A BRIEF HISTORY OF MICROPILING IN WASHINGTON, DC

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ABSTRACT

The challenging geology and the historic and sensitive character of much of the public and government structures are two conditions that made the District of Columbia (DC) the perfect environment for the micropile industry to flourish as an appealing foundation alternative for new structures and, of course, for retrofitting and underpinning of existing structures.

The DC market is territorial and is dominated by a small group of general contractors who have the tendency to first explore old fashioned and outdated alternatives (such as underpinning pits that can often be self performed) that are cheap but labor intensive, instead of the generally speaking less risky and technology-based micropiles for underpinning of existing structures. Contractors' attentions only focus on other technologies, like micropiles, when there are conditions that make it virtually impossible to build underpinning pits, or schedule is of utmost importance.

However, the quest for more profitable buildings and reuse of existing structures in expansion projects has inevitably required the use of micropiles in retrofitting existing buildings with tight access and low clearance. DC is, in the opinion of the writers, the niche market for micropiles.

This paper discusses the local conditions that make micropiles advantageous with respect to other technologies, and looks into the history of micropiling in DC by collecting in a table format in-house and specialty contractors' information regarding the projects where micropiles have been used, including design and construction constraints, design and construction details, and load test data. The table is not all inclusive. Furthermore, three projects designed by the authors have been selected to further illustrate the design, construction, and performance details typically in use by engineers and specialty contractors in the DC market.

BACKGROUND

Development of the District of Columbia

In 1790 the United States Senate passed the Residence Act, which proposed the location of the federal district on the basis of convenience of access to all parts of the country. The Residence Act defined the location of the capital district as a 10-mile square "located as hereafter direct on the river Potomac, at some place between the mouths of the Eastern Branch [the present Anacostia River] and Connogocheague [Conococheague Creek] be,…" The exact site was to be determined by President Washington.

It appears that George Washington's final selection of the city boundaries was based on two main considerations: encompassing as much as possible of the tidewater of the Potomac and Anacostia River to have easy access to both land and sea, and being at the head of a long and navigable but easily defended estuary. Thus, the western boundary was aligned with the Fall Line at Little Falls, the head of the Potomac tidewater, and the boundary between the Piedmont Plateau and the Atlantic Coastal Plain. Figure 1 shows the selected boundaries of DC.

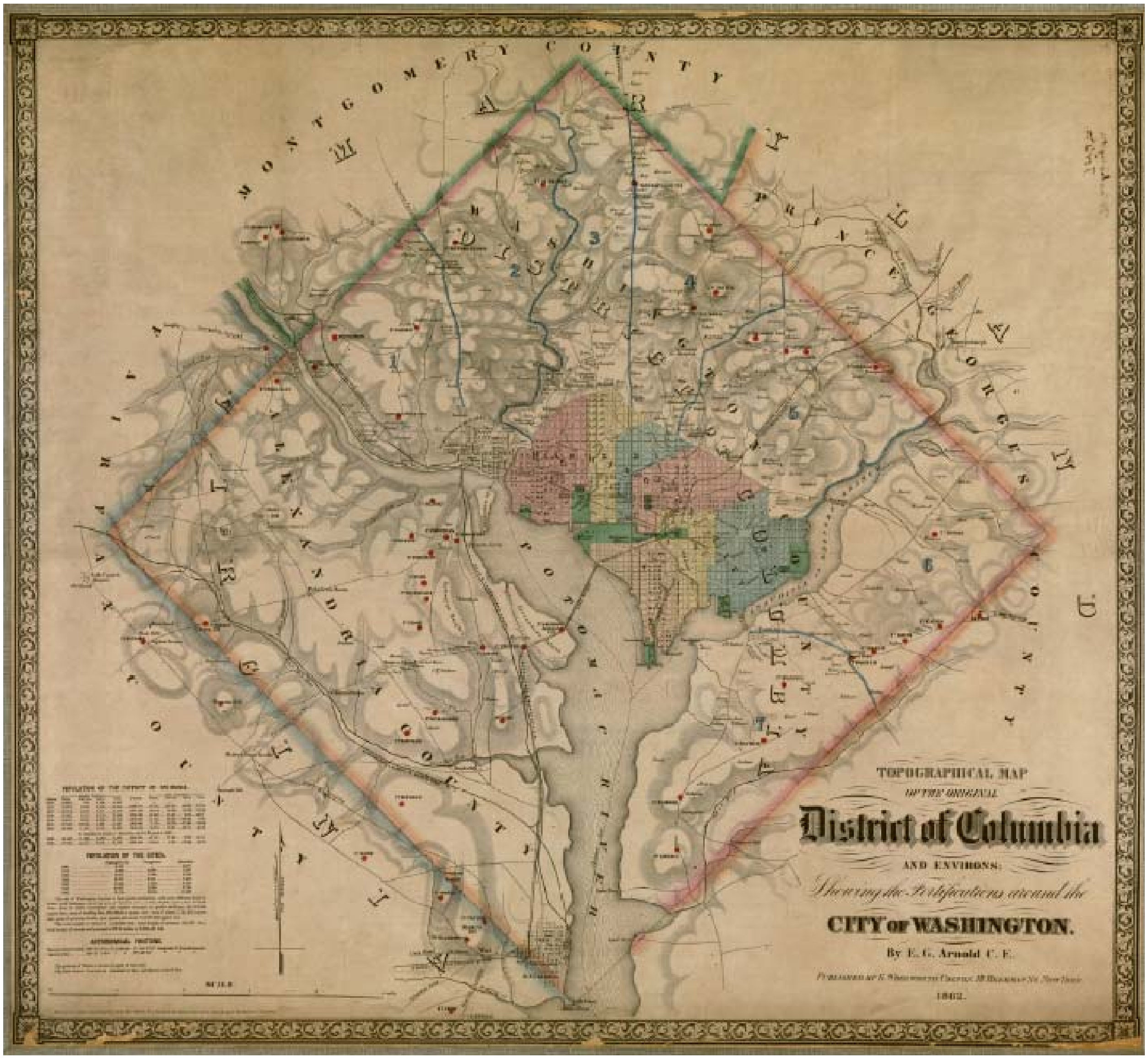

Fig. 1. Topographical map *of the District of Columbia and environs by E.G Arnold C.E.*. Map. New York: G. Woolworth Colton, 1862. Map Collections: 1500-2004. Library of Congress. < g3851s cw0674000 http://hdl.loc.gov/loc.gmd/g3851s.cw0674000>

DC is no longer 100 square miles (260 km^2) due to the retrocession of the southern portion of DC back to the Commonwealth of Virginia in 1846. In its current configuration, DC has a total area of 68.3 square miles (177 km^2), of which 61.4 square miles (159 km^2) is land, and 6.9 square miles (18 km^2) (10.16%) is water. *State & County QuickFacts*. United States Census Bureau. 2008-01-02. http://quickfacts.census.gov/qfd/states/11000.html.

The heart of DC is bounded by what is now Florida Avenue to the north, Rock Creek to the west, and the Anacostia River to the east as illustrated in Figure 2. The design for the City of Washington was entrusted to Pierre Charles L'Enfant, a French-born architect, engineer, and city planner. The L'Enfant plan was modeled in the Baroque style and incorporated broad avenues radiating out from the Capitol, providing room for open space and landscaping. His design also envisioned a garden-lined "grand avenue" that later became the National Mall. The DC growth and development were largely influenced by the local geology.

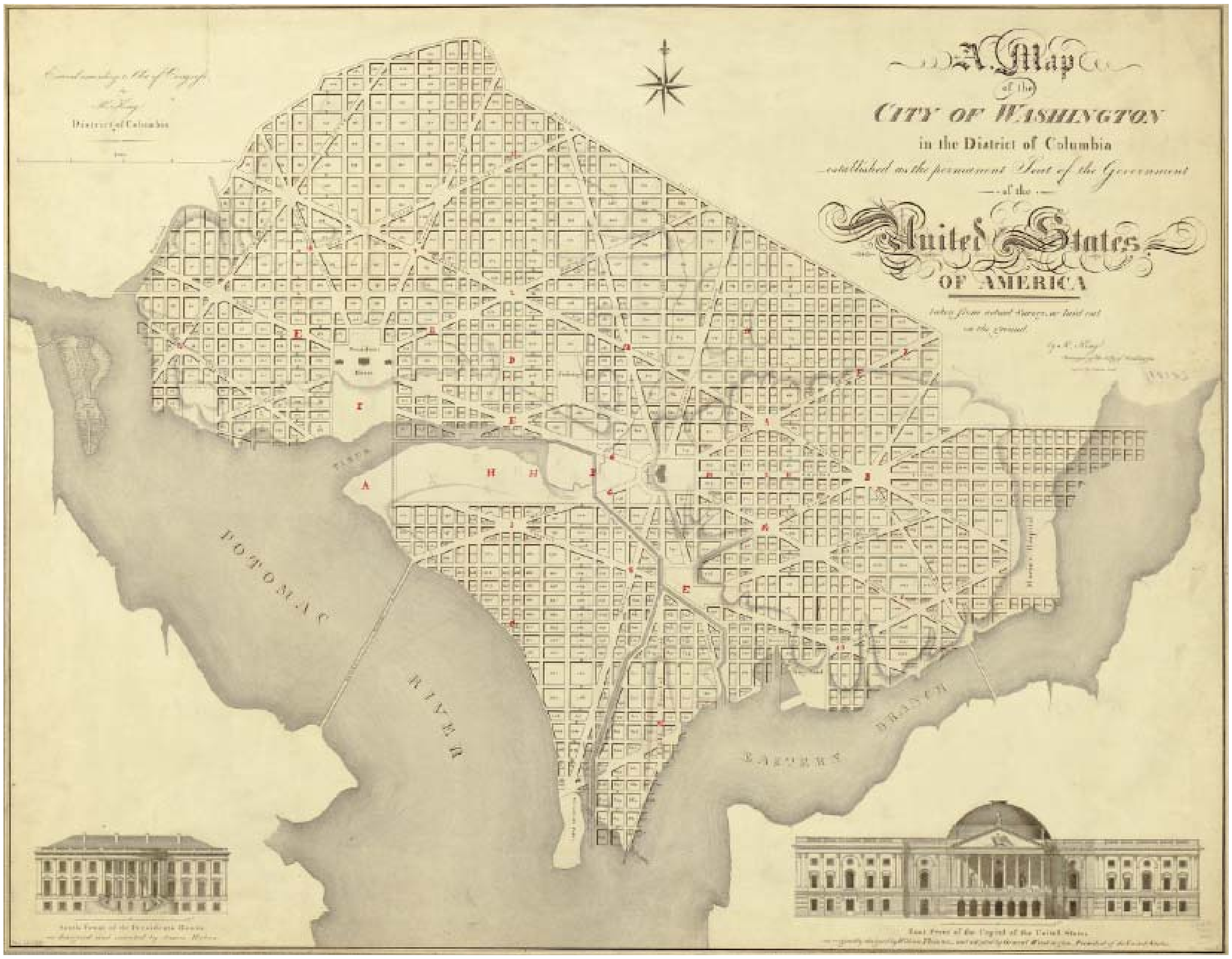

Fig. 2. *Map of the City of Washington in the District of Columbia/taken by actual survey, as laid out on the ground, by R't King*. Map. Washington: W. Cooper, 1818. Map Collections: 1500-2004. Library of Congress.
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Geologic Challenges

As shown in Figure 3, the western part of DC is on the Piedmont Plateau, an upland underlain by metasedimentary and metaigneous rocks of late Precambrian or early Paleozoic age. The metasedimentary rocks include phyllite, politic schist, rhythmically-bedded metagraywacke, and medium-to-coarse grained massive to well foliated gneiss. These crystalline rocks are mantled by soil, saprolite, and weathered rock to depths of as much as 50 m.

The City of Washington and the eastern part of DC are on the Atlantic Coastal Plain.

The Coastal Plain is underlain by fluvial and marine strata of Cretaceous through Miocene age. These deposits form a wedge that thickens southeastward from the Fall Line to as much as 1350 ft in the southeastern end. The Cretaceous sediments are lenticular on a large scale as a result of changing conditions of deposition but are much more regular in stratification than the younger overlying soils. The lowermost Cretaceous strata are grouped in the Potomac Formation and consist primarily of sands and clays. Erosion has removed a great thickness of the Potomac Formation in downtown DC.

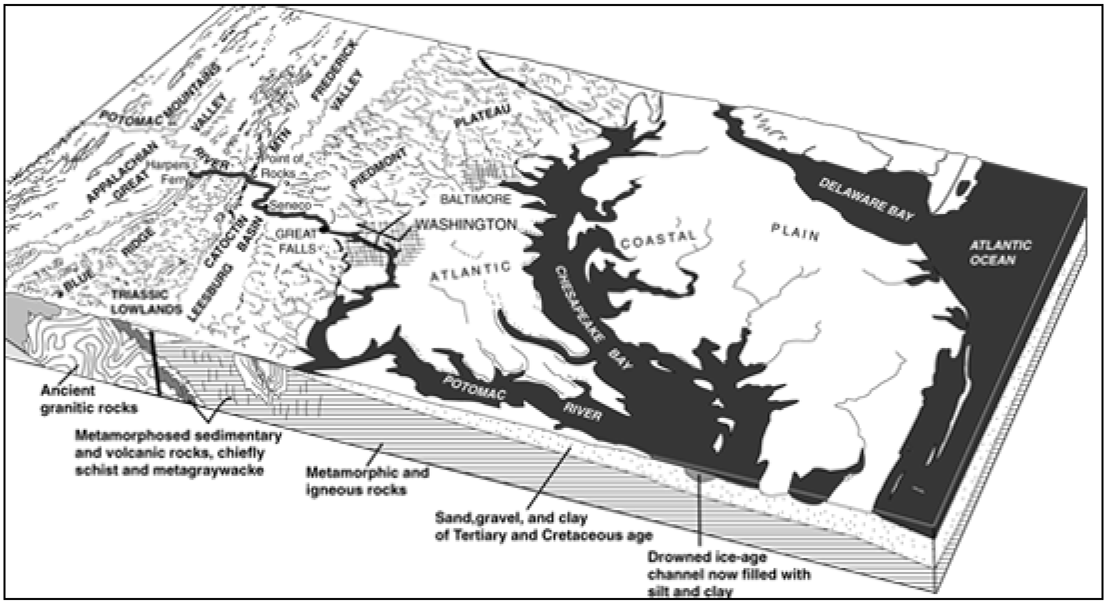

Fig. 3. Physiographic Provinces and Geologic and Geographic Features of the District of Columbia region. Taken from *Building Stones from our Nation's Capital*, U.S. Department of Interior and U.S. Geological Survey, 1999.

In the downtown DC area, the Cretaceous Formation is overlain by a succession of river terrace deposits of Pleistocene times. These Pleistocene terraces consist of a mixture of silty and sandy clays with sands, interlayered and lensed in a complex pattern. Pleistocene terraces were formed by debris carried in streams charged by glacial melt water flowing from the north and northwest. A series of flattop terraces at several characteristic elevations have been identified in the DC area. These include the 25-foot terrace, the 50-foot terrace, and the 90-foot terrace. Each terrace exhibits a characteristic change in gradation in a vertical profile from coarse-grained and gravelly soils at its base, to sands, silts, and clays at shallower depths, corresponding to the change from low sea level at the start of ice retreat to high sea level at the warmest time of the interglacial period.

Estuarine and marsh deposits flank the tidal reaches of the Potomac and Anacostia rivers. Most of the National Mall west of the Washington Monument, all of East Potomac Park and Haines Point, and much of Reagan International Airport are on land reclaimed from tidal marshes.

This complex geology, plus the historic and monumental character of many buildings and structures in the area, serves as a real life laboratory for the advancement of foundation techniques and knowledge. Depending upon the location and size of the structures, the foundation alternatives typically used are ample, ranging from spread and mat foundations to belled or straight drilled shafts, driven piles, auger cast piles, and micropiles; even the use of a combination of two or more of the above in one project is commonplace.

Micropile Advantages

Two of the key advantages of the micropile technology are the ability to deal with challenging and highly variable ground conditions, and tight access construction environments. Both of these are well demonstrated in the DC area.

The challenging geology of the area, such as: a highly variable bedrock surface elevation with the presence of a very thick and weak saprolite layer on top of weathered rock and bedrock; the presence of old fills with rubble on top of very soft and weak swamp and estuarine deposits with highly variable thicknesses; and the presence of boulders in the buried terrace deposits, add to the complexity of selecting, designing, and constructing foundation systems in the area.

In addition to the geologic challenges, the historic and sensitive character of much of the public structures (such as museums, government agencies, etc.), the lack of space, and the environmental restrictions (such as noise, vibration, etc.) made the perfect environment for the micropile industry to flourish as an appealing foundation alternative for new structures, and for retrofitting and underpinning of existing structures.

Case Histories

In collaboration with the main specialty contractors in the area, and modifying the summary table of micropile projects in the US (Xanthakos et al., 1994), the authors developed Table 1 (located at the end of this paper) which summarizes and presents the history and development of micropiles in the DC area. Special attention was given to record construction procedures and load test data when available. The table is not all inclusive, and the authors request information regarding other missing projects that will make this table more complete for future publications and sharing among the micropiling community.

Three projects designed by the authors have been selected to further illustrate the design, construction, and performance details typically in use by engineers and specialty contractors in the DC market. Other projects have already been subjects of technical papers, magazine articles, or presented in technical bibliography, and are referenced in case further details are required.

Katzen Arts Center – American University

Situated at the top of Embassy Row on a very long, narrow site abutting Ward Circle, the new Katzen Arts Center brings all the visual and performing arts programs at American University (AU) into one 130,000-square foot space (see Figure 4). Designed to foster interdisciplinary collaboration in the arts, the new center provides state-of-the-art instructional, exhibition, and performance space for all the arts disciplines. The building, beautifully wrapped in pale French limestone and precast concrete panels, could easily house the 555-ft tall Washington Monument horizontally. The building was skillfully located within a narrow site, creating spectacular vistas within a curvilinear envelope.

Fig. 4. Katzen Arts Center View from *Ward Circle.*

The structure required installation of deep foundations within an area of difficult access and limited space. The requirements mandated that the new foundations be designed to withstand significant permanent lateral loads induced by earth pressures against the basement walls. Due to the space restrictions and the magnitude of the lateral loads, Schnabel Engineering proposed a foundation system consisting of micropiles. Each column was supported on a micropile group that included vertical micropiles as well as micropiles battered in several directions.

The ground conditions at the site consisted of 5 ft of sandy silt terrace deposits on top of 15 to 20 ft of silty sand residual soils underlain by 10 to 30 ft of weathered gneiss. Micropiles were bonded 10 ft into competent (Nspt > 100 blows/ft) gneiss bedrock. Ultimate bond strengths of 50 psi and 250 psi were assigned to the bond zone in the overburden soils and bedrock, respectively.

Micropile layout and batter were designed in a case-by-case basis using a soil-pile-pile cap interaction model, as shown on Figure 5. The analyses were performed using a finite element algorithm that allowed the calculation of the loads and deflections of each micropile under different loading conditions. This study permitted the optimization of the micropile configuration.

Due to limitations in the available software, soil models, and structural element models, the algorithm consisted of first determining the pile stiffness to lateral load, as well as the depth to zero bending moment (fixity point) using Lpile. The micropiles were then: (1) modeled as structural bars with axial stiffness in Sigma/W; (2) restrained laterally at the fixity point and at the connection with the pile cap elements; (3) a modified Young's modulus to account for the axial deformation of the entire micropile was also considered; and (4) a spring boundary condition with the previously calculated micropile lateral stiffness was placed at the micropile-to-cap connection, and the model was run to find a combination of micropile batter and location to simultaneously maintain deformations of the system within the allowable range, and the micropile axial loads within the micropile allowable capacity.

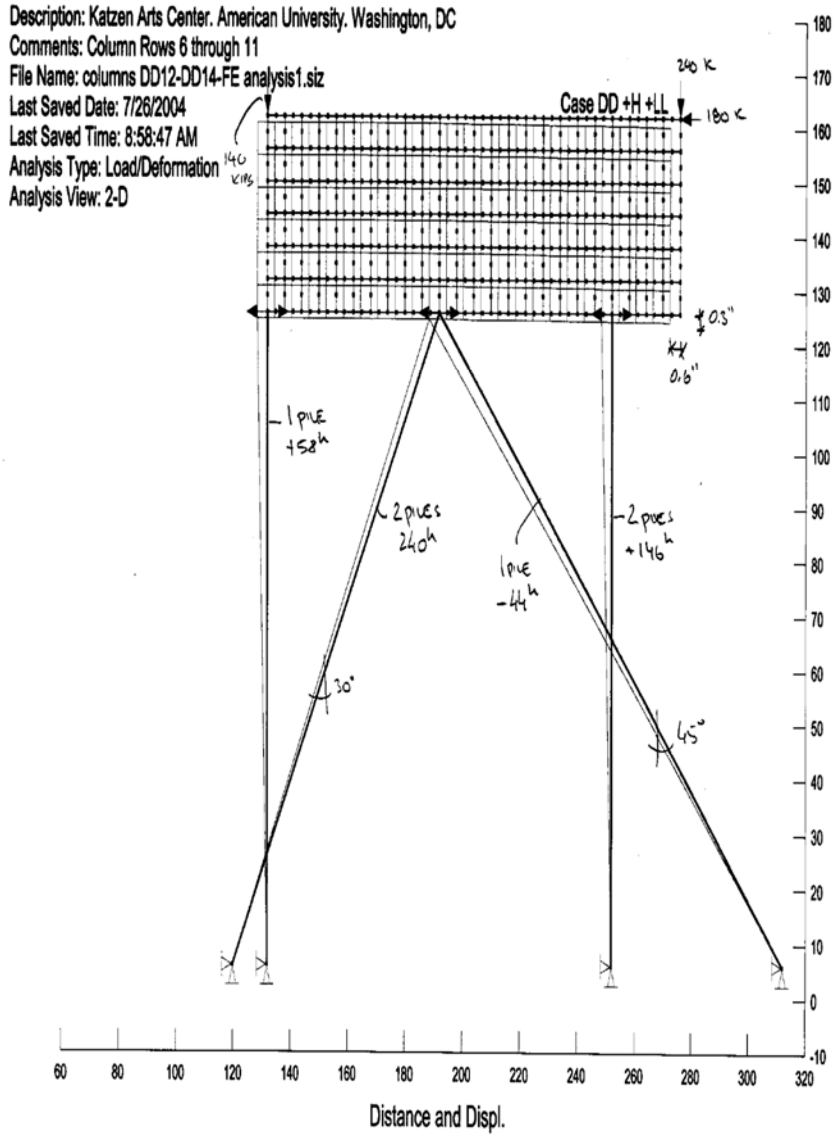

Fig. 5. Soil-Micropile-Pile Cap Interaction Model.

A total of 109 (150-kip axial capacity) micropiles were installed by the Traylor Group. The micropiles were reinforced with a 2.25-inch diameter 75-ksi steel bar full length. In addition, the upper 12 ft were reinforced with a 5.5-inch diameter casing (0.415 inch wall thickness), grade 80 ksi. The micropiles were tremie grouted with grout mix intended for 5,000 psi 28-day compressive strength. The micropiles had a total length varying from 50 to 65 ft depending on the depth to top of rock. The pile bonded length was approximately 38 to 53 ft, including a 10-ft rock socket. The unbonded length, including stick up, was approximately 12 ft. The casing was advanced to top of rock with air flush. A 6-inch diameter rock socket was open-hole drilled with a downhole hammer.

One sacrificial load test was performed prior to installation of production piles to confirm design bond strength, as well as drilling and grouting procedures. The gross settlement at 50% of the test load (150 kips) was approximately 0.17 inch. The maximum test load of 300 kips was maintained for approximately 60 minutes. Creep during the 60-minute hold period was measured at 0.027 inch. The gross settlement measured at the end of the 60-minute holding period was 0.581 inch. The pile was unloaded in 37.5-kip decrements. The net pile settlement after removal of the test load back to alignment load was approximately 0.127 inch. The load test results are presented in Figure 6.

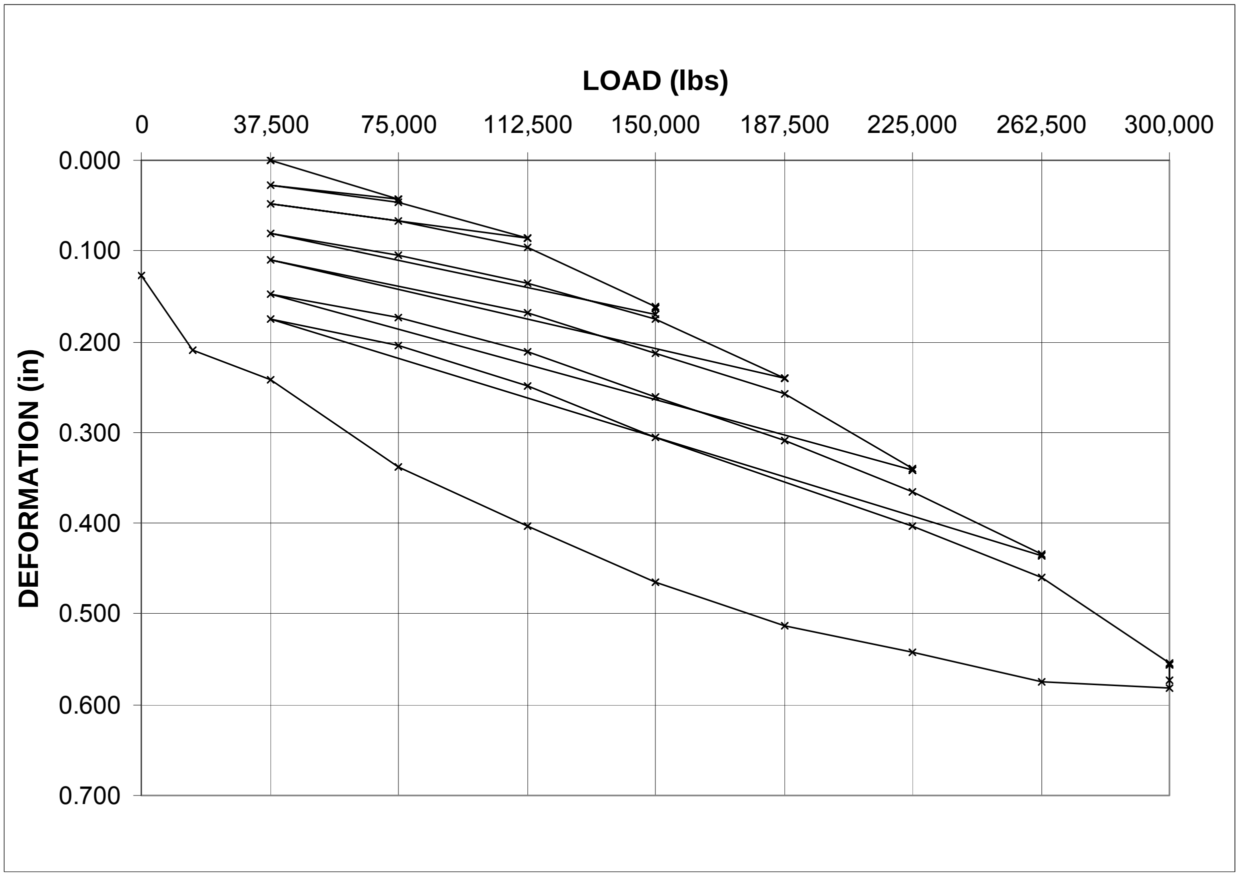

Fig. 6. Load-Settlement plot. Load Test of a 150-kip Design Load Micropile at Katzen Arts Center.

One NoMa Station

NoMa is a rapidly developing new neighborhood in DC, located just north of Capitol Hill and Union Station and named for its location: north of Massachusetts Avenue (see Figure 7). A former industrial area, NoMa is quickly transforming into a dynamic mixed-use neighborhood with over 8,000 new apartments and condominiums, modern office towers, 1,200 hotel rooms, nearly one million square feet of retail amenities, new restaurants, shops, and cafes.

For over 150 years, most of the 35-block area now known as NoMa served as an industrial warehouse and distribution area for freight trains coming in and out of DC. The southern portion of NoMa around Union Station included the old Swampoodle residential district, first settled in the 1850s by immigrants fleeing the Irish potato famine. This neighborhood was roughly bounded by K Street to the north, G Street to the south, 1st Street NW to the west, and 2nd Street NE to the east. Through the center of it, just east of North Capitol Street, ran the principal branch of Tiber Creek, creating the low swampy ground and "swamp puddles" from which the area took its name. Most of the neighborhood was torn down for construction of Union Station and its railroad track extensions in the early 1900s.

Fig. 7. One NoMa Station Building, formerly the Woodward & Lothrop Service Warehouse.

As trucking displaced rail service as the main means of delivering goods to cities, the area declined and many warehouse structures were abandoned. Beginning in the 1990s, the DC government planned to redevelop NoMa first as an arts and residential district, and later as a center for high-tech industry growth.

The old Woodward & Lothrop Service Warehouse located at 131 M Street, NE in the NoMa neighborhood of DC (designed by Abbott, Merkt & Co. in 1937) is an example of Streamline Modern architecture and is listed on the National Register of Historic Places. After the local department store company Woodward & Lothrop (known locally as Woodies) foundered in the 1990s, the warehouse sat vacant for several years. Re-development of the NoMa neighborhood has resulted in this warehouse becoming the new U.S. Equal Employment Opportunity Commission (EEOC) Headquarters and Washington Field Office (WFO).

Redevelopment of the building required the construction of deeper elevator pits within the existing north and south elevator banks. The cores extended approximately 6.5-ft below the existing concrete slab. Construction of the elevator banks required removal of a portion of the existing shallow spread foundation at eight (8) column footing locations. To compensate for the loss of footing bearing areas and support for additional loads due to the proposed building renovation, retrofitting of the existing eight column footings was performed.

Schnabel was retained by the Traylor Group to provide the micropile design for retrofitting the existing foundations, as well as construction support during installation of the micropiles. Thirty-four micropiles (nominal six inches in diameter) were installed in low headroom conditions, see Figure 8. The micropiles consisted of 5-ft sections to a total depth of 50 ft of threaded Titan 40/16 high strength bar surrounded by neat cement or sand-cement grout with a 28-day strength of 4 ksi. The allowable design compressive load of the micropile was 78 kips. The micropiles were installed prior to removing portions of the existing column footing base.

The ground conditions at the site consisted of 17 to 20 ft of soft lean clay alluvial deposits on top of medium to dense silty sand deposits. Micropiles were bonded 20 ft into the silty sand deposits.

Fig. 8. Low Headroom Installation of Titan Micropiles at One NoMa Station.

One tension sacrificial load test was performed prior to installation of production piles to confirm design bond strength, as well as drilling and grouting procedures. The gross settlement at 50% of the test load, 80 kips, was approximately 0.40 inch. The design load of 80 kips was maintained for approximately 20 minutes. Creep during the 20-minute hold period was measured at 0.018 inch. The gross settlement measured at the maximum test load of 160 kips was 1.252 inch. The net pile settlement after removal of the test load back to alignment load was approximately 0.44 inch. The load test results are presented in Figure 9.

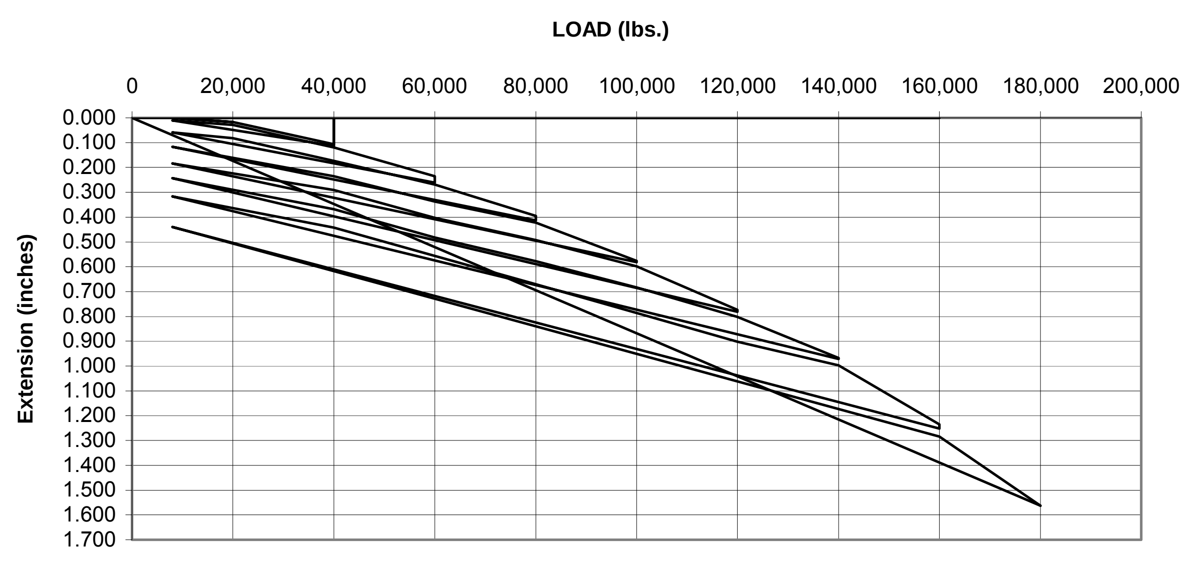

Fig. 9. Load-Extension Plot. Tension Load Test of an 80-kip Design Load Micropile at One NoMa Station.

Children's National Medical Center

Opening its doors over 140 years ago, the DC Children's National Medical Center (CNMC) is consistently ranked among the best pediatric hospitals in America by US News & World Report (see Figure 10). As the reputation of the hospital grows, so do its patients and hospital personnel, creating a significant demand for the available space.

Fig. 10. Children's National Medical Center Building.

Located at 111 Michigan Avenue in Northwest DC, portions of the hospital extended five stories above grade and three levels below grade. The hospital expanded the surgical wing to the north up to the full build out of five stories above the existing three-story below-grade parking garage.

Raymond Step-Tapered piles, designed for 80 tons each, supported the existing parking garage. Schnabel Engineering provided the original subsurface investigation in 1969, and construction monitoring of pile installation in 1971.

The additional five stories above grade required that each Raymond pile be capable of supporting 150 tons. An investigation of the conditions and allowable capacity of the existing piles was carried out by performing three quick load tests and pile-integrity testing of the existing Raymond piles. The load tests and pile integrity testing confirmed the 80-ton allowable capacity of the existing Raymond piles. Two entire column lines would experience loads beyond their capacity, requiring micropiles to be installed at these locations.

The existing foundations at the exterior basement wall were founded on eccentric Raymond piles and had a six-foot wide strap beam connecting and transferring the eccentricity moment to the nearest column line pile caps, which were also in need of retrofitting. Consequently, the overall design considered the retrofitting of the strap beam.

The final retrofitting system consisted of compression micropiles connected to the existing pile cap by doweled concrete attachments, and pretensioned micropiles through the exiting strap beam to counteract the additional eccentricity moments and minimize the disturbance of busy and congested parking.

A total of 94 micropiles (nominal eight inches in diameter) were installed in low headroom conditions. The micropiles consisted of Titan 73/53 high strength bars surrounded by neat cement or grout with a 28-day strength of 4 ksi. The allowable design compressive load of the micropiles was 110 kips. The micropiles were also provided with an 8-inch diameter casing above the bonded length. Micropiles were 40 ft long.

The ground conditions at the site consisted of intermingled soft lean clay and medium to dense silty sand alluvial deposits.

One compression and one tension sacrificial load test were performed prior to installation of production piles to confirm design bond strength, as well as drilling and grouting procedures. The compression load test was taken to around 303 kips. The gross settlement at the design load of 110 kips was approximately 0.046 inch. The design load was maintained for approximately 30 minutes. Creep during the 30-minute hold period was measured at 0.003 inch. The gross settlement measured at the maximum test load of 303 kips was 0.415 inch. The net pile settlement after removal of the test load back to alignment load was approximately 0.095 inch. The compression load test results are presented in Figure 11.

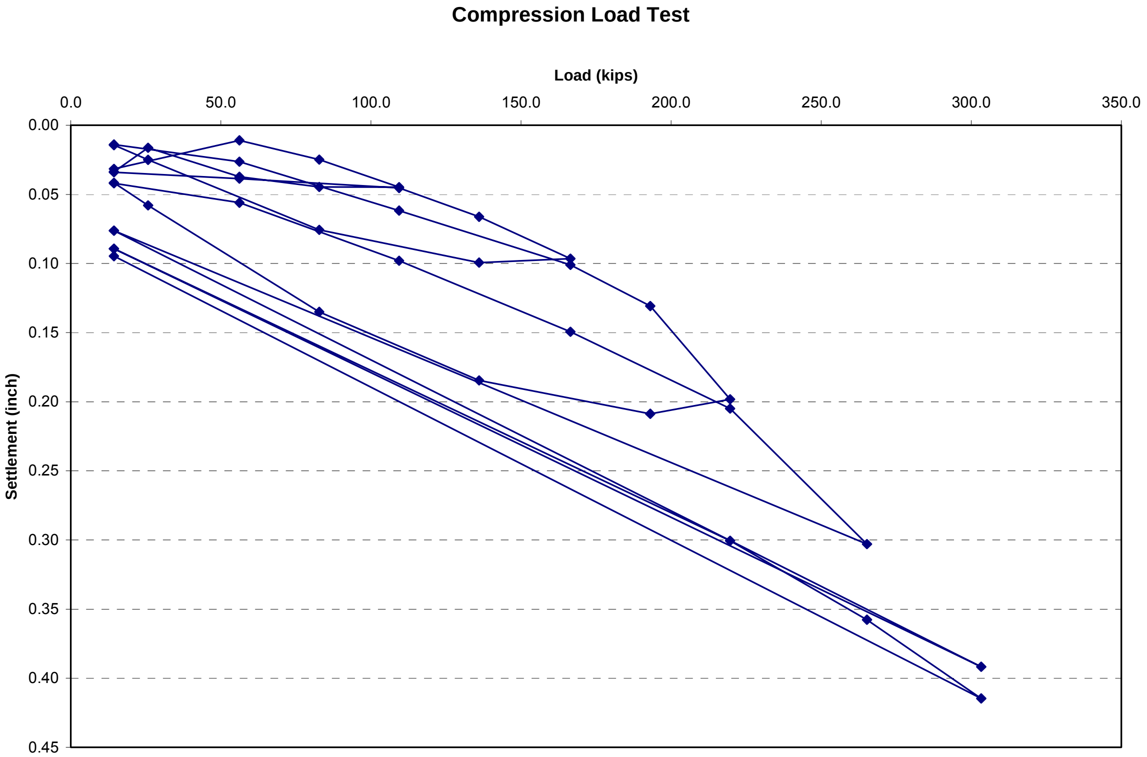

Fig. 11. Compression Load Test Plot for Children's National Medical Center.

CONCLUSIONS

The excavation and shoring market in DC is territorial, and is dominated by a small group of general contractors who have the tendency to first explore old fashioned and outdated alternatives (such as underpinning pits that can often be self performed) that are cheap but labor intensive, instead of the generally speaking less risky and technology-based micropiles for underpinning of existing structures. Contractors' attentions only turn towards a focus on alternative technologies like micropiles when there are conditions that make traditional methods virtually impossible, or schedule is of utmost importance.

However, the quest for more profitable construction and reuse of existing structures in expansion projects inevitably requires the use of micropiles in retrofitting existing buildings with tight access and low overhead clearance. This, in the opinion of the writers, makes the market for micropiles in DC a niche area.

This paper explored the history, local practices, and trends of the DC micropile market, showing that the market is probably dominated by a few specialty contractors and engineering firms that are regularly involved in underpinning and retrofitting projects within the city limits.

Table 1 contains in-house and specialty contractor information regarding the projects where micropiles have been used, and includes design and construction constraints, design and construction details, and load test data. From the analysis of the projects shown in Table 1, it could be concluded that local practices have developed over the years, passing from conventional bar reinforced and cased micropiles to the more frequent use of injection bore hollow-core bars. It also shows that verification load tests are the norm to confirm design parameters and construction methods.

Drilling equipments, tools, and materials are improving and developing very fast. The load test data presented shows that, in general, the design criteria are conservative in terms of bond strength, indicating that designers have room for improvement in this regard particularly with the advent of new technologies, as demonstrated by the high loads and factors of safety achieved in the instances of injection bore hollow-core bar applications.

Finally, it seems that continuing the great synergy between equipment manufacturers, materials suppliers, specialty contractors and engineering consultants is the key for advancement of the market and technology in the coming years.

Continued education for both owners and architects regarding the advantages of micropiles versus the more traditional alternatives will also benefit the advancement of this industry. A key to this is the demonstration of successful micropile projects as presented herein.

REFERENCES AND BIBLIOGRAPHY

Christie, Douglas W. and Lacy, Hugh S., 2006, "Deep Foundations in Washington, DC," Proceedings of the 31st Annual Conference on Deep Foundations, Washington, DC.

"Contractors Tackle the Challenges of Historic Renovations, Preservation as Critical as Modernization," Magazine Article about Georgetown Library Published by AGC of DC, Washington Contractor, Summer 2010.

Englert, Carlos et al., 2007, "Use of Micropiles for Slope Stabilization," Proceedings of the 13th Pan-American Conference on Soil Mechanics and Geotechnical Engineering, Margarita Island, Venezuela.

Gómez, Jesús E. et al., 2009, "Micropiles Take off at Dulles Airport," Deep Foundations Institute, Deep Foundations Magazine, Spring 2009, pp 8-11.

Map Collections: 1500-2004. Library of Congress.

Moore, John E. and Jackson, Julia A., editors, 1989, "Geology, hydrology, and history of the Washington, D.C. Area," American Geological Institute:
James V. O'Connor, "The District of Columbia," pp 3-8.
John C. Reed, Jr. and Stephen F. Obermeir, "The Geology beneath Washington, D.C. – The Foundations of a Nation's Capital," pp 27-50.

Nicholson Construction Provided the Following In-house Records and Marketing Material:
"Potomac Center North"

Schnabel Engineering – In-house Records and Marketing Material:
    “1602 L Street”
    “Bowen Building”
    “Children’s National Medical Center”
    “Dulles Int’l Airport Concourse B APM”
    “Dulles Int’l Airport Main Terminal”
    “Hirshorn Museum of Art”
    “Katzen Arts Center”
    “Oak Hill Cemetery”
    “One NoMa Station”

Steele, Andrew et al., 2005, “Hollow-Bar Micropiles: Underpinning the Façade of the Historic Bowen Building,” ADSC Foundation Drilling Magazine, February 2005, pp 12-18.

Steele Foundations Provided the Following In-house Records and Marketing Material:
    “Georgetown Library”

United States Census Bureau, 2008-01-02, “State & County QuickFacts.”

U.S. Department of Interior and U.S. Geological Survey, 1999, “Building Stones from our Nation’s Capital.”

Xanthakos, Petros et al., 1994, Ground Control and Improvement,” John Wiley and Sons, Inc.

Table 1: Timeline and Summary of Micropile Projects in the Washington, DC, Area

Year	Project	Engineer	Specialty Contractor	Application Type	Significance	Micropile Type	# of Piles	Ground Conditions	Installation Conditions	Micropile Design and Construction Details						Design Load (tons)	
										L (ft)	ϕ (in)	Reinforcement Details	Grouting Details	Drilling Method Tools	Drilling Fluid	Work	Test
	Smithsonian Institute Castle		Nicholson Construction	Case 2 SOE-Underpinning with soil nails	Protection of sensitive building.	Type B	21	Fill over dense sands with gravel	Very restrictive access.	69-77	5½	#11 full length, 5½-inch casing above bond zone	w/c=0.5 140 psi			50	100 δ=0.653” δp=0.078”
1991	Postal Square		Nicholson Construction	Case 1 Underpinning and new foundation	Protection of sensitive historic building. Concrete-grout interface tested (Bond = 350 psi).	Type B	609	Fill over various alluvial fine-medium sands with cobbly/clayey horizons	Existing basement with 8-17 ft of headroom.	51-58	7	25-30 ft of 7-inch casing (N80) plus 25 ft of 1⅜ inch rebar in bond zone	w/c=0.45 80-110 psi	Flush casing	Water	75	150 δt=0.173”-0.461” δp=0.113”-0.313” δc=0.059”-0.174”
2003	Potomac Center North	SK&A	Nicholson Construction	Case 1 Foundation retrofit for additional stories and new foundations	First TITAN bar application for contractor.	TITAN	188	Rubble fill over the Potomac clays, silts and sands	Existing basement with only 7 ft of headroom. The exterior piles installed through abandoned building foundations.	20-35	5-10	TITAN 30/16, 52/26, 103/78		Self Drilling Hole Bars, 90 mm, 115 mm, and 175 mm bits	Grout	10-90	100&180
2009	Georgetown Library		Steele Foundations/ Traylor Group	Case 1 Foundation retrofit new loads	Protection of sensitive historic building.	Type A	19	Fill over stiff clays and silts, over dense silty sands (saprolite)	Installed inside existing building with only 11 ft of headroom.	37	8	#11 full length, 7-inch casing (N80) above bond zone	w/c=0.45 tremie	Duplex with Numa Superjaw bit	Air	50	100
2003	Bowen Building	Schnabel Eng.	Steele Foundations/ Traylor Group	Case 1 Foundation underpinning	Underpinning of historic building façade. Internal building demolished. Basement extended.	TITAN		Fill over sand and clay Terrace deposits on top of interbedded Potomac clay and sands on top of gneiss	Micropiles were installed from existing basement.	64	4½	TITAN 52/26	w/c=0.45 dynamic	Self Drilling Hole Bars, 115 mm	Grout	50	75 δt=1.670” δp=0.776” δc=0.0465”
2004	Dulles Int’l Airport Main Terminal	Schnabel Eng.	Layne Geo Construction	Case 1 Foundation underpinning	Underpinning and temporary structural support of main terminal columns. Concrete-grout interface tested (Bond = 350 psi).	Type A	220	25 ft of fill and residual soils on top of siltstone	Aircraft traffic, Control tower restrictions; tight grid of underground utilities.	70	8	7-inch casing (N80) full length	w/c=0.45 tremie	Downhole hammer	Air		
2004	Dulles Int’l Airport Concourse B APM	Schnabel Eng.	Layne Geo Construction	Case 1 Foundation underpinning	Underpinning of existing pedestrian bridge linking Concourses A and B. Concrete-grout interface tested (Bond = 344-466 psi).	Type A	34	25 ft of fill and residual soils on top of siltstone	Heavy luggage tug and construction traffic; installed thru existing concrete.	13-20	6-8	#18-20 full length. No unbonded zone thru potential slip surface	w/c=0.45 tremie	Downhole hammer	Air	60	120
2004	Katzen Arts Center	Schnabel Eng.	Traylor Group	Case 1 New foundation	Significant lateral loading.	Type A	109	5 ft of sandy silt terrace deposits on top of 15 to 20 ft of silty sand residual soils underlain by 10 to 30 ft of disintegrated gneiss	Stretch job site, difficult access and limited space.	50-65	6	#18 full length. 5½-inch casing (N80) upper 12 ft	w/c=0.45 tremie	Downhole hammer	Air	75	150 δt=0.581” δp=0.127” δc=0.027”
2006	Children’s National Medical Center	Schnabel Eng.	Traylor Group	Case 1 Foundation retrofit	Extensive foundation retrofit and construction of grade beams in an active hospital.	TITAN	94	Unbonded zone through loose silty sand terrace deposits. Bonded in stiff clay and dense sands of the Potomac Formation	Installed inside existing building with limited headroom.	40	6-8	TITAN 73/53 full length. 8-inch casing (N80) above bond zone	w/c=0.45 dynamic	Self Drilling Hole Bars, 175 mm	Grout	55	150 δt=0.415” δp=0.095”
2005	1602 L Street	Schnabel Eng.	Traylor Group	Case 1 Foundation retrofit	High capacity micropiles for new construction using existing basement walls.	Type A	87	15 ft of soft clay and loose sand terrace deposits on top of 15 ft of silty sand residual soil underlain by Biotite Meta-Arenite and Muscovite-Biotite Schist bedrock	Installed from existing basement. Installed with eccentricity close to existing basement wall to remain.	35-45	8	7-inch casing (N80) full length	w/c=0.45 tremie	Duplex	Air	150	275 δt=0.583” δp=0.156”

Table 1: Timeline and Summary of Micropile Projects in the Washington, DC, Area

Year	Project	Engineer	Specialty Contractor	Application Type	Significance	Micropile Type	# of Piles	Ground Conditions	Installation Conditions	Micropile Design and Construction Details						Design Load (tons)	
										L (ft)	ϕ (in)						
2003	Oak Hill Cemetery	Schnabel Eng.	Steele Foundations/ Traylor Group	Case 2 Slope stabilization	A-Wall for slope stabilization at historic cemetery.	Type A	160	5 to10 ft of fill and residual soil on top of 10 to 15 ft of disintegrated rock	Installed from 2 narrow pathways located amid a large density of historic graves, tombstones, and steep slopes.	19-35	6	4-inch casing (N80) full length	w/c=0.45 tremie	Rotary-Percussion	Air	27.5	45 Tension δt=0.58” δp=0.17”
2008	Hirshhorn Museum of Art	Schnabel Eng.	Hayward Baker	Case 1 Foundation underpinning	Retrofitting of uncharacteristic short and unreinforced caissons.	Type B	13	Rubble fill underlain by Pleistocene sand and clay Terrace deposits on top of Potomac sand and clay Cretaceous deposits	Low headroom installation.	37-67	8	#10 full length, 7-inch casing (N80) above bond zone	w/c=0.45 80 psi	Roller bit	Air	50	125 δt=0.450” δp=0.114” δc=0.020”
2004	One NoMa Station	Schnabel Eng.	Traylor Group	Case 1 Foundation retrofit	First titan bar application for contractor.	TITAN	34	30 ft of very soft lean clay alluvial deposits on top of dense to very dense silty sand deposits	Micropiles were installed from existing basement. Micropiles drilled through existing footings.	50	6	TITAN 40/16 full length	w/c=0.45 dynamic	Self Drilling Hole Bars, Modified Bit	Grout	39	80 Tension δt=1.252” δp=0.440” δc=0.018”

Source: Adapted and modified from Xanthakos et al. 1994

δt = Total Deformation at Maximum Test Load

δp = Plastic Deformation at end of Test

δc = Deformation during Creep Testing