Empirically Based Design of Driven Piles in Expansive Soils

- CLAYTON SIGNOR, MSE, MBA, PRESIDENT OF TEXAS PILE, LLC

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By: Clayton Signor, MSE, MBA, President of Texas Pile, LLC

Clayton Signor, Texas Pile, LLC President/Owner

Education

- ★ Master of Business Administration, The University of Texas at Austin, 2017
- ★ Master of Science, Geotechnical Engineering, The University of Texas at Austin, 2011
  - – Master Thesis: Driven Piles in Central Texas Expansive Soils (2011)
- ★ Master of Engineering, Construction Management, Vanderbilt University, 2006
- ★ Bachelor of Engineering, Civil Engineering, Vanderbilt University, 2005

Experience

- ★ Texas Pile, LLC: President, Owner – Jan 2020 to Present
- ★ TX Pile, LLC: Vice President, Member – Jan 2011 to Dec 2019
- ★ Signor Enterprises, LP: Vice President of Operations – Sept 2007 to Dec 2011

★ Deep Foundation Institute: Driven Pile Committee Chair, 2013

★ Pile Driving Contractors Association: Technical Committee Co-Chair, 2024 to present

Pre-production pile test programs were performed on four sites along the Taylor/Navarro geologic formation ranging from western San Antonio to Jarrell, Texas, approximately 150 miles apart. The geological conditions consisted of over-consolidated, highly expansive, stiff fat clay soil. The test programs consisted of performing dynamic testing during initial drive and during restrikes after a 7-day wait period along with a static load test. Test results were used/correlated to establish the pile design for foundation pile layout. Two of the four sites have had piles installed already, 3700 in total, whereas the other two sites are planned to begin in 2025 and 2026 with a combined pile count of 3000 to 4000 piles. The two completed sites had over 110 production piles dynamically tested during initial drive and restrike of 3+ days to establish driving criteria for each building pad. The purpose of this presentation is to provide a guide for driven pile design in highly expansive clay soils based off these test results and installation experience. The ultimate capacities, unit skin friction, end bearing pressure, soil set up rates, plastic soil dampening factors, and WEAP production matching will be included. It will also provide recommendations for soil analysis, expansive force assumptions, WEAP analysis, pre-production & production pile tests, pile design, driving criteria, inspection guidelines, and accommodating for variability in local soil conditions. This empirically based design was implemented on a fifth site in San Marcos and will be discussed in detail.

Part 1: Background (5 Minutes)

- Application in expansive soils is a highly successful use of driven pipe piles because of the small diameter resulting in less uplift forces. Small diameter piles have been tested to support much higher capacities than static soil analysis: San Marcos Z-Modular - 36 kips from geotechnical recommendation vs 338 kips static load test

Part 2: Empirical Data (15 Minutes)

- Empirical data from 4 locations ranging 150 miles using the exact same pipe (8 IN sch 40) for the exact same loading conditions (59 kips) in the same geologic formation (Taylor/Navarro). Over 3700 piles have been driven for 2 of these locations (5 to 6 month total schedule) and 1900+ piles on a third for Summer 2025 (planned 2 to 3 month schedule).

Part 3: Empirically Based Design (10 Minutes)

- Design derived from 7 statically tested piles and 138 dynamically tested piles during pre-production and production.

Part 4: Case Study – San Marcos Development (15 Minutes)

- Empirically based design implemented for a different developer for three tilt-wall warehouses using 673 pipe piles (4 week schedule) for 82.5 and 100 kip design loads.

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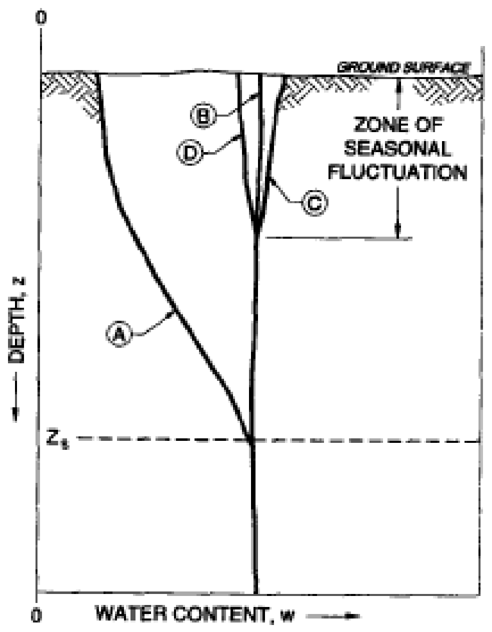
BACKGROUND

Highly expansive smectite/montmorillonite clay combined with inconsistent and intense weather events, along with local considerations (drainage, vegetation, etc.) cause movement in soil and slab failures.



Idealized Water Content Profile (Nelson, et al. 2001)

Expansive Soils

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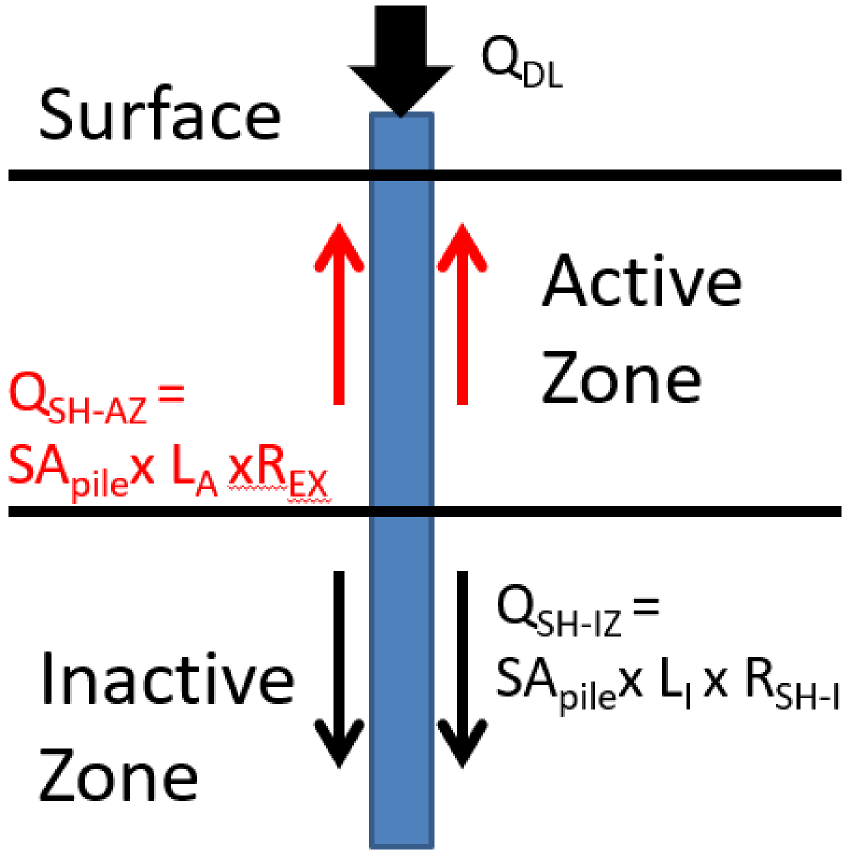
- Soil in the active zone exerts an upward load along driven piles
- Embedment depth should be based on shaft resistance below active zone to overcome upward loads
- Upward loads are reduced by the deadweight of the superstructure
- Embedment depth =

$$L_{I-Wet} = \frac{SA_{pile} \text{ x } L_A \text{ x } R_{EX} - Q_{DL}}{SA_{pile} \text{ x } R_{SH-I}{}^{F}}$$



Wet Conditions

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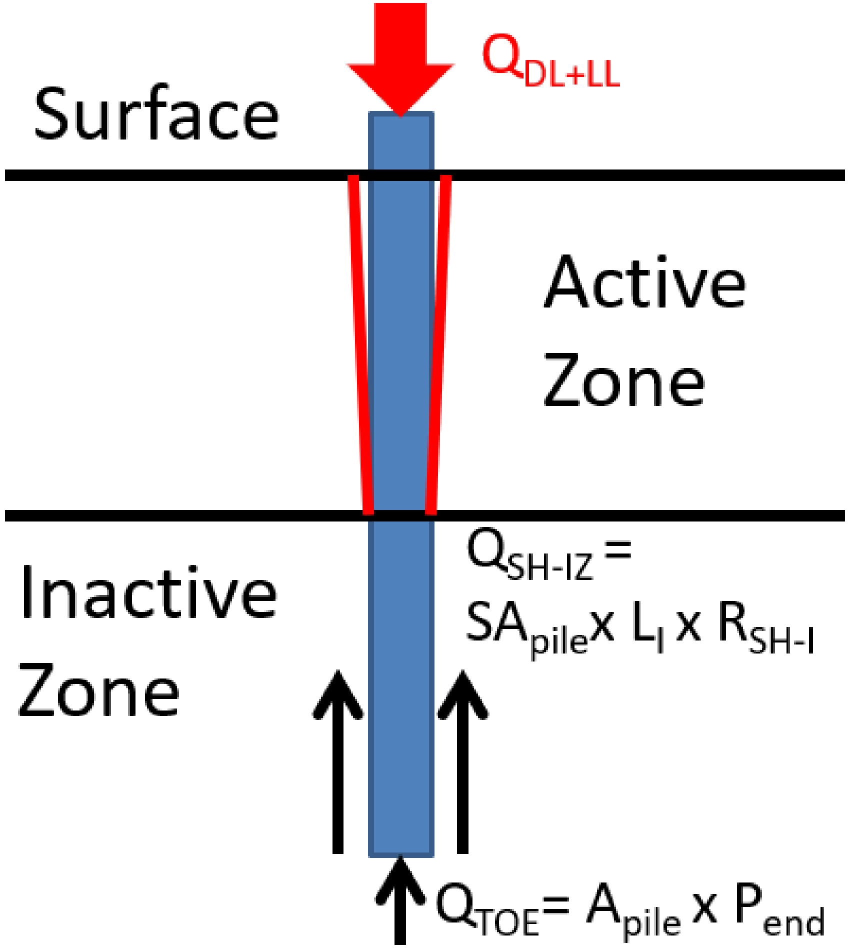
Dry Conditions

- Soil in the active zone completely separates from the driven pile
- Embedment depth should be based on length of pile to bear all structural loads below active zone
- Embedment depth =

$$L_{I-Dry} = \frac{Q_{DL+LL} - A_{pile} \text{ x } P_{end}{}^{F}}{SA_{pile} \text{ x } R_{SH-I}{}^{F}}$$



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Dynamic Load Testing (DLT)

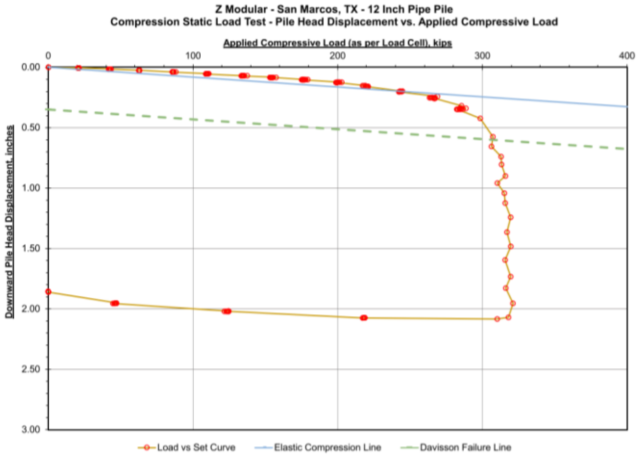
High Strain Dynamic Load Test – ASTM D4945

- Use strain gauges and accelerometer to measure the energy wave produced by an impact hammer and recorded with a Pile Driving Analyzer (PDA).
- Signal Matching (CAPWAP) is used as a rigorous analysis for dynamically tested piles.
- Results include ultimate capacity, shaft resistance by depth, toe capacity, driving stresses, and hammer energy.

Static Load Test – ASTM D1143

- Use reaction piles and beam to resist a loading cell that directly loads the test pile.
- Quick Test loads the pile in 5-10% increments of anticipated failure load for 4-minute intervals while recording displacements.
- Failure is typically reached at 2 inches of total pile displacement.
- Loading cell incrementally reduces load to zero to determine the rebound curve.
- Load v Settlement plots are compared to Davisson's Criterion. Example shown on the right.

Static Load Testing (SLT)



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Pile Testing

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SOIL DAMPING AND RATE DEPENDENT SOIL STRENGTH CHANGES DUE TO IMPACT AND RAPID LOADS ON DEEP FOUNDATIONS

- Authored by Frank Rausche PHD PE, Patrick Hannigan PE, Camilo Alvarez PE
- For certain plastic soils, it has been found that the static resistance derived by analysis from the dynamic test may not completely account for the fact that quickly loaded materials exhibit a strength greater than a slowly loaded material.
- Recommendations are given aimed at both reducing the possibility of overestimations of capacity and the need for accurately knowing the soil characteristics near the location of the dynamically tested foundation.
- https://www.grlengineers.com/wp-content/uploads/2022/09/Soil-damping-and-rate-effects-conf-submittal-1.pdf

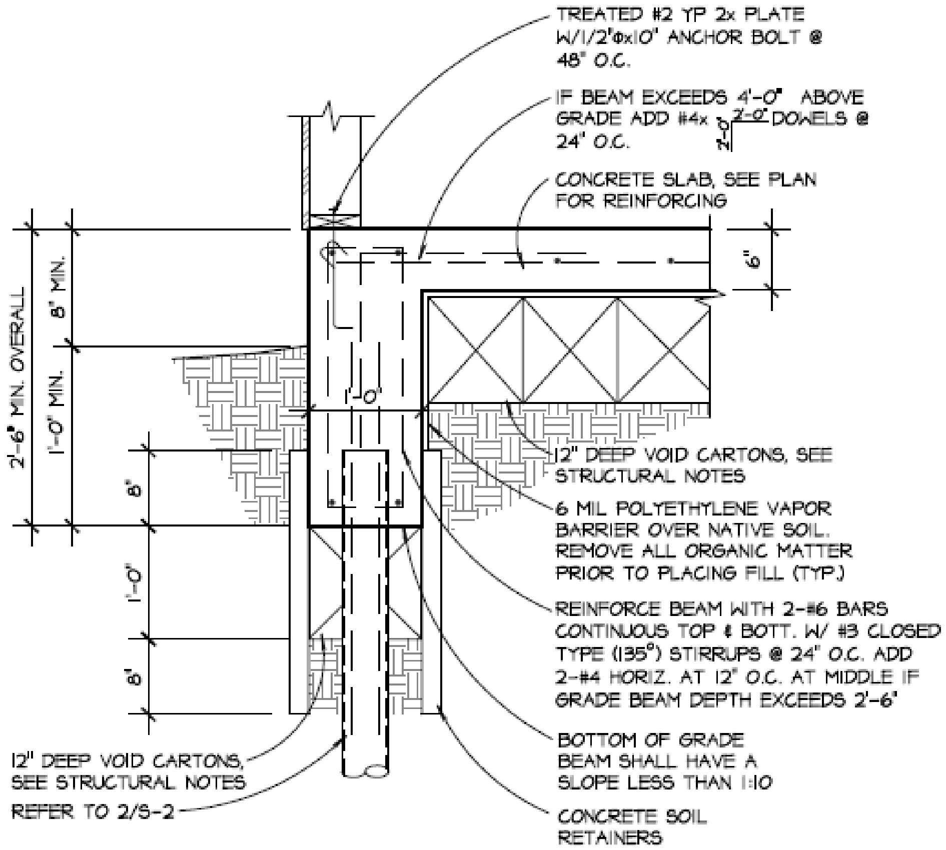
Initial Unit Skin Friction (ksf)		Taylor - 12 FT Active				Del Rio - 15 FT Active	CL - 7 FT Active: Webberville	CH - 10 FT Active: Webberville	
		Manor 6-5/8"	Manor HP10x42	San Marcos 7-5/8"	San Marcos 8" Conc	Tarry Town 7-5/8"	7-5/8"	7-5/8"	12-3/4"
Active Zone	Max	4.37	3.88	3.77	1.57	3.95	0.45	1.12	1.41
	Min	1.98	0.94	0.60	0.00	0.00	0.08	0.37	0.67
	Average	3.55	2.41	2.09	0.84	0.84	0.20	0.58	1.17
Inactive Zone	Max	2.62	4.15	3.02	2.86	4.67	0.90	1.38	1.41
	Min	0.58	2.82	2.49	1.01	0.52	0.22	0.72	1.38
	Average	1.40	3.18	2.74	2.27	2.44	0.69	1.06	1.39

Averaged Unit Skin Friction % Increase	Taylor 6-5/8"	Del Rio 7-5/8"			CH	
					7-5/8"	12-3/4"
	D0 to D6	D0 to D5	D5 to D10	D0 to D10	D0 to D17	D0 to D7
Active Zone	14%	10%	10%	22%	70%	32%
Inactive Zone	298%	39%	34%	86%	23%	33%

Unit Skin Friction Values for Initial Driving & Averaged Unit Skin Friction Percent Increase by Zone of Seasonal Moisture Change (Signor 2011)

Unit Skin Friction by Zone & Setup

- Remove and replace with 6" lifts of compacted base (typically maximum of 6 to 10 feet)
- Soil treatment
- Grading and landscaping
- Shallow foundations on remove and replace
  - Post-tensioned slabs
- Deep Foundations
  - Drilled piers installed straight or belled
  - Driven piles (highly under-utilized)
  - Supporting structural slabs: carton form void boxes or crawl space



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Void Box Detail

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Pier & Beam

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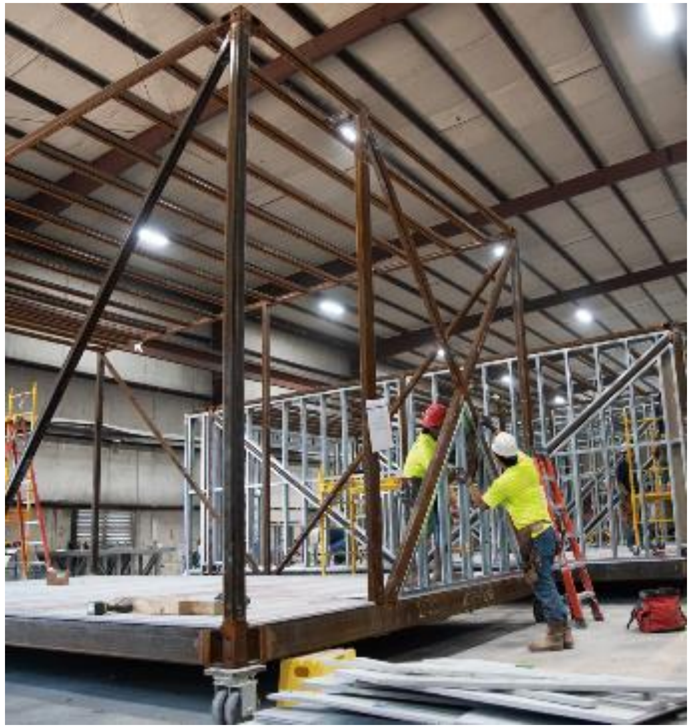
EMPIRICAL DATA

- Proprietor connection piece allows modular units to be pinned to 7+ stories.
- Factory built modular units of 12 FT x 12 FT x 20 to 66 FT.
- Modular units built with tube steel provided by Zekelman Industries (parent company of Z-Modular).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Owner/Contractor: Z Modular

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- Foundation built as pier and beam with relatively light structural loads due to tube steel spans. Exterior grade beams close in the foundation.
- Modular units craned into place once foundation is complete.
- Large reduction of schedule with main structure built off site and during permitting process.

Owner/Contractor: Z Modular

- Largest private manufacture of structural steel (squares, recs & rounds) in North America
- All shapes produced on ERW mills which allows for fast & cost-effective production
- Specific to pipe piles Atlas Tube has supported both the private & public markets; including USACE, Caltrans & DOT's
- In addition to producing pipe piles Atlas Tube offers the following
  - 100% domestic pipe with full traceability
  - Value-Add services such as bevel and plate / point attachment
  - Customs lengths, grades, gauges and project specific rollings
  - Ability to produce over 1,000 tons per shift
  - Ability to deliver by truck, rail or barge

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Supplier: Atlas Tube

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Texas Pile, LLC (formally TX Pile and Signor Enterprises) is based in Austin, Texas and serves Central Texas and surrounding areas for driven piles and marine construction. Over the past several decades, Texas Pile has been exposed to all the local soil conditions (river deposits, expansive soils, fill sites, granite sands, etc.) and driven pile applications (foundation piles, dock piles, soldier pile and timber lagging for shoring, pile and road plate wall for blast walls, light gauge sheet piles for bulkheading and cofferwalls, and large profile sheet piles). Barge supported rigs have been on the Highland Lakes since the early 1980s, building docks and marinas on Lake Austin, Lady Bird Lake, and Lake LBJ, along with barge services for geotechnical investigation and dam stabilization for Lake Travis and Lake Marble Falls.

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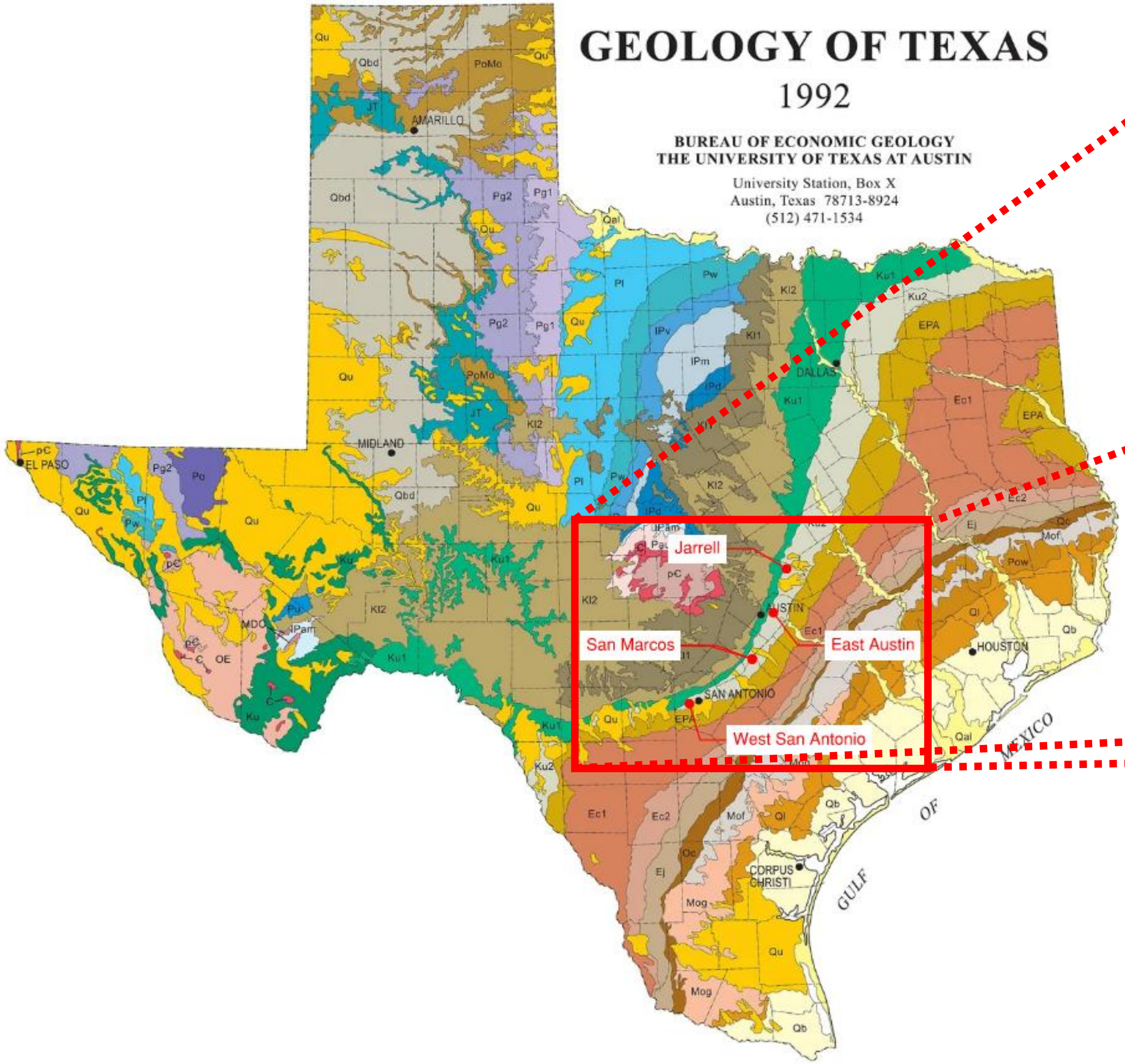

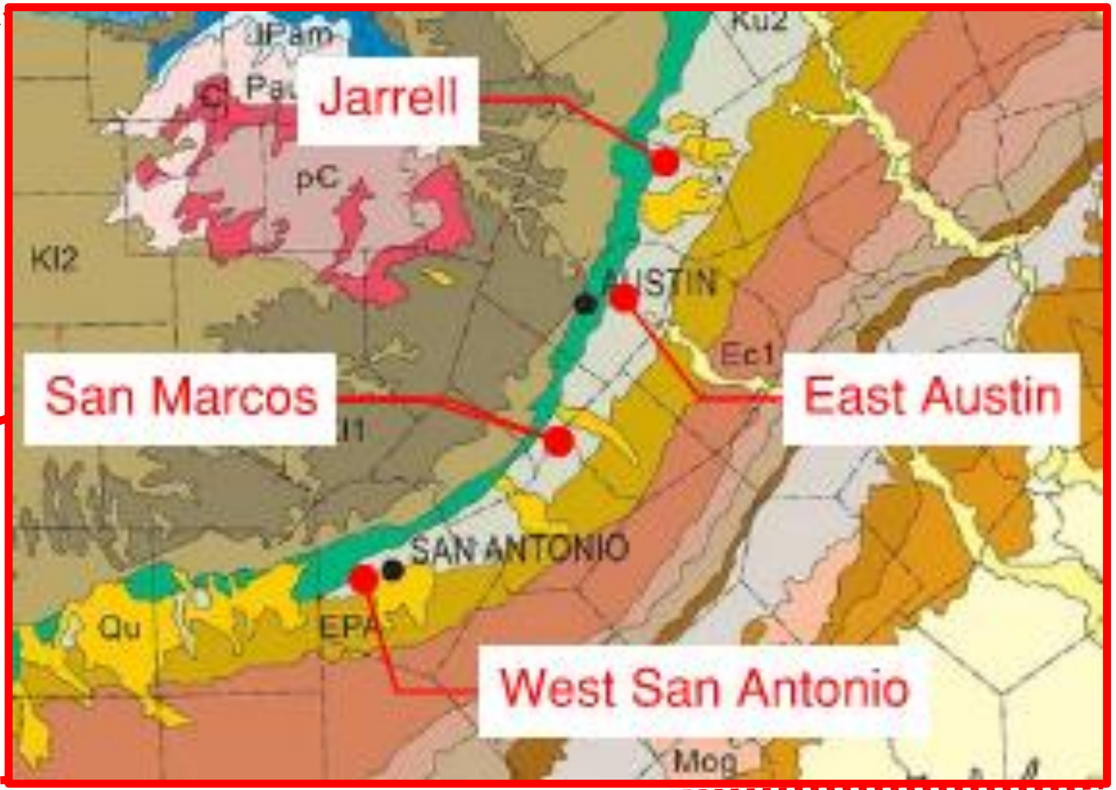

All four locations in the same geologic formation of Navarro and Taylor Groups (Ku2). Late Cretaceous marine deposits.

Locations of Testing Sites

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- San Marcos (Completed Summer 2022)
  - Fat Clays/Lean Clays
  - 8 three-story apartment buildings, 440,000 Sq. Ft.
  - 2051 Piles at 25 Ft. Embedment
- Jarrell (Completed Summer 2023)
  - Heiden and Houston Black,
  - 5 three-story apartment buildings, 279,000 Sq. Ft.
  - 1655 of Piles at 30 to 32 FT Embedment
- East Austin at Decker Lake (Starting Summer of 2025)
  - Taylor Formation, expansive fat/gravelly fat clays
  - 10 three-story apartment buildings, 384,000 Sq. Ft.
  - 1902 Piles w/ Depth to be Determined
- West San Antonio (TBD)
  - Fat Clays/Gravelly Clays
  - 8 three-story apartment buildings, 370,000 Sq. Ft.
  - 1900+ Piles w/ Depth to be Determined

- ALL PILES DESIGNED TO 59,000 POUNDS

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Site Descriptions

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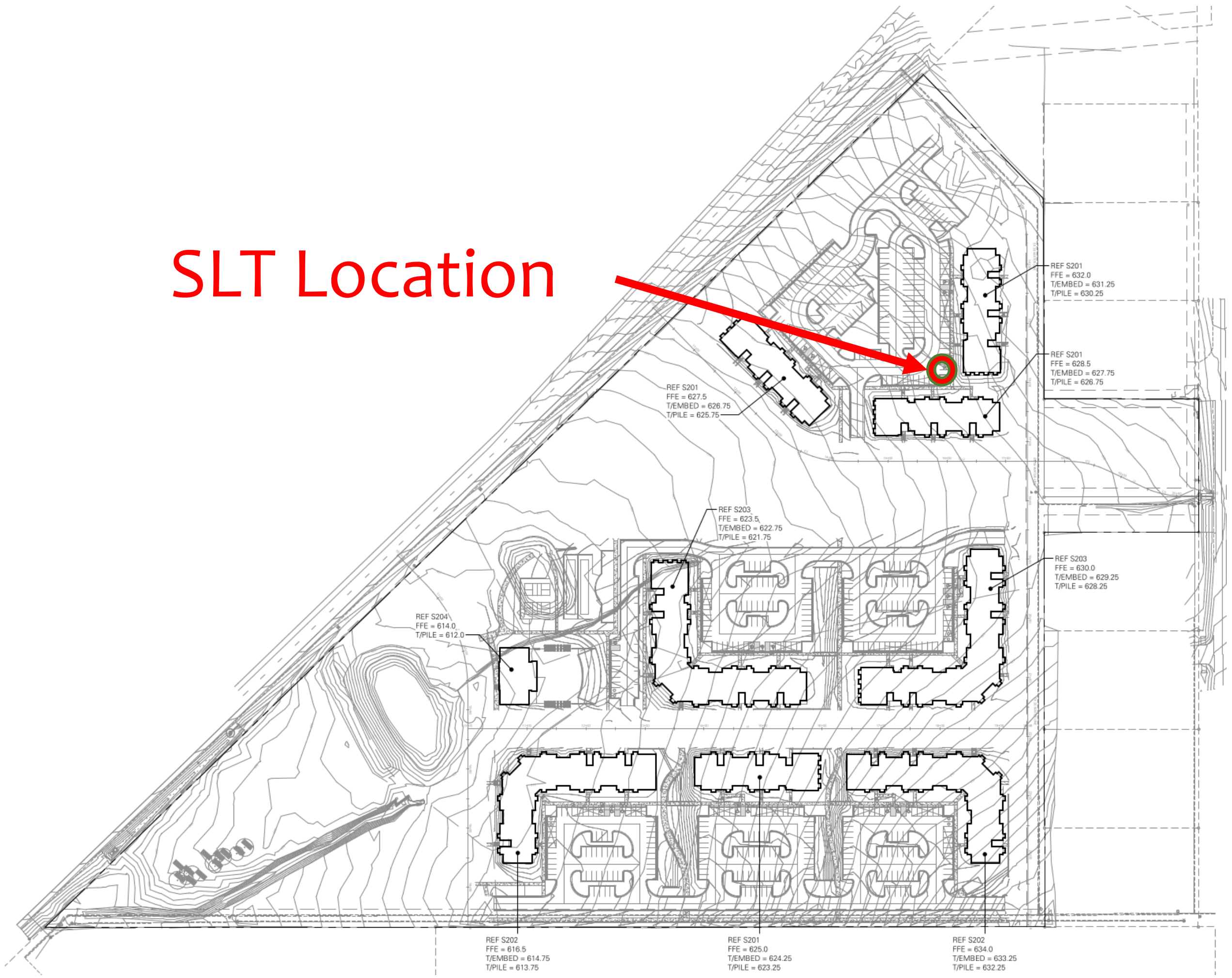

- San Marcos (Completed Summer 2022)
  - Fat & Lean Clays
  - 8 three-story apartment buildings, 440,000 Sq. Ft.
  - 2051 Piles at 25 Ft. Embedment

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Site Descriptions: San Marcos

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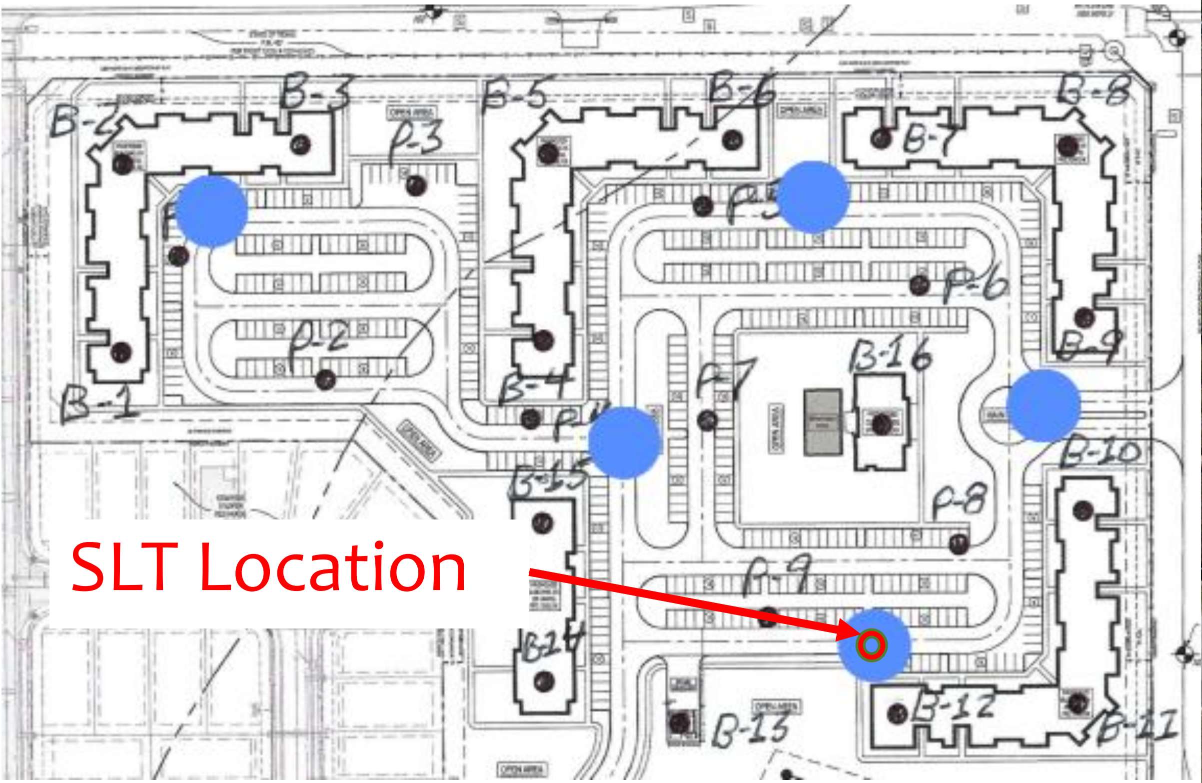

- Jarrell (Completed Summer 2023)
  - Heiden and Houston Black,
  - 5 three-story apartment buildings, 279,000 Sq. Ft.
  - 1655 of Piles at 30 to 32 FT Embedment

Site Descriptions: Jarrell

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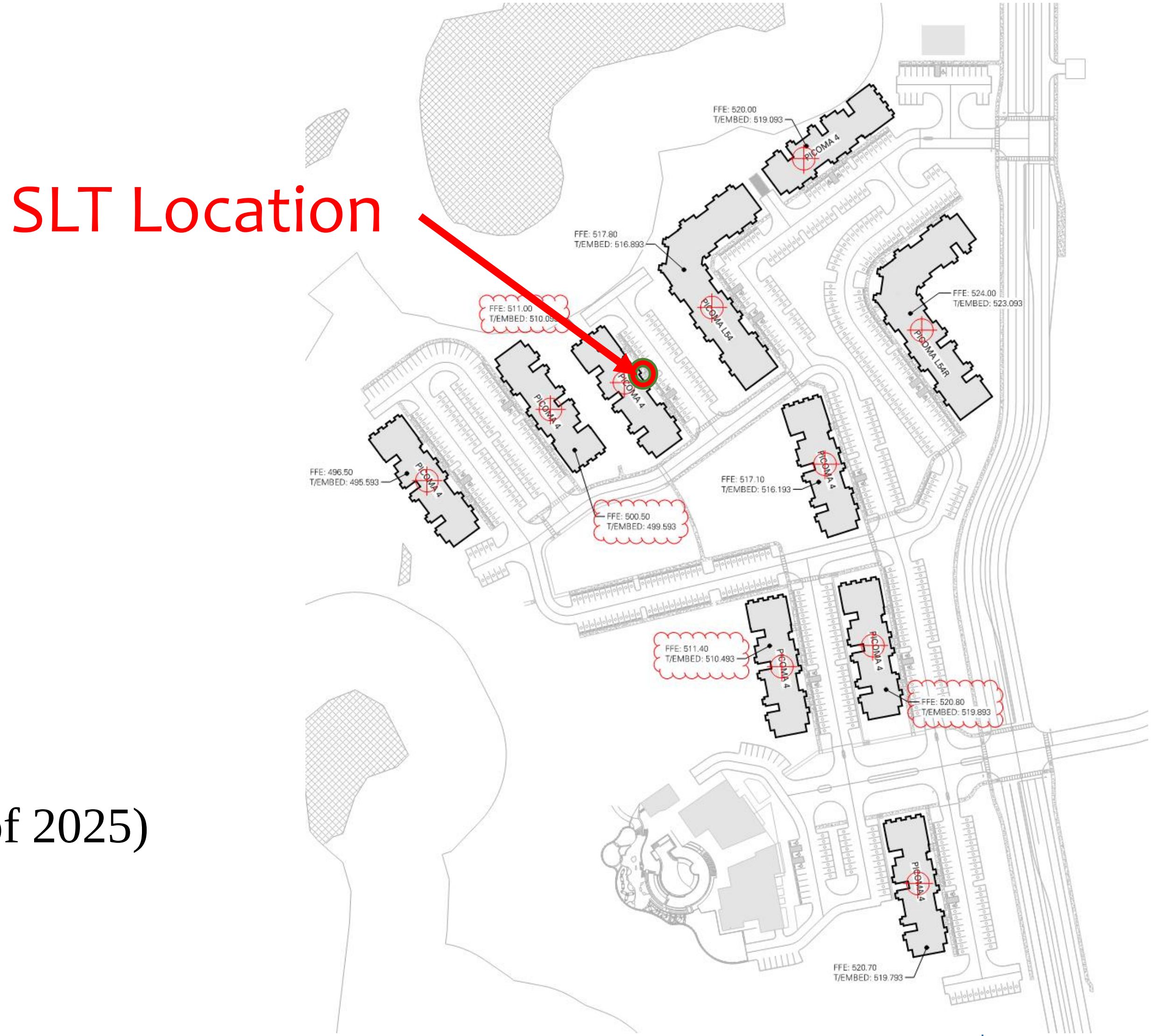

- East Austin at Decker Lake (Starting Summer of 2025)
  - Taylor Formation, expansive fat/gravelly fat clays
  - 10 three-story apartment buildings, 384,000 Sq. Ft.
  - 1902 Piles w/ Depth to be Determined

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Site Descriptions: East Austin

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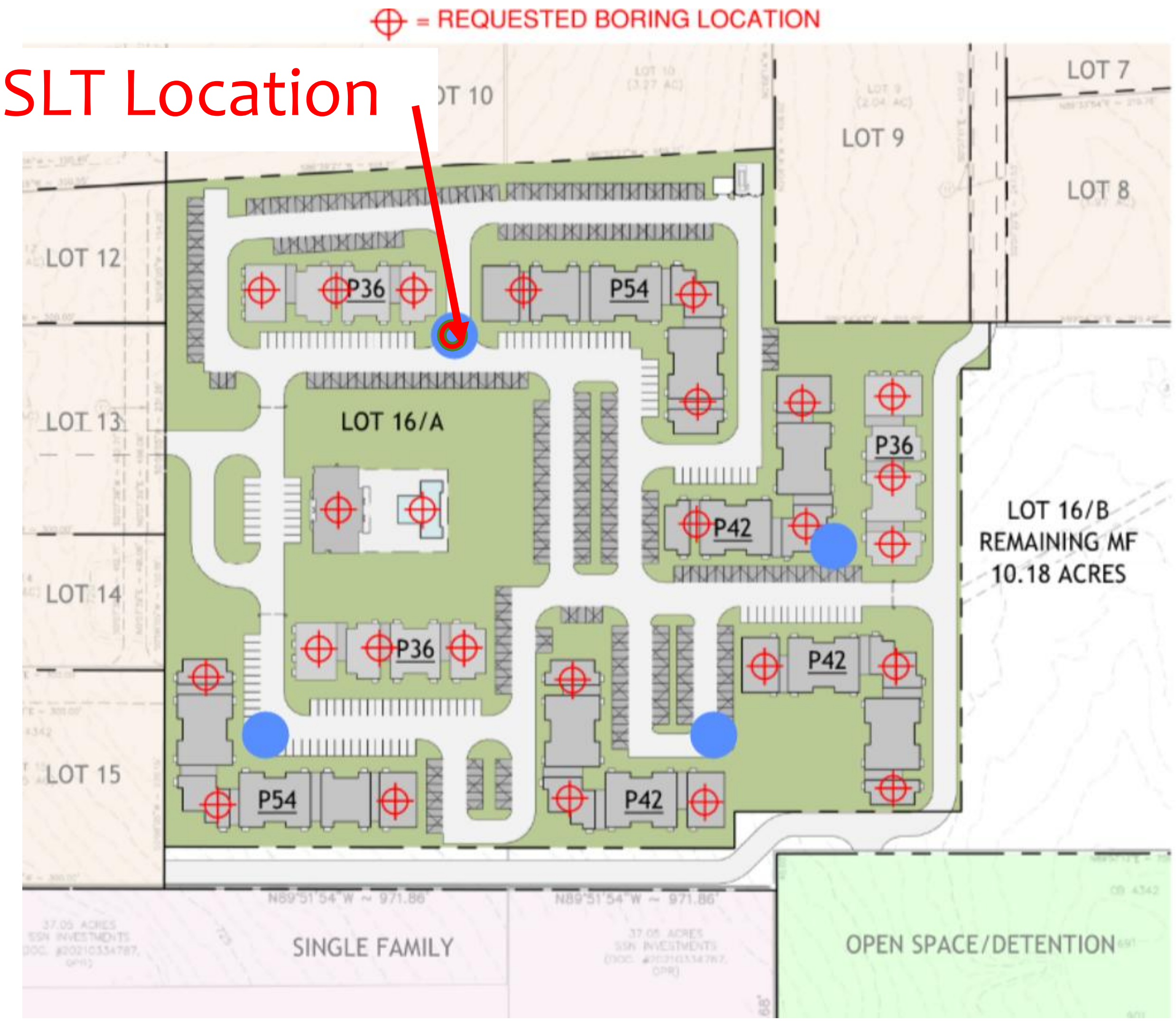

- West San Antonio (TBD)
  - Fat Clays/Gravelly Clays
  - 8 three-story apartment buildings, 370,000 Sq. Ft.
  - 1900+ Piles w/ Depth to be Determined

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Site Descriptions: West San Antonio

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Location		San Marcos		Jarrell			East Austin	West San Antonio
Pipe Diameter		8.625 IN	12.75 IN	8.625 IN	8.625 IN	8.625 IN	8.625 IN	8.625 IN
Pipe Thickness		0.322 IN	0.375 IN	0.322 IN	0.322 IN	0.322 IN	0.322 IN	0.322 IN
Depth		30 FT	27 FT	25 FT	25 FT	41 FT	25 FT	25 FT
Open or Closed End		CEP	CEP	CEP	OEP	OEP	OEP	OEP
Units		(kips)	(kips)	(kips)	(kips)	(kips)	(kips)	(kips)
Test Results	Initial: Total	130	290	-	160	210	175	134
	Initial: Toe	70	160	-	40	40	30	25
	Initial: Shaft	60	130	-	120	170	145	109
	One HR	185	335	-	-	-	-	-
	One DAY	255	355	-	-	-	-	-
	Restrike: Total	-	-	-	170	260	260	187
	Restrike: Toe	-	-	-	40	40	30	23
	Restrike: Shaft	-	-	-	130	220	230	164
	Static	338	321	104	117	180	220	136
	187 Days	330	430	-	-	-	-	-

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Static Load v Dynamic Tests

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Location	San Marcos		Jarrell			East Austin	West San Antonio
Pipe Diameter	8.625 IN	12.75 IN	8.625 IN	8.625 IN	8.625 IN	8.625 IN	8.625 IN
Pipe Thickness	0.322 IN	0.375 IN	0.322 IN	0.322 IN	0.322 IN	0.322 IN	0.322 IN
Depth	30 FT	27 FT	25 FT	25 FT	41 FT	25 FT	25 FT
Open or Closed End	CEP	CEP	CEP	OEP	OEP	OEP	OEP
Units	(kips)	(kips)	(kips)	(kips)	(kips)	(kips)	(kips)
Test Results: Static	338	321.2	103.9	116.5	179.8	220	133.6
Test Results: Restrike: Total	348*	377*	-	170	260	260	186.6
Test Results: Restrike: Toe	70*	120	-	40	40	30	22.7
Test Results: Restrike: Shaft	278*	257*	-	130	220	230	163.9
Test Results: Static: Shaft = Static – Restrike: Toe	268	201.2	-	76.5	139.8	190	110.9
Test Results: Dampening Factor = Static: Shaft / Restrike: Shaft	98.3%	78.3%	-	65.7%	77.8%	82.6%	67.7%
	* Extrapolated						

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Dampening Factors

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Dampened (82.6%) Initial Skin Friction (ksf) – East Austin Test Piles												FS	2.00
Depth (FT)	Test Pile #									Avg	Median	Min	Max
	1	2	3	4	5	6	7	8	9	10				
0-10	0.99	0.44	0.73	0.62	0.52	0.52	0.52	0.34	0.34	0.34	0.54	0.52	0.34	0.99
10-15	1.35	1.35	1.88	1.35	1.18	1.20	0.82	0.84	0.83	1.21	1.20	1.20	0.82	1.88
15-20	1.90	1.90	1.90	1.54	1.35	2.00	1.54	2.44	1.90	2.44	1.89	1.90	1.35	2.44
20-25	1.90	1.90	1.90	1.90	1.73	2.17	1.90	2.44	1.90	2.44	2.02	1.90	1.73	2.44

Dampened (82.6%) Restrike Skin Friction (ksf) – East Austin Test Piles												FS	2.00
Depth (FT)	Test Pile #										Avg	Median	Min	Max
	1	2	3	4	5	6	7	8	9	10				
0-10	1.27	0.54	0.83	0.73	0.71	0.62	0.71	0.53	0.34	0.62	0.69	0.66	0.34	1.27
10-15	1.89	2.26	2.44	2.26	1.73	1.73	1.36	1.38	1.58	1.75	1.84	1.74	1.36	2.44
15-20	2.17	2.44	3.26	2.63	2.44	2.63	2.63	3.37	3.18	3.54	2.83	2.63	2.17	3.54
20-25	2.17	3.17	3.26	3.35	2.81	3.35	2.99	4.07	3.53	3.53	3.22	3.31	2.17	4.07

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Unit Skin Friction by Depth (East Austin)

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Depth	Geotech	Initial - Min	Restrike - Min
	ksf	ksf	ksf
0-10	0	0.34	0.34
10-15	0.125	0.82	1.36
15-20	0.7	1.35	2.17
20-25	0.85	1.73	2.17
End (25 FT)	9	73.9	73.9

Recommended vs. Actual Minimum Dampened Allowable Values at East Austin Site

DEPTH (FT)	ALLOWABLE SKIN FRICTION (PSF)	ALLOWABLE END BEARING CAPACITY (PSF)
0 to 6½	Neglect	Neglect
6½ to 15	125	Neglect
15 to 20	700	Neglect
20 to 30	850	9,000
30 to 60	1,300	12,000
60 to 75	1,300	20,000

Driven Pile Recommended Design Values per Geotechnical Engineer of Record at East Austin Site

U_f = 55·d (areas without a reduced PVR building pad)

U_f = 25·d (with building pad prepared for a 1-inch PVR and/or with 6½-foot crawlspace)

Where: U_f = uplift force acting on pier due to expansive soils (kips)

d = outside diameter of pile (feet)

The uplift forces created on the piles due to the expansive soils plus any live loading conditions can be resisted by the dead load on the pile and the weight of the pier. Additional uplift resistance can be achieved using the allowable skin friction values listed above for the portion of the pile below a depth of 15 feet.

Uplift Force

- U_f = 55 x 8.625/12 = 39.5 kips
- Force/SF = 39.5 kips/ (15 ft x 8.625/12 x π) = 39.5 kips/ 15 ft x 2.26 ft = **1.17 ksf**

Geotechnical Unit Skin Friction by Depth

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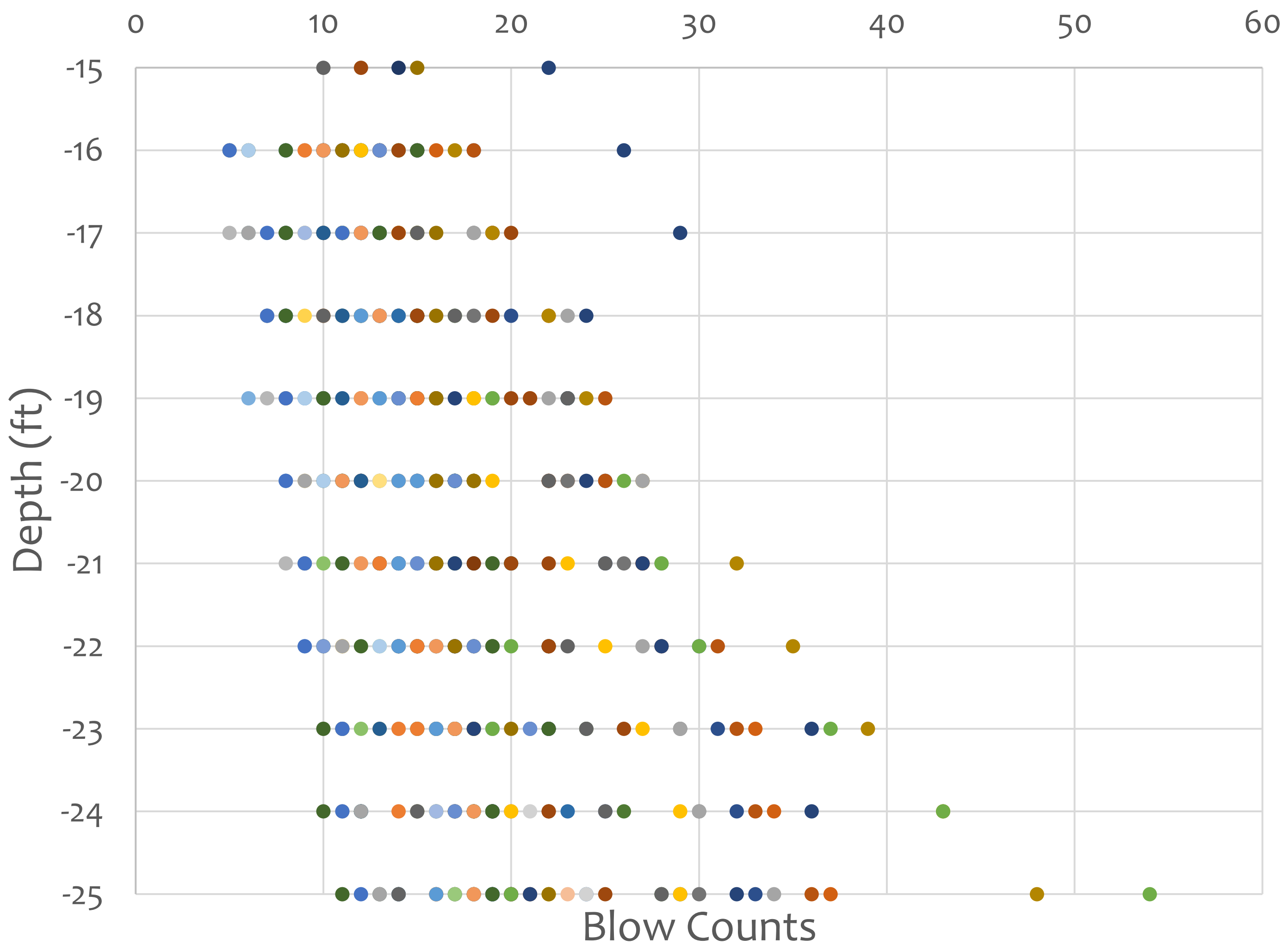
- Blow counts vary by depth on any given project site.
- Soil variability not found in geotechnical soil borings can be proven at each pile by the blow count of blows per foot.



San Marcos Site Range of Blow Counts by Depth

Blow Count by Depth (San Marcos)

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Jarrell – Surface Rock Not Found in Geotechnical Borings.

Variations Not in Geotechnical Report

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Pile Caps

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San Marcos: Test Pile (CEP) vs Reaction (OEP) 12” Piles

- Initial: 290 v 305 kips (15 kips or 5.2%)
- 1-HR: 335 v 375 kips (40 kips or 11.9%)
    - Setup: 116% v 123% (7%)
- 1-Day: 355 v 425 kips (70 kips or 19.7%)
    - Setup: 122% v 139% (17%)
- Set Up is higher for OEP

Jarrell: confirmed observations from San Marcos by driving OEP & CEP at each of the 5 test locations.

- Jarrell – East Test Piles BOR: 150 v 175 kips (25 kips or 16.7%)
- Jarrell – West Test Piles BOR: 195 v 255 kips (60 kips or 30.8%)
- Jarrell – South Test Piles Static Loaded at 25 FT: 105 v 120 kips (15 kips or 14.3%)

Jarrell:

- For all recorded depths open end piles (OEP) had a higher blow count than closed end piles (CEP).
- There was an average of 34% increase in total blows from CEP to OEP for recorded depths.

	Blows per Depth									
Location	Far West		North		West		South		East	
Depth	CEP	OEP*	CEP	OEP*	CEP*	OEP	CEP	OEP*	CEP	OEP*
11	8	12	9	11	7	11	6	8	6	8
12	9	12	10	11	7	11	5	9	5	8
13	10	13	14	13	8	12	5	9	5	8
14	11	14	13	13	10	14	5	11	6	9
15	12	16	13	14	13	14	5	12	7	10
16	13	21	14	17	15	16	6	14	8	11
17	15	21	15	18	17	18	6	15	9	12
18	16	19	16	20	17	18	8	15	10	14
19	16	21	17	22	17	20	10	17	10	13
20	17	21	19	25	18	20	10	17	11	14
21	18	22	21	26	17	20	11	17	11	14
22	18	25	21	28	20	21	13	20	13	16
23	22	25	23	28	20	23	13	20	14	16
24	23	29	23	29	21	25	13	20	15	17
25	23	29	25	29	24	27	16	23	16	20
TOTAL	231	300	253	304	231	270	132	227	146	190

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Closed End v Open End Piles

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- Soil plugs were observed in all open-ended pipe piles
- East Austin measured soil plugs – plugs varied from 8.2 to 14.4 FT thick with no seen correlation between capacity and plug thickness

Soil Plugs

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Depth	Shaft (ksf)	End (ksf)
0.0	1.6	35.5
10.0	5.0	35.5
20.0	5.0	75.0
30.0	5.0	75.0

San Marcos – GRLWEAP Production Match for Future Use

GRL ENGINEERS, INC 9/12/2022

DICEP 2022 GRLWEAP 14.1.19.2

Gain/Loss 1 at Shaft and Toe 0.500/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str. ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	28.3	13.9	14.4	3.1	25.22	0.44	3.00	22.4	HH 3600
10.0	51.7	37.3	14.4	5.9	25.56	0.83	3.00	22.6	HH 3600
15.0	87.9	65.5	22.4	9.8	29.49	1.51	3.00	22.5	HH 3600
20.0	124.2	93.8	30.4	13.8	37.85	1.75	3.00	22.4	HH 3600
25.0	152.4	122.0	30.4	17.3	44.02	1.52	3.00	22.2	HH 3600
30.0	180.6	150.2	30.4	21.4	49.15	0.78	3.00	22.1	HH 3600

Total Number of Blows: 89 (starting at penetration 5.0 ft)

Driving Time(min):	2	2	1	1	1	1	0	0	0	0
@Blow Rate:	30	40	50	60	70	80	90	100	110	120

Driving Time for continuously running hammer; any wait time not included.

Gain/Loss 2 at Shaft and Toe 1.000/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str. ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	42.1	27.7	14.4	4.8	25.17	0.79	3.00	22.5	HH 3600
10.0	89.0	74.6	14.4	10.0	30.06	1.82	3.00	22.5	HH 3600
15.0	153.5	131.1	22.4	17.0	44.04	3.41	3.00	22.2	HH 3600
20.0	217.9	187.5	30.4	26.7	52.55	3.86	3.00	21.6	HH 3600
25.0	274.4	244.0	30.4	40.4	59.34	3.21	3.00	21.2	HH 3600
30.0	330.8	300.4	30.4	65.6	63.63	1.36	3.00	20.9	HH 3600

Total Number of Blows: 197 (starting at penetration 5.0 ft)

Driving Time(min):	6	4	3	3	2	2	2	1	1	1
@Blow Rate:	30	40	50	60	70	80	90	100	110	120

Driving Time for continuously running hammer; any wait time not included.

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GRLWEAP – Production Match

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- Ultimate Static Load: for 25 FT depth ranged from 105 to 220 kips with factors of safety of 1.78 to 3.72 kips for a design load of 59 kips.
- Dampening Effect: observed as low as 66% but typically around 80%.
- Unit Skin Friction: actual minimum dampened initial and restrike values were 2 to 3 times more than geotechnical engineer values for the East Austin site.
- End Bearing Pressure: actual minimum value was 8 times more than geotechnical engineer values for the East Austin site.
- End plates: reduce pile capacity and decrease pile resistance. Cost of more than $100 per pile each, removing them from Jarrell saved the owner over $165,000 plus headaches of extra coordination.
- Soil plugs: observed in all open end piles ranging from 8 to 14 FT thick.
- GRLWEAP Production Match: San Marcos unit skin friction values when factored are similar to East Austin's at 2 ksf.

Empirical Data Conclusions

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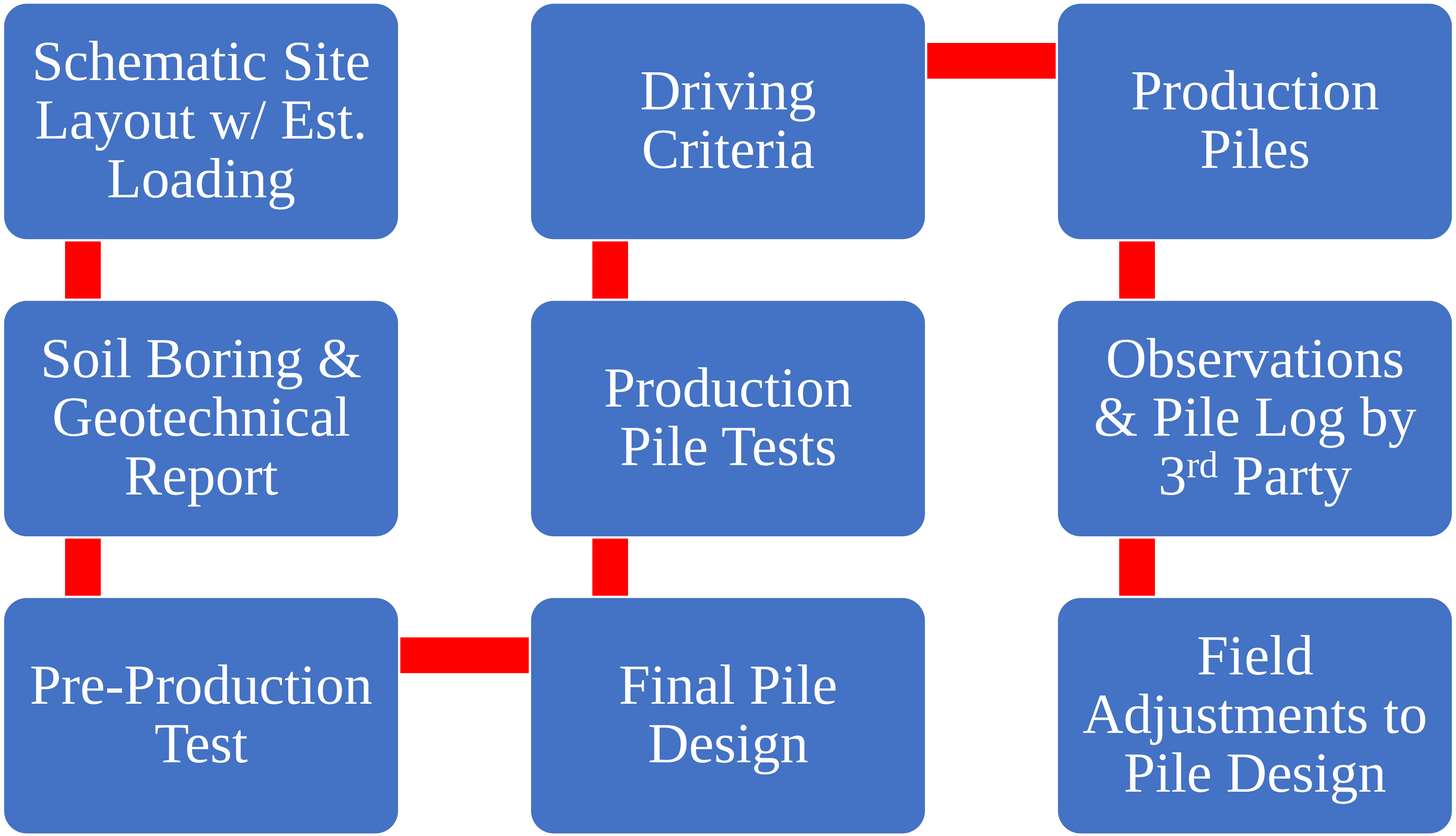
EMPIRICALLY BASED DESIGN



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Design Overview

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- Building layout on site
- Grading plan to determine cut/fill
- Load schedule by building
    - Max/min loads
    - Site specific loading
- Pile groups

Schematic Site Layout w/ Est. Loading

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- Information on Borings: soil types, soil reactivity, standard penetration test (no Pocket Penometer), and laboratory tests (plasticity limit & shear strength).
- Estimated Expansive Forces & Active Zone Depth
- Deep Foundation Recommendations
  - Historical Data: Unit Skin Friction and End Bearing Pressure
  - GRLWEAP Analysis
  - Estimated Design Load Table for Various Pile Size and Depths

Why to test? (Cost-Benefit Analysis)

- To confirm historical data when geotechnical recommendations underestimate capacities.
- To decrease factors of safety by reducing the assumptions of soil conditions prior to production driving.
- To confirm drivability of pile type with possible production hammer.
- Owner requirement.

How to test? (Methodology)

- High Strain Dynamic Load Tests:
  - Initial and Restrike piles at 7+ days for pre-production and 3+ days for production tests to determine soil set up.
  - 2 to 4% of total pile count depending on if SLT was performed.
- Static Load Tests:
  - Weakest dynamic test location

Where to test? (Site Profiling)

- Areas of high building load concentration.
- Areas of variable soil conditions.

When to test? (Schedule)

- Pre-Production (Basis of Design): Dynamic pile tests representing a building or group of building & static load test at weakest location.
- During Production (Basis for Driving Criteria): ~ 2-4% of production pile count depending on if static load test was performed.

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Determining Testing Program

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Geotechnical Variables

- Active Zone Depth
- Expansive Force Magnitude
- Unit Skin Frictions & Bearing Pressure
- P-Y Curve/L-Pile Inputs: Eff. Unit WGT, C_U, ε50

Structural Variables

- Live Load
- Dead Load
- Lateral Load – Use of L-Pile

Testing Variables

- Shaft Resistance by Depth
- Dampening Factor
- Toe Resistance or End Bearing Capacity
- Lateral Load

Factor of Safety by Design Method	Recommended Factor of Safety	Ultimate Capacity for 59 Kip Pile
Historical Data	3.0 – 3.5	177 kips
GRLWEAP	2.75	162 kips
Dyn. Load Test	2.25	132 kips
Static Load Test w/ Dyn.	2.00	118 kips

Factor of Safety: Determined by Design Method

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Pile Design Variables

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Pile Size		8.625	in
Factor of Safety	FOS	3.5	
Pile Surface Area	SA_{PIle}	2.26	SF/FT
X-Sect Area	A_{PIle}	0.41	SF
Unit Skin Friction: Active Zone	$R_{SH\text{-}A}$	3	ksf
Unit Skin Friction: Inactive Zone	$R_{SH\text{-}I}$	5	ksf
Structural Load: Live and Dead	Q_{DL+LL}	59	kips
Structural Load: Dead	Q_{DL}	29.5	kips
End Bearing Pressure	P_{end}	75	ksf
Depth of Active Zone	L_A	10	ft
Expansive Unit Force	R_{EX}	3	ksf
Length in Inactive Zone: Dry	$L_{I\text{-}Dry}$	15.6	FT
Length in Inactive Zone: Wet	$L_{I\text{-}Wet}$	11.9	FT
Embedment		**25.6**	**FT**

		Ultimate kips	Factored kips
Toe Capacity	Q_{TOE}	30.4	8.7
Active Zone	$Q_{SH\text{-}AZ}$	67.7	30.0
Inactive Zone	$Q_{SH\text{-}IZ}$	176.1	50.3
Total Capacity	Q_{TOTAL}	274.2	89.0
Useable Capacity		206.5	59.0

$$L_{I-Dry} = \frac{Q_{DL+LL} - A_{pile} \text{ x } P_{end}}{SA_{pile} \text{ x } R_{SH-I}}$$

$$L_{I-Wet} = \frac{SA_{pile} \text{ x } L_A \text{ x } R_{EX} - Q_{DL}}{SA_{pile} \text{ x } R_{SH-I}}$$

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ULTIMATE FACTORED CAPACITY

1. Start with Ultimate Capacity from DLT/SLT
2. Remove End Bearing Capacity: (no setup in end bearing)
3. Remove Upper 10 FT of Shaft Resistance for Dry Condition
4. Factor Remaining Shaft by Rausche et. al. Dynamic Dampening Factor
5. Identify Lower 5 FT to Extrapolate Deeper Piles
6. Add Factored Shaft to End Bearing Capacity

Factor of Safety: Ultimate Factored Capacity/Structural Design Load

- Factor of Safety: determined by testing

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Determine Pile

- Pile Type, Size, & Groups – match structural loading with tested piles.
- Pile Embedment Depth – wet conditions, dry conditions, or lateral loading govern.
- Pile Wall Thickness or Coating – driving stresses and longevity of pile material.

Determine Additional Lengths

- Building specific additions/deletions to embedment length due to cut/fill.
- Localized pile damage & Soil variability. Roughly 10% of embedment length.
- Foundation construction method: form above or trench below subgrade.

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- 8” Sch 40 Pipe
- Grade: 50 ksi
- Corrosion Rate: 0.0012 IN/YR or 0.03 MM/YR (confirm with Geotechnical Report)

For 59 Kip Pile (FOS = 2.0)

- OEP = 92 YRS
- CEP = 182 YRS

Open-Ended Pipe Pile						Closed-End Pipe Pile					
Year	**Corrosion (in)**	**OD (in)**	**ID (in)**	**Area Steel (sq. in)**	**Steal Load (kips)**	**Year**	**Corrosion (in)**	**OD (in)**	**ID (in)**	**Area Steel (sq. in)**	**Steal Load (kips)**
0	0.000	8.63	7.98	8.40	378.0	0	0.000	8.63	7.98	8.40	378.0
5	0.006	8.61	7.99	8.09	363.9	10	0.012	8.60	7.98	8.07	363.4
10	0.012	8.60	8.01	7.77	349.8	20	0.024	8.58	7.98	7.75	348.8
20	0.024	8.58	8.03	7.15	321.6	40	0.048	8.53	7.98	7.11	319.8
30	0.036	8.55	8.05	6.52	293.5	60	0.072	8.48	7.98	6.46	290.9
40	0.048	8.53	8.08	5.90	265.3	80	0.096	8.43	7.98	5.83	262.2
50	0.060	8.51	8.10	5.27	237.1	100	0.120	8.39	7.98	5.19	233.7
60	0.072	8.48	8.13	4.64	208.9	125	0.150	8.33	7.98	4.41	198.2
70	0.084	8.46	8.15	4.02	180.8	150	0.180	8.27	7.98	3.62	163.1
80	0.096	8.43	8.17	3.39	152.6	182	0.218	8.19	7.98	2.63	118.4
92	0.110	8.40	8.20	2.64	118.8	200	0.240	8.15	7.98	2.08	93.5
100	0.120	8.39	8.22	2.14	96.3	220	0.264	8.10	7.98	1.46	65.9
115	0.138	8.35	8.26	1.20	54.0	250	0.300	8.03	7.98	0.55	24.9
134	0.161	8.30	8.30	0.01	0.5	268	0.322	7.98	7.98	0.01	0.5

Corrosion Rates

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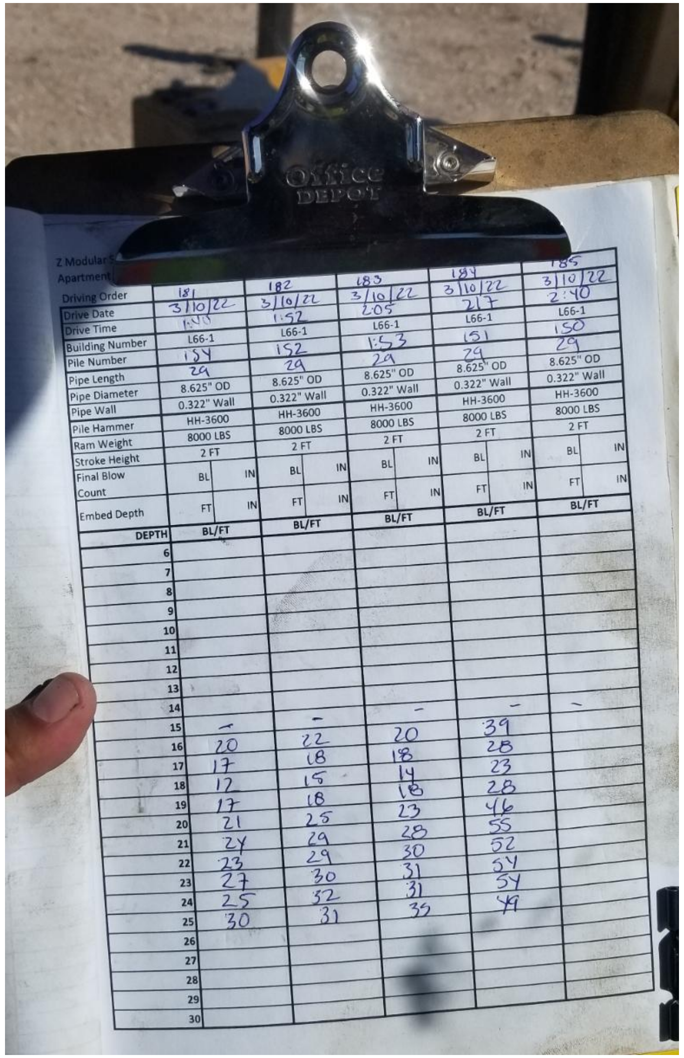
- **Profile the site.**
- 2% of total piles with Pre-Production Test Program or 4% without SLT.
- Test 2 of each different pile types or loading conditions.
- Test at initial driving and 3+ days to correlate initial blow counts with setup capacity.
- Determine driving criteria per area (depth & blow count).
  - Target depth
  - Stroke of hammer
  - Min. embedment depth to satisfy Wet Conditions & Lateral Loads
  - Min. blow count per foot to satisfy Dry Conditions
  - Max blow count per hammer type to reduce equipment breakdown

Production Test Piles & Driving Criteria

- Real time data recorded on pile log that is reviewed by pile contractor, general contractor, and 3rd party inspector on daily basis to ensure design criteria are met.
- Pile log serves as a final quality control document of record.
- Pile contractor's ground personnel communicates directly with 3rd party inspector. Directs operator to continue or stop driving depending on soil conditions.



Production Pile Observations & Pile Log

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Adjustments to driving criteria due to variable soil conditions.

- Soil too soft – Drive deeper. Order longer pipe if possible or splice as needed.
- Soil too hard – Drive shallower when meeting wet condition embedment depth and reduce hammer stroke.

Field Adjustments to Final Pile Design

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CASE STUDY:
SAN MARCOS DEVELOPMENT

San Marcos Development

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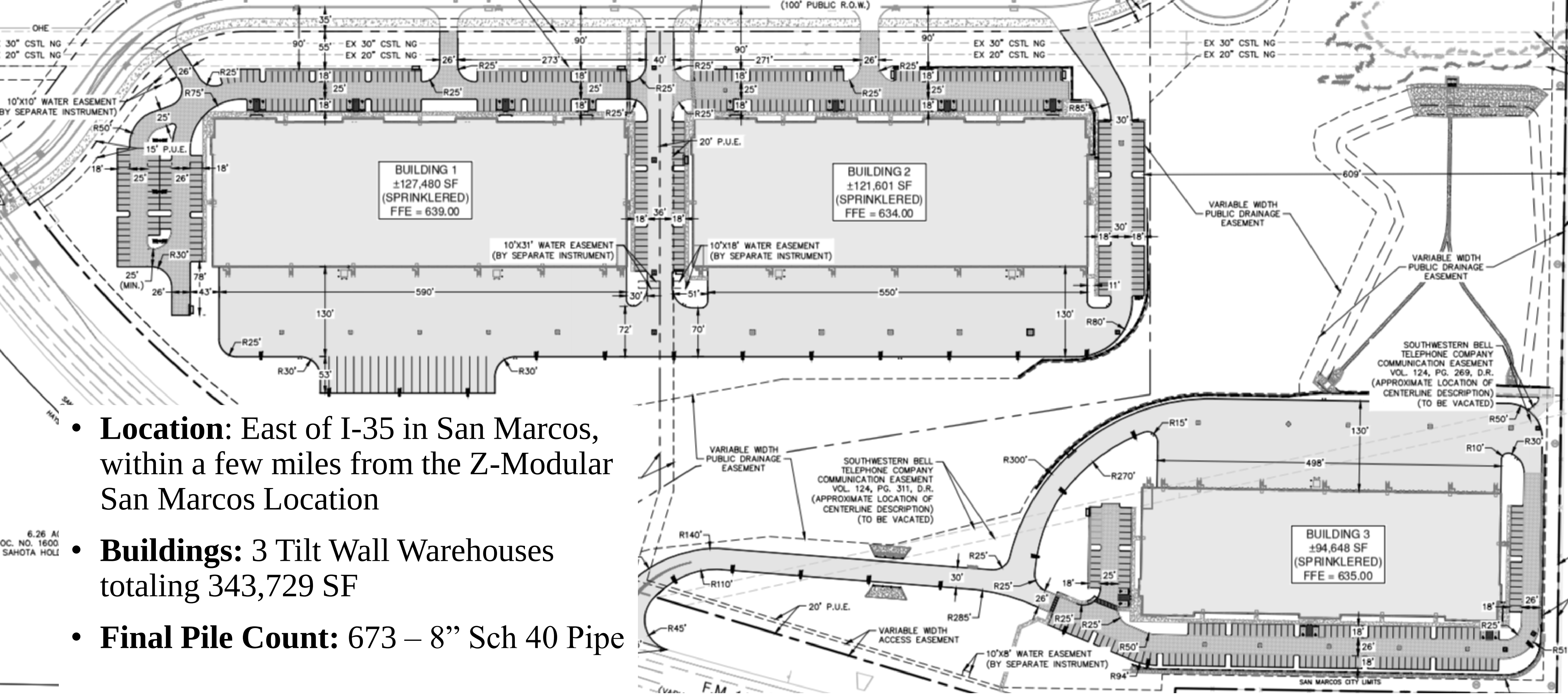

- **Location**: East of I-35 in San Marcos, within a few miles from the Z-Modular San Marcos Location
- **Buildings:** 3 Tilt Wall Warehouses totaling 343,729 SF
- **Final Pile Count:** 673 – 8" Sch 40 Pipe

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San Marcos Summary

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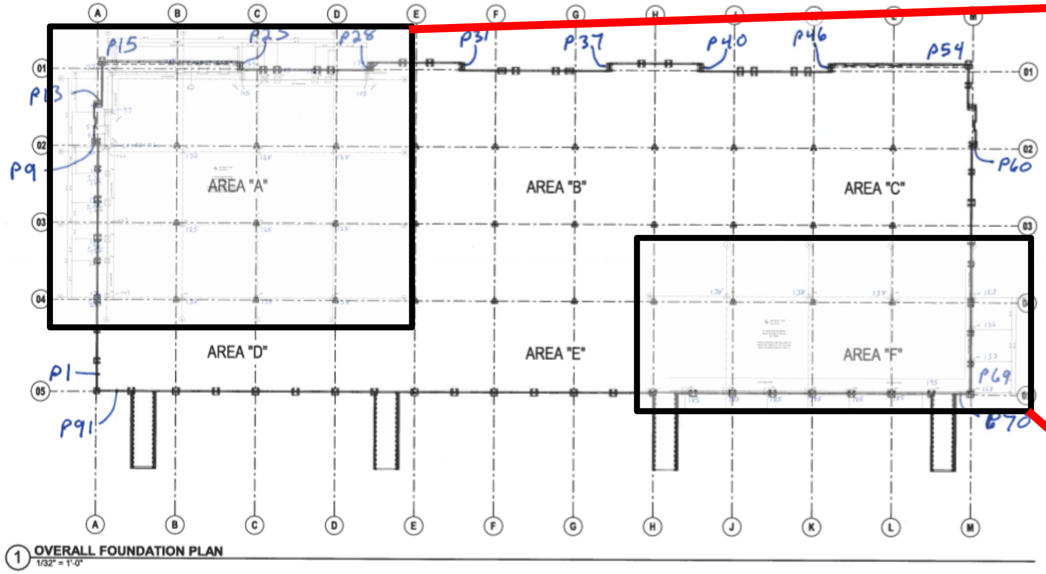

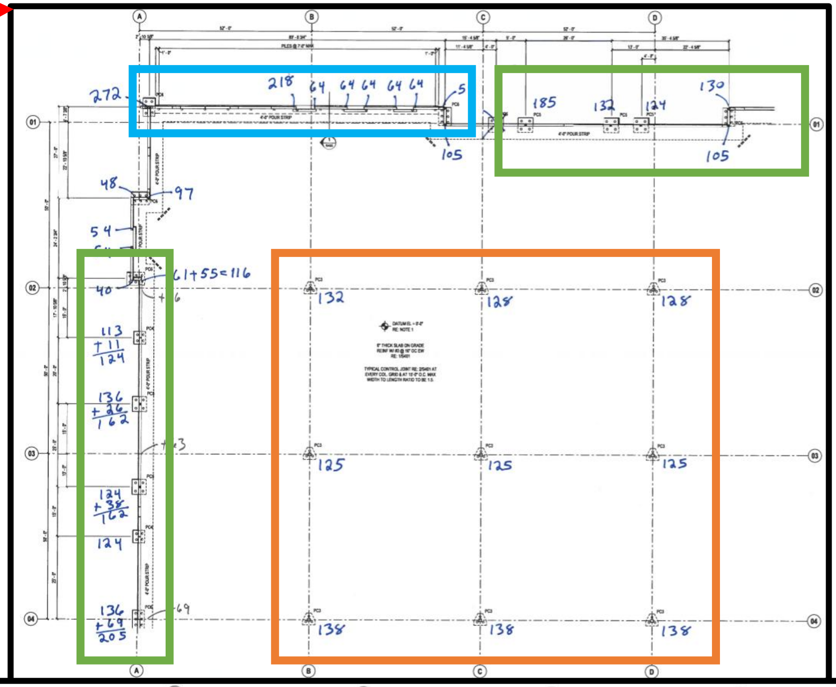

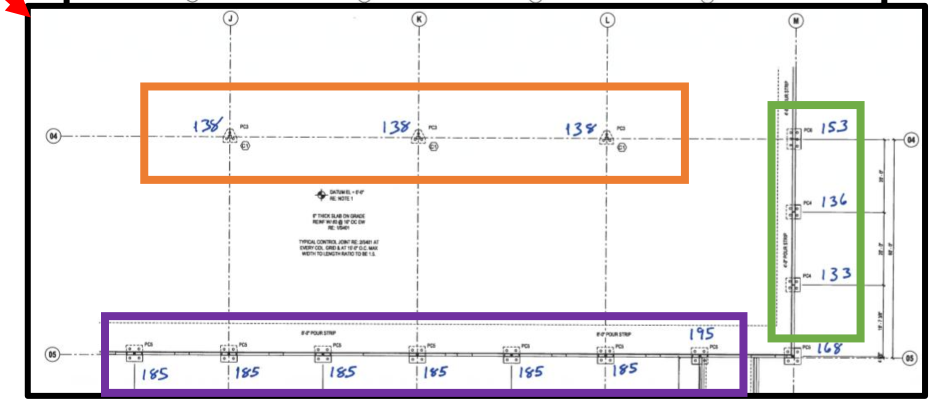

- Tilt-wall warehouses have 4 main loading conditions:
  1. Column Loads: one to three pile cap depending on roof & wind loads.
  2. Panel Loads: double pile cap at each side to reduce eccentric loading.
  3. Loading Dock Loads: higher loaded with a 3 to 6 FT cut.
  4. Grade Beam Loads for Office Glazing.
- Structural engineer of record provided loading for each pile cap.
- Pile caps divided into PC 1 – PC 5 initially.

Model Layer/ Stratum	Layer Name	General Description
1	Highly Expansive Clays	Dark brown to brown, very stiff to hard, Fat Clays (CH)
2	Moderately High Expansive Clays	Light brown to yellowish brown to orangish brown, very stiff to hard, Lean Clays (CL) to Fat Clays (CH)
3	Shaley Fat Clays	Dark gray to gray, hard, Shaley Fat Clay (CH)

- PVR of up to 6.5 inches
- Expected cut/fill ranged from -4 to +13

BORING LOG NO. B-8

Page 1 of 1

Approximate Surface Elev.: 632 (Ft.) +/-

MODEL LAYER	DEPTH / MATERIAL DESCRIPTION / ELEVATION (Ft.)	FIELD TEST RESULTS	SWELL (%)	UNCONFINED COMPRESSIVE STRENGTH (tsf)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS LL-PL-PI	PERCENT FINES
1	**FAT CLAY (CH)**, dark brown, hard	4.5 tsf (HP)						
	2.0 — 630+/-							
2	**LEAN CLAY (CL)**, light brown, hard	4.5 tsf (HP)			12.2		35-18-17	99
		21-41-46 N=87						
	becomes yellowish brown to light brown, with iron stains below 6 feet	13-34-35 N=69						
		4.5 tsf (HP)			16.1		41-17-24	
		4.5 tsf (HP)		19.06	15.8	118		
		4.5 tsf (HP)						
		4.5 tsf (HP)		13.45	16.5	116		
		4.5 tsf (HP)						
		4.0 tsf (HP)						
	35.0 — 597+/-							
	Boring Terminated at 35 Feet							

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

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Geotechnical Report

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Depth below FFE [1]	Factored Design Pile Capacity [2]
	7" Close-End Steel Pipe Pile Diameter
Minimum 20 feet, bearing in Stratum 2 Soils	30 kips/pile
Minimum 25 feet, bearing in Stratum 2 Soils	45 kips/pile
Minimum 30 feet, bearing in Stratum 2 Soils	55 kips/pile
Description	**Driven Pile Design Parameter**
Approximate total settlement	1 inch
Estimated differential settlement	Approximately ½ to ¾ of total settlement

1. Due to the planned fills to achieve final grades in the buildings, the total pile lengths will vary across the structures, therefore, appropriate base bid depths should be determined for the project.
2. Factored design pile capacities are estimated assuming a factor of safety of at least 2 compared to ultimate pile capacities correlated from prior tests during construction at previously-constructed buildings within Park 183. ***Test piles must be performed prior to final design to either confirm and/or modify the estimated pile capacities given above. Final depths and blow counts to be determined after test pile results.***

Initial Design Based on Geotech Report

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Pile Option	Pile Length	Pile Count	Pile Cost	Pile Total	Mob + Testing	TOTAL	Schedule
18" Concrete	30	304	$3,300	$1,003,200	$75,000	$1,078,200	5 to 7 WKS
10" Concrete	27.5	608	$2,275	$1,383,200	$75,000	$1,458,200	6 to 8 WKS
HP10x42	27.5	608	$1,425	$866,400	$75,000	$941,400	5 to 6 WKS
8" Prime Pipe	27.5	608	$1,170	$711,360	$75,000	$786,360	5 to 6 WKS
7" Secondary Pipe	32*	608	$1,175	$714,400	$75,000	$789,400	4 to 6 WKS

- Pricing from summer 2022, 2 years before project began.
- * Secondary Pipe would come in 40 FT randoms and there would be a salvageable waste. Also does not come with mill reports.

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Pile Cost Analysis

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Test Pile Conditions

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- Texas Pile conducted test piles at three locations. Building 3 location could not be accessed due to wet conditions so the third location was close to the drainage easement.

- Texas Pile used a 45-ton crane with swinging leads and a 4340-pound drop hammer to drive all piles. Site had chest height weeds and mesquite trees that would not allow tired air compressor to be safely moved around with Skytrak.

- Initial plan was to drive a 25-foot and 30-foot deep 8.625" OD open-end pipe pile at each of the three locations. Location 1 had 21.4 FT, 25 FT, and 30 FT deep piles. Location 2 had 24 FT and 25 FT deep piles due to hard driving conditions. Location 3 had 25 FT and 30 FT deep piles. All 7 pile locations had dynamic pile tests with CAPWAP analysis at initial driving and restrike at 1 week.

- Location 3 was the weakest location, so a static load test was performed on the 30 FT deep pile.

- Indicator Piles were driven along the eastern limits of Building 1 & 2 to determine blow counts closer to the drainage easement. Blow counts were 66 to 100 blows per foot at 20 to 25 FT of embedment.

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Pre-Production Test Pile Summary

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Test Pile Locations

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Pile No.	Pile Size	Test Date	Test Type	Reference [2] Penetration Depth (ft)	Blow [4] Count blows/set	Mobilized Capacity			Soil Damping		Soil Quake	
						Total (kips)	Shaft (kips)	Toe (kips)	Shaft (sec/ft)	Toe (sec/ft)	Shaft (in)	Toe (in)
TP 01	8.625" X 0.25" X 40'	7/29/2024	EOID	25.000	65 / ft	240	110	130	0.40	0.32	0.04	0.12
		8/6/2024	8 D BOR	25.010	9 / 0.125 in	307	186	121	0.15	0.40	0.06	0.04
TP 02	8.625" X 0.25" X 40'	7/29/2024	EOID	21.410	193 / .41 ft	240	118	122	0.40	0.09	0.04	0.04
		8/6/2024	8 D BOR	21.430	10 / 0.25 in	305	189	126	0.34	0.38	0.04	0.04
TP 03	8.625" X 0.322" X 37'	7/30/2024	EOID	21.000	97 / ft	291	146	145	0.40	0.11	0.04	0.04
		8/6/2024	7 D BOR	21.000	No Movement	388	261	128	0.26	0.40	0.05	0.04
TP 04	8.625" X 0.322" X 37'	7/30/2024	EOID	25.000	95 / ft	275	144	131	0.40	0.02	0.12	0.06
		8/6/2024	7 D BOR	25.005	10 / 0.0625 in	368	237	131	0.21	0.40	0.04	0.04
TP 05	8.625" X 0.322" X 37'	7/30/2024	EOID	24.000	120 / ft	290	162	128	0.40	0.02	0.05	0.16
		8/6/2024	7 D BOR	24.000	No Movement	385	215	170	0.24	0.40	0.05	0.04
TP 06	8.625" X 0.322" X 37'	7/30/2024	EOID	30.000	30 / ft	176	115	61	0.34	0.02	0.05	0.23
		8/6/2024	7 D BOR	30.020	10 / 0.25 in	285	225	60	0.38	0.37	0.04	0.04
TP 07	8.625" X 0.322" X 37'	7/30/2024	EOID	25.000	20 / ft	150	108	42	0.15	0.02	0.07	0.25
		8/6/2024	7 D BOR	25.270	10 / 3.25 in	222	165	56	0.24	0.02	0.04	0.25

TP 06 - Ultimate Capacity at 285 kips

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CAPWAP Results

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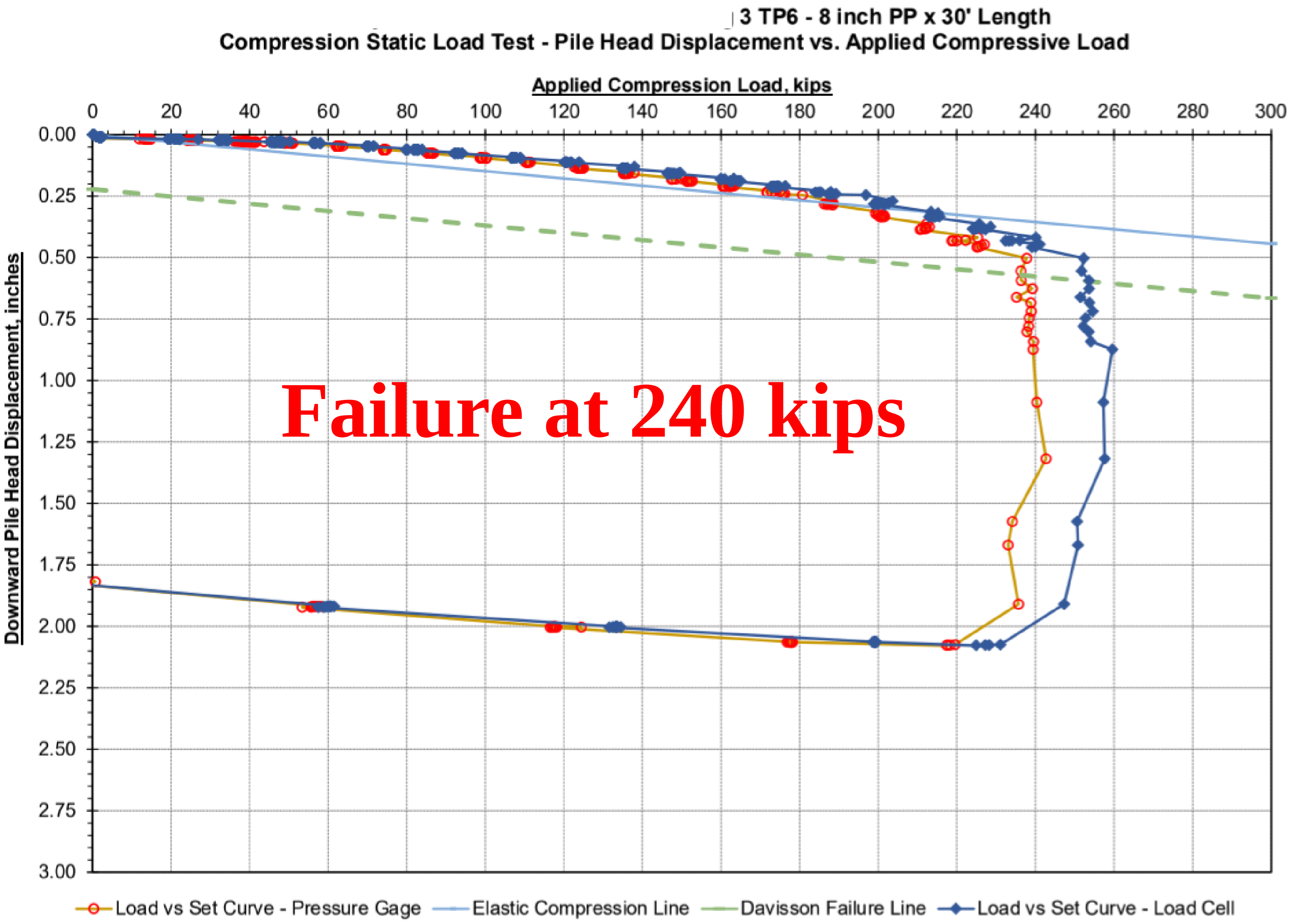
Dampening Factor

- Dynamic Shaft = 225 kips
- Dynamic Toe: 60 kips
- Static Shaft = Static Ultimate – Dynamic Toe = 180 kips
- Dampening = Static Shaft/ Dyn Shaft = 180/225 = **80%**



Static Load Test Result – TP 6 @ Location 3

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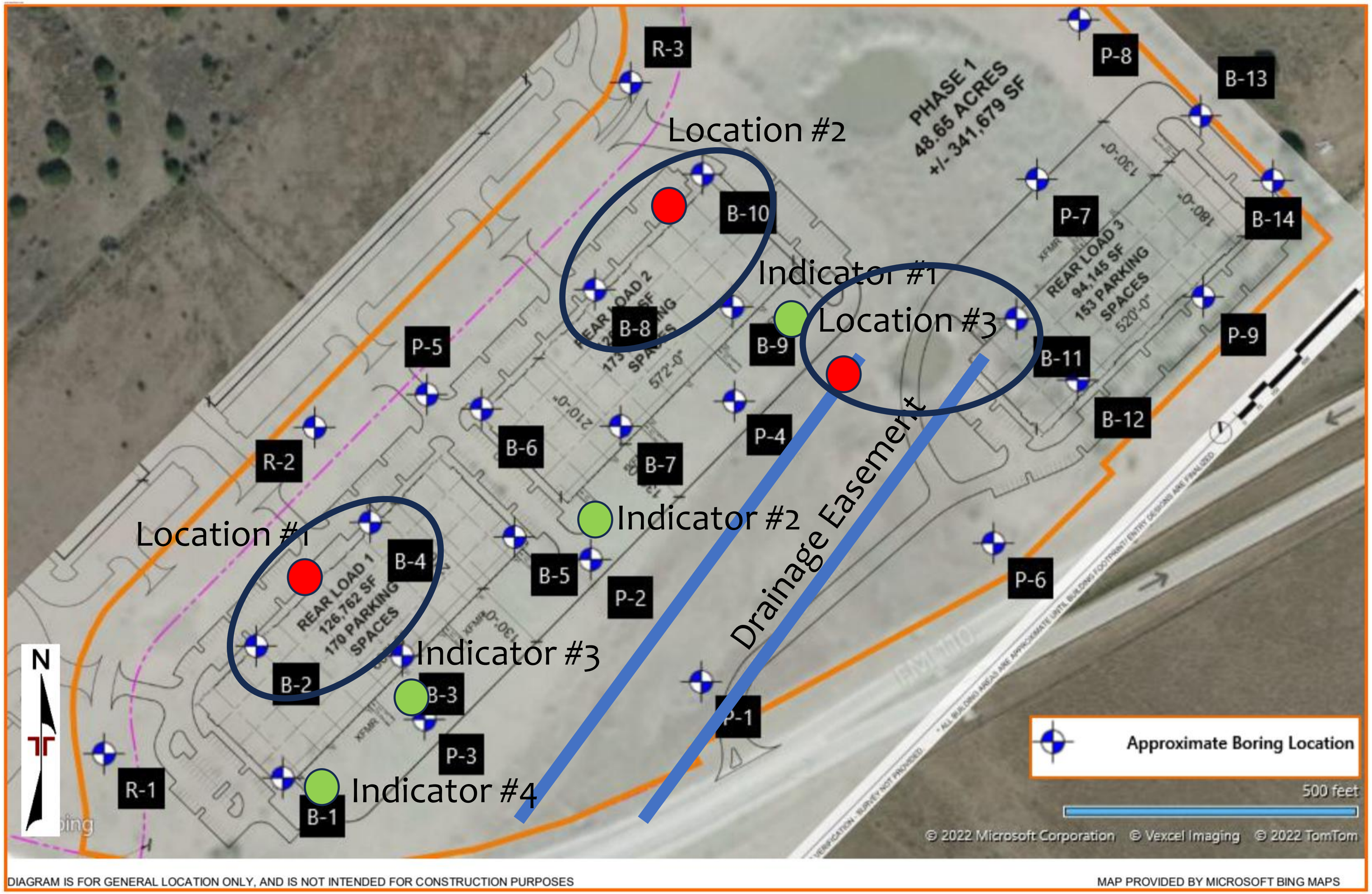

Indicator Pile Locations

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- Driven to confirm that the drainage area's soft soil would not be encroaching Building 1 or 2.
- Four locations were laid out in the proposed parking/load dock area.
- Consistently hard soil was found.

Drive Date	8/6/2024				8/6/2024				8/6/2024				8/6/2024			
Pile Number	Indicator #1				Indicator #2				Indicator #3				Indicator #4			
Final Blow Count	66	BL	12	IN	82	BL	12	IN	65	BL	6	IN	100	BL	12	IN
Embed Depth	25	FT	0	IN	23	FT	0	IN	20	FT	6	IN	21	FT	0	IN
DEPTH	BL/FT				BL/FT				BL/FT				BL/FT			
11	15				15				20				18			
12	11				17				20				17			
13	12				18				24				20			
14	15				22				26				20			
15	16				25				26				25			
16	16				28				26				27			
17	18				32				26				28			
18	18				38				32				27			
19	21				35				44				34			
20	18				46				75				55			
21	24				66				130				100			
22	30				70											
23	54				82											
24	44															
25	66															

Indicator Piles

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Test Pile	Location	Delta Time	Depth	Factored Capacity		Factor of Safety		Top 10 FT	
				Initial	Restrike	Initial	Restrike	Initial	Restrike
		days	ft	kips	kips			kips	kips
1	1	7.89	25	208.9	235.9	2.53	2.86	11	42
2	1	7.86	21.4	196.8	246.1	2.39	2.98	24	29
3	1	6.95	30	248.4	308.3	3.01	3.74	17	24
4	2	6.92	25	230.6	290.5	2.80	3.52	19	37
5	2	6.91	24	246.1	311.5	2.98	3.78	15	38
6	3	7.05	30	147	215	1.78	2.61	8	31
7	3	6.77	25	113.9	171.6	1.38	2.08	18	22

Factor of Safety = Factored Capacity/ 82.5 kips

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Factored Results w/ Dampening of 80%

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- 25 FT piles for Building 1 & 2 had a factored capacity more than double the design load of 82.5 kips.
- An additional loading condition, Loading Dock, was introduced to reduce pile caps of 3 piles each to 2 piles. These piles would be 100 kip design load. The TP 6 would handle that design load with a factor of safety of 2.4. TP 6 was 30 FT, so 5 FT was added to these locations and tagged "XL".
- Building 1 & 2 were directly tested. 25 FT depth for 82.5 kip & 30 FT depth for 100 kip
- Building 3 was not directly tested so kept conservative: 30 FT depth for 82.5 kip & 35 FT depth for 100 kip
- Additional 3 FT of pipe was ordered to allow for soft soils and damage during driving.

Final Design

- GRLWEAP Program
  - Junttan HHK4S
    - Ram Weight – 8818 pounds (4 Metric Tons)
    - Stroke Range – 0.5 to 5 FT
  - Soil Inputs Based on Boring B-8
  - Pipe: 8.625” OD x 0.322” Wall
  - Embedment: 25 FT Deep
- Blow Count at Depth: 34 BL/FT
- Total Drive Time: 7 Minutes

JUNTTAN USA, INC. 6/24/2024

Default + Default GRLWEAP 14.1.20.1

Gain/Loss 1 at Shaft and Toe 0.500/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str. ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	22.4	19.8	2.6	3.5	26.51	1.74	2.00	15.0	HHK4SL
10.0	42.1	39.5	2.6	6.4	27.29	0.44	2.00	15.6	HHK4SL
15.0	61.9	59.3	2.6	9.4	29.50	0.68	2.00	15.8	HHK4SL
20.0	81.6	79.0	2.6	12.5	29.15	0.40	2.00	15.4	HHK4SL
25.0	101.4	98.8	2.6	15.7	32.45	0.00	2.00	14.4	HHK4SL

Total Number of Blows: 189 (starting at penetration 16.4 ft)

Driving Time(min):	6	4	3	3	2	2	2	1	1	1
@Blow Rate:	30	40	50	60	70	80	90	100	110	120

Driving Time for continuously running hammer; any wait time not included.

Gain/Loss 2 at Shaft and Toe 1.000/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str. ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
5.0	42.1	39.5	2.6	6.4	25.46	0.57	2.00	15.8	HHK4SL
10.0	81.6	79.0	2.6	12.2	28.20	1.58	2.00	15.6	HHK4SL
15.0	121.2	118.5	2.6	18.2	35.49	1.45	2.00	15.3	HHK4SL
20.0	160.7	158.1	2.6	25.4	42.81	0.58	2.00	14.9	HHK4SL
25.0	200.2	197.6	2.6	33.8	49.54	0.00	2.00	13.6	HHK4SL

Total Number of Blows: 379 (starting at penetration 16.4 ft)

Driving Time(min):	12	9	7	6	5	4	4	3	3	3
@Blow Rate:	30	40	50	60	70	80	90	100	110	120

Driving Time for continuously running hammer; any wait time not included.

Drivability Analysis by Junttan USA

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Building	Hammer	Stroke	Pile Design Load	Piles Tested	Ave Days of Setup	Factors of Safety at Restrike		Ave. Soil Setup	Ave. Blow Count at Depth
		FT	KIP			Ave	Min		bl/ft
1	HHK4S	1.5	82.5	3	2.8	3.27	3.17	36%	36
1	HHK4S	1.5	100	2	2.8	3.11	2.67	41%	54
2	HHK4S	1.5	82.5	2	4.3	3.86	3.34	47%	51
2	HHK4S	1.5	100	3	3.0	2.67	2.46	65%	35
3	HHK4S	1.5	82.5	2	2.9	3.56	3.38	36%	53
3	HHK4S	1.5	100	2	3.0	2.53	2.51	44%	67

Production Test Pile Summary

	Building 1		Building 2		Building 3	
	82.5 Kip	100 kip	82.5 Kip	100 kip	82.5 Kip	100 kip
Goal Depth	25 FT	30 FT	25 FT	30 FT	30 FT	35 FT
Min Depth	20 FT	25 FT	20 FT	25 FT	20 FT	20 FT
Min Blow Count	25 BL/FT	30 BL/FT	25 BL/FT	30 BL/FT	35 BL/FT	35 BL/FT
Max Blow Count	60 BL/FT	60 BL/FT	60 BL/FT	60 BL/FT	60 BL/FT	60 BL/FT
Hammer Stroke	1.5 FT	1.5 FT	1.5 FT	1.5 FT	1.5 FT	1.5 FT

Driving Criteria by Building

Production Test Piles

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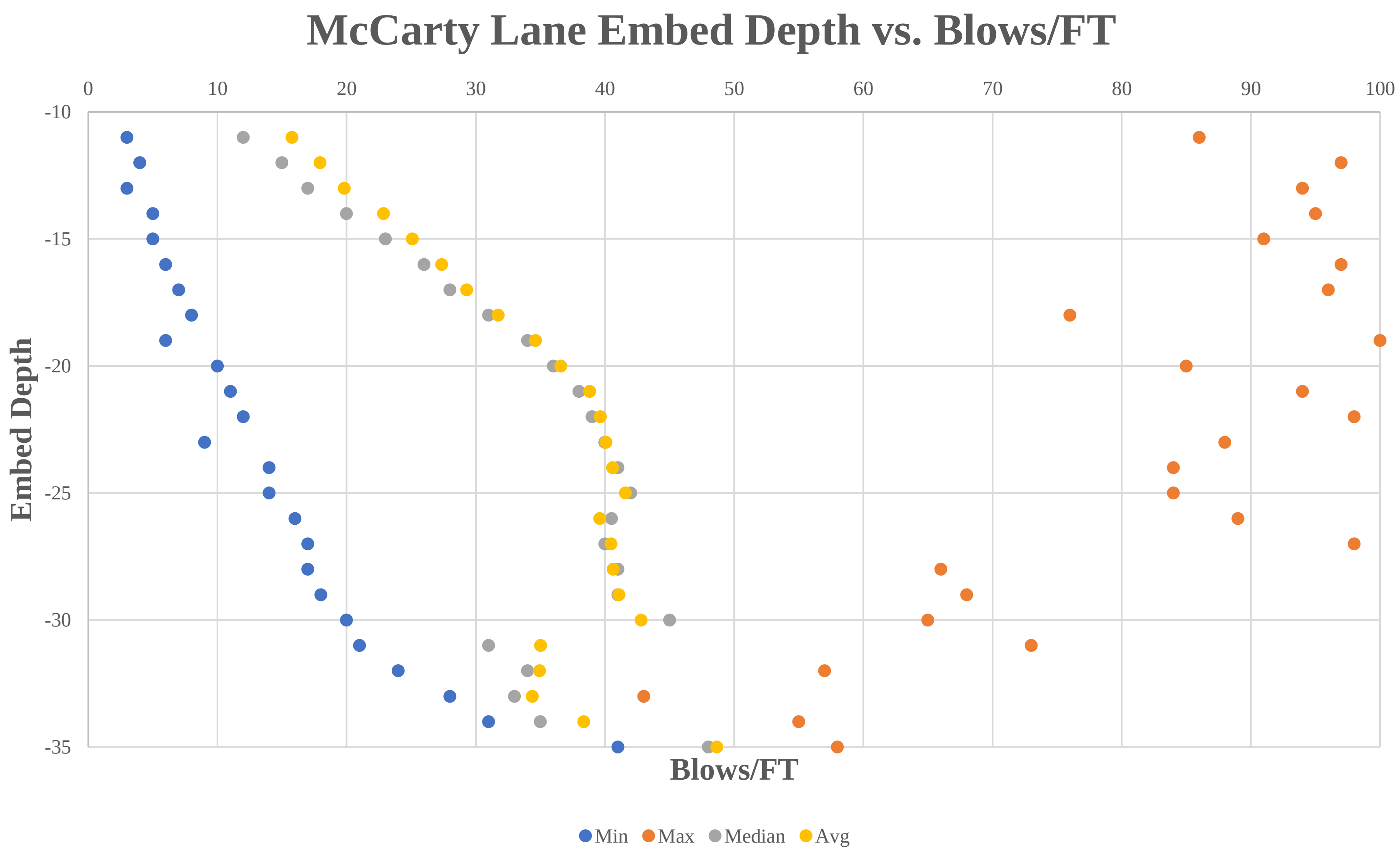

- 673 data points (Piles)
- Strong empirical relationship between Median and Average.
- Max blow counts explained by hard soil layer found at Building 3. Below that layer, driving behavior trended like min values.

Shaft Resistance by Depth

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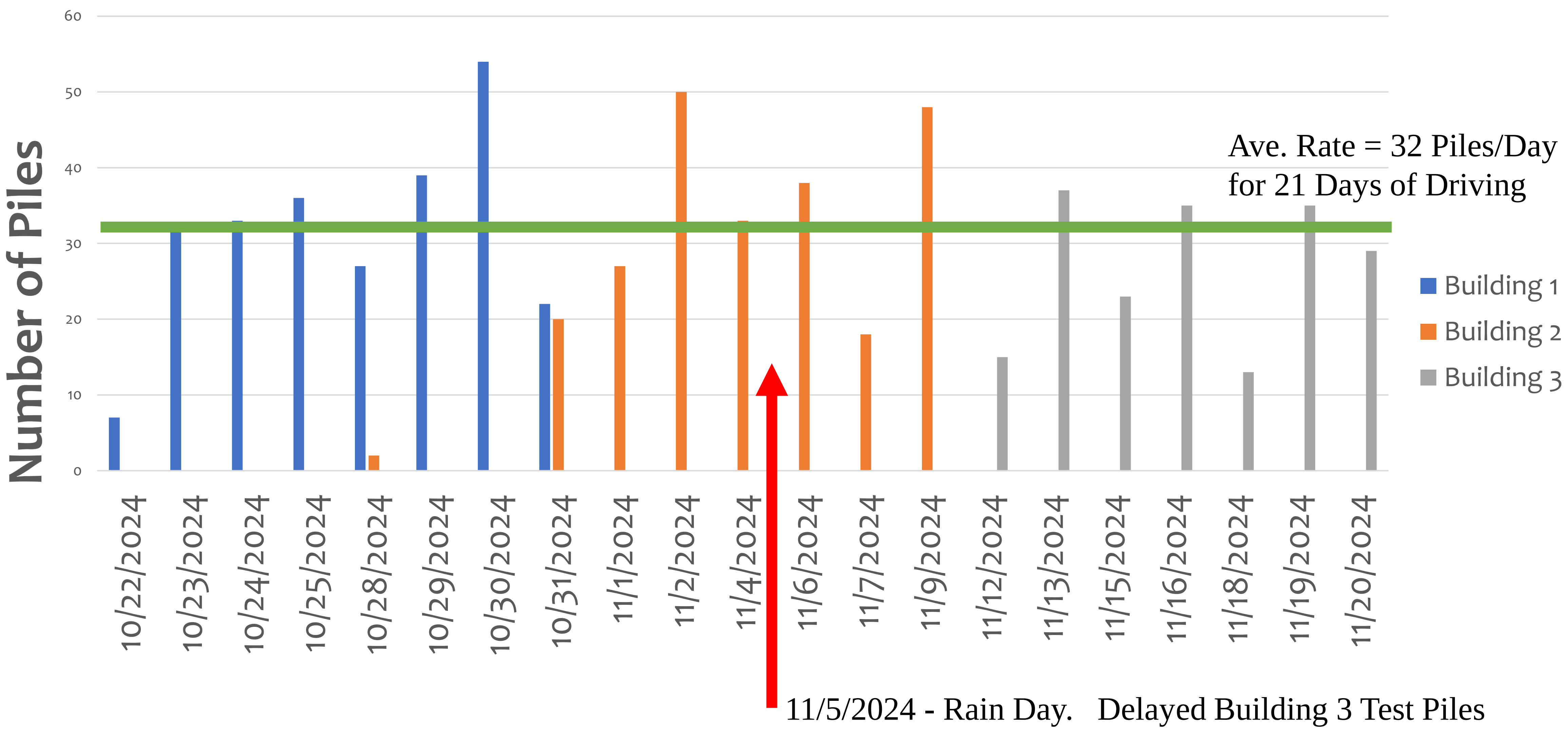

Production Rate

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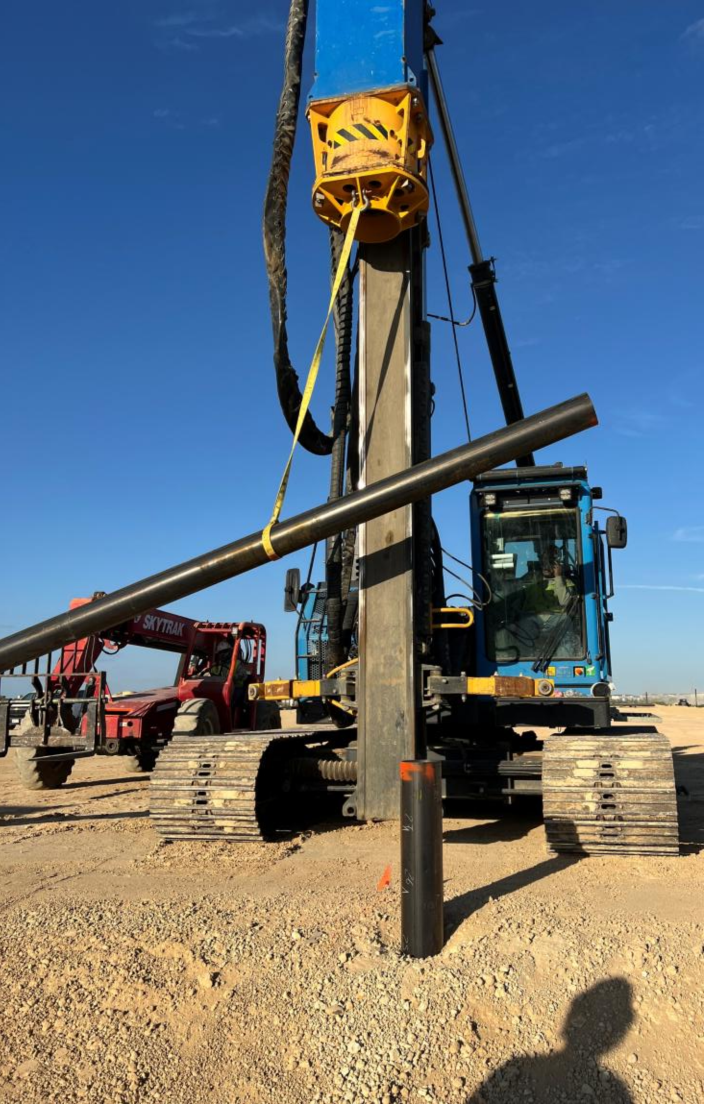

Production Piles

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Production Piles Video

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Production Rate: Rain Days (minor delay)

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Problem: Hard Layer

- A number of piles stopped at 14 to 16 FT and bent.
- Found a layer of calcified clay that acted like a rock layer per dynamic pile test readings.

Variable Conditions: Building 3

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Solution

- Drove indicator piles to find the extent of the hard layer
- Pre-Drill first 18 FT in area indicated as hard.
- Abandon piles that did not meet minimum depth and pre-drill for an additional pile location in pile cap.
- 7 Total piles were abandoned.
- Piles driven in pre-drilled locations experienced softer soils below hard layer and reached target depth.

Variable Conditions: Building 3

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- Pre-production testing revised 7” pipe pile design (946 piles at 33 FT lengths) with 8” pipe pile (673 piles at 28 to 38 FT lengths), reducing overall cost and schedule.
- Ultimate capacity in soft, drainage easement was 240 kips for 30 FT deep 8.625” OD x 0.322” OEP.
- Dampening Factor = 80%
- Additional loading condition was addressed by adding 5 FT of pile embedment at those locations.
- Driven pipe pile factor of safety exceeded 2.0 for all piles of 82.5 and 100 kip design load.
- Drove close to 700 piles in 21 working days with an average production rate of 32 piles per day. After one week head start, concrete subcontractor was not able to catch up.

San Marcos Summary

Driven piles are highly underutilized in expansive soils.

Desirable for Expansive Soil Application

- Driven piles have a desirable ratio of small surface area for uplift forces to high overall capacity. This reduces the overall material needed to support structural slabs resulting in lower costs and lower environmental impact.

Higher QA/QC & Reduced Liability

- Pre-production and production testing coupled with 3rd party pile log decreases overall liability for all stakeholders. Design criteria is strictly adhered too with flexibility in the field to adjust for natural soil variability.

Reduced Schedule

- Dedicated pile rigs install driven pipe piles faster than other trades can keep up with allowing for schedule compression. Driven piles can be loaded immediately after installation for concrete work. Limited waste is produced by cutting tops of piles.

Questions and Comments?

"A driven pile is a tested pile."