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ACIP PILE PERFORMANCE AND INSTALLATION IN THE NORTHEASTERN UNITED STATES

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ABSTRACT

Augered-cast-in-place (ACIP) pile installation technology has matured extensively since the first auger, pressure grouted pile was patented in 1959. The current technology allows for successful pile installation across a variety of stratigraphies to meet various project load resistance requirements. This paper presents an overview of current ACIP techniques by comparing a number of case histories in a variety of geologic settings from Eastern Pennsylvania, New York City and New Jersey to demonstrate ACIP pile constructability in soft soils as well as the penetration, and resulting significant loads resisted, of ACIP piles in dense soils and intermediate geo-materials. Geologic settings that will be discussed include the Piedmont and Coastal Plain geologic provinces as well as glacial till deposits.

Keywords: Deep Foundations, Piles, Augercast, Augered-cast-in-place, Auger pressure grouted, ACIP, APG

INTRODUCTION

The author, along with two colleagues, published an article in Deep Foundations magazine (NeSmith et al, 2013) which described a number of the advances in equipment, techniques, installation monitoring and post-construction testing that have expanded the geologies in which Augered Cast-in-place (ACIP) piles are installed as well as increasing their efficiency in some traditional ACIP pile geologies. The author uses the term efficiency to refer to the load resisted by a pile of a certain diameter and the increased efficiency noted refers to increased allowable loads over those traditionally resisted by piles of certain diameter (or a reduction in pile diameter from that which was traditionally used to support a certain design load). The performance and installation of ACIP piles in a variety of geologies in the Northeastern U.S. are discussed herein.

PIEDMONT PHYSIGRAPHIC PROVINCE

The Piedmont physiographic province stretches from Alabama to the east through Georgia and up the east coast, just west of the Coastal Plain to Pennsylvania and New York (Brown, 2002). It generally consists of soils weathered in place from the underlying bedrock, which is typically a combination of granite, schist and gneiss depending on the location within the province. The author's experience in the Northeastern US has been on sites where alluvial or coastal plain soils overly the residual soils and partially weathered or intact rock of the Piedmont. The example presented here, from a site on Walnut St in Philadelphia PA, is representative of these projects.

A log of boring with the representative stratigraphy at the site is presented in Figure 1. The stratigraphy includes urban fill and four layers of alluvial soils over residual soil (referred to as weathered rock) with SPT N-values of 80 to 100. Not shown are the underlying weathered rock with N-values > 100 (a drillable intermediate geo-material often referred to as Partially Weathered Rock, PWR) and auger refusal on bedrock.

Project requirements called for piles to be installed from a basement level approximately 25-ft below boring level. The resulting test pile (with applied compressive load vs pile-head deflection shown in Figure 2) was approximately 60-ft long. It can be seen that there is a small change in slope of the load-deflection plot at a load of about140 tons, after which the relationship is fairly liner to the maximum applied load of 500 tons (the design load of the piles was 200 tons).

Depth (ft)	Sample Number Depths Below Surface (ft)	Standard Penetration Test Results 0-6"	6-12"	12-18"	18-24"	"N" Value (bpf)	Visual Description / Comments
0	S - 1	2	18	50/4		**68/10**	0.3 ft 4 inches of TOPSOIL
	0' - 2'	Sample Recovery =			11		
	S - 2	8	7	8	5	**15**	Medium compact to very compact grayish brown Silty fine to coarse SAND, some Concrete, Brick, Asphalt, Coal, and Steel fragments (Urban Fill) *Hard drilling through obstructions.
	4' - 6'	Sample Recovery =			14		
	S - 3	5	12	11	7	**23**	
	6' - 8'	Sample Recovery =			10		
	S - 4	16	19	32	21	**51**	
10	8' - 10'	Sample Recovery =			17		
	S - 5	6	7	21	25	**28**	
	14' - 16'	Sample Recovery =			9		
	S - 6	39	31	36	53	**67**	20.0 ft
20	19' - 21'	Sample Recovery =			12		Compact to very compact dark yellowish brown Silty fine to coarse SAND, trace to some fine to coarse Gravel (Alluvial Soil - A)
	S - 7	11	14	17	17	**31**	
	24' - 26'	Sample Recovery =			2		
	S - 8	19	37	29	13	**66**	
30	29' - 31'	Sample Recovery =			15		
							34.0 ft
	S - 9	3	4	5	6	**9**	Stiff light gray to dark gray Clayey SILT, interbeds of fine to medium Sand, trace Organic Matter (Alluvial Soil - B)
	34' - 36'	Sample Recovery =			15		
	S - 10	1	4	7	10	**11**	
40	39' - 41'	Sample Recovery =			22		

Depth (ft)	Sample Number Depths Below Surface (ft)	Standard Penetration Test Results 0-6"	6-12"	12-18"	18-24"	"N" Value (bpf)	Visual Description / Comments
40							Stiff light gray to dark gray Clayey SILT, interbeds of fine to medium Sand, trace Organic Matter (Alluvial Soil - B)
							44.0 ft
	S - 11	1	4	5	12	**9**	Medium compact orangish brown Silty fine to coarse SAND, trace fine to coarse Gravel (Alluvial Soil - C) * Heaving soils in auger at 54 feet.
	44' - 46'	Sample Recovery =			16		
	S - 12	7	10	15	17	**25**	
50	49' - 51'	Sample Recovery =			19		
	S - 13	11	17	12	23	**29**	
	54' - 56'	Sample Recovery =			21		
							59.0 ft
	S - 14	24	40	37	35	**77**	Very compact brown Gravelly fine to coarse SAND, little(+) to some(-) Silt (Alluvial Soil - D) * Cobbles and boulders at 69 feet.
60	59' - 61'	Sample Recovery =			12		
	S - 15	4	19	44	45	**63**	
	64' - 66'	Sample Recovery =			13		
	S - 16	16	28	29	50/5	**57**	
70	69' - 70' 11"	Sample Recovery =			15		
	S - 17	50/3				**50/3**	
	74' - 74' 3"	Sample Recovery =			2		
							77.0 ft
	S - 18	25	32	50/5		**82/11**	Very compact bluish gray Micaceous Silty fine to medium SAND, little Quartzite fragments (Decomposed Rock)
80	79' - 80' 5"	Sample Recovery =			14		

Figure 1 – Boring showing Alluvial Soil Over Weathered Rock of Piedmont

In the author's experience, these results are typical where modern techniques are employed to ensure auger penetration through the PWR to refusal on the underlying bedrock. These include using a gearbox with appropriate torque, an auger tip with teeth conducive to penetrating the very densely packed PWR, and often introducing compressed air to force the PWR up the auger flights. The allowable load on an ACIP pile so installed is typically limited by structural code limitations rather than geotechnical capacities. Thus, rather large compression loads (e.g. over 200 tons on a single 18-in diameter pile or 500 tons on a single 24-in diameter pile) can be resisted. ACIP piles can then be very efficient due to the speed at which they can be installed (typically one drill down and one withdrawal as the pile is cast) as well as the cost of grout compared to the cost of steel for an equivalently loaded driven pile. In urban areas, such as the subject site, the relative reduction in noise and vibrations compared to driven piles is also advantageous. It should be noted that if insufficient equipment or techniques are used and refusal is encountered at or within the PWR, the geotechnical capacity may govern and the pile may not perform as efficiently as it could have. Also, where the underlying bedrock of the Piedmont is very shallow or very large axial or lateral loads are to be resisted (particularly within a small footprint), large diameter drilled shafts may be more efficient than large groups of ACIP piles.

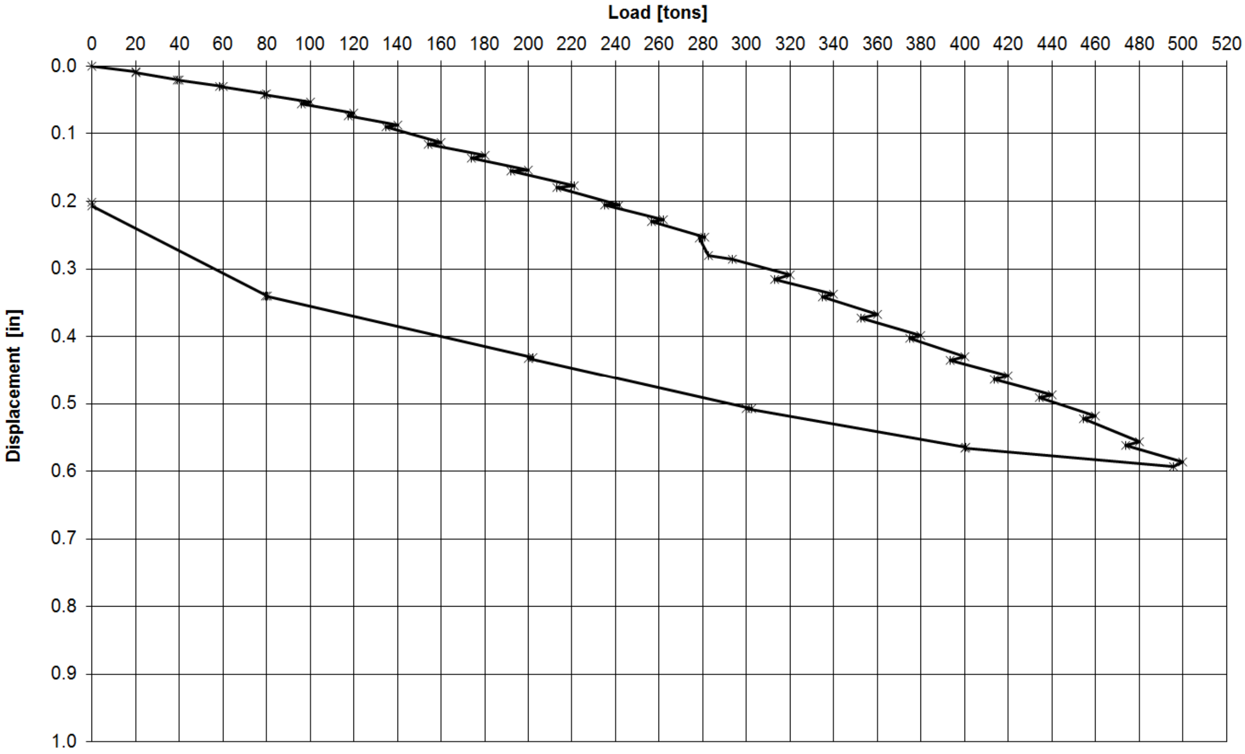


Figure 2 – Applied Compressive Load vs. Pile-head Displacement – 18-in dia. ACIP Pile x 59-ft

SOFT ALLUVIAL SOILS

In contrast to the previous example, soft soils are easily penetrated by augering, however, constructability and pile shaft integrity may be questioned without appropriate monitoring and post-construction verification testing. The following example is from an industrial/utility site adjacent to the Raritan River in Sayreville NJ. The site included existing facilities in close quarters. The proposed expansion was within the footprint of existing facilities. Because of this, the owner/designer preferred a drilled and grouted system to reduce noise and vibrations during installation.

Design compression loads were 60 tons per pile an although a 12-in diameter bored pile would have been suitable based on structural code limitations, due to the presence of very soft alluvial deposits, 14-in diameter piles were proposed to provide excess pile diameter beyond the structural requirements.

The results of a Cone Penetrometer Test (CPT) are shown in Figure 3 and results of a Dilatometer Test (DMT), performed due to the very low qt values recorded during the CPT, are shown in Figure 4. Based on the interpreted shear strengths from the DMT, it was considered that the 14-in piles could be successfully installed into the lower dense alluvial sand to the underlying bedrock (see refusal level in Figure 3).

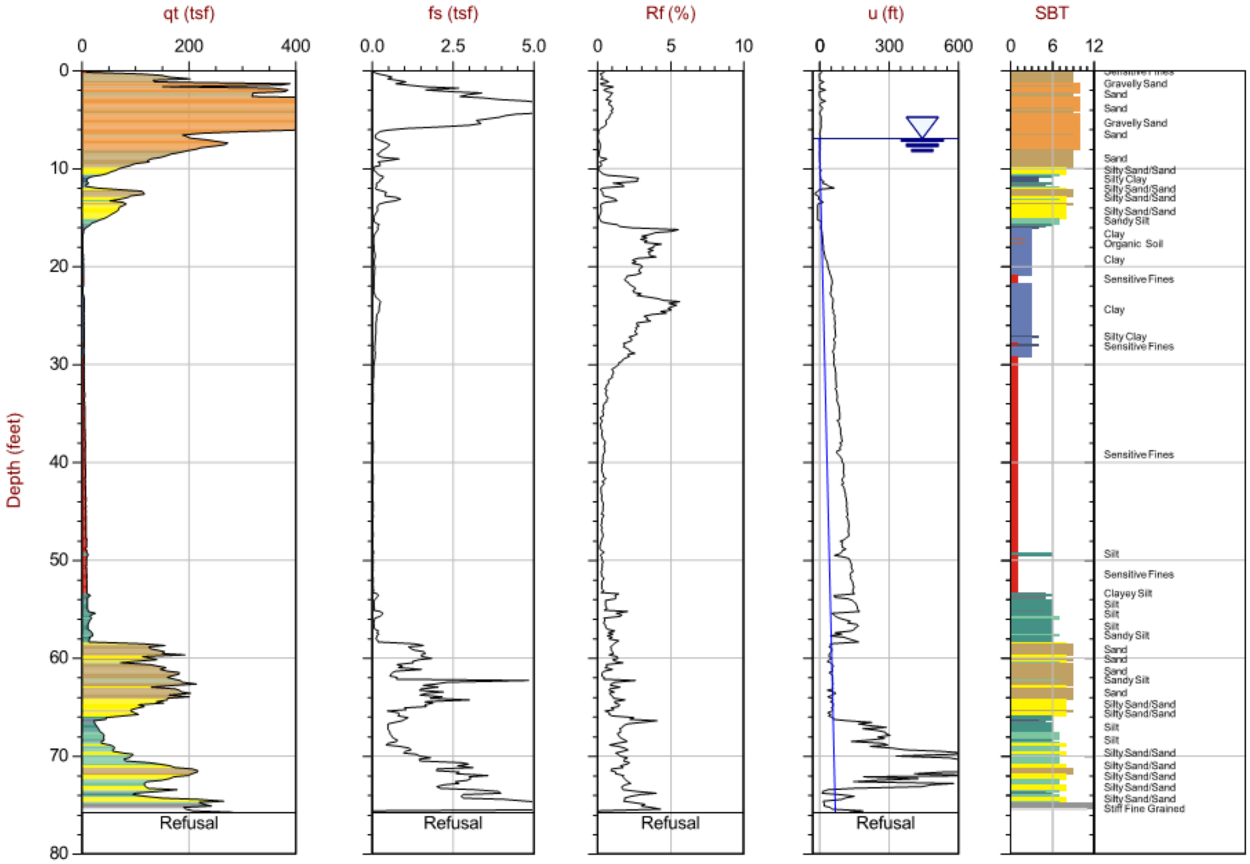


Figure 3 – CPT Result from Soft Alluvial Site

Shaft integrity of the piles was verified by using Thermal Integrity Profiling. In this method, a wire with temperature sensors located at 1-ft intervals is attached to the center bar inserted into the pile and temperature along the entire length of the pile is automatically recorded through the peak heat of hydration (typically for 24 to 36 hours). There is also a method where a PVC tube is attached to the center bar and a temperature probe is lowered through the tube to measure temperature along the length of the pile, however the wire method was used for the subject project. The temperature at the peak heat of hydration is plotted with depth and the diameter of the pile is then estimated from the temperature vs. depth readings along with the volume of grout placed in the pile.

For the subject project, the test pile and twenty percent of production piles were profiled. Temperature vs. depth and the corresponding estimated pile radius of the compression test pile at the subject site are presented in Figure 5. It can be observed that the estimated pile radius increased in the very soft soils until such depth as the shear strength of the soils increases to a level as to prevent this increase and keep the pile radius closer to plan.

The pile radius in the dense alluvial soils is also much closer to plan, as would be expected. For this project, assuring the grouted piles had the appropriate diameter when completed was more important than the particular installation equipment selected. This relatively new method of evaluating the diameter of cast-in-place piles allowed for the use of ACIP piles, which could be installed more quickly than other cast-in-place methods, used less expensive materials than driven steel piles, and avoided vibration issues with the new facilities being situated directly between and next to existing facilities.

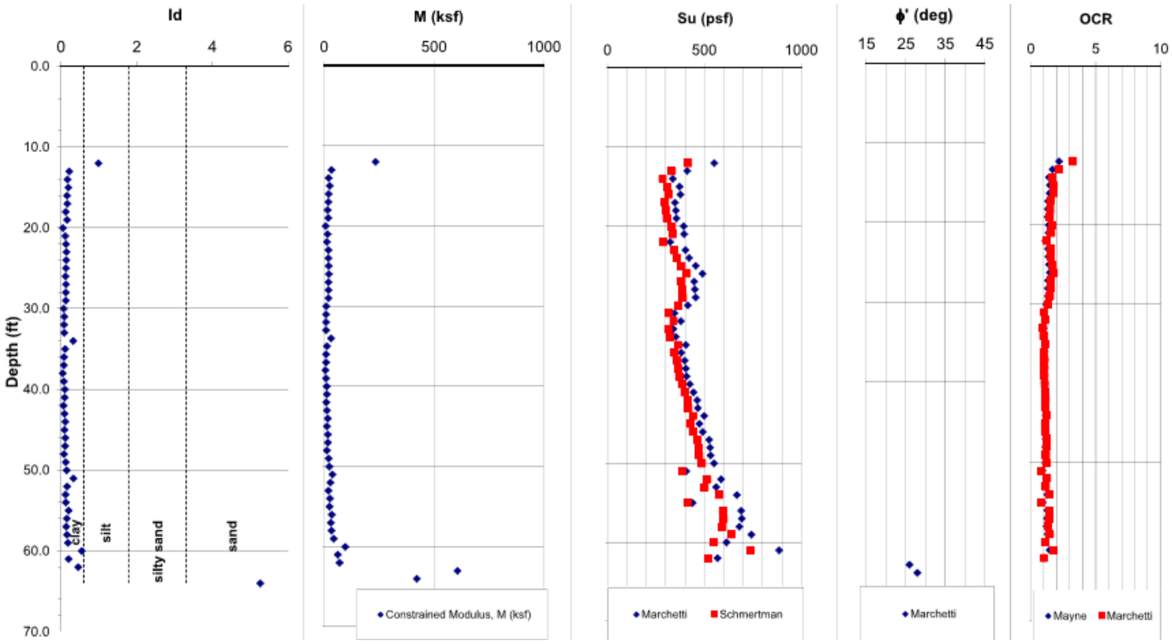
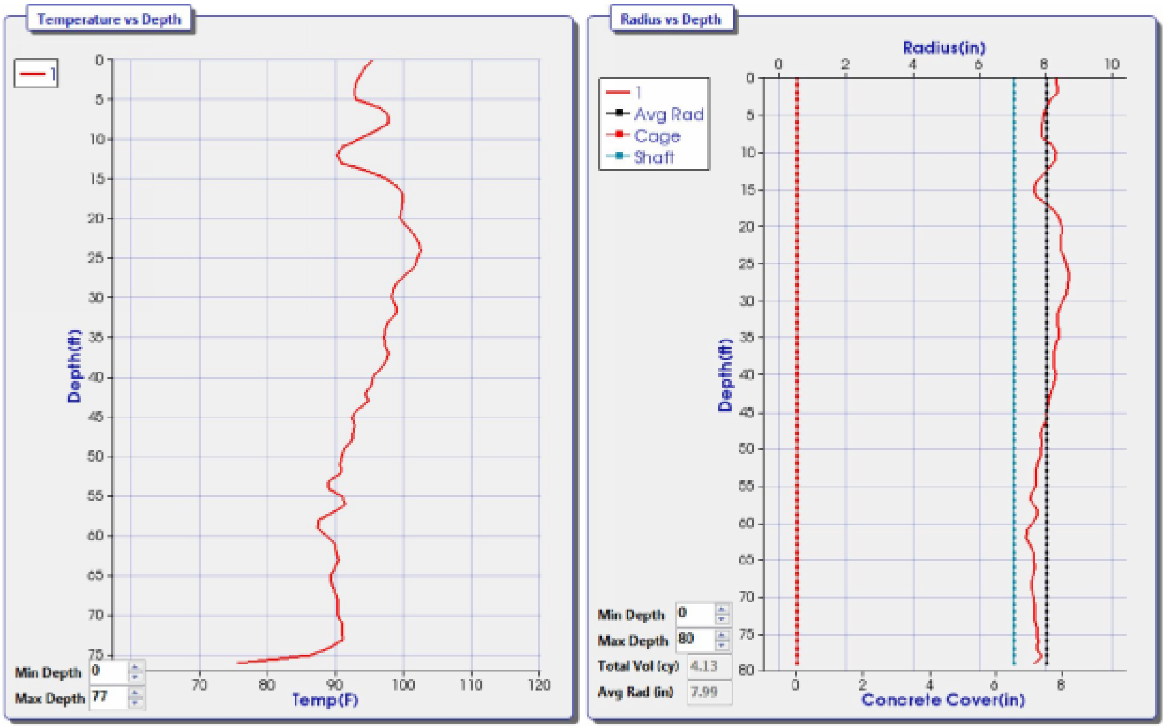


Figure 4 – Dilatometer Results from Soft Alluvial Site



Min Depth 0
Max Depth 77

Min Depth 0
Max Depth 80
Total Vol (cy) 4.13
Avg Rad (in) 7.99

Figure 5 – Thermal Integrity Profiling of 14-in dia. x 76-ft ACIP Pile

SOFT TO STIFF COASTAL PLAIN SOILS

Coastal Plain soils in the Northeastern US often consist of interbedded layers of various density and soil make-up from the deposition (and often subsequent partial erosion) of these soils during different historic geological events. Figure 6 is a CPT result from a typical site in Mercer County NJ and is an excellent example of this. Fill soils and medium dense sands overly firm fine-grained soils, below which are a layer of dense sand followed by a heavily overconsolidated fine-grained deposit. ACIP piles were proposed to resist 200-ton design compression loads. Based on available design methods for coarse and fine-grained soils, 18-in diameter ACIP piles to a depth of 80-ft below boring level were proposed.

In this example, it is important for an ACIP pile to quickly penetrate the dense sands from 40-ft to 55-ft depth, as well as the stiff to hard fine-grained soils below, so as not to over-excavate any sandy soil layers. This requires a gearbox with significant torque and in this example, the potential introduction of compressed air in the lower fine-grained stratum to aid in moving these stiff to hard soils up the auger flights.

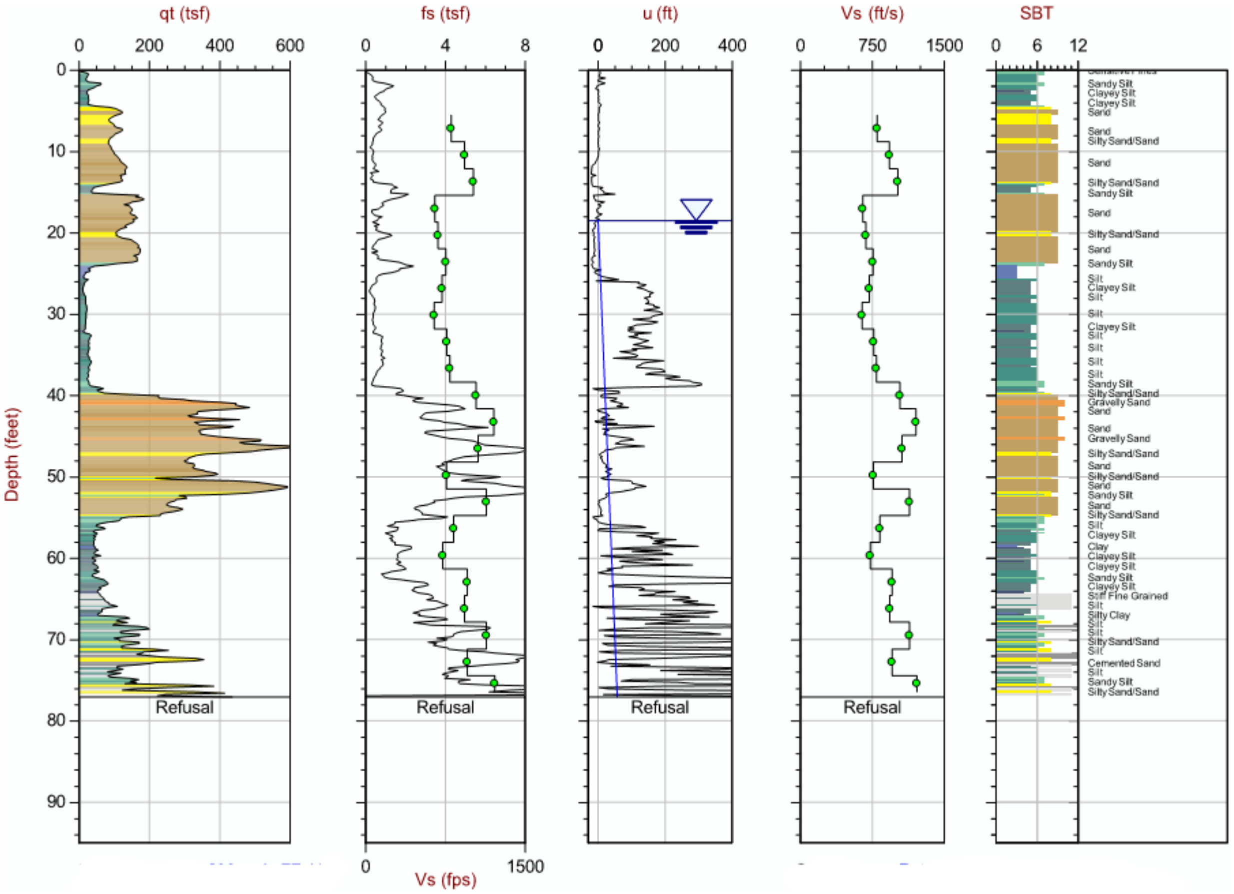


Figure 6 – CPT of Interbedded Coastal Plain Soils

A plot of applied compression load vs. pile-head deflection is presented in Figure 7. The plot unfortunately includes the estimation of ultimate load as per the Davison Offset Limit (by others), which the author considers inappropriate for the estimation of ultimate load of ACIP piles (NeSmith and Siegel, 2009; Studlien et al, 2013). Regardless, it is clear that the pile-head deflection does not reach a level to apply any of the methods listed in the International Building Code (IBC, 2015) and that the ultimate load is in excess of the maximum applied load.

In turn, it is also well in excess of the predicted performance by available design methods. The successful installation of ACIP piles into a stratum where the code-based structural limits of the allowable load are reached before geotechnical failure made the ACIP piles very efficient due to the speed at which they are installed compared to other bored and cast-in-place methods as well as material costs.

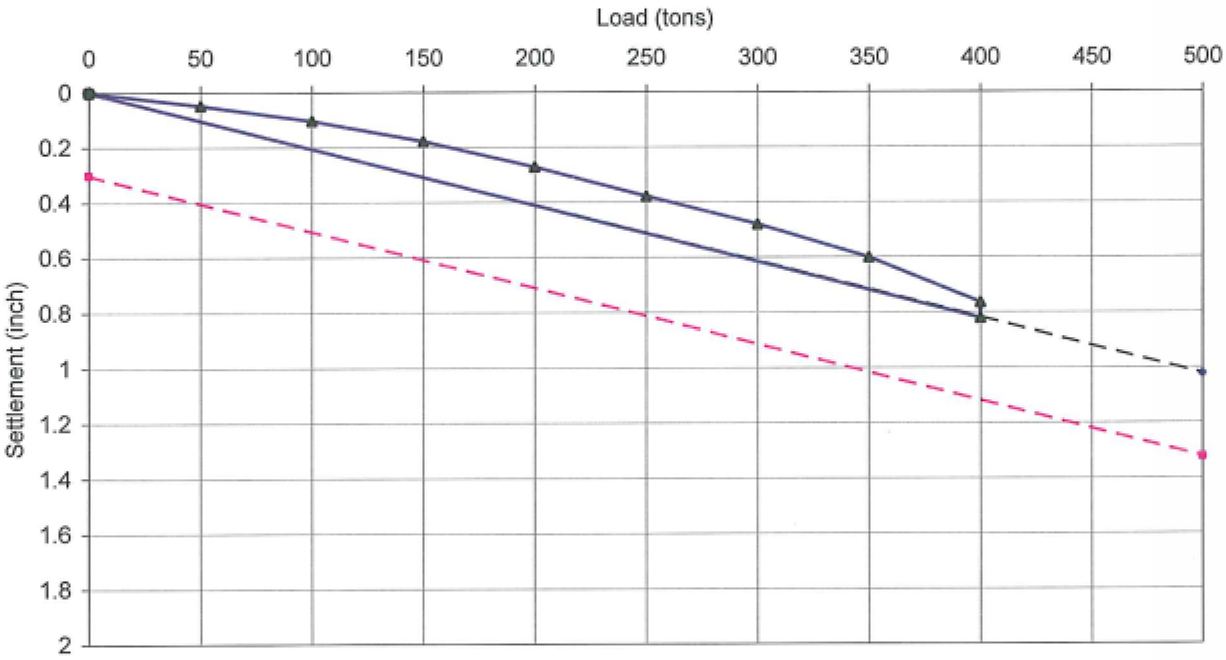


Figure 7 – Applied Compression Load vs Pile-head Deflection of 18-in dia. X 80-ft ACIP Pile

COARSE-GRAINED GLACIAL TILL

The final example included is a site near the water at a New York City municipal facility in the northern section of Queens which consisted of a series of sites with facilities that required pile support. The general stratigraphy is shown in Figure 8 and is representative of the various separate locations. SPT N-values are typically shown at 5-ft intervals with corresponding soil descriptions. Generally, below up to 10-ft of urban fill, typically dense to very dense sandy till was present, however, a portion of the site included significant stiff to very stiff clay till was present.

ACIP piles, 16-in in diameter, were proposed to resist 150-ton to 160-ton design compression loads, depending on the location within the project extents. Figure 10 shows the applied load vs. pile-head deflection for the test pile installed in the predominantly clay till portion of the site (2nd boring profile from right in Figure 8) while Figure 11 shows the same results for the test pile installed in a predominately coarse-grained till portion of the site (in this case, near the boring profile shown on the far right of Figure 8). The successful application of ACIP piles required, again, a high-torque gear box and appropriate auger-tips (cutting teeth) depending on the predominant soil type at each discrete facility location.

The test pile in Figure 10 is probably about at its interpreted ultimate load according to the Butler-Hoy method (Studlein et al, 2013) at its maximum applied load of about 375 tons. The test pile in Figure 11 did not have enough pile-head deflection to estimate ultimate load, however, it is clear that the ultimate load is well in excess of the maximum applied load of 300 tons. In both cases, the ultimate load of the test piles was in excess of that which would be predicted by currently available design methods. Historically similar facilities have been supported on driven piles or other cased and bored-piles. The high-torque equipment and development of more specific cutting-teeth for different predominant soil types allowed ACIP piles to be installed to a level to provide a more economical foundation in this case.

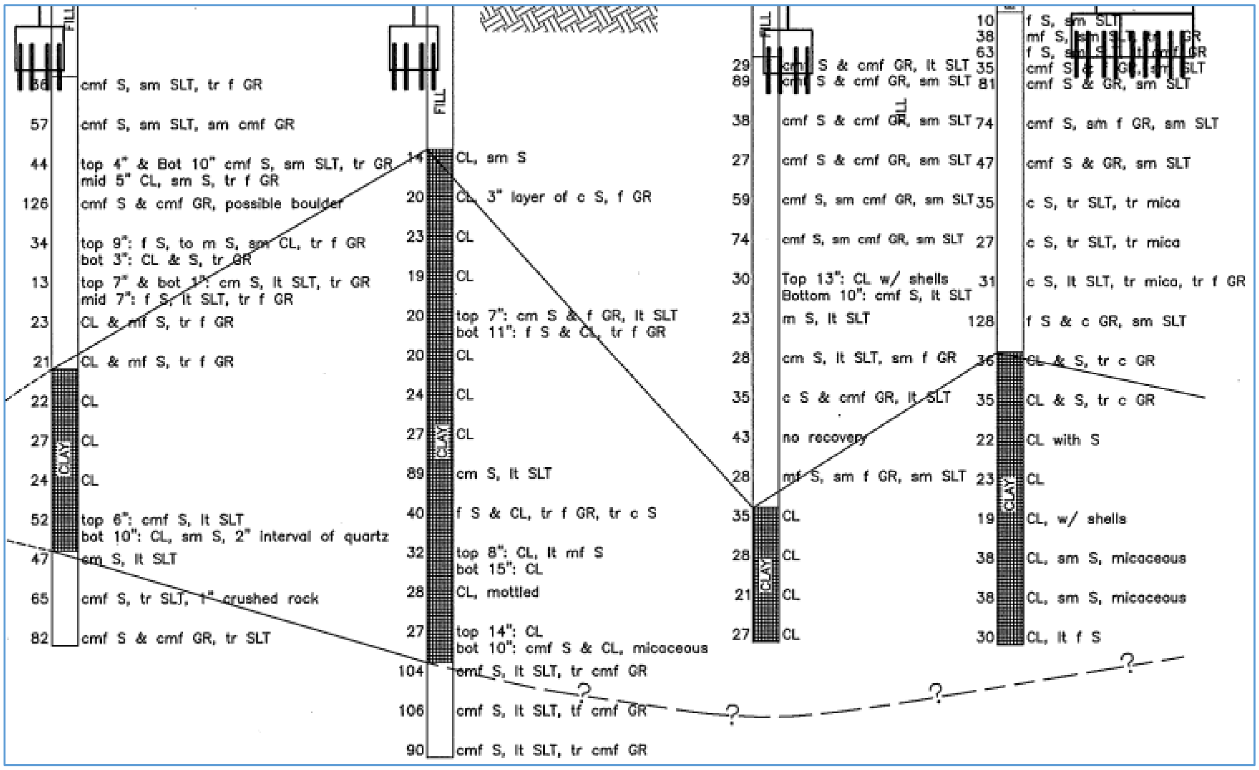


Figure 8 – N-values and Soil Descriptions of Glacial Till in Queens NY

Figure 9 – Boulders Removed in the Upper 25-ft of Queens NY Site to Facilitate ACIP Pile Installation

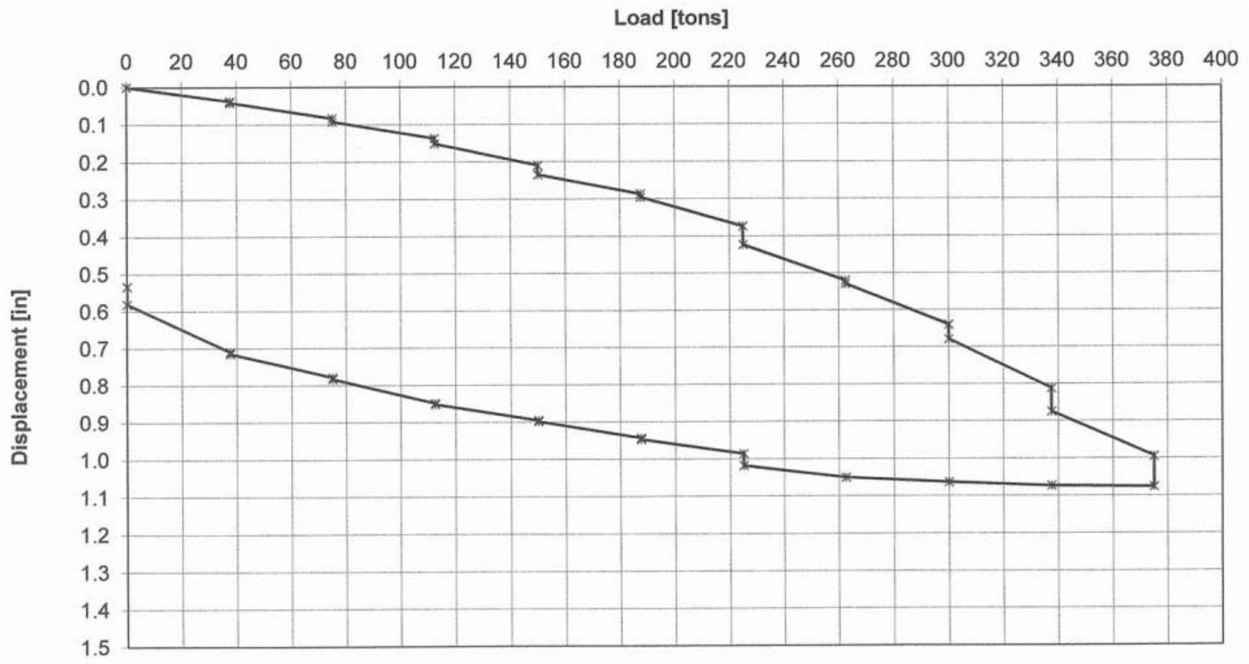


FIGURE 10 – 16-in ACIP Pile x 82-ft in Predominantly Clay Profile

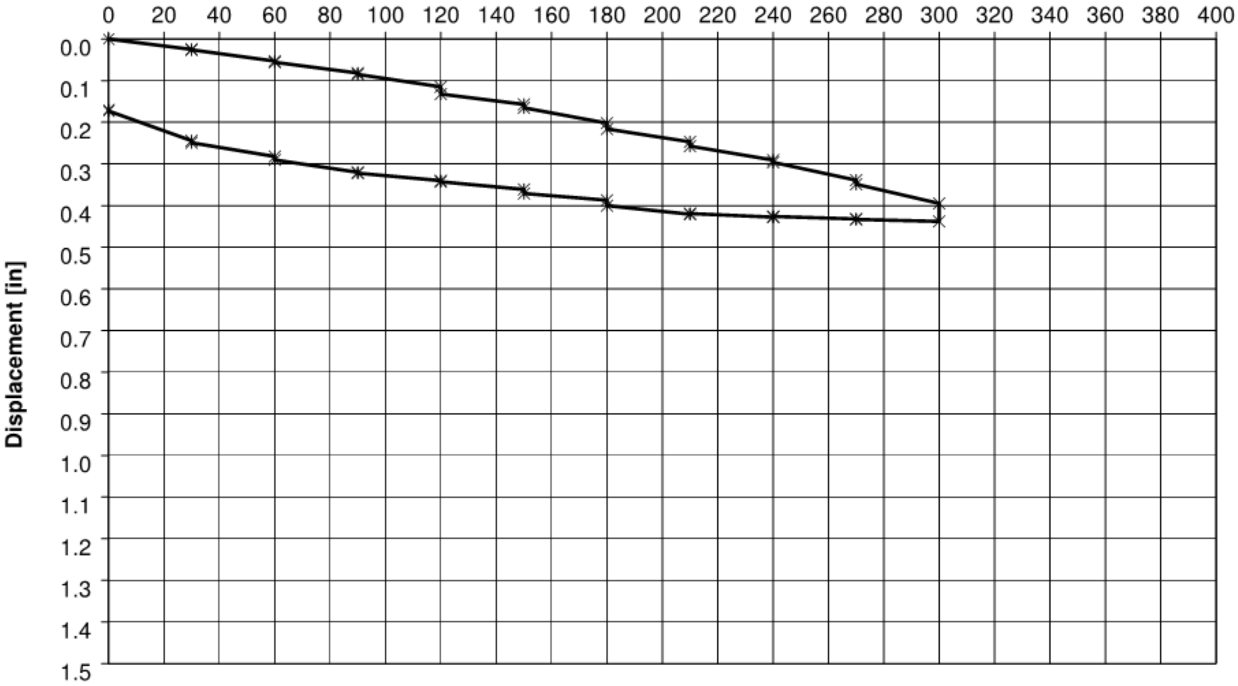


FIGURE 11 – 16-in ACIP Pile x 77-ft in Predominantly Sand Profile

CONCLUSIONS

When they can be properly installed, ACIP piles offer an efficient foundation option due to their speed of installation compared to other bored, cast-in-place piles as well as the cost of materials compared to driven piles. ACIP pile equipment and installation technology has advanced to a point where piles are being successfully installed in geologies which, in previous generations, they might not have been, often resulting in higher loads being resisted by these piles than were previously available. Additionally, post-construction verification technology has advanced to a level where successful construction of ACIP piles can be verified on very soft, potentially problematic soils. These advances have expanded both the geographic areas in which ACIP piles can be installed as well as the projects on which they may offer some efficiencies (more heavily loaded than moderately loaded structures).

In very dense coarse grained soil, as well as stiff to hard fine-grained soils, recent measured ACIP pile performance is often greater than would be predicted by available models/methods. The same phenomenon has been observed for ACIP piles installed in fine and coarse grained till and, in particular, in intermediate geo-materials (including the PWR used as an example here) where unit shaft resistances are SIGNIFICANTLY higher than dense or hard soil model would predict. So while industry advances have expanded the range of materials into which ACIP piles can be installed and increased the maximum loads these piles can support, current design models should only be considered a potentially lower-bound guide to ACIP pile performance in these materials.

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