

A DROP WEIGHT HAMMER FOR DYNAMICALLY TESTING MICROPILES IN CHARLESTON, SC

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ABSTRACT: With increasing frequency, micropiles (a.k.a. micropiles or pin-piles) are being used as a foundation solution within the Charleston, South Carolina area. Micropiles typically used in this area consisted of 76.2 mm (3 inch) nominal diameter Schedule 80 steel pipe with a grout bulb at the tip or self-drilling hollow injected grouted micropiles. Micropile lengths typically range from 7.6 to 18.2 meters (25 to 60 feet). Past experience with static load testing of micropiles around Charleston, SC has verified design capacities ranging from 89 to 178 kN (10 to 20 tons). However, the static load tests of micropiles have not been conducted to failure and consequently the ultimate axial capacities are not known. In addition, performing static load testing of these piles is costly and time consuming, especially in tightly spaced urban environments. Therefore, a drop weight testing hammer was developed to quickly determine the capacity of the micropiles by dynamic methods.

The following paper presents the development, construction, and field testing of a drop weight hammer system for dynamically testing micropiles. The first two case histories using this hammer are presented. The initial case history showed that the hammer could mobilize ultimate axial capacities greater than those required. The subsequent case history showed good correlation between the dynamic and static capacity results.

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INTRODUCTION

In the Charleston, SC area, the presence of soft clays and loose sand deposits in the local soil stratigraphy require many structures to be founded on deep foundation systems. Typically, driven piles bearing with the underlying Cooper Marl Formation are the deep foundation system selected for use. However, driven piles often generate vibrations that can affect adjacent and surrounding buildings and disturb neighboring residents in tightly spaced urban environments. In Charleston, South Carolina, construction vibrations are of special concern due to the tight spacing, age, construction, and historic significance of many of the city's buildings. As such, micropiles (a.k.a. minipiles or pin-piles) are being used with increasing frequency as a deep foundation solution. There are several distinct advantages to using micropiles as a deep foundation solution: they can be installed in space restricted environments; installation generates little to no vibrations; and they are cost competitive when compared to most deep foundation alternatives. The following two types of micropiles are typically installed within the Charleston, SC area:

- 7.6 cm (3 in) nominal diameter Schedule 80 steel pipe with a lean grout bulb at the pipe tip. In addition, the steel pipe is also filled with grout. Typical grout design compressive strengths range from 20.7 MPa to 27.6 MPa (3,000 psi to 4,000 psi). This type of micropile is classified by the FHWA as CASE 1 Type B3 (pressure grouted, casing left in place) based on applied loading and construction method (FHWA 2000).
- Self-drilling hollow injected grouted micropiles. These piles consist of threaded hollow steel drill rods with various diameter cutting heads. As the drill rods are installed, grout is pumped through the drill rods, creating a grout body around the drill rod. Typical grout design compressive strengths range from 20.7 MPa to 27.6 MPa (3,000 psi to 4,000 psi). This type of micropile is classified by the FHWA as CASE 1 Type B1 (pressure grouted, casing left in place) based on applied loading and construction method (FHWA 2000).

One of the major disadvantages of micropile use within the Charleston, SC area is the ability to verify the actual ultimate vertical capacity. In the past, micropile capacity was determined from static load testing. However, the installation of micropiles in space restrictive areas, coupled with the cost and time required to perform static load testing, makes this type of testing undesirable and limited to one to two micropiles per site. An alternative to static load testing for other deep foundation systems (e.g. driven piles, cast-in-place piles, drilled shafts, etc.) has been high strain dynamic testing. High strain dynamic testing has been shown to be a quick, accurate method of testing deep foundations and allows for multiple piles to be tested on the same day for a fraction of the cost of static load testing. In addition, high strain dynamic testing is now sufficiently accepted and standardized so that several standards and specifications defining proper procedures have been written and accepted (Goble and Likins, 1996). The following paper discusses the development of a micropile drop

weight hammer system to test micropiles and presents the results of the initial field testing case history for this hammer system.

DROP WEIGHT HAMMER SYSTEM

Development of a drop weight hammer system for dynamically testing micropiles began with a review of relevant technical literature. Given the lack of technical literature regarding the dynamic testing of micropiles and other small diameter piles, the authors looked at developments regarding hammers for testing cast-in-place piles and drilled shafts. Apart from the size difference, development of drop-weight hammers for these applications was considered a reasonably close analogy to micropiles. This review revealed the following guidelines for selecting a hammer for dynamically testing cast-in-place shafts:

- Hammer weight should be at least 1.5% of the ultimate soil static resistance (Hussein et al. 1996).
- As a rule of thumb the ram should have a weight of 1% to 1.5% percent of the capacity to be proven (Goble & Likins 1996).
- Drop heights should be approximately 8.5% of the pile length (Hussein et al. 1996).

Typical micropile designs within the Charleston, SC area have had ultimate capacities ranging from 89 kN to 445 kN (20 kips to 100 kips) with lengths ranging from 7.6 m to 18.2 m (25 ft to 60 ft). Using the guidelines described above, a ram weight of 4.45 kN (1 kip) and a maximum drop height of 1.2 m (4 ft) were selected for the micropile testing hammer. Other factors considered when developing the hammer were cost, availability of components for constructing the hammer, and the requirement of keeping the hammer system compact and lightweight enough to provide easy handling with routine construction equipment in tightly spaced environments. Based on these considerations, it was decided to use equipment already available to the authors and “off-the-shelf” (i.e. commercially available) products and equipment. The final hammer system design consisted of the following:

- A 4.45 kN (1kip) ram, comprised of a 25 cm (10 in) nominal diameter Schedule 40 by 70 cm (27.5in) long lead filled steel pipe. A 3.8 cm (1.5 in) thick steel plate was welded to the end of the ram.
- A 2.17 m (85.5 in) long ram/pile enclosure, with the ram enclosure comprised of a 30.5 cm (12in) nominal diameter Schedule 40 by 152 cm (59.75in) long steel pipe and the pile enclosure comprised of a 25.4 cm (10 in) nominal diameter Schedule 40 x 61 cm (24 in) long steel pipe. A 4.4 cm (1.75 in) hammer cushion/striker plate was placed between the two enclosures. Holes were drilled in the ram enclosure to allow for air to escape while the ram was in free-fall. The final weight of the main body of the drop weight hammer system is 1.9 kN (0.43 kips).
- A pile extension, consisting of a 7.6 cm (3 in) nominal diameter Schedule 80 by 76 cm (30 in) long steel pipe and a 8.9 cm (3.5 in) nominal diameter Schedule 80 by 30.5 cm (12 in) steel pipe end, to allow testing of micropiles below the ground surface that the hammer cannot reach.

- A “quick disconnect” steel wire that attaches to the ram and then to the lifting system via lifting rings. A torch was used to burn through this wire to allow for free-fall of the ram.

Figure 1 presents a cross-section and photograph of the micropile drop weight hammer system. If desired, a pile cushion (e.g. plywood) can be placed on top of the tested micropile, although the limited space within the pile enclosure would make for difficult removal and replacement of the pile cushion. Guidelines attached to the ram enclosure and adjacent micropiles were used to provide lateral support to the hammer system. The ram/pile enclosure and ram can be lifted using equipment common to most construction sites, such as backhoes, excavators, or compact track loaders. Alignment of the hammer and ram can be verified by placing levels on the enclosures and ram on-site. The drop height is measured using sight holes drilled at 0.30 m (1ft) increments along the ram enclosure. Depending on the equipment used to lift the ram weight, the micropile drop weight hammer system can be used to test micropiles in spaces with minimum headroom of 3 m (10 ft). Future modifications to the hammer will include removable pile enclosures for different size micropiles and different weight rams.

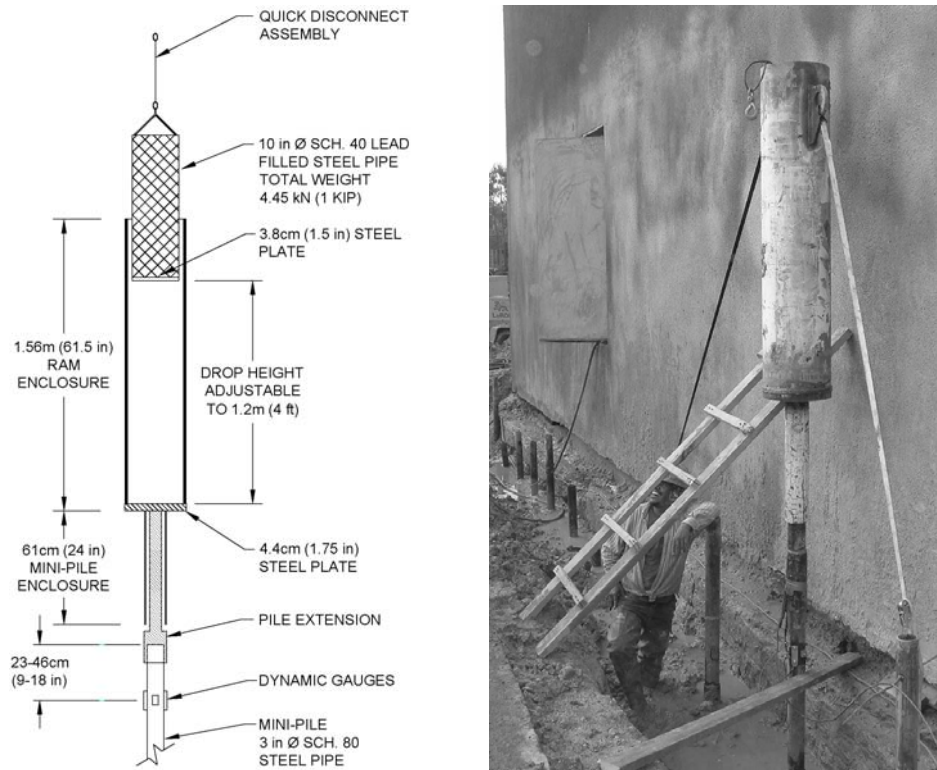


Figure 1. Micropile Drop Weight Hammer System.

A major design concern was that the drop weight hammer would cause damage to the piles being tested, negating the benefit of quick testing and require pile replacement. Wave equation analyses of piles (i.e. WEAP) using the computer program

GRLWEAP were therefore conducted using the hammer and several steel micropiles with grout bulbs designs from past projects. The WEAP analyses showed that the stresses within the micropiles would not exceed recommended driving stresses as determined by common engineering practice (e.g. FHWA HI-96-033).

INITIAL FIELD TESTING CASE HISTORY

The micropile drop weight hammer system was initially field tested at a project in Summerville, SC where 54 micropiles were installed as part of a seismic retrofit of an existing building with new additions. Six (6) production micropiles were selected for dynamic testing. The micropiles for this site consisted of 7.6 cm (3 in) nominal diameter Schedule 80 by 7.6 m (25 ft) long steel pipe with a grout bulb at the pipe tip. In addition, the steel pipes were also filled to various levels with grout. Using the measured grout volume and known installation methods, the grout bulbs were calculated to be approximately 0.46m (1.5ft) in diameter and 0.9m (3ft) in height. A typical micropile cross-section for this site, developed from the measured grout volume and known steel pipe lengths, is presented in Figure 2. The Schedule 80 pipe is comprised of API 5L Grade B PSL 1 steel, which has a minimum yield stress of 241 MPa (35,000 psi). The grout design compressive strength was 27.6 MPa (4,000 psi). The micropiles were designed for an ultimate axial load capacity of 222 kN (50 kips). Refer to Casey et al. (2003) for additional details concerning the micropile installation and design.

The generalized site soil profile consists of 3.7 m (12 ft) of very stiff to firm silty clays underlain by interbedded layers of silty clays and silty sands to a depth of 12.2 m (40 ft). The relative density of the sands ranged from medium dense to very dense and typically exhibited an increased density with depth. The consistency of the clays in this layer typically ranged from stiff to very stiff (Casey et al. 2003). Groundwater was encountered at 2.4 m (7.9 ft) from the ground surface. Figure 2 presents the piezocone penetration test (CPTu) results for the site.

To avoid problems with overstressing the grout within the steel pipe and tip bulb, dynamic testing was performed only after the grout test cylinders achieved compressive strengths of greater than 75% of the design value (i.e. 20.7 MPa (3,000 psi)). For all six (6) micropiles tested, this compressive strength was achieved four (4) days from the date of placement. Therefore, dynamic testing was conducted during five day hammer restrikes (5DR) on all six micropiles. Dynamic testing was conducted using a Model 586 PAK Pile Driving Analyzer in accordance in accordance with ASTM D4945. Drop heights during dynamic testing ranged from 0.3m (1ft) to 1.1m (3.5ft), with the lower drop heights being used to verify hammer alignment (i.e. level hammer blows). Micropile dynamic testing was conducted on two (2) separate days, with three (3) micropiles being tested within four (4) hours on each day.

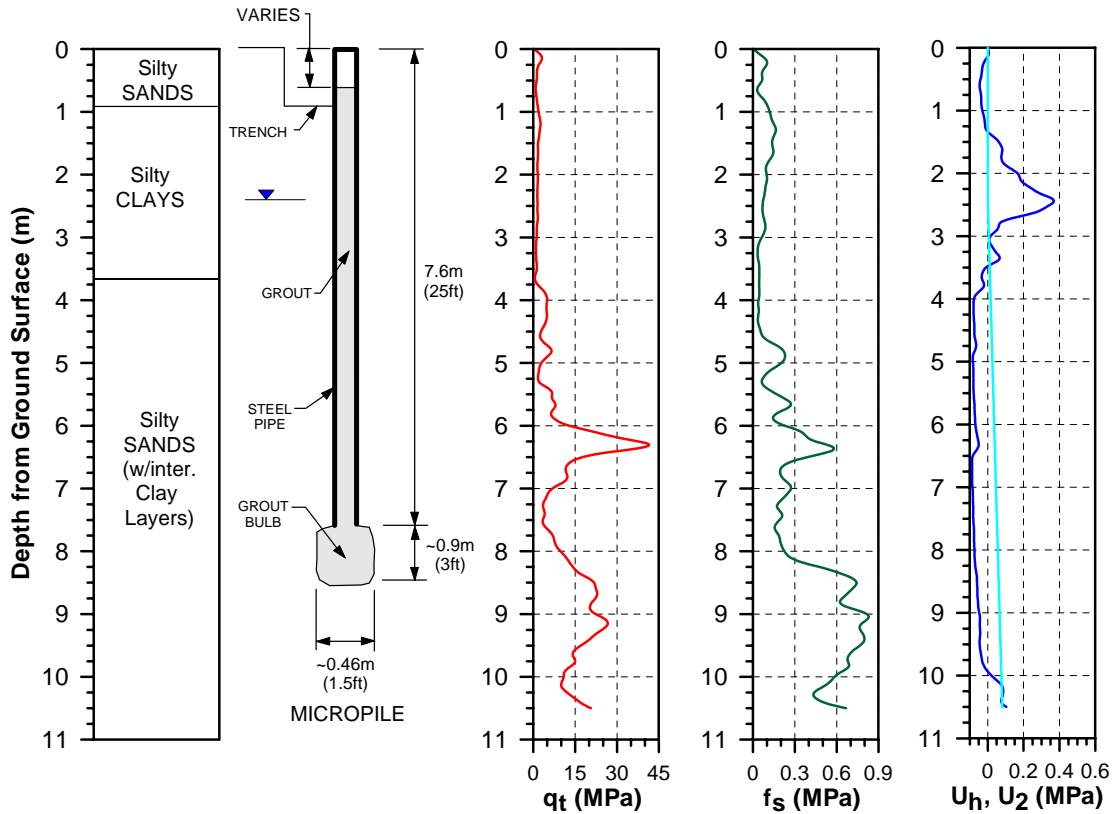


Figure 2. Typical Micropile Cross-section and Soil Profile (Initial Case History Site).

Analysis of the dynamic testing results was conducted using CAPWAP signal matching software. Elastic modulus for the grout was calculated from the four day compressive strength results using relationships between compressive strength and elastic modulus developed by the American Concrete Institute (ACI 318). A composite modulus assuming equal strain was calculated for lengths of the steel pipe which were filled with grout. Typical micropile dynamic test data and CAPWAP signal matching results for Pile 1 – NW are presented in Figure 3. A summary of the dynamic testing results is presented in Table 1, while Table 2 presents a summary of the individual CAPWAP capacity analyses, to include a summary of the maximum calculated compressive and tensile stresses within the steel pipe and grout bulb.

As shown in Table 1, the energy transfer ratios (i.e. ETR) for the micropile drop weight hammer system ranged from 17% to 57% with an average value of 35%. ETR was calculated by dividing the measured energy delivered to the pile by the rated energy of the individual blow (i.e. drop height multiplied by ram weight). The range of ETR values seemed low for a drop weight system. The CAPWAP results showed that four of the six (4 of 6) tested micropiles had capacities within 8% of each other (i.e. $480\text{kN} \pm 36\text{kN}$ ($108\text{ kips} \pm 8\text{ kips}$)). Of the remaining two piles, a plywood pile cushion was used during testing of Pile 8 – SW. As shown in Table 1, this pile cushion reduced the energy delivered to the pile for the same drop weight height, thereby reducing the axial capacity that could be mobilized. For Pile 3 – NW, quality

dynamic data was only obtained for the 0.3m (1ft) drop height. The reduced CAPWAP capacity of this pile is related to the reduced energy delivered to the pile.

Table 1. Summary of Dynamic Testing Results

Pile	Observed Blow Count bp100mm (bpi)	Drop Height m (ft)	EMX ¹ kN-m (kip-ft)	ETR ² (%)
Pile 1-NW	63 (16)	1.1 (3.5)	1.49 (1.1)	31
Pile 3-NW ³	31 (8)	0.3 (1.0)	0.54 (0.4)	40
Pile 6-NW	63 (16)	1.1 (3.5)	2.71 (2.0)	57
Pile 2-SW	126 (32)	1.1 (3.5)	1.36 (1.0)	29
Pile 8-SW ⁴	126 (32)	1.1 (3.5)	0.81 (0.6)	17
Pile 22-SW	126 (32)	1.1 (3.5)	1.76 (1.3)	37

NOTES:

1. EMX = Maximum Energy delivered to pile.
2. ETR = Energy Transfer Ratio = EMX/Rated Energy
3. Only 0.3m (1ft) drop height yielded quality dynamic data.
4. 2.5cm (1in) plywood pile cushion used.

Table 2. Summary of CAPWAP Results.

Pile	CAPWAP Capacity kN (kips)			Maximum Stresses MPa (ksi)			
	Side	Tip	Total	Compressive		Tensile	
				Steel	Grout Bulb	Steel	Grout Bulb
Pile1-NW	365 (82)	142 (32)	507 (114)	223 (32.3)	0.8 (0.12)	10.3 (1.5)	0.07 (0.01)
Pile3-NW	254 (57)	31 (7)	285 (64)	112 (16.2)	1.0 (0.15)	11.0 (1.6)	0.48 (0.07)
Pile6-NW	258 (58)	187 (42)	445 (100)	234 (33.9)	1.2 (0.18)	9.7 (1.4)	0.07 (0.01)
Pile2-SW	214 (48)	254 (57)	467 (105)	196 (28.4)	1.9 (0.27)	4.1 (0.6)	0.41 (0.06)
Pile8-SW	262 (59)	27 (6)	289 (65)	30 (4.3)	0.3 (0.04)	4.8 (0.7)	0.07 (0.01)
Pile22-SW	222 (50)	294 (66)	516 (116)	233 (33.8)	2.4 (0.35)	13.8 (2.0)	0.28 (0.04)

The CAPWAP analyses did not detect any indications of pile damage along the length of all six (6) micropiles. The maximum compressive and tensile stresses within the hollow steel pipe and grout bulb calculated from the CAPWAP analyses, summarized in Table 2, were examined to determine if the allowable driving stresses

were exceeded. The maximum allowable driving stresses were determined in accordance with standard engineering practice (e.g. FHWA HI-96-033). As shown in Table 2, the dynamic compressive stresses within the hollow steel pipe routinely exceeded the allowable driving stress at a drop height of 1.1m (3.5ft), while the steel pipe tensile stresses and the compressive and tensile stresses within the grout bulb did not exceed the maximum recommended values.

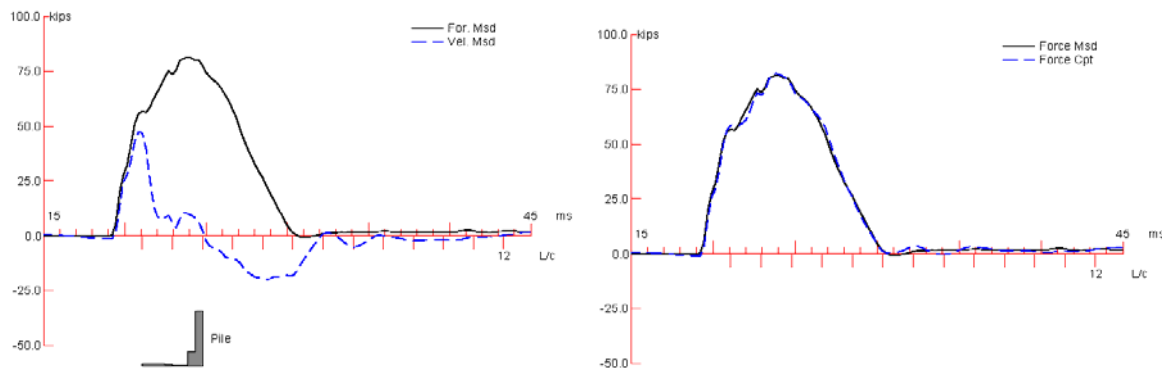


Figure 3. Dynamic Force-Velocity*Impedance Data and CAPWAP Results.

SECOND FIELD TESTING CASE HISTORY

The second field testing case history was conducted at a micropile testing site located within the Palmetto Gunite Construction company work yard in Ravenel, SC. A total of twelve (12) self-drilling hollow injected grouted micropiles of various lengths and diameters were installed at this location for the purpose of conducting field testing and examining design parameters.

A subsurface investigation of the site was conducted using piezocone penetration testing (CPTu) and soil test borings with standard penetration testing (SPT). The general subsurface conditions of the site consisted of very loose to loose silty sands and sands extending from the existing ground surface to a depth of 8.8 m (29 ft). Interbedded clay layers were encountered in these sands between depths of 4.3 m to 8.8 m (14 ft to 29 ft). Underlying the sands is a stiff sandy silt known locally as the Cooper Marl Formation. This soil formation is the traditional bearing layer for deep foundations in the Charleston, SC area. The Cooper Marl is typically classified according to the Unified Soil Classification System as a low plasticity sandy silt (ML) or sandy clay (CL). Refer to Klecan et al. (2001) for additional details of the Cooper Marl Formation. The CPTu and SPT testing results are presented with respect to the general soil profile in Figure 4.

For this study, one (1) self-drilling hollow injected grouted micropile was tested both statically and dynamically 14 days after installation. Due to the cohesionless nature of the soils in which the pile was founded, time dependent pile capacity gain (i.e. “setup” or “freeze”) was not considered when planning the testing schedule. This

pile, designated as TP6, was comprised of Titan IBO 40/16 drill rods with a 100 mm (3.9 in) diameter cutting head and grout with a design compressive strength of 27.6MPa (4,000 psi). The grout design mix was the same used in the micropiles for the initial case history. The average grout diameter for this micropile was 15.9 cm (6.25 inches), based on measurements taken along the upper 0.9m (3 ft) of the grout length. This average diameter matched well with similar measurements taken on seven (7) other micropiles at the site with the same cutting head diameter. The grout diameter measurements were taken after testing by excavating around the pile tops. The micropile was installed to a depth of 8.5 m (28 ft) from the ground surface, with 0.9 m (3 ft) of pile stickup above the ground surface for a total pile length of 9.4 m (31 ft). The nature of this type of micropile (i.e. thin steel drill rod and grout body) prevented a standard attachment of the gages to the pile. To accommodate the dynamic testing gages, a 127 mm (5 in) outside diameter by 6.4 mm (0.25in) wall thickness by 2.14 m (7 ft) long oil casing steel pipe was added to the top of the pile. This pipe, which is not typically part of this type of micropile, was present throughout the testing. The dynamic gages were attached to this steel pipe section via ¼-20 UNC bolts, which are typically used for pipe piles. A typical cross-section of TP6 is presented with respect to the soil profile in Figure 4.

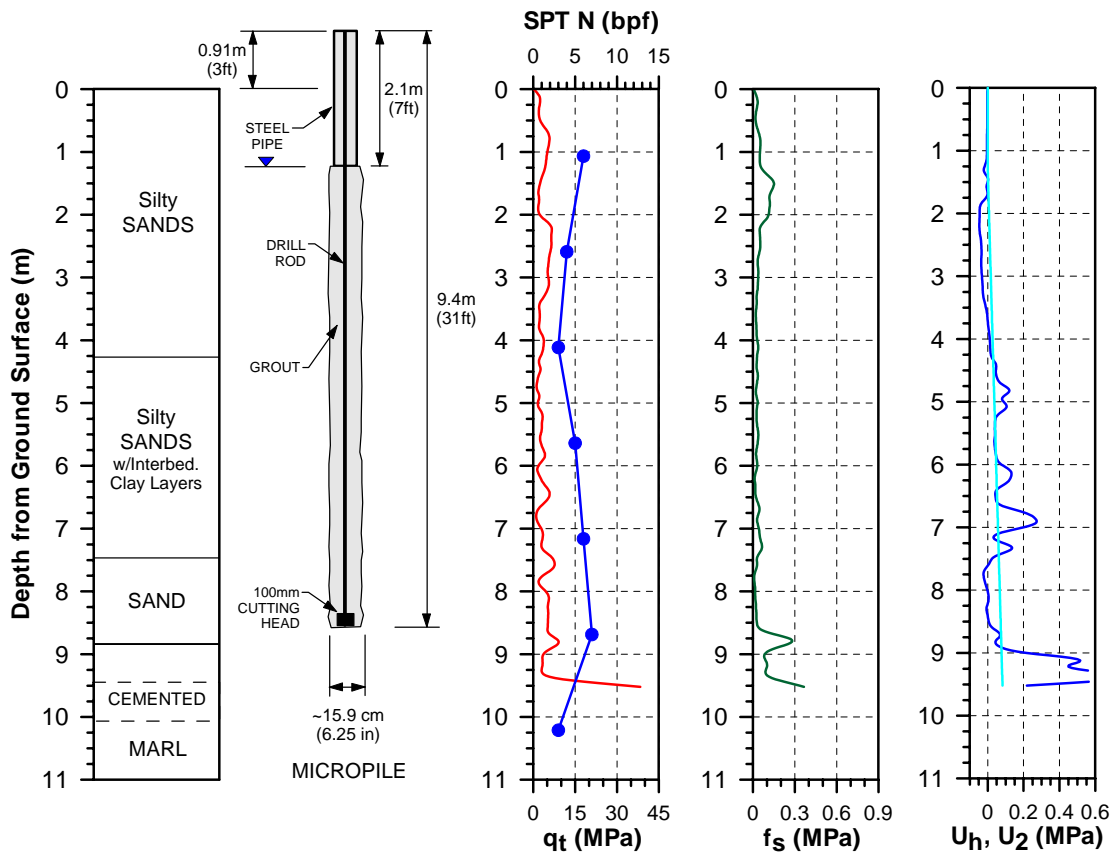


Figure 4. Typical Micropile Cross-section and Soil Profile (2nd Case History Site).

The load testing for TP6 consisted of a compressive static load test followed by dynamic load testing at 14 days after micropile installation. Previous experience with the grout mix showed that this timeframe would be adequate for the grout to achieve 75% of the design compressive strength value (i.e. 20.7 MPa (3,000 psi)) and thereby prevent grout overstressing. The compressive static load test was conducted in accordance with ASTM D1143 using the Quick Load Test Method (Section 5.6). Dynamic testing was conducted using a Model 586 PAK Pile Driving Analyzer in accordance with ASTM D4945. Drop heights during dynamic testing ranged from 0.3 m (1 ft) to 1.1 m (3.5 ft), with the lower drop heights being used to verify hammer alignment (i.e. level hammer blows). The maximum stroke height was set at 1.1 m (3.5 ft) to avoid damaging the pile during testing.

The static load test results for TP6 are presented in Figure 5. During the static load testing of TP6, the load frame experienced a localized failure at the last loading increment, causing the loading apparatus to shift off the pile. Therefore, no rebound data was collected for this test. A summary of the dynamic test data and CAPWAP capacity analysis results for final hammer blow (i.e. blow 5) for TP6 is presented in Table 3.

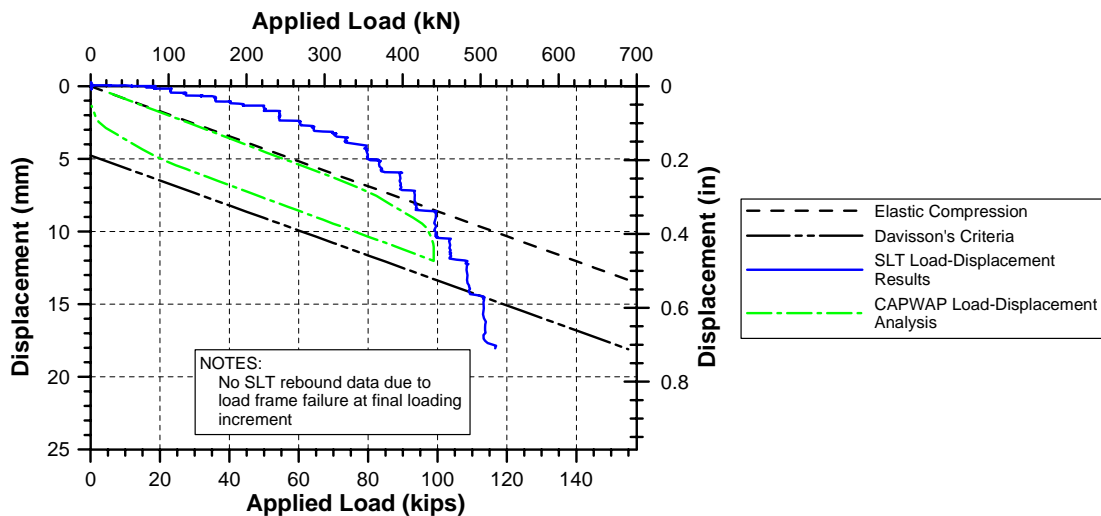


Figure 5. TP6 Static Load Test Results.

Table 3. Summary of TP6 Dynamic Testing Results

Blow	Observed Blow Count bp100mm (bpi)	Drop Height m (ft)	EMX ¹ kN-m (kip-ft)	ETR ² (%)	CAPWAP Capacity kN (kips)		
					Side	Tip	Total
5	126 (32)	1.1 (3.5)	(2.2)	63	387 (87)	53 (12)	440 (99)

NOTES:

1. EMX = Maximum Energy delivered to pile.
2. ETR = Energy Transfer Ratio = EMX/Rated Energy

The ultimate pile capacity was calculated from the static load test data using the offset failure (i.e. Davisson’s) criterion (Davisson, 1972). Davisson’s criterion is commonly used in geotechnical practice throughout the US and has been statistically shown to be the best overall method for determining failure of deep foundations (Paikowsky et al., 2005). CAPWAP signal matching analysis was used for determining the ultimate pile capacity for the selected blow (i.e. blow 5) from the dynamic testing data. For both tests, elastic modulus for the grout was calculated in a similar manner as the initial field testing, while a composite modulus assuming equal strain was calculated for lengths of the steel pipe which were filled with grout. A summary of the ultimate pile capacities determined from the test program is presented in Table 4.

Table 4. TP6 Ultimate Axial Capacity Summary.

Test Method	Analysis Method	Ultimate Axial Capacity kN (kips)
SLT	Davisson’s Criteria	503 (113)
DLT	CAPWAP	440 (99)

The static load test capacity for TP6 is 503 kN (113 kips), while the CAPWAP capacity is 440 kN (99 kips). The difference between the static and dynamic load test results is approximately 12%. Further comparison of the static and dynamic load test results was conducted by comparing the simulated static load test calculated from the CAPWAP analysis to the actual static load test data. This comparison is presented in Figure 4. As shown in Figure 4, the simulated load test curve does not cross the offset criteria for failure. This observation, coupled with the high blow count observed during dynamic testing (i.e. 126 blows per 100mm or 32 blows per inch), indicate that the hammer did not deliver enough energy to the pile to fully mobilize the ultimate capacity.

CONCLUSIONS

A drop weight system was designed and constructed for the purpose of testing micropiles within the Charleston, SC area. Based on the results of the first two field case histories for this hammer, the following conclusions were made:

- A drop weight hammer system was successfully designed, built, and utilized for dynamically testing micropiles in the Charleston, SC area.
- The drop weight hammer successfully mobilized up to 516 kN (116 kips) during the initial field testing and 440 kN (99 kips) during the subsequent field testing.
- The results of the initial testing showed that the designed drop weight hammer system could effectively dynamically test multiple micropiles to verify pile capacity in a short time period without causing pile damage.
- The second field testing case history for this hammer showed good agreement between the dynamic and static load test ultimate axial capacities. Based on the

comparison of the static load test results with calculated CAPWAP and relatively high observed blow counts, the drop weight hammer most likely did not deliver enough energy to fully mobilize the pile capacity for TP6. The authors are currently designing improvements to the drop weight hammer system for testing of micropiles with ultimate capacities greater than 516kN (116kips).

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