Load Testing Drilled Displacement Piles in Difficult Conditions: Jane Hotel Project in Manhattan New York

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ABSTRACT

During a remodel of the historic Jane Hotel in Manhattan, NY a new elevator shaft was designed that would require deep foundations to be installed in the existing basement. Drilled Displacement Piles (DDM) were selected for the deep foundation elements to accommodate the low overhead constraints of the Jane Hotel basement which remained in service during the construction. During pile installation (drilling and grouting), the proposed drilled displacement piles encountered refusal at depths approximately 20 ft shallower than the designed minimum tip elevation. The design loads of the piles were initially reduced to eliminate the requirement of the static load test per NYC building codes, however, the piles could not be accepted by the engineer of record due to the shallow pile refusal and traditional static load testing could not be performed in the basement with the new proposed footprint of the elevator shaft due to the existence of neighboring structures. Dynamic testing utilizing a 2-ton drop hammer allowed for capacity evaluation within the limitations of the spatial constraints. Capacity was computed and resulted in at least 1.5 times the required ultimate capacity, which lead to the piles being accepted.

BACKGROUND

The historic Jane Hotel located in Manhattan, New York underwent renovations to modernize the hotel. This landmark's nameplate on the front entrance indicated the building to have been constructed in 1907 and was famous for housing ship crew members in the 20th century. Located right off the Hudson River, near many historic shipping piers, royalty often stayed at this hotel when entering the US. Titanic survivors were also reported to have been brought to this hotel once rescued.

The design included deep foundations to support a new elevator shaft inside the existing building. Drilled displacement piles were selected with installation in 5-ft sections to accommodate the limited headroom and site constraints inside the existing basement. Typical pile design included 5.5-inch outside diameter by 0.361-inch wall thickness pipe sections, also referred to as the pile shaft, which included a reverse grout auger. The bottom section, or "standard lead section", consisted of an 18-inch drive plate with a 16-inch soil displacement head.

The purpose of the 18-inch drive plate is to aid in advancing the pile downward during pile installation while the purpose of the 16-inch soil displacement head is to displace the soil laterally to develop the grout-to-ground bond interface. Figure 1 depicts the 5-ft sections utilized in the design for the deep foundation element for the elevator shaft.

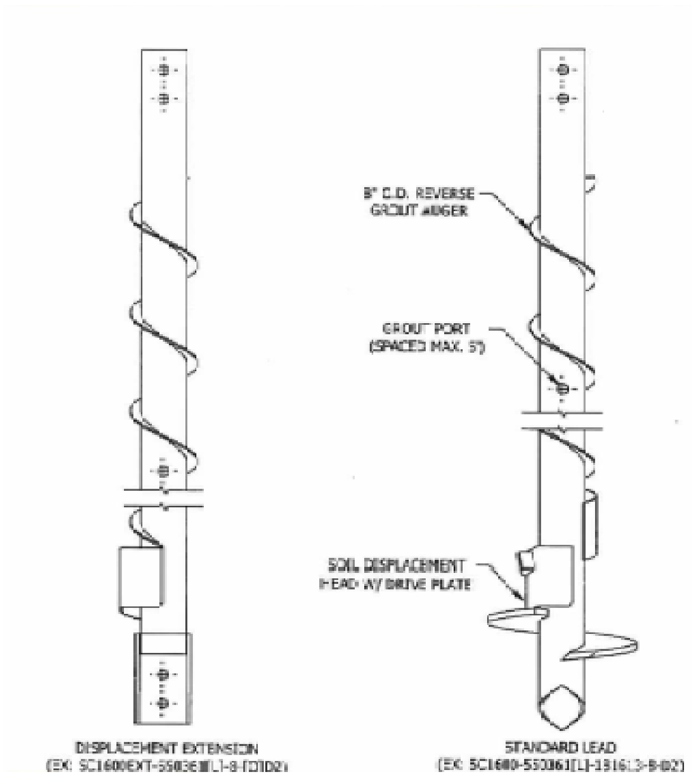


Figure 1. DDM design utilizing 5-ft standard lead and displacement extension sections.

Installation methods included installing the 5-ft sections with a hydraulic rotary drive head equipped with a torque monitoring device. Initial lead sections with the 18-inch drive plates were installed approximately 12-inches and then lifted above grade to create a void or reservoir for grout. The lead section would be re-advanced below the reservoir, and grout flow by use of gravity would commence according to the Manufacturer's (Ideal Group) installation sequencing. Grout is drawn into the pile annulus by means of the reverse grout auger, and grout flow was monitored to measure grout intake. The final design of the pile considers a nominal 16-inch grout column for the grout-to-ground bond interface generated by the combination of the soil displacement head and reverse grout auger [1]. Figure 2 depicts the conceptual Drilled displacement pile.

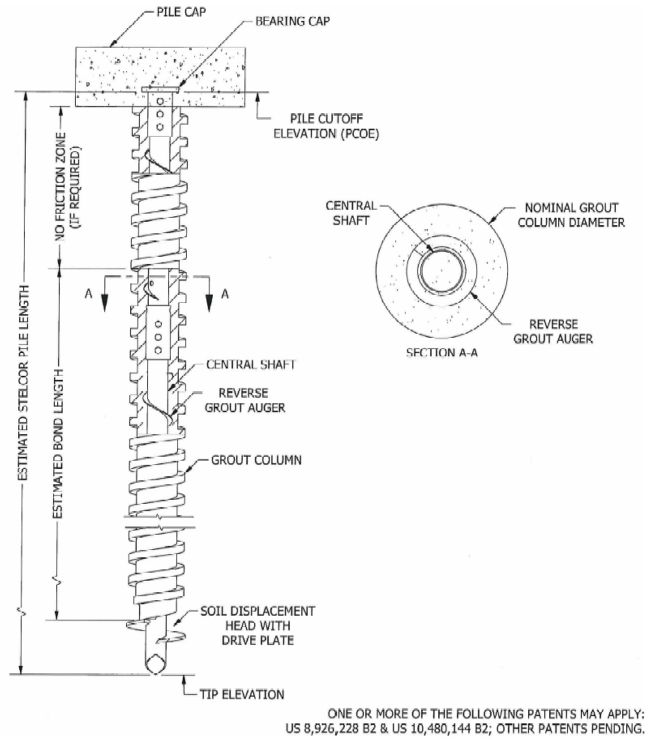
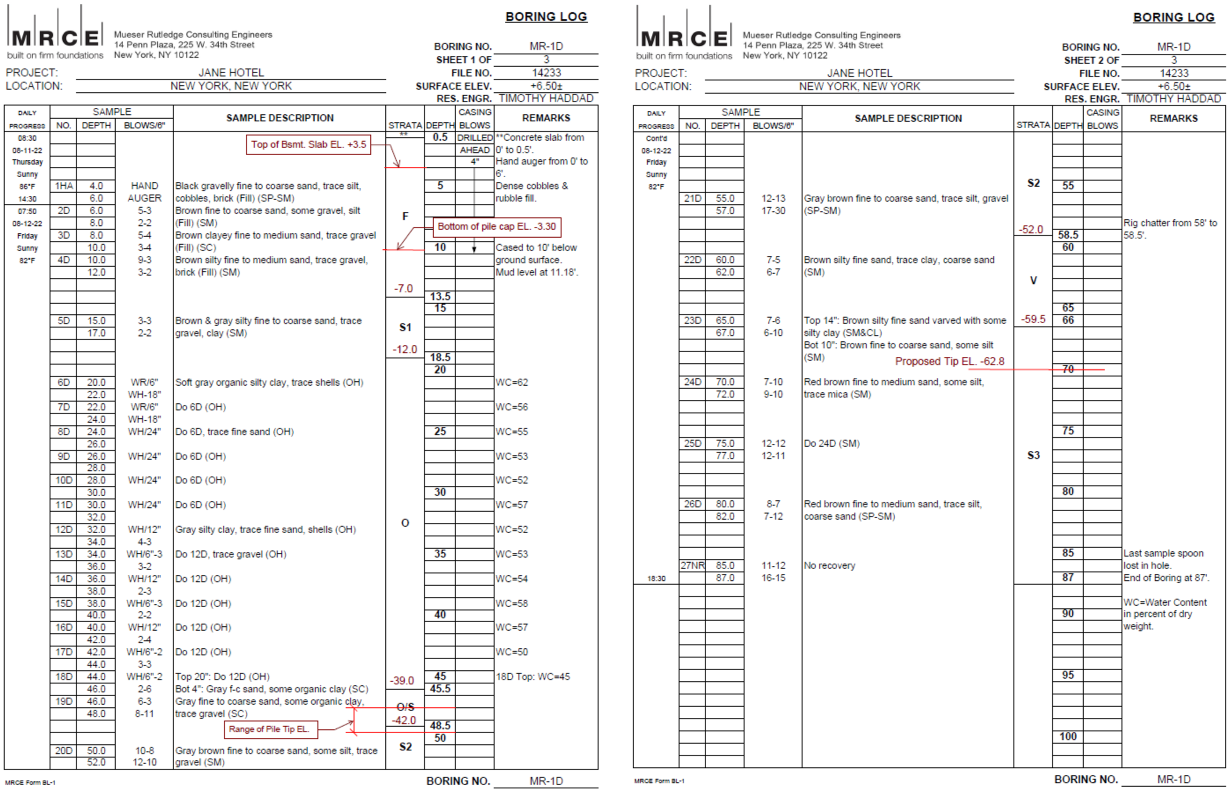


Figure 2. DDM Conceptual pile from design submittal.

DESIGN AND INSTALLATION

Driven by spatial constraints, the DDMs were revised to a maximum design load of 40 kips (20 tons) and a grout strength of 5 ksi in an attempt to eliminate the need of a static load test per NYC Building Code.

Limited soil information was available from the original construction and in order to accommodate ongoing business operations of the hotel, new soil borings were conducted outside of the existing footprint, rather than at the elevator shaft location. The obtained soil boring, MR-1D, can be reviewed in Figure 3. Considering the limited available information of soil stratigraphy, part of the design and installation sequence provided direction in the event of early refusal being encountered during pile installation, such that, "Where refusal is reached prior to the designed depth…the pile should be tested and thereby establish additional criteria for acceptance."



BORING LOG

MRCE — built on firm foundations
Mueser Rutledge Consulting Engineers
14 Penn Plaza, 225 W. 34th Street
New York, NY 10122

PROJECT: JANE HOTEL
LOCATION: NEW YORK, NEW YORK
BORING NO. MR-1D
SHEET 1 OF 3
FILE NO. 14233
SURFACE ELEV. +6.50±
RES. ENGR. TIMOTHY HADDAD

DAILY PROGRESS	SAMPLE NO.	SAMPLE DEPTH	SAMPLE BLOWS/6"	SAMPLE DESCRIPTION	STRATA	DEPTH	CASING BLOWS	REMARKS
08:30					**	0.5	DRILLED	**Concrete slab from
08-11-22							AHEAD	0' to 0.5'.
Thursday							4"	Hand auger from 0' to
Sunny								6'.
86°F	1HA	4.0	HAND	Black gravelly fine to coarse sand, trace silt,		5		Dense cobbles &
14:30		6.0	AUGER	cobbles, brick (Fill) (SP-SM)				rubble fill.
07:50	2D	6.0	5-3	Brown fine to coarse sand, some gravel, silt	F			
08-12-22		8.0	2-2	(Fill) (SM)				
Friday	3D	8.0	5-4	Brown clayey fine to medium sand, trace gravel				
Sunny		10.0	3-4	(Fill) (SC)		10		Cased to 10' below
82°F	4D	10.0	9-3	Brown silty fine to medium sand, trace gravel,				ground surface.
		12.0	3-2	brick (Fill) (SM)				Mud level at 11.18'.
					-7.0	13.5		
						15		
	5D	15.0	3-3	Brown & gray silty fine to coarse sand, trace	S1			
		17.0	2-2	gravel, clay (SM)				
					-12.0	18.5		
						20		
	6D	20.0	WR/6"	Soft gray organic silty clay, trace shells (OH)				WC=62
		22.0	WH-18"					
	7D	22.0	WR/6"	Do 6D (OH)				WC=56
		24.0	WH-18"					
	8D	24.0	WH/24"	Do 6D, trace fine sand (OH)		25		WC=55
		26.0						
	9D	26.0	WH/24"	Do 6D (OH)				WC=53
		28.0						
	10D	28.0	WH/24"	Do 6D (OH)				WC=52
		30.0				30		
	11D	30.0	WH/24"	Do 6D (OH)				WC=57
		32.0			O			
	12D	32.0	WH/12"	Gray silty clay, trace fine sand, shells (OH)				WC=52
		34.0	4-3					
	13D	34.0	WH/6"-3	Do 12D, trace gravel (OH)		35		WC=53
		36.0	3-2					
	14D	36.0	WH/12"	Do 12D (OH)				WC=54
		38.0	2-3					
	15D	38.0	WH/6"-3	Do 12D (OH)				WC=58
		40.0	2-2			40		
	16D	40.0	WH/12"	Do 12D (OH)				WC=57
		42.0	2-4					
	17D	42.0	WH/6"-2	Do 12D (OH)				WC=50
		44.0	3-3					
	18D	44.0	WH/6"-2	Top 20": Do 12D (OH)	-39.0	45		18D Top: WC=45
		46.0	2-6	Bot 4": Gray f-c sand, some organic clay (SC)		45.5		
	19D	46.0	6-3	Gray fine to coarse sand, some organic clay,	O/S			
		48.0	8-11	trace gravel (SC)	-42.0	48.5		
						50		
	20D	50.0	10-8	Gray brown fine to coarse sand, some silt, trace	S2			
		52.0	12-10	gravel (SM)				

Top of Bsmt. Slab EL. +3.5
Bottom of pile cap EL. -3.30
Range of Pile Tip EL.

MRCE Form BL-1
BORING NO. MR-1D

BORING LOG

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14 Penn Plaza, 225 W. 34th Street
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PROJECT: JANE HOTEL
LOCATION: NEW YORK, NEW YORK
BORING NO. MR-1D
SHEET 2 OF 3
FILE NO. 14233
SURFACE ELEV. +6.50±
RES. ENGR. TIMOTHY HADDAD

DAILY PROGRESS	SAMPLE NO.	SAMPLE DEPTH	SAMPLE BLOWS/6"	SAMPLE DESCRIPTION	STRATA	DEPTH	CASING BLOWS	REMARKS
Cont'd								
08-12-22								
Friday								
Sunny								
82°F					S2	55		
	21D	55.0	12-13	Gray brown fine to coarse sand, trace silt, gravel				
		57.0	17-30	(SP-SM)				
								Rig chatter from 58' to
					-52.0	58.5		58.5'.
						60		
	22D	60.0	7-5	Brown silty fine sand, trace clay, coarse sand				
		62.0	6-7	(SM)	V			
						65		
	23D	65.0	7-6	Top 14": Brown silty fine sand varved with some	-59.5	66		
		67.0	6-10	silty clay (SM&CL)				
				Bot 10": Brown fine to coarse sand, some silt				
				(SM)				
						70		
	24D	70.0	7-10	Red brown fine to medium sand, some silt,				
		72.0	9-10	trace mica (SM)				
						75		
	25D	75.0	12-12	Do 24D (SM)				
		77.0	12-11		S3			
						80		
	26D	80.0	8-7	Red brown fine to medium sand, trace silt,				
		82.0	7-12	coarse sand (SP-SM)				
						85		Last sample spoon
	27NR	85.0	11-12	No recovery				lost in hole.
18:30		87.0	16-15			87		End of Boring at 87'.
								WC=Water Content
						90		in percent of dry
								weight.
						95		
						100		

Proposed Tip EL. -62.8

MRCE Form BL-1
BORING NO. MR-1D

Figure 3. Project Boring MR-1D.

Figure 3, boring MR-1D, was annotated to show the pile tip elevation where refusal was encountered compared to the proposed pile tip elevation from the design such that the DDM design required a pile tip elevation of -62.8 ft, which would be approximately 60 ft of pile penetration below the bottom of the pile cap and a target drilled depth of approximately 64.3 ft. During installation, refusal was encountered 21 to 22 ft above the target tip elevation. Torque values at the refusal condition on the installation equipment reached 23,000 ft-lbs, reaching the limitation of the installation equipment. Due to the limited headroom inside the basement, a larger machine would not be feasible. Based on the project boring, capacity of the installed DDM was uncertain. The installation record from pile P5 is referenced in Figure 4. The boring shows loose to medium dense gray sands with some organic clays and trace gravel at the elevation of the in-place pile tip, where the refusal condition was observed. SPT N-values appear to vary between 9 and 19 including the approximate ft below and above where the refusal condition was observed.

DRILLED DISPLACEMENT PILE
STELCOR PILE INSTALLATION RECORD

MRCE
built on firm foundations

PROJECT: JANE HOTEL — PILE NO. P-5
PILE CONTRACTOR: BREAKING SOLUTIONS INC — FILE NO. 14233
REF. CODE/STDS:

PRIMARY INSPECTOR: PETER MADARASZ — PE LICENSE # 081217
SUPPLEMENTAL INSPECTOR: DYLAN GRACE

INSTALLATION — INSTALLATION DATE: 07/17/2023

Time	Depth (ft)	Section Length (Ft)	Total Length (Ft)	Drilling Rate (Min/Ft)	Torque (Ft-Lbs) (Beginning/Middle/End)	Remarks
1046-1047	0-5	5	5	0.2		
1050-1051	5-10	5	10	0.2	1300/6000/5000	
1053-1054	10-15	5	15	0.2	1500/200/300	
1056-1057	15-20	5	20	0.2	600/1100/1700	Grout level dropped ~1'
1114-1115	20-25	5	25	0.2	2000/2300/2200	
1117-1118	25-30	5	30	0.2	2400/2200/2700	
1120-1121	30-35	5	35	0.2	3000/3700/3900	
1136-1137	35-40	5	40	0.2	4000/4000/4400	Grout level dropped ~1'
1140-1143	40-43.5	5	45	0.5	5500/9500/23000	Refusal encountered at 44'
			Avg:	0.2		

PILE DATA

STELCOR PILE TYPE: SC1600-550361-181613-8-2
LENGTH OF LEAD: 5 (FT)
LENGTH OF EXTENSIONS: 5 (FT)
DESIGN LOAD (Compression): 20 (TONS)
DESIGN LOAD (Tension): 0 (TONS)
DESIGN LOAD (Lateral): 0 (TONS)
DESIGN HEAD ELEV.: ± (FT, NAVD 88)
DESIGN TIP ELEV.: -62.8 ± (FT, NAVD 88)
REFERENCE ELEV.: +1.5 ± (FT, NAVD 88)
TARGET DRILL DEPTH: 64.3 (FT)
ACTUAL DRILL DEPTH: 43.5 (FT)

STEEL CORE:

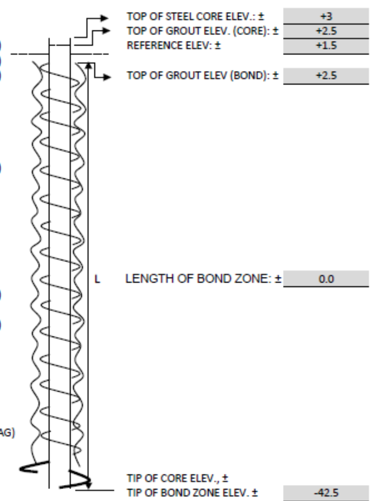
TOP ELEV.: +3 ±
TIP ELEV.: -42.0 ±
TOP OF GROUT ELEV.: +2.5 ± (FT, NAVD 88)
LENGTH: 43.5 (FT)
OUTSIDE DIA.: 5.5 (INCHES)
INSIDE DIA.: 4.778 (INCHES)
GRADE: 80 (KSI)
NO. OF JOINTS: 8
JOINT TYPE: BOLTED

BOND ZONE:

TOP OF GROUT ELEV.: +2.5 ± (FT, NAVD 88)
LENGTH: 0.0 (FT)
TIP ELEV.: -42.5 ± (FT, NAVD 88)
DIAMETER: 16 (IN)
STRATA IN BOND ZONE: SAND

GROUTING DATA

DESIGN GROUT STRENGTH: 5000 (PSI)
THEORETICAL GROUT VOLUME: 59.0 (CF)
THEORETICAL NO. OF BAGS: 51.2 (.85 LF/50 LB BAG)
ACTUAL GROUT VOLUME: (CF)
ACTUAL NO. OF BAGS: 59
GROUT TAKE: 1.2



REMARKS: PILE DOES NOT MEET NYCBC REQUIREMENT FOR BOND LENGTH. PILE NOT APPROVED BY MRCE.

DDP-3_APRIL2020

Figure 4. Installation Record for pile P5.

Refusal was encountered at similar depths for all the drilled displacement piles. These piles would not be accepted, nor the designs modified, without additional soil borings indicating the soil conditions varied at the elevator shaft location. As this was not feasible to obtain, a load test would need to be performed.

The project had to be placed on hold until further direction was given. As mentioned previously, traditional static load testing would not be feasible with the adjacent walls to the elevation shaft and the limited head room in the basement. Figure 5 depicts the in-place condition of the six DDMs showing the adjacent walls that would hinder the possibility of performing static load testing.

Figure 5. In-place conditions of the DDM inside the elevator shaft.

TESTING AND ANALYSIS

The project team developed a plan to evaluate the feasibility of performing high strain dynamic load testing, as per ASTM D4945 [2], inside the basement of the Jane Hotel. Typically, high strain dynamic testing is performed with a pile driving hammer, or a sufficiently large drop weight which may require a crane, to induce an impact force which translates into a compression wave that is measured and analyzed. The drop weight dynamic test system was modified from its traditional design and mobilized into the basement. The frame consisted of a 2-ton ram weight with a hydraulic winch to self-lift the ram weight, eliminating the need of a crane or lifting device. Figure 6 depicts the drop weight frame being modified and mobilized into the basement via existing doorway.

Figure 6. The modified dynamic load testing frame.

The revised acceptance plan from the project team would require testing two of the DDMs, or 33% of installed piles, to evaluate the total capacity along with skin friction and end bearing components. For frame stability, a concrete pad was poured in the pile cap area around two of the selected DDM piles, designated as “P6” and “P5”, which were to be tested. Figure 7 depicts the poured pad to provide high strain dynamic load testing frame stability.

Figure 7. Poured concrete pad for dynamic load testing frame stability.

Supports and anchors were provided in two directions of the dynamic load testing frame to ensure the impact would be centered on the pile and the frame would remain in-place after each impact. Figure 8 shows the dynamic load frame anchoring system to maintain centered and vertical impacts.

Figure 8. Anchoring system utilized to provide stability to dynamic load testing frame.

Strain gages and accelerometers were attached near the pile head to measure strain and acceleration. These measurements would be digitized and converted to force and velocity. The gages and data acquisition system. After the data was collected and digitized, signal-matching is conveniently done by the signal-matching program CAPWAP® ` and was utilized to model the piles assumed non-uniformity and composite properties, and compute unit resistances and calculate pile stresses along the length of each tested pile. Future improvements can be to utilize Thermal Integrity Profiling (TIP) as a means of determine the as-built pile geometry so modeled pile non-uniformity would not need to be assumed, particularly of the grout column, owing to the fact that drilled foundation are very often non-uniform[4]. A mobilized ultimate static capacity was then computed along with skin friction and end bearing components along with a simulated load-set curve. Figure 9 depicts the installed strain gages and accelerometers on the pile as prepared for high strain dynamic testing.

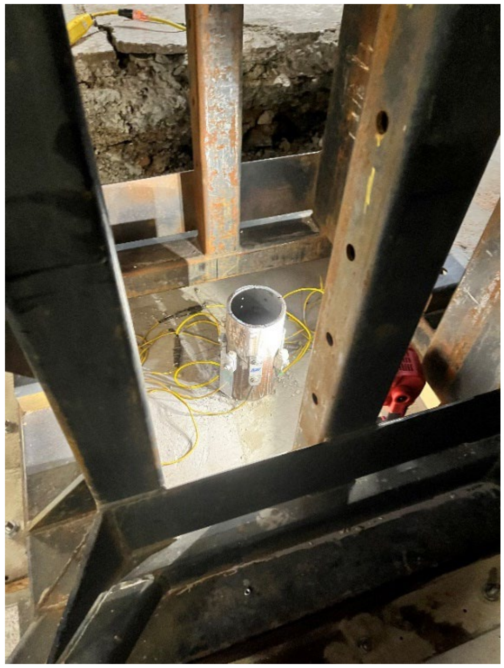


Figure 9. Instrumented pile with strain gages and accelerometers.

The testing procedure consisted of impacts being applied from varying drop heights while monitoring pile head displacements with a surveyor's sight level for each applied impact. Figure 10 shows the testing setup with the dynamic load testing frame over the pile and surveyors site level monitoring the pile head displacement or pile set. Drop heights ranged from 0.5 to 2.83 ft. The maximum pile top displacement, or set value, was measured at 1/32 of an inch with a maximum total cumulative displacement over the entire test of 1/16 of an inch.

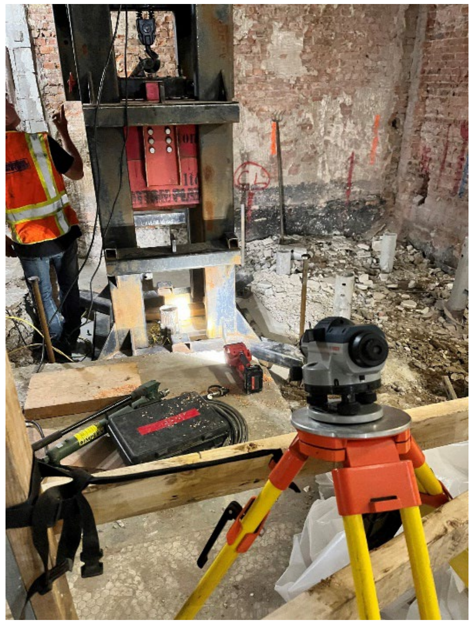
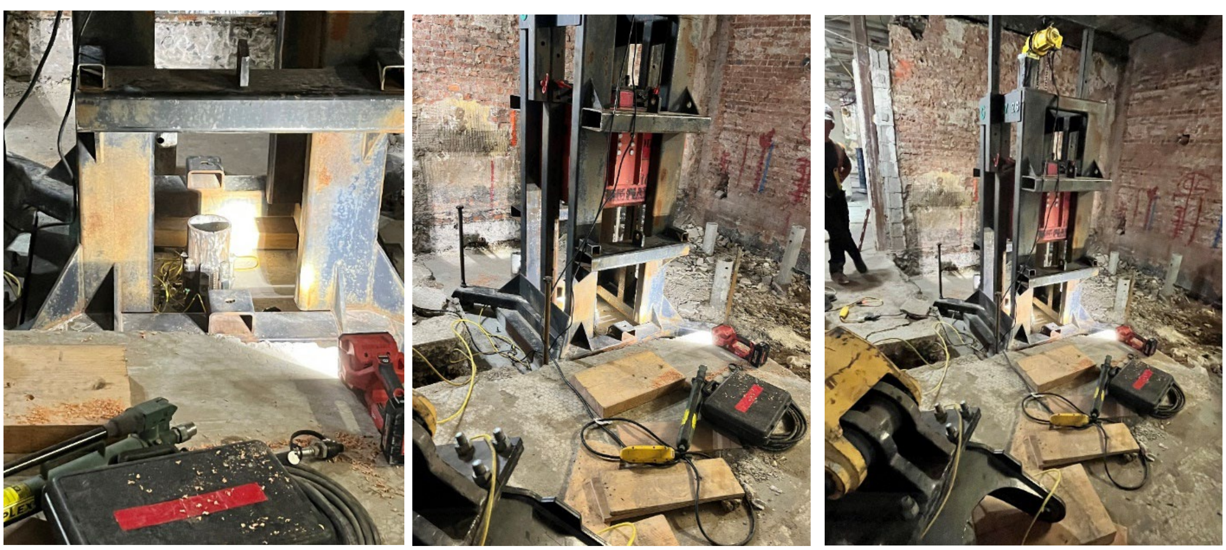


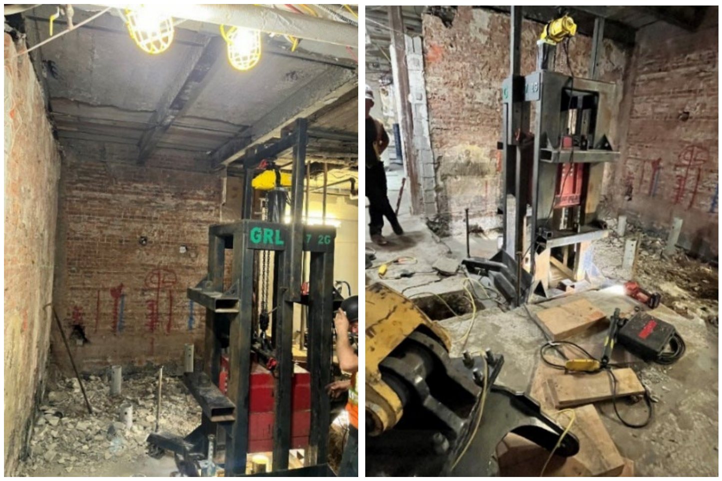
Figure 10. Dynamic load testing setup with surveyor site level to monitor pile set for impacts.

Figure 11 is a close-up of the testing setup just prior to the ram impacting the top of a pile. Figures 12 and 13 show the 2-ton ram being lifted by the hydraulic winch as the drop height is set.



Figures 11, 12, 13. Dynamic pile load testing frame setup with hydraulic winch lifting the ram.

Figures 14 and 15 show the dynamic load testing frame with the ram lifted over the pile.



Figures 14 and 15. Dynamic load testing frame with elevator shaft footprint in background.

RESULTS

Table 1 indicates the dynamic testing results and values related to utilized drop heights, observable pile set per impact, measured transferred energy, measured average pile top force, and mobilized total capacity for each tested pile. Table 2 presents the summary of the signal matching results from CAPWAP® which summarizes the total capacity which is comprised of the de-coupled shaft and toe resistance components, along with computed compression and tension stresses for the analyzed impacts across the composite cross-section of each tested pile.

Table 1. Summary of the dynamic pile testing results.

Pile Designation	Drop Height	Approx.[1] Pile Set	Transf'd Energy	Maximum[2] Force	CAPWAP Mobilized Capacity
	(ft)	(inch)	(kip-ft)	(kips)	(kips)
P6	0.50	NMS	0.4	83	-
	1.00	NMS	0.4	78	-
	1.50	NMS	3.1	272	-
	1.50	1/32	0.8	85	-
	1.50	NMS	2.1	218	-
	2.00	NMS	0.9	99	-
	1.50	NMS	2.0	187	-
	2.50	NMS	1.4	154	-
	2.00	NMS	4.0	287	**120**
	2.83	NMS	3.2	252	-
P5	0.50	NMS	1.4	199	-
	1.50	NMS	2.7	257	-
	2.00	1/32	1.6	186	-
	2.00	1/32	4.5	311	**165**
	2.50	NMS	3.2	259	-
	2.83	NMS	4.1	293	-

Notes:
1 - As observed on site using a sight level; NMS- No Measurable Set
2 - Measured Force from uniform axial average at gage location

Table 2. Summary of CAPWAP® results.

Pile No.	Mobilized Capacity Total (kips)	Shaft (kips)	Toe (kips)	Maximum[3] Compression Stress (ksi)	Tension Stress (ksi)
P6	**120**	70	50	1.4	0.08
P5	**165**	75	90	1.3	0.21

Figures 16 and 17 show force and velocity records from the raw data collected from impacts that were analyzed with CAPWAP®. Analyses for both tested piles were performed on data collected at corresponding drop heights of 2.0 ft.

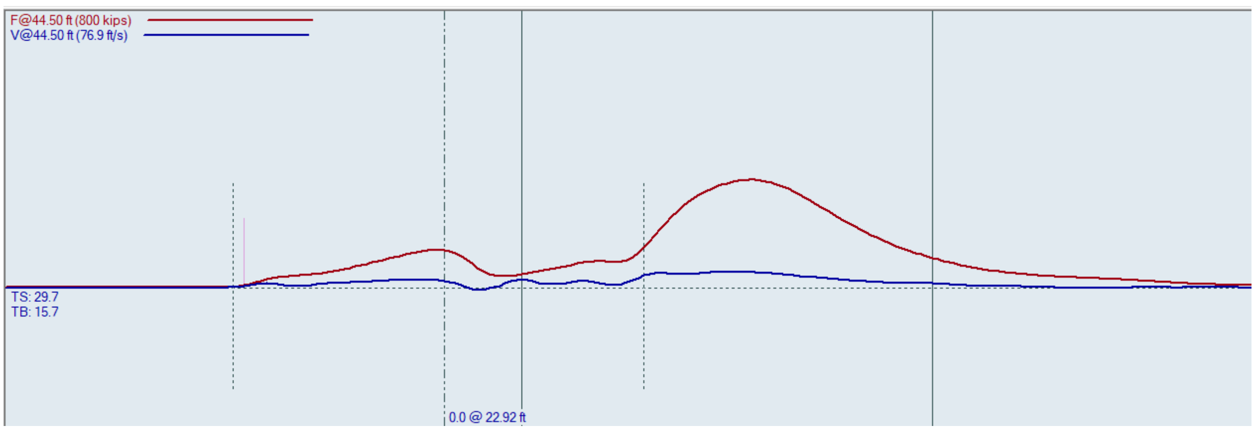


Figure 16. Force and velocity record for pile P5 (2-foot drop height).

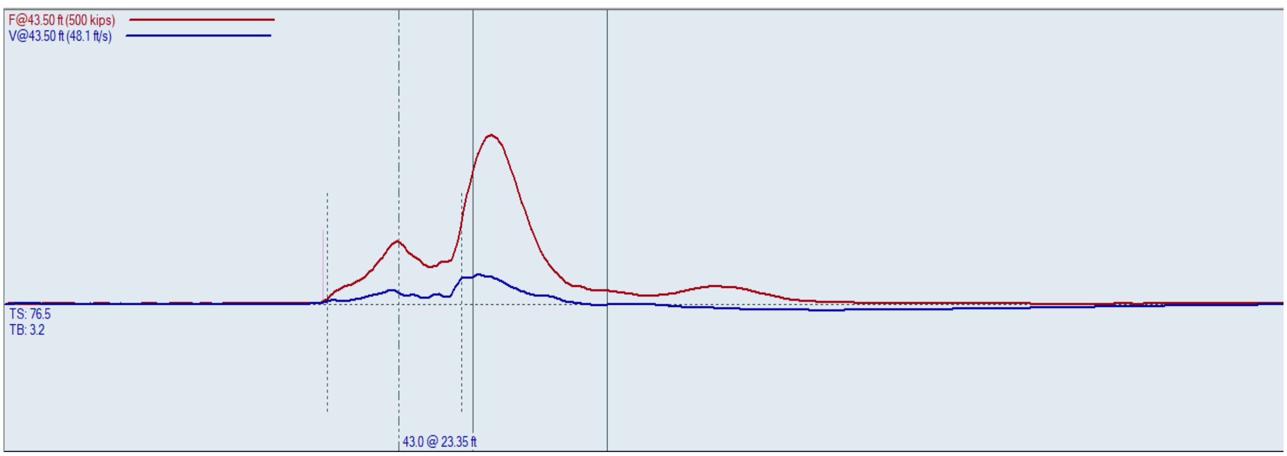


Figure 17. Force and velocity record for pile P6 (2-foot drop height).

The impacts selected for analysis were selected based on data quality, permanent pile head displacement (if it occurred) and engineering judgement from field observations. Professional practice recommends selecting the impact with the best data quality, which may include forces returning to 0, proportionality near 1.0, alignment of the two forces with the least amount of bending, and the impact with reduced noise or distortion in the records. Analyses results, as shown in Table 1, indicated a mobilized static capacity of 120 kips for pile P6 which equates to a safety factor of 3.0, and 165 kips for pile P5 which equates to a safety factor of 4.125. Therefore, both piles indicated mobilized static capacities exceeding the required ultimate capacity of 80-kips, based on the design load of 40 kips with a factor of safety of 2.0. The wave up curve in the data shown in Figures 18 and 19, indicate the soil response from the impact and can qualitatively assess the skin friction and end bearing resistance even prior to inputting any non-uniform pile model. Integrity evaluation was performed with review of the data in the field at the time of testing along with a more rigorous integrity evaluation performed during the CAPWAP® analysis. For the two dynamically tested drilled displacement piles, no detectable integrity concerns were apparent in the collected data.

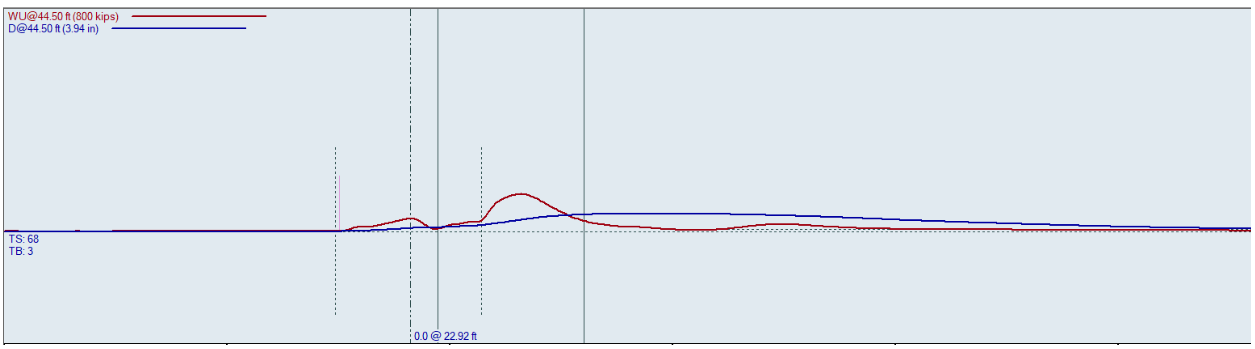


Figure 18. Wave up curve and displacement record for pile P5 (2-foot drop height).

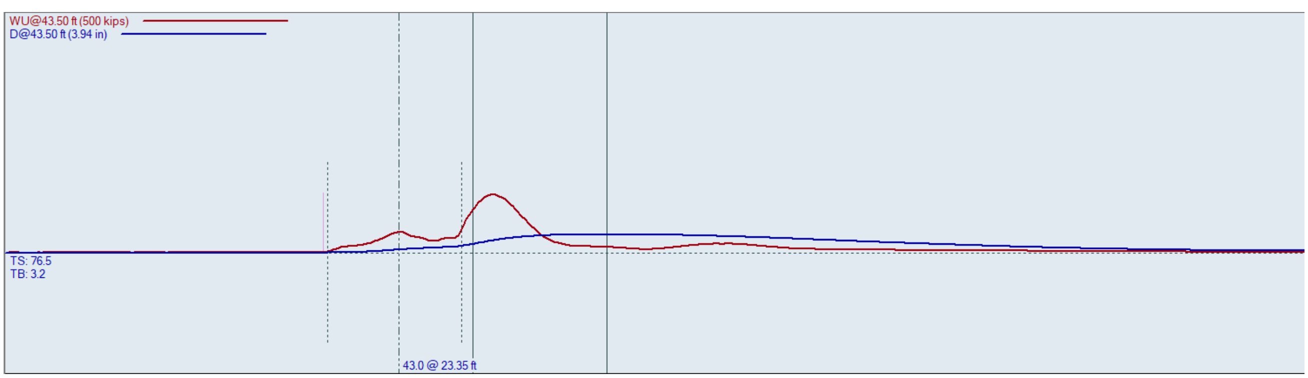


Figure 19. Wave up curve and displacement record for pile P6 (2-foot drop height).

SUMMARY AND CONCLUSIONS

Drilled displacement piles are designed based on an anticipated installed depth, and unlike helical piles which typically have a corresponding specified torque to capacity which serves as a means of inspection and quality control during installation, changes in anticipated installation depths may require additional assessment and testing to be performed to verify that the required design loads can be met with sufficient resistances for load-carrying requirements. Due to the nature of the installation of drilled displacement piles which results in a means of ground improvement by way of laterally displacing soil as the pile is advanced[5], any unanticipated soil strength changes by way of potential ground improvement and/or varying stratigraphy may manifest as relatively shallow pile refusal, which may limit the maximum achievable total pile capacity and would require further evaluation. One reliable method of further evaluation would be by way of performing load testing.

For this project, the design method involved interpretation of limited available soil information, however, the installed piles encountered refusal at shallower depths than anticipated. The next steps would be to either obtain additional soil information to redesign based on new information or to perform load testing of the piles in-situ to evaluate their load carrying capacities. As several spatial and clearance constraints made the options of obtaining additional soil information, as well as performing static load testing infeasible, dynamic load testing was identified as a reliable and acceptable load testing method to further assess the installed piles load-carrying capacity.

While static load testing is often recommended in industry practice or required by local building codes for piles for various reasons, it may not always be appropriate or feasible to perform due to spatial constraints and/or can also be cost prohibitive. Furthermore, while dynamic testing has been an acceptable test method for many decades on driven piles and has been reliably correlated to static load testing results, drilled piles have also been successfully tested with reliable correlation in part due to the limited or no time-dependent soil strength changes that occur during testing compared to driven piles [6].

In the case of the Jane Hotel project, the attractive alternative of high strain dynamic testing was utilized and accepted by the engineer of record for DDMs, allowing for load testing to be performed on multiple piles in one day which provided results indicating that the piles had resistances well in excess of the required safety factors. This allowed for the installed piles to be accepted and permitted for the remainder of the project to continue progressing. These capabilities can translate to practically any project as high strain dynamic testing continues to be successfully utilized in conjunction with or in place of static load testing on driven and drilled piles alike for most circumstances.

Specific cases where dynamic testing can be utilized to overcome feasibility constraints of static load testing may include but not be limited to projects with deep foundation elements where spatial constraints (such as overhead clearances, or neighboring structures) exist, or on sites with very soft soils overlying hard/stiff material which may make it difficult or impractical to install reaction piles without risk of them pulling out, or where a reaction system may excessively settle.

More universally, dynamic testing can be performed with less pre-construction planning and does not require a reaction frame or reaction piles to be constructed, and can often be performed on multiple piles or shafts in one day, which provides a larger sample size of testing while having a lower unit rate per pile or shaft tested compared to static load testing. Additionally, engineering advantages of dynamic testing naturally include the ability to evaluate pile integrity, quantification of the shaft resistance with depth, and the capability to de-couple the end-bearing component from the total resistance as a whole. Furthermore, capabilities which can be utilized with planned pre-construction can include embedded instrumentation in a pile or shaft to allow for direct measurement for correlation of effective dimensions and/or strain measurements and velocities. All of these capabilities can provide further insight to the load transfer mechanisms of the foundation element being tested, which can then in turn be used as a proof test to confirm design assumptions, and/or be used to obtain measurements to allow for further optimization of design assumptions, which can then allow for adjustment of pile/shaft dimensions for construction.

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