…THIS IS ENGINEERING

…THIS IS AUBURN

ANALYSIS AND DESIGN OF STEEL PILE BRIDGE BENTS

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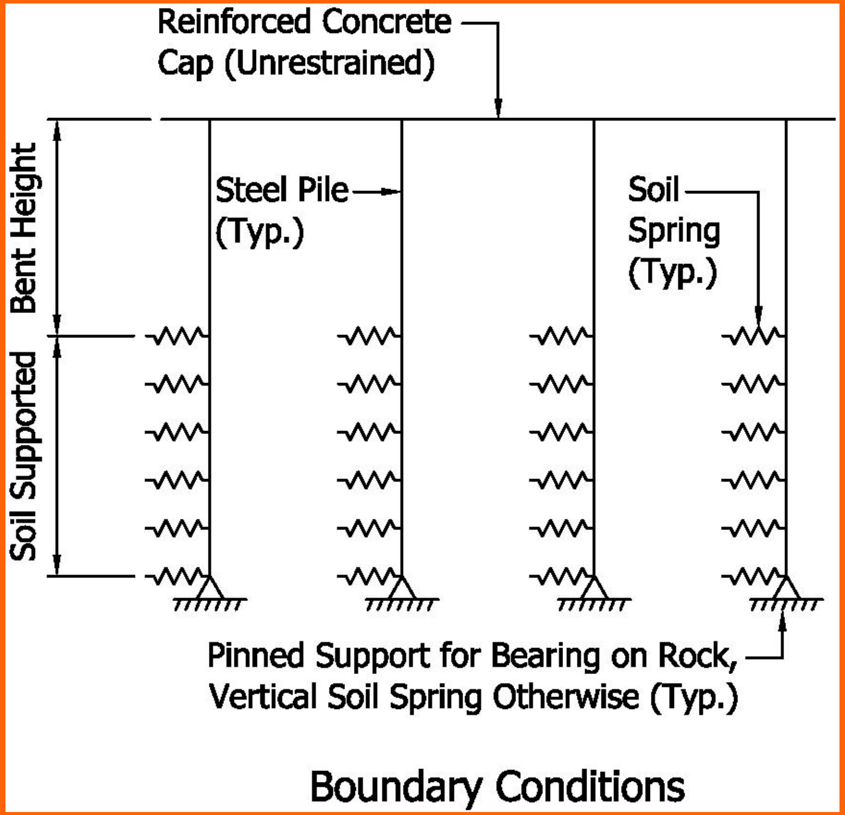
INTRODUCTION

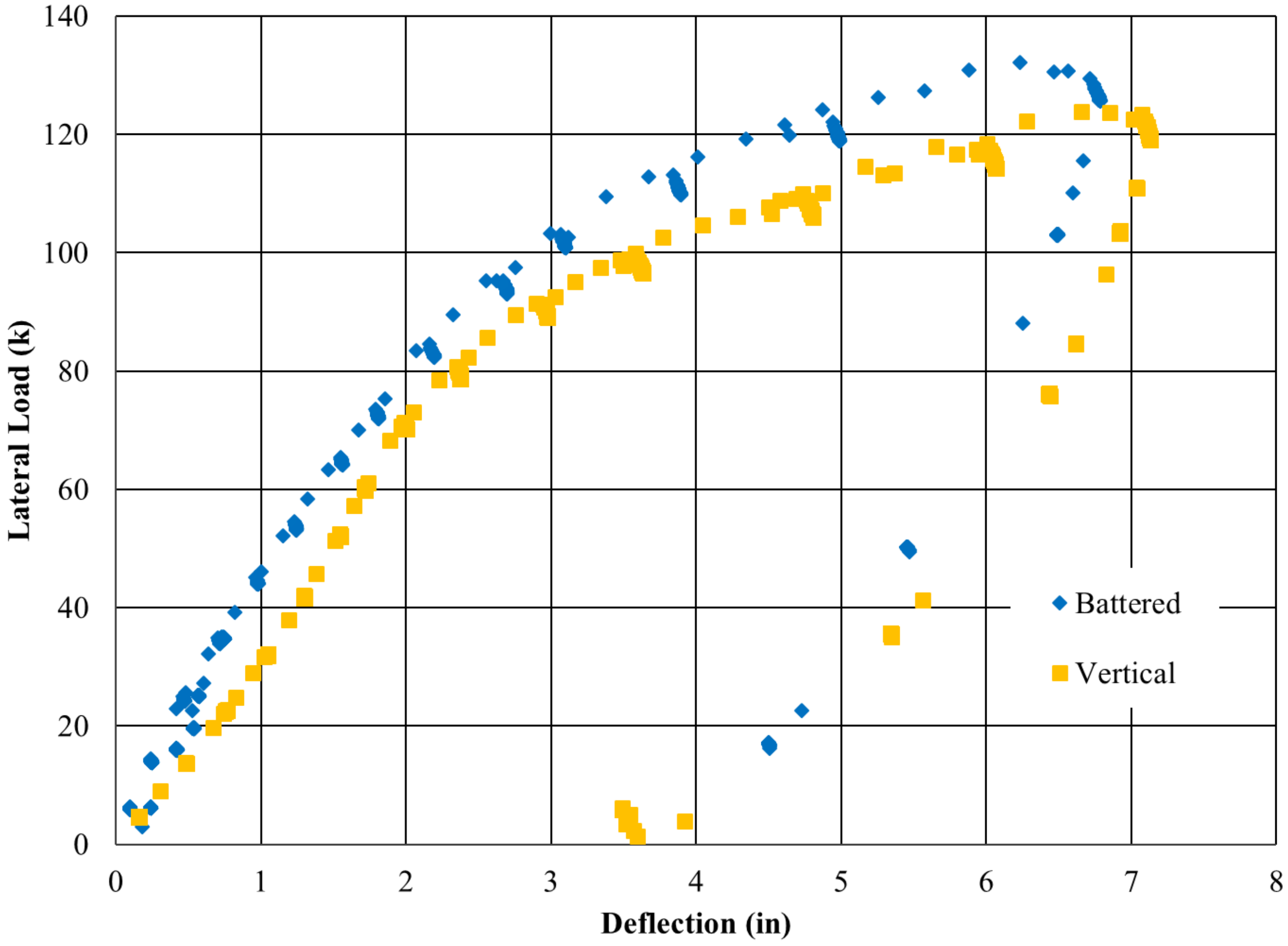
- Modeling of pile bents
  - Numerous analysis methods
  - Results can vary greatly depending on analysis model
  - Primary difficulty is accurately capturing soil-structure interaction (SSI)
  - Is the model shown here reasonable?



SCOPE AND MOTIVATION

- Provide pile bent analysis and design example
- Previous efforts have identified two primary parameters of interest:
  - Battering of exterior piles
  - Soil-structure interaction
- Single analysis and design example to highlight the process with a focus on evaluating the two primary parameters in question
- Presented results are selected based on a snapshot of certain load cases and may not represent an in-depth evaluation of all cases

BATTERED VERSUS STRAIGHT PILE TESTS



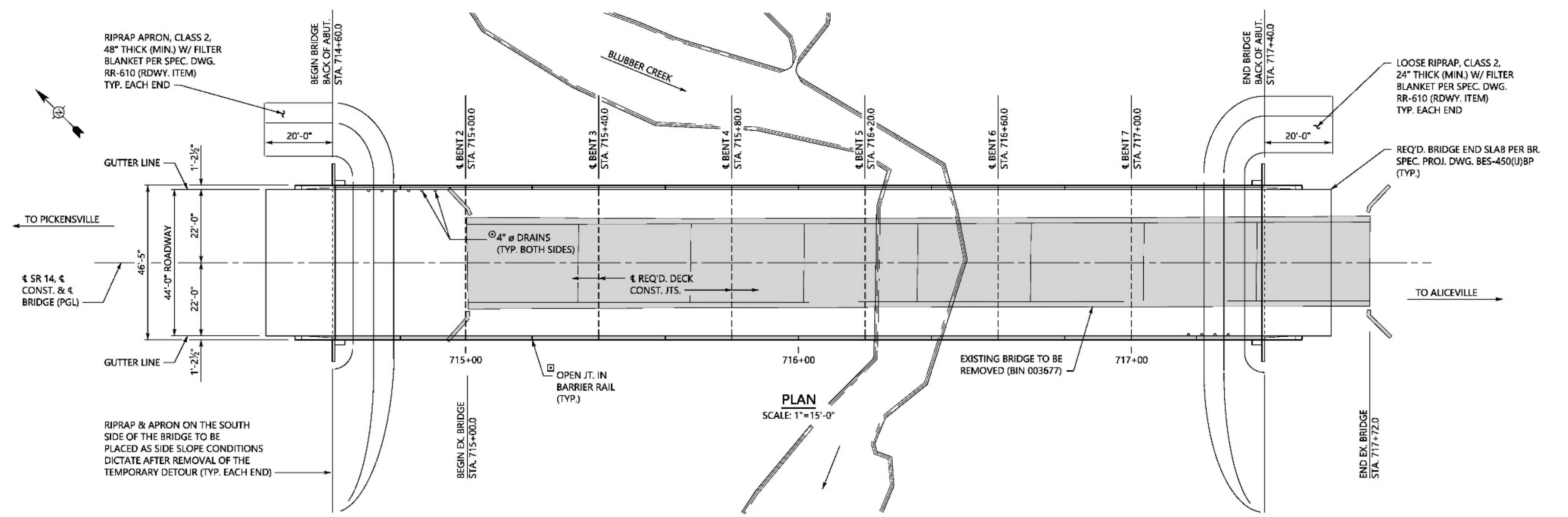
BATTERED VERSUS STRAIGHT PILE TESTS

INTRODUCTION

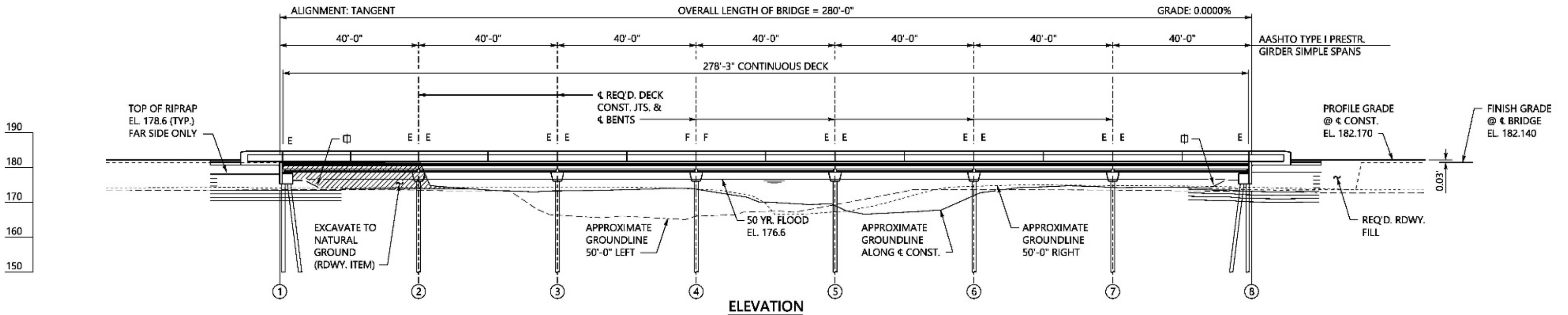
- How should soil-structure interaction be modeled?
  - A few examples are:
    - Nonlinear horizontal soil springs. Friction along pile length and vertical spring at tip provide axial capacity.
    - Linear horizontal soil springs with fixed vertical support at tip
    - Depth to fixity with sidesway included
    - Depth to fixity with the assumption that battered piles provide lateral bracing
    - Combinations of the above assumptions

INTRODUCTION

- The goal of this presentation is to provide a comparison between several modeling approaches.
- Plans for the bridge replacement on SR-14 over Blubber Creek (Pickens County) were recently completed. The following data from this project were used in our analyses:
  - Roadway and Site Geometry
  - Geotechnical
  - Hydraulic
  - Scour



PLAN
SCALE: 1"=15'-0"



ELEVATION
SCALE: 1"=15'-0"

HYDRAULIC DATA

DRAINAGE AREA = 16.8 SQ.MI.

	DISCHARGE (CU. FT./S)	STAGE (FT.)
Q50	3940	176.6
Q100	4655	176.9
Q200	5440	177.3
Q500	6635	177.8

OPENING PROVIDED = 1,070 SQ.FT.
V50 = 3.7 FT./S

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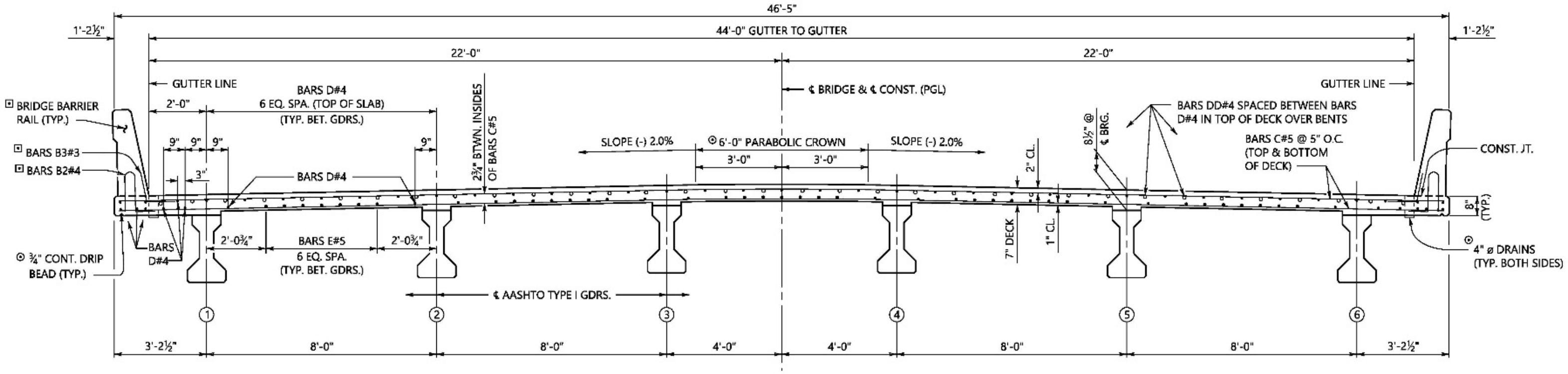
NOTES

1. SLOPE END FILLS @ 2:1
2. SEE BR. SPEC. PROJ. DWG. BBR-1 FOR DETAILS
3. SEE BR. SPEC. PROJ. DWG. SBD-1 FOR DETAILS

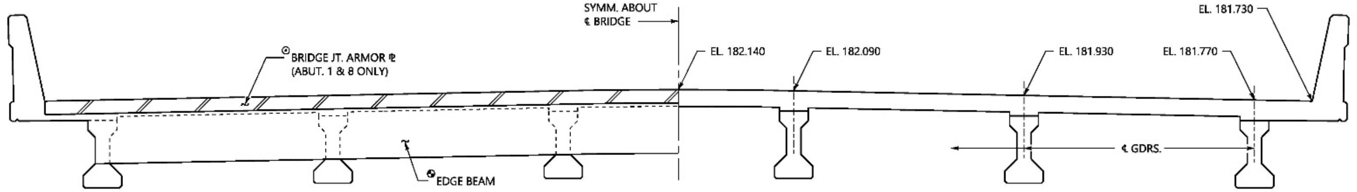
GENERAL PLAN & ELEVATION

JTH
7/18
SHOWN



TYPICAL CROSS-SECTION

SCALE: ½"=1'-0"



HALF END VIEW

SCALE: ½"=1'-0"

FINISH GRADE ELEVATIONS

SCALE: ½"=1'-0"

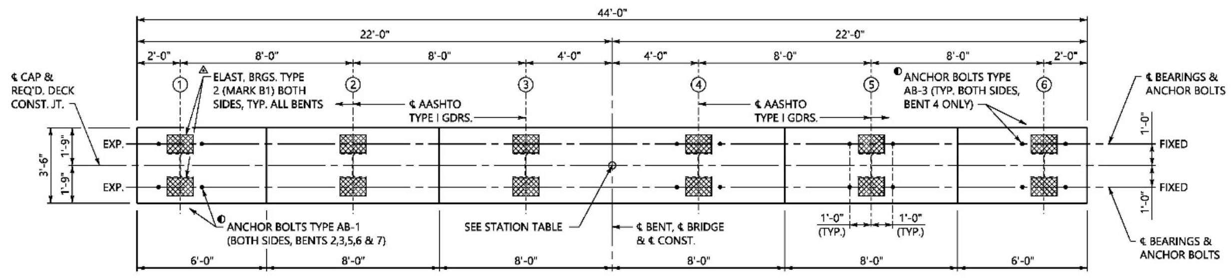
NOTES

1. SEE BR. SHT. 4 FOR PLAN VIEW OF SPANS.
2. SEE BR. SHT. 6 FOR GIRDER DETAILS.
3. SEE BR. SPEC. PROJ. DWG. SBD-1 FOR DETAILS.
4. SEE BR. SPEC. PROJ. DWG. BBR-1 FOR DETAILS.
5. SEE BR. SPEC. PROJ. DWG. EBEW1 FOR DETAILS.

5

SPANS 1 THRU 7
SHEET 2 OF 2

SMJ/JTH
7/18
SHOWN

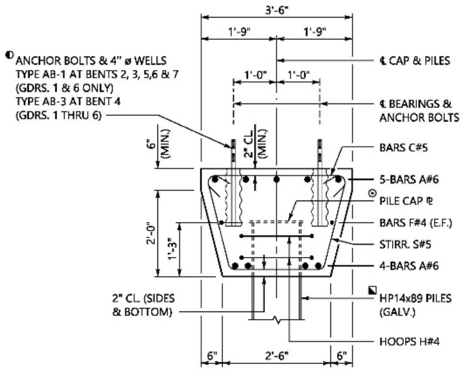


HALF-PLAN (BENTS 2, 3, 5, 6 & 7)

SCALE: 3/8"=1'-0"

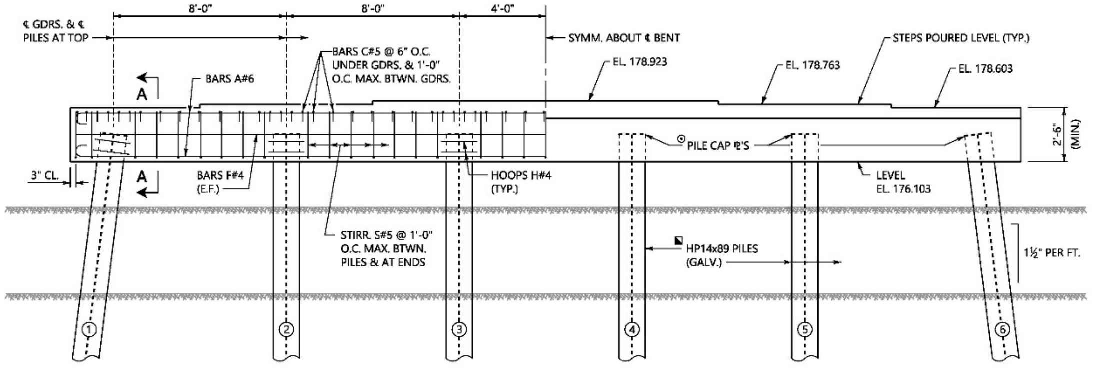
HALF-PLAN (BENT 4)

SCALE: 3/8"=1'-0"



SECTION A-A

SCALE: 3/4"=1'-0"

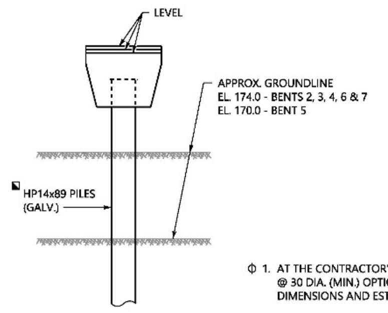


HALF-ELEVATION (BENTS 2, 3, 5, 6 & 7)

SCALE: 3/8"=1'-0"

HALF-ELEVATION (BENT 4)

SCALE: 3/8"=1'-0"



END VIEW

SCALE: 3/8"=1'-0"

NOTES

Φ 1. AT THE CONTRACTOR'S OPTION, BARS F MAY BE SPLICED @ 30 DIA. (MIN.) OPTIONAL SPLICE NOT INCLUDED IN BAR DIMENSIONS AND ESTIMATED QUANTITIES SHOWN.

◐ 2. HORIZONTALLY ADJUST REINFORCEMENT AS NECESSARY TO ENSURE CORRECT LOCATION OF ANCHOR BOLTS WELLS. SEE BR. SPEC. PROJ. DWG. SBD-1 FOR DETAILS AND NOTE 23 ON BR. SPEC. PROJ. DWG. SBN-1.

⊙ 3. SEE BR. SPEC. PROJ. DWG. SBD-1 FOR DETAILS.

⚠ 4. SEE BR. SPEC. PROJ. DWG. SPGD-1 FOR DETAILS.

◪ 5. SEE PILE GALVANIZATION NOTES ON BR. SHT. 1.

STATION TABLE

BENT 2	STA. 715+00.0
BENT 3	STA. 715+40.0
BENT 4	STA. 715+80.0
BENT 5	STA. 716+20.0
BENT 6	STA. 716+60.0
BENT 7	STA. 717+00.0

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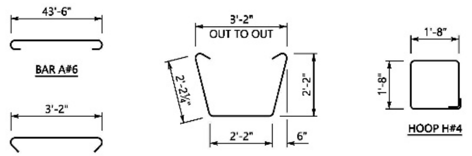
BILL OF REINFORCEMENT

	MARK	SIZE	NUMBER	LENGTH	BENDING
			CAP		
	A	6	9	44'-10"	SEE DIAG.
	C	5	63	4'-1"	SEE DIAG.
Φ	F	4	2	43'-6"	STRAIGHT
	H	4	12	7'-5"	SEE DIAG.
	S	5	39	7'-5½"	SEE DIAG.



ESTIMATED QUANTITIES (PER BENT)

1,300	POUND	502A	STEEL REINFORCEMENT
192	POUND	508A	STRUCTURAL STEEL
13.7	CUBIC YARD	510A	BRIDGE SUBSTRUCTURE CONCRETE

BENTS 2 THRU 7

JTH
7/18
SHOWN

MODEL OVERVIEW AND ASSUMPTIONS

- FB-MultiPier -- Two Scenarios
  - Case 1: All vertical piles
  - Case 2: Exterior piles are battered
    - Nonlinear horizontal soil springs, side friction and axial spring at tip provide connection to external world for both cases.
- GT STRUDL -- Three Scenarios
  - Case 1: All vertical piles with horizontal soil springs
    - Horizontal subgrade modulus assumed to be linear
      - 60 pci along top three feet
      - 125 pci along remainder
  - Case 2: Depth to fixity assumption with all vertical biles
  - Case 3: Depth to fixity assumption with exterior piles battered

MODEL OVERVIEW AND ASSUMPTIONS

Bassett Creek Bridge: Equivalent Pile Length for Bent Design

Project: 2019 Preconstruction Conference — Client: ALDOT — Sheet 1/1

Basic Pile Length

Top of Pile Elev. (ft)	177.353
Existing Finished Grade Elev. At Bent 4 (ft)	173.800
Pile Length to Existing Grade (ft)	3.553
Design Scour (ft)	20.000
Pile Length to Bearing Strata (ft)	23.553

Depth to Fixity

Modulus of Horiz. Subgrade Reaction (kcf)	216

Longitudinal Direction (Strong Axis):

Ix (in4)	904
E (ksi)	29,000
Depth to Fixity, D (ft)	6.93

Transverse Direction (Weak Axis):

Iy (in4)	326
E (ksi)	29,000
Depth to Fixity, D (ft)	5.65

Design Depth to Fixity, D (ft)	6.93

Notes:

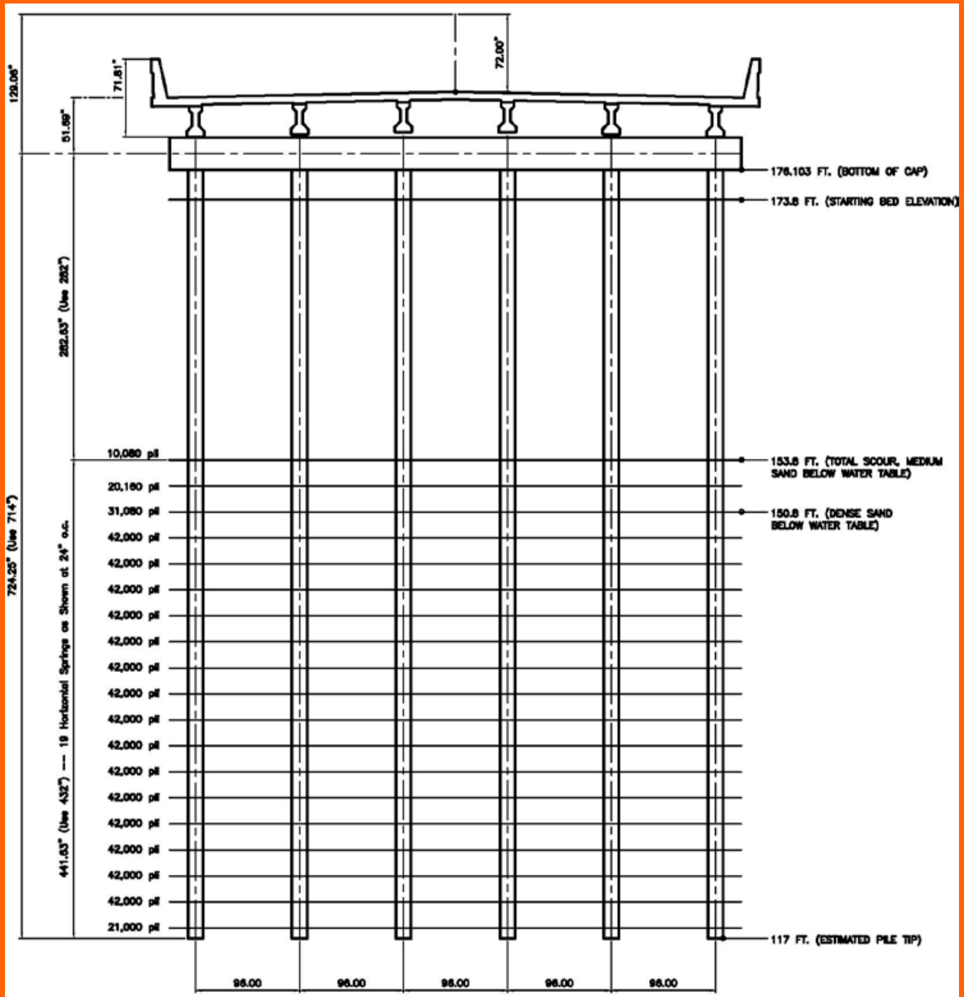
1) Depth to Fixity, D = 1.8(EI/(N*144))**0.2, where N is the modulus of horizontal subgrade reaction.

Equivalent Pile Length

Pile Length to Bearing Strata (ft)	23.553
Design Depth to Fixity (ft)	6.930
Combined Length (ft)	30.483
Equivalent Pile Length for Design (ft)	**31.0**

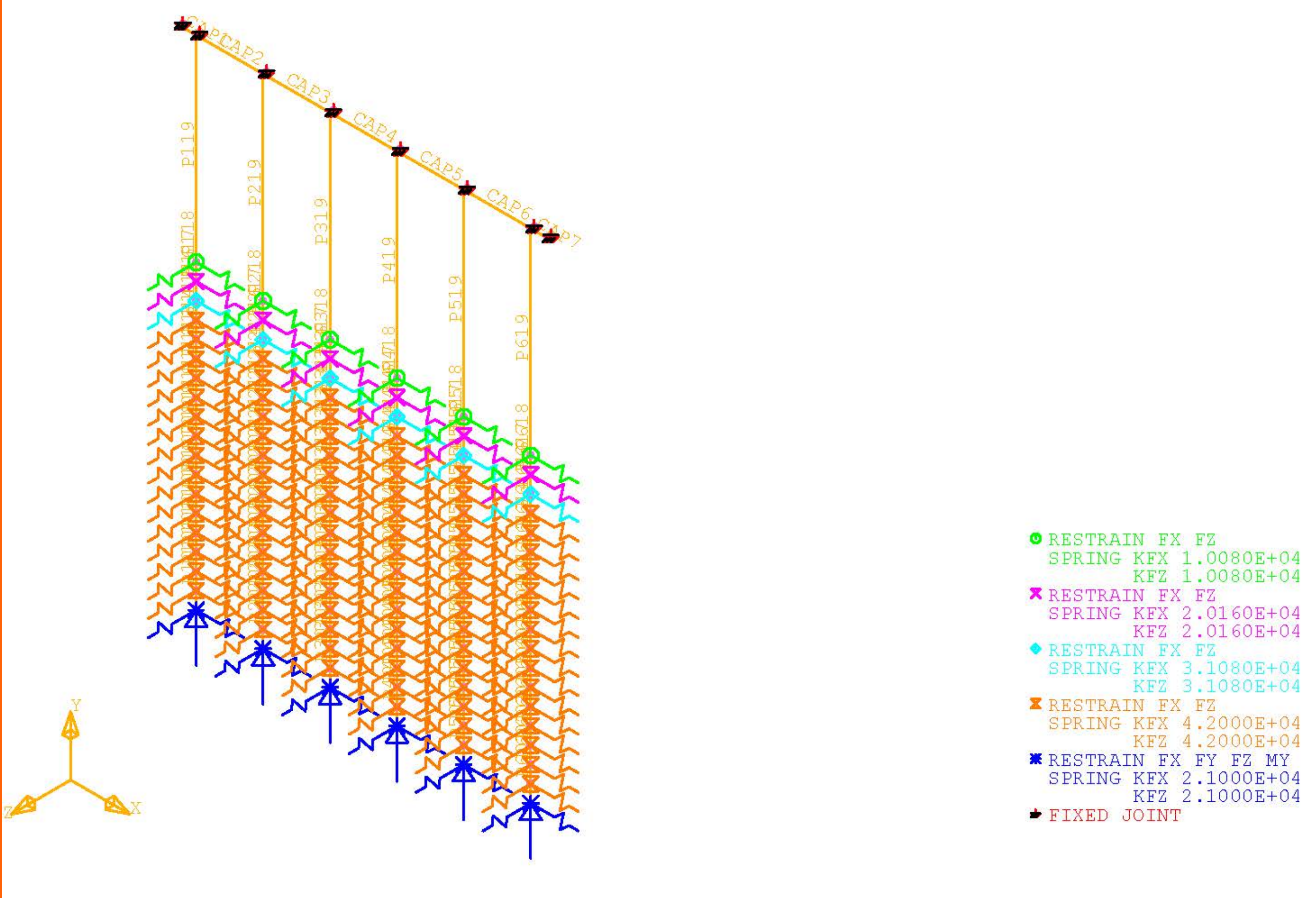
MODEL OVERVIEW AND ASSUMPTIONS

- Piles
  - Displacements in plane of bent causes weak axis bending in piles
- Total scour of 20 feet
- Stream velocity is 4.9 fps
- Longitudinal braking force, BR is resisted entirely by this bent until deck joint closes
- Three traffic lanes



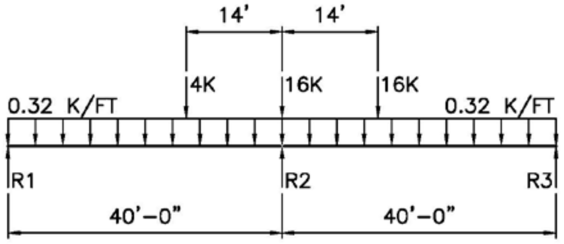
MODEL OVERVIEW AND ASSUMPTIONS

- Horizontal soil springs placed at 24” o.c. along embedded length
- Gap element at the bent cap allows 1.5” displacement at cap



MODEL OVERVIEW AND ASSUMPTIONS

- Single wheel line reaction at bent
- Live Load condition for all models



REACTION FROM LEFT SPAN (SUM MOMENTS ABOUT R1):

$R_{TRUCK}=4(40-14)/40=2.6$ KIPS

$R_{LANE}=0.32(40)(20)/40=6.4$ KIPS

REACTION FROM RIGHT SPAN (SUM MOMENTS ABOUT R3):

$R_{TRUCK}=16(40-14)/40=10.4$ KIPS

$R_{LANE}=0.32(40)(20)/40=6.4$ KIPS

REACTION COMPONENTS AT R2:

$R_{TRUCK}=2.6+16+10.4=29$ KIPS

$R_{LANE}=6.4+6.4=12.8$ KIPS

IMPACT FACTOR (APPLIED TO TRUCK ONLY):

$I = 1+(33/100) = 1.33$

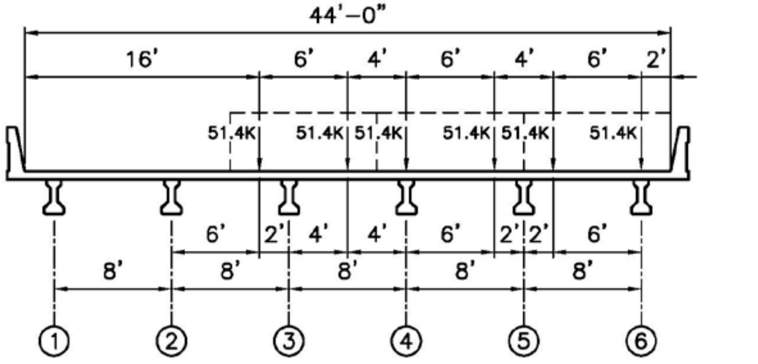
TRUCK REACTION AT R2 WITH IMPACT:

$R_{TRUCK+I}=29(1.33)=38.6$ KIPS

TOTAL LIVE LOAD REACTION AT R2:

$R_{TOTAL}=R_{LANE}+R_{TRUCK+I}=12.8+38.6=51.4$ KIPS

SINGLE WHEEL LINE REACTION AT BENT (HL–93)



NOTE: BOXED AREAS REPRESENT THE 10 FOOT WIDTH OF EACH DESIGN VEHICULAR LIVE LOAD AS SPECIFIED BY THE AASHTO LRFD SPECIFICATIONS, ARTICLE 3.6.1.2.1.

REACTIONS:

R1 = 0 KIPS

R2 = 51.4(2)/8 = 12.85 KIPS

R3 = 51.4(6+4)/8 = 64.25 KIPS

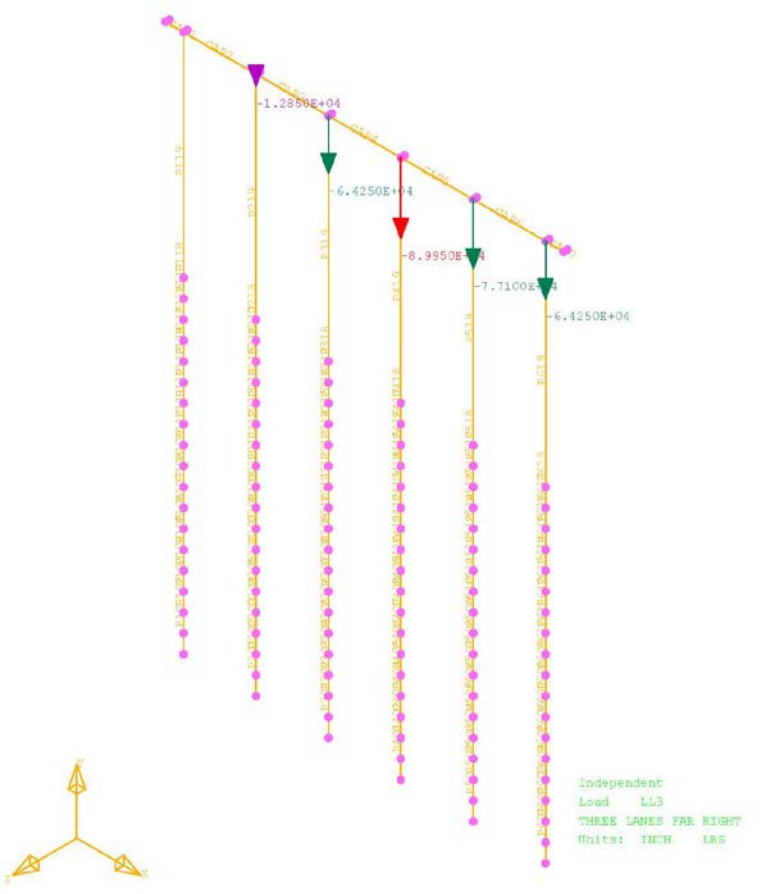
R4 = 51.4(4+8+2)/8 = 89.95 KIPS

R5 = 51.4(6+6)/8 = 77.1 KIPS

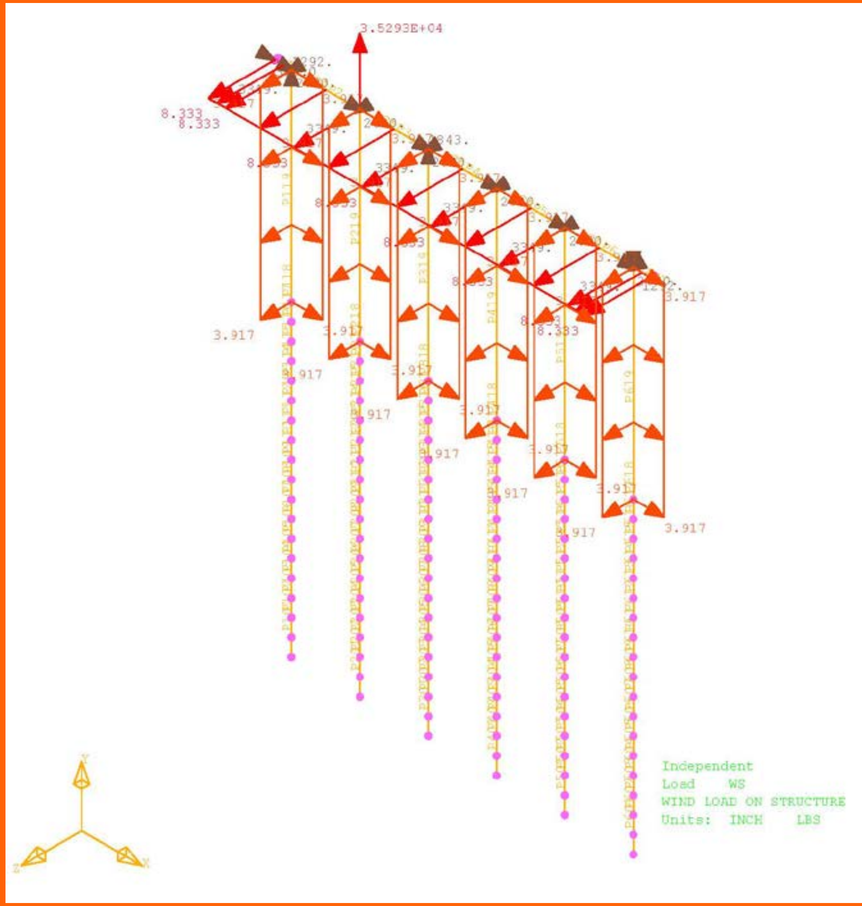
R6 = 51.4(2+8)/8 = 64.25 KIPS

LL3 (THREE LOADED LANES, FAR RIGHT)

MODEL OVERVIEW AND ASSUMPTIONS



Live Load (Three Trucks, Far Right)



Wind on Structure

RESULTS

- 15 independent load cases
- 38 load combinations
- Results for five load combinations provided for each scenario:
  - Service I (SR120)
  - Strength I (ST130)
  - Extreme Event II (EE220)
  - Strength III (ST300)
  - Strength V (ST520)

LOAD COMBIINATIONS

STRENGTH I

ST100	=	1.25(DC1+DC2)		
ST110	=	1.25(DC1+DC2)	1.75(LL1+BR)	WA
ST120	=	1.25(DC1+DC2)	1.75(LL2+BR)	WA
ST130	=	1.25(DC1+DC2)	1.75(LL3+BR)	WA
ST140	=	1.25(DC1+DC2)	1.75(LL4+BR)	WA
ST150	=	1.25(DC1+DC2)	1.75(LL5+BR)	WA
ST160	=	1.25(DC1+DC2)	1.75(LL6+BR)	WA
ST170	=	1.25(DC1+DC2)	1.75(LL7+BR)	WA
ST180	=	1.25(DC1+DC2)	1.75(LL8+BR)	WA
ST190	=	1.25(DC1+DC2)	1.75(LL9+BR)	WA

STRENGTH III

ST300	=	1.25(DC1+DC2)	WA	1.4(WS)

STRENGTH V

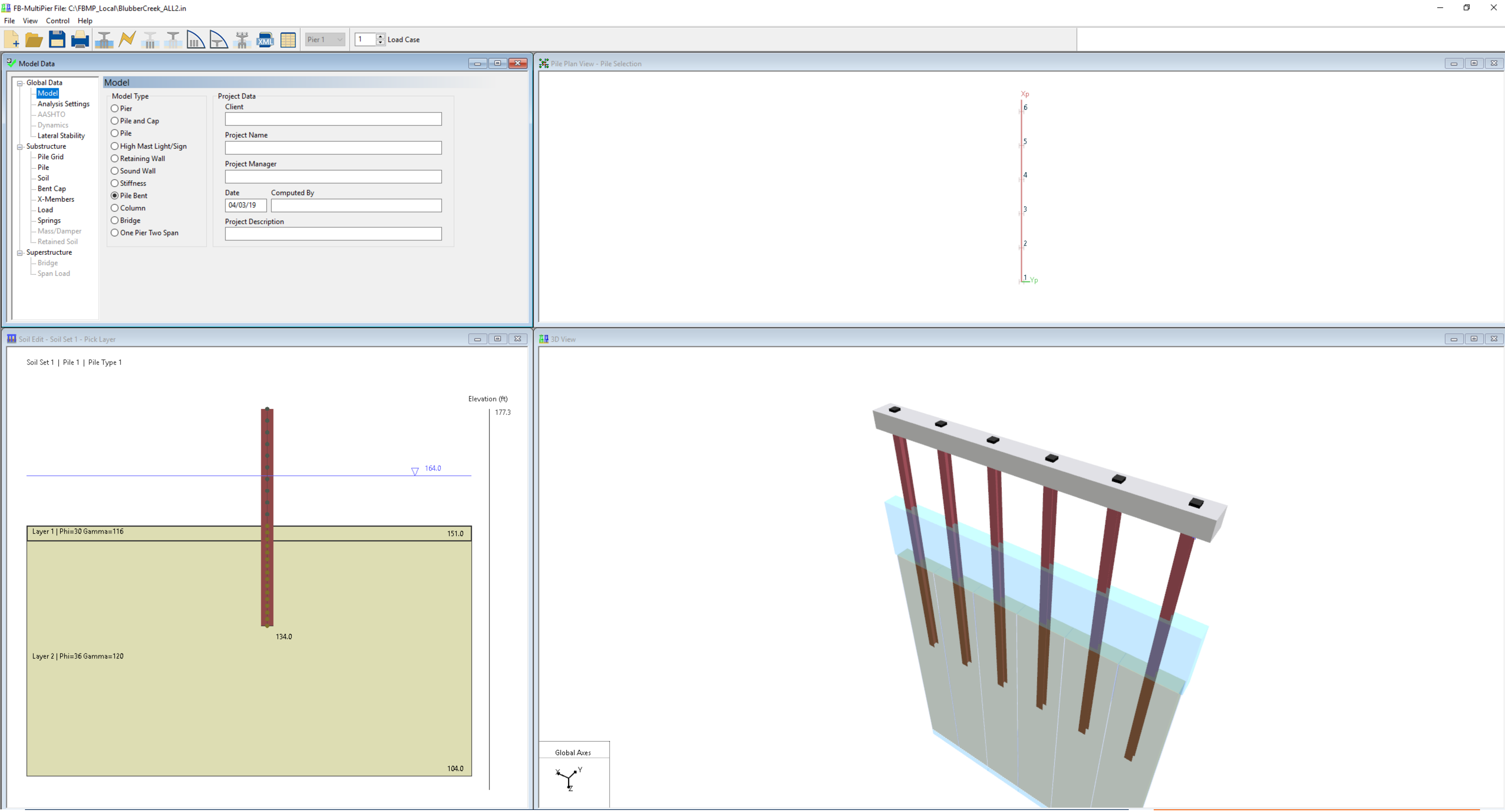
ST500	=	1.25(DC1+DC2)	1.35(LL1+BR)	WA	0.4(WS)	WL
ST510	=	1.25(DC1+DC2)	1.35(LL2+BR)	WA	0.4(WS)	WL
ST520	=	1.25(DC1+DC2)	1.35(LL3+BR)	WA	0.4(WS)	WL
ST530	=	1.25(DC1+DC2)	1.35(LL4+BR)	WA	0.4(WS)	WL
ST540	=	1.25(DC1+DC2)	1.35(LL5+BR)	WA	0.4(WS)	WL
ST550	=	1.25(DC1+DC2)	1.35(LL6+BR)	WA	0.4(WS)	WL
ST560	=	1.25(DC1+DC2)	1.35(LL7+BR)	WA	0.4(WS)	WL
ST570	=	1.25(DC1+DC2)	1.35(LL8+BR)	WA	0.4(WS)	WL
ST580	=	1.25(DC1+DC2)	1.35(LL9+BR)	WA	0.4(WS)	WL

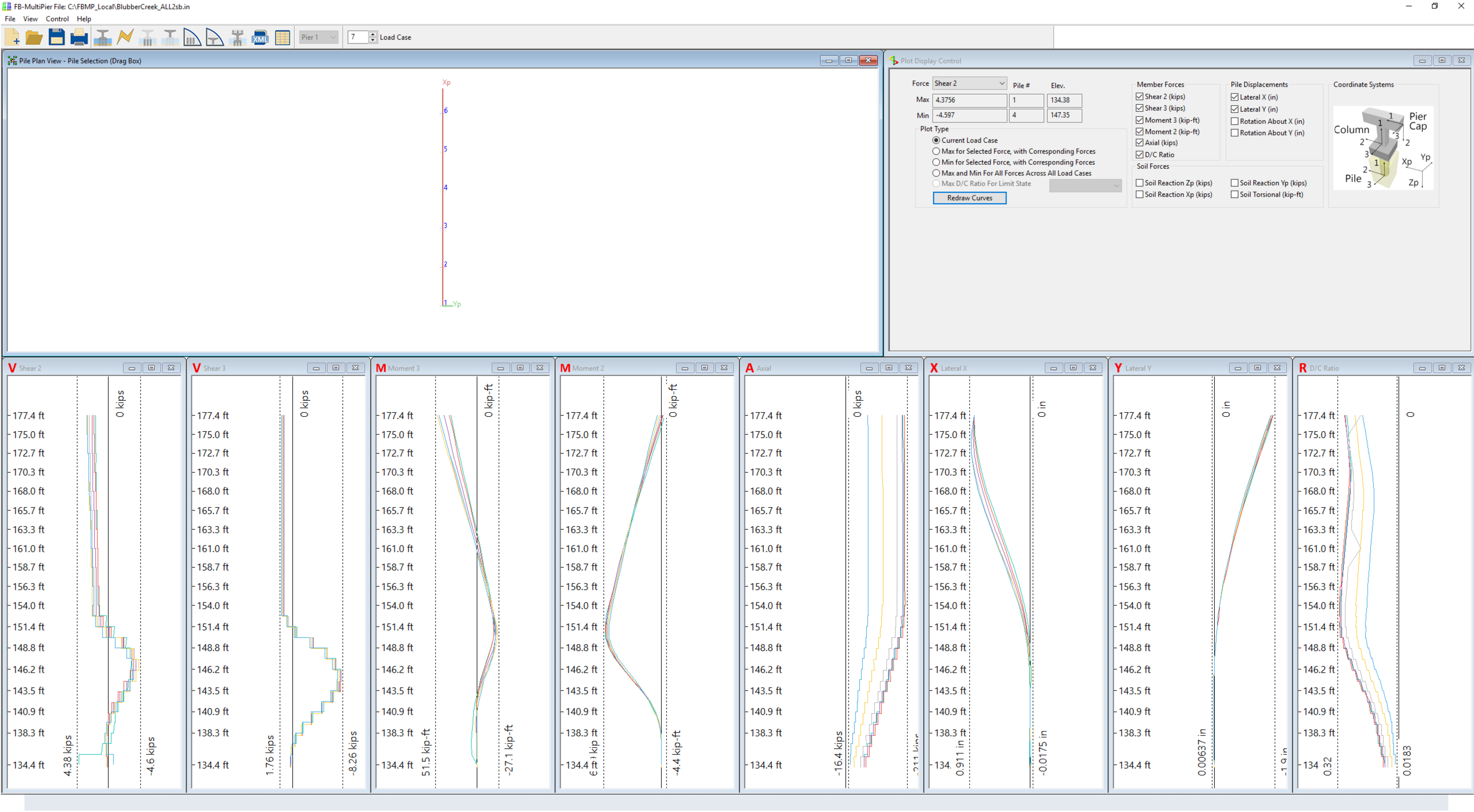
EXTREME EVENT II

EE200	=	1.25(DC1+DC2)	0.50(LL1+BR)	WA
EE210	=	1.25(DC1+DC2)	0.50(LL2+BR)	WA
EE220	=	1.25(DC1+DC2)	0.50(LL3+BR)	WA
EE230	=	1.25(DC1+DC2)	0.50(LL4+BR)	WA
EE240	=	1.25(DC1+DC2)	0.50(LL5+BR)	WA
EE250	=	1.25(DC1+DC2)	0.50(LL6+BR)	WA
EE260	=	1.25(DC1+DC2)	0.50(LL7+BR)	WA
EE270	=	1.25(DC1+DC2)	0.50(LL8+BR)	WA
EE280	=	1.25(DC1+DC2)	0.50(LL9+BR)	WA

SERVICE I

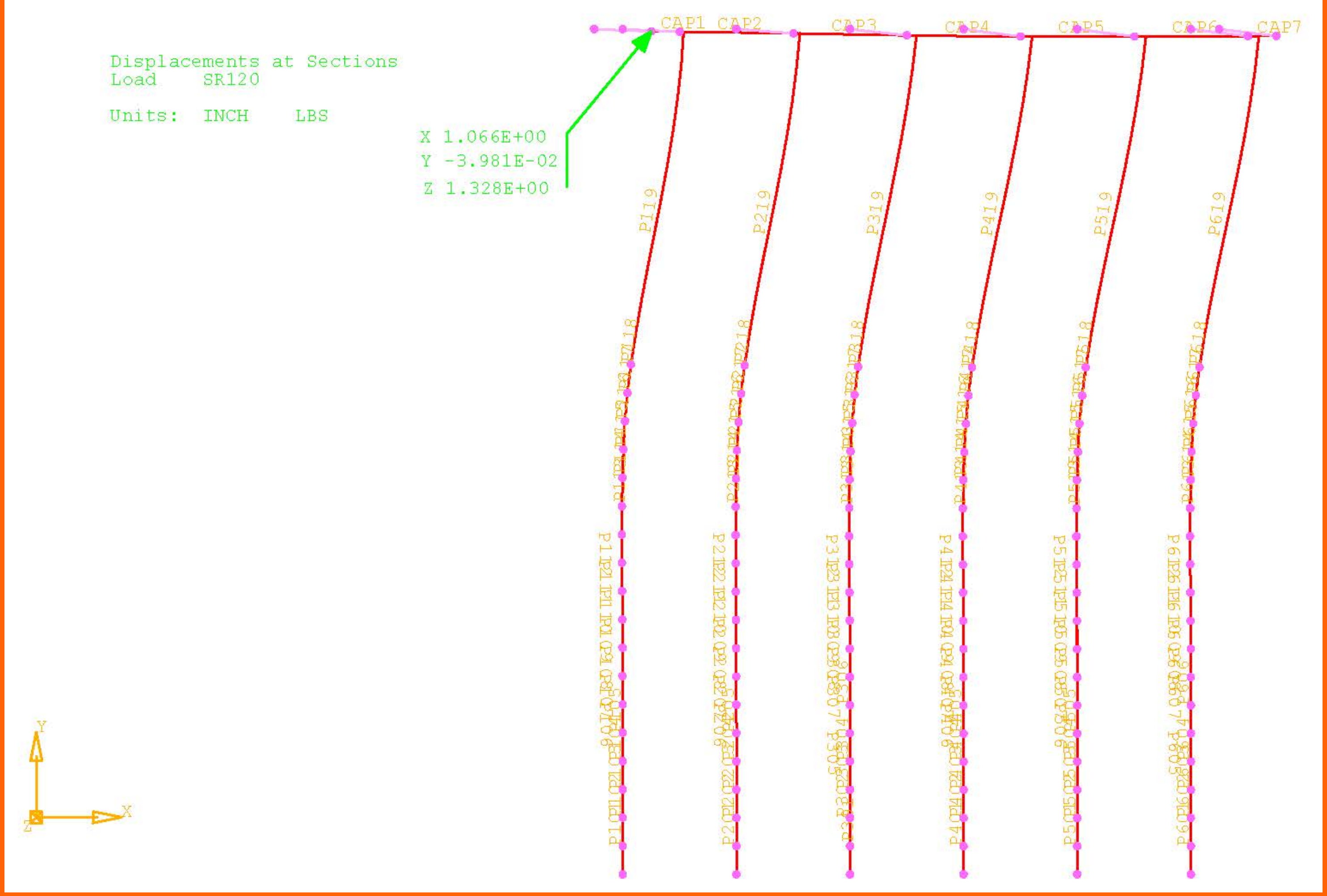
SR100	=	DC1	DC2	LL1	BR	WA	0.3(WS)	WL
SR110	=	DC1	DC2	LL2	BR	WA	0.3(WS)	WL
SR120	=	DC1	DC2	LL3	BR	WA	0.3(WS)	WL
SR130	=	DC1	DC2	LL4	BR	WA	0.3(WS)	WL
SR140	=	DC1	DC2	LL5	BR	WA	0.3(WS)	WL
SR150	=	DC1	DC2	LL6	BR	WA	0.3(WS)	WL
SR160	=	DC1	DC2	LL7	BR	WA	0.3(WS)	WL
SR170	=	DC1	DC2	LL8	BR	WA	0.3(WS)	WL
SR180	=	DC1	DC2	LL9	BR	WA	0.3(WS)	WL


FB-MultiPier File: C:\FBMP_Local\BlubberCreek_ALL2.in
File View Control Help
Pier 1
1 Load Case
Model Data
Global Data
Model
Analysis Settings
AASHTO
Dynamics
Lateral Stability
Substructure
Pile Grid
Pile
Soil
Bent Cap
X-Members
Load
Springs
Mass/Damper
Retained Soil
Superstructure
Bridge
Span Load
Model
Model Type
Pier
Pile and Cap
Pile
High Mast Light/Sign
Retaining Wall
Sound Wall
Stiffness
Pile Bent
Column
Bridge
One Pier Two Span
Project Data
Client
Project Name
Project Manager
Date
Computed By
04/03/19
Project Description
Pile Plan View - Pile Selection
Xp
6
5
4
3
2
1
Yp
Soil Edit - Soil Set 1 - Pick Layer
Soil Set 1 | Pile 1 | Pile Type 1
Elevation (ft)
177.3
164.0
Layer 1 | Phi=30 Gamma=116
151.0
134.0
Layer 2 | Phi=36 Gamma=120
104.0
3D View
Global Axes



FB-MultiPier File: C:\FBMP_Local\BlubberCreek_ALL2sb.in
File View Control Help
Pier 1
7 Load Case
Pile Plan View - Pile Selection (Drag Box)
Plot Display Control
Force Shear 2
Pile #
Elev.
Max 4.3756 1 134.38
Min -4.597 4 147.35
Plot Type
Current Load Case
Max for Selected Force, with Corresponding Forces
Min for Selected Force, with Corresponding Forces
Max and Min For All Forces Across All Load Cases
Max D/C Ratio For Limit State
Redraw Curves
Member Forces
Shear 2 (kips)
Shear 3 (kips)
Moment 3 (kip-ft)
Moment 2 (kip-ft)
Axial (kips)
D/C Ratio
Soil Forces
Soil Reaction Zp (kips)
Soil Reaction Xp (kips)
Pile Displacements
Lateral X (in)
Lateral Y (in)
Rotation About X (in)
Rotation About Y (in)
Soil Reaction Yp (kips)
Soil Torsional (kip-ft)
Coordinate Systems
Column
Pier Cap
Pile
Shear 2
Shear 3
Moment 3
Moment 2
Axial
Lateral X
Lateral Y
D/C Ratio
177.4 ft
175.0 ft
172.7 ft
170.3 ft
168.0 ft
165.7 ft
163.3 ft
161.0 ft
158.7 ft
156.3 ft
154.0 ft
151.4 ft
148.8 ft
146.2 ft
143.5 ft
140.9 ft
138.3 ft
134.4 ft
0 kips
4.38 kips
-4.6 kips
1.76 kips
-8.26 kips
0 kip-ft
51.5 kip-ft
-27.1 kip-ft
-4.4 kip-ft
-16.4 kips
0 in
0.911 in
-0.0175 in
0.00637 in
0
0.32
0.0183

DEFORMED STRUCTURE DUE TO LOAD SR120



RESULTS SUMMARY

Lateral Cap Displacement (Inches)					
Software	FB-MultiPier		GT STRUDL		
Modeling Assumptions	Nonlinear Soil Springs	Nonl. Soil Spring (Batt.)	Linear Soil Springs	Point of Fixity	Point of Fixity (Battered)
Load					
ST130	0.53	0.87	0.36	0.33	0.56
ST300	2.42	1.41	2.09	2.11	1.10
ST520	1.46	0.06	1.28	1.28	0.09
EE220	0.25	0.08	0.29	0.28	0.04
SR120	1.11	0.15	1.07	1.07	0.15

Maximum Pile Axial Force (kips)					
Software	FB-MultiPier		GT STRUDL		
Modeling Assumptions	Nonlinear Soil Springs	Nonl. Soil Spring (Batt.)	Linear Soil Springs	Point of Fixity	Point of Fixity (Battered)
Load					
ST130	209.6	208.7	219.2	227.4	249.5
ST300	88.2	104.7	89.7	90.7	119.2
ST520	182.6	179.9	188.4	193.2	193.8
EE220	116.5	117.5	121.1	123.3	123.6
SR120	142.4	139.3	144.4	147.9	148.5

RESULTS SUMMARY

Maximum Weak Axis Pile Bending (ft-kips)					
Software	FB-MultiPier		GT STRUDL		
Modeling Assumptions	Nonlinear Soil Springs	Nonl. Soil Spring (Batt.)	Linear Soil Springs	Point of Fixity	Point of Fixity (Battered)
Load					
ST130	14.5	51.5	11.3	13.5	28.4
ST300	69.6	49.1	64.7	77.6	49.0
ST520	42.8	14.1	40.2	45.9	6.7
EE220	7.2	8.7	7.9	11.6	5.7
SR120	34.3	5.7	33.2	38.6	8.8

Maximum Cap Bending Moment (ft-kips)					
Software	FB-MultiPier		GT STRUDL		
Modeling Assumptions	Nonlinear Soil Springs	Nonl. Soil Spring (Batt.)	Linear Soil Springs	Point of Fixity	Point of Fixity (Battered)
Load					
ST130	267.1	287.6	117.4	71.8	125.0
ST300	113.0	266.9	104.3	94.4	339.7
ST520	197.6	202.7	108.3	73.0	84.4
EE220	56.6	57.5	31.0	20.2	14.1
SR120	132.0	128.7	81.2	55.3	81.6

PRELIMINARY CONCLUSIONS

- Variability in the design demands , both displacement and forces, depends on the selection of soil-pile interaction modeling
- For the GT-STRUDL (Structural) analysis model battering the piles resulted in an increase in the axial pile demands
- Represents a single case with a snapshot of load combinations that should be explored further to identify the best process to analyze and design the piles and bents

ACKNOWLEDGEMENTS

- ALDOT Bridge Bureau
- ALDOT Bureau of Materials and Tests
- Building & Earth Sciences, Inc.

QUESTIONS?