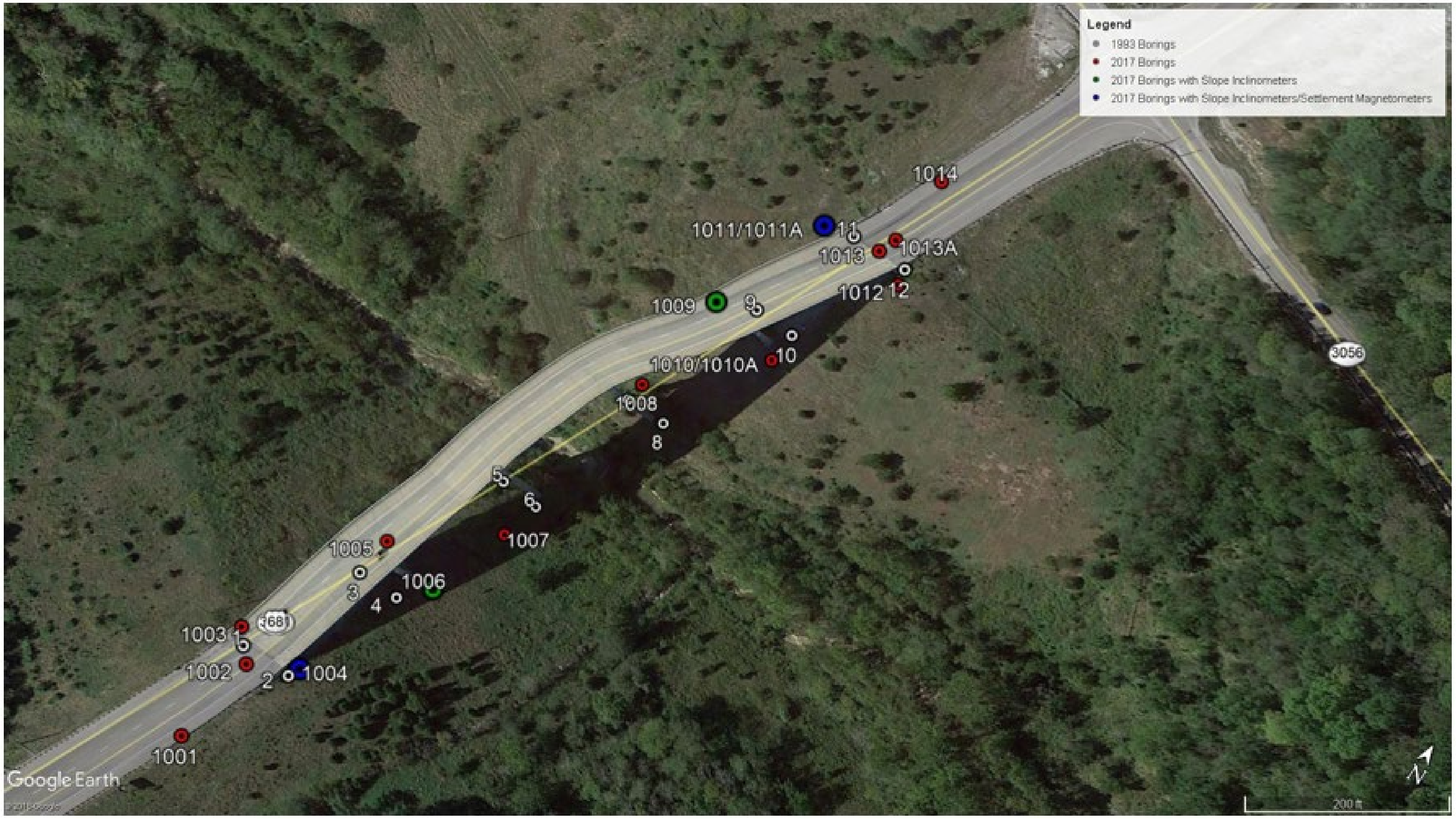
2017 Fieldwork

- 14 geotechnical borings
    - 3 offset holes at Hole 1003, 1010, and 1011
- 4 slope inclinometers installed at Holes 1004, 1006, 1009, and 1011A
- Modified Sondex installations in Holes 1004 and 1011A for settlement monitoring

Analysis

- Embankment Analysis
- Slope Stability Analysis
- Settlement Analysis
- Batter Pile Analysis
- Pile Downdrag Analysis

Instrumentation



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Subsurface Conditions

Bedrock Formations

- Kope Formation: 80% Shale & 20% Limestone
- Fairview Formation: 60% Limestone & 40% Shale
- Grant Lake Limestone: 65-85% Limestone & 15-35% Shale

Shot-rock Fill

- Comprised of Grant Lake Limestone & Fairview Formation

Pile Core Material

- No. 57 stone

Driven Piles

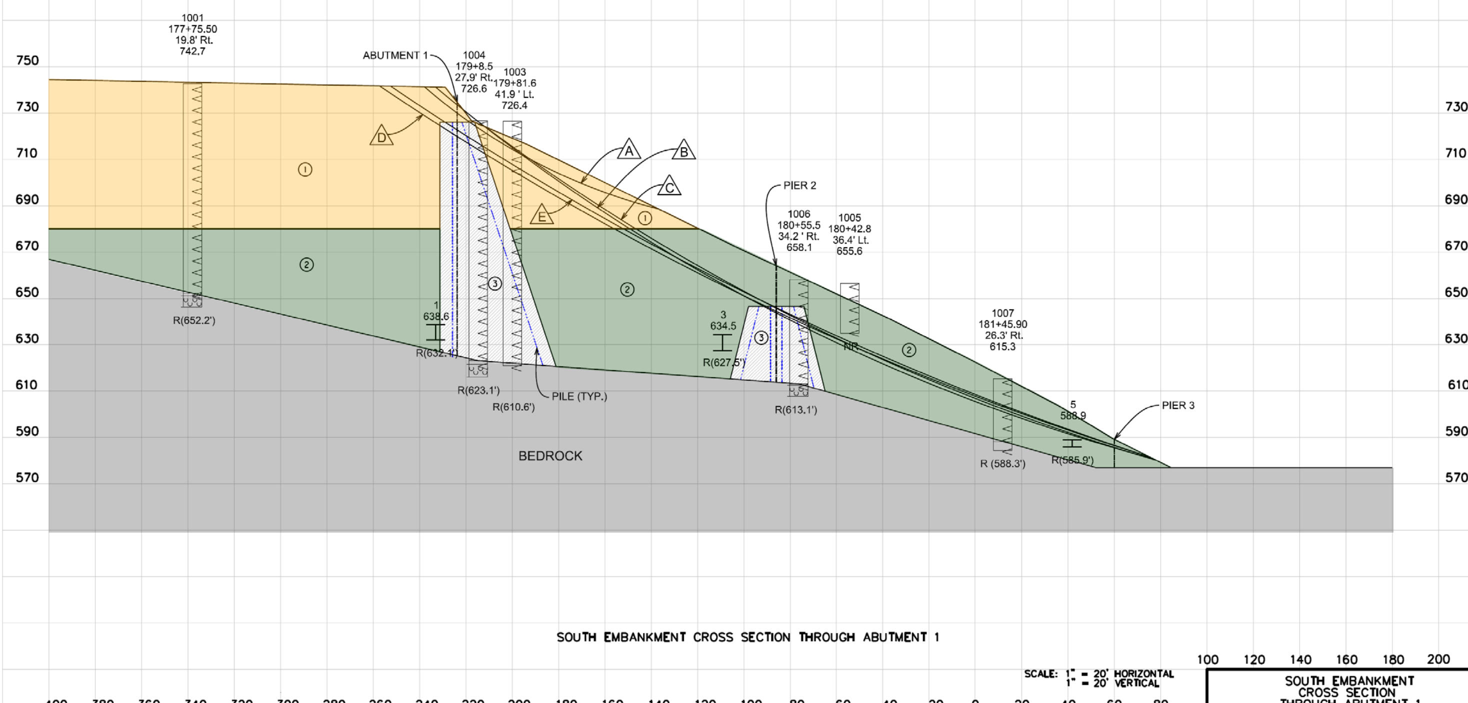
- Bear in Kope Formation

Abutment 1 – South Embankment

COUNTY OF	ITEM NO.	SHEET NO.
MASON	9-1095	----

ASSUMED SOIL STRENGTH PARAMETERS				
MATERIAL ID	MATERIAL DESCRIPTION	1993 PARAMETERS	2017 LINEAR PARAMETERS	2017 NONLINEAR PARAMETERS
1	FAIRVIEW/GRANT LAKE LIMESTONE FORMATION FILL	γ = 125 pcf c' = 0 psf ϕ' = 38°	γ = 125 pcf c' = 200 psf ϕ' = 20°	γ = 125 pcf $\tau' = 1.050\,(\sigma')^{0.904}$
2	GRANT LAKE LIMESTONE FORMATION FILL	γ = 125 pcf c' = 0 psf ϕ' = 40°	γ = 125 pcf c' = 0 psf ϕ' = 30°	γ = 125 pcf $\tau' = 0.820\,(\sigma')^{0.954}$
3	PILE CORE	γ = 125 pcf c' = 0 psf ϕ' = 38°	γ = 100 pcf c' = 0 psf ϕ' = 32°	γ = 100 pcf c' = 0 psf ϕ' = 32°

FACTORS OF SAFETY		
1993 PARAMETERS	A	1.50
2017 LINEAR PARAMETERS - OUTSIDE OF PILE CORE LIMITS	B	1.21
2017 NONLINEAR PARAMETERS - OUTSIDE OF PILE CORE LIMITS	C	1.20
2017 LINEAR PARAMETERS - 20' DEEP FAILURE AT PIER 2	D	1.18
2017 NONLINEAR PARAMETERS - 20' DEEP FAILURE AT PIER 2	E	1.18



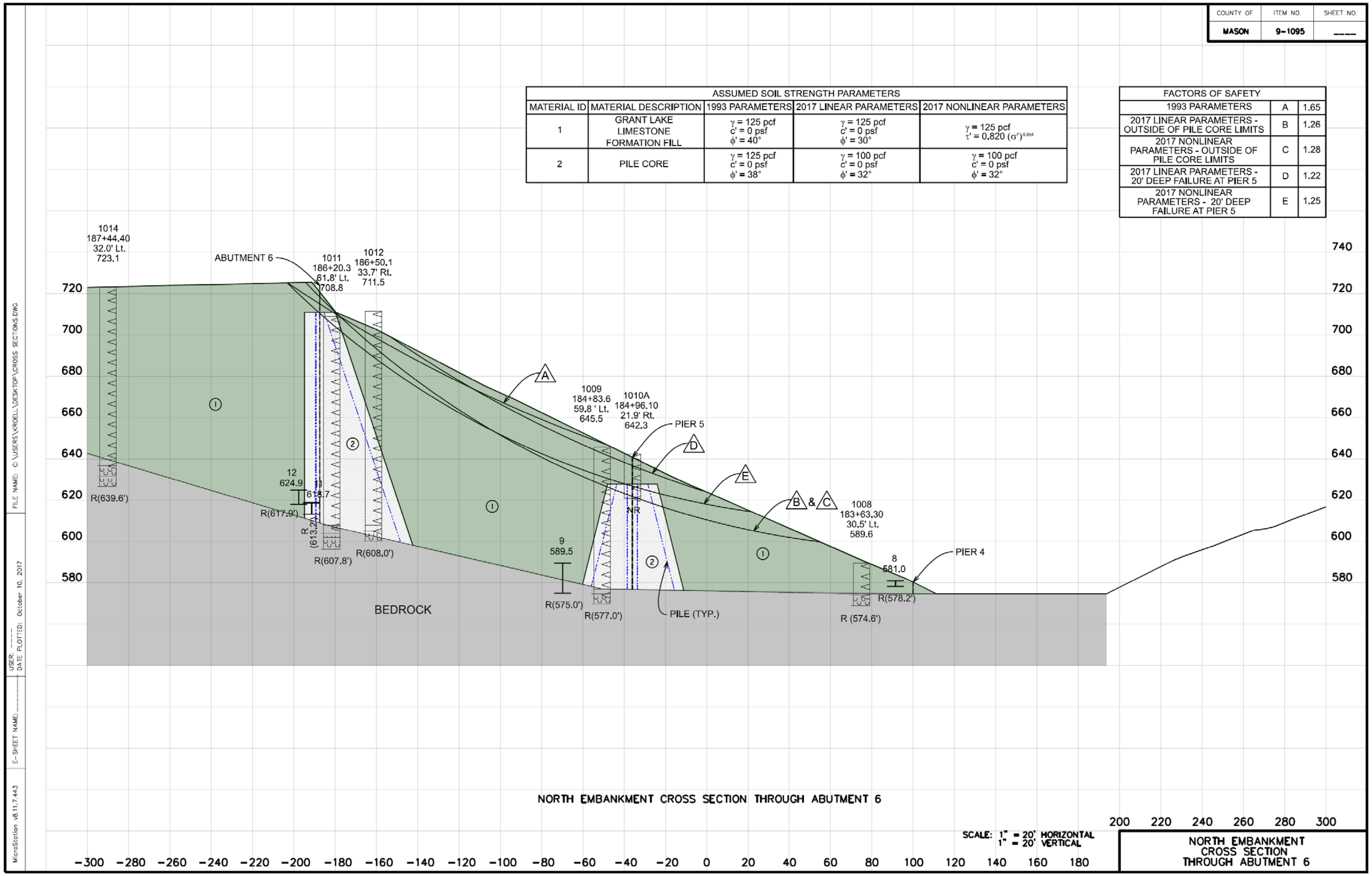
SOUTH EMBANKMENT CROSS SECTION THROUGH ABUTMENT 1

SCALE: 1" = 20' HORIZONTAL
1" = 20' VERTICAL

SOUTH EMBANKMENT CROSS SECTION THROUGH ABUTMENT 1

FILE NAME: C:\USERS\KROELL\DESKTOP\CROSS SECTIONS.DWG
USER: ---- DATE PLOTTED: October 10, 2017
E-SHEET NAME: ----
MicroStation v8.11.7.443

Abutment 6 – North Embankment



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MATERIAL ID	MATERIAL DESCRIPTION	1993 PARAMETERS	2017 LINEAR PARAMETERS	2017 NONLINEAR PARAMETERS
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FACTORS OF SAFETY		
1993 PARAMETERS	A	1.65
2017 LINEAR PARAMETERS - OUTSIDE OF PILE CORE LIMITS	B	1.26
2017 NONLINEAR PARAMETERS - OUTSIDE OF PILE CORE LIMITS	C	1.28
2017 LINEAR PARAMETERS - 20' DEEP FAILURE AT PIER 5	D	1.22
2017 NONLINEAR PARAMETERS - 20' DEEP FAILURE AT PIER 5	E	1.25

Slope Stability

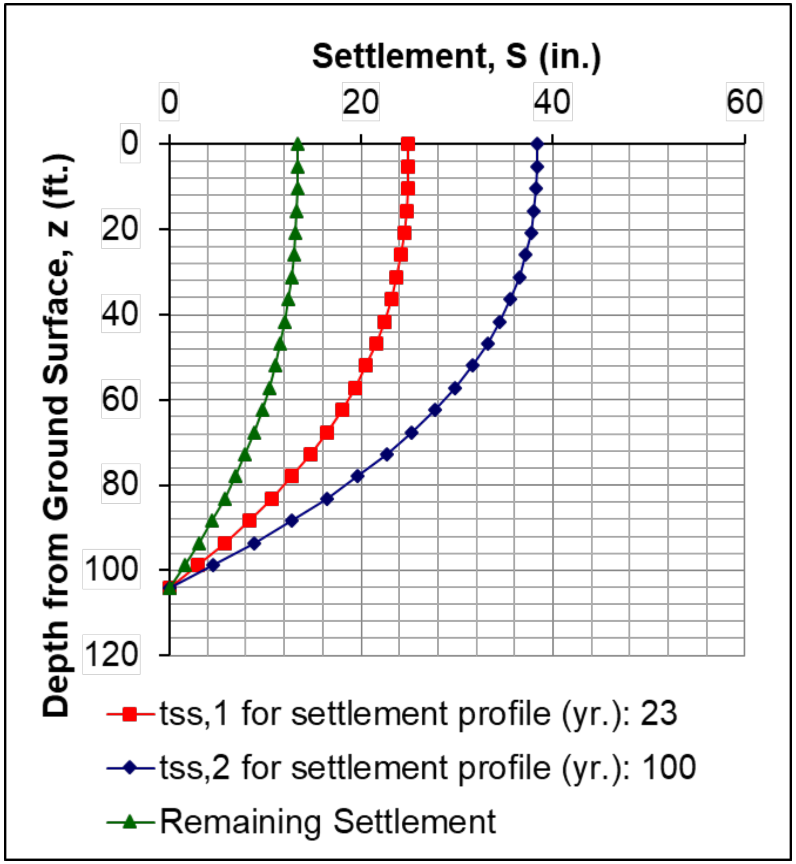
Scenario	Factor of Safety
South Embankment (Abutment 1)	
2017 linear parameters – outside of pile core limits	1.21
2017 nonlinear parameters – outside of pile core limits	1.20
2017 linear parameters – 20-foot-deep failure at Pier 2	1.18
2017 nonlinear parameters – 20-foot-deep failure at Pier 2	1.18
North Embankment (Abutment 6)	
2017 linear parameters – outside of pile core limits, 20-foot-deep failure	1.26
2017 nonlinear parameters – outside of pile core limits, 20-foot-deep failure	1.28
2017 linear parameters – 20-foot-deep failure at Pier 5	1.22
2017 nonlinear parameters – 20-foot-deep failure at Pier 5	1.25

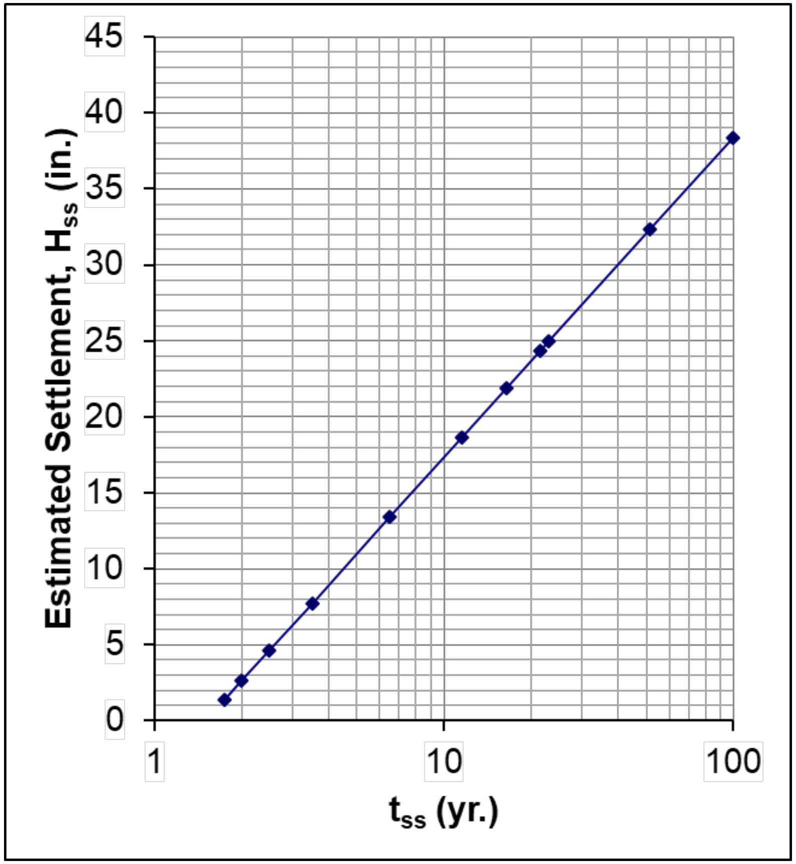
Settlement

Location	Embankment Height, H (ft.)	Observed Settlement (in.)		Shale Settlement from Hopkins and Beckham, H_{ss} (in.)	
		Ground Surface[a]	Beneath Pile Cap[b]	At Ground Surface	At Top of Pile
South Approach	115	30[c]	N/A	32.1	N/A
Abutment 1	103	20-25	**16-28**	24.4	**24.4**
Pier 2	56	N/A	**2-4[d]**	5.3	**4.6**
Pier 5	70	N/A	**2-8[d]**	9.3	**8.8**
Abutment 6	104	26-29	**13-30**	24.9	**24.9**
North Approach	115	27[c]	N/A	32.1	N/A

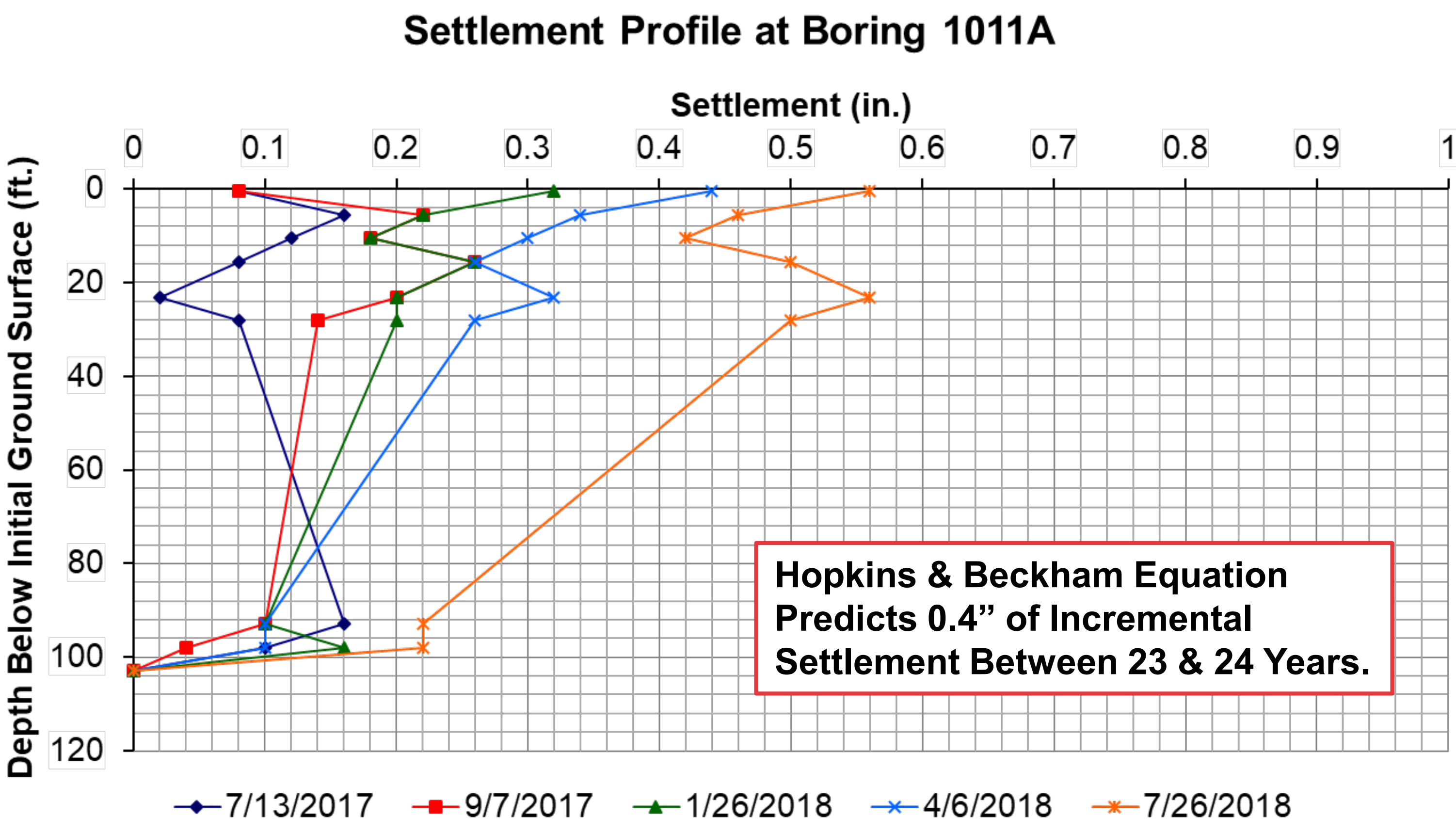
[a] Ground surface settlements were interpreted from the concrete paint coatings on the abutments and the pavement cores in the approach slabs.
[b] Measured from the test pits.
[c] Settlement at the approach slabs assumes the original approach slab thickness was 12 inches.
[d] Beneath the pile caps at Piers 2 and 5, the settlements were greater around the perimeter in the area of the batter piles and lesser in the interior areas between piles.

Settlement Profile – Abutment 6 (Hopkins & Beckham 1998)

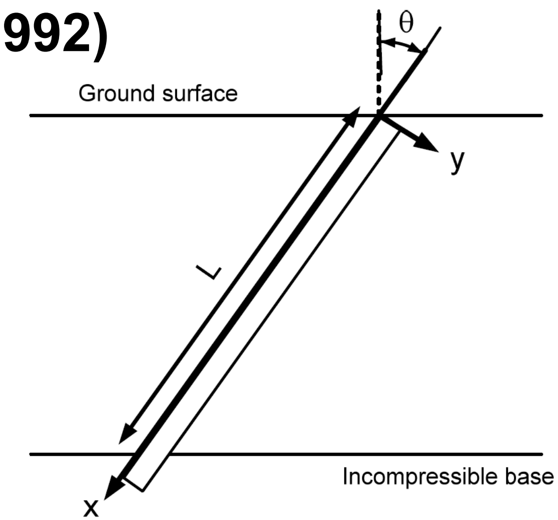




Boring 1011A Sondex Instrumentation at Abutment 6

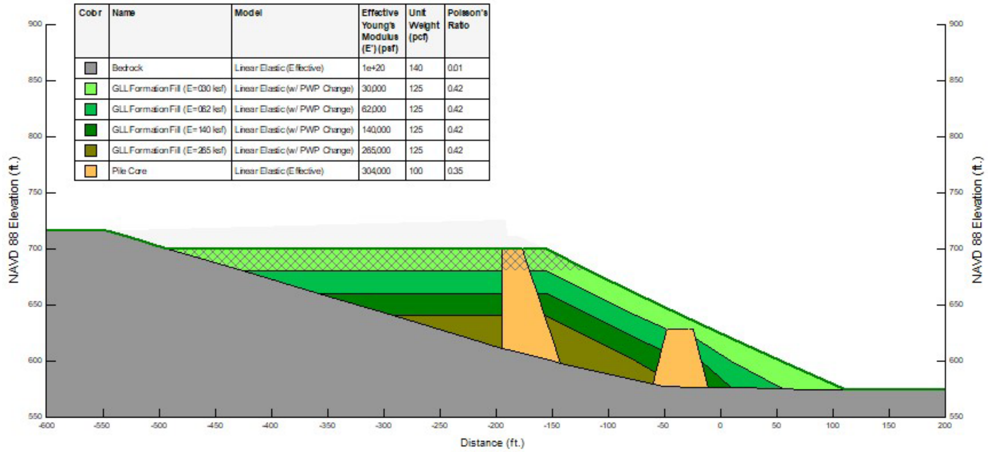


Battered Pile Analyses– (Shibata et al 1992)

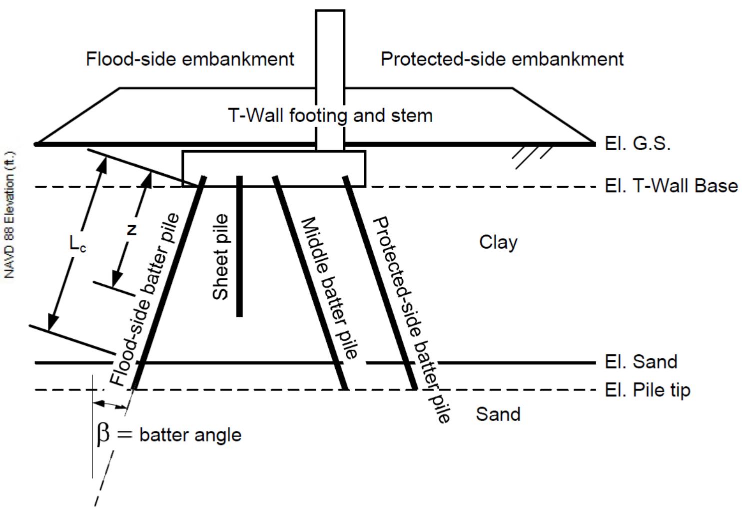


Battered piles analyses for evaluating bending moment:

- Empirical method by Shibata et al (1992)
- LPILE method (USACE 2012)
- FEM using SIGMA/W



Color	Name	Model	Effective Young's Modulus (E') (psf)	Unit Weight (pcf)	Poisson's Ratio
	Bedrock	Linear Elastic (Effective)	1e+20	140	0.01
	GLL Formation Fill (E=030 ksf)	Linear Elastic (w/ PWP Change)	30,000	125	0.42
	GLL Formation Fill (E=062 ksf)	Linear Elastic (w/ PWP Change)	62,000	125	0.42
	GLL Formation Fill (E=140 ksf)	Linear Elastic (w/ PWP Change)	140,000	125	0.42
	GLL Formation Fill (E=265 ksf)	Linear Elastic (w/ PWP Change)	265,000	125	0.42
	Pile Core	Linear Elastic (Effective)	304,000	100	0.35



Summary of Findings

Deformation of shot-rock fill resulted from:

- Softening of shale
- Rearrangement of particles from groundwater infiltration
- Collapsing of nested limestone or shale that bridged voids

Lateral movements and structural distress of bridge abutments resulted from:

- Bending of batter piles, which “pulled” creek side of pile caps down and towards the creek
- Time-dependent horizontal deformations within the fill, related to primary compression of the shot-rock fill, which “pushed” the piles towards the creek

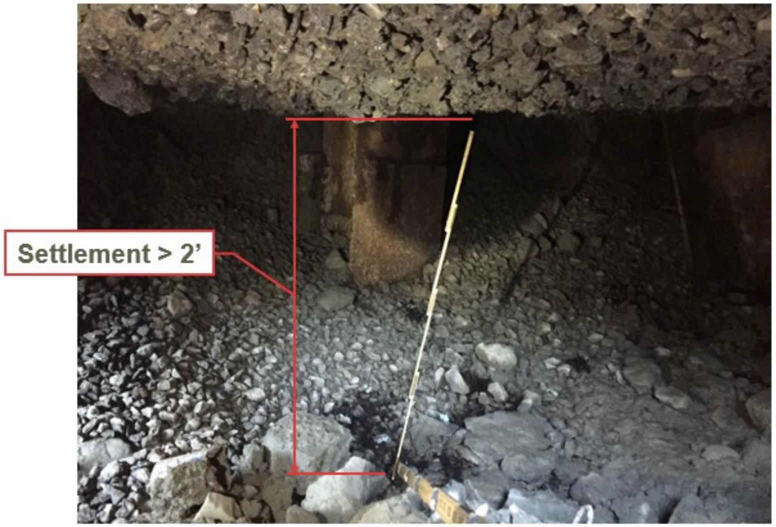
Slope Stability:

- Signs of global stability were not visible
- Factor of safety for long-term conditions = 1.2 for north and south embankments
- Typical target values for the factor of safety are between 1.6 and 1.8

Summary of Findings

Settlements

- Observed settlements are in reasonable agreement with settlements computed by Hopkins and Beckham equation
- Effects of embankment deformation on existing pile foundations per empirical and finite element (FE) analysis methods:
  - Abutments 1 & 6 and Piers 2 & 5:
  - Additional deep foundations should be provided to improve the factor of safety and provide additional resistance for potential continued settlement of the fill embankment



Bridge Evaluation

Scope of Work

- Review of Project Documents
- Surveying / Monitoring
- Bridge Inspection
- Geotechnical Investigation
- Structural Analysis
- Evaluation of Rehabilitation Alternatives
- Report Preparation
- Final Design

Survey & Monitoring

BTM Engineering

Baseline

- Ground Topography
- Embankment Monitoring Locations
- Structure Monitoring Locations
- Roadway Elevations
- LiDAR Scan

Quarterly Comparisons

Embankment monitoring

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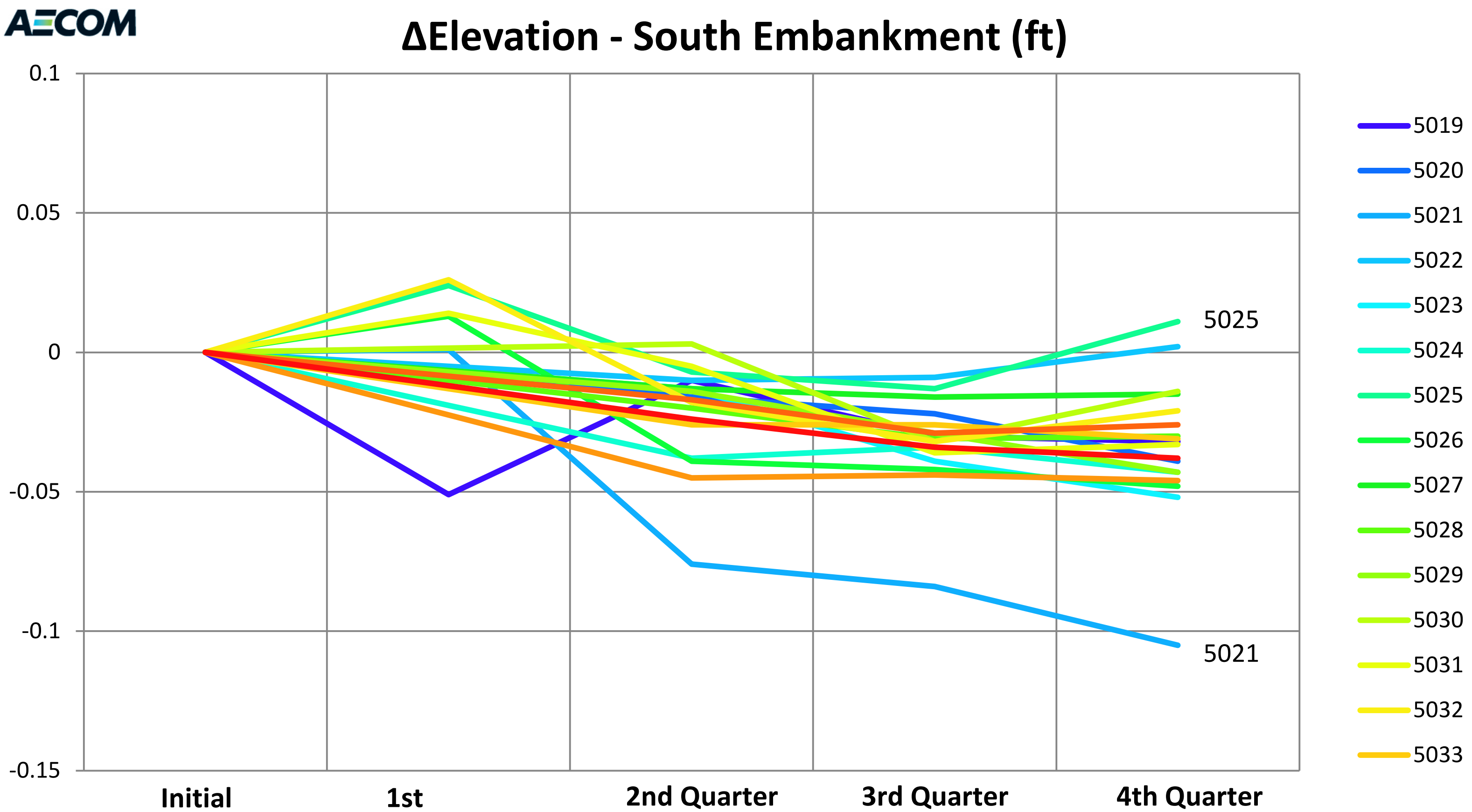
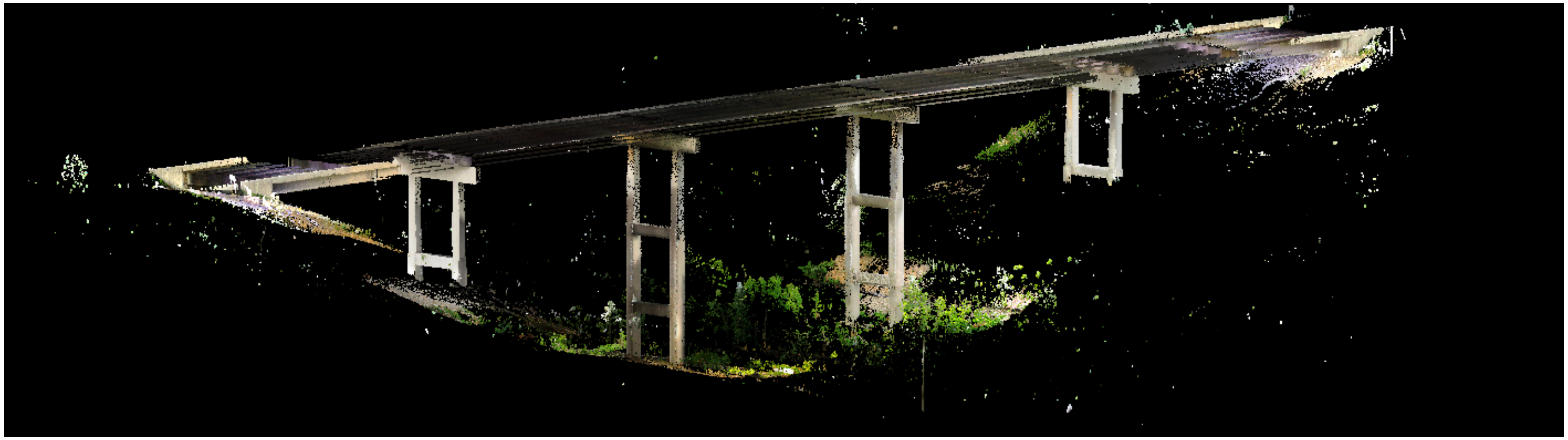
Embankment monitoring



Bridge Evaluation

LiDAR scan



Conclusions and Recommendations

Summary

- Slope Stability
- Structural Observations
- Embankment Settlement
- Pile Distress

Recommendations

- Reconstruct Abutments 1 & 6
- Strengthen Piers 2 & 5
- Increased Inspection & Monitoring Cycle

Proposed Solutions

Project Team Goals

- Address evaluation recommendations
- Correct deterioration in abutment caps, end diaphragms, and piles
- Account for future settlement in deep foundation design
- Provide ongoing traffic service during construction

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Remediation Alternatives

- **No Build**
  - Inexpensive
  - Does not address problem
- **Long Term Monitoring**
  - Inexpensive
  - Can alert KYTC of problems
  - Does not address damaged structural concerns.
- **Complete Reconstruction**
  - Expensive
  - No benefit in addressing geotechnical challenges
- **Rehabilitation & Strengthening**
  - Bridge can maintain in-service
  - Constructability challenges

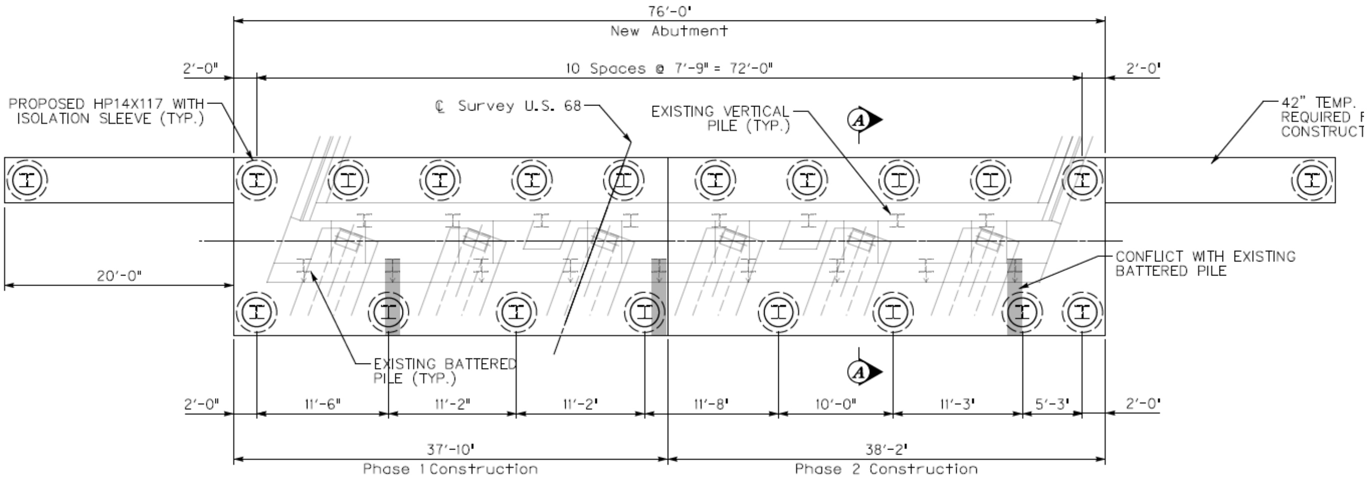
Abutment Rehabilitation & Strengthening Alternatives

- **Abutment Strengthening**
  - Center of Cap
  - Widening the Cap
- **Abutment Reconstruction**
  - In-situ
  - Behind Existing Abutment
  - In-front Existing Abutment
- **Deep Foundation Support**
  - Battered H-piles
  - H-piles
  - Drilled Shafts
  - Micropiles

Proposed Solutions

Abutment Strengthening Challenges

- Battered Piles
- Skewed Abutments
- Wide Top Girder Flanges



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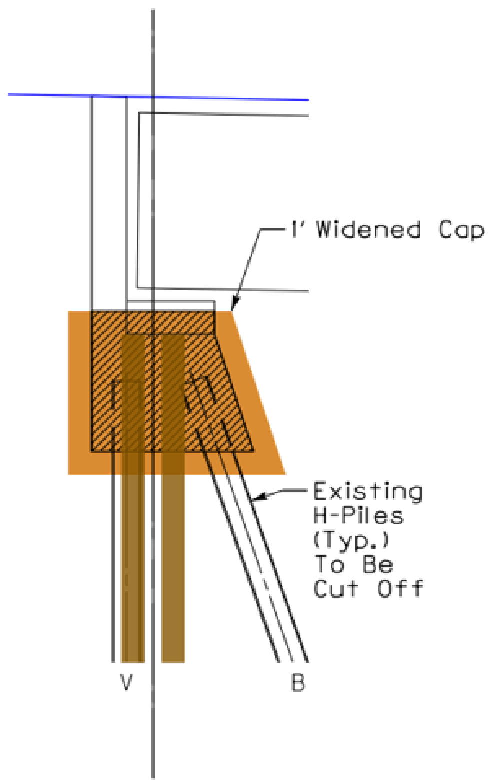
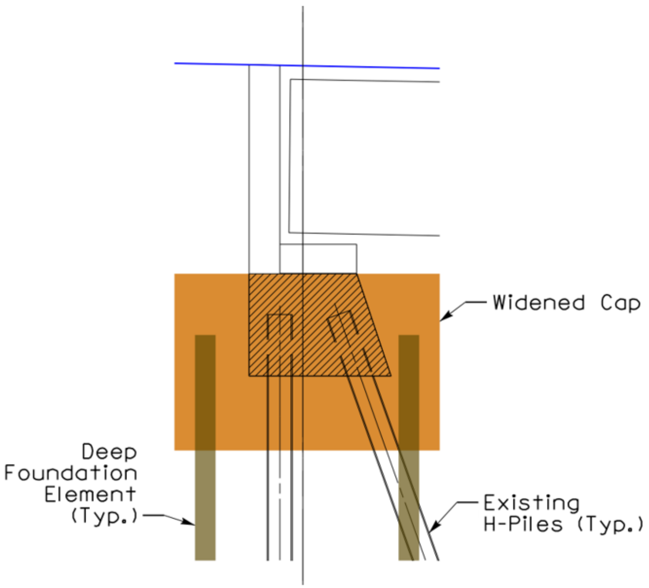
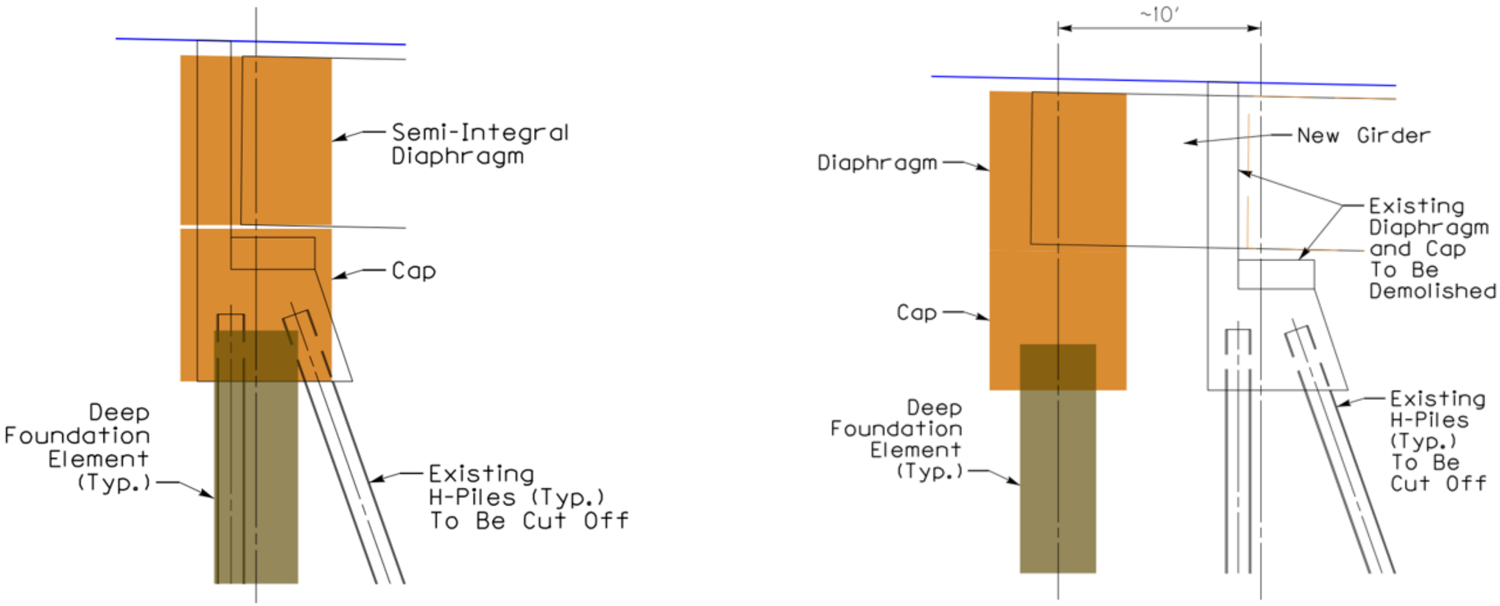
Abutment Strengthening



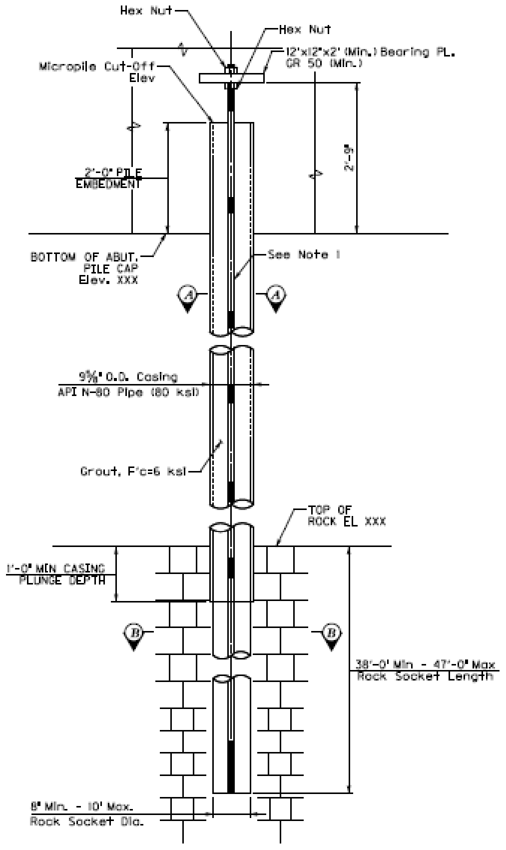


Abutment Reconstruction



Abutment Deep Foundation Alternatives

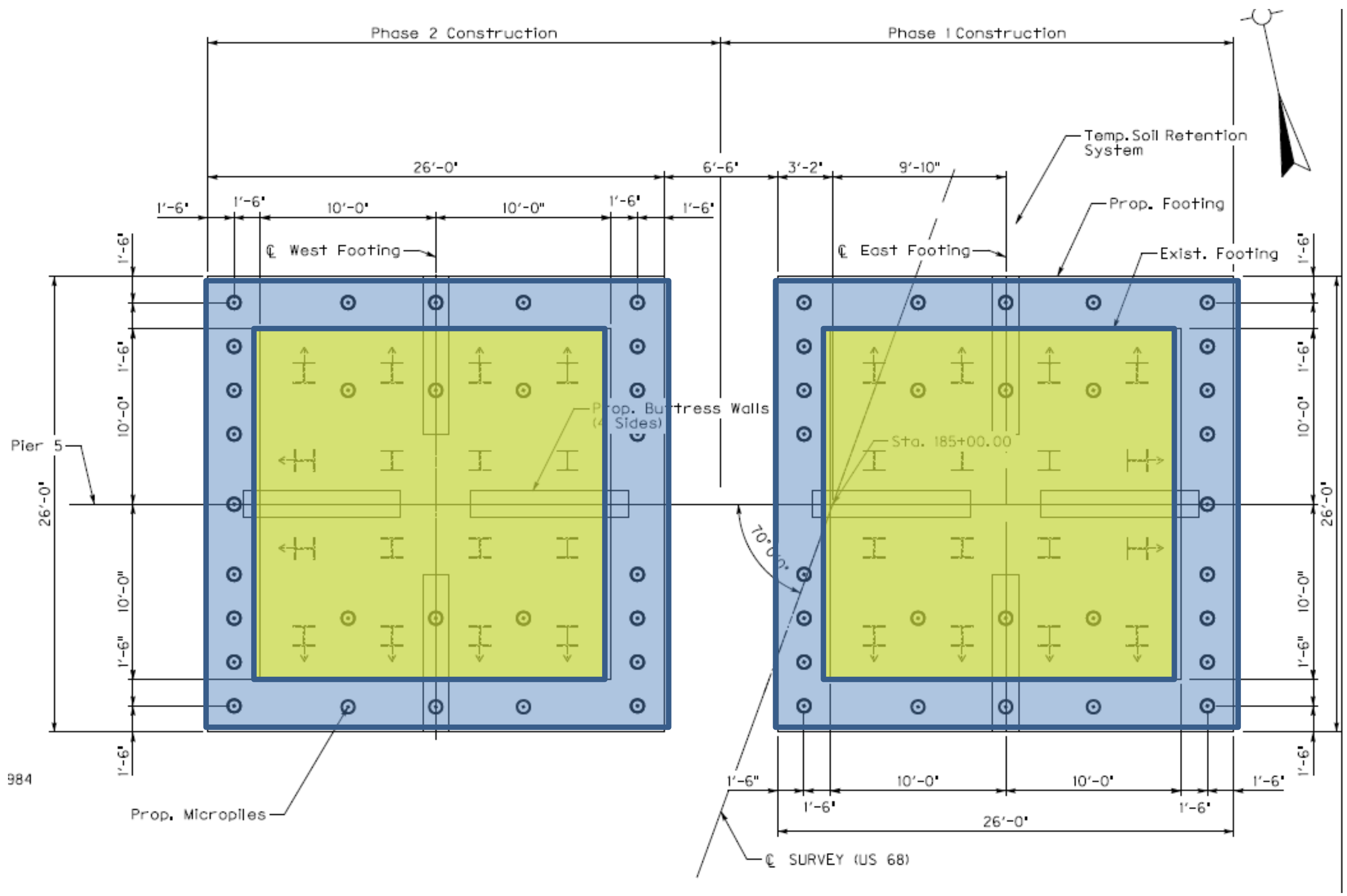
- **Battered H-piles**
  - Continued downdrag problems
- **Vertical H-piles**
  - Requires downdrag isolation casings
  - Large diameter similar to shaft option
- **Drilled Shafts**
  - Large diameter attracts significant downdrag loads
  - Requires deep rock socket
- **Micropiles**
  - Small diameter can be installed in between existing piles and girders



Pier Strengthening

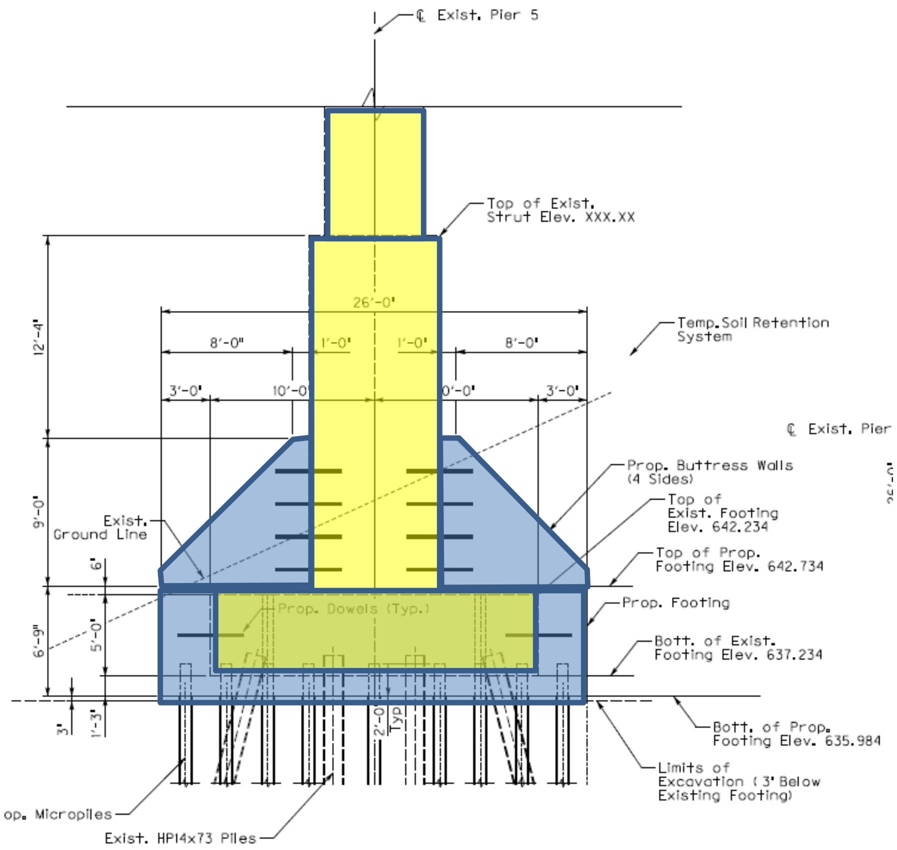
- **Piers 2 & 5**
  - Downdrag
- **Raft Footings**
  - 10 battered piles
  - 6 vertical piles
- **Strengthening**
  - Design to support 100% load

Pier Strengthening



Proposed Solutions

Pier Strengthening



Construction

- **Schedule**
  - October 25, 2019 Letting
  - Completion in 2021

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Questions?