COST EFFECTIVE DESIGN VERIFICATION AND VALIDATION FOR MICROPILES IN ROCK

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ABSTRACT

The use of micropiles is often chosen to mitigate urban construction risks and limitations for many ongoing projects at risk from coastal flooding. To ensure cost effective construction methods are being utilized, the process will need to include cost effective designs, construction and testing methods for the micropiles. The main design parameter for axial loading (tension or compression) is often the bond stress of the rock for design. Typically for micropiles, static testing is done via tension or compression loading. Compression tests require, most often, four (4) reaction piles and tension tests, with significantly higher loads, often require large center bars or reaction piles to provide compressive reaction. Utilizing high strain dynamic testing on micropiles allows for the differentiation between the friction in the unbonded zone, bond zone friction, and end bearing. Dynamic testing on micropiles avoids the necessity of the reaction piles or anchors that are used in tensile tests, as well as the limit of the center bar or ground conditions. Considering the differentiation of the capacity components, along with time savings, dynamic testing for micropiles can be selected as the more cost-effective testing method for design verification while providing more information than traditional static load tests without embedded strain gauges.

Keywords: high strain dynamic testing, differentiation between bond zone friction, unbonded zone friction and end bearing, cost effective testing of micropiles, micropile proof testing, micropile load testing

INTRODUCTION

Concerns of rising sea levels or coastal flood risks have developed the need over the past decade to invest in coastal resiliency programs and projects. Typically, the highest risk locations with the most expensive assets often are in highly urban areas. With projects focused on dense urban areas, concerns regarding overhead clearance, spatial constraints, ground settlement and vibration effects on nearby buildings are often a main concern. The use of micropiles is often chosen to mitigate some of the urban construction risks and limitations.

To benefit all parties, cost-effective engineering and construction is being utilized to better serve the owner or client, where the process will need to include cost effective designs, construction, and testing methods for micropiles when chosen. In urban areas like Manhattan, where micropiles in rock are often feasible, the main design parameter for axial loading (tension or compression) relies on the bond stress of the rock. The use of a dedicated load test program via static or dynamic load testing would be valuable to evaluate bond stress of the rock and validate the design bond stress or allow for design modifications. Furthermore, performing load and/or integrity evaluation during the construction sequence can provide feedback to the designer and contractor alike regarding design assumptions, as well as pile performance across a project.

Static testing may be done via compression or tension loading on micropiles. Compression tests historically require deadweight and/or most often four (4) reaction piles, while tension tests require large center bars to be installed in the test pile, and/or additional reaction piles to provide the compressive reaction, depending on the nearby ground conditions. With increasing required loads, higher resistances would be required through a reaction system transferring the reaction loads. Unless specified or required, static load testing is often not performed with embedded strain gauges, and even more rarely on proof

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tests that are performed at a high percentage across the site. Therefore, reliable separation of the resistances in a cased zone (often treated as an unbonded zone), bond zone (where the resistance developed as side friction is anticipated), and end-bearing is unknown for load tests performed in compression. Furthermore, while a tension test can remove the end-bearing component from resistance (neglecting any anchoring effects), uncertainties in the friction resistance of an unbonded zone and bond zone still exist. This is true even in cases where embedded strain gauges are utilized due to unknown mechanical behavior of cementitious materials in tension – a topic that will be discussed in more detail later in the paper.

While verification testing requires loading up to 2.0 times the design load, proof testing requires loading up to 1.6 times the design load. A common requirement for proof testing is to test 5 percent of the production micropiles, however, as this may not always be applicable, FHWA provides table 7-3 to correlate specific application with proof test frequency (FHWA NHI-05-039).

Utilizing high strain dynamic testing on micropiles allows for the differentiation between the friction in the unbonded zone, bond zone, and end bearing. Just as is routinely done for testing performed on piles in soil, unit resistances in rock can be computed and compared to the initial design rock ultimate bond stress and can allow for the modification of the bond zone during the production phase as testing is continued. Furthermore, dynamic testing on micropiles avoids the need for a reaction system, the structural strength limit of the center bar is not a factor, and soft ground conditions are also not a restriction.

HIGH STRAIN DYNAMIC TESTING OVERVIEW

Correct application of the dynamic testing method requires the collection of strain and acceleration measurements near the pile head. This is routinely done on driven piles, and the same principle is applied to any non-driven, spun, cast-in-situ piles such as micropiles. These measurements are digitized and converted to force and velocity. After data is collected and digitized, signal matching is performed by utilizing the CAPWAP® program, which can model piles with assumed or measured non-uniformity and composite properties. The CAPWAP software computes unit resistances and pile stresses along the entire length of the tested pile (Santulli & Ryberg 2024). This indicates that unit resistances can be computed in different portions of the bond zone, in the unbonded zone and be differentiated from the end bearing and bond zone resistance.

The testing procedure consists of several impacts being applied at various drop heights, while monitoring pile head displacements for each impact. When a limited pile set is observed, CAPWAP analysis is often performed on one impact, which may be the one with highest energy as the highest resistance is often mobilized, however, impacts for analysis are also performed based on engineering judgment, pile head displacement and field observations. Professional practice recommends selecting the impact with the bes data quality, which may include forces going back to 0, proportionality near 1.0, alignment of the forces, and the impact with reduced noise and distortion (Santulli & Ryberg 2024).

Statistical evaluations of previous studies and current compilations show CAPWAP analysis of dynamic testing data for restrikes to be very reliable in determination of ultimate capacity of both driven piles and cast-in-situ piles. Considering the low cost of dynamic testing and relatively good accuracy of the CAPWAP capacity prediction, further application of the CAPWAP method for capacity evaluation is justified both economically and technically for both driven and cast-in-situ piles (Likins & Rausche 2004).

The first published usage of high strain dynamic testing for micropiles, and specifically for micropiles in rock, was referenced in 2004 in Gomez et al. Results in 2004 showed PDA or high strain dynamic testing may provide very accurate estimates of capacity for micropiles bonded into rock (Gomez et al., 2004).

Various types of hammers or dynamic testing systems can be utilized including traditional drop hammers, air hammers or hydraulic hammers. Although, considering the ability to control stroke heights, if a pile driving hammer is utilized, a hydraulic hammer is more convenient for micropile testing (Gomez et al., 2004). One option in-lieu of pile driving hammer is a dynamic load testing system as shown in Santulli & Ryberg 2024, which was used for performing dynamic testing on stelcor drilled displacement piles, which have a similar design methodology as micropiles. In the case study discussed in Gomez et al. 2004, a total of 25 micropiles were tested with dynamic testing and 3 of the 25 were also tested with a static compression load test. Based on the three piles tested statically in compression and dynamically in compression, it was concluded that the dynamic testing could provide a reasonably accurate estimate of capacity for all the remaining piles requiring testing on that site (Gomez et al., 2004).

Estimation of uplift or tension resistance by way of dynamic testing has been performed for many decades and correlates very well with static load testing results (Hussein, et al., 1994). A common empirical correlation for computing tension resistance from compressive results for non-tapering piles where calculated shaft resistances are not abruptly variable with depth was applied here and considers 80% of the calculated skin friction (Teferra et al., 2008) as this approach offsets the difference in direction of loading due to the Poisson effect of steel/concreted/grouted piles as the applied load is in compression, while the estimated load would be in tension. As such, dynamic load testing in compression simultaneously provides insight and allows for the estimation of a pile's uplift capacity. Further evaluation for appropriate estimation of uplift on non-uniform piles and/or for materials other than steel/concrete/grout should be performed as a 20% reduction may not be appropriate for all cases.

TENSION STATIC LOAD TESTS AND DYNAMIC TESTING

Industry practice during design and testing often assumes no friction is present in the unbonded/cased zone. This assumption is often applied during tensile load test interpretation when no embedded strain gauges are installed. This assumption may lead to overestimation of mobilized bond stress in the bonded zone if resistances are actually present above the bond zone by assuming the full tensile load is transferred to the bond zone.

Performing tension load testing without the use of reaction piles is more cost effective if feasible. If embedded strain gauges are installed in an attempt to characterize the frictional resistance above the bond zone and assess potential for varying rock strengths throughout the bond zone as discussed in Robertson et al. 2024, a composite-section elastic modulus or rigidity (EA) will need to be determined to convert the measured strains to calculated internal forces.

Considering micropiles typically are constructed with grout, the grout modulus E, is very likely not known to a reasonable degree of certainty, being commonly estimated from a laboratory test on grout samples (Robertson & Komurka 2023). Also, the American Concrete Institute "ACI" method for determining an elastic modulus from grout samples comes from compressive strength results (Robertson & Komurka 2023). This would indicate the ACI method for estimating a grout modulus or any grout modulus estimation from compressive break results, would provide a compressive modulus and therefore would not be applicable for grout (or any cementitious material) loaded in tension. For cementitious materials, it is inappropriate to use their compressive modulus to convert measure tensile strains to calculated internal force (Van E. Komurka, personal communication March 3, 2026).

The Incremental Rigidity method as discussed in Komurka & Moghaddam 2020 may provide the only applicable alternative to obtain reasonable internal force distribution interpretations from tensile strain data in cementitious material (Van E. Komurka, personal communication March 3, 2026). Tensile tests may result in atypical strains which would need to be evaluated using the Incremental Rigidity Method as presented in (Komurka & Robertson 2025).

The addition of embedded strain gauges in a tensile test is still encouraged for any potential to characterize the unit resistances along the shaft when compared to a tensile static load test without embedded strain gauges. However, the engineer performing the analysis to develop the internal force profile should remain cautious with the potential unwarranted results referenced above. Special care may be required on the reviewing engineer's side when reviewing finalized reports and submittals with embedded strain gauge analysis from tensile load tests with the above referenced limitations.

Therefore, considering the often default, non-warranted use of a compressive modulus for tension loading, the possibility of atypical strains and the cautions listed above, high-strain dynamic load testing provides an attractive alternative to tensile load testing with embedded strain gauges. It provides for the ability to reliably separate the friction in different zones and end bearing while avoiding the uncertainties of applying tension static load test results with embedded strain gauges to compute the bond stress in micropiles for compressive loading.

CASE HISTORY

Pile design and installation methods

The pile design consisted of a 9.625-inch outer diameter casing with a 0.5-inch wall thickness. Center bars were either #10 or #18 bars, depending on the tension loading. The highest ultimate bond stress was 150 psi in the bond zone, however design loads in the bond zone for each pile type were developed according to Table 1. The bond zone and installation for the micropiles consisted of a permanent casing that extended the full length of the micropile. An underreaming bit at 10.4 inches, was used to drill the bond zone, which would allow for the casing to advance to the bottom of the bond zone and bottom of pile. During grouting, the casing is raised and plunged into the bond zone to allow for grout to flow outside of the casing. Therefore, the final installed pile has an as-built diameter of 9.625 inches in the unbonded zone and 10.4 inches in the bonded zone with a 9.625-inch x 0.5-inch casing throughout the full length of the pile. This design allows for higher stresses during dynamic testing and higher loading in service conditions, considering the avoidance of the stress limitation of typical uncased bond zones.

Soil information

The overburden consisted of generally soft sands and silts, which was assumed to have minimal resistance, followed by limestone that was identified as having voids throughout the stratum during drilling operations. This drew concerns as the presence of a void at the bottom of an installed micropile may result in negligible end bearing resistance. Therefore, required bond zones in competent rock had to be maintained continuously and if voids were present during drilling, then the required bond length would need to become longer, which would lead to varying total pile lengths. However, often the presence of voids was coupled with the anticipated unbonded zone being composed of limestone layers, which may potentially result in higher resistances developing in the unbonded zone. Flooding concerns and/or sinkholes were considered in the overburden layers, which required any resistance in the unbonded zone to have to be neglected. As such, if the resistance in the unbonded zone is not quantified or assumed to be negligible, a traditional static load test without embedded gauges could lead to nonconservative results.

Testing requirements and loads

Proof testing was required on a total of 49 production micropiles (5% of the total production piles) along with several pre-production verification tests that were performed in compression. One additional static load test pile that is discussed below, was also performed in tension statically along with dynamic testing (for comparison) and one sacrificial dynamic load test pile was only tested in compression dynamically. The overview of the proof testing requirements is provided in Table 1.

Table 1. Proof testing requirements for the project

Pile Type	Number of Tests	Design Load (kips)	Test Load (kips)
1	2	166	266
2	27	440	704
3	9	80	128
4	11	440	704

The initial specified testing method was to perform 49 proof tests via traditional static load testing. If the proof testing was performed by means of compression tests, 4 reaction piles would be required along with the uncertainty of the end-bearing influence in the resistance. Considering the requirement for end-bearing to be neglected, the proof tests were originally anticipated to be performed by means of tensile static load tests. Considering 38 of the 49 proof tests had required test loads of 704 kips, which equates to 160% of the design load, the contractor needed to perform evaluation prior to testing if utilizing the adjacent soil as the compressive reaction would be feasible. The pre-testing engineering evaluation concluded that reaction piles or anchors were required to provide compressive reaction.

In addition to the reaction piles, an increased bar diameter would be required to avoid the structural failure of the bar in order to transfer a load of 704 kips in tension. In addition to the cost of the up-sized bar and reaction pile installation (installation manpower and materials), it was anticipated only one micropile would be able to be proof tested per day considering setup of the reaction system, testing and break down and mobilizing the equipment/system across the site. This drew concerns on the already tight schedule and the owner desiring to place the finished project into service as soon as possible. Dynamic testing was provided as an alternative as testing approximately 2 or 3 piles each day was feasible, which resulted in time and cost savings by avoiding reaction piles and assembly of a load transfer system along with preserving the approved center-bar pile design.

Considering 49 proof tests were required across the site, it would be cost prohibitive to expect pre-planned embedded strain gauges installed for all of the micropile proof tests. Therefore, assumptions would have been made about the load transfer to the bond zone and resistance above the bond zone, and no characterization on the unit resistances in the bond zone across the site. Therefore, dynamic testing became the most cost-effective testing method for the proof tests and allowed for providing insight into the bond stress resistances, along with potential verification or validation on the design assumptions throughout the full length of the pile and including end-bearing.

Dynamic testing system

Dynamic testing would be performed according to ASTM D4945 (2017). Typically, high strain dynamic testing is performed with a pile driving hammer or 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 (Santulli & Ryberg 2024). The dynamic testing system as shown in Fig. 1 consisted of a 20 ton (40-kip) ram that had a maximum drop height of approximately 6 ft. However, maximum drop heights during proof testing did not exceed 2.5 ft. During the initial sacrificial dynamic tests, a maximum drop height of 3 ft was utilized. The dynamic testing system's ram weight and anticipated drop heights were decided based upon pre-testing GRLWEAP analysis. Prior to mobilizing to the site, extensive review of the geotechnical report and site conditions were performed to estimate or predict potential end bearing resistance being mobilized during testing along with potential resistance above the bond zone. This was needed to forecast potential total capacities that would need to be mobilized during testing to mobilize the required bond zone resistance to properly size the dynamic testing system.

Static tension test comparison

Prior to changing the acceptable test method from the previously approved static load testing to dynamic load testing on the project for the required proof tests, a comparison study similar to what was presented in Gomez et al. 2004 was to be performed. However, due to the high required loads anticipated to fail the pile in compression, the comparison would be performed on a sacrificial static tensile loaded pile. Testing would then be followed by dynamically load testing the pile in compression and the comparison would be done via computing the tensile capacity from dynamic testing vs the computed ultimate tensile capacity from the static test. It is noted that, for a comparison between testing methods (static vs dynamic), significant pile set or displacement is required and an effort should be made to load the pile in both methods to geotechnical ultimate for a technically sound comparison. If this is not followed, one test method may be under-predicting due to not mobilizing sufficient capacity, while the other method is simply mobilizing higher resistance as shown in one of the static tested piles in Gomez et al. 2004.



Fig. 1. Dynamic load testing system with a 20-ton ram weight

The installed micropile for the comparison study (VT1) was load tested in tension to achieve geotechnical pullout failure such that it was permanently displaced upwards approximately 0.32 inches. The maximum attained load was approximately 382.7 kips at which the pile pulled out as shown on Fig. 2. We note that the distribution of this resistance is unknown as no embedded strain gauges were utilized.

VT1 was then tested with dynamic testing under several impacts. The analyzed fifth impact provided the below simulated pseudo-static load set curve as shown in Fig. 3, which estimated 480 kips of shaft resistance (and only 70 kips in end-bearing). Applying a 20% reduction resulted in an estimated uplift resistance of 384 kips, practically identical to the maximum attained load from the tension test for a reliable comparison. Furthermore, modeling the pile's non-uniform cased sections allowed unit friction values to be computed such that even in the unbonded section there was evidence of non-negligible shaft resistance of 190 kips. After the pile was further impacted and displaced back downward on top of rock, analyzing the eleventh impact, as shown in Fig. 4, estimated 455 kips in shaft resistance (and 645 kips in end bearing). Note that for this impact, only 108 kips of resistance above the bond zone are now estimated. In turn, the additional impacts resulted in the breakdown of resistance above the bond zone, which therefore allowed for more resistance to be mobilized in the bond zone (from 15.8 to 19.0 ksf), as well as end-bearing during testing.

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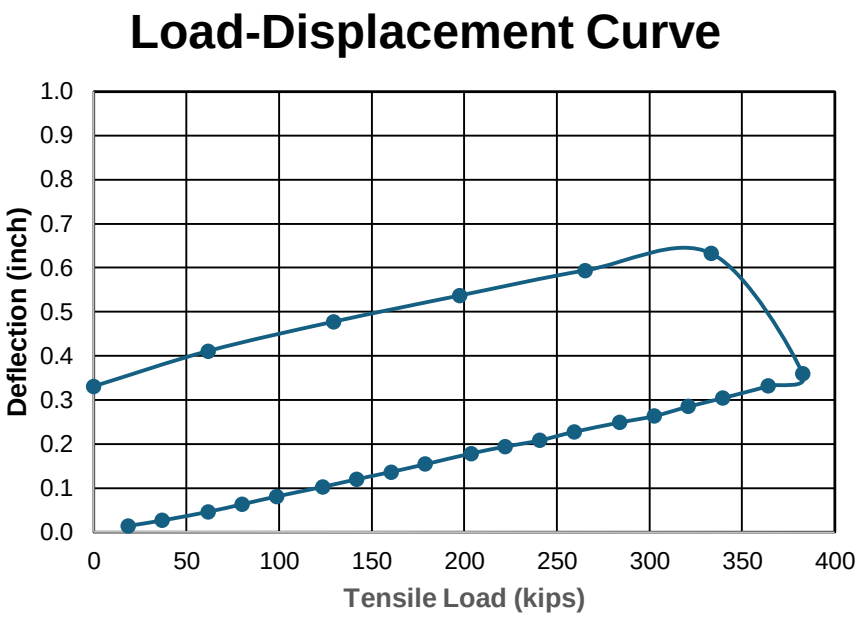


Fig. 2. Static tensile test results from Pile VT1 for comparison with dynamic testing

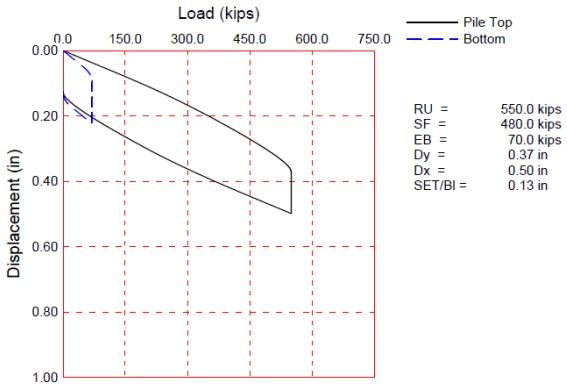


Fig. 3. CAPWAP for Blow #5 on pile VT1

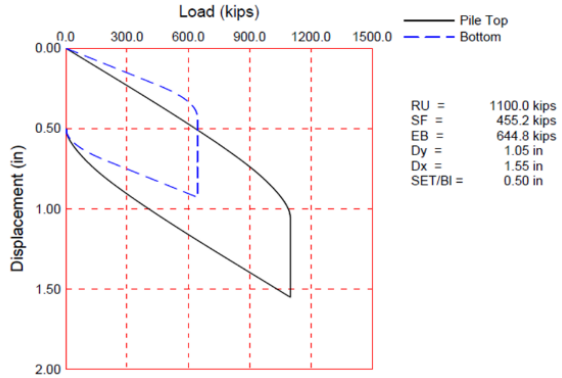


Fig. 4. CAPWAP for Blow #11 on pile VT1

Testing results

The second sacrificial dynamic load test pile (type 3 test pile) was tested prior to proof testing, in an attempt to reach the ultimate bond stress for comparison from the design assumptions. The results indicated on the seventh impact, when the observed set was 0.34 inches under the impact, a unit resistance of 23.38 ksf, which equates to 162.4 psi, was computed. The design assumed the highest ultimate bond stress across the site of 150 psi, which, therefore, indicated the second sacrificial dynamic test pile validated the design assumptions. Figure 5 shows the CAPWAP tabular outputs for this pile.

Prior to CAPWAP analyses performed, case method results including tension stress (TSX), compression stress (CSX), transferred energy (EMX) and peak force (FMX), are evaluated in the field during the time of testing. Figure 6 below shows an example on pile 124-2 on the case method results that are observed during testing. Based upon the pile's measured set, which was measured by means according to Santulli & Ryberg 2024, along with the results depicted in Fig. 6, the testing engineer in the field can decide to increase the hammer's stroke accordingly or to terminate the test.

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After CAPWAP analyses are performed, the friction along the full pile length can be computed along with the mobilized end-bearing. The final results are provided in Table 2, which shows five (5) specific piles and the computed required bond zone friction along with the full-length friction and end bearing. We note that similar outputs and conclusions were provided for all 50 micropiles that were tested, however, they are not included in this paper for brevity. Based upon the pile type and the required test load in the bond zone as shown in Table 1, the reviewing engineer can interpret if the bond zone had the required bond zone test load and if the proof test can be deemed acceptable.

CAPWAP SUMMARY RESULTS

Total CAPWAP Capacity: 1050.0; along Shaft 415.6; at Toe 634.4 kips

Soil Sgmnt No.	Dist. Below Gages ft	Depth Below Grade ft	Ru kips	Force in Pile kips	Sum of Ru kips	Unit Resist. (Depth) kips/ft	Unit Resist. (Area) ksf	Smith Damping Factor s/ft
				1050.0				
1	6.6	5.6	0.0	1050.0	0.0	0.00	0.00	0.00
2	9.9	8.9	0.0	1050.0	0.0	0.00	0.00	0.00
3	13.1	12.1	0.0	1050.0	0.0	0.00	0.00	0.00
4	16.4	15.4	4.8	1045.2	4.8	1.46	0.58	0.02
5	19.7	18.7	201.6	843.6	206.4	61.36	23.37	0.02
6	23.0	22.0	209.2	634.4	415.6	63.67	23.38	0.02

Fig. 5. CAPWAP output for type 3 test pile, utilized for ksf determination in the bond zone

FMX: Maximum Force
CSXLC: Compression Stress Maximum, Load Cell
CSILC: Comp Stress Max-Indiv Sens,Load Cell
CSX: Compression Stress Maximum
TSX: Tension Stress Maximum - Full Record Search
DH: Drop Height
EMX: Maximum Energy
SET: Set
CUSET: Cumulative Set

BL#	FMX kips	CSXLC ksi	CSILC ksi	CSX ksi	TSX ksi	DH ft	EMX k-ft	SET in	CUSET in
1	479	9.24	9.9	6.6	0.0	1.00	5.9	0.03	0.03
2	629	12.12	13.0	8.6	0.0	1.00	10.5	0.02	0.05
3	729	14.05	16.1	10.0	0.0	1.00	14.4	0.03	0.08
4	874	16.84	19.0	12.0	0.0	1.50	21.6	0.03	0.11
5	1,124	21.68	24.0	15.5	0.5	2.00	40.5	0.06	0.17

Fig. 6. Example of dynamic testing results for pile 124-2 prior to CAPWAP analysis

Table 2. Dynamic testing results example for 5 tested piles

Pile No.	Pile Type	Drop Height (ft)	Bond Zone Length (ft)	Mobilized Capacity				Maximum[2]
				Total (kips)	Shaft (kips)	Toe (kips)	**Bond Zone (kips)**	Compression Stress (ksi)
124-2	2	2.00	19	**1195**	945	250	**925**	15.7
181-3	4	2.00	19	**1255**	1005	250	**1000**	17.6
27-1	2	2.00	21	**1235**	1010	225	**970**	16.7
35-2	2	2.00	17	**1255**	980	275	**975**	17.9
69-2	2	2.00	19	**1350**	1100	250	**925**	16.6

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Frictional resistance above the bond zone breakdown

For driven piles, dynamic tests are often performed during initial drive and restrike after some wait period to assess soil strength changes. For drilled foundations, piles or foundation elements are required to achieve sufficient strength prior to testing. Therefore, the soil has indirectly been able to recover from the drilling process and the pile or foundation element could potentially be tested in long term conditions by allowing the soil strength changes to stabilize (Likins and Rausche 2004).

When performing dynamic testing on micropiles, soil strength changes can be computed and become evident. The initial impacts depict long term friction in the unbonded zone, and after sufficient pile set, energy, or number of impacts, the friction in the upper layers is often reduced as seen typically on restrikes on pile driving. The comparison of the five impacts analyzed for pile 124-2 shown in Fig. 7 indicates the change in friction in the upper layers and the ability to mobilize more friction in the lower layers or bond zone in the later impacts. The significance of this relates to the comparison to static testing without embedded strain gauges, as the breakdown in friction, if it occurred during a static test, would be unknown. This would potentially lead to mobilizing less resistance in the bond zone than anticipated and static testing may not be able to break down the friction in the upper layers as compared to later impacts in dynamic testing, which leads to requiring higher static testing loads to mobilize equivalent resistances in the bond zone.

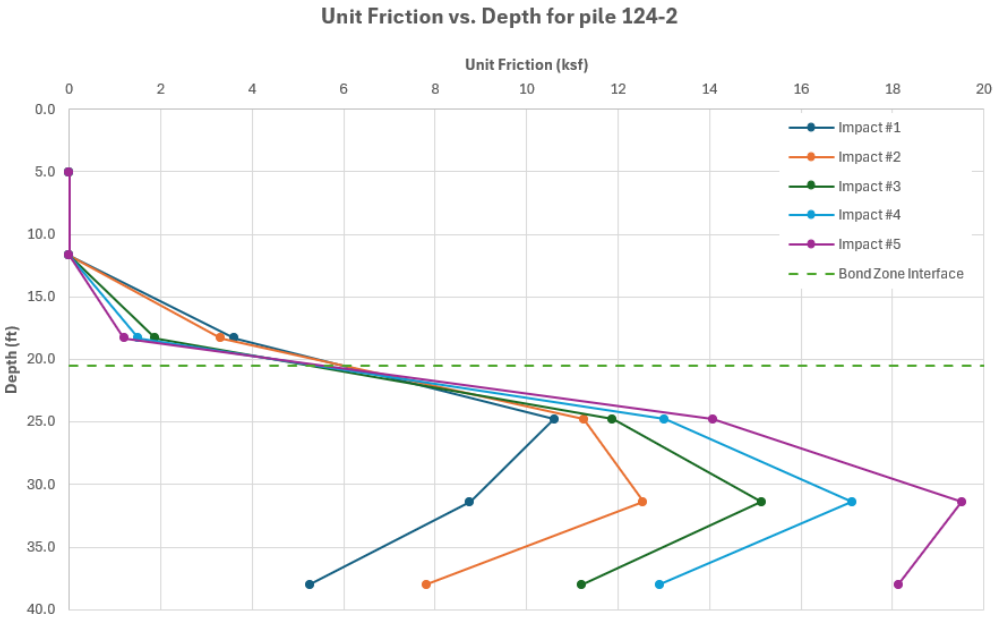


Fig. 7. Comparison between impacts on frictional resistance

CONCLUSIONS

A general overview of dynamic testing of micropiles was presented including the advantages as compared to traditional static load testing. Overall dynamic testing of micropiles can be a cost-effective alternative to static load testing as reaction piles are not required, as it would also be unnecessary to increase the center-bar diameter to account for tensile loading. In addition to the cost benefits listed above, time savings can be contributed to the ability of testing multiple piles in one day with dynamic testing as compared to the required effort to perform a static load test. Along with cost and time savings, dynamic testing can provide design verification and validation on the design assumptions in the bond zone along with information regarding resistance above the bond zone and end-bearing resistance. When compared to

tensile static load tests with embedded strain gauges, dynamic testing can be an alternative option with less uncertainty in the calculated unit resistances and internal forces due to ambiguity in grout modulus in tensile loading vs a compressive modulus often computed from compressive grout breaks. From the case history referenced here within, the following conclusions can be drawn:

- Dynamic testing was able to be performed on over 50 micropiles and the mobilized bond stress was able to be computed by CAPWAP analysis and separation of friction along the entire pile length and separation of end-bearing resistance.
- The comparison produced practically identical results when the estimated uplift resistance was taken as 80% of the CAPWAP-calculated compression shaft resistance.
- Dynamic testing proved to be the cost-effective testing method allowing for the avoidance of reaction piles and upsizing the center bar as compared to tensile static load tests.
- Dynamic testing was a suitable testing method that did not cause any detectable pile damage to any tested piles.
- A sacrificial pile test allowed for evaluation of ultimate bond stress (ksf) in the bond zone by displacing the pile 0.34-inches on the final impact, which can be compared to the original designed ultimate bond stress.
- Unit resistance throughout the entire pile length was able to be computed via CAPWAP analysis including the resistance above the bond zone that is typically assumed to be negligible.
- Results indicated in this stratum there was consistent friction present above the bond zone, which reached up to 190 kips in the static load tested comparison pile.
- Frictional resistance in the upper portions of the pile can be observed in dynamic testing data to reduce over the impacts, which allows for less required force to mobilize higher resistance in the bond zone (similar to soil setup breaking down on a driven pile restrike) on later impacts.

FURTHER CONSIDERATIONS

A recent project separate from the case history listed here indicated dynamic testing can also be utilized to evaluate differing bond stress across the site with varying rock formations. When varying rock strengths are present across the site, leading to differing design and ultimate bond stress and bond design lengths, dynamic testing can be an attractive alternative to evaluate the differing bond zone capacities by means of CAPWAP analysis and separation of the friction and end bearing along the full pile length.

Although a comparison study with static testing was performed in the referenced case history, along with being depicted in (Gomez et al., 2004), numerous projects each year utilize dynamic testing on micropiles in rock or other soils (clays, sands) without a comparison study. Therefore, a comparison study with static testing and dynamic testing is not required on every site.

ACKNOWLEDGMENTS

Rosendo R. Domingo, P.E.
Berkel and Company Contractors, Inc.
ECS Mid-Atlantic, LLC

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