Evaluation of Static Design Resistance for Deep Foundations, FB-DEEP

(BDV31 977-05)

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Researchers: Lin Huang, Thai Nguyen, John Schwartz

Grip

August 21, 2015

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Evaluation of Static Design Resistance for Deep Foundation, FB-DEEP

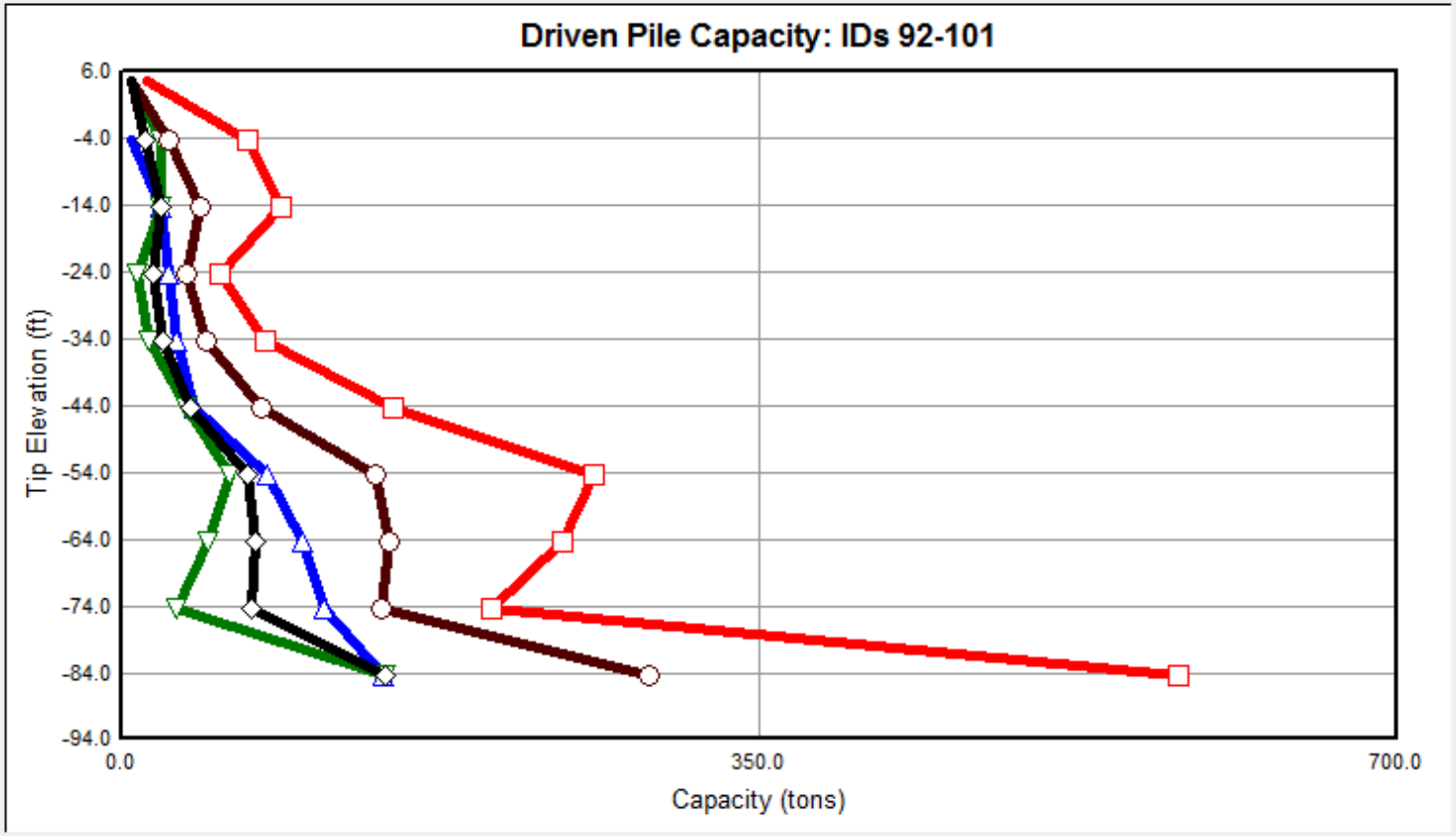
- FB-DEEP Software Predicts Nominal Side (R_s), Tip (R_T) and Total ($R_N = R_s + R_T$) Resistance for Driven (steel H, Prestressed Concrete, and Steel Pipe) Piles and Drilled Shafts based on In situ data(SPT, CPT - piles) and laboratory (rock strength - drilled shafts); Used In FB-MultiPier for Substructure Pier Analysis and Design

- FB-DEEP also identifies LRFD Design Resistances (ΦR_N) for piles and shafts based on database of mean biases [measured nominal resistance (e.g. Davisson, FHWA) divided predicted resistance], and Coefficient of Variations (CV) of biases.

FB-DEEP PCP Prediction

Job Name: South Bear

State Job (Project) #: 409040



Curves

- Ultimate Side Friction
- Mobilized End Bearing
- Ultimate Pile Capacity
- Estimated Davisson Capacity
- Allowable Pile Capacity

*The 'Save to File' button saves the currently selected Curves to a text file.

Driven Pile Data

Boring Number:	B-5	
Ground Surface Elevation	15.72	(ft)
Section:	Square	
Width	24.00	(in)

Project Data

File:	Pile_Example1
Date:	Aug 03, 2015
Engineer:	Ahmed

Analysis Data

Analysis Type:	SPT

Customize | Update Plot | Close | Print Graph | Print Window | Save To File

Objectives of FB-DEEP Research

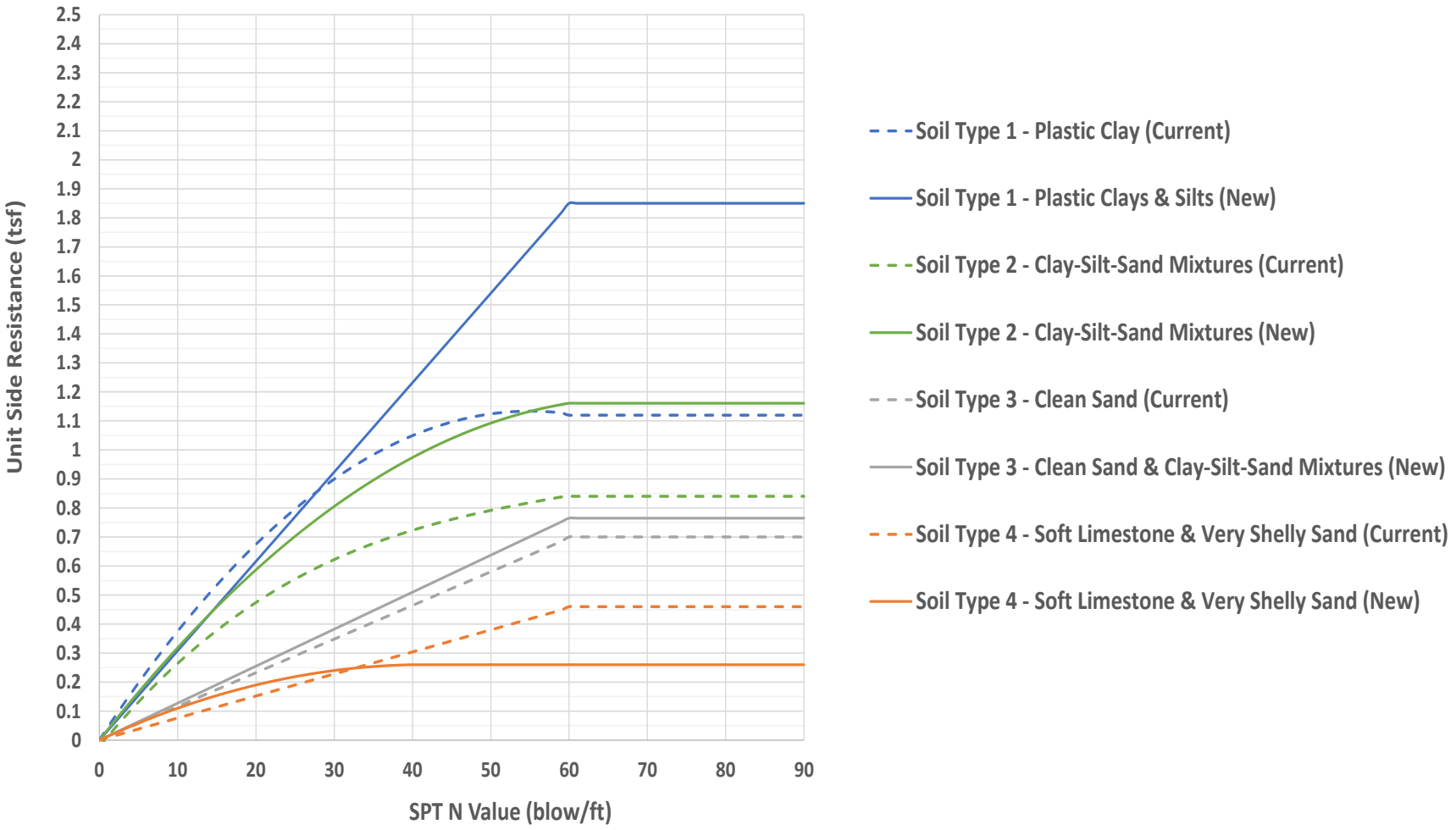
- For H piles, re-evaluate predicted side and tip resistances for piles driven through multiple layers of sand, clay and limestone;
- Evaluate side resistance for **permanent** cased drilled shafts in Limestone (FB-DEEP currently neglects);
- For prestressed concrete piles (PCP) re-evaluate side and tip resistance for piles driven into weathered (FHWA IGM – Intermediate Geotechnical Material) versus competent limestone (FB-DEEP currently treats both same);

Collection of In Situ and Pile Data for FB-DEEP

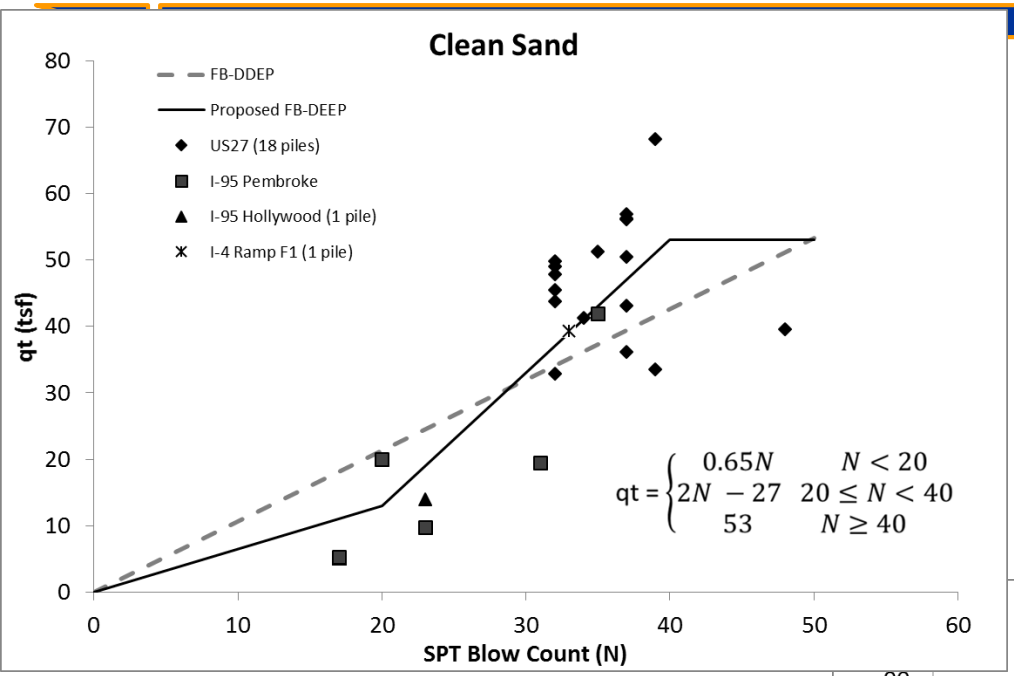
Sites with H Piles Evaluated in Florida:

Site Information		Insitu Information		Pile Information			
Project Number (Financial)	Project Site	# of Soil Borings	Predominant Soil Type	Dimensions (in)	Length (ft)	# of Piles with CAPWAP	# of BOR CAPWAP Analyses
208466-2-52-01	SR 51 from Taylor County Line to Dixie County Line	66	Sand & Rock	14 x 89	60 - 120	3	1
221754-1-52-01	CR 146 over Aucilla River	9	Sand, Clay & Rock	14 x 117	150 - 220	5	0
422796-1-52-01 & 422796-2-52-01	Widening I 95 (SR 9) over Hallandale Beach Boulevard Bridge	5	Sand & Rock	18 x 135	90 - 116	8	5
	Widening I 95 (SR 9) over Hollywood Boulevard (SR 820)	3	Sand & Rock	18 x 135	90 - 115	11	3
	Widening I 95 (SR 9) over Stirling Road (SR 848)	3	Sand & Rock	18 x 135	110 - 168	5	4
	Widening I 95 (SR 9) over Pembroke Road Bridge	3	Sand & Rock	19 x 135	85	9	6
403984-1-52-01	Eller Drive Overpass (SR 862)	29	Sand & Rock	14 x 73	90 - 140	3	0
242484-2-52-01	I-4 (SR 408)/SR 408 interchange (Widening at Church Street Viaduct; Phase 1)	29	Sand & Clay	14 x 89 & 12 x 53	90 - 140	37	5
	I-4 (SR 408)/SR 408 interchange (Widening over Robinson Street; Phase 2)	1	Sand	14 x 89	100 - 150	14	1
	I-4 (SR 408)/SR 408 interchange (Widening over South Street; Phase 3)	2	Sand & Clay	12 x 53	150	3	0
	Ramp E (Phase 4)	3	Sand & Clay	14 x 89	150	3	0
	Ramp F2 (Phase 5)	5	Sand	14 x 89	105 - 135	3	0
	Ramps D & D1 (Phase 6)	20	Sand & Clay	12 x 53	90 - 115	18	1
	Anderson Street Overpass & Ramp F1 (Phase 7)	7	Sand & Clay	14 x 89	---	4	1
	Ramp C (Phase 8)	12	Sand	14 x 89	---	12	0
238429-3-52-01	US 27 (SR 50) Interchange at SR 50	7	Sand	14 x 73	99 - 120	33	18
	Total # of Soil Borings	**204**		**Total # of CAPWAP Analyses**		**171**	**45**

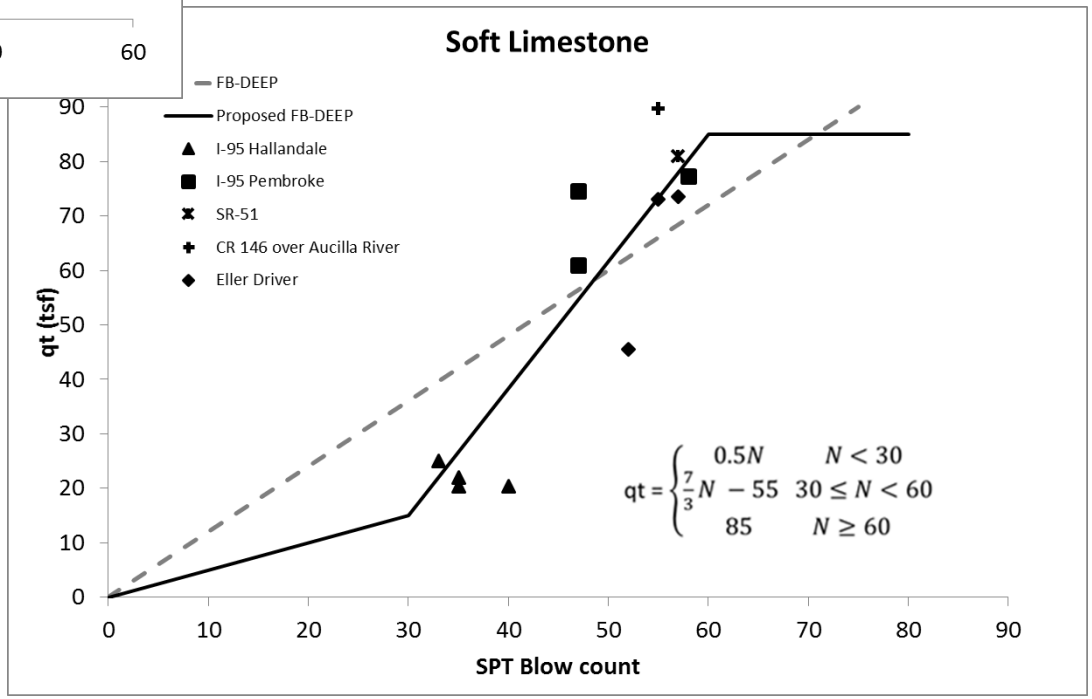
Analysis of Side Friction for H Piles in FB-DEEP



Analysis of Tip Resistance for H Piles in FB-DEEP



Average 8B Below the Pile Tip



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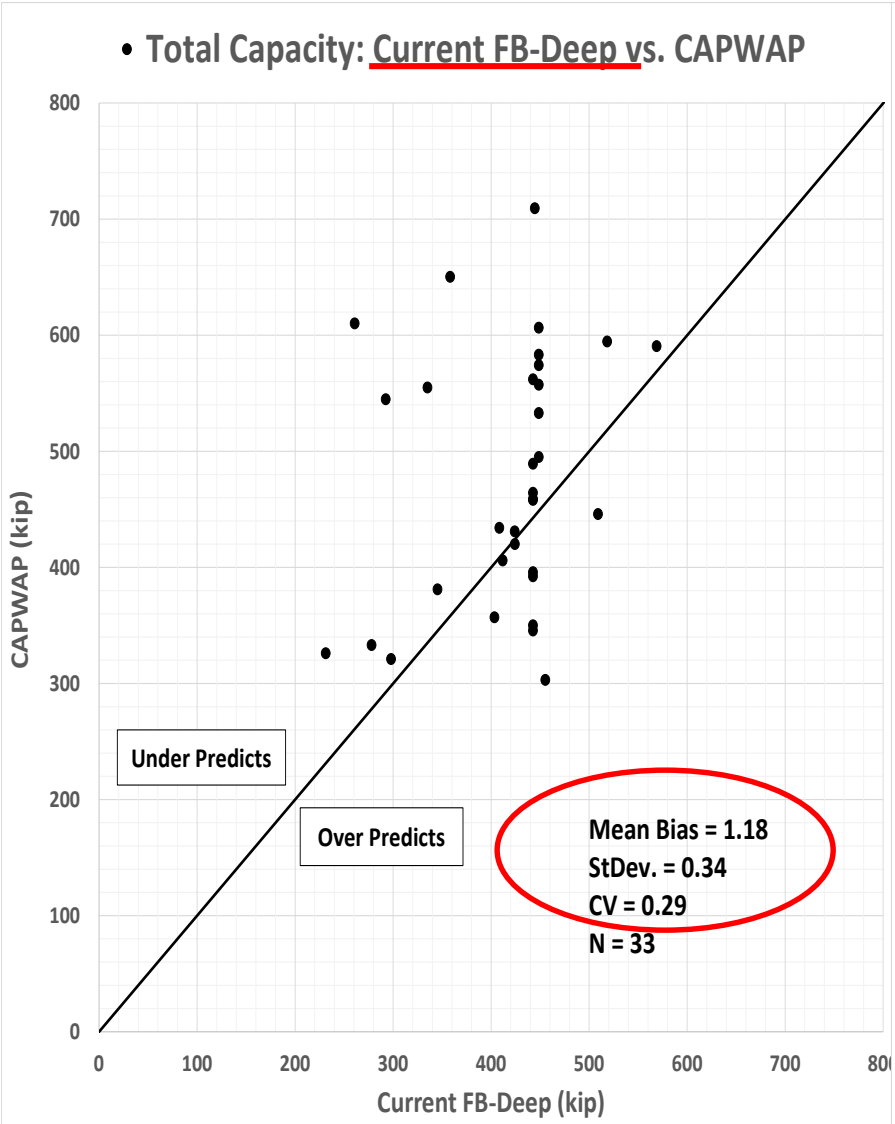
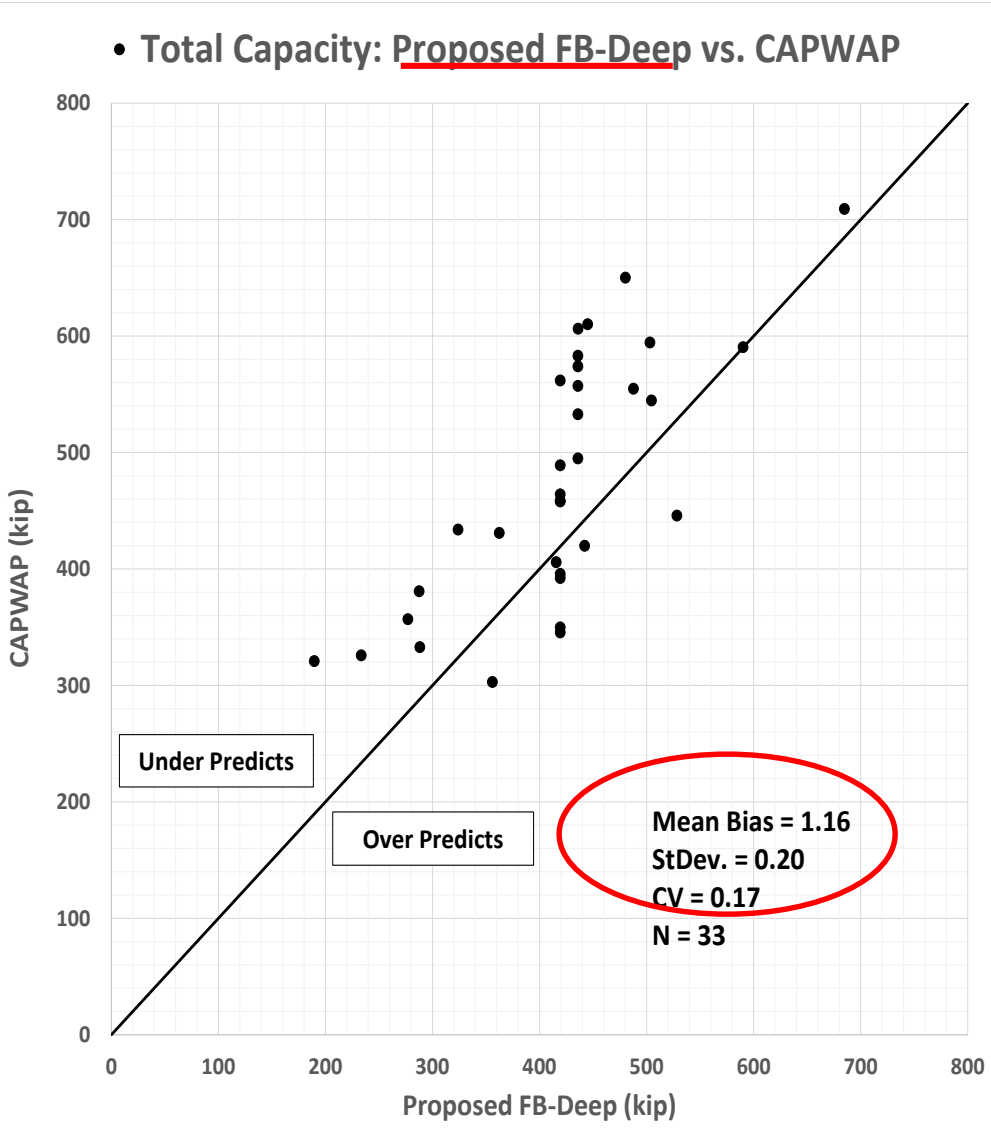
Predicted & Measured H Pile Response forFB-DEEP





H Piles Plug Conditions

- Difficulties in Matching Results with Measured Data
  1. Soil Borings

H Piles Plug Conditions

- Difficulties in Matching Estimates with Measured Data
  1. Soil Borings

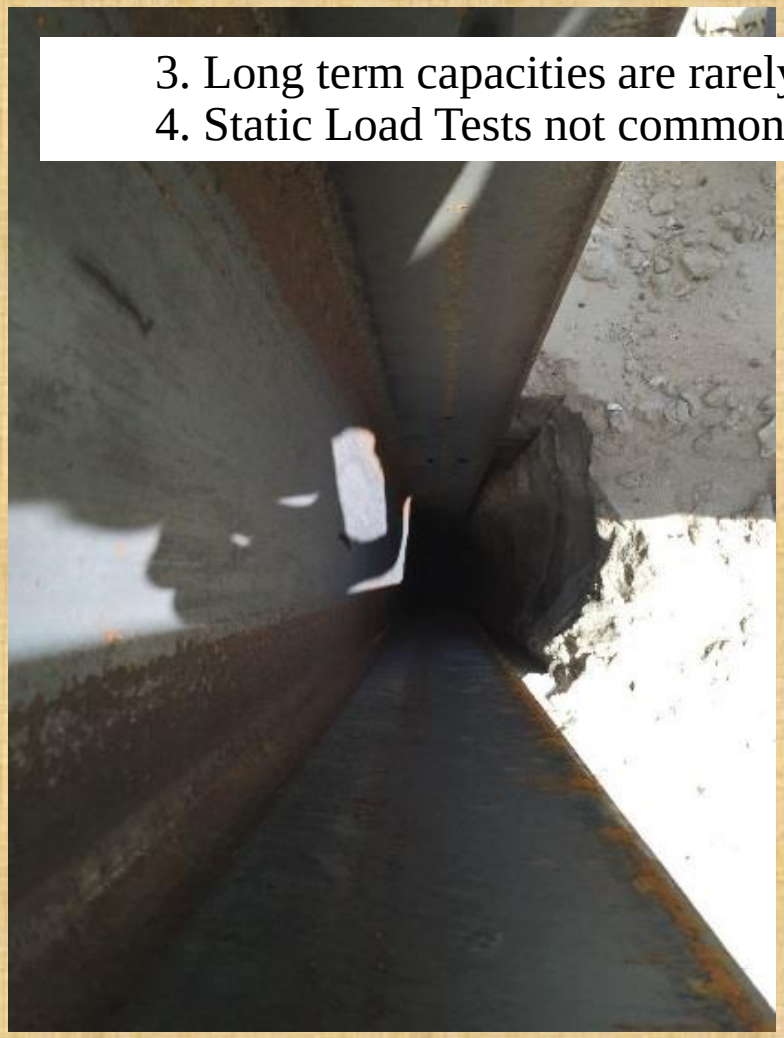
H Piles Plug Conditions

- Difficulties in Matching Estimates with Measured Data
  1. Soil Borings

Contractor built a dirt road to get to the site

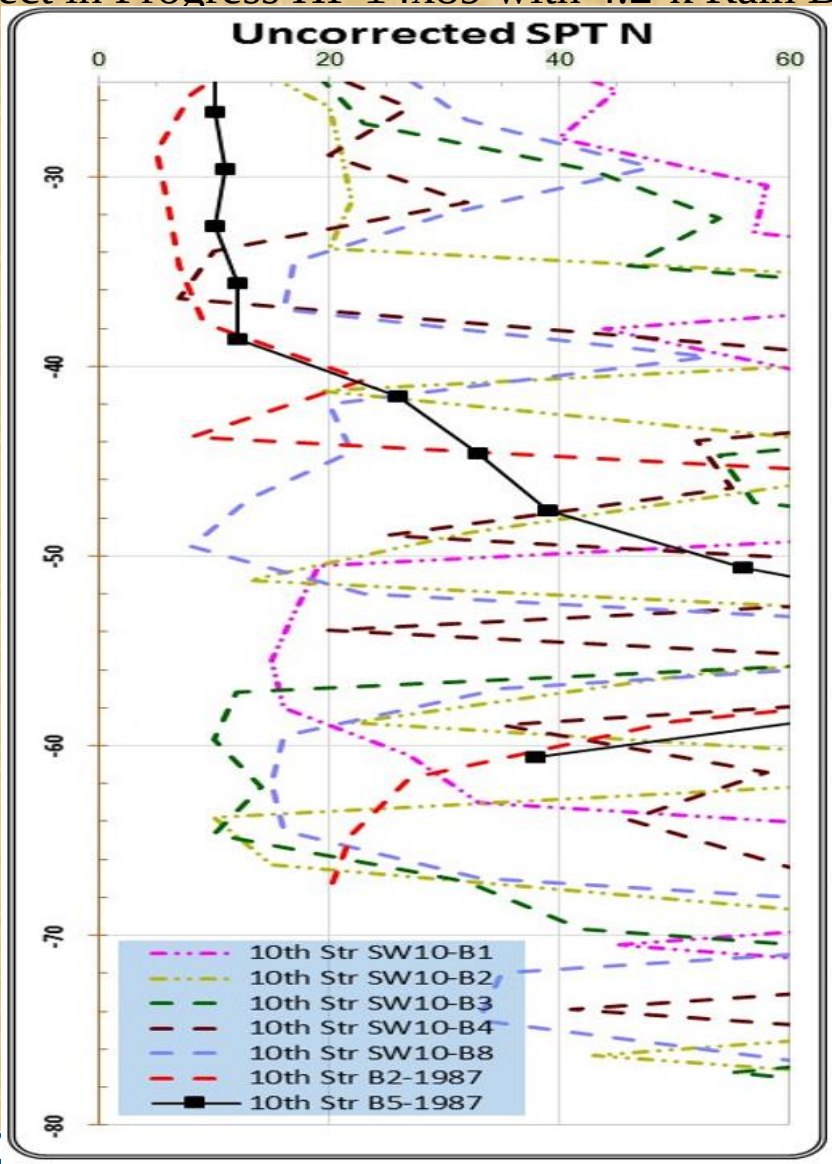
H Piles Plug Conditions

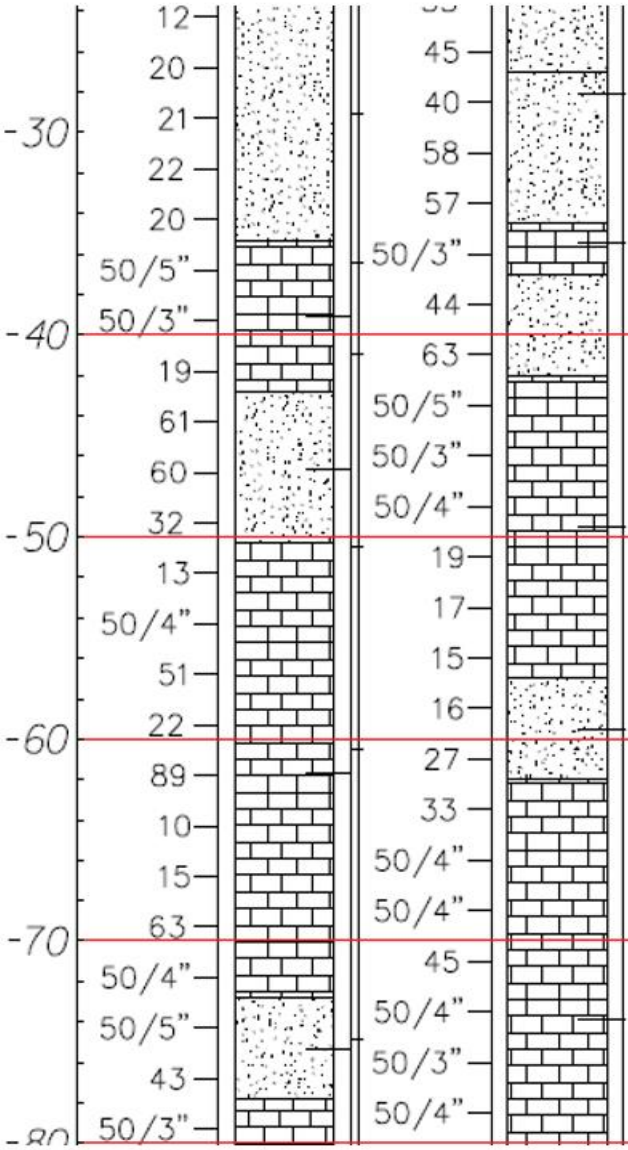
- Difficulties in Matching Estimates with Measured Data
  2. Soil Gaps (between the H Pile Flanges) have not been recorded
  3. Long term capacities are rarely evaluated (7-day RESTRIKE or longer)
  4. Static Load Tests not common



H Piles Plug Conditions – Case Studies

1) Project in Progress HP 14x89 with 4.2-k Ram D19-42 Hammer



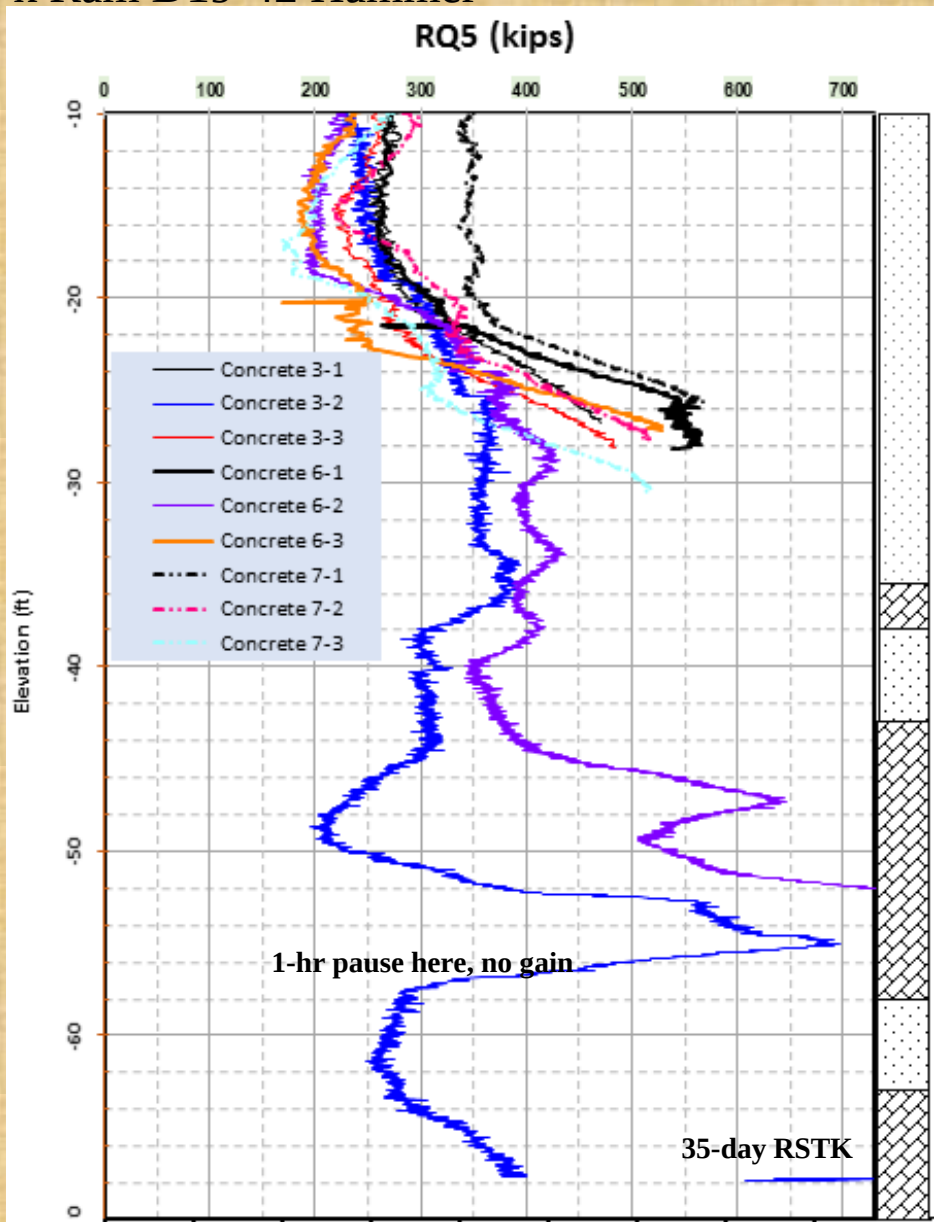


Variability in Soil Profiles

H Piles Plug Conditions – Case Studies

1) Project in Progress HP 14x89 with 4.2-k Ram D19-42 Hammer

Variability in PDA results (Concrete Piles at the same site)



H Piles Plug Conditions – Case Studies

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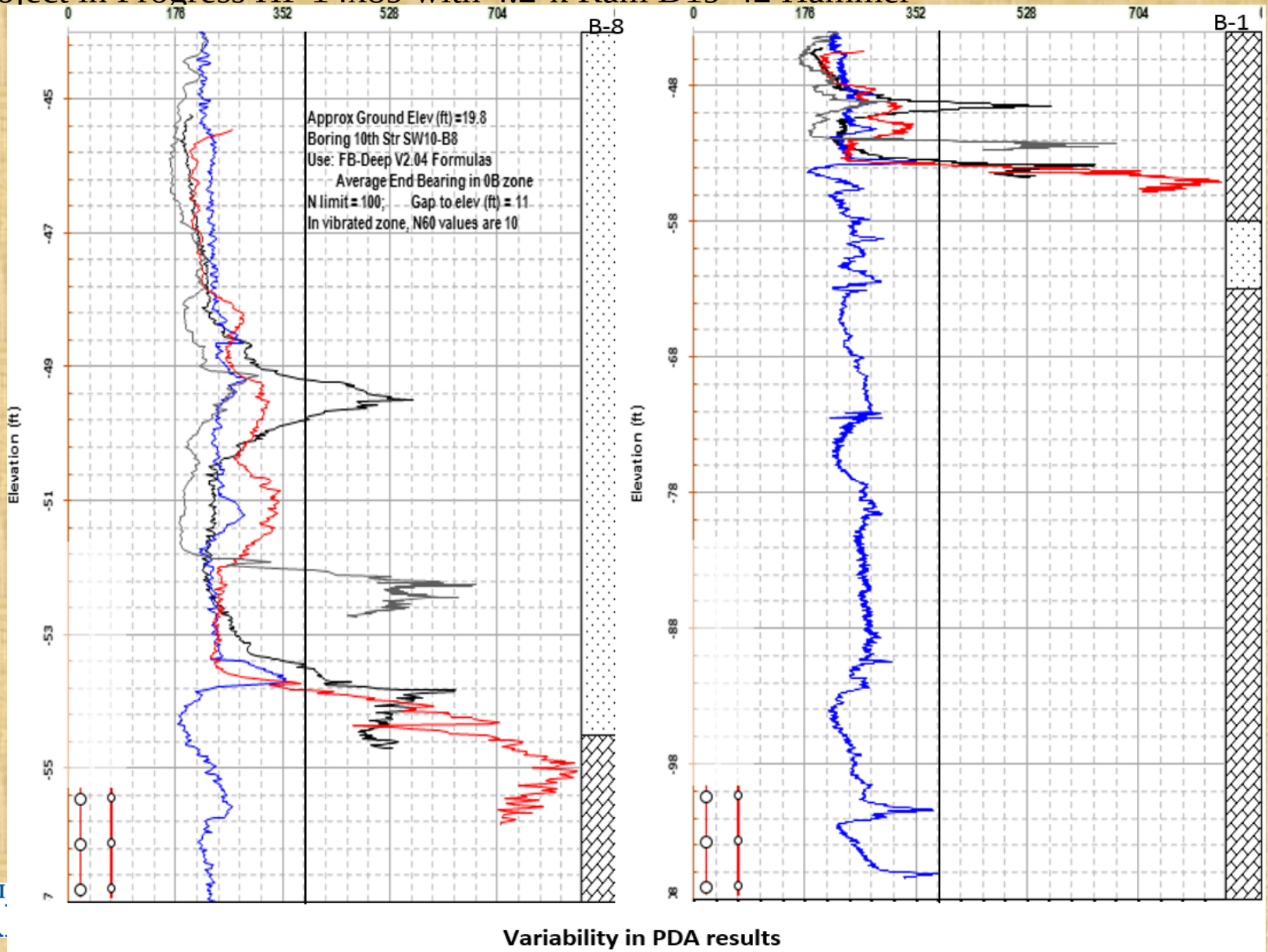
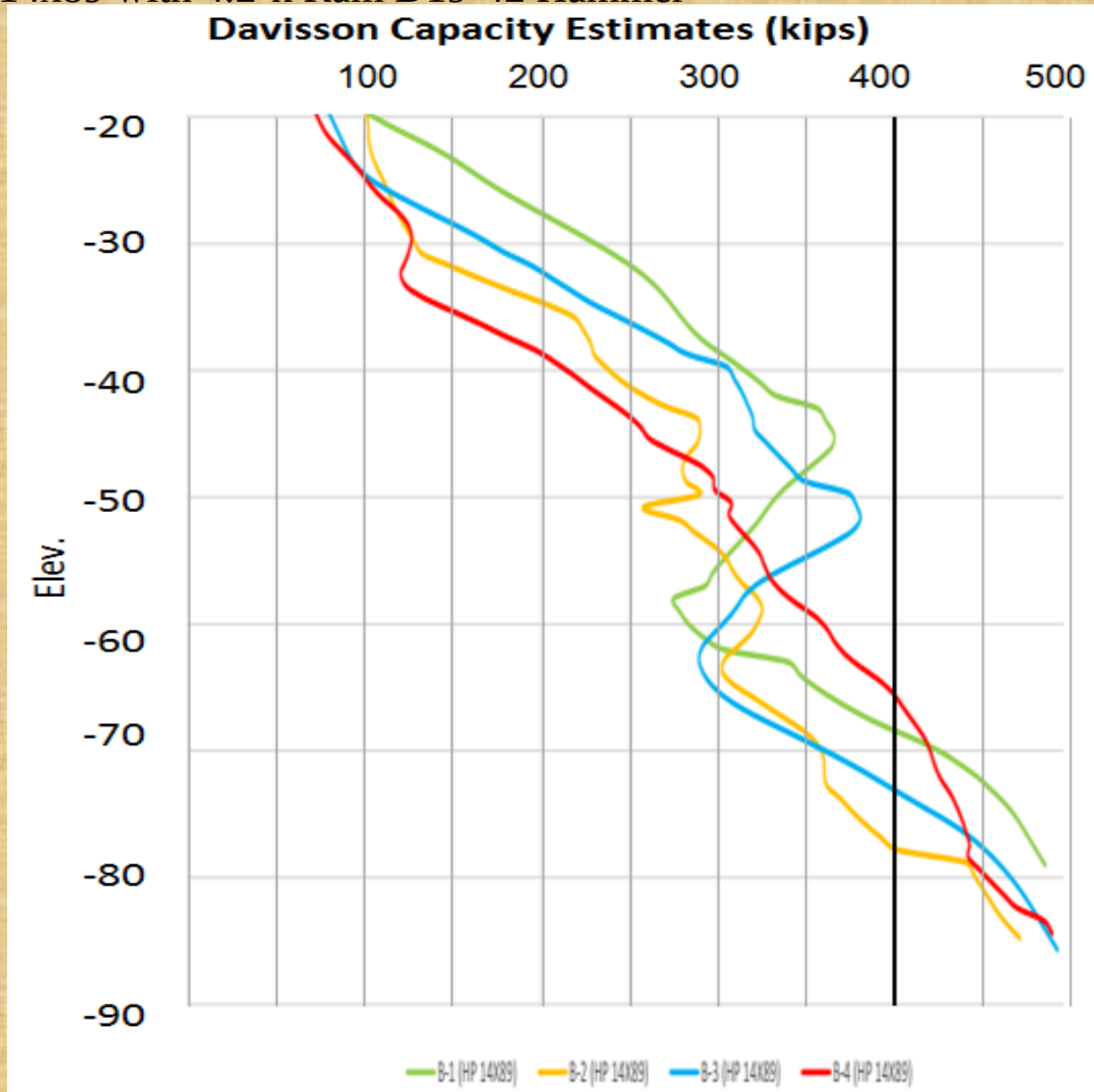


Variability in PDA results

H Piles Plug Conditions – Case Studies

1) Project in Progress HP 14x89 with 4.2-k Ram D19-42 Hammer

However, due to the averaging (8B+3.5B) and critical depth correction, all current FB-Deep curves looks quite similar, with all of them expecting 400 kips (required) at around elev. -70 ft. No curve is showing 500 to 700 kips at elev. – 50 to -56 ft.



H Piles Plug Conditions – Case Studies

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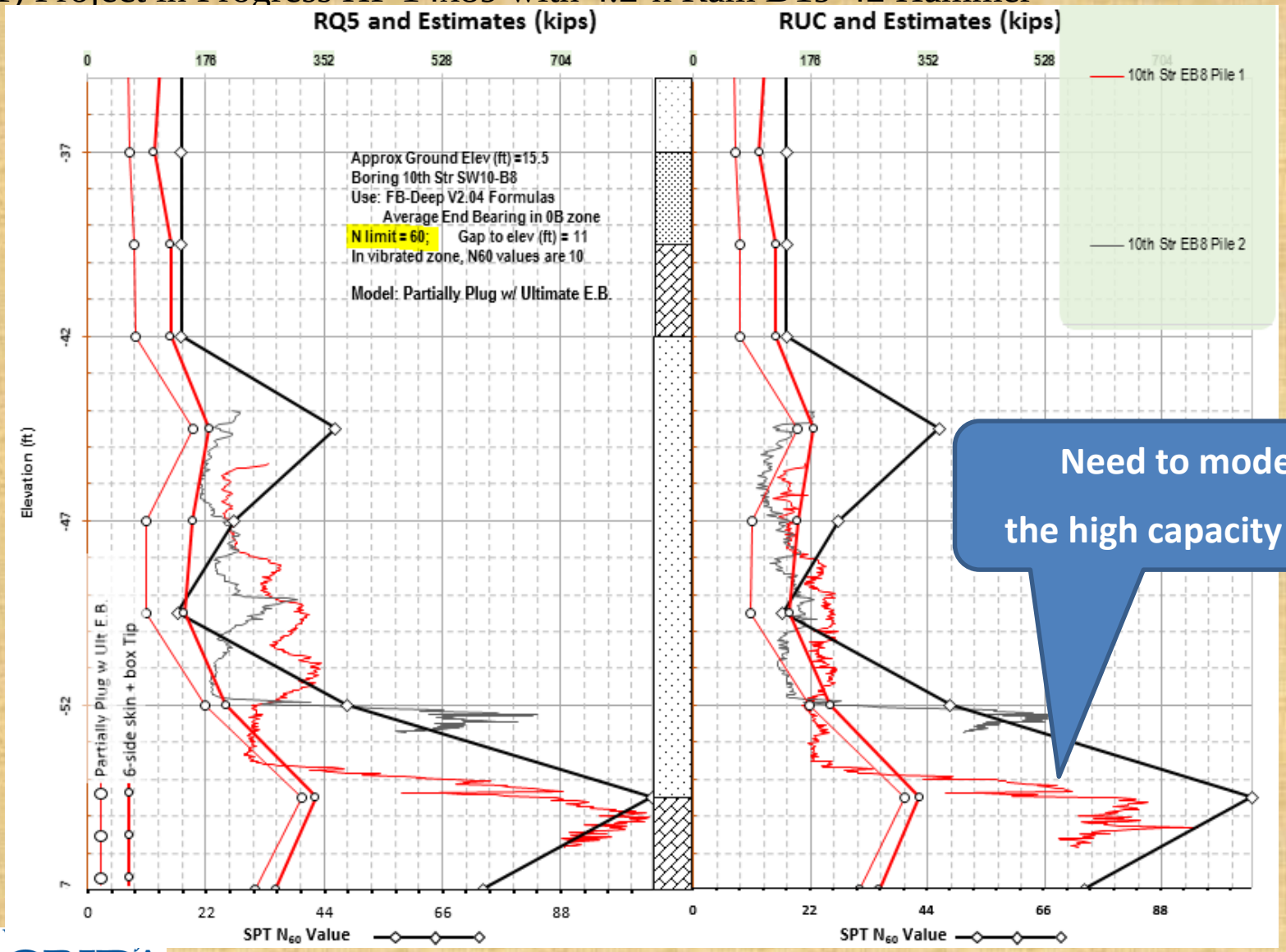
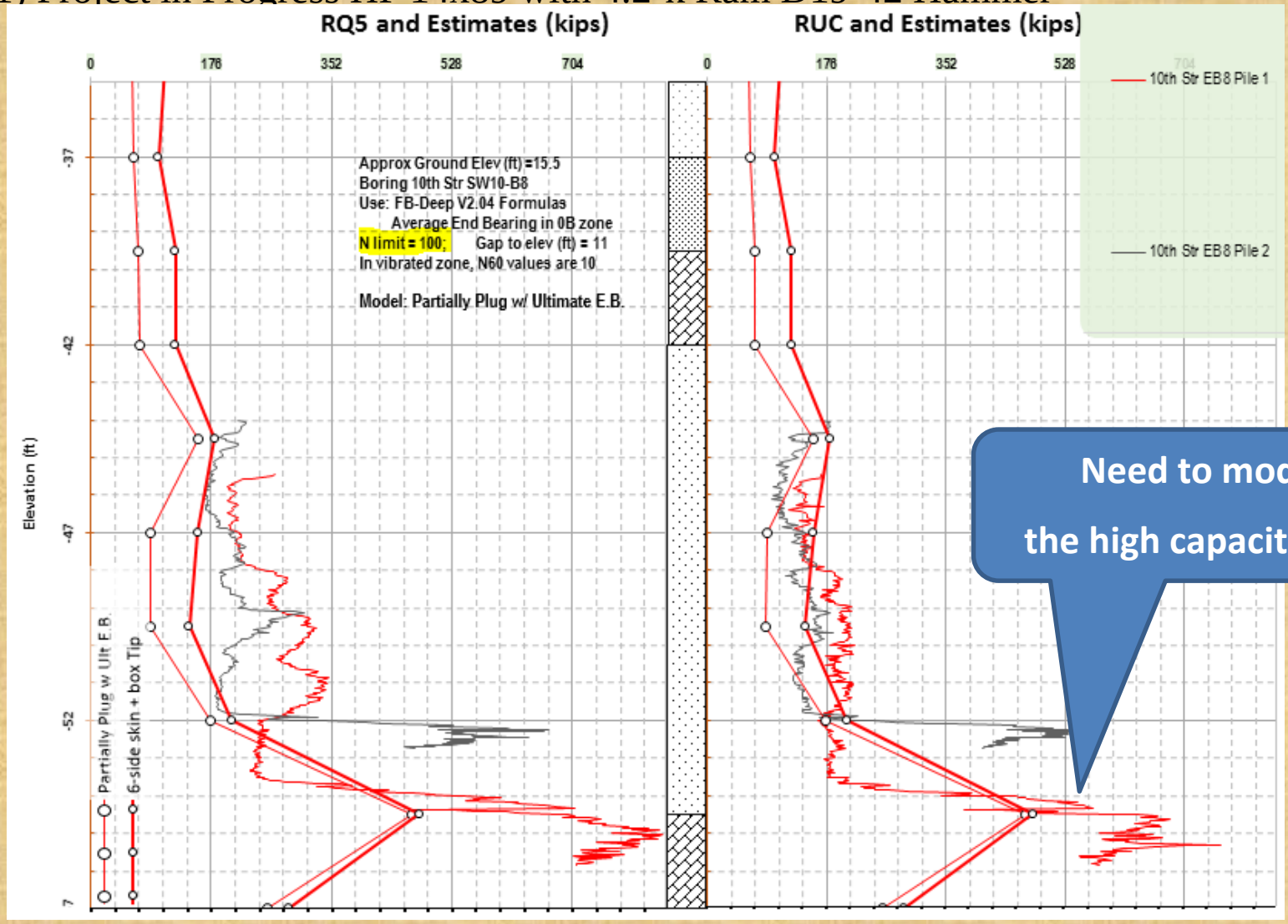


Research boring done within 3-ft of Pile

H Piles Plug Conditions – Case Studies

1) Project in Progress HP 14x89 with 4.2-k Ram D19-42 Hammer



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H Piles Plug Conditions – Case Studies

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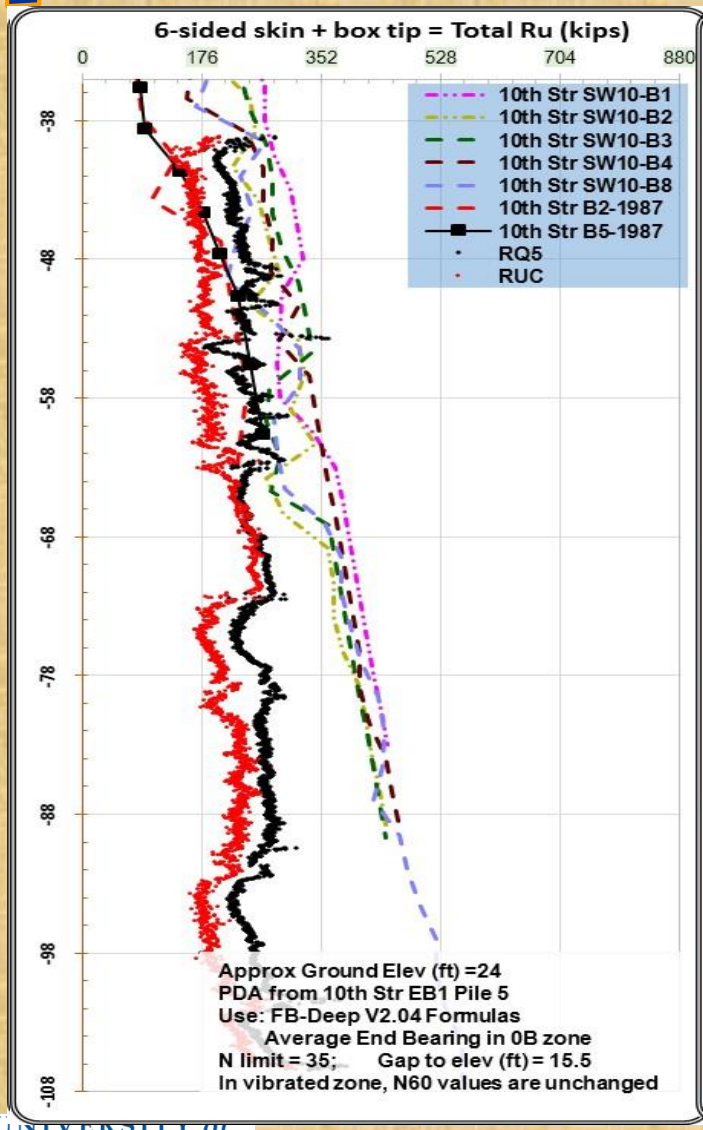
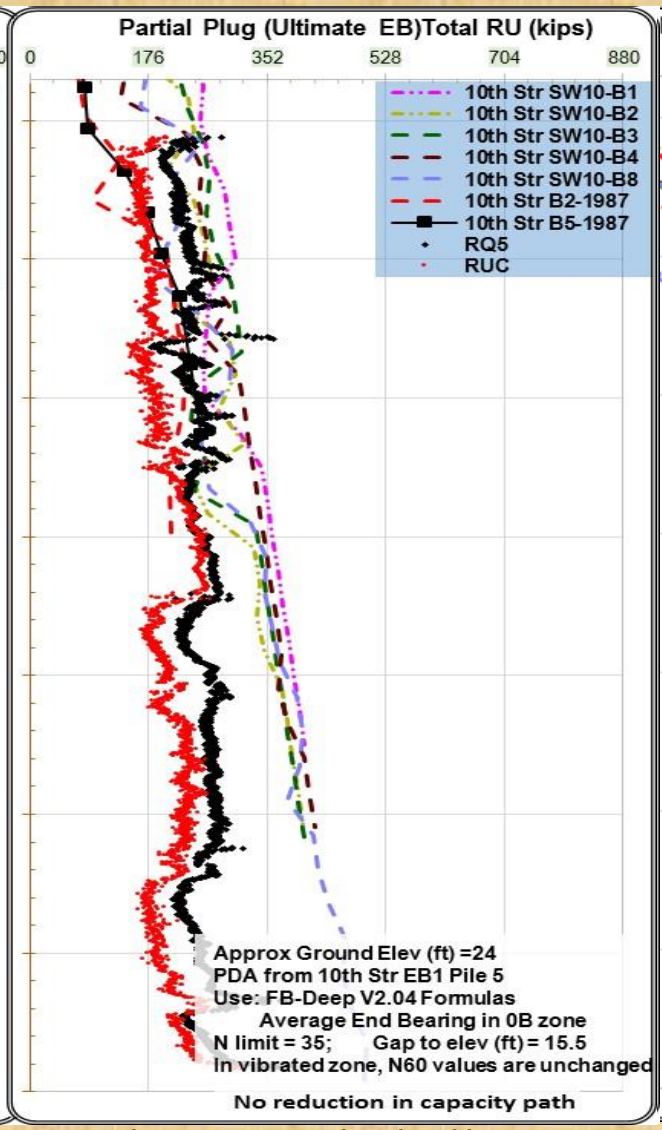
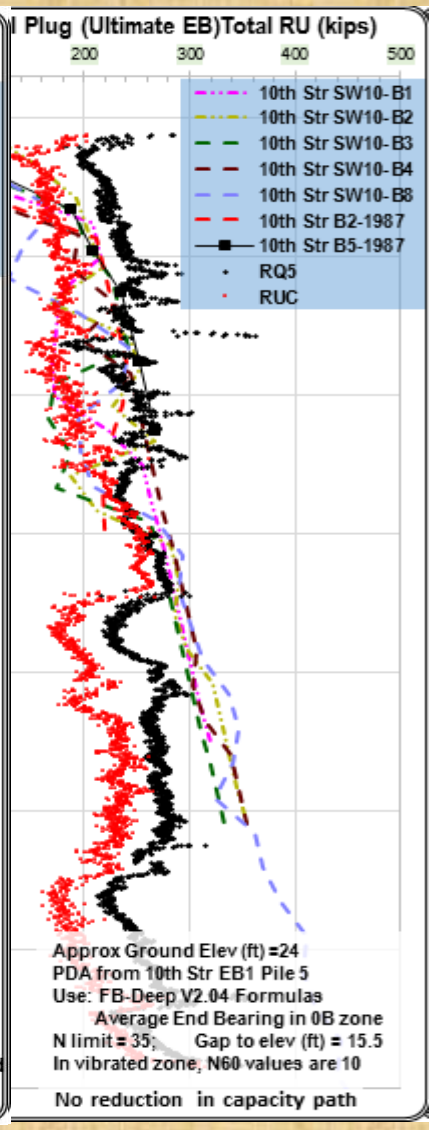




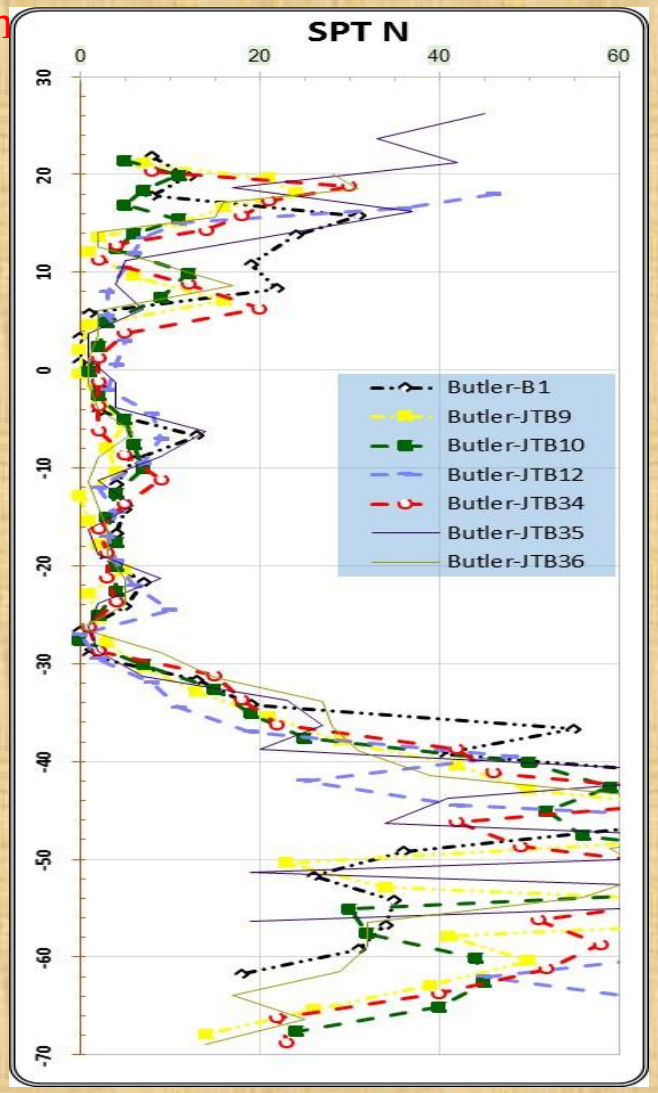


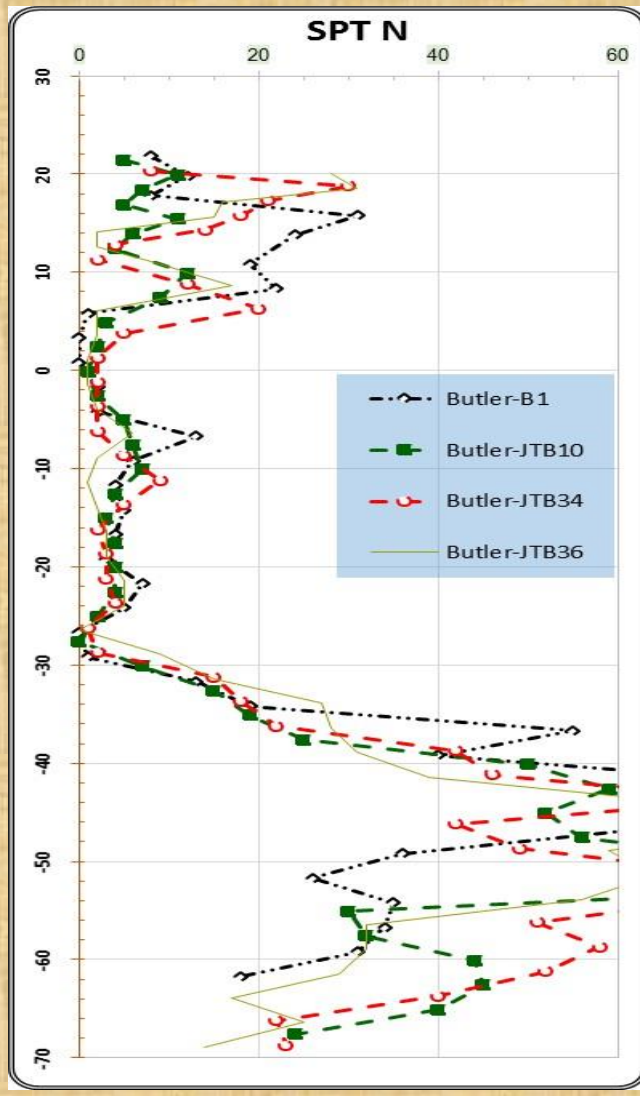
Bent 1, Pile 5 experienced no hard limestone.

N limited to lower values to reflect the thin limestone shelves; Vibrated Zone also has great influence

H Piles Plug Conditions – Case Studies

2) I-95 over Butler Blvd (Jacksonville) HP 14x89 with 6.6-k Ram D30-42 Hammer
Site is quite uniform





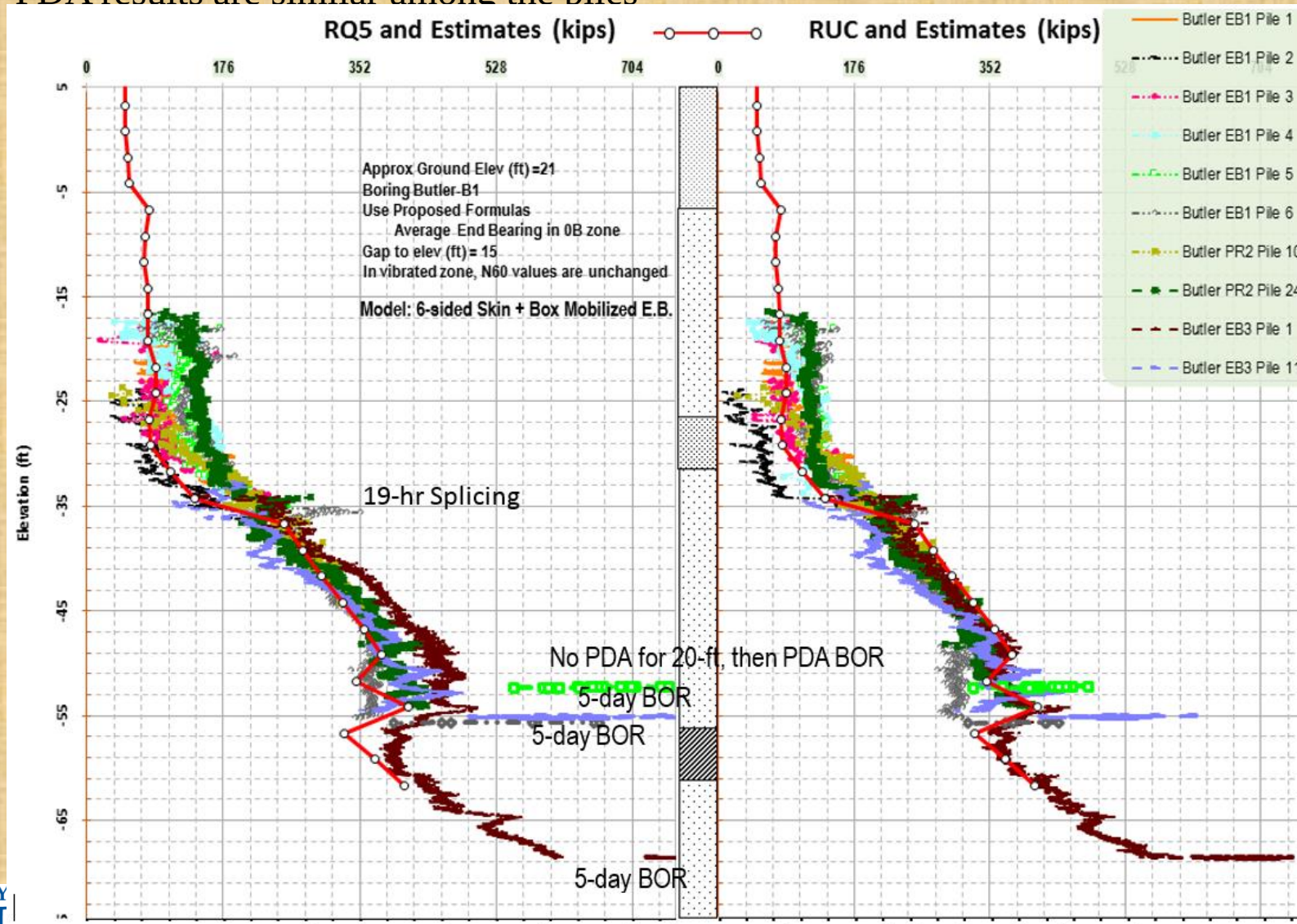
2 furthest borings are approx 200-ft apart

Borings closest to EB1 piles (within 100-ft)

H Piles Plug Conditions – Case Studies

2) I-95 over Butler Blvd (Jacksonville) HP 14x89 with 6.6-k Ram D30-42 Hammer

- PDA results are similar among the piles



PDA Results of EB1, Pier 2, and EB3 piles (compared to prediction from boring B-1)

H Piles Plug Conditions – Case Studies

2) I-95 over Butler Blvd (Jacksonville) HP 14x89 with 6.6-k Ram D30-42 Hammer

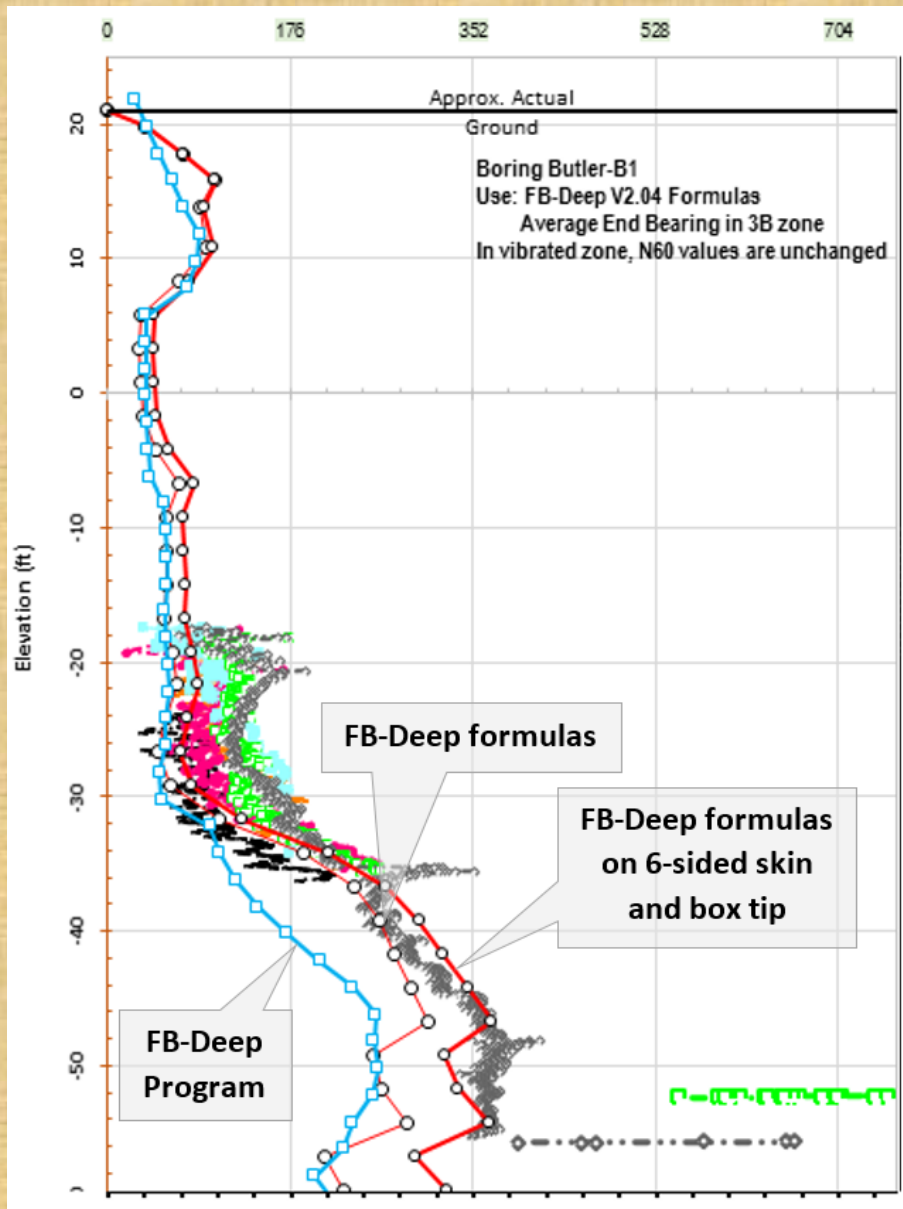
Ultimate skin friction in layers
above bearing layer = 25.58(tons)
Average SPT in Bearing layer
above tip = 46.24(blow/ft)
Ultimate skin friction in
bearing layer = **30.77(tons)**
Corrected Ultimate skin friction
in bearing layer = **18.08(tons)**
Total Skin Friction = 43.66(tons)
End bearing capacity
ELEVATION SPT Blows UNIT E. B.

(ft)	(Blows/ft)	(tsf)	
-34.41	26.57	28.34	<-- 8B above tip
-36.70	60.00	64.00	
-39.20	49.60	52.91	
-41.70	60.00	64.00	
-44.20	60.00	64.00	<-- Pile tip elevation
-46.70	78.12	64.00	
-48.48	54.22	52.30	<-- 3.5B below tip

Average unit end bearing above pile tip= 56.99(tsf)
Average unit end bearing below pile tip= 61.56(tsf)
Average unit end bearing of pile tip =59.28(tsf)

Critical depth of embedment in bearing layer = 14.69(ft)
Actual depth of embedment = 12.50(ft)

Maximum mobilized end bearing capacity = **83.63(tons)**
Corrected mobilized end bearing capacity = **74.68(tons)**



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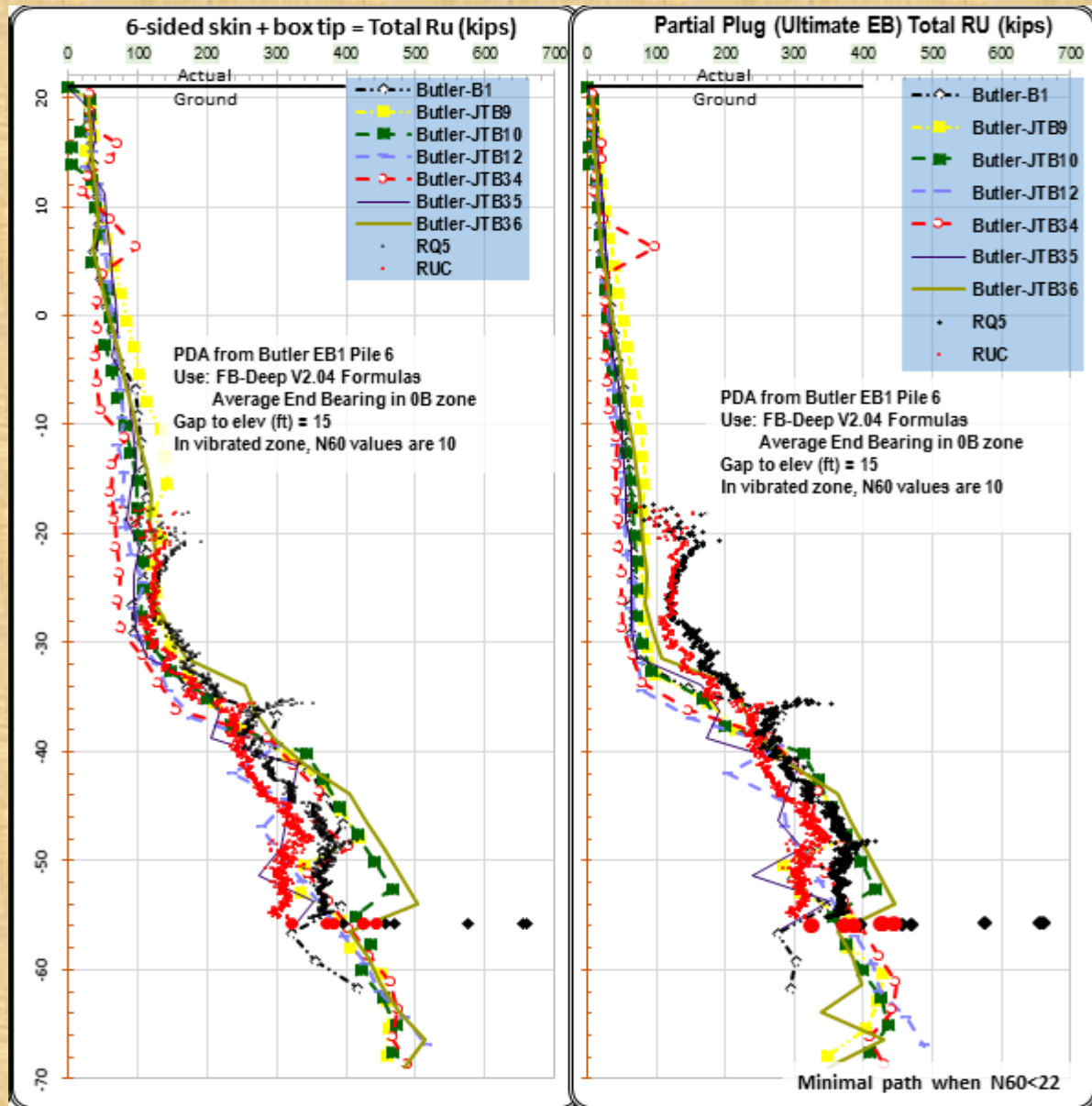
H Piles Plug Conditions – Case Studies

2) I-95 over Butler Blvd (Jacksonville) HP 14x89 with 6.6-k Ram D30-42 Hammer

Predictions of 7 borings within 200-ft agree well with the PDA results from EB1, Pile 6



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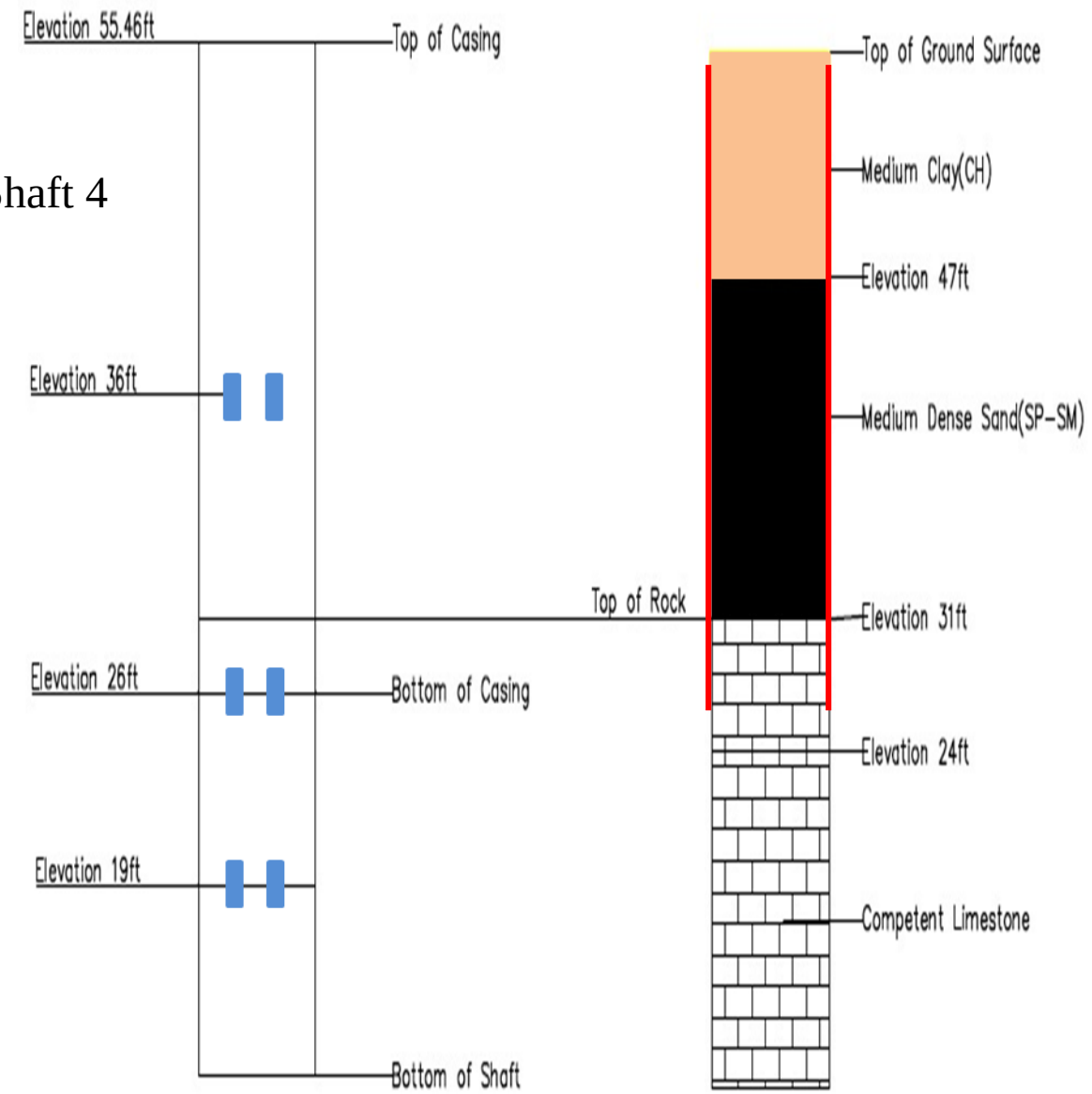
H Piles Plug Conditions – DRAFT RECOMMENDATIONS

1) Let Engineers decide Upper Limit of SPT-N (not default to N=60). E.g. Limit of 60, 80, or 100
2) If the limestone shelves are thin, let Engineers select Upper Limit of says N = 30 or 35
3) Resistance should be included when N < 5. To be still conservative, this lower limit can be N<2 or N<3. However, it is best for the Engineers to select this Lower Limit as well
4) Gap should be included in the analyses
5) In the Vibrated Depth, let the Engineers decide to overwrite the SPT-N values (e.g. N=10)
6) Average 8B+3.5B zone and Critical Depth correction maybe suitable for other soil types, but may not be suitable for H piles due to its shape.
7) Current formulas (including recently proposed formulas) will need to be further evaluated to best fit the results at other analyzed sites.
8) It appears that the following 2 models best reflect the PDA EOD results:
   (i) "6-sided Side Resistance" plus "Box Mobilized End Bearing"
   (ii) "Partially Plugged Side Resistance" plus "Partially Plugged Ultimate End Bearing"
9) All other models produce much lower capacity predictions (compared to PDA EOD results)
10) For BOR (long term) capacity, let the Engineers enter the setup factors for each layer. FB-Deep will then have 2 curves: EOD and Longterm. Example: Sand (Soil 3) – A_0 = 1 to 1.2
    Silt (Soil 2) – A_0 = 1 to 1.5
    Limestone (Soil 4) – A_0 = 1 to 2
    Clay (Soil 1) – A_0 = 1.2 to 2

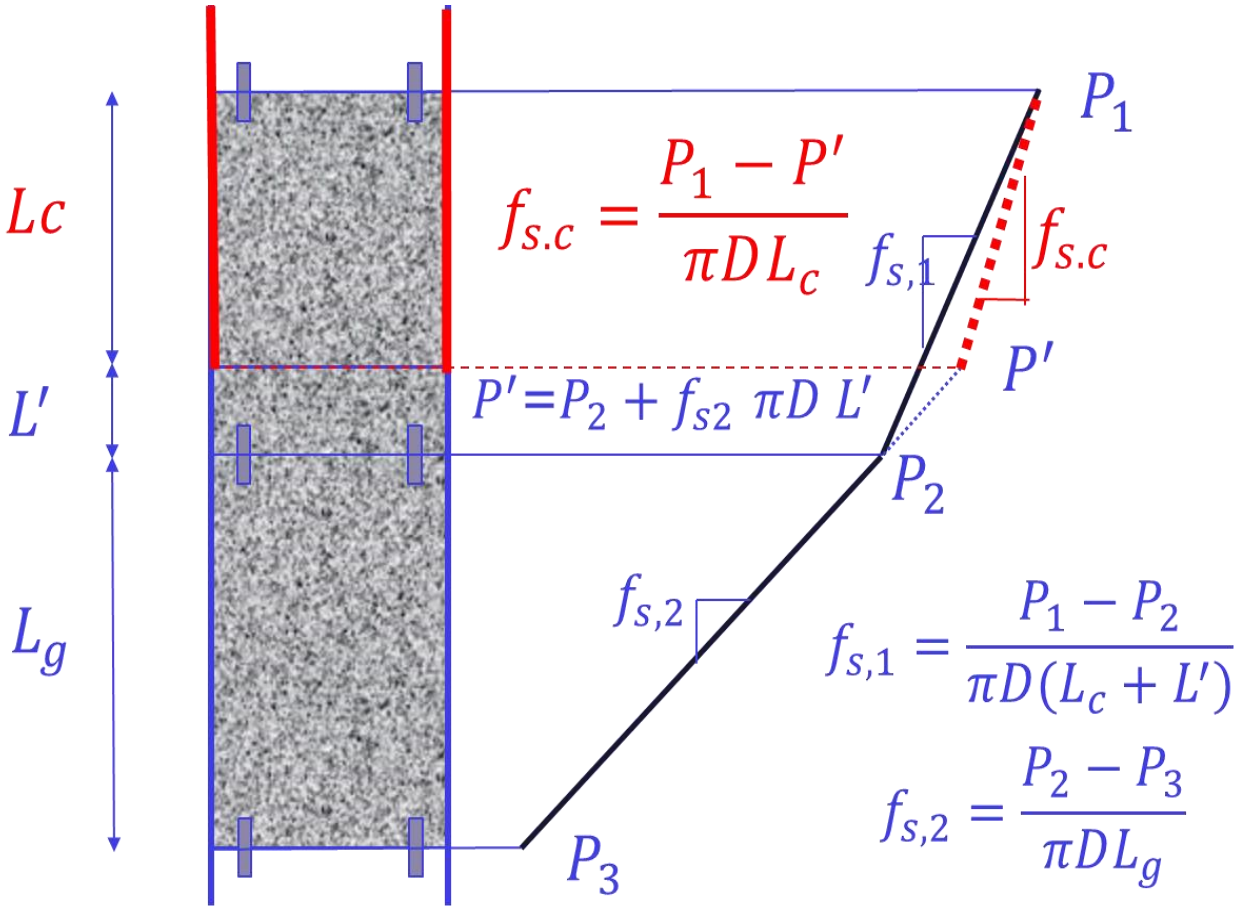
Side Friction of Cased Drilled Shafts in Limestone

Victory Bridge Pier 52 Shaft 4



Side Friction of Cased Drilled Shafts in Limestone

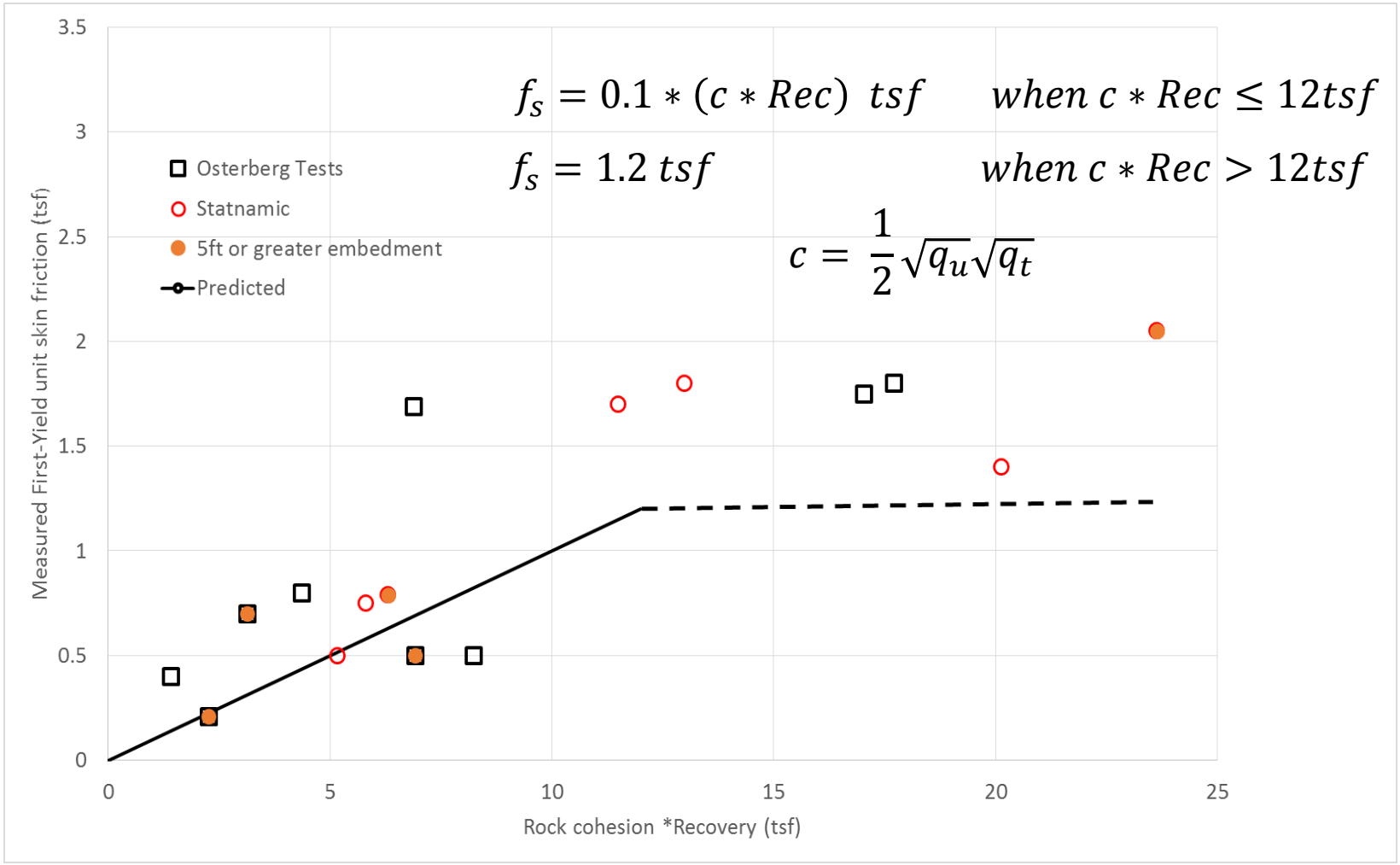
Casing Ends Between Instrumentation



7 Sites, 16 Cased Drilled Shafts in Limestone

Project Site	Load Test Shaft	Load Test Method	Embedment Depth in Limestone (ft)	Diameter (ft)	Unit Skin Friction & Displacement in Cased Zone					
					First-Yield		Peak		Residual	
					fs_y (tsf)	Disp (in.)	fs_P (tsf)	Disp (in.)	fs_R (tsf)	Disp (in.)
Gandy Bridge	Pier 26 Shaft 2	O-cell	2.5	4	0.5	0.030	1.1	0.321	0.5	0.536
	Pier 52 Shaft 3	Statnamic	1	4	1.7	0.340	2.8	0.488	2.4	0.488
	Pier 91 Shaft 4	O-cell	2.5	4	1.69	0.850	1.7	0.850	1.69	1.200
	Pier 26 Shaft 1	Statnamic	1	4	1.4	0.030	2.5	0.150	2.3	0.588
Victory Bridge	Bent 3 Shaft 2	O-cell	2.03	4	1.8	0.080	3.6	0.835	2.6	1.480
	Bent 3 Shaft 1	O-cell	1	4	1.75	0.090	3.4	1.549	2.7	1.965
	Test Shaft #5	Statnamic	5	4	2.05	0.030	2.9	0.472	2.9	0.472
Hillsborough Avenue	Pier 4 Shaft 4-1	O-cell	5	4	0.7	0.080	0.8	0.260	0.65	0.499
	Pier 4 Shaft 4-2	O-cell	3.7	4	0.8	0.170	1.17	0.498	1.17	0.498
	Pier 5 Shaft 10	Statnamic	10.33	4	0.79	0.220	1.06	0.465	1.06	0.465
Lee Roy Selmon	Test Shaft #3	Statnamic	4.4	4	1.8	0.400	2.4	1.290	2.4	1.290
17^{th} Street	LTSO-1	O-cell	9.2	4	0.5	0.020	0.91	0.071	0.91	0.071
	LTSO-2	O-cell	18.5	4	0.21	0.040	0.23	0.057	0.23	0.057
Apalachicola River	Pier 59, TS#8	O-cell	3	9	0.4	0.100	0.82	0.574	0.82	0.574
Jewfish Creek	Test Shaft #1	Statnamic	2	4	0.5	0.022	1.5	0.215	1.5	0.215
	Test Shaft #2	Statnamic	2.5	4	0.75	0.037	1.05	0.072	0.75	0.264

Side Friction of Cased Drilled Shafts in Limestone



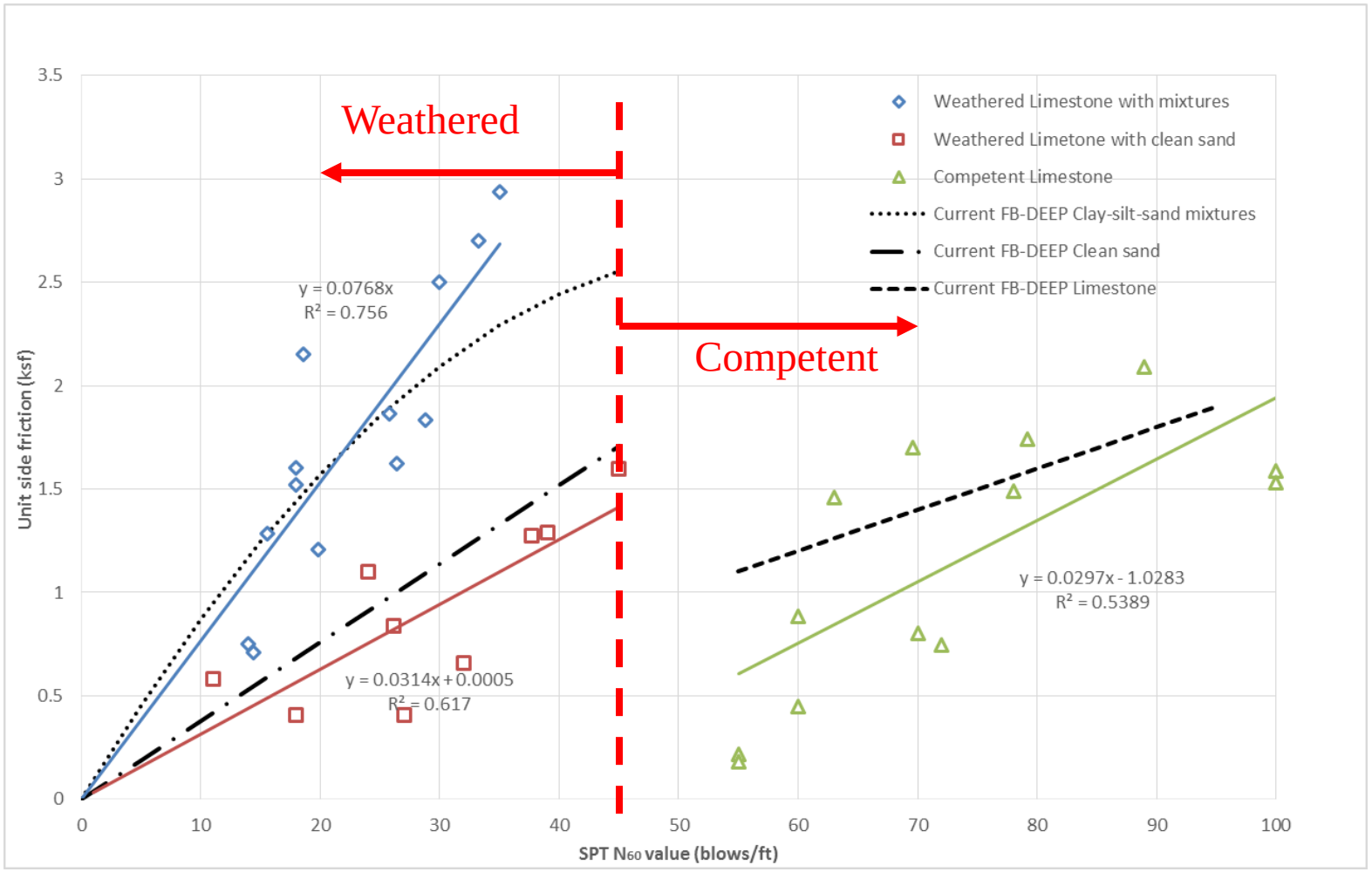
Collection of In Situ and Pile Data for FB-DEEP

Sites with Prestressed Concrete Piles Evaluated in Florida:

Site Information		Insitu Information		Pile Information		
Project Number (Financial)	Project Site	# of Soil Borings	Predominant Soil Type	Dimensions (in)	Length (ft)	# of Piles with CAPWAP
242484-2-52-01	I-4/SR 408	58	Sand	18 & 24	90 - 107	112
210448-2-52-01	San Sebastian Bridge	11	Sand & Clay	24	38 - 111	111
211449-1-52-01	CR 229 over South Prong of St. Mary's River	2	Sand & Clay	18	47 - 90	14
209293-2-52-01, 209294-1-52-01, 209294-9-52-01	SR 98	121	Sand & Rock	24	45 - 119	183
208166-1-52-01	Plantation Oaks Boulevard over SR 23	50	Sand & Rock	18	55 - 100	11
208466-2-52-01	SR 51	6	Clay & Rock	24	73 - 99	5
420809-3-52-01	I-595	234	Sand & Rock	18 & 24	30 - 115	170
213304-3-52-01	I-95 Overland Bridge Replacement	133	Sand & Rock	24	22 - 66	5
406813-6-52-01	CR 245 over Olustee Creek	10	Sand & Rock	24	61 - 69	7
210687-3-52-01	SR 200 North of Callahan	11	Clay & Rock	24	36 - 66	25
429551-1-52-01	SR 200 South of Callahan	31	Sand & Rock	24	46 - 111	33
422796-1-52-01 & 422796-2-52-01	I-95 over Snake Creek	5	Sand & Rock	18	55 - 80	8
	Total # of Soil Borings:	**672**		**Total # of Piles with CAPWAP Data:**		**684**
				Total # of Piles with Limestone Bearing Layer:		**264**
				Total # of BOR CAPWAP Analyses on Piles with Limestone Bearing Layer:		**65**

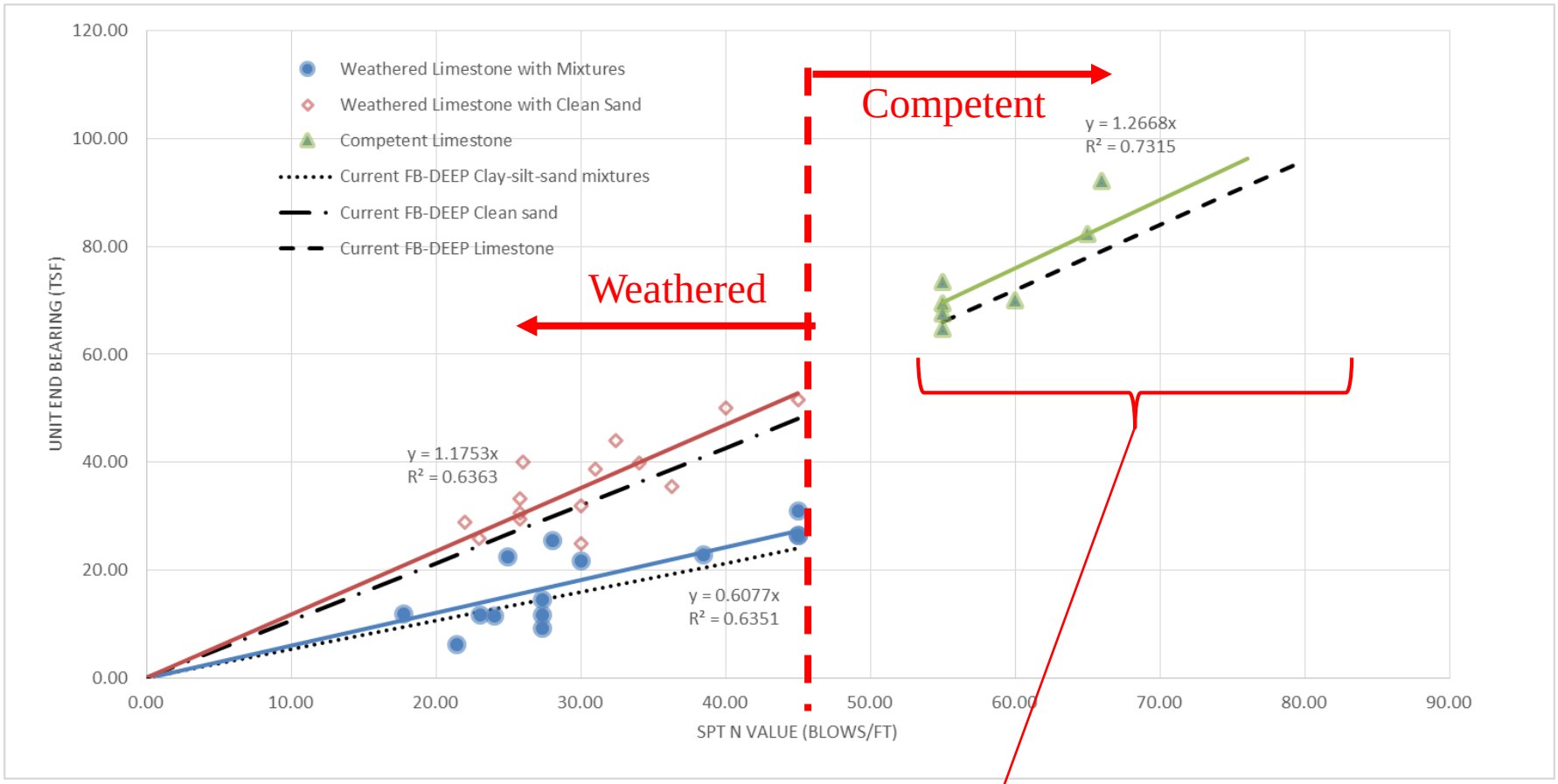
Analysis of PCP in weathered& Competent Limestone

Unit Side Friction:



Analysis of PCP in weathered& Competent Limestone

Unit End Bearing (Average N – 8B below):



Currently Adding Palmetto Expressway, District 6 (19 Bridges PCP in Limestone)

Thank You