Field Investigation of Downdrag on Concrete Piles in Sandy Soil

GRIP 2023

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Civil & Environmental Engineering

Outline

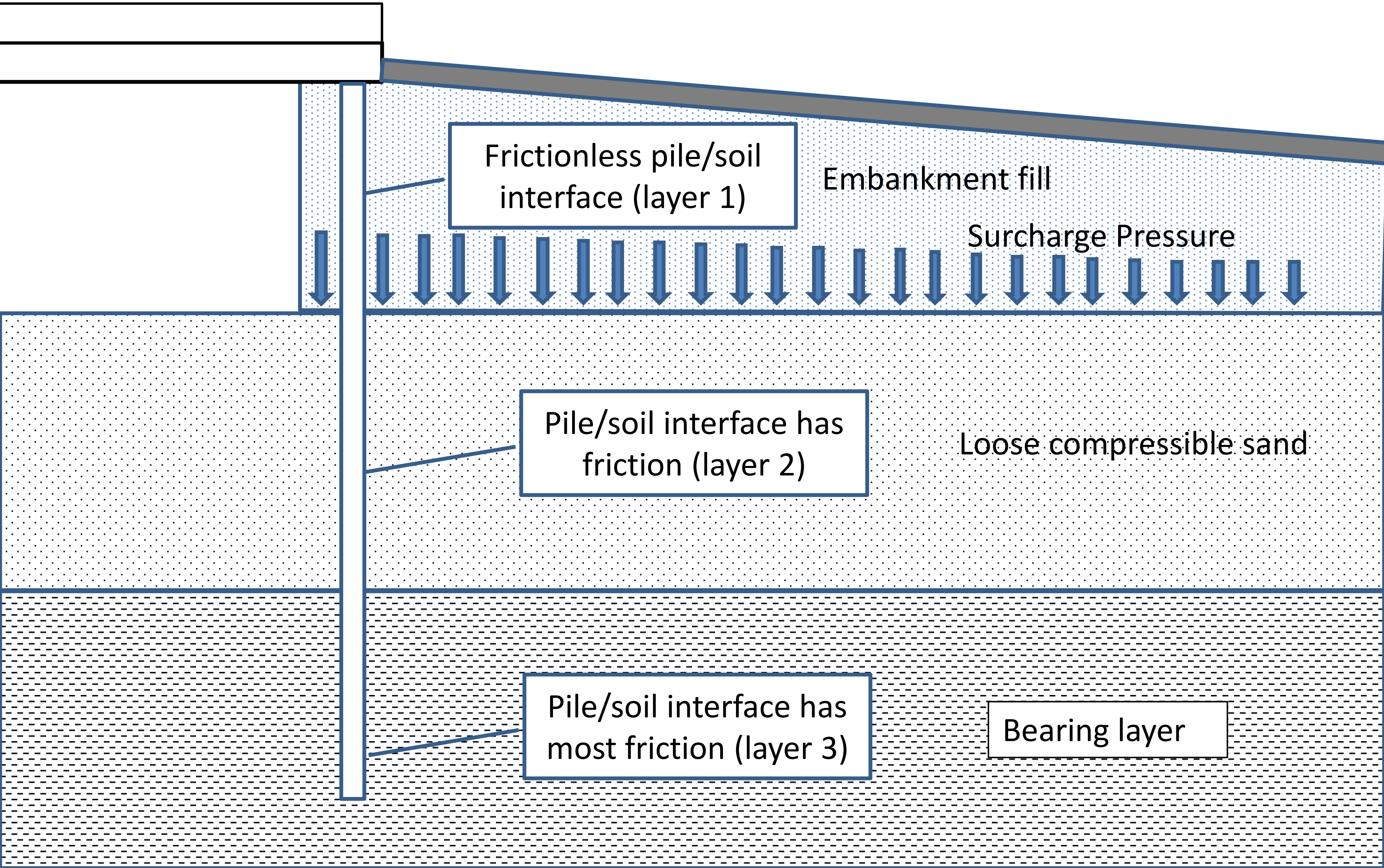
- Background / Problem Statement
- Objectives / Approach
- Tasks
- Conclusions
- Recommendations
- Acknowledgments

Background / Problem Statement

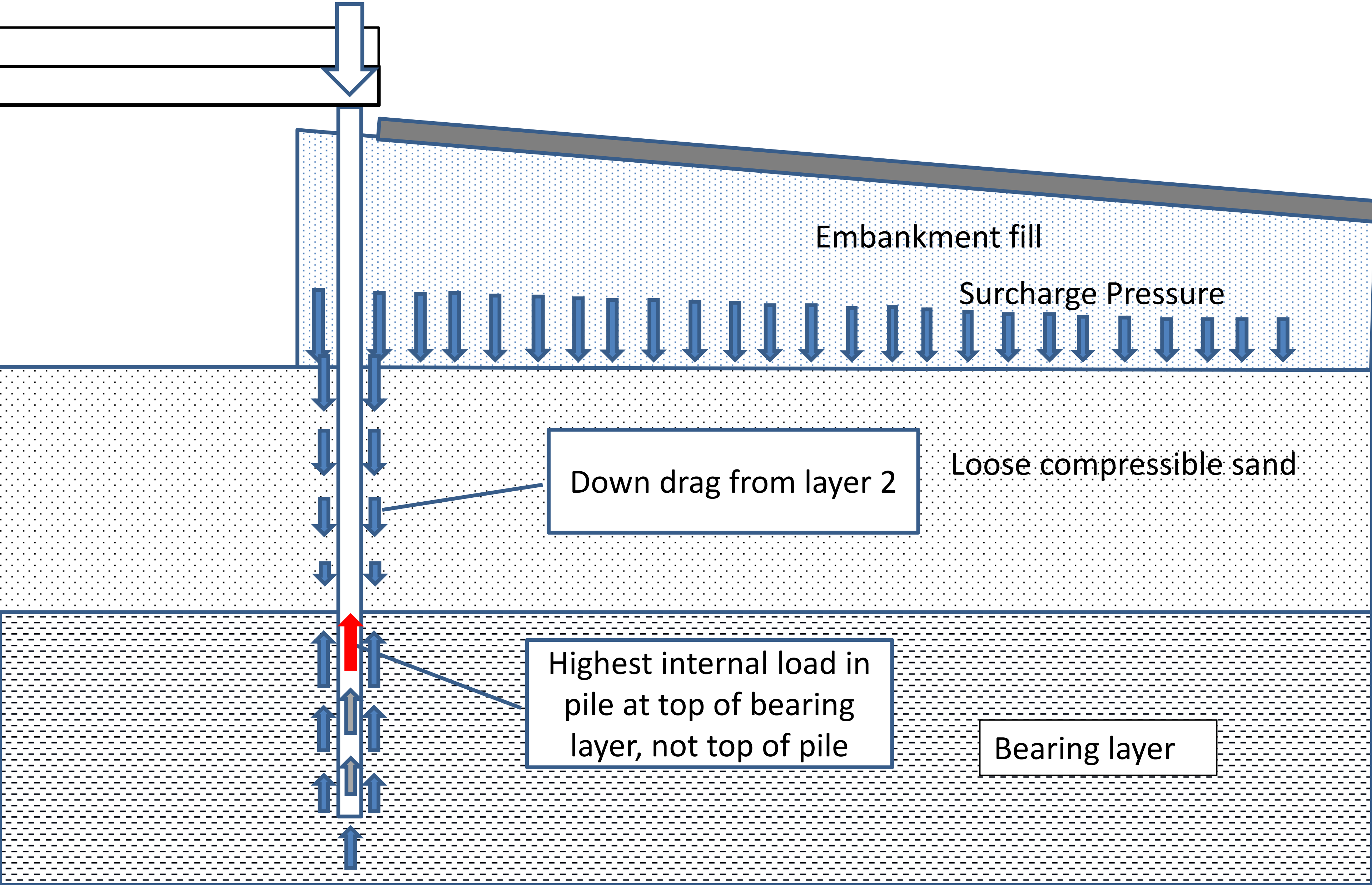
- Piles in end bents are subjected to settlement induced surcharge loads in addition to structural bridge loads.
- Depending on the site-specific conditions it is conceivable that the additional loads may exceed the structural and/or geotechnical pile capacity.
- This study investigates these conditions.

Misconception: sandy soils settle immediately so there are no downdrag forces

Simple Embankment Model



Can DL + LL cause enough elastic compression to offset/reverse downdrag side shear on piles???



Objective

- Determine the effects of downdrag on pile load from compressible sandy soils

Approach

- Instrument and monitor three bridge sites for pile forces and ground settlement

Project Tasks

- Task 1: Literature Review (not discussed today)
- Task 2: Instrumentation and Monitoring
- Task 3: Data Analysis and Scenario Evaluation
- Task 4: Model Simulations
- Task 5: Develop Recommendations

Task 2: Field Instrumentation and Monitoring

- Select sites with compressible sand beneath embankment
- Evaluate for potential downdrag
- Instrument piles for internal loads
- Instrument existing soils with settlement sensors
- Long-term monitoring

SR 23 Northbound over CR-739B Sandridge Road

- Clay County, District 2
- Bridge No. 710113
- (6) 18-inch square prestressed concrete piles
- End Bent 1, Pile 4
- Pile instrumented: 3/29/21
- Site instrumented: 5/4/21 – 5/5/21

Paseo al Mar Boulevard I-75 Flyover

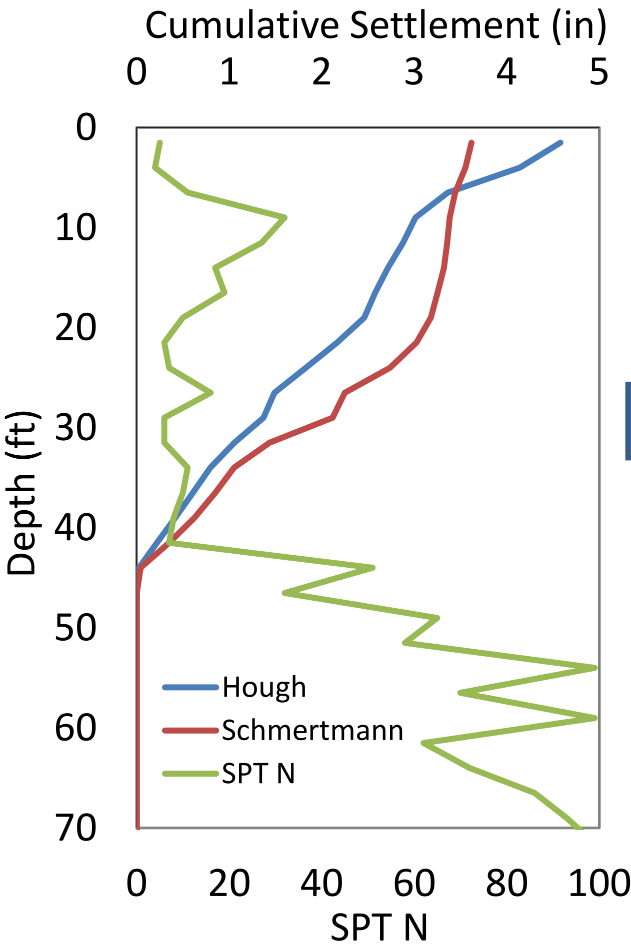
- Hillsborough County, District 7
- Bridge No. 104495
- (16) 24-inch square prestressed concrete piles
- End Bent 3, Pile 12
- Pile instrumented: 4/15/21
- Site instrumented: 5/1/21 and 5/3/21

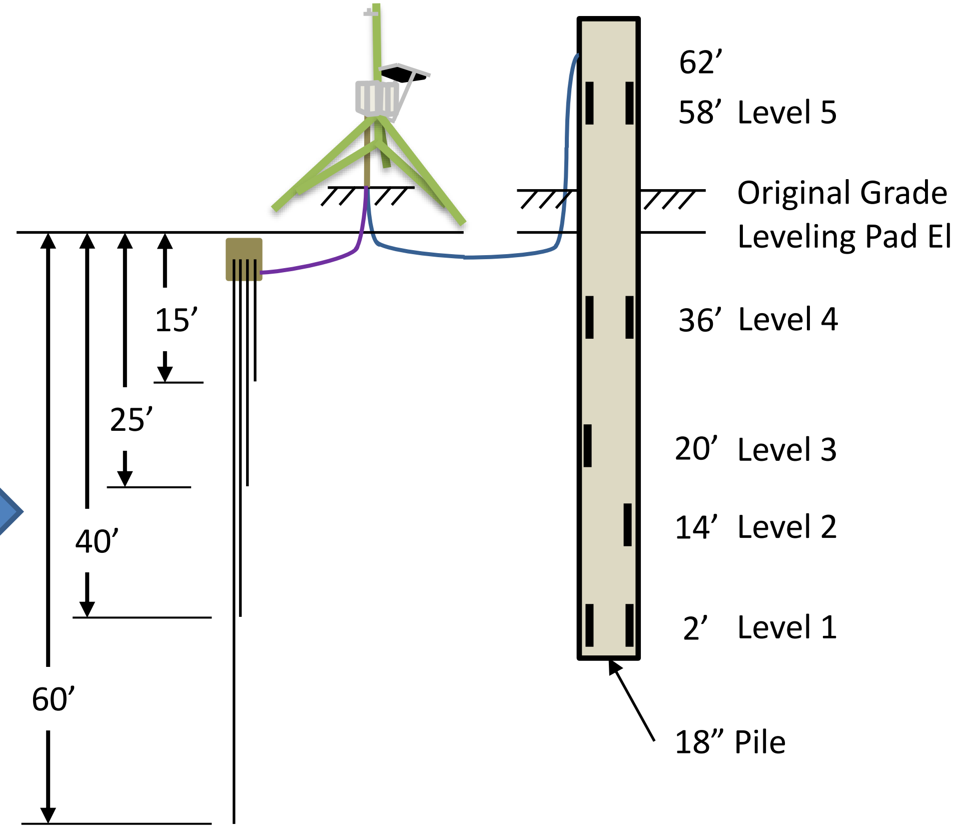
SR 23 Southbound over CR-739 Henley Road

- Clay County, District 2
- Bridge No. 710120
- (5) 24-inch square prestressed concrete piles
- End Bent 1, Pile 3
- Pile instrumented: 1/28/21
- Site instrumented:

  9/6/21 – 9/8/21

Sandridge Road





Pile Instrumentation

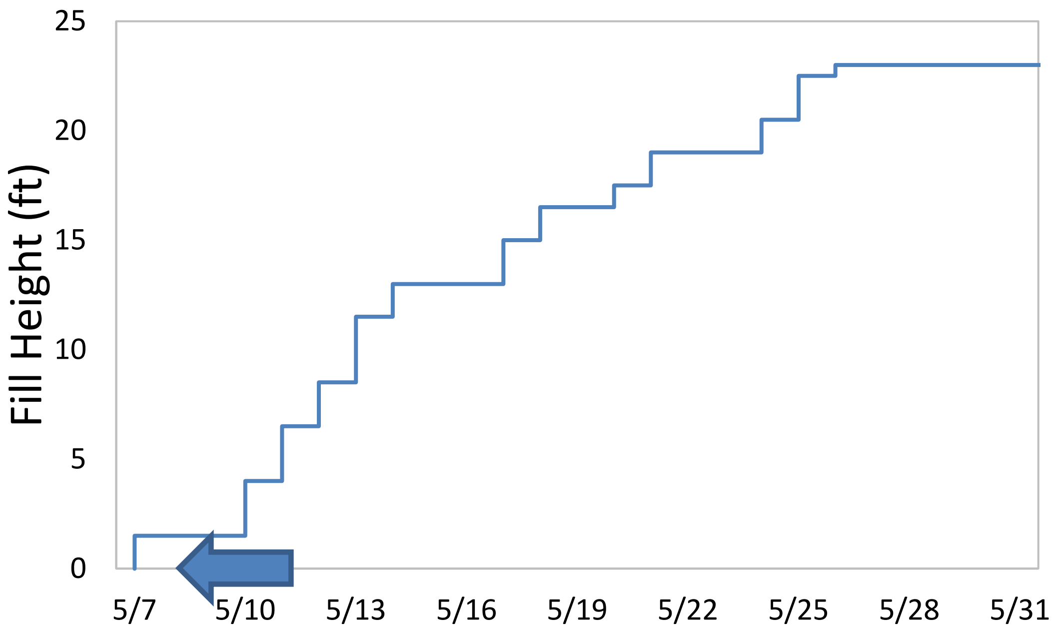
Pile Instrumentation

Settlement Instrumentation

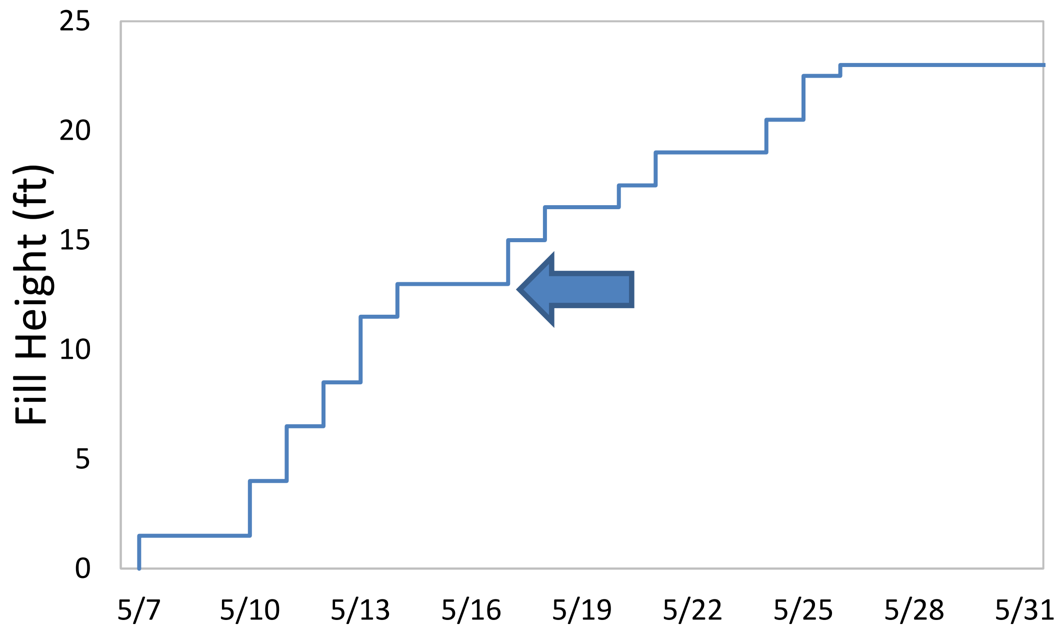
Settlement Instrumentation

Monitoring Systems

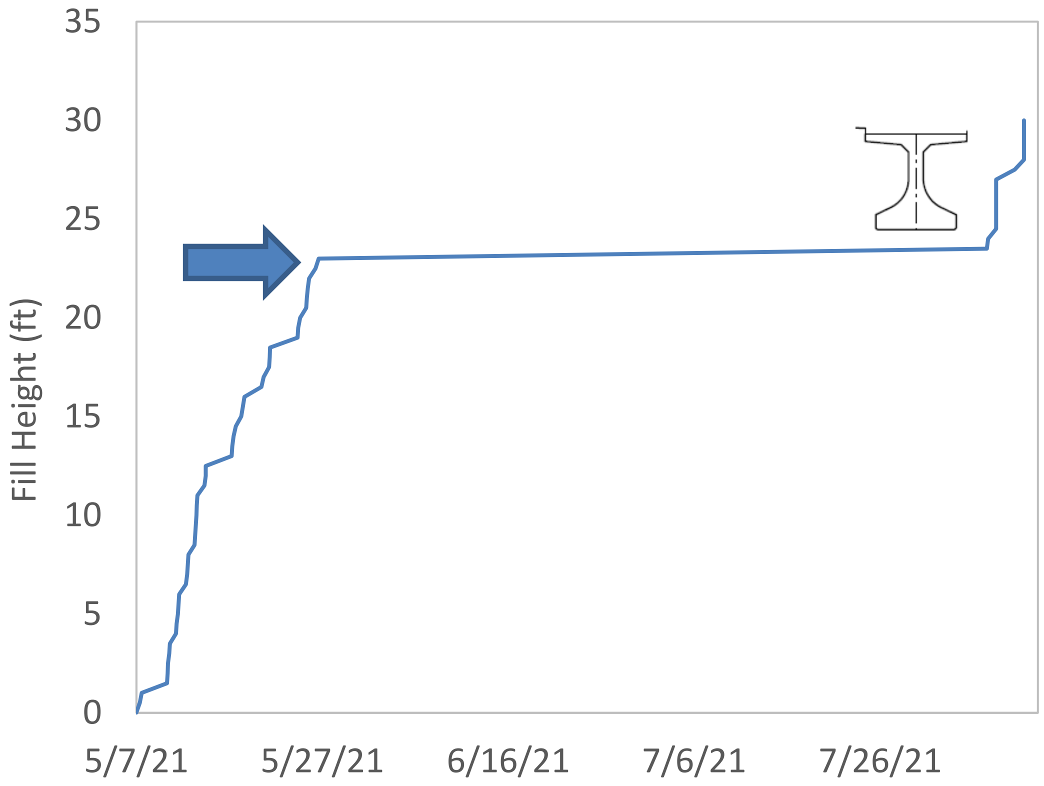
Sandridge Road Backfill



Sandridge Road Backfill

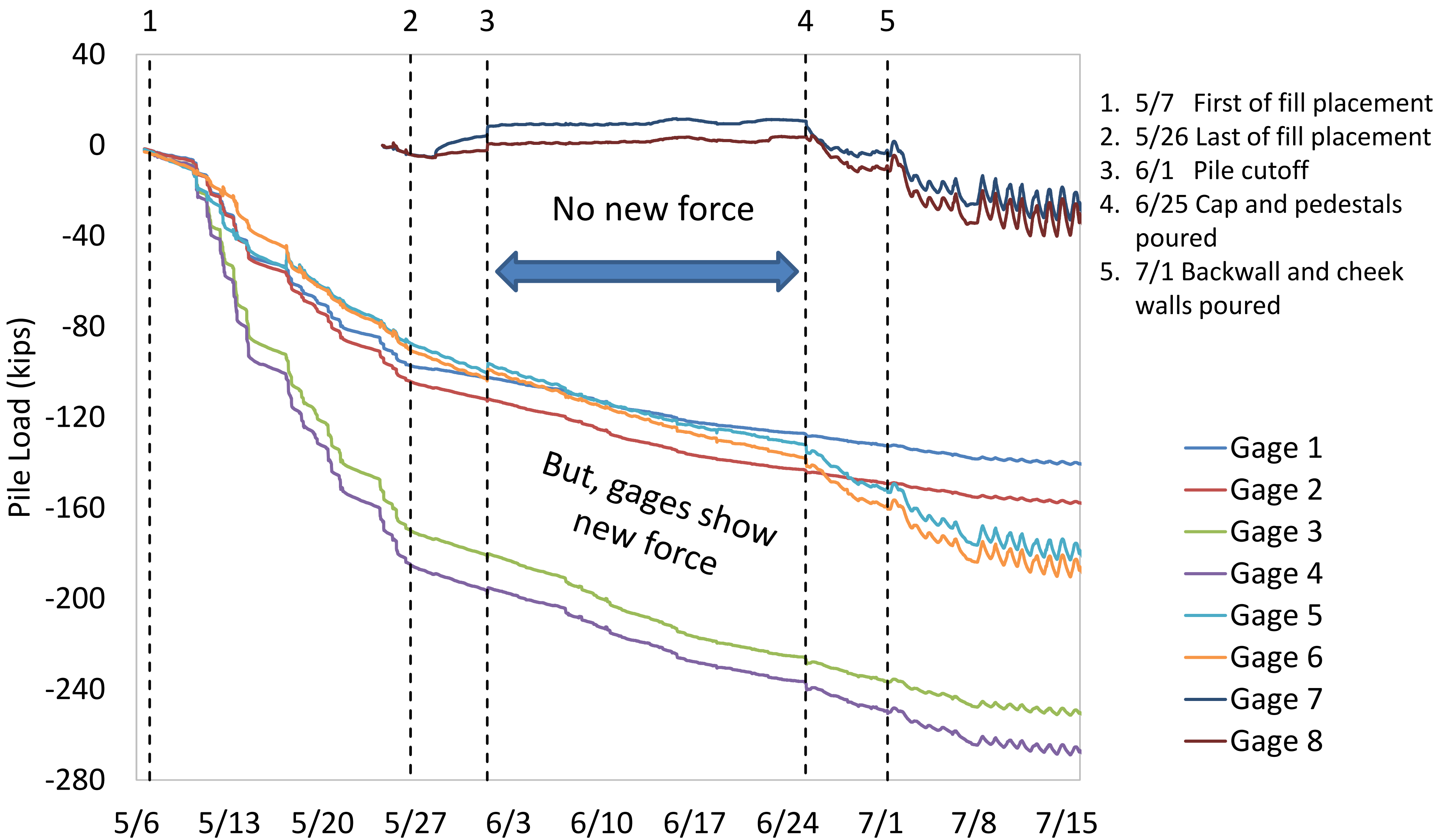


Sandridge Road
Backfill

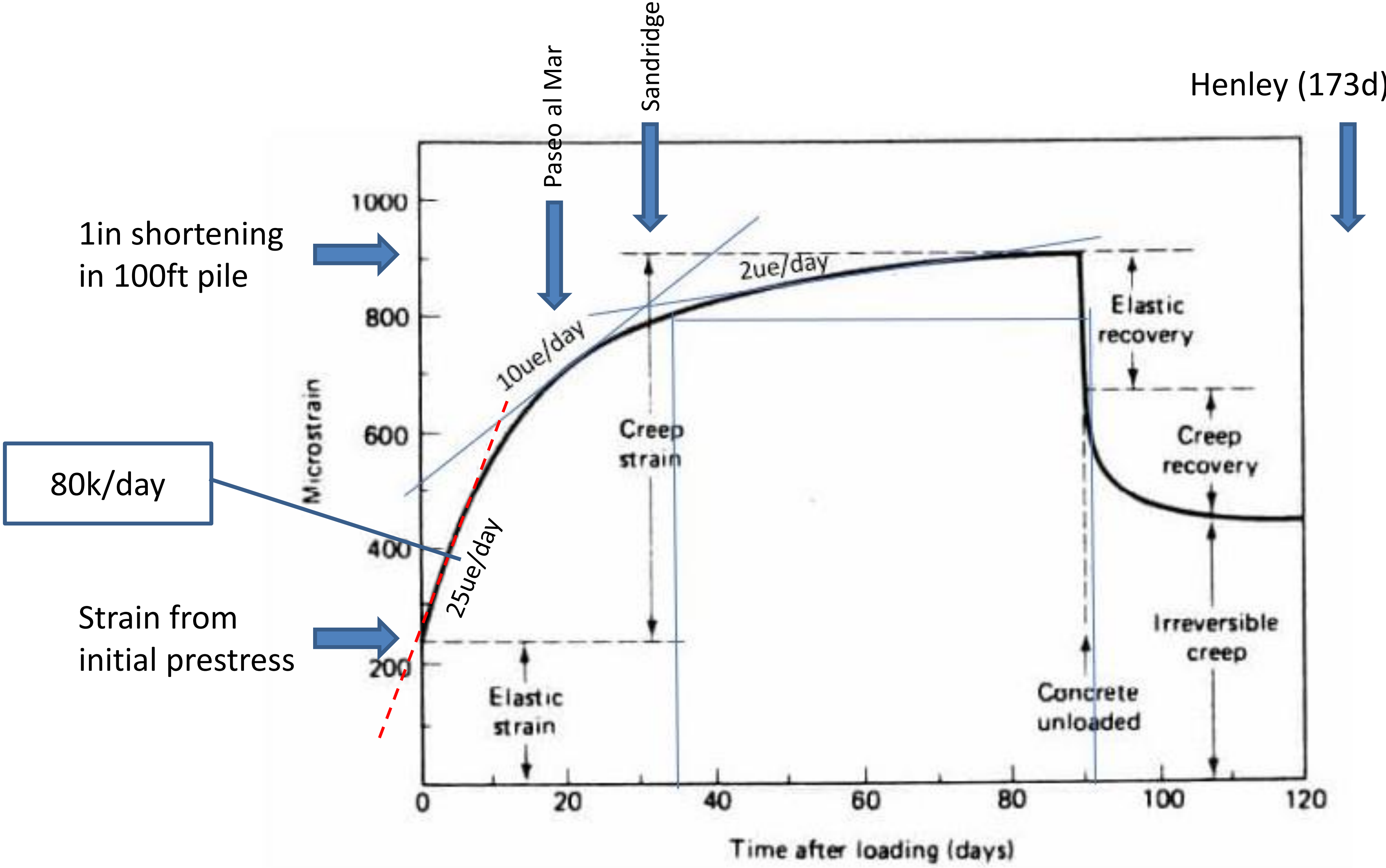


September 8, 2021

Sandridge Road (Raw Pile Force)

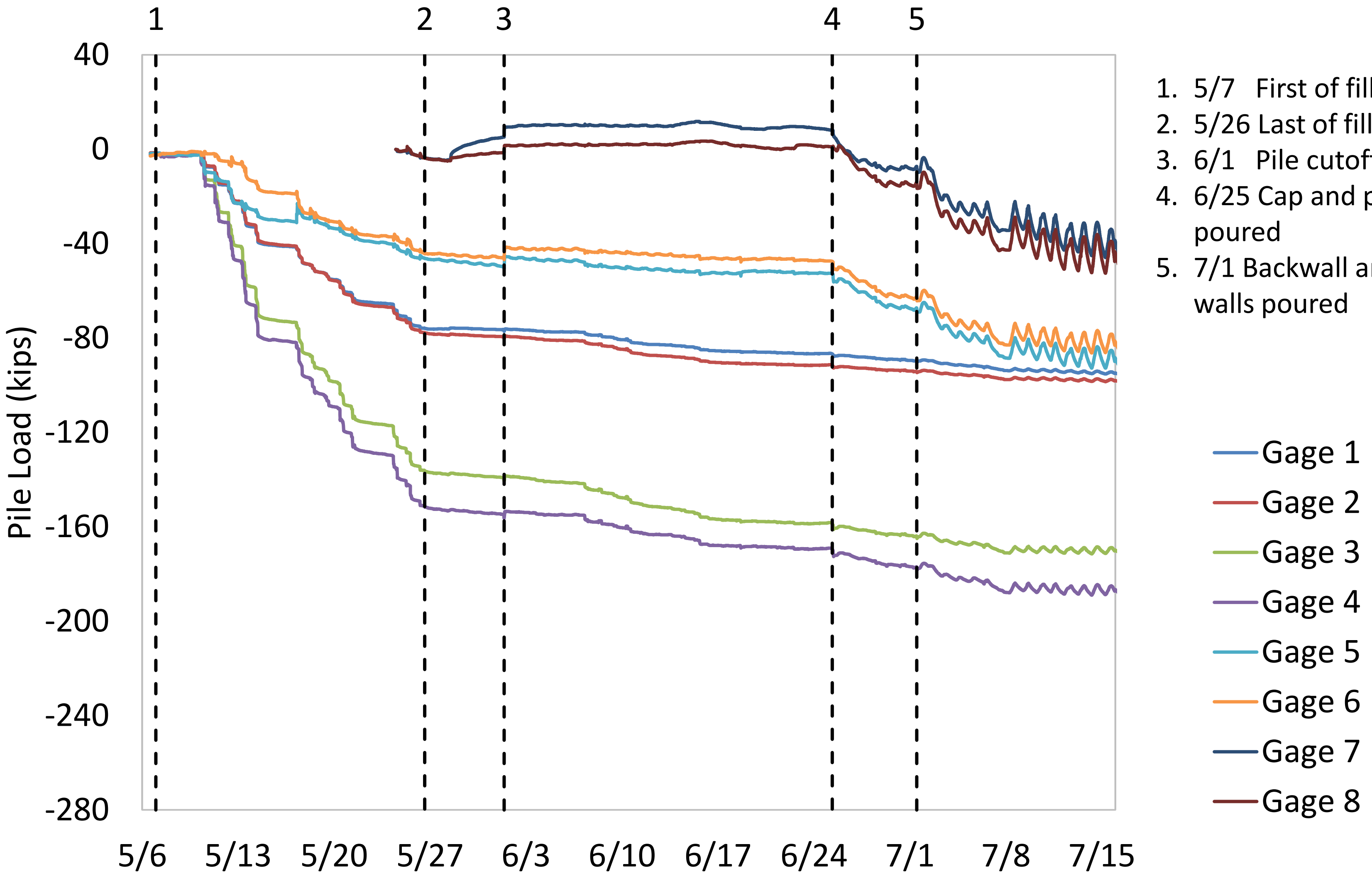


Creep



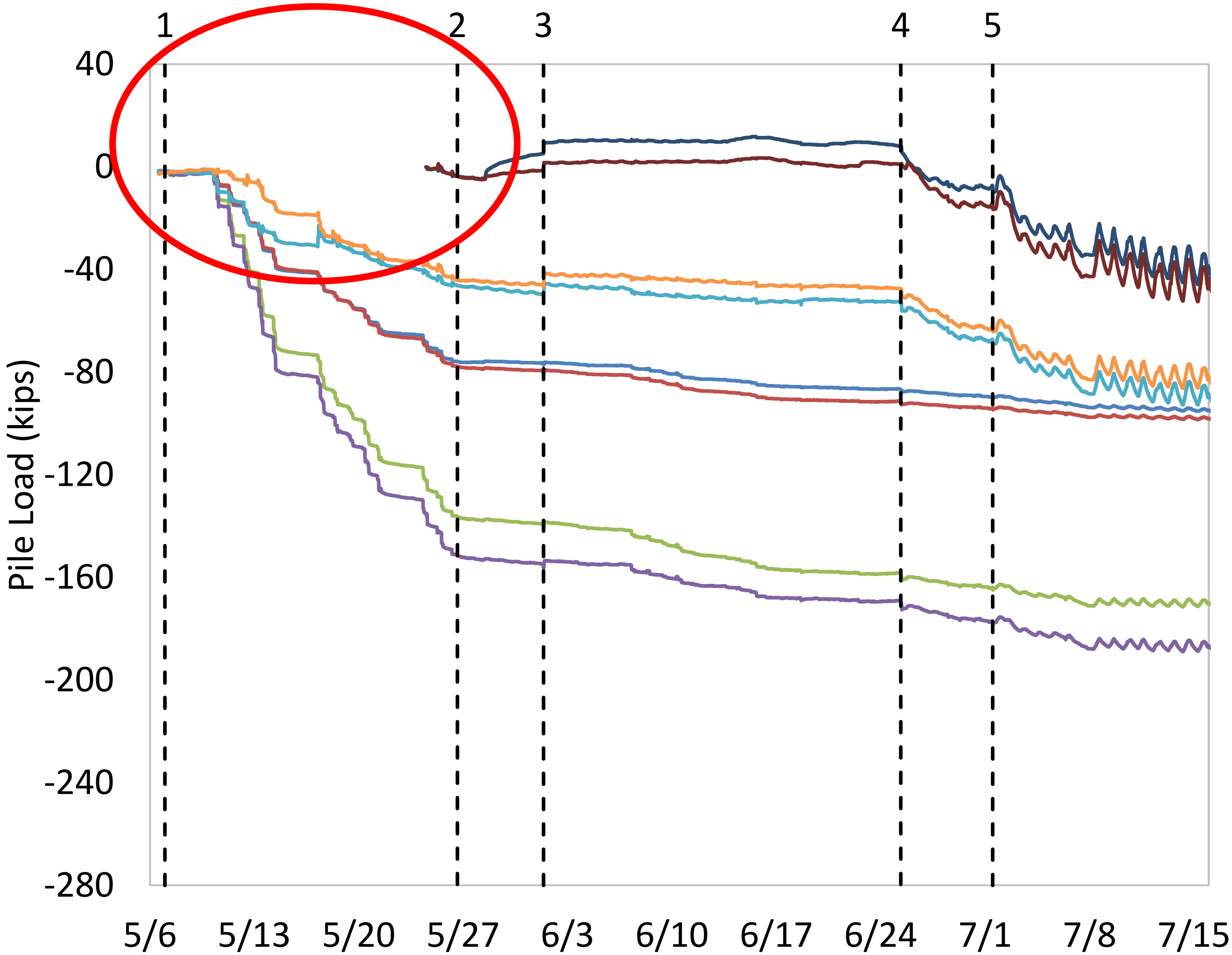
https://civildigital.com/concrete-creep-definition-creep-deformation-stages-design-strategies/

Sandridge Road (Corrected Pile Force)



1. 5/7 First of fill placement
2. 5/26 Last of fill placement
3. 6/1 Pile cutoff
4. 6/25 Cap and pedestals poured
5. 7/1 Backwall and cheek walls poured

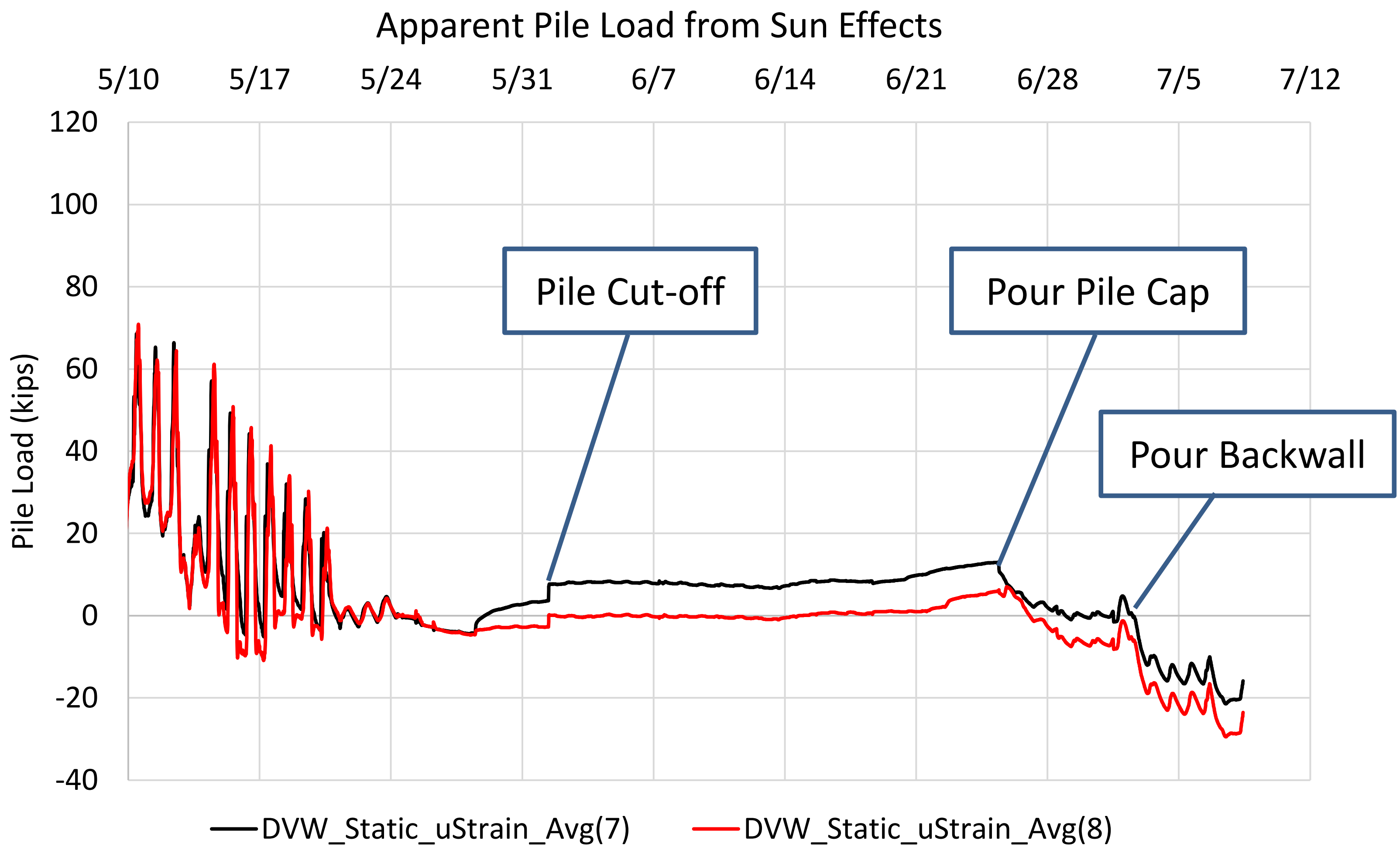
Sandridge Road (Corrected Pile Force)

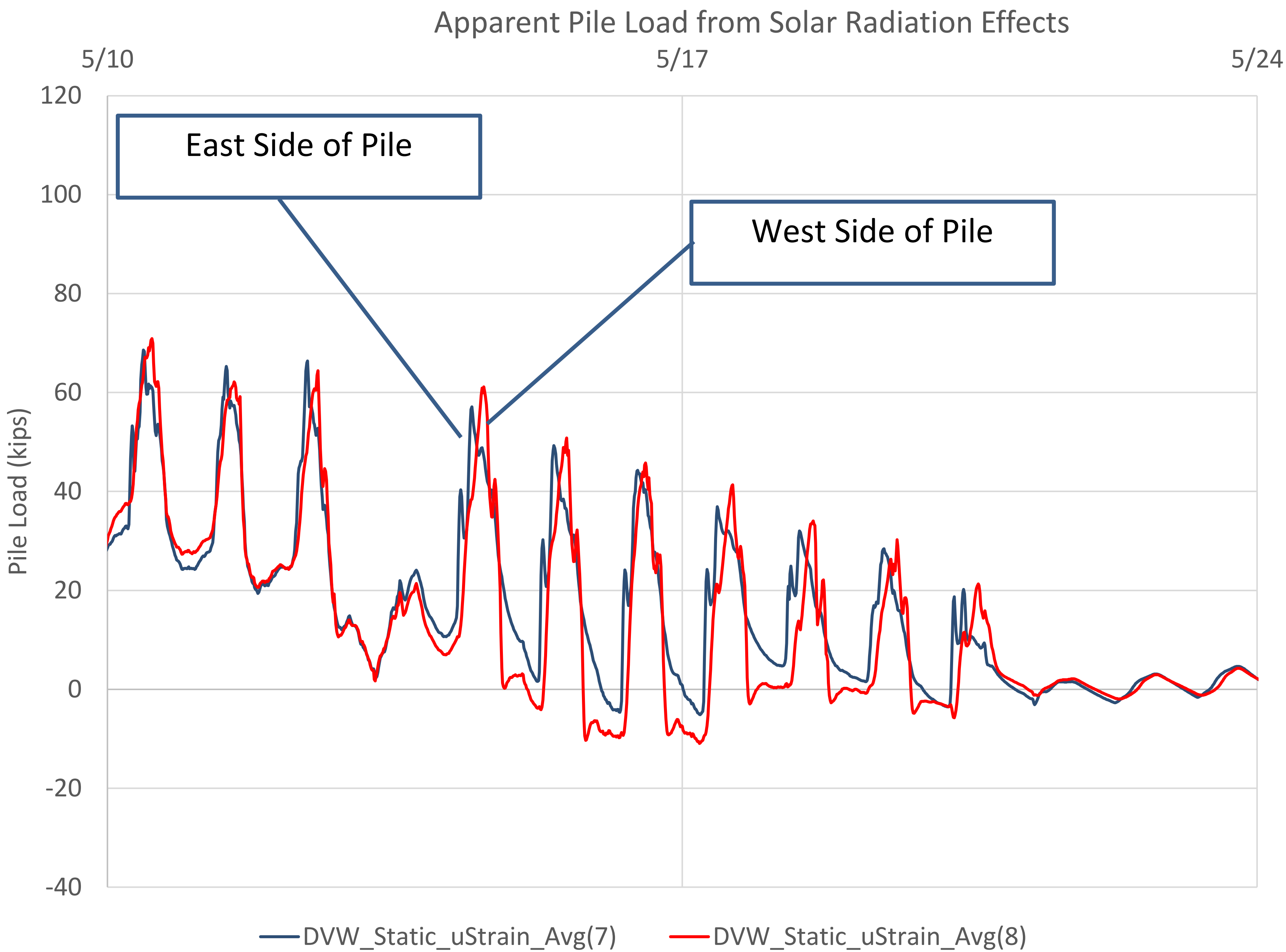


1. 5/7 First of fill placement
2. 5/26 Last of fill placement
3. 6/1 Pile cutoff
4. 6/25 Cap and pedestals poured
5. 7/1 Backwall and cheek walls poured

Sandridge Road

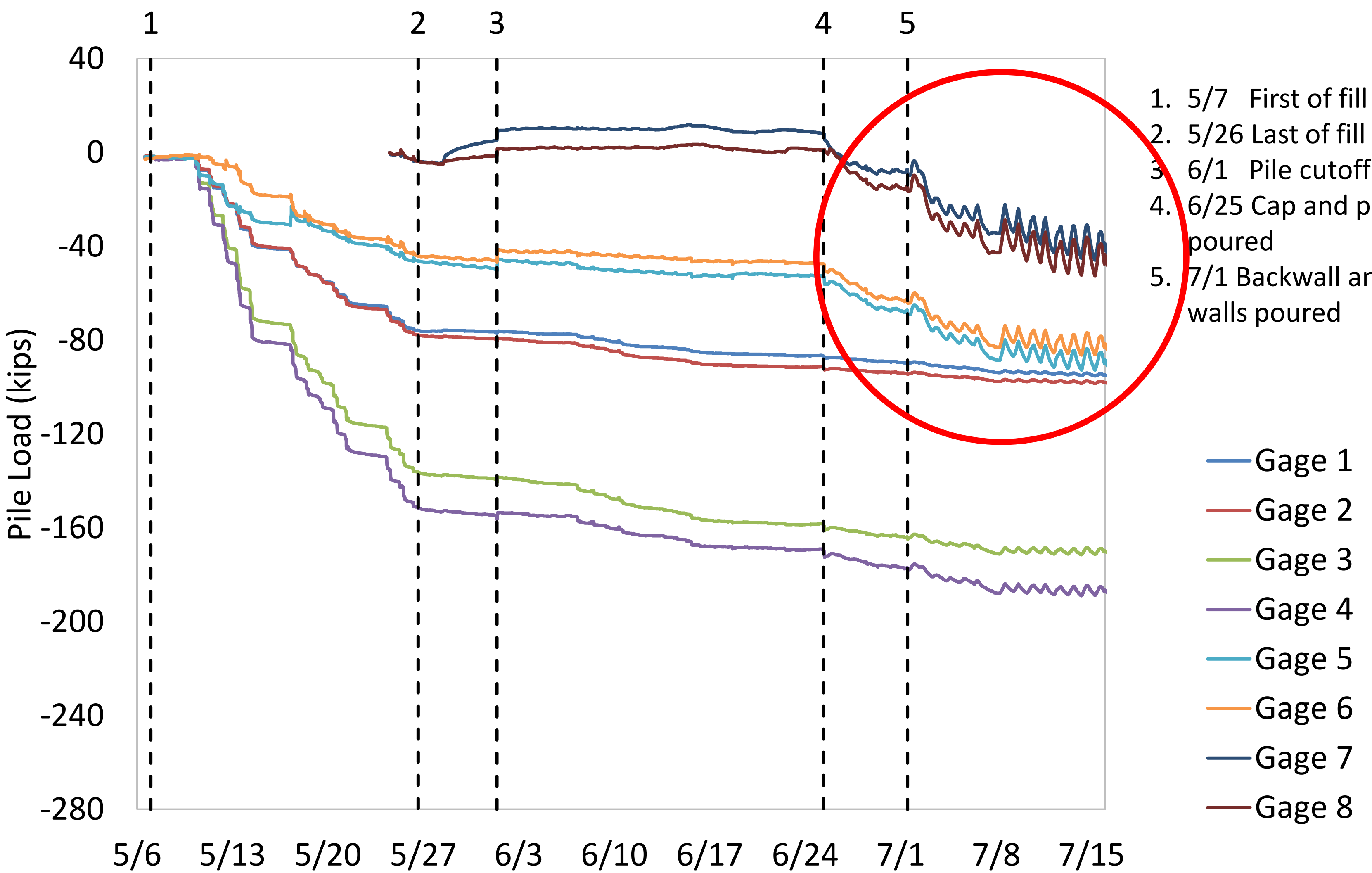
(Top of Pile Gauges)





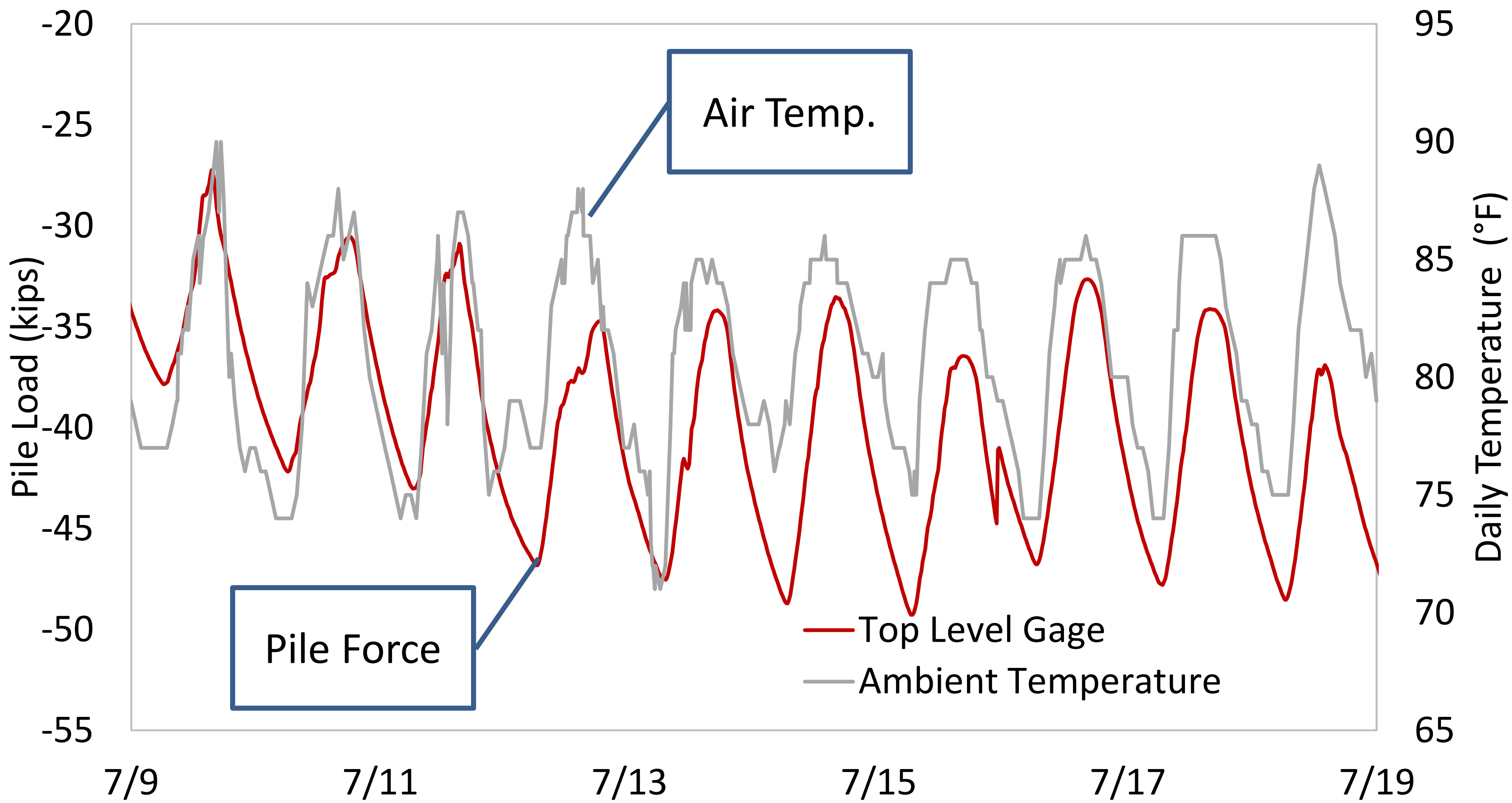
Apparent Pile Load from Solar Radiation Effects
5/10
5/17
5/24
120
100
80
60
40
20
0
-20
-40
Pile Load (kips)
East Side of Pile
West Side of Pile
DVW_Static_uStrain_Avg(7)
DVW_Static_uStrain_Avg(8)

Sandridge Road (Corrected Pile Force)

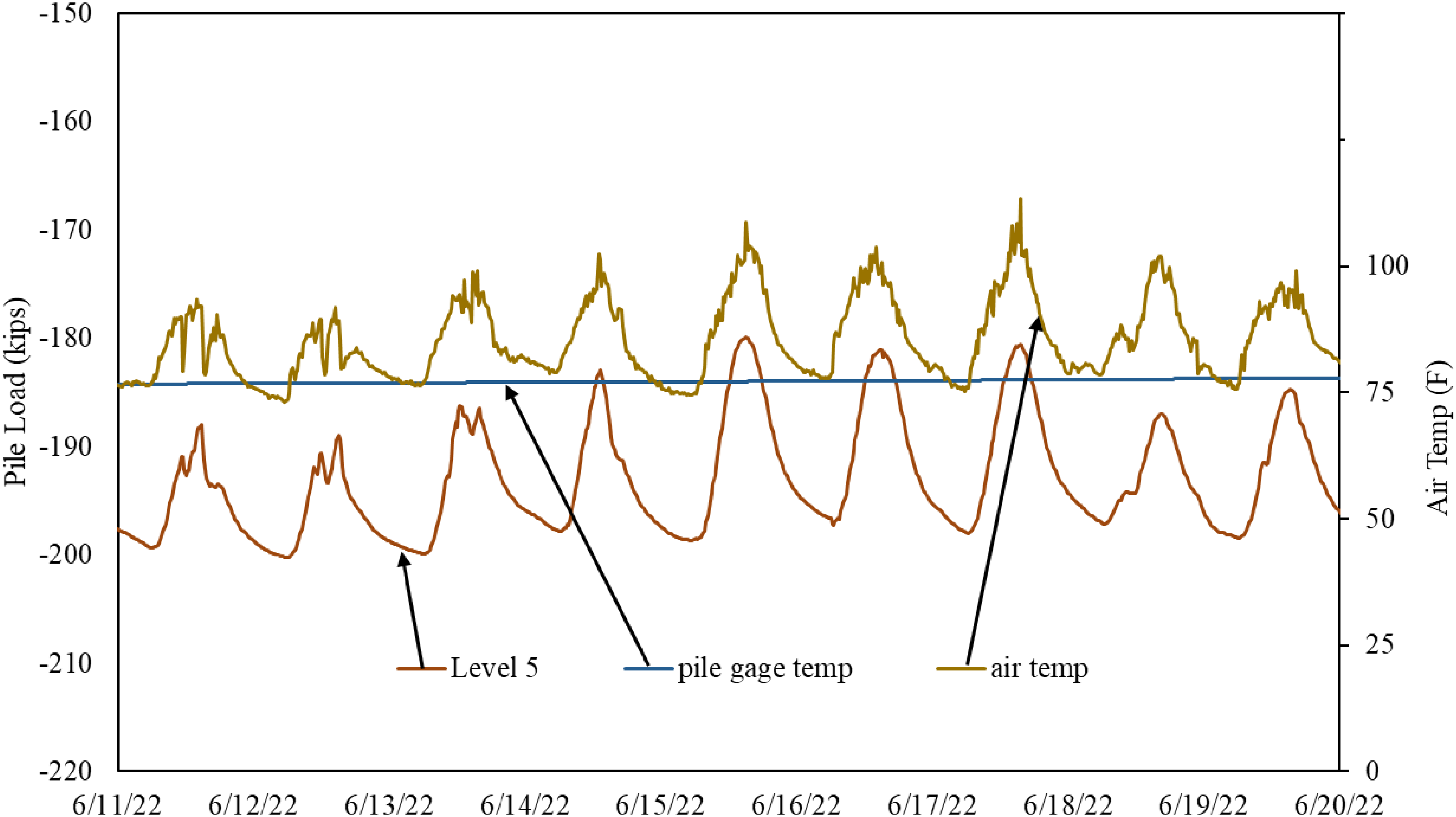


1. 5/7 First of fill placement
2. 5/26 Last of fill placement
3. 6/1 Pile cutoff
4. 6/25 Cap and pedestals poured
5. 7/1 Backwall and cheek walls poured

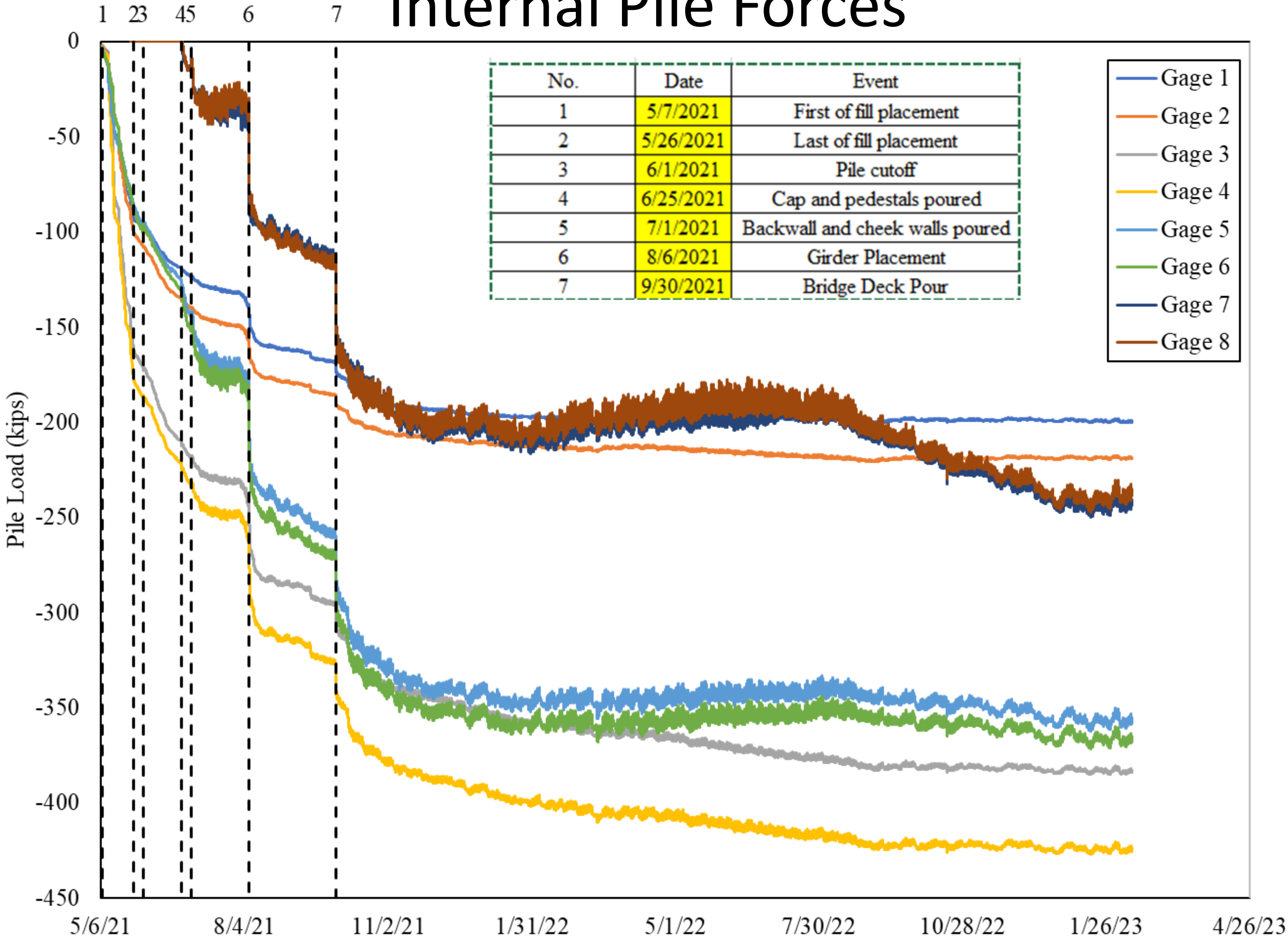
Sandridge Road



Not caused by change in pile temp

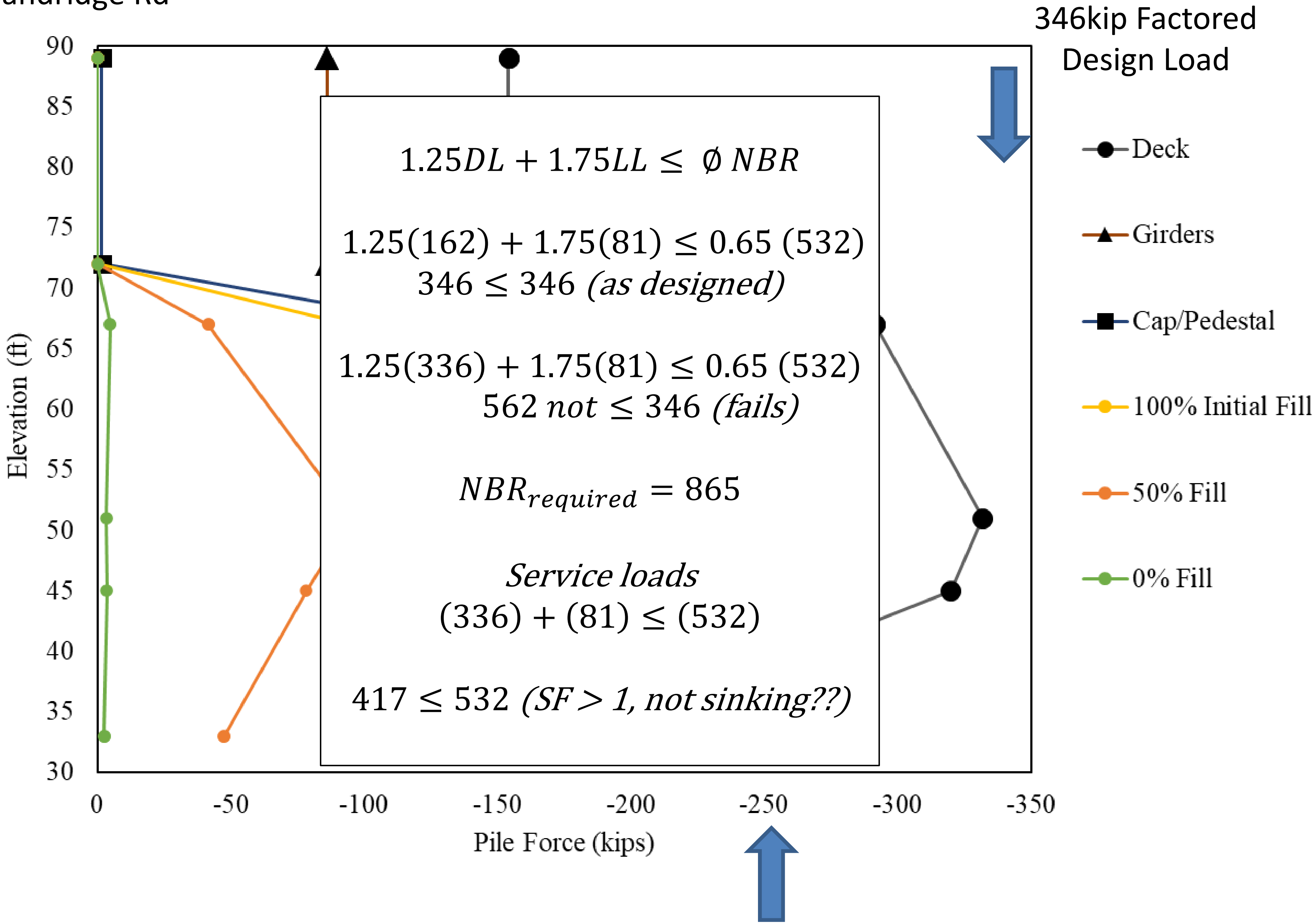


Internal Pile Forces



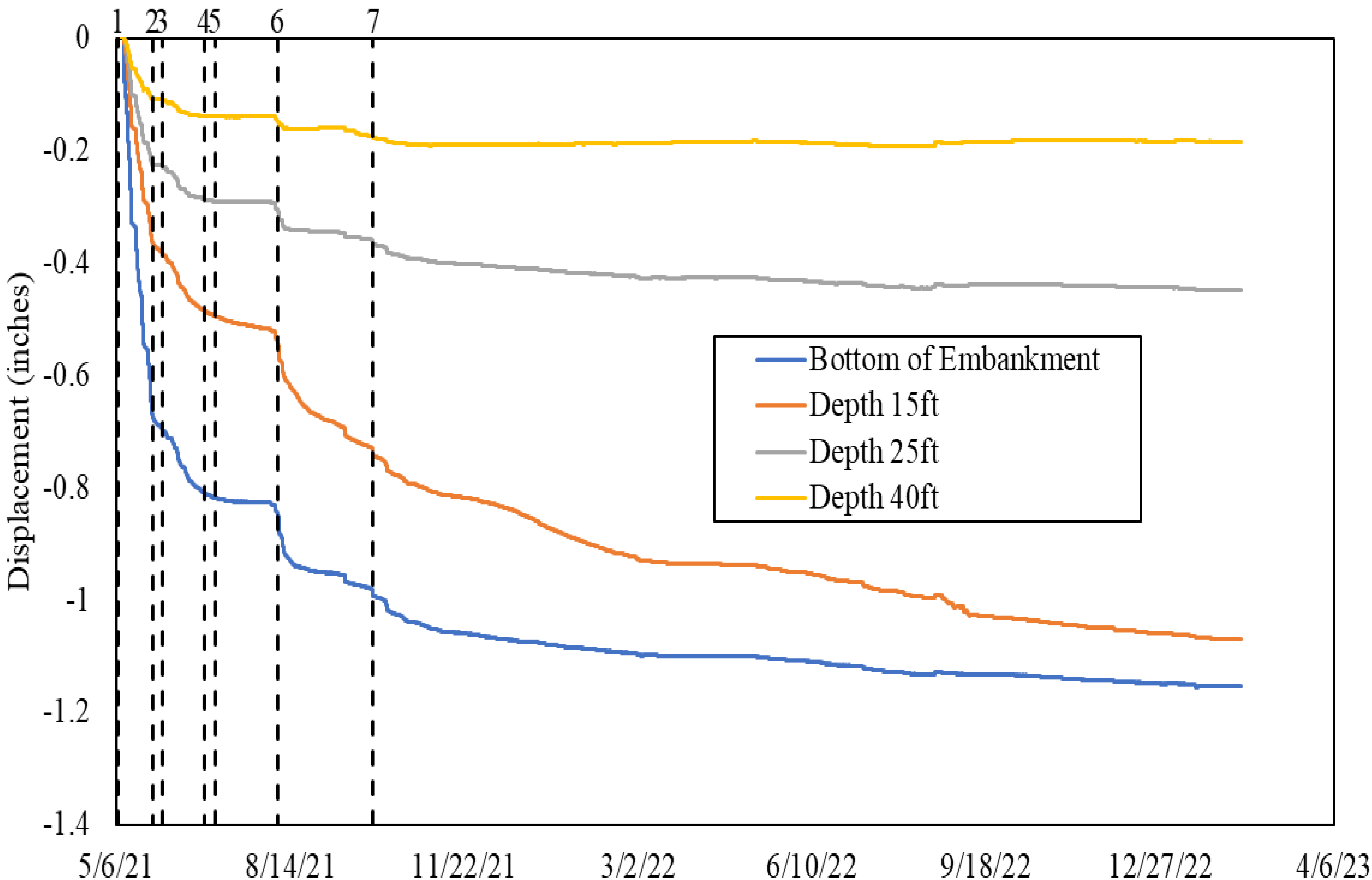
No.	Date	Event
1	5/7/2021	First of fill placement
2	5/26/2021	Last of fill placement
3	6/1/2021	Pile cutoff
4	6/25/2021	Cap and pedestals poured
5	7/1/2021	Backwall and cheek walls poured
6	8/6/2021	Girder Placement
7	9/30/2021	Bridge Deck Pour

Sandridge Rd

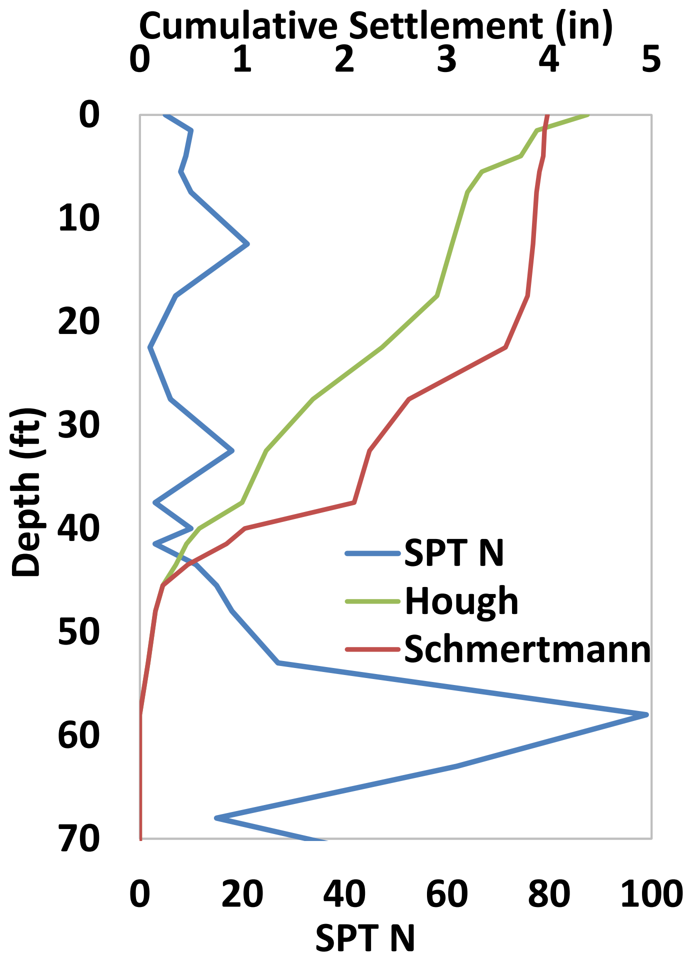


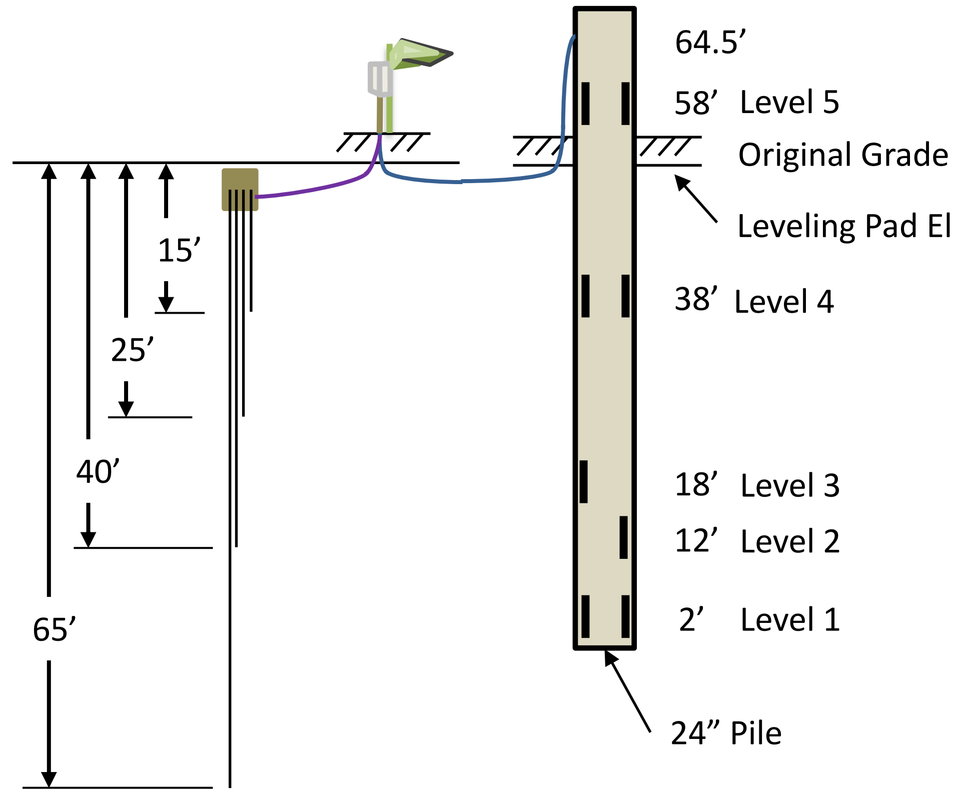
243-251kip Service Load (DL/LL = 2 or 3, respectively)

Sandridge Rd Settlement Data

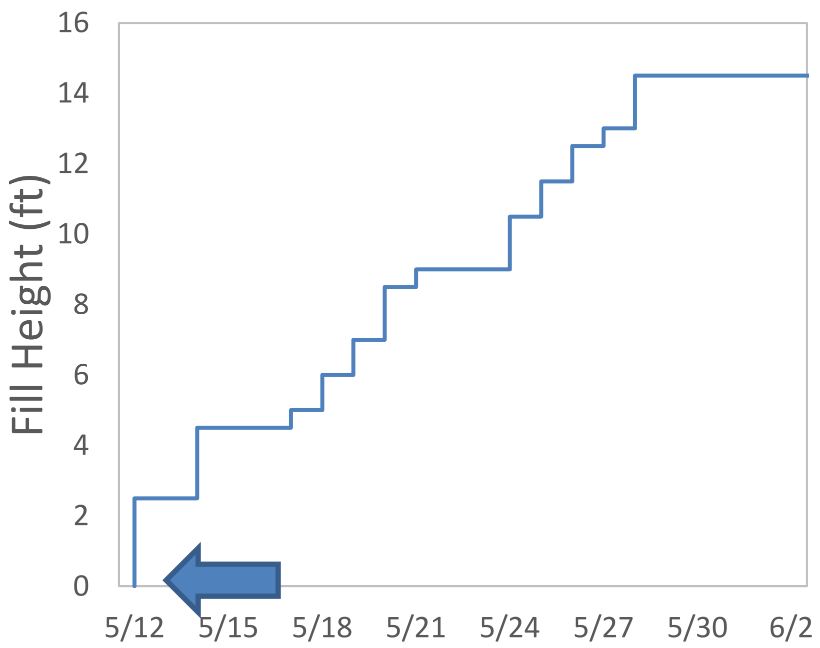


Paseo Al Mar Blvd

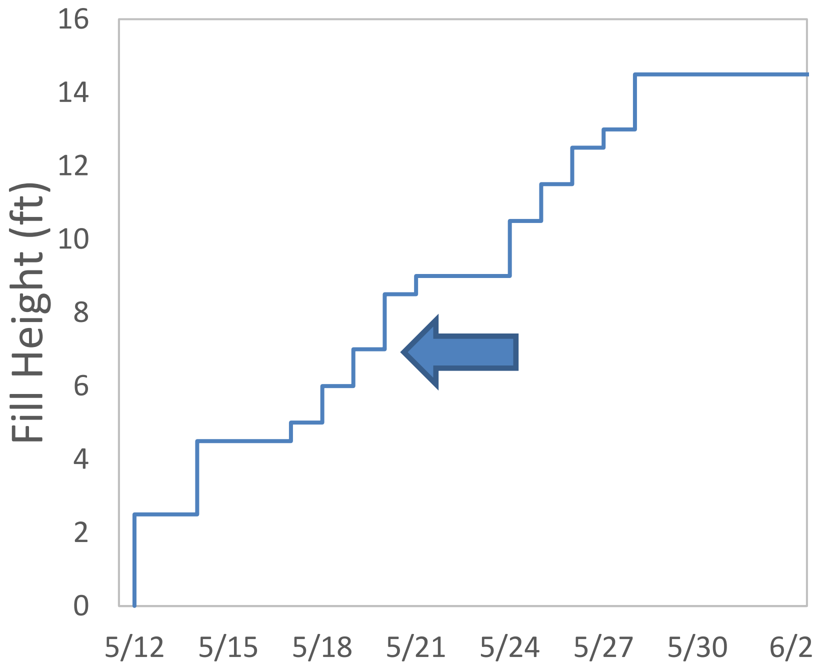




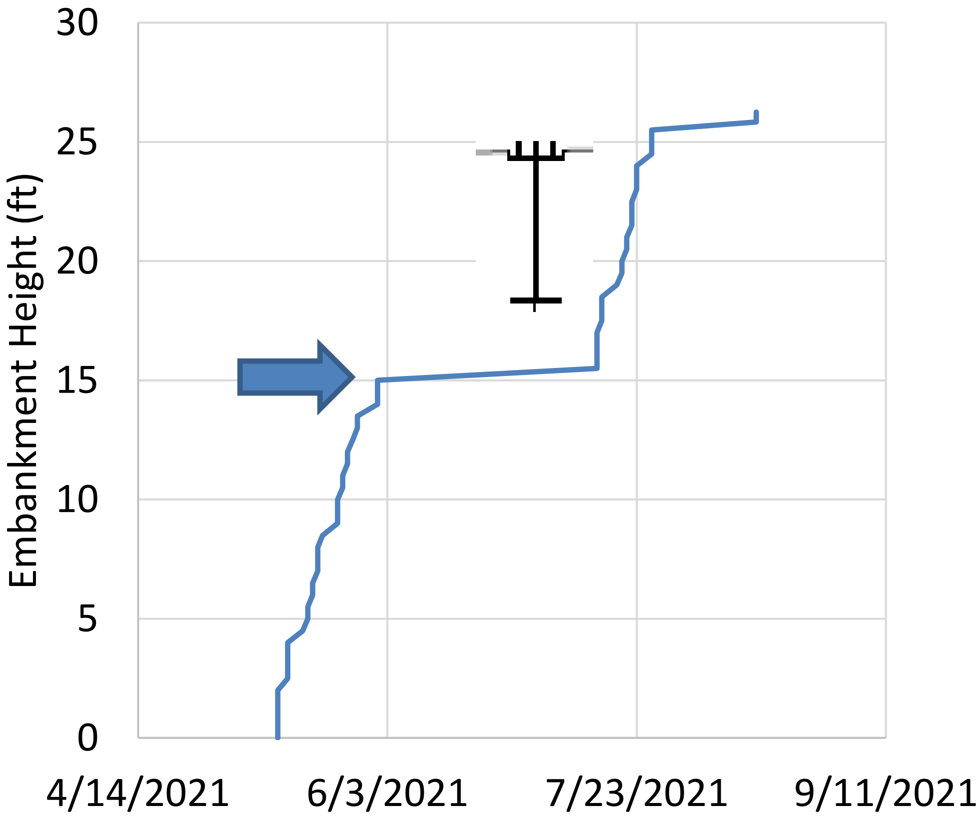
Paseo Al Mar Blvd
Backfill



Paseo Al Mar Blvd Backfill



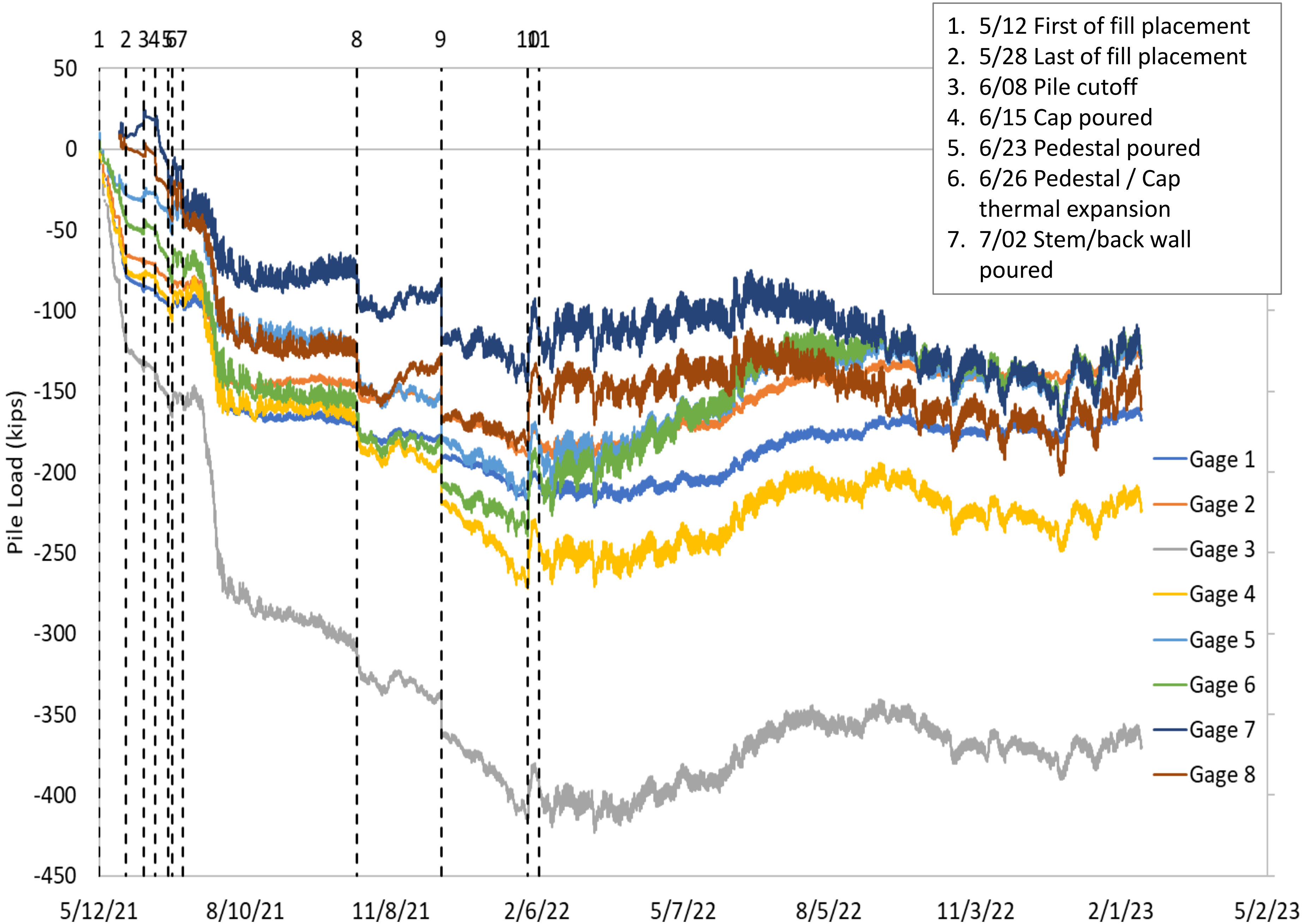
Paseo Al Mar Blvd Backfill



October 12, 2021

East End (EB 3) Looking West


East End (EB 3) Looking East
Down Approach Embankment



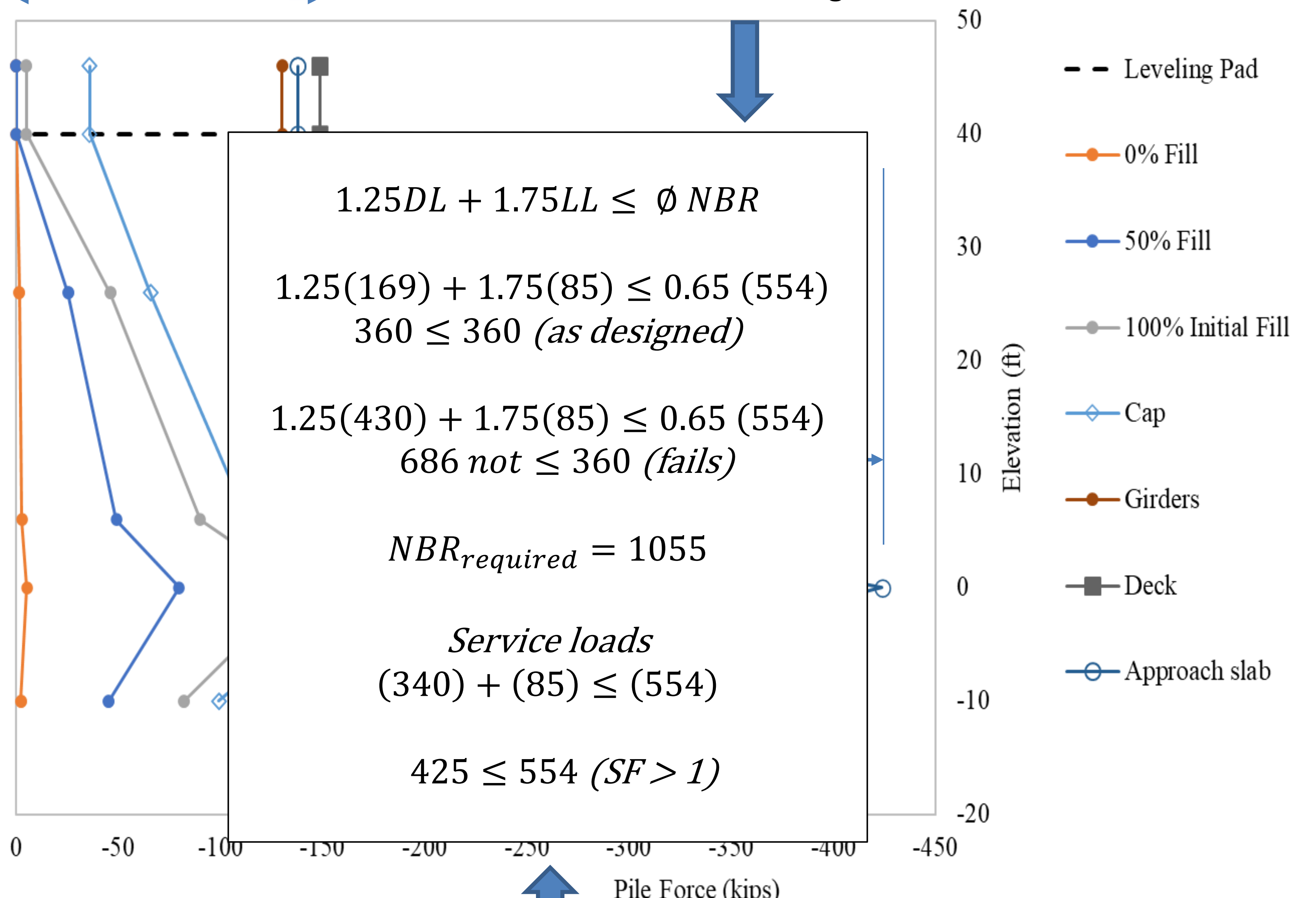
1. 5/12 First of fill placement
2. 5/28 Last of fill placement
3. 6/08 Pile cutoff
4. 6/15 Cap poured
5. 6/23 Pedestal poured
6. 6/26 Pedestal / Cap thermal expansion
7. 7/02 Stem/back wall poured
1 2 3 4 5 6 7 8 9 10 11
Pile Load (kips)
50
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
5/12/21
8/10/21
11/8/21
2/6/22
5/7/22
8/5/22
11/3/22
2/1/23
5/2/23
Gage 1
Gage 2
Gage 3
Gage 4
Gage 5
Gage 6
Gage 7
Gage 8

Paseo Al Mar Milestones

1	5/12/21	Begin fill placement
2	6/2/21	Fill completed to pile cutoff elevation
3	6/8/21	Pile cutoff
4	6/21/21	Cap poured
5	6/23/21	Pedestal poured
6	6/26/21	Diurnal temperature induced forces begin
7	7/2/21	Stem/back wall poured
8	10/19/21	Girder Placement
9	12/8/21	Bridge Deck Poured
10	1/13/22	Barriers
11	2/7/22	Approach Slab

DL = 155k; 169 design

360k Factored Design Load



$$1.25DL + 1.75LL \leq \emptyset\ NBR$$

$$1.25(169) + 1.75(85) \leq 0.65\ (554)$$
$$360 \leq 360\ \textit{(as designed)}$$

$$1.25(430) + 1.75(85) \leq 0.65\ (554)$$
$$686\ not \leq 360\ \textit{(fails)}$$

$$NBR_{required} = 1055$$

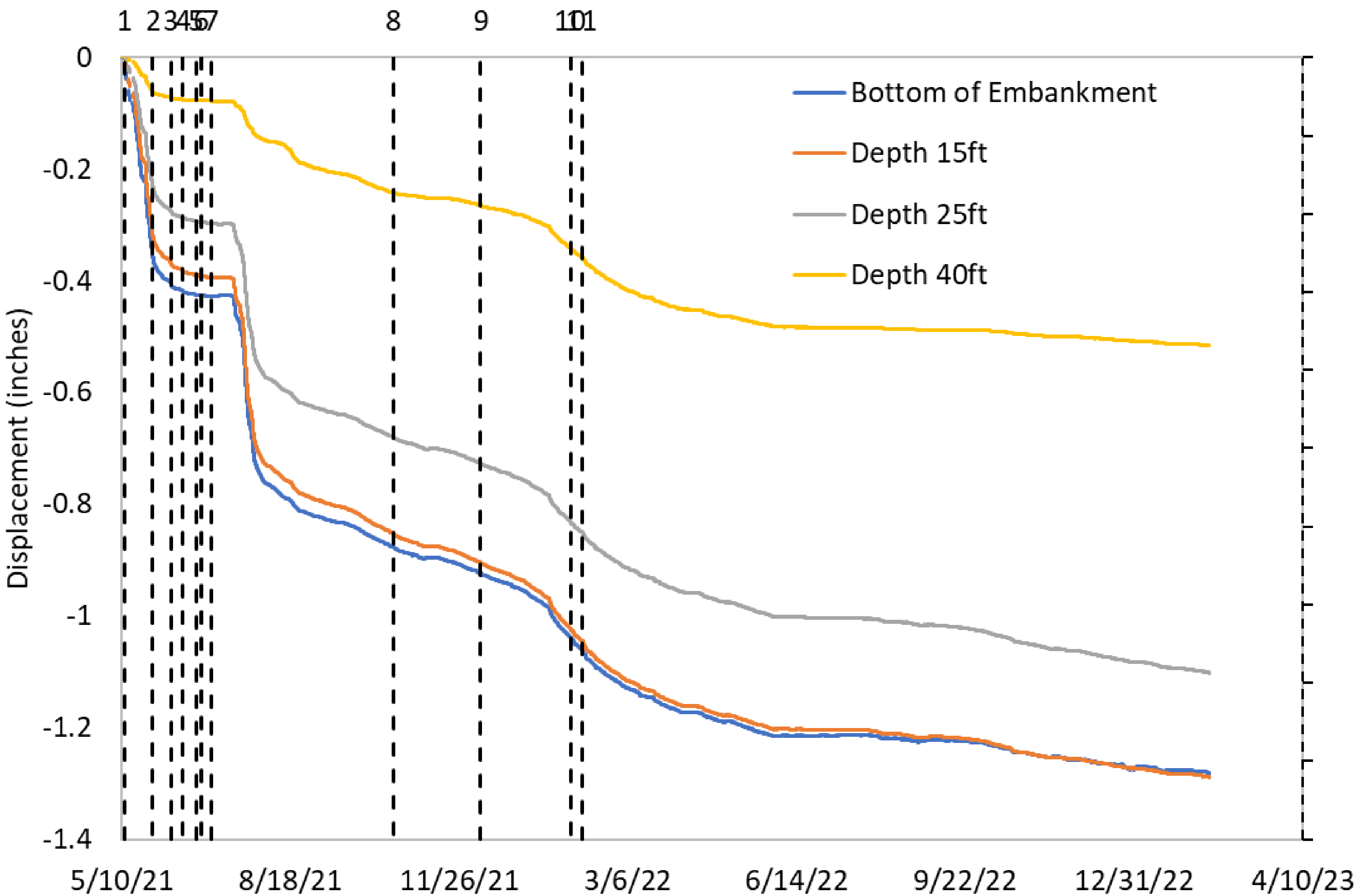
Service loads

$$(340) + (85) \leq (554)$$

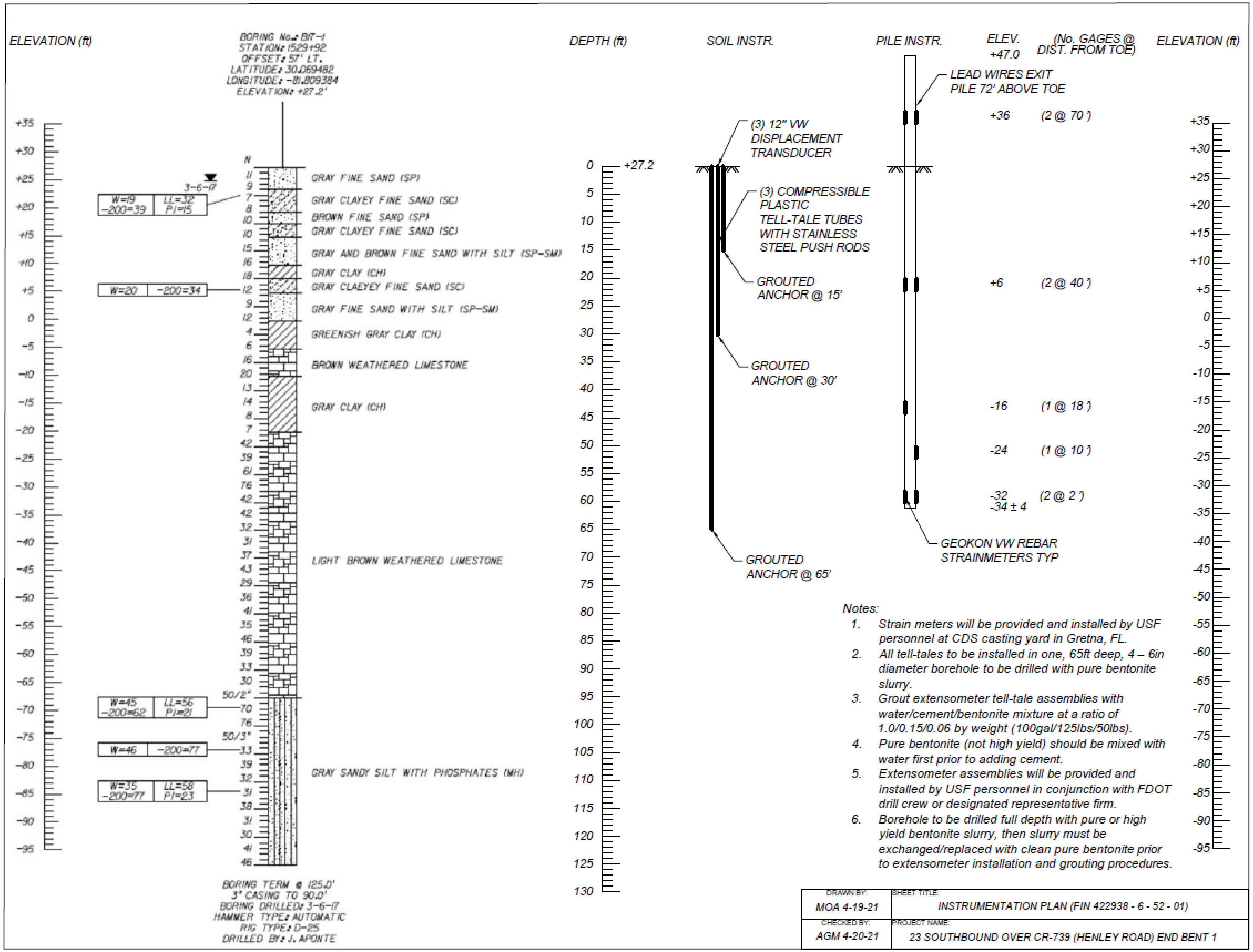
$$425 \leq 554\ \textit{(SF > 1)}$$

253-261kip Service Load (DL/LL = 2 or 3, respectively)

Paseo Al Mar Blvd Settlement Data



Henley Rd Instrumentation



Henley Rd.

- Additional instruments
- Rain gauge
- Air temperature
- Digital camera


HENLEYRD
SEP 08, 2021 16:13 302K


HENLEYRD
SEP 10, 2021 17:00 300K


HENLEYRD
SEP 15, 2021 12:00 305K


HENLEYRD
SEP 16, 2021 07:00 295K


HENLEYRD
SEP 17, 2021 10:00 301K


HENLEYRD
SEP 21, 2021 09:00 299K


HENLEYRD
SEP 21, 2021 15:00 307K


HENLEYRD
SEP 21, 2021 17:00 299K


HENLEYRD
SEP 23, 2021 10:00 298K


HENLEYRD
SEP 23, 2021 11:00 301K


HENLEYRD
SEP 23, 2021 15:00 305K


HENLEYRD
SEP 24, 2021 15:00 304K


HENLEYRD
SEP 29, 2021 09:00 297K


HENLEYRD
SEP 30, 2021 08:00 293K

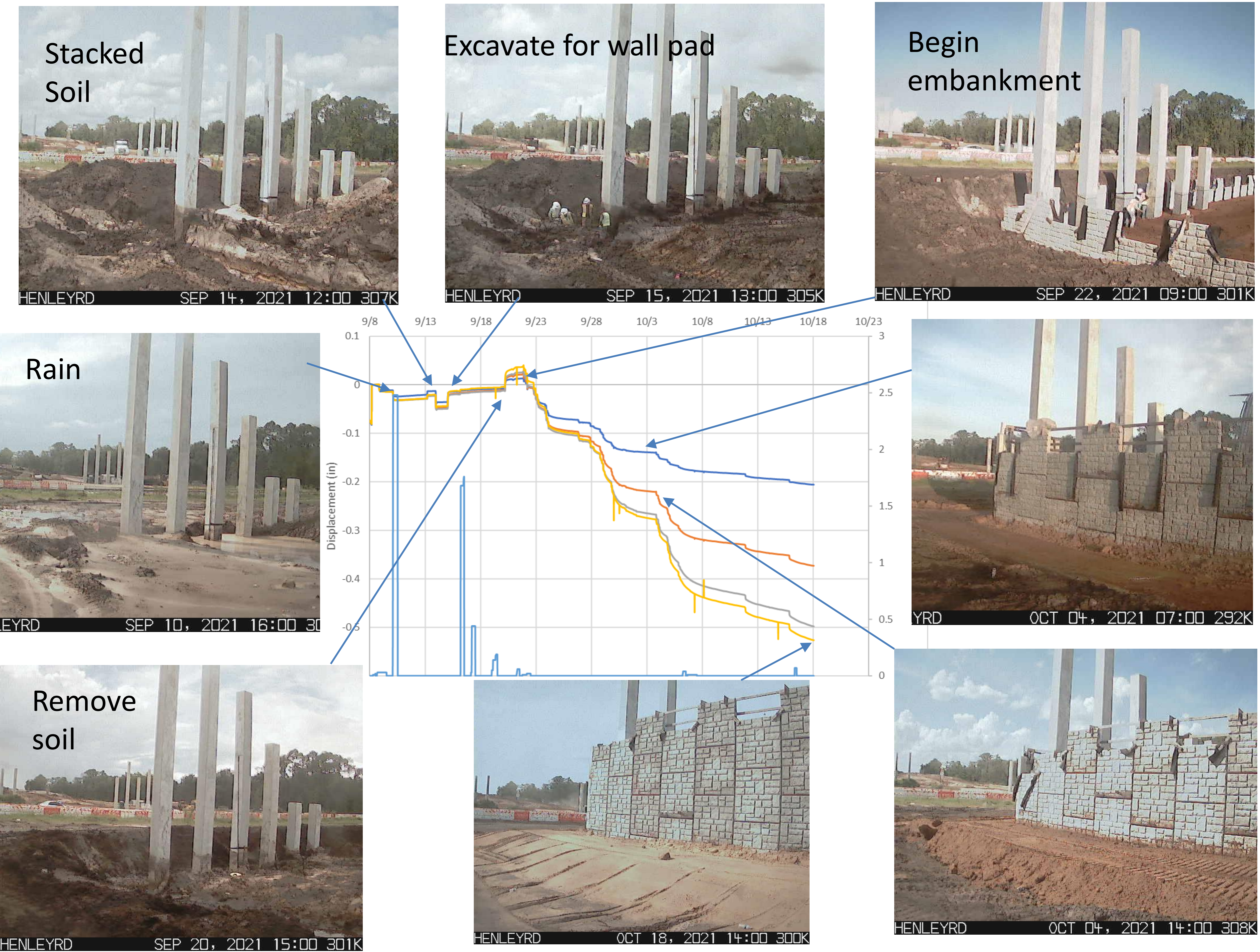

HENLEYRD
OCT 04, 2021 09:00 302K


HENLEYRD
OCT 05, 2021 15:00 307K


HENLEYRD
OCT 12, 2021 15:00 304K

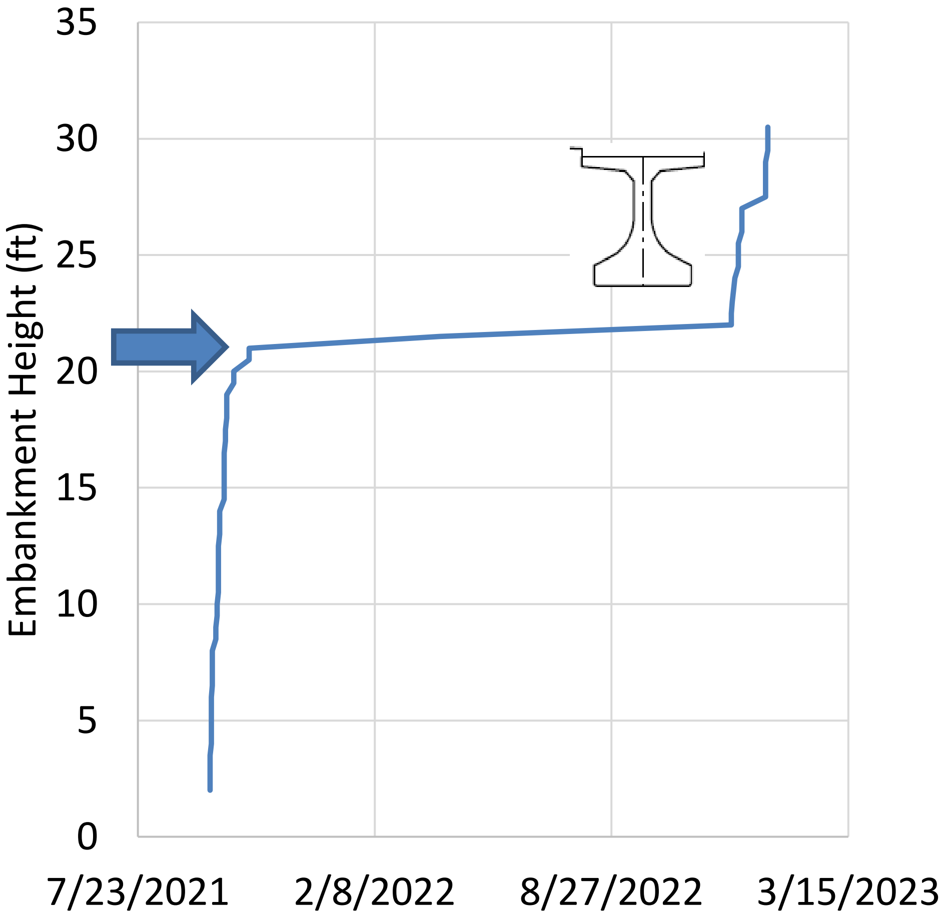

HENLEYRD
OCT 18, 2021 14:00 300K

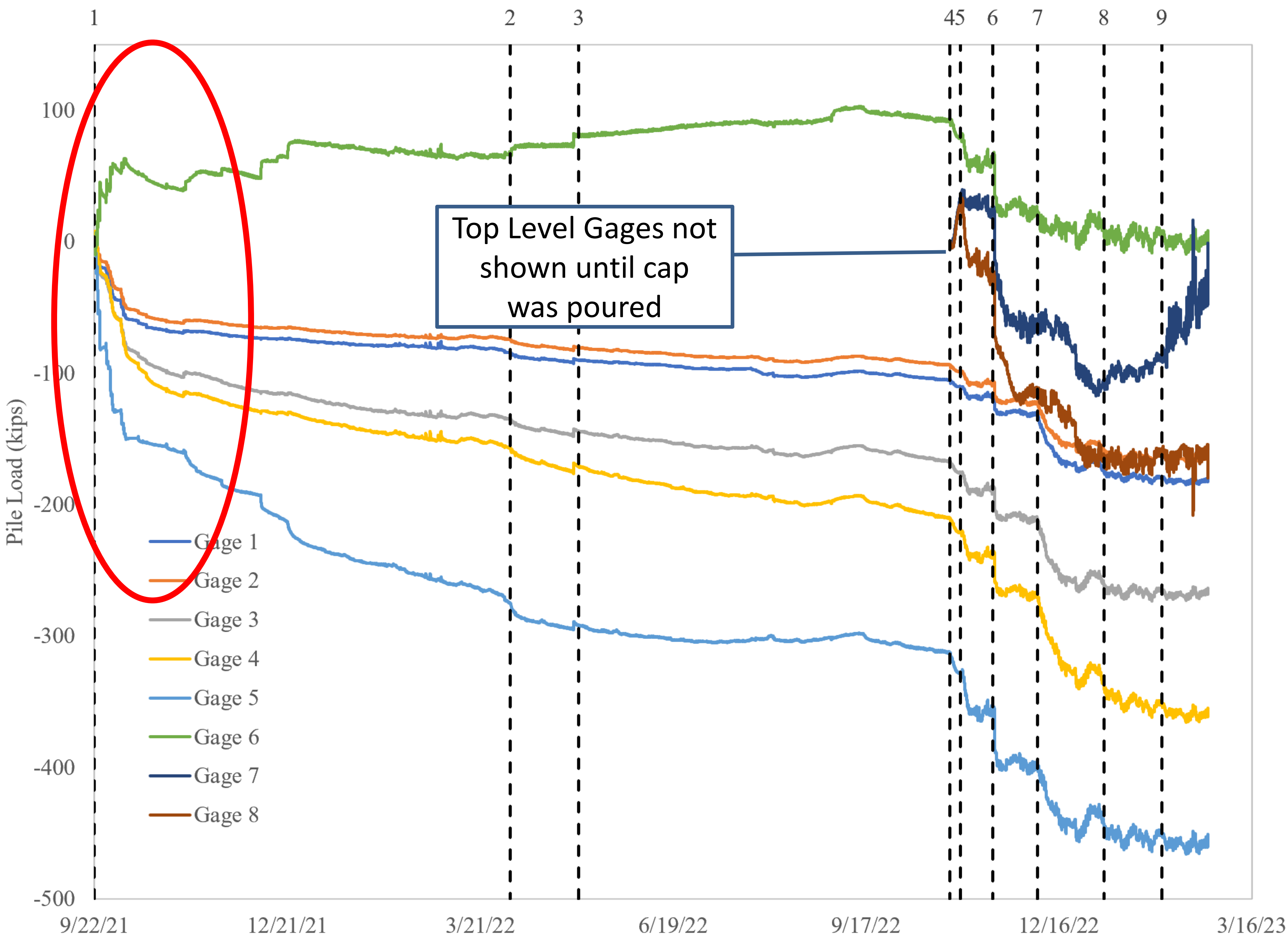

HENLEYRD
JUL 13, 2022 11:00 309K



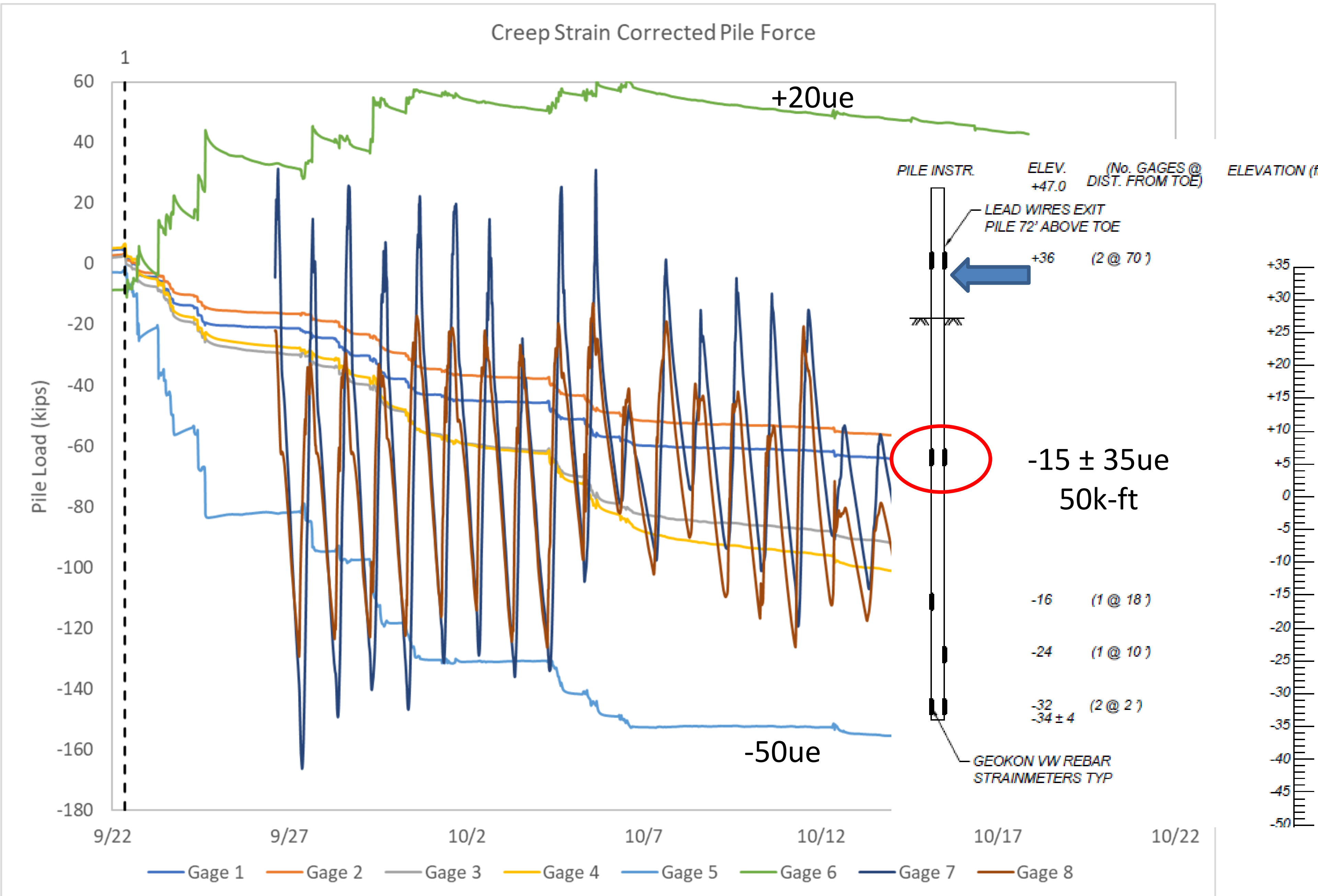
Stacked Soil
HENLEYRD SEP 14, 2021 12:00 307K
Excavate for wall pad
HENLEYRD SEP 15, 2021 13:00 305K
Begin embankment
HENLEYRD SEP 22, 2021 09:00 301K
Rain
EYRD SEP 10, 2021 16:00 30
9/8 9/13 9/18 9/23 9/28 10/3 10/8 10/13 10/18 10/23
0.1 0 -0.1 -0.2 -0.3 -0.4 -0.5
Displacement (in)
3 2.5 2 1.5 1 0.5 0
YRD OCT 04, 2021 07:00 292K
Remove soil
HENLEYRD SEP 20, 2021 15:00 301K
HENLEYRD OCT 18, 2021 14:00 300K
HENLEYRD OCT 04, 2021 14:00 308K

Henley Rd Piles at Cutoff





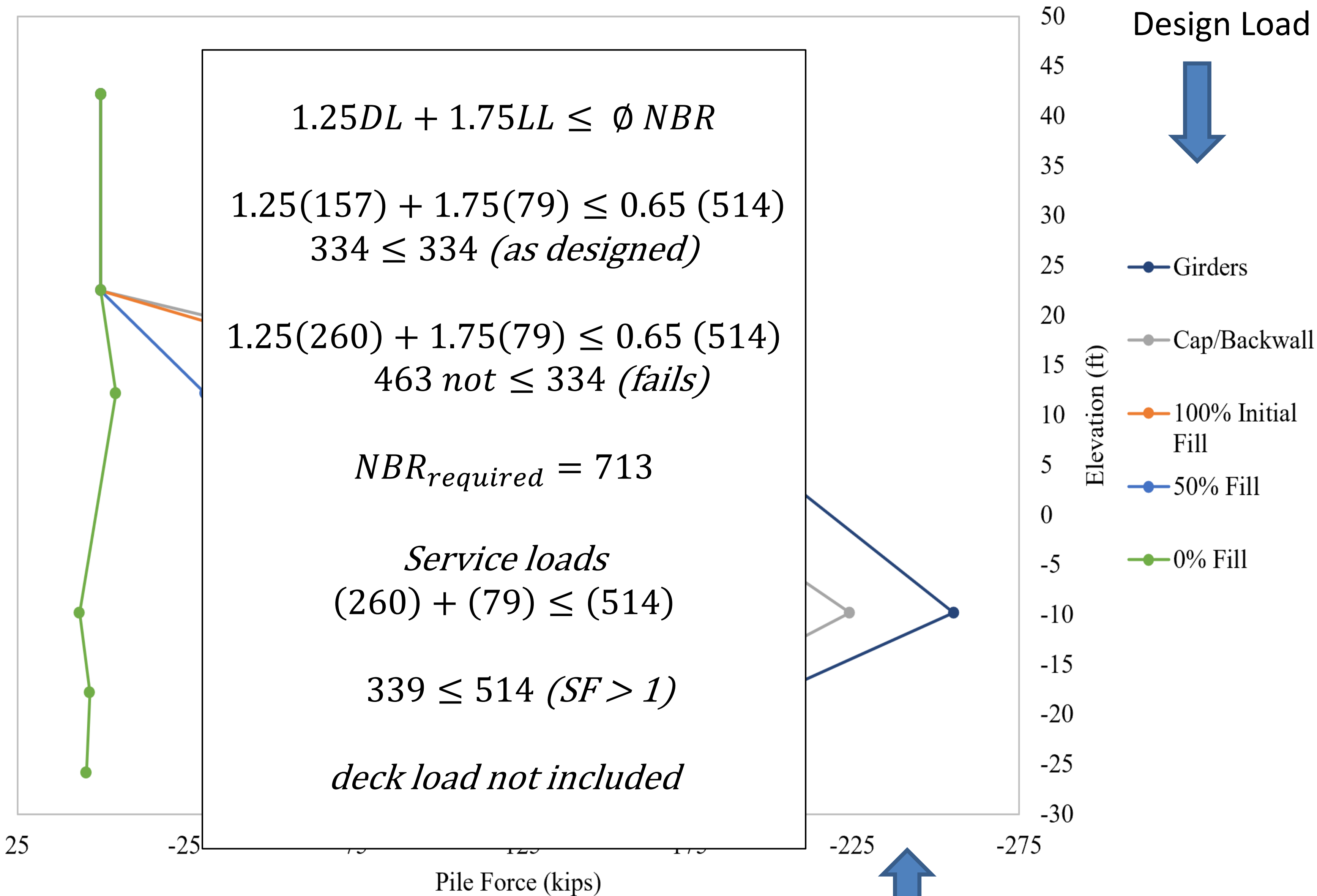
1
2
3
45
6
7
8
9
100
0
-100
-200
-300
-400
-500
Pile Load (kips)
9/22/21
12/21/21
3/21/22
6/19/22
9/17/22
12/16/22
3/16/23
Top Level Gages not shown until cap was poured
Gage 1
Gage 2
Gage 3
Gage 4
Gage 5
Gage 6
Gage 7
Gage 8



Creep Strain Corrected Pile Force
1
Pile Load (kips)
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
9/22
9/27
10/2
10/7
10/12
10/17
10/22
+20ue
-15 ± 35ue
50k-ft
-50ue
PILE INSTR.
ELEV.
+47.0
(No. GAGES @ DIST. FROM TOE)
ELEVATION (f
LEAD WIRES EXIT PILE 72' ABOVE TOE
+36
(2 @ 70)
-16
(1 @ 18)
-24
(1 @ 10)
-32
-34 ± 4
(2 @ 2)
GEOKON VW REBAR STRAINMETERS TYP
Gage 1
Gage 2
Gage 3
Gage 4
Gage 5
Gage 6
Gage 7
Gage 8

Henley Rd Pile Force Evolution

334k Factored Design Load



$$1.25DL + 1.75LL \leq \emptyset\, NBR$$

$$1.25(157) + 1.75(79) \leq 0.65\,(514)$$
$$334 \leq 334 \textit{ (as designed)}$$

$$1.25(260) + 1.75(79) \leq 0.65\,(514)$$
$$463 \textit{ not} \leq 334 \textit{ (fails)}$$

$$NBR_{required} = 713$$

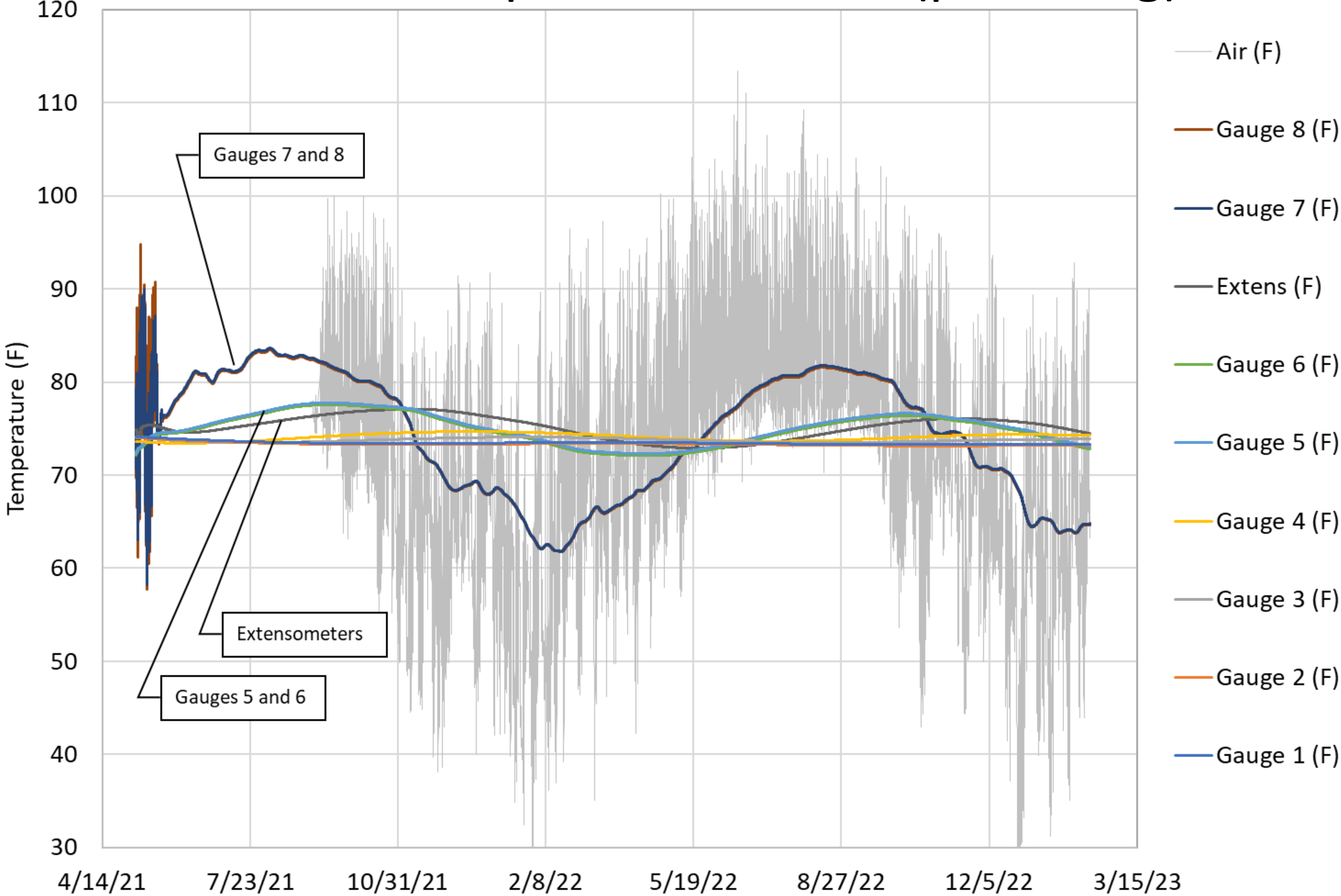
Service loads
$$(260) + (79) \leq (514)$$

$$339 \leq 514 \textit{ (SF > 1)}$$

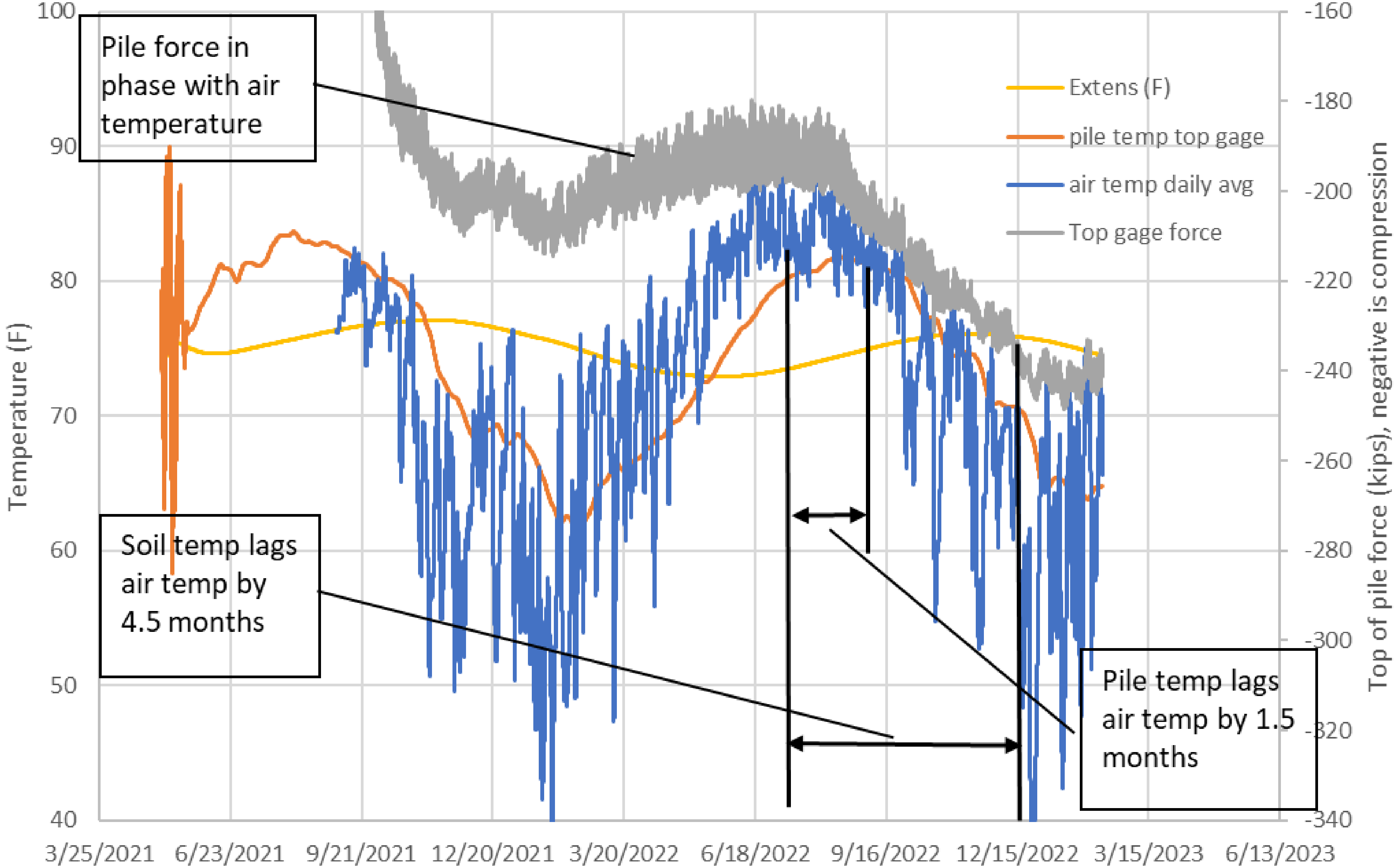
deck load not included

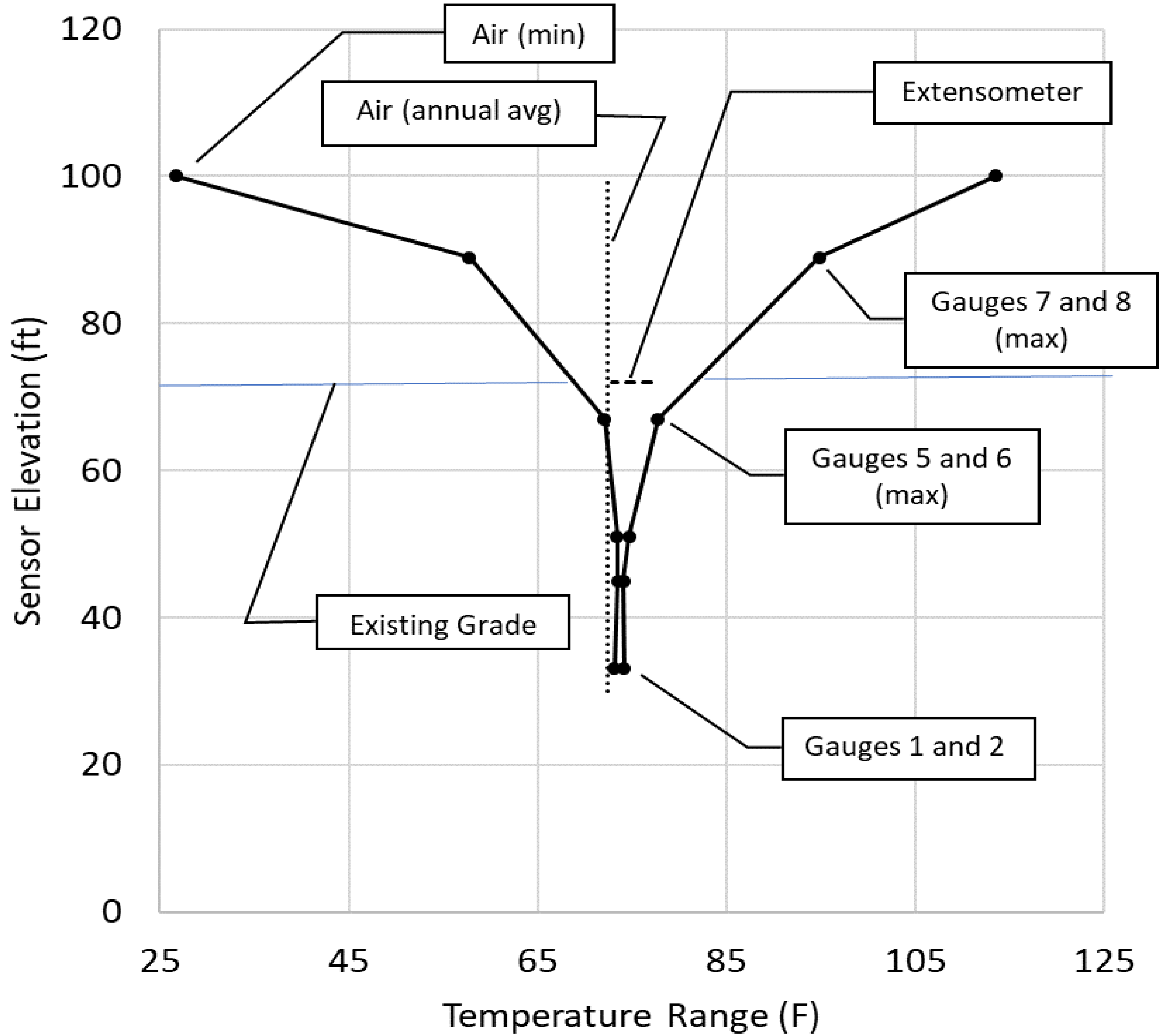
234-242kip Service Load (DL/LL = 2 or 3, respectively)

Season Temperature Effects (phase lag)

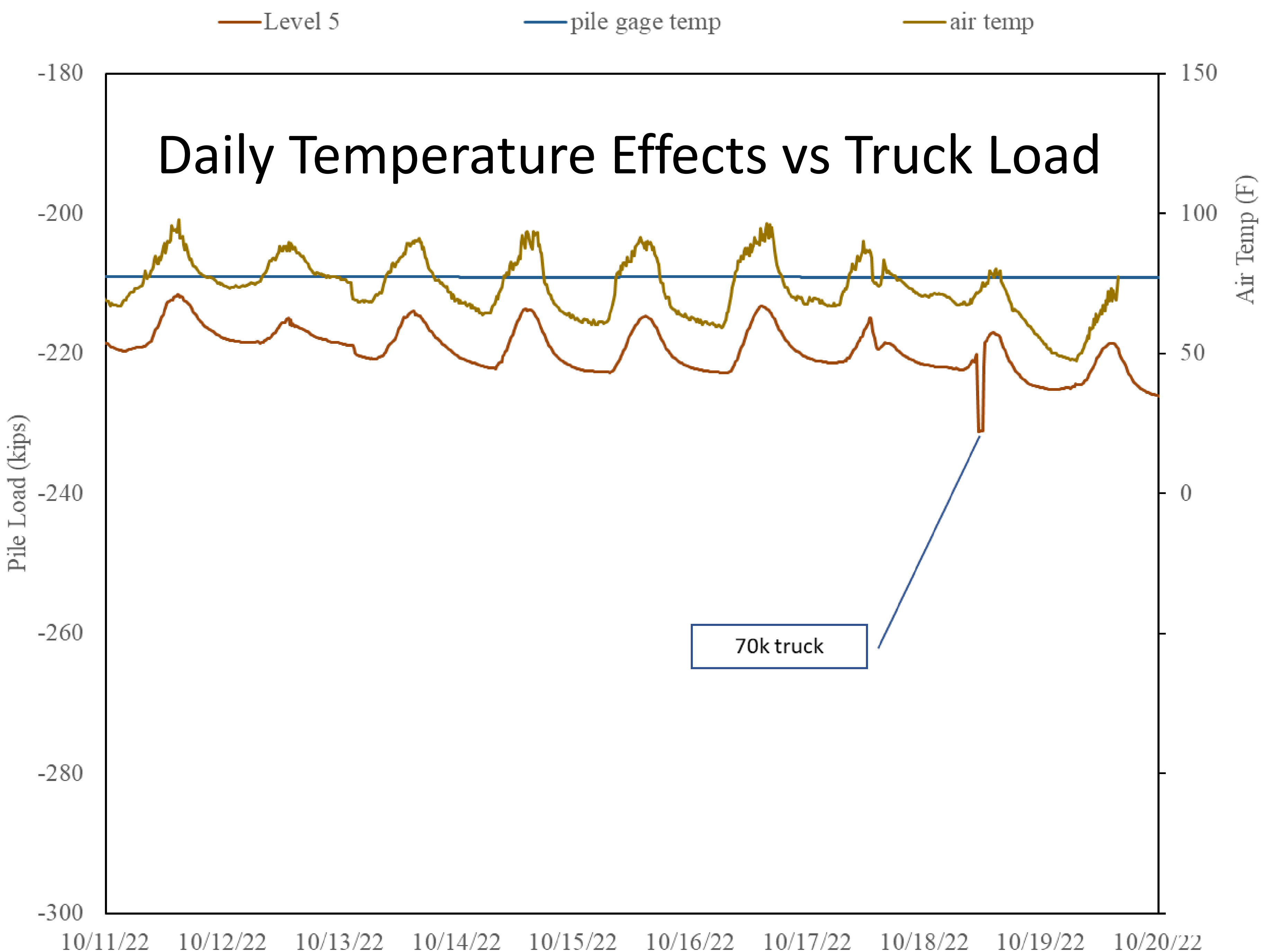


Pile Force (daily and seasonal temperature effects)



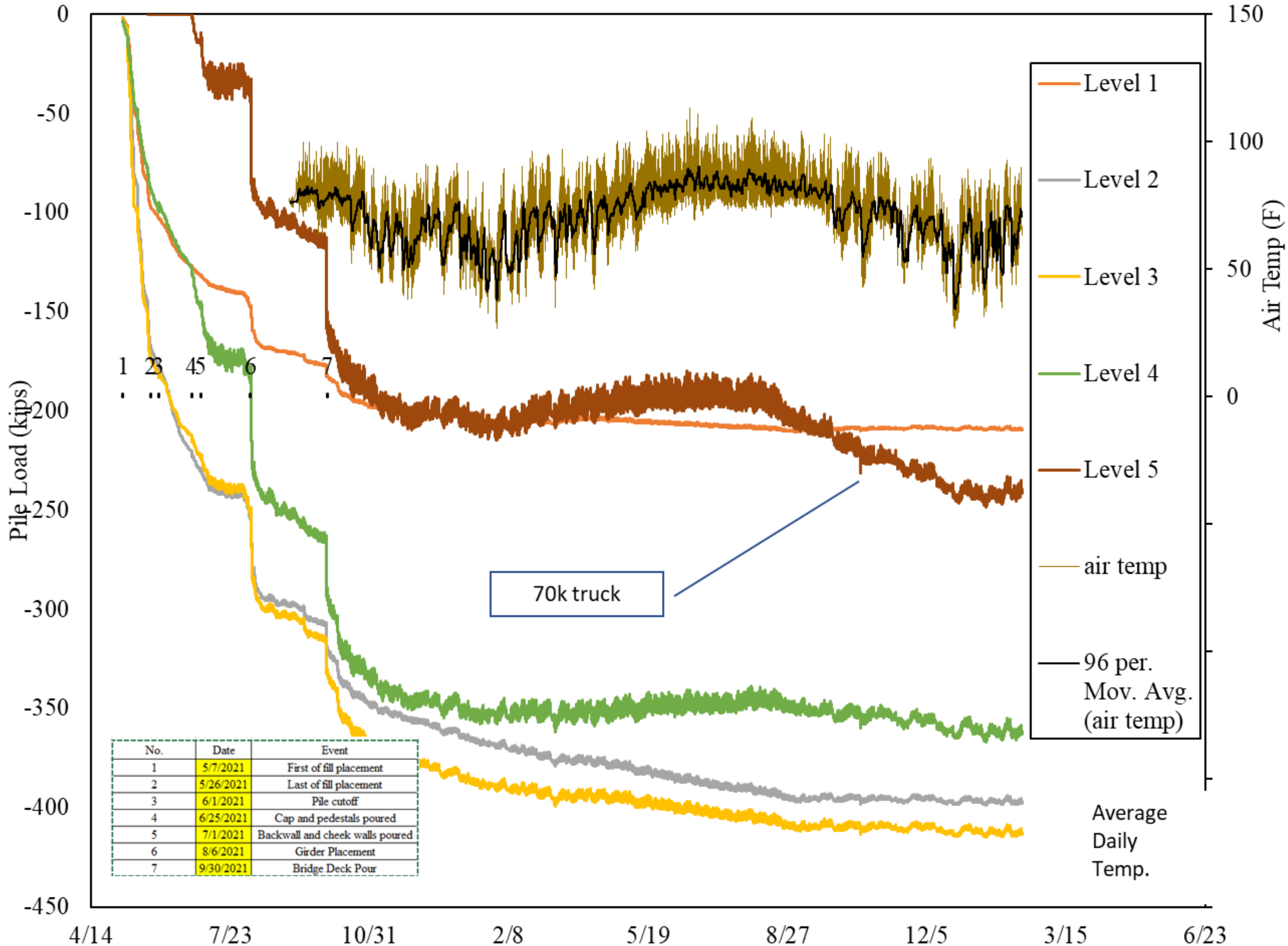


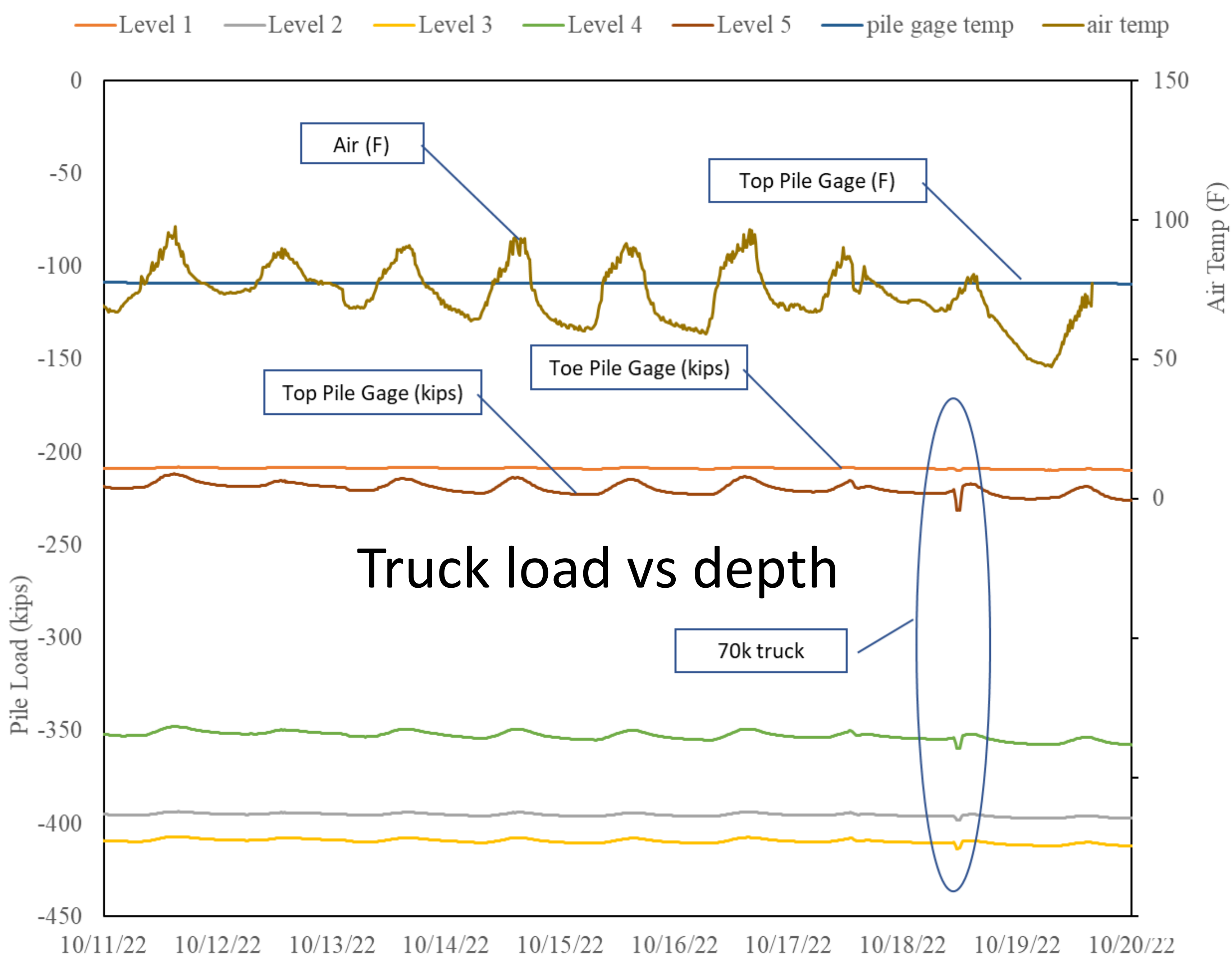
Air (min)
Air (annual avg)
Extensometer
Gauges 7 and 8 (max)
Gauges 5 and 6 (max)
Existing Grade
Gauges 1 and 2
Sensor Elevation (ft)
120
100
80
60
40
20
0
25
45
65
85
105
125
Temperature Range (F)



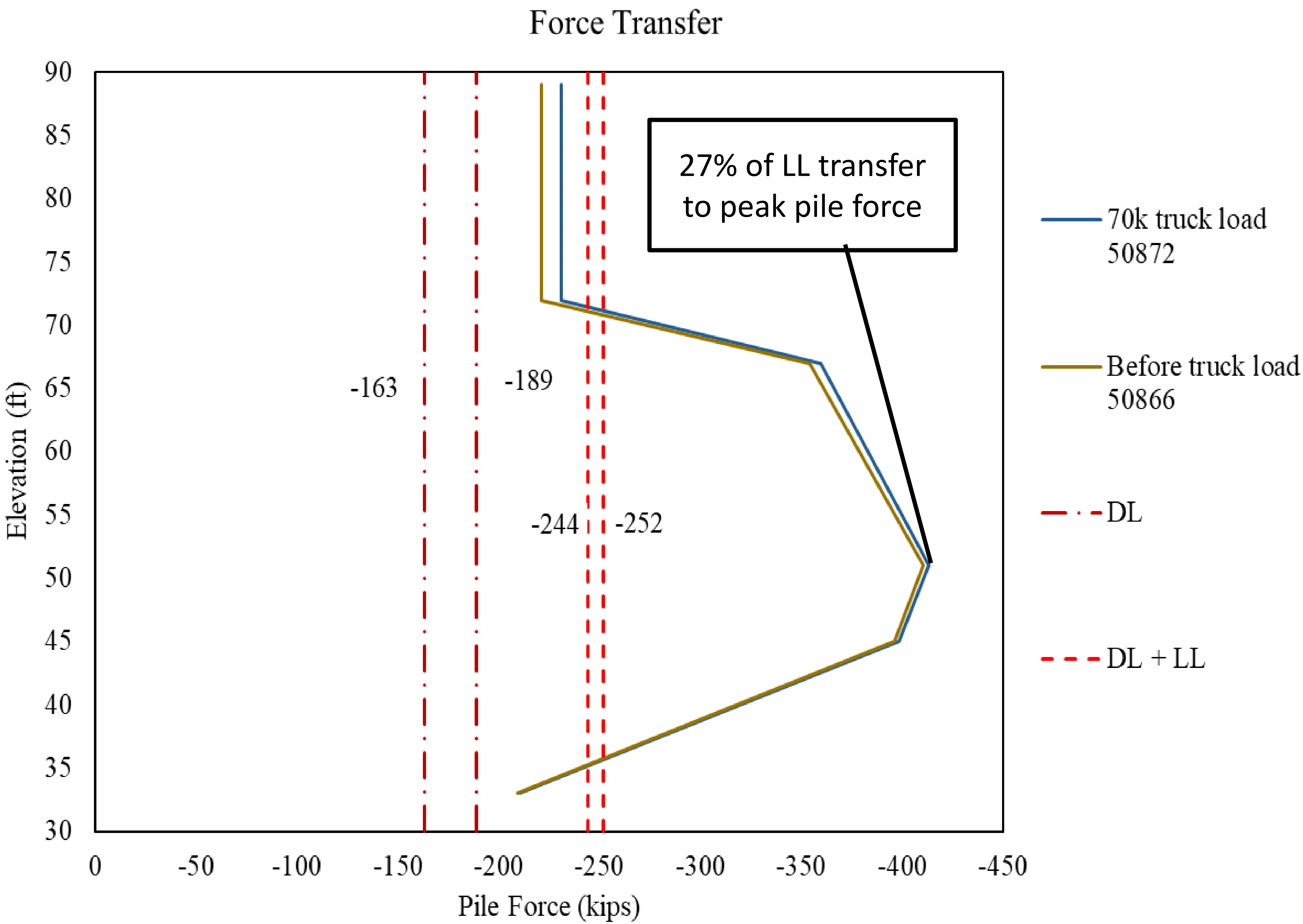
Level 5
pile gage temp
air temp
Daily Temperature Effects vs Truck Load
70k truck
Pile Load (kips)
Air Temp (F)
-180
-200
-220
-240
-260
-280
-300
150
100
50
0
10/11/22
10/12/22
10/13/22
10/14/22
10/15/22
10/16/22
10/17/22
10/18/22
10/19/22
10/20/22

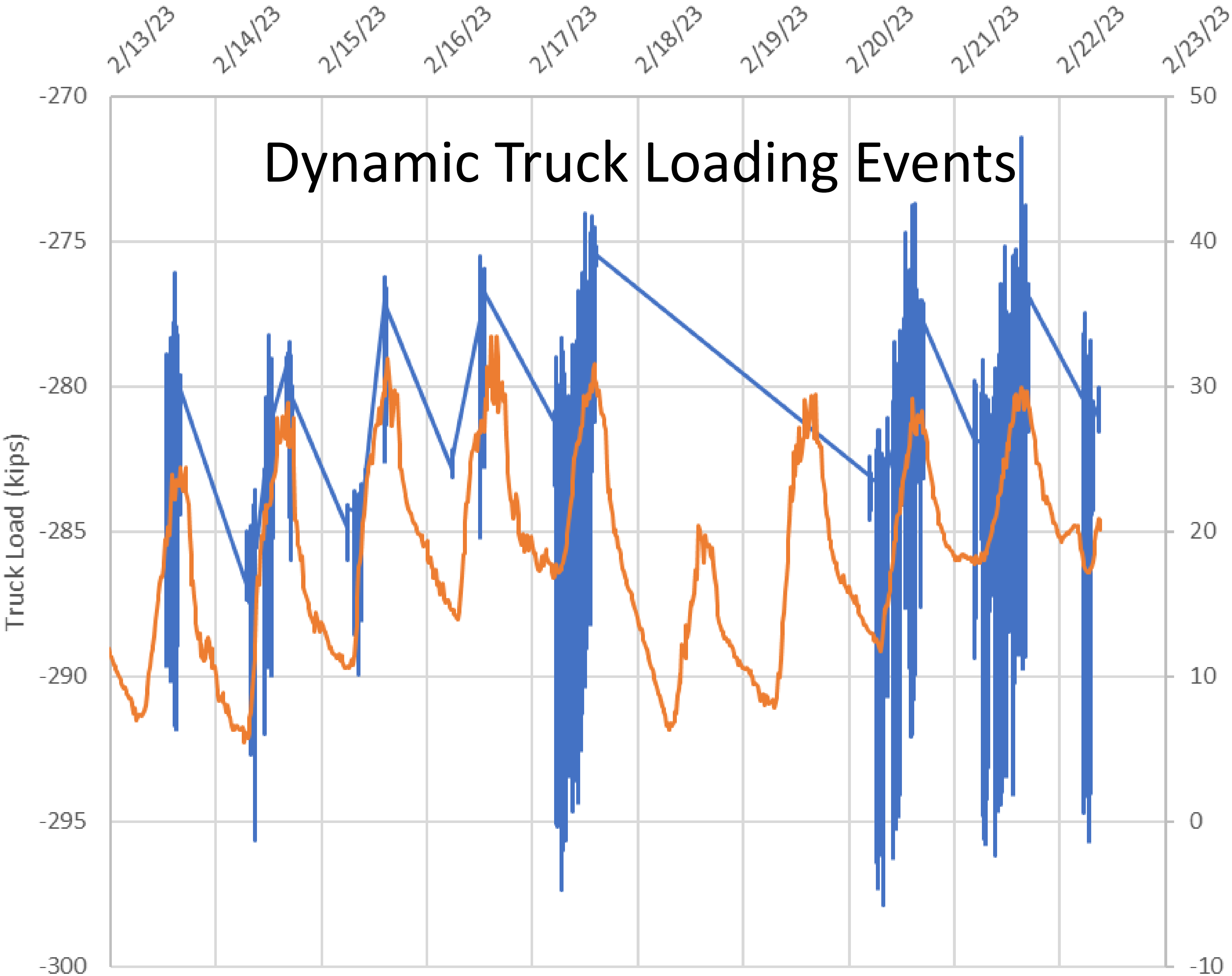

sacyr
USDOT 3213201
Instrumented Pile

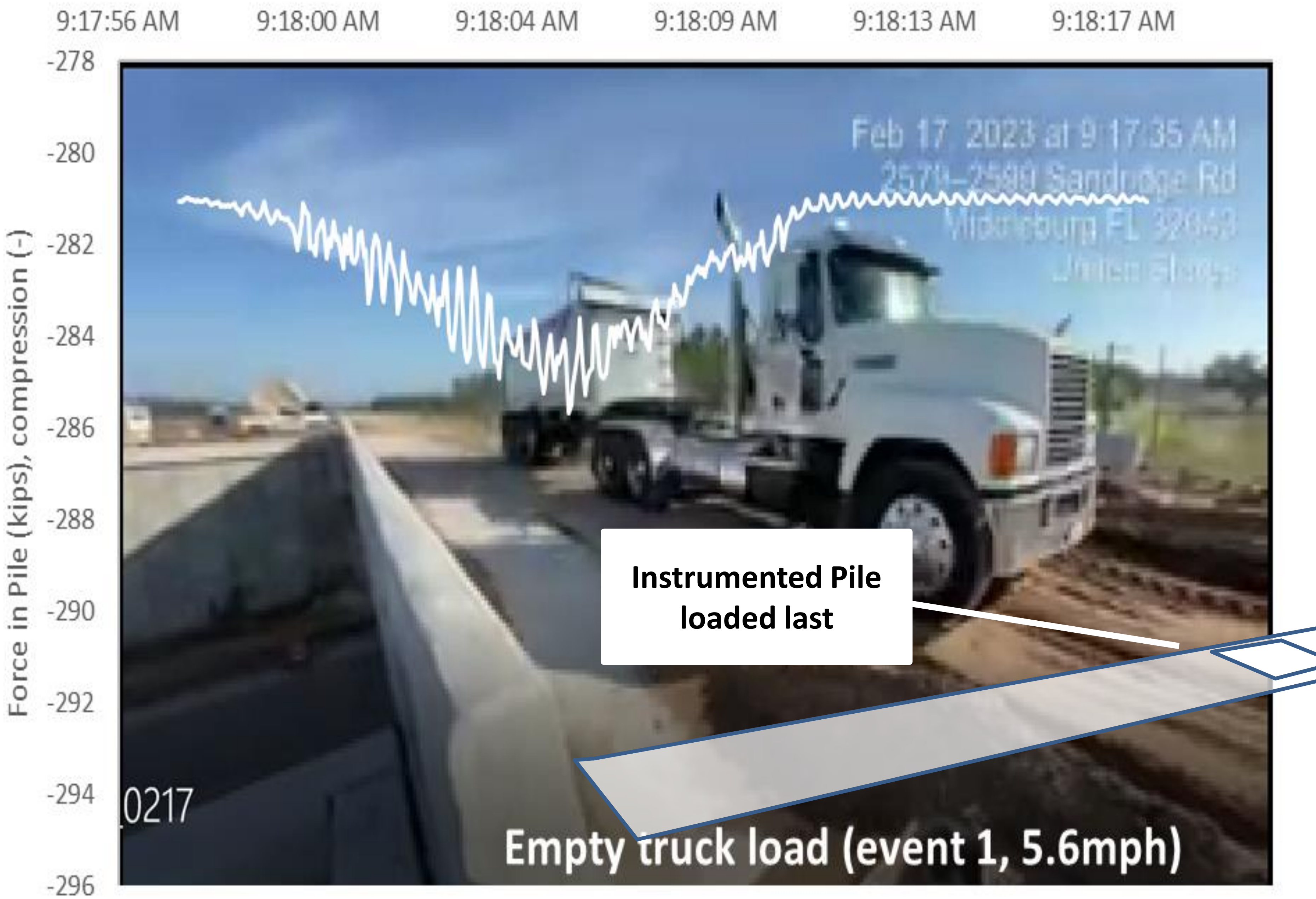

Pile Load (kips)
Air Temp (F)
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
150
100
50
0
4/14
7/23
10/31
2/8
5/19
8/27
12/5
3/15
6/23
1
23
45
6
7
Level 1
Level 2
Level 3
Level 4
Level 5
air temp
96 per. Mov. Avg. (air temp)
70k truck
Average Daily Temp.
No. Date Event
1 5/7/2021 First of fill placement
2 5/26/2021 Last of fill placement
3 6/1/2021 Pile cutoff
4 6/25/2021 Cap and pedestals poured
5 7/1/2021 Backwall and cheek walls poured
6 8/6/2021 Girder Placement
7 9/30/2021 Bridge Deck Pour



Level 1
Level 2
Level 3
Level 4
Level 5
pile gage temp
air temp
Air (F)
Top Pile Gage (F)
Top Pile Gage (kips)
Toe Pile Gage (kips)
Truck load vs depth
70k truck
Pile Load (kips)
Air Temp (F)
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
150
100
50
0
10/11/22
10/12/22
10/13/22
10/14/22
10/15/22
10/16/22
10/17/22
10/18/22
10/19/22
10/20/22


Force Transfer
27% of LL transfer to peak pile force
-163
-189
-244
-252
Elevation (ft)
Pile Force (kips)
90
85
80
75
70
65
60
55
50
45
40
35
30
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
70k truck load 50872
Before truck load 50866
DL
DL + LL

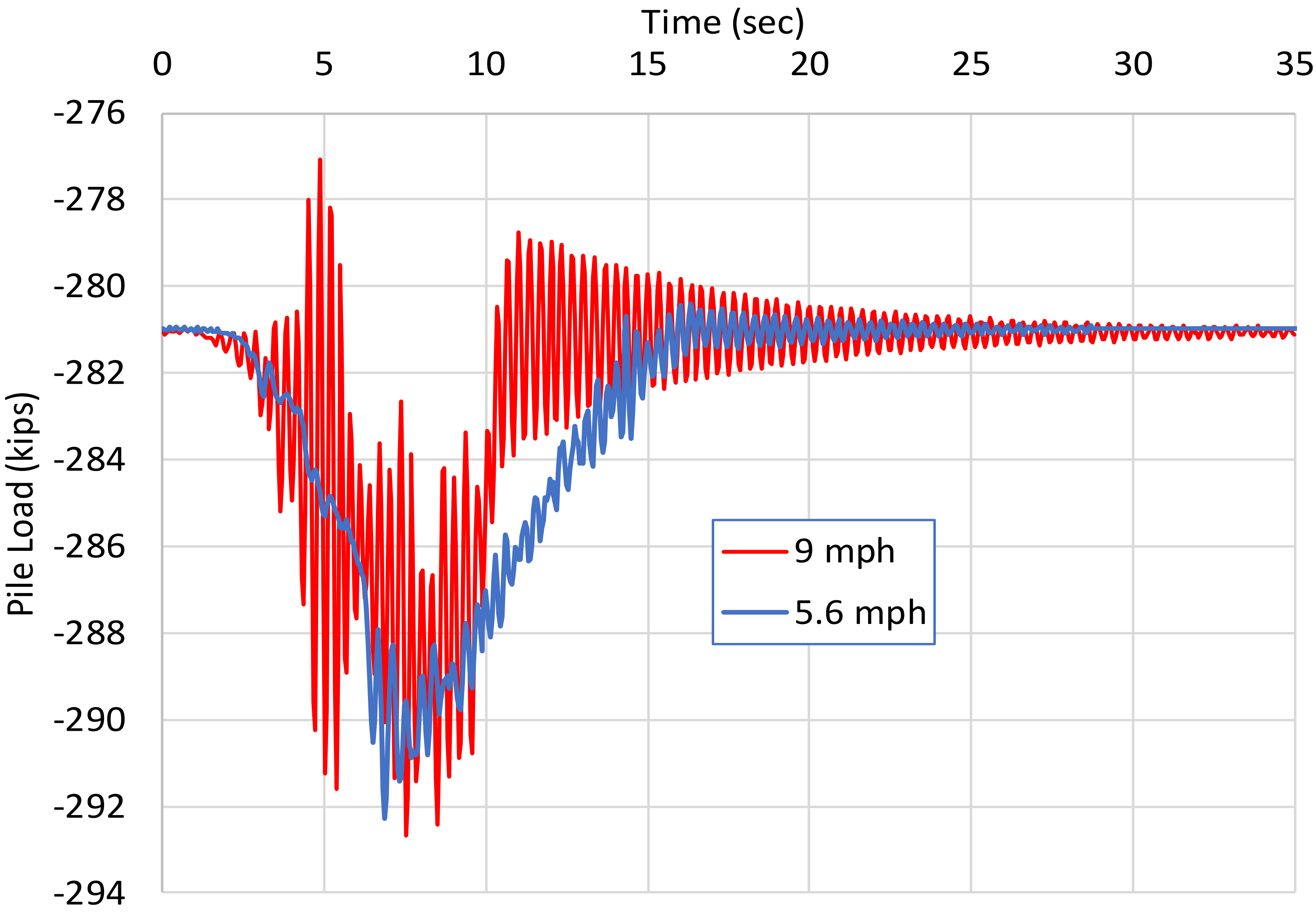

Dynamic Truck Loading Events
Truck Load (kips)
2/13/23
2/14/23
2/15/23
2/16/23
2/17/23
2/18/23
2/19/23
2/20/23
2/21/23
2/22/23
2/23/23
-270
-275
-280
-285
-290
-295
-300
50
40
30
20
10
0
-10


9:17:56 AM
9:18:00 AM
9:18:04 AM
9:18:09 AM
9:18:13 AM
9:18:17 AM
-278
-280
-282
-284
-286
-288
-290
-292
-294
-296
Force in Pile (kips), compression (-)
Feb 17, 2023 at 9:17:35 AM
Instrumented Pile loaded last
0217
Empty truck load (event 1, 5.6mph)

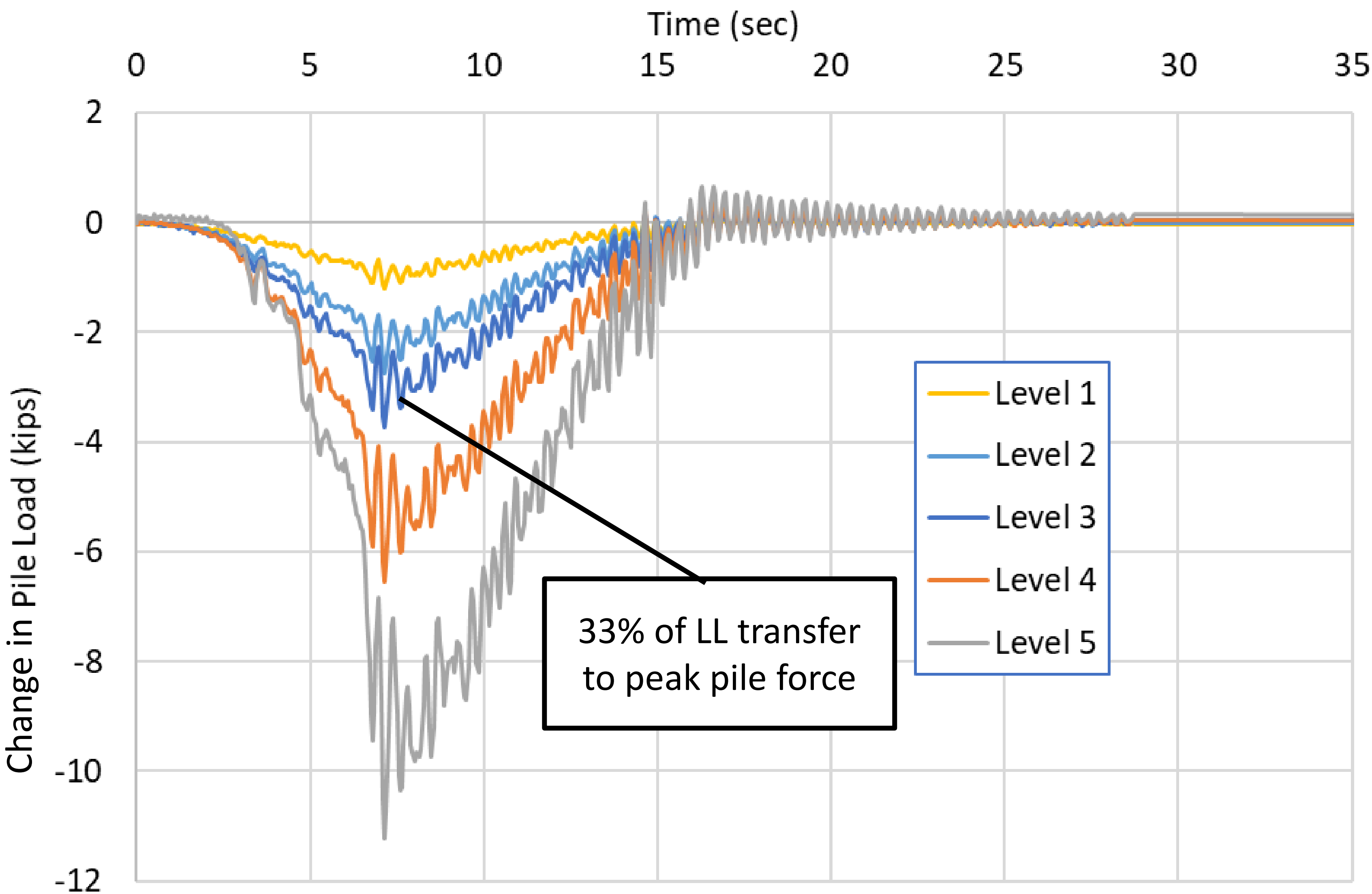

9:22:15 AM
9:22:19 AM
9:22:24 AM
9:22:28 AM
9:22:32 AM
9:22:36 AM
9:22:41 AM
9:22:45 AM
-278
-280
-282
-284
-286
-288
-290
-292
-294
-296
Force in Pile (kips), compression (-)
Feb 17, 2023 at 9:22:01 AM
United States
Instrumented Pile
other side loaded first
0222
Full truck load (event 4, 4.6mph)

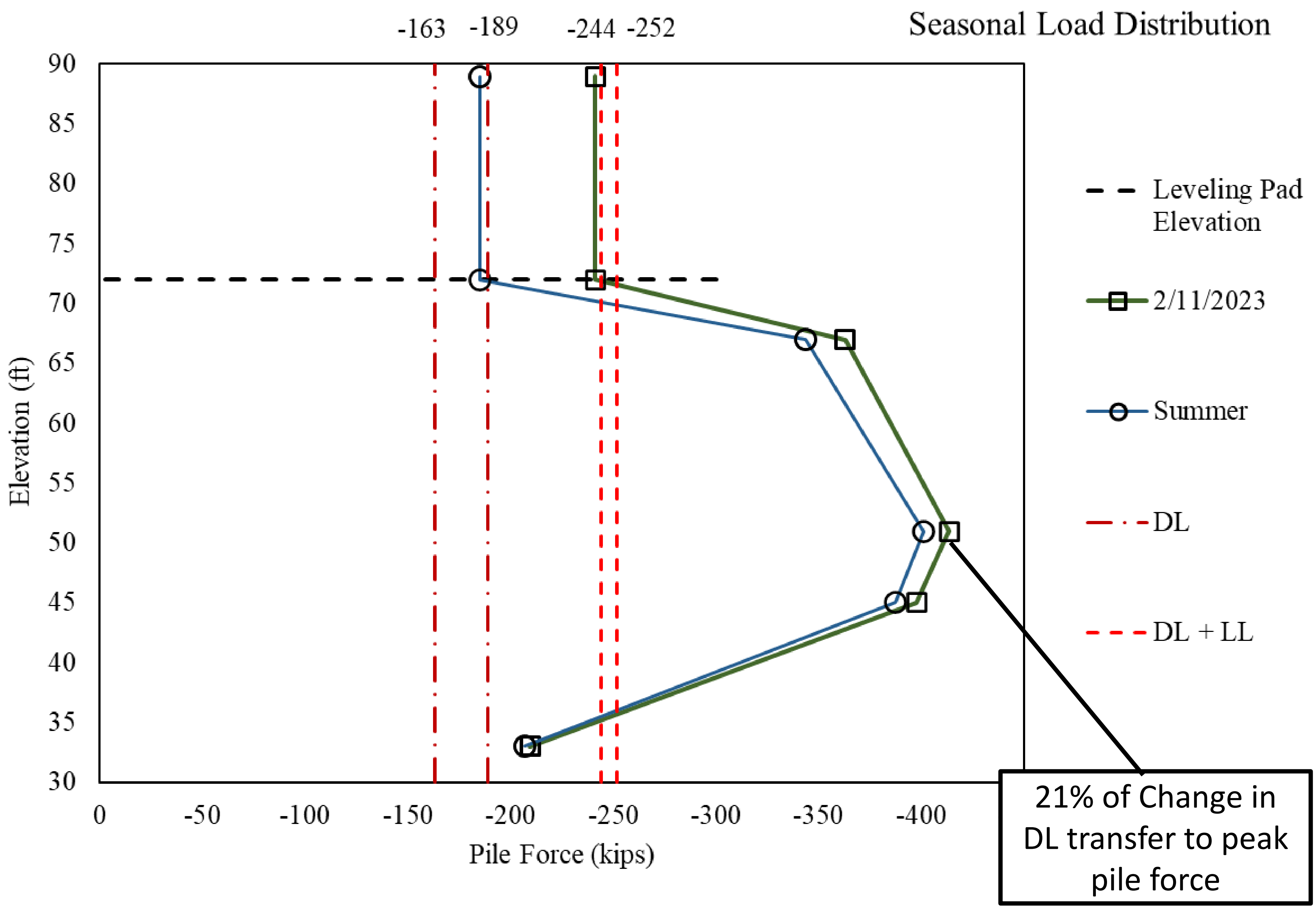
-280
-285
-290
-295
Force (kips)
Feb 17, 2023 at 9:21:49 AM
2540–2548 Sandridge Rd
Green Cove Springs FL 32043
United States
Full Truck Load (Event 4, 4.6mph)

Effect of Truck Speed



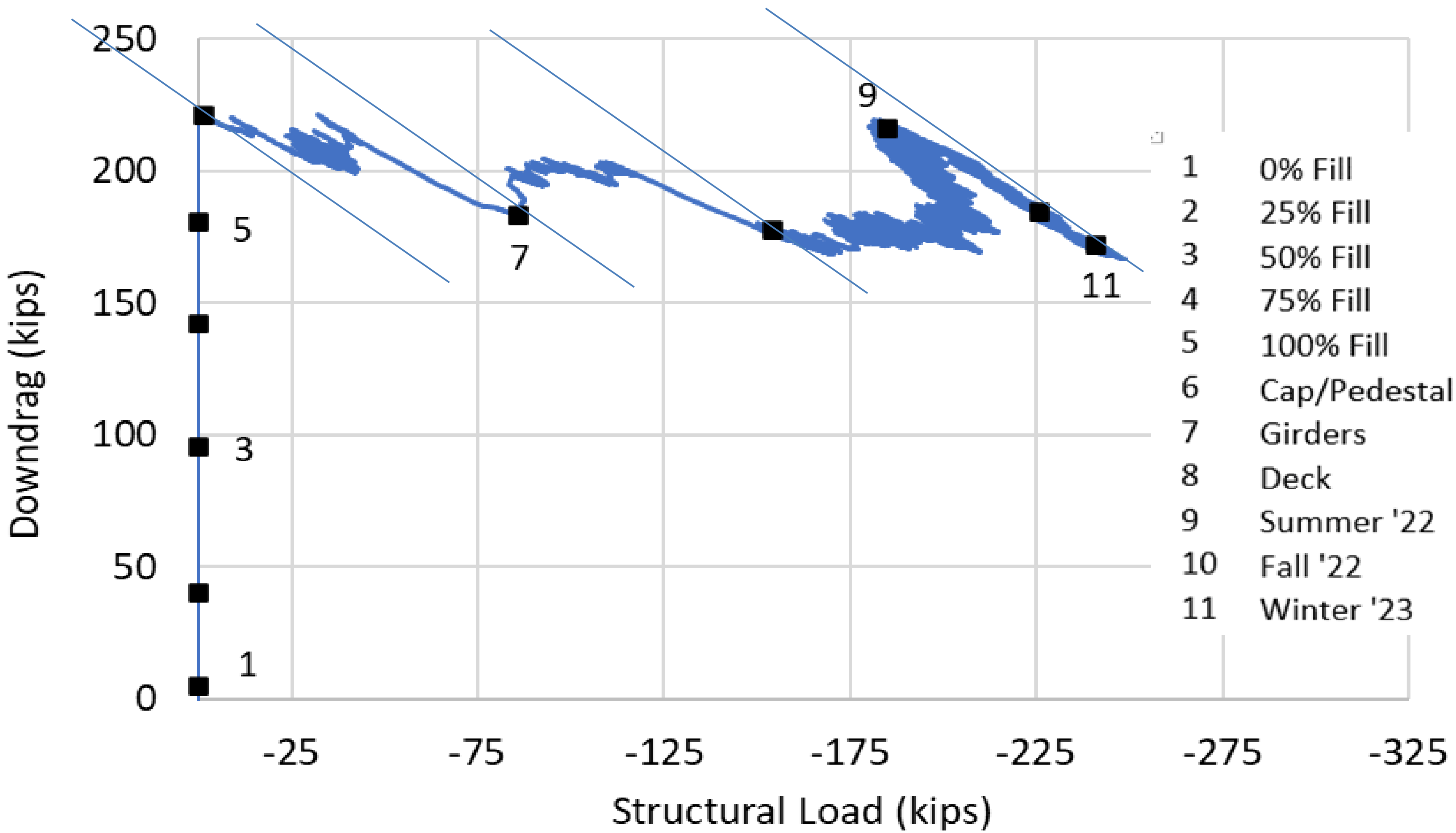
Live Load vs Depth





Seasonal Load Distribution
-163
-189
-244
-252
Elevation (ft)
Pile Force (kips)
90
85
80
75
70
65
60
55
50
45
40
35
30
0
-50
-100
-150
-200
-250
-300
-350
-400
Leveling Pad Elevation
2/11/2023
Summer
DL
DL + LL
21% of Change in DL transfer to peak pile force

Effect of New Load on Peak Pile Force



Additional structural load (DL or LL) does not decrease downdrag 1 for 1. Hence, 20 to 33% of new load is added to highest pile force at neutral plane.

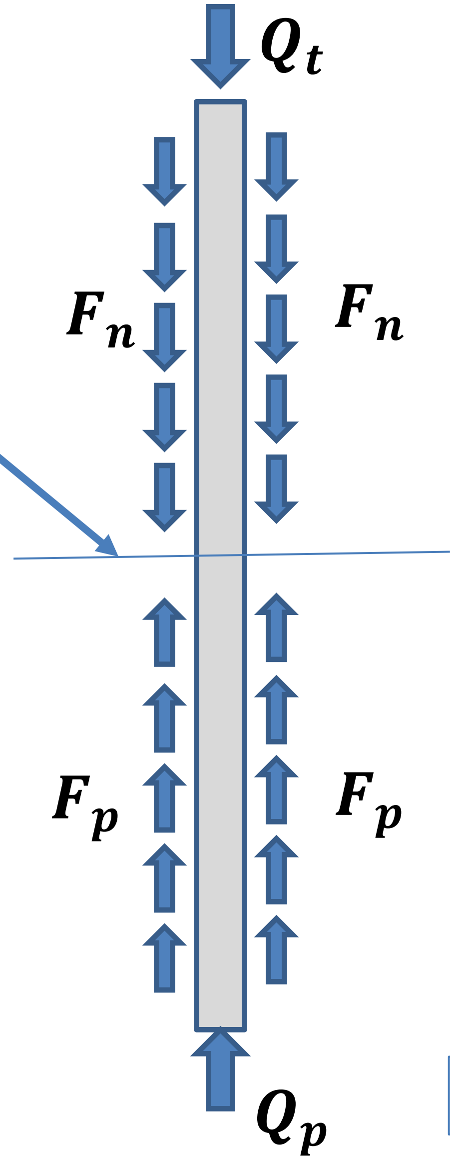
Computing Downdrag

Explicit Method

- Assume a neutral point location
- Solve equilibrium equation for $\boldsymbol{Q_p}$

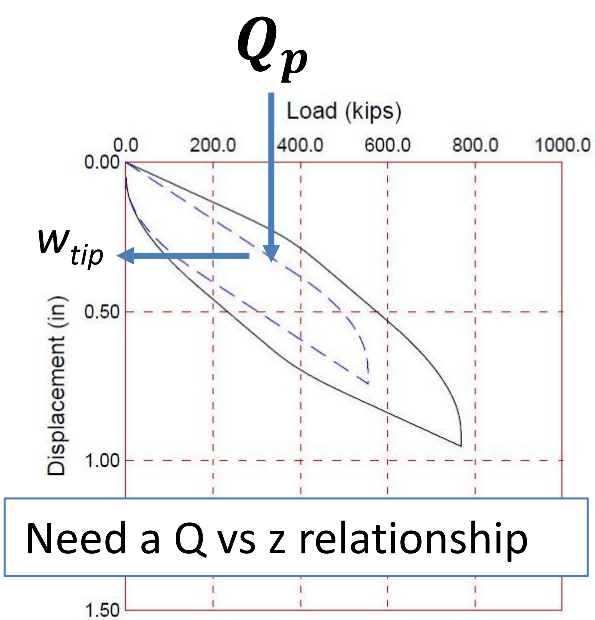
$$\boldsymbol{Q_p} = Q_t + F_n - F_p$$

- Find tip movement at $\boldsymbol{Q_p}$, w_{tip}



Equilibrium / Force Balance

$$Q_t + F_n = F_p + \boldsymbol{Q_p}$$



Need a Q vs z relationship

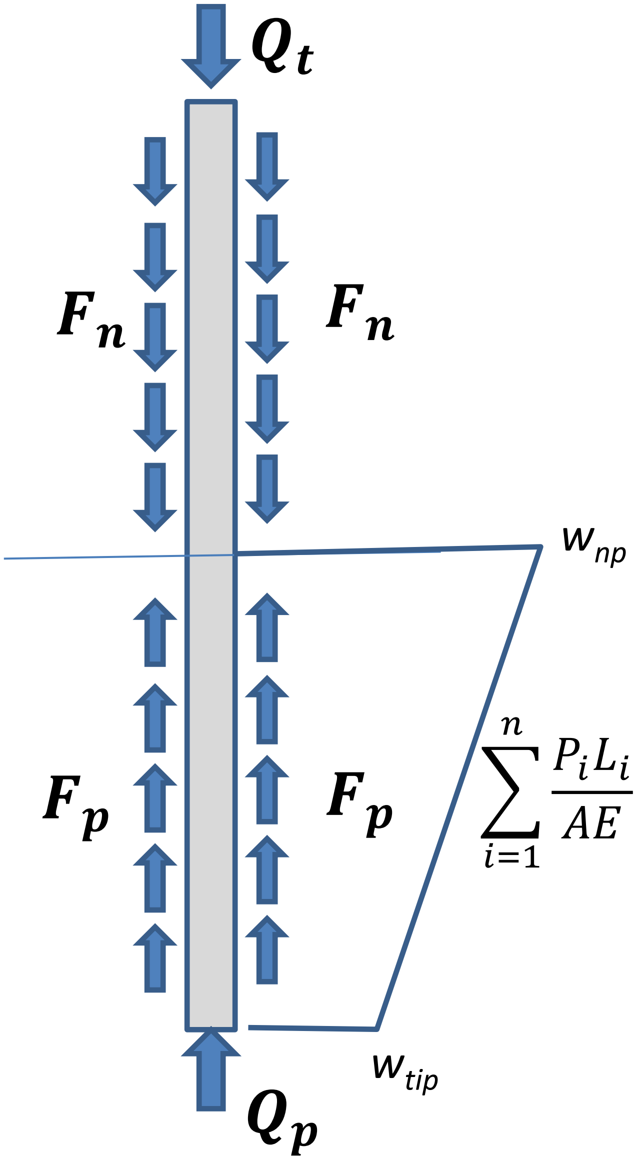
Computing Downdrag

Explicit Method

- Compute elastic shortening in pile between tip and neutral point

- $w_{np} = w_{tip} + \sum_{i=1}^{n} \frac{P_i L_i}{AE}$

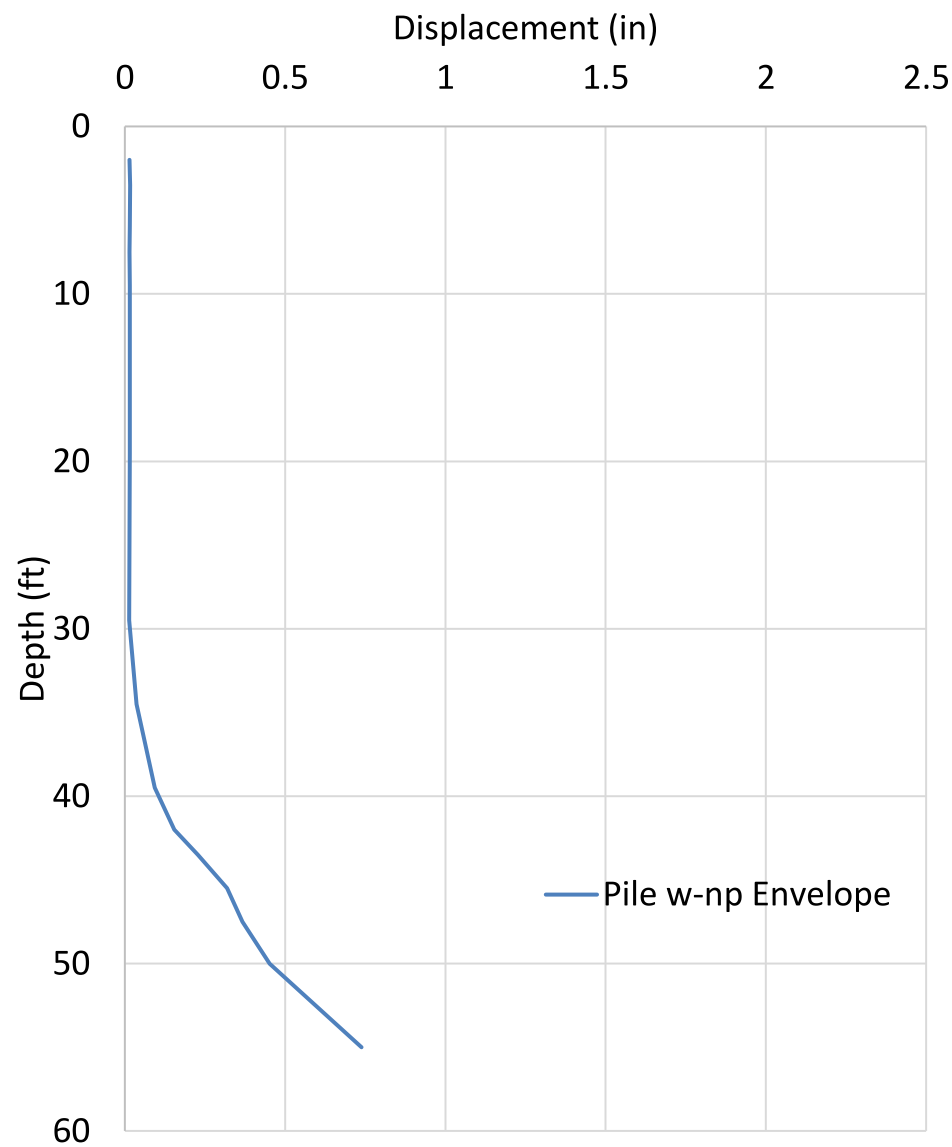
- Compute soil settlement only to tip of pile



Computing Downdrag

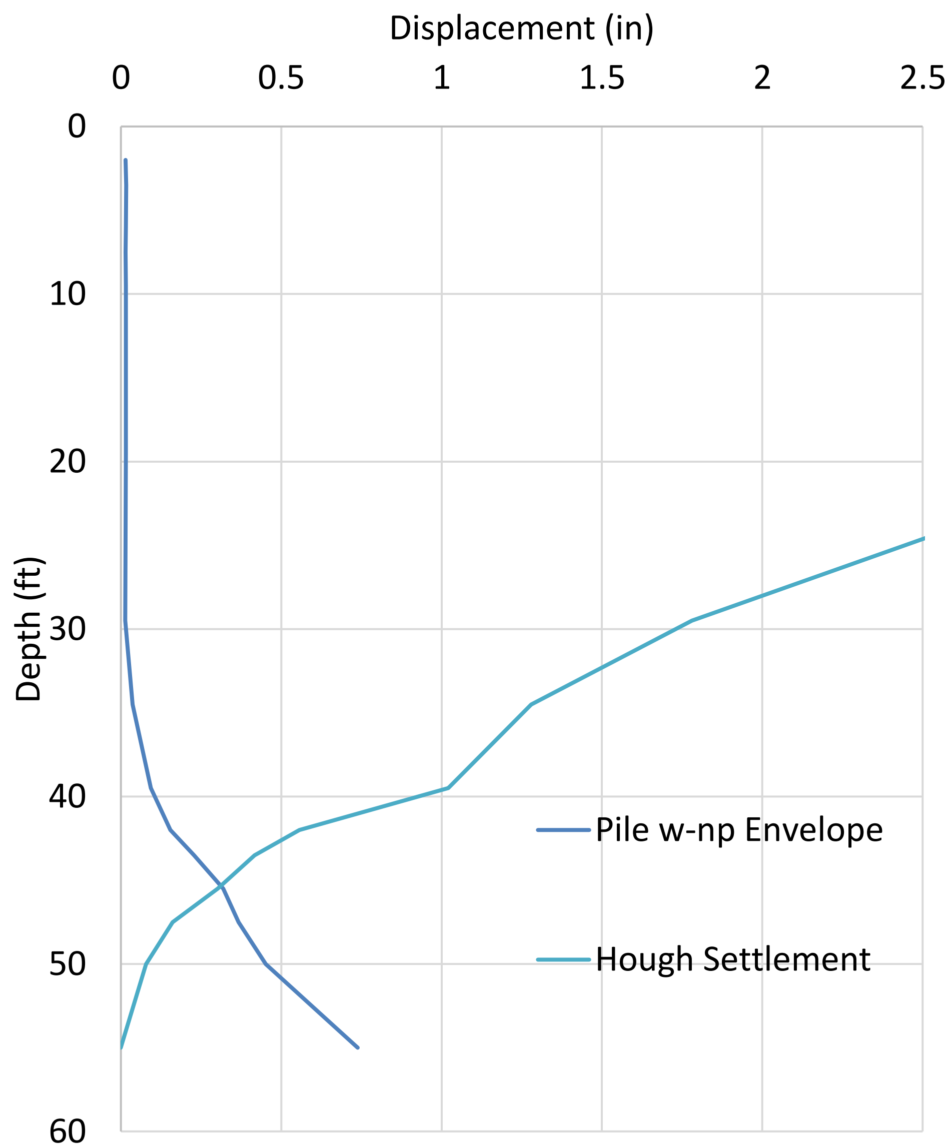
Explicit Method

- Compute w_{np} for all depths
- $\boldsymbol{Q_p}$ will be negative at shallow depths; elastic shortening will be very small w_{np} is below these depths; solution does not exist
- $\boldsymbol{Q_p}$ can exceed $\boldsymbol{Q_{ult}}$ at very deep depths; this solution does not exist



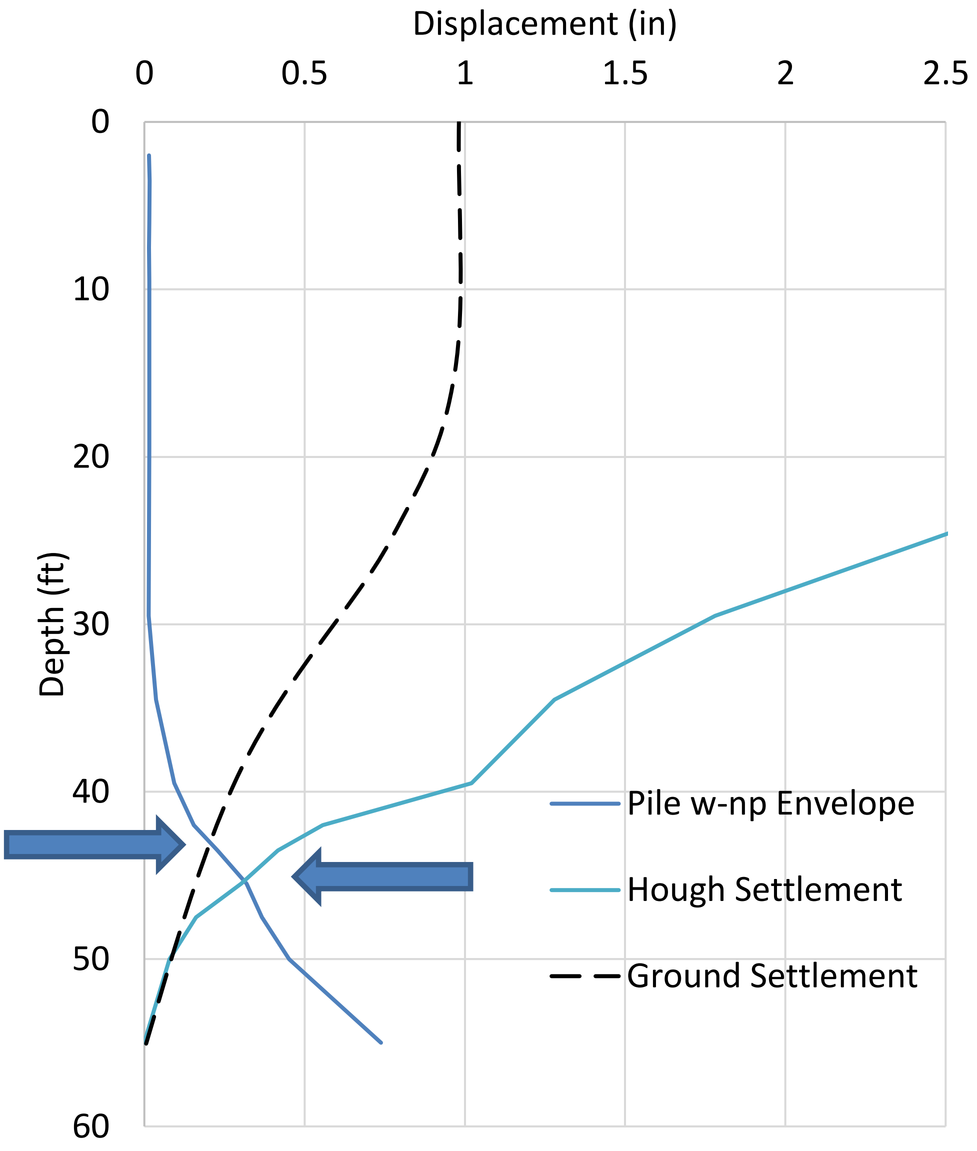
Computing Downdrag

- Superimpose predicted settlement, but only including soil layers where the pile exists
- Intersection is NP where there is no relative movement



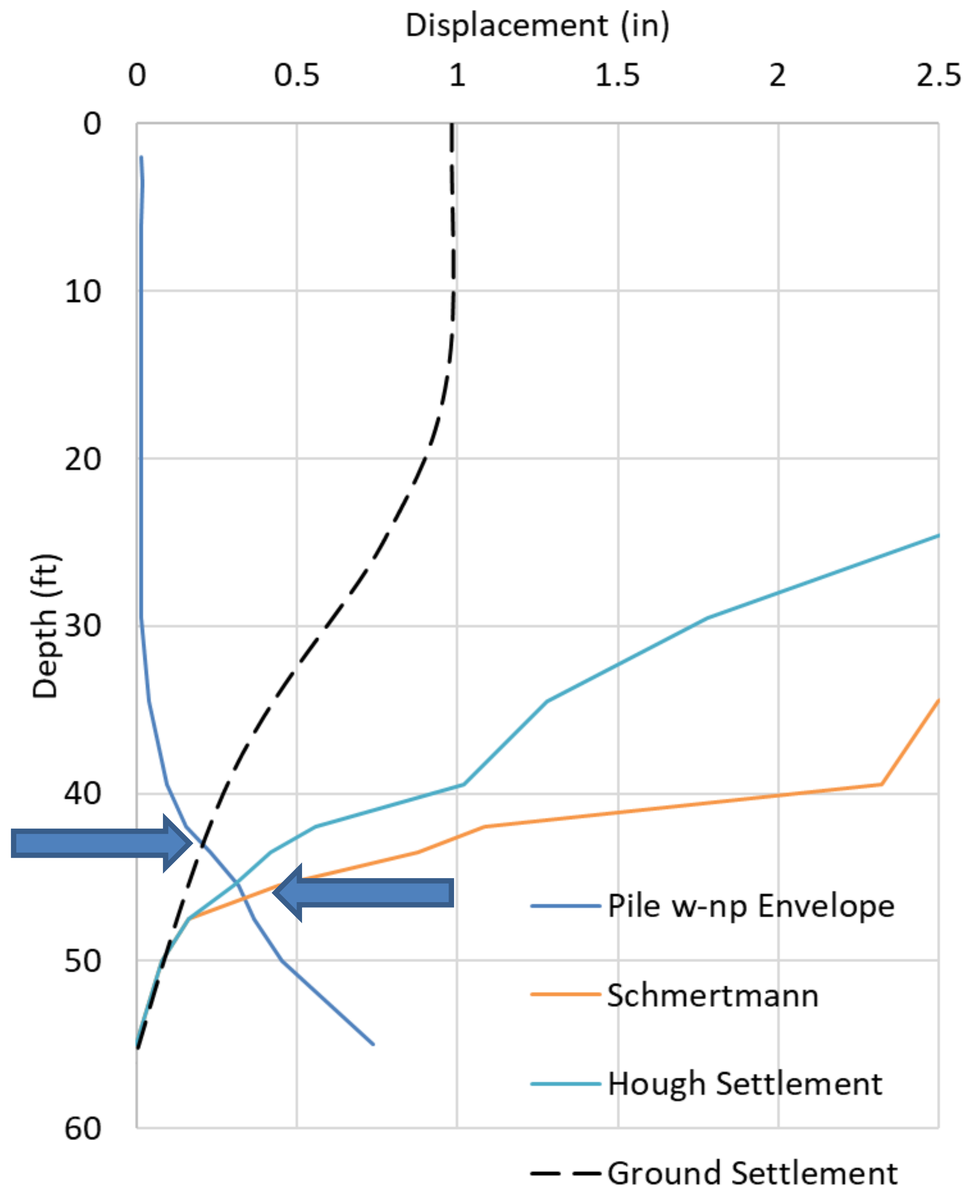
Computing Downdrag

- Predicted settlement is more than measured settlement
- Subtle change in NP location
- Slightly conservative adding more DD



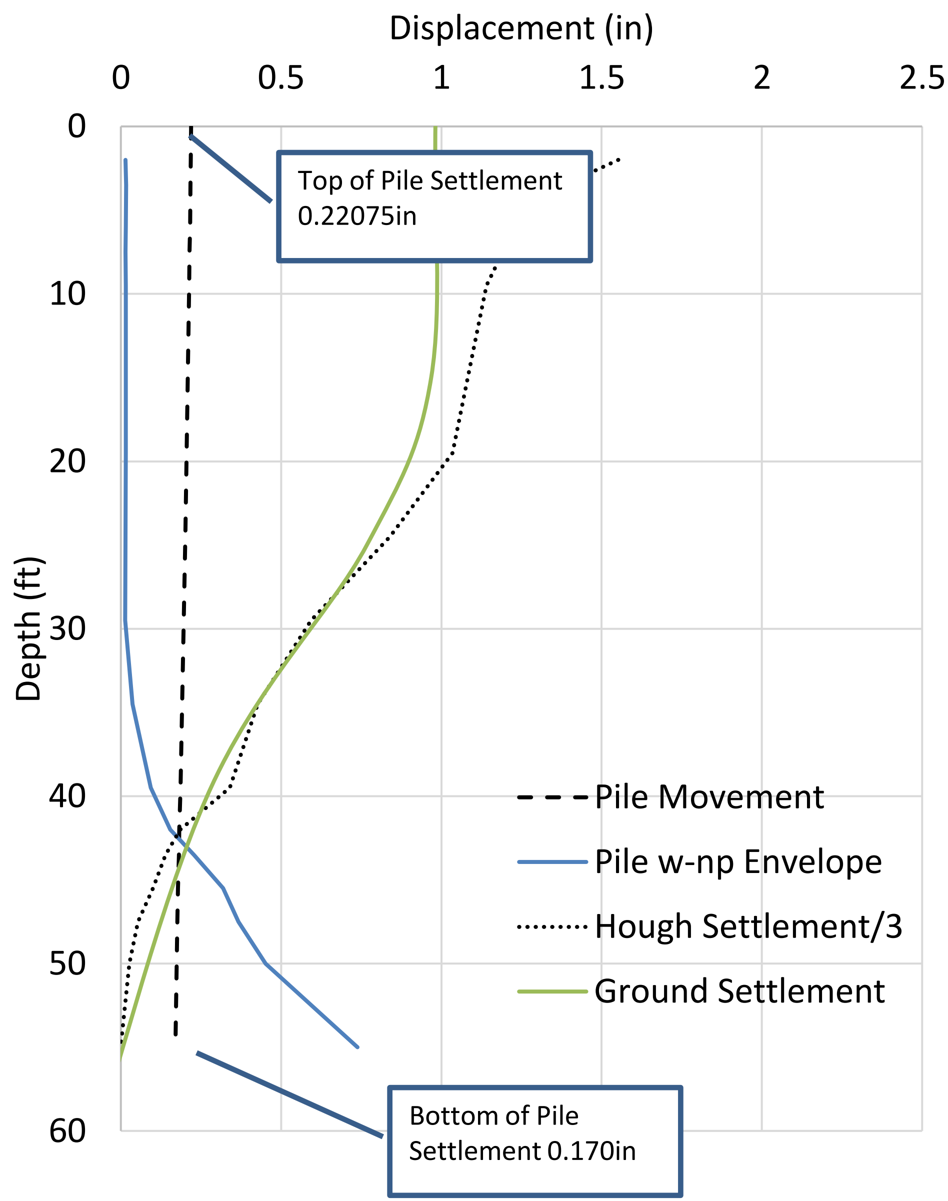
Computing Downdrag

- Predicted settlement is more than measured settlement
- Subtle change in NP location
- Slightly conservative adding more DD
- Somewhat insensitive to settlement calculation method

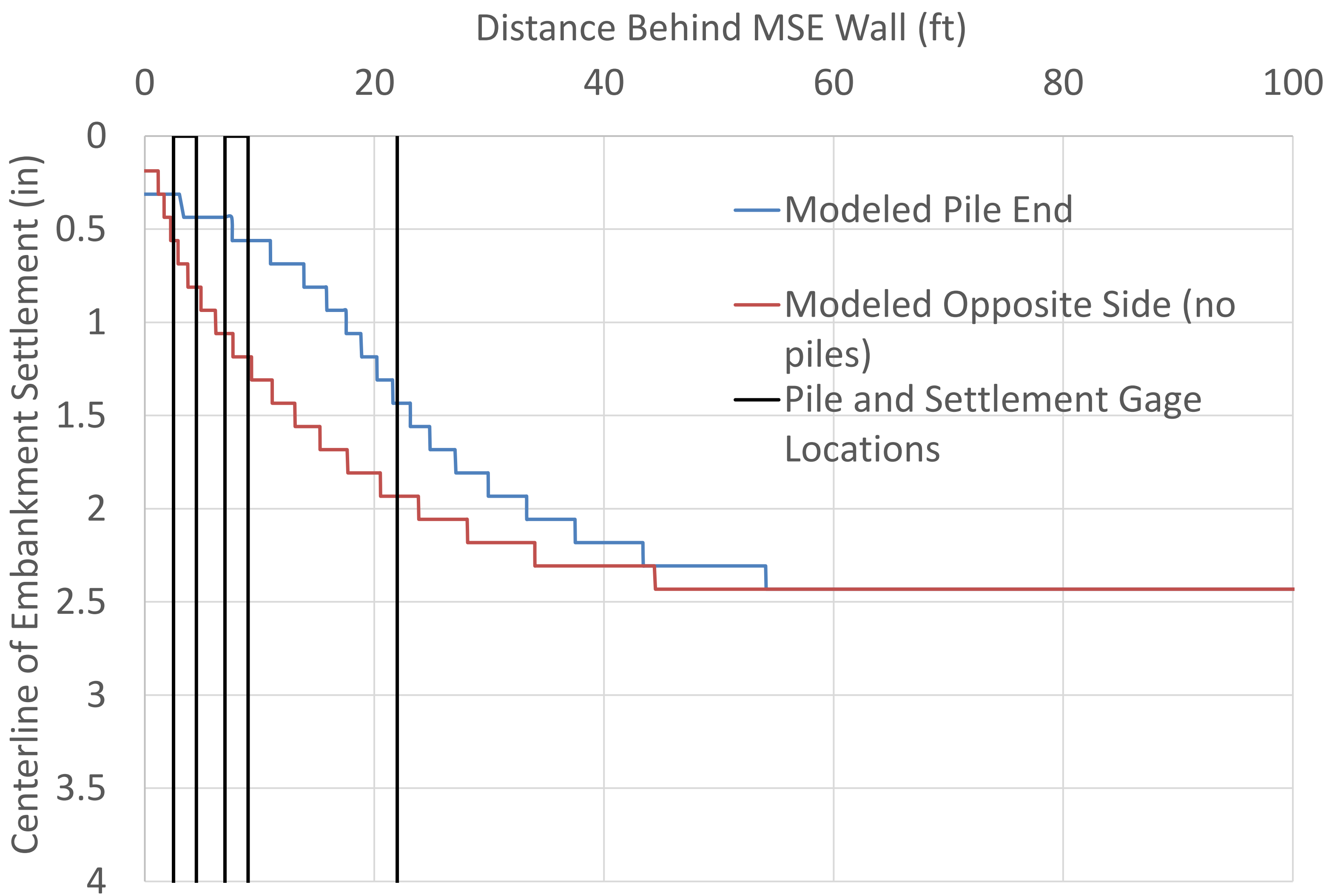


Computing Downdrag

- One-third predicted settlement very close to actual
- Full length pile movement profile also intersects true settlement curve at NP (by definition)



Settlement around piles

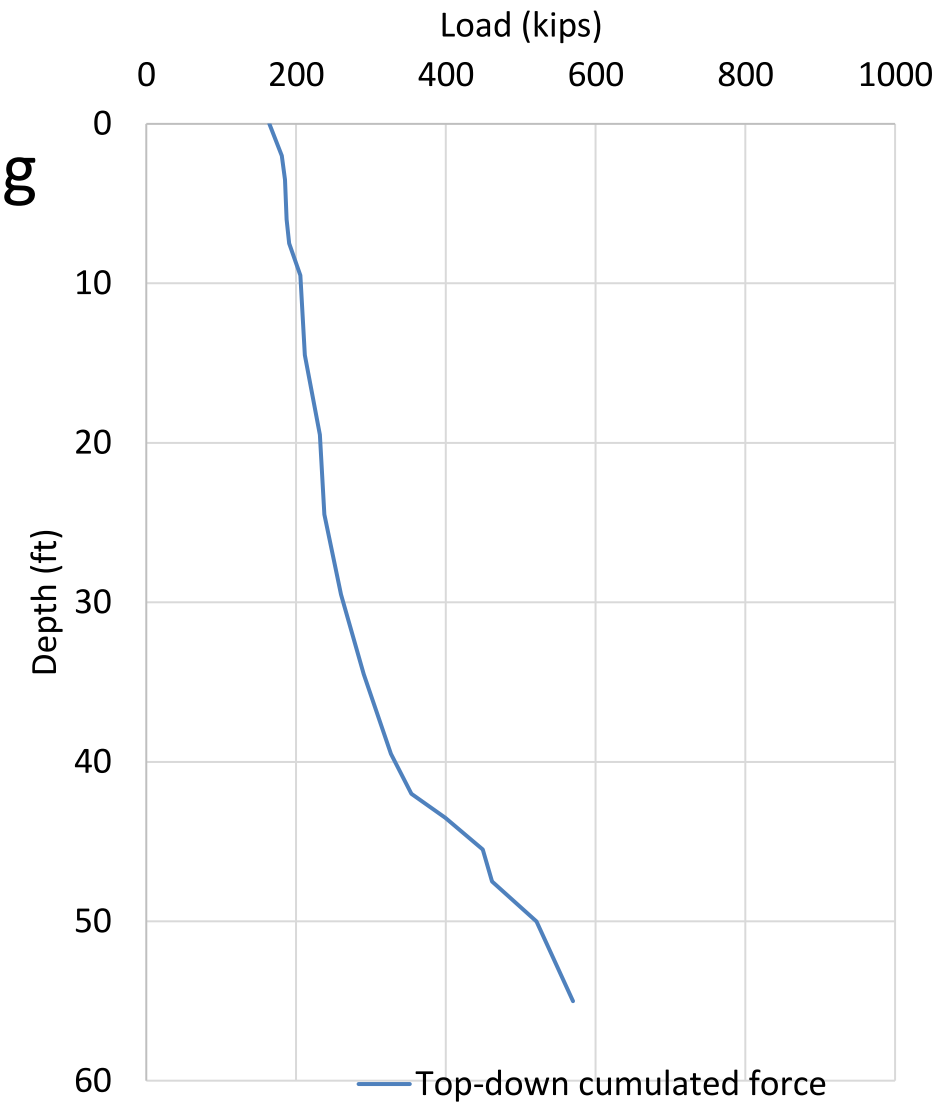


Computing Downdrag

Neutral Plane Method

(Force Balance w/o computing end bearing movement)

- Cumulate side shear from top down added to top of pile load



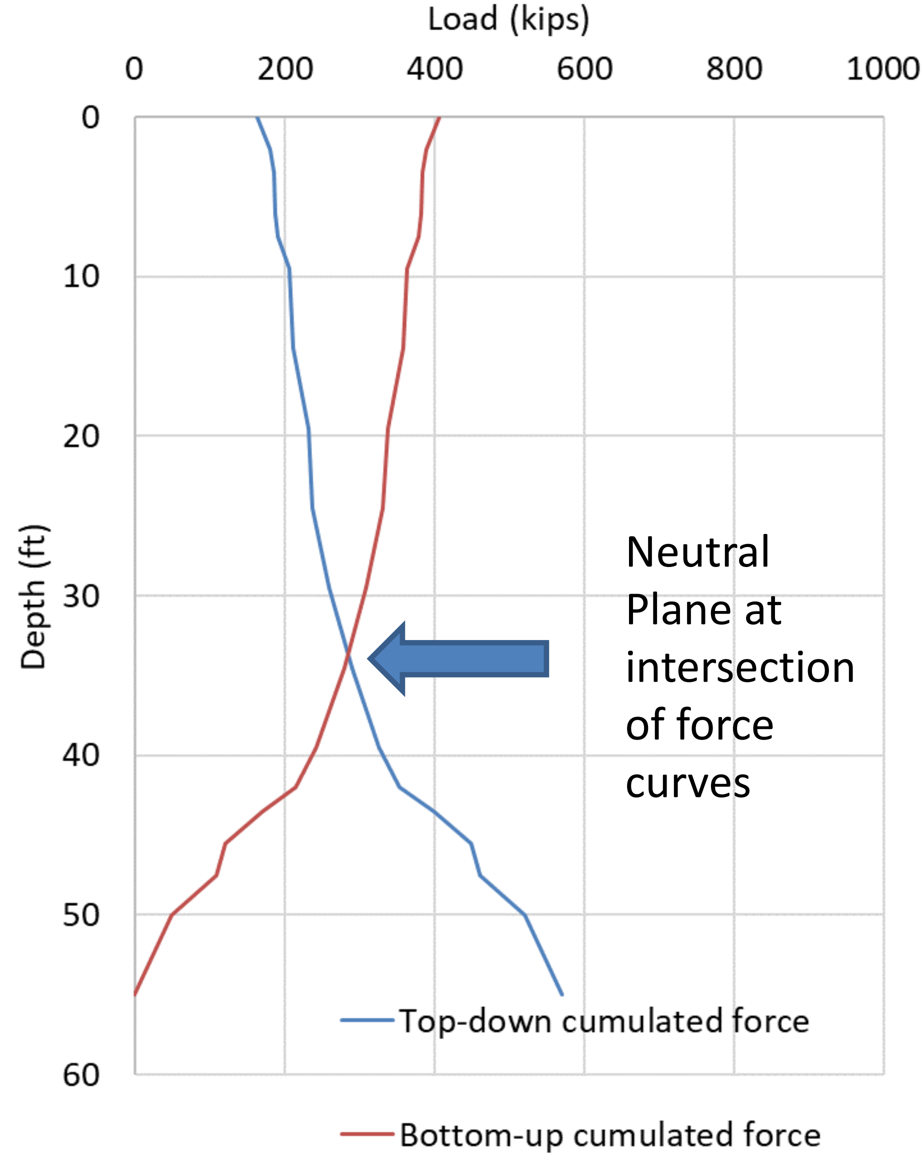
Computing Downdrag

Neutral Plane Method

- Cumulate side shear from bottom up added to an assumed Q_p
- Range of possible neutral plane locations from

  $Q_p = 0$ to $Q_p = Q_{ult}$

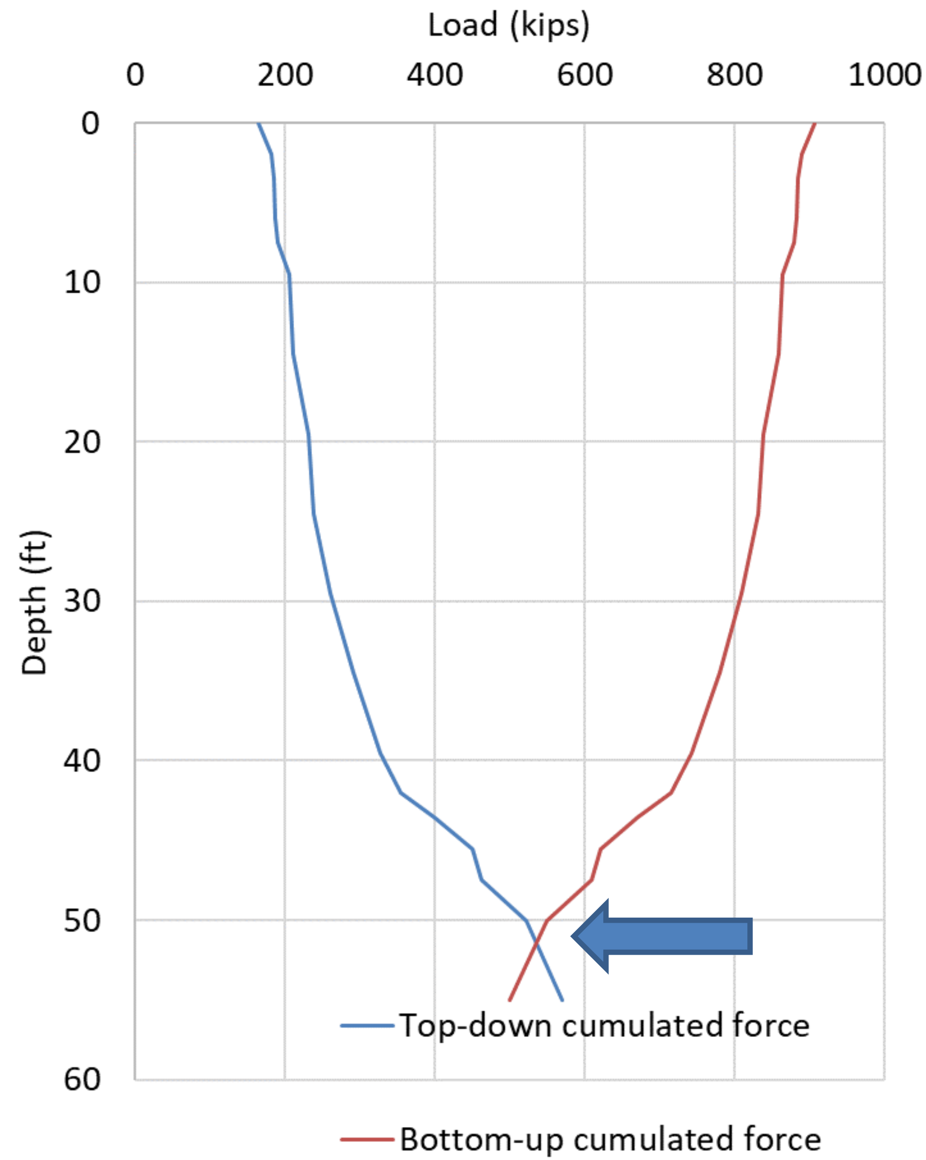
- When $Q_p = 0$
  - NP at 34ft
  - Max pile force 280k



Computing Downdrag

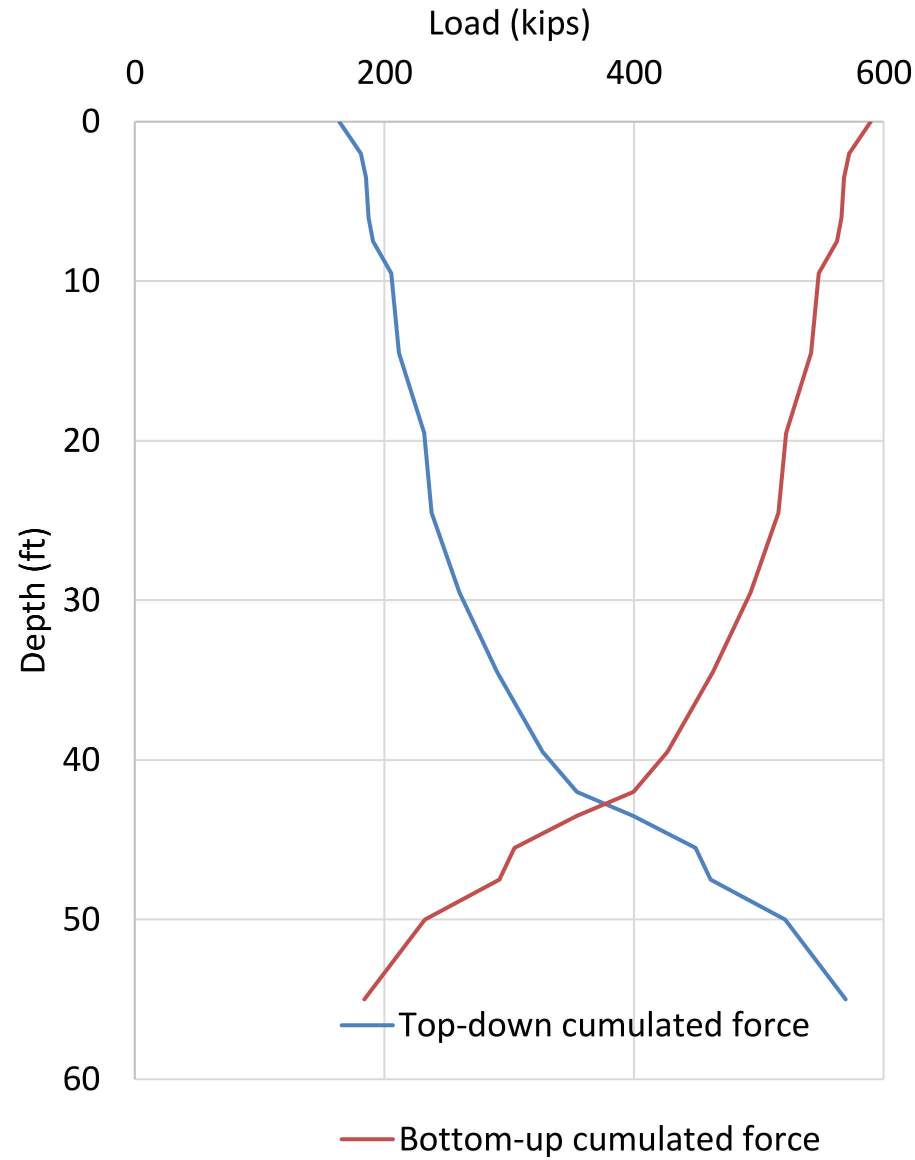
Neutral Plane Method

- When $Q_p = Q_{ult}$ (500k)
- NP at 52ft, 4ft above tip
- Max force 521k
- Top of pile force 164k
- NP at tip gives highest structural load in pile (worst case) but which may never exist
- Pile must pass this structural load



Computing Downdrag

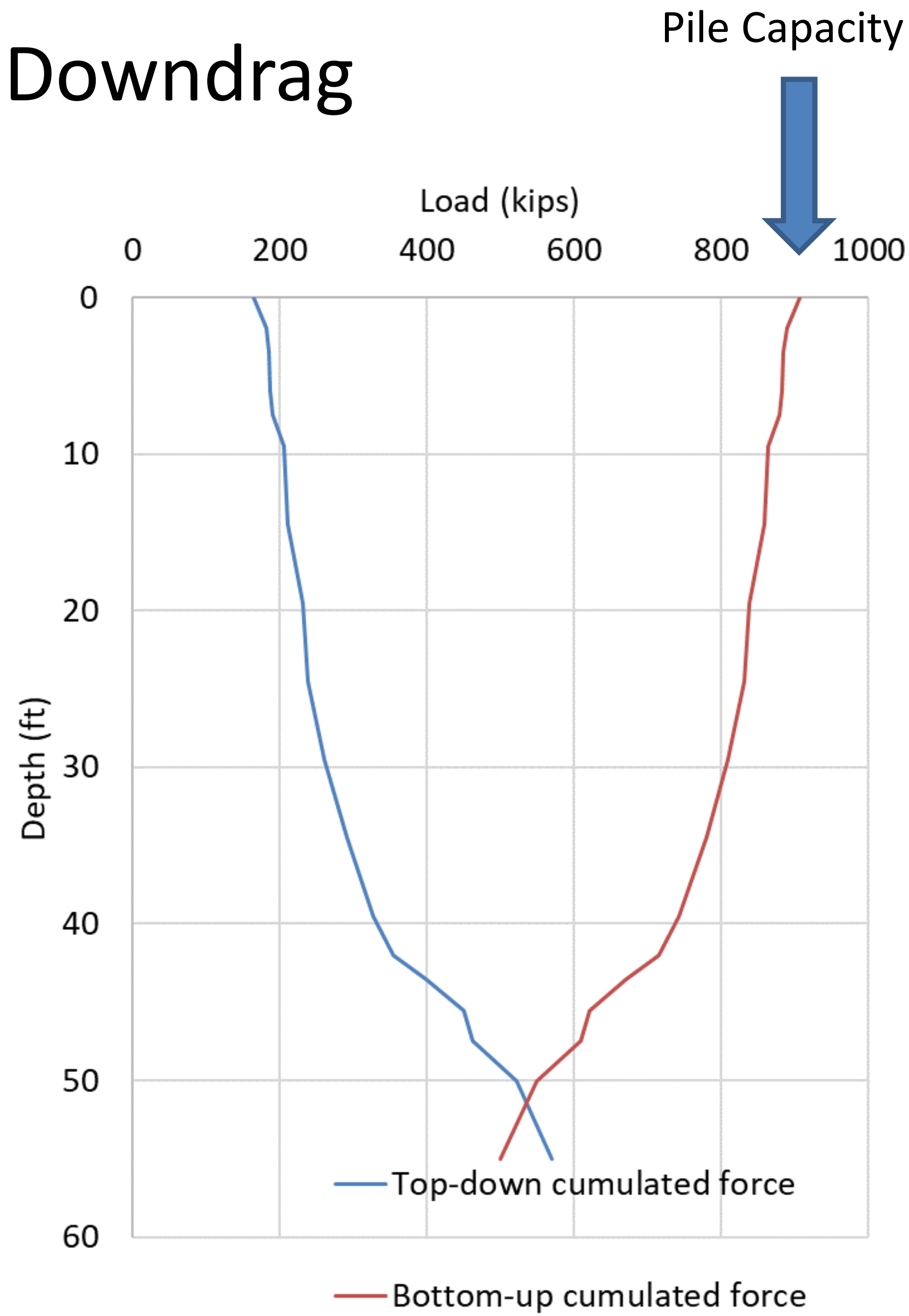
- True NP at 43ft from Briaud and Tucker method above
- Q_p = 183k
- Max structural load 354k (not 521k)
- Top of pile force 164k



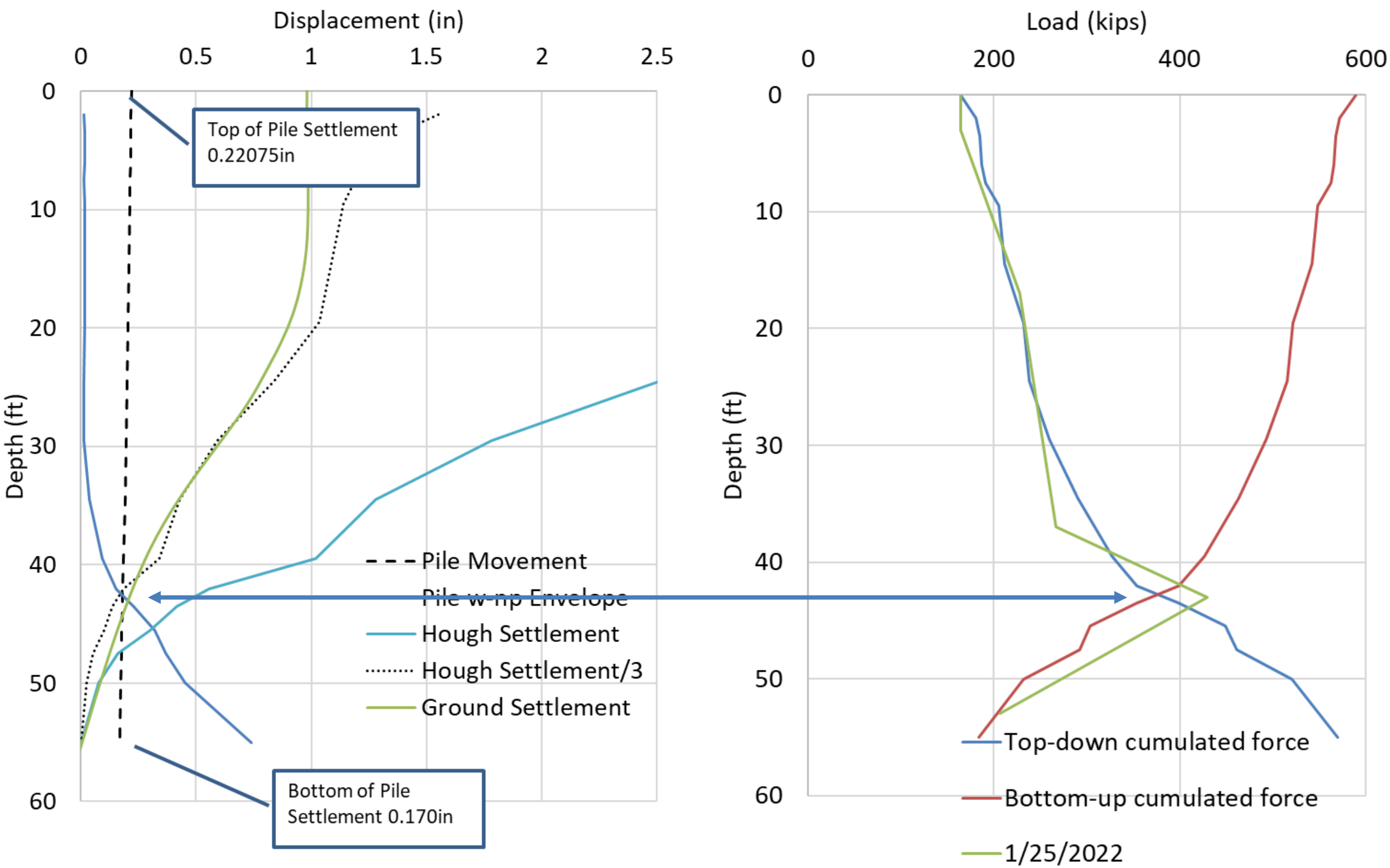
Computing Downdrag

Neutral Plane Method

- Assumes geotechnical strength limit state can use all side shear and end bearing to resist structure loads
- No consideration for the amount of pile movement for reversal to occur



Computing Downdrag



Briaud and Tucker predicted neutral point (left) Field measured neutral point (right)

SDG 2023

- Section 3.5.6 (Piles)
  - Downdrag = (1.5 to 2.0)R_{dd} – LL ≈ 1.75R_{dd} – LL
  - (Factored Design Load + Net Scour Resistance + Downdrag) / Ø < Rn
    - $1.25DL + 1.75LL$ + scour + $1.75Rdd$ – LL ≤ $\emptyset\ NBR$
    - $1.25DL + 0.75LL$ + scour + $1.75Rdd$ ≤ $\emptyset\ NBR$
- Section 3.6.3 (Shafts)
  - Downdrag = R_{dd} – LL
  - Factored Design Load + Downdrag) / Ø < Rn

SFH 2021

- Appendix C
  - Downdrag = R_{dd} + (Driving Resistance to R_{dd})
  - Factored Design Load + Net Scour Resistance + Downdrag) / Ø < Rn

Nominal Bearing Resistance

DD shou... oad case

NBR wou...

1.25... $\leq \ \emptyset\, NBR$

$1.25DL$ + ... $our \leq \ \emptyset\, NBR$

$$\frac{1.25DL + 1.75LL}{\emptyset} \leq \ NBR$$

$$\frac{1.25(169) + 1.75(85)}{0.65} \leq 554$$

$$or$$

$$\frac{1.25DL + 1.75LL + 1.25DD}{\emptyset} \leq \ NBR$$

$$\frac{1.25(169) + 0.5(85) + 1.25\ (261)}{0.65} \leq 892$$

Paseo Al Mar load cases

Present Design Eqn.

0.5 f... % *(27%avg)* LL transferred to the location of peak pile force (1.75*0.27= 0.47)

Conclusions

- Downdrag is significant and should be computed for most embankment designs; let the numbers in new load case decide if to ignore
- Live loads are not large enough to reverse side shear and offset downdrag; 21-33% of LL was shown to add to the total pile load
- AASHTO does not have a DD load factor for sand
- This project showed the measured to predicted ratio to be 1.26 to 1.5; Seigel suggested 1.25 which might be reasonable until enough case studies are identified.

Conclusions

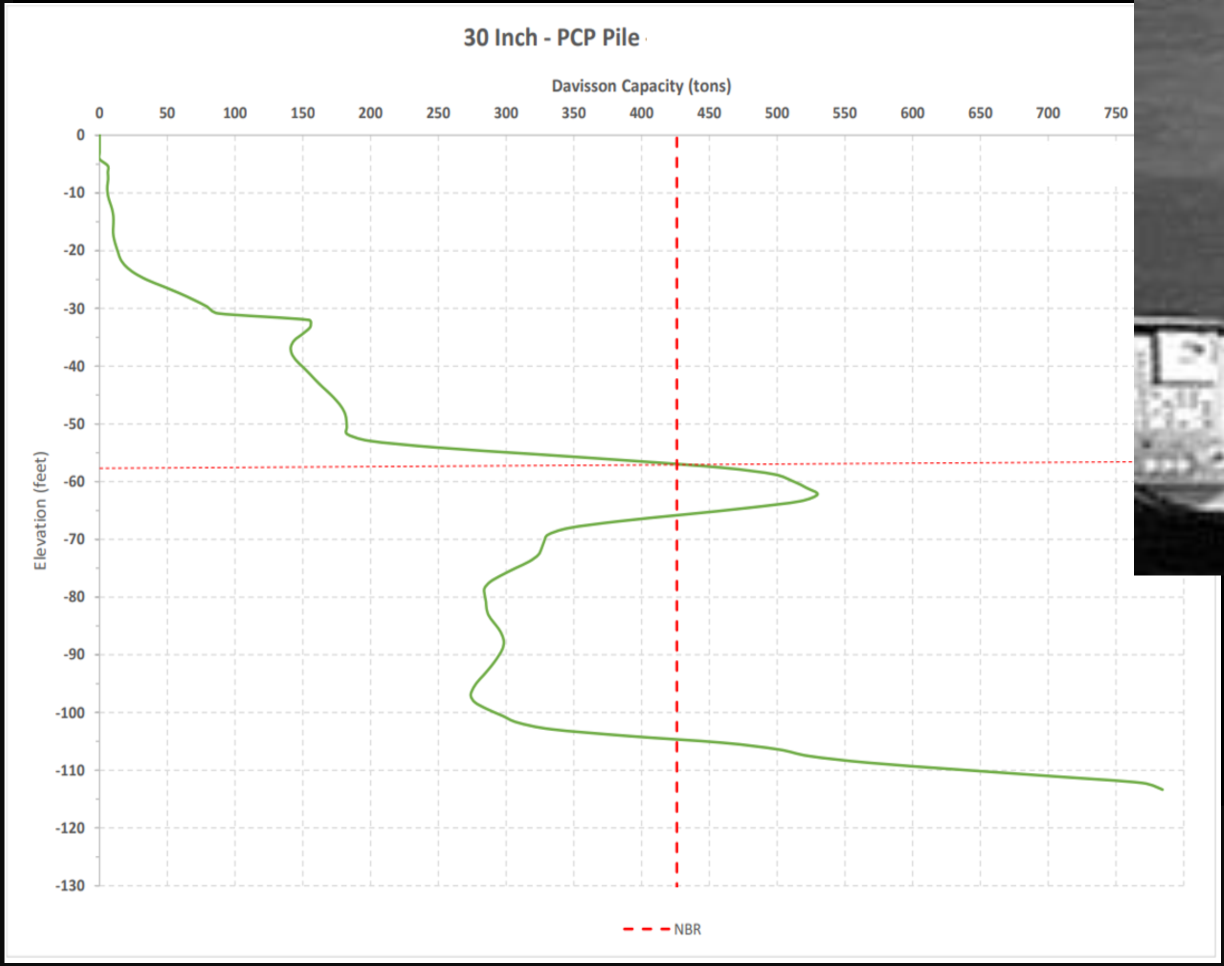
- Settlement around piles is not the same as predicted by calculations at the edge of an embankment
- Presence of piles acts as soil reinforcement and alters settlement response
- It is not just a small amount of downward pile movement to reverse side shear direction. Rather, the effect of soil reinforcement suggests it could take inches not just fractions of an inch
- The piles in this study all failed current design equation but are likely to be ok given good bearing below the tip

Conclusions

- Neutral plane method is reasonable in concept, but actual reversal displacement should be verified and only plausible where there are no indications of weaker soils beneath

Danger Will Robinson

Computing ultimate capacity assuming side shear reversal may push pile into an unsafe condition



Recommendations

- The 0.5in relative movement criterion should be dropped; this study and others suggest less than 0.1in can develop full side shear. Downdrag is presently underestimated. Example:
  - Predicted R_{dd} was calculated to be 130k at Sandridge Rd
  - Applying the 0.5in criterion, R_{dd} drops to 30K
  - Measured R_{dd} was 200K
- Recommend Briaud and Tucker method to determine NP and DD forces
- Drop DD from present design equation with 1.25DL and 1.75LL
- Add 2nd geotechnical load case

$$1.25DL + 0.5LL + 1.25DD + net\ scour \leq \ \emptyset\ NBR$$

Paseo Al Mar Blvd


Sandridge Rd


Final Report
HENLEYRD
MAR 05, 2023 14:00 300K


This week
HENLEYRD
AUG 15, 2023 15:00 298K

Acknowledgments

- CSD Manufacturing
- EXP U.S. Services Inc.
- FDOT District Engineers
- FDOT Project Manager and Reviewers
- FDOT SMO Drill Crew
- FGE, LLC
- GRL Engineers, Inc.
- HNTB Corporation
- Prince Construction
- SACYR Construccion
- Southern Concrete Products
- Graduate Research Team

Questions