HIGH CAPACITY MICROPILES AT PROJECT IN CAMBRIDGE, MA, USA

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INTRODUCTION

A new 25 story tower in an open parking lot will be supported on high capacity micropiles. The tower will consist of luxury apartments plus commercial space on the first floor.

The original foundation design consisted of over 400 driven H-piles with a design capacity of 200 tons. One of the adjacent structures is utilized by a valuable innovation tenant who would not allow disruption to their work without breaking their lease. The impact of pile driving on the existing structure from its vibration and noise on personnel within the structure is an unacceptable risk to the viability of these companies and their long-term occupancy as valued tenants.

Hub Foundation was contacted by the construction manager to develop an alternate piling foundation system that could be installed without vibrations and noise. Hub, working closely with the project designers developed a solution utilizing 300 ton micropiles that was technically acceptable but somewhat more expensive than the original driven pile design.

Hub offered to perform a high capacity pile load test during the design phase to demonstrate that much higher capacity micropiles could be achieved which would narrow the financial gap. Hub designed a test pile that could be tested to much higher test loads than had been achieved in the Boston area. The goal was to perform a successful test in compression to at least 1500 tons. The test pile was successfully loaded to 1619 tons. The results from this test indicates that if a higher capacity jacking system could have been utilized, that a test load of at least 2000 tons could have been successfully applied.

The hope from achieving these test results was to develop and install a pile capacity of at least 400 tons, possibly 450 tons. Unfortunately, due to a combination of column loads and geometry, the highest design capacity that could be efficiently utilized was 362 tons. Although disappointed that higher design loads could not be used, the overall reduction to a total of 224 micropiles resulted in an attractive financial solution to the owner which resolved their concerns about impacts to their highly valuable innovation tenants.

TEST PILE DESIGN

The test pile consisted of a 10 ¾” OD; 0.545” wall steel casing drilled into stable rock. The rock socket was reinforced with a 7.0” OD; 0.408” wall core pipe. A total of four reaction piles were required to provide the reaction capacity for the test. A No.32 Grade 80 bar was installed for the full-length of the reaction piles. The minimum yield of the No.32 Grade 80 bar is 502 tons. This would provide a potential reaction of 2000 tons. The reinforcement within the test pile is shown in Figure 1. Note that extra reinforcement (core pipe plus 12 No. 8 deformed bars) were added in the upper 20 feet of the test pile to provide bending moment capacity (not required to this level for the production piles) in the event that some eccentricity developed during the anticipated high test loads. The socket was also reinforced with additional steel (12 No.8 deformed bars) as a safety blanket.

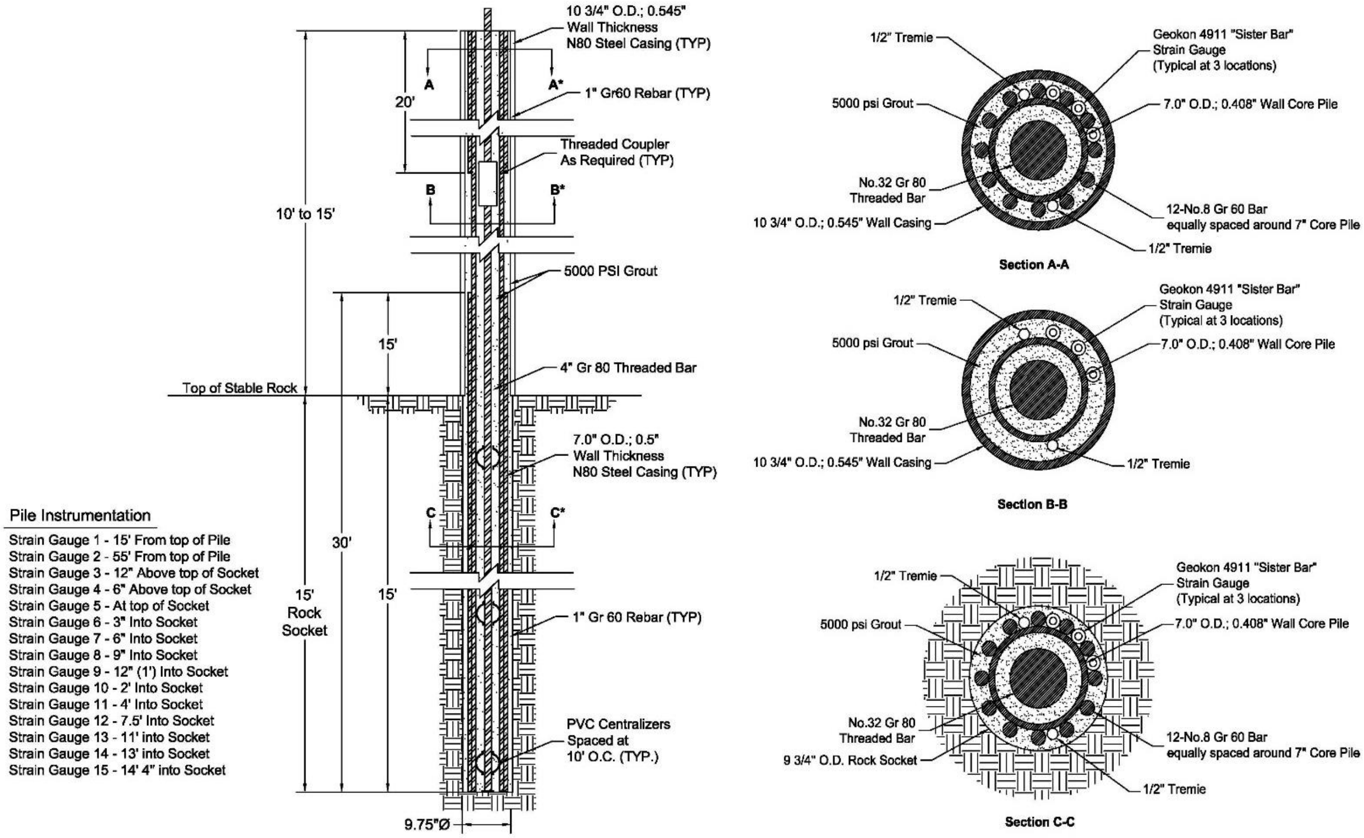

Figure 1: Test Pile Detail and location of the instrumentation

It was our intent to document very high bond values in the rock. For this reason, we selected a relatively short rock socket length of only 15 feet. Note that we presented at the Vancouver ISM the results of a pile load test to 1010 tons where we documented that the majority of the test load was transferred in the upper 5 feet of the rock socket. Hence, we were very comfortable with the 15 ft rock socket.

Run No.	Sample Depth [Feet]	Sample Recovery [Inch]	RQD%	Drill Time [Min./Foot]	Sample Description
RC-1	102'-107'	13"/60" 22%	0%	4-3-5-5-5	Soft, severely weathered, extremely fractured, grey, amorphous CAMBRIDGE ARGILLITE. Too weathered to describe joints, dipping or bedding.
RC-2	107'-112'	32"/60" 53%	0%	7-8-7-8-8	Soft to medium hard, severely weathered, extremely fractured, grey, fine grained CAMBRIDGE ARGILLITE, close, smooth to rough joints, with thin, moderately dipping bedding.

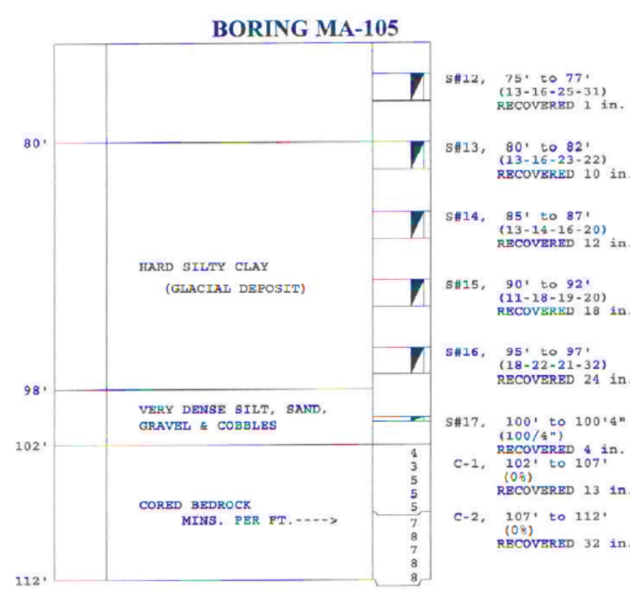

Figure 2: Rock coring portion of the boring log

PILE LOAD TEST

The pile load test was performed on the site immediately adjacent to a new test boring that was performed to better identify the rock quality at the test pile location. Refer to Figure 2 for the rock coring portion of the boring log. The rock cores indicated the upper 10 feet to be weathered and highly fractured with low to moderate recovery and very low RQDs (0%). The rock is a fairly soft sedimentary rock - the Cambridge Argillite formation.

Photo 1: Test Pile Socket Reinforcing and Instrumentation

The test pile was drilled on 1/19/18 and grouted on 1/10/18. The test pile was heavily instrumented. Figure 1 also shows the location of the instrumentation (strain gauges and tell-tales). Note the high frequency of the strain gauges in the upper 4 feet of the rock socket where we anticipated that most of the test loads would be dissipated in. The strain gauges are utilized to monitor very small movements to correlate to load at that location. Tell-tales are utilized to determine movement at the top and bottom of the rock sockets. As seen in Photo 1, a high level of detail was required to accurately set the reinforcing steel and the large amount of instrumentation, and to make it all fit within the permanent drill casing. The entire length of the socket reinforcing, which consisted of the No.32 Grade 80 bar and the 7" O.D.x 0.408" casing, was constructed prior to setting it into the pile. This was done with a service crane. Photo 2 shows the test bar being lowered while the installation crew guided this bundle down the hole while holding the many strain gauge wires to avoid damaging them. The remaining threaded bars were set in 25 ft lengths and coupled together. Photo 3 shows the installation crew threading the massive No.32 couplers and bars together.

Photo 2: Lowering the Test Bar

Three dial gauges were utilized to record the movements at the top of the test pile. For safety, an optical level was used monitor the dial gauges from a safe distance at the higher test loads.

The test frame consisted of two double beams stacked one atop the other. This double stacked setup can provide over 1800 tons of reaction capacity with reasonable deflection. Photo 4 shows the crew constructing the large frame. Double beam reaction beams were used to tie the reaction tiedowns into the system. Also seen in Photo 4, a network of H-beams were used to transfer the 2000 tons of tiedown force evenly to the soil. If the load was not transferred evenly, the frame could undergo differential settlement during the lockdown process which would necessitate redoing this time-consuming process.

Photo 3: Threading together No.32 Bars

Photo 4: Constructing the Test Frame

TEST RESULTS

The test pile was loaded in three separate cycles. The first two were performed on 1/22/18 to test loads of 699.7 tons and 998.6 tons, using a single hydraulic jack. The last cycle was performed on 1/29/18 after the entire test frame was removed to insert a triple jacking system. This allowed the maximum test load of 1619.3 tons to be applied.

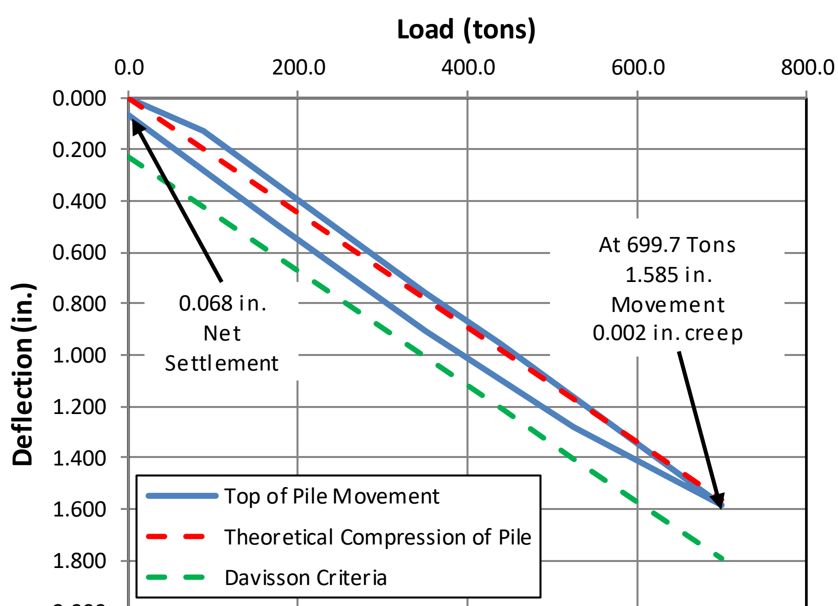

Figure 3: 700 Ton Settlement v Load Graph

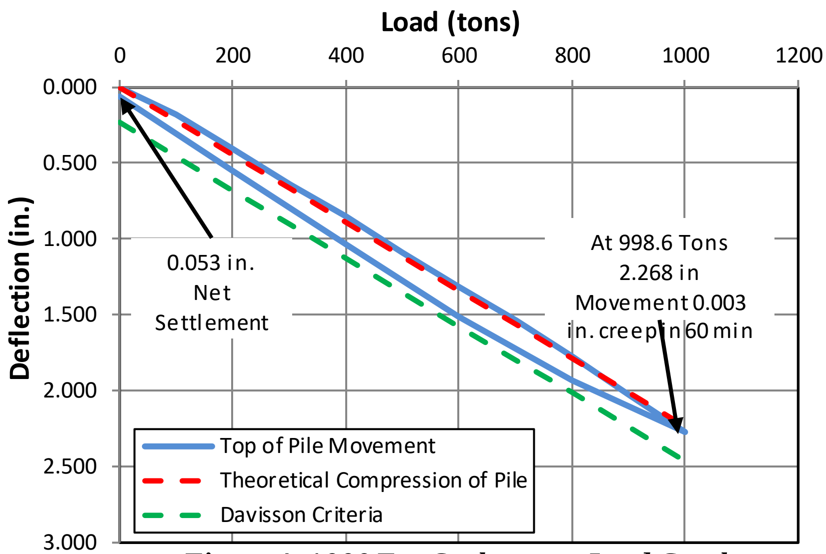

Figure 4: 1000 Ton Settlement v Load Graph

Figure 3 provides the settlement v load test plot for the first cycle to 699.7 tons. The total settlement was 1.585" with a 60 minute creep rate of 0.002" and a net settlement of 0.068". The settlement of the pile plotted along the theoretical compression of the pile. The rebound of the pile close to zero confirms that the pile behaved elastically within this test load. This test would have been used for a pile with a 350 ton allowable design.

Figure 4 provides the settlement v load test plot for the second cycle to 998.6 tons. The total settlement was 2.268" with a 60 minute creep rate of 0.003" and a net settlement of 0.053". Like the first cycle, the pile settlement followed the theoretical compression for the full test load and the rebound of only 0.053" shows minor non-elastic settlement. This test would have documented a 500 ton allowable design load.

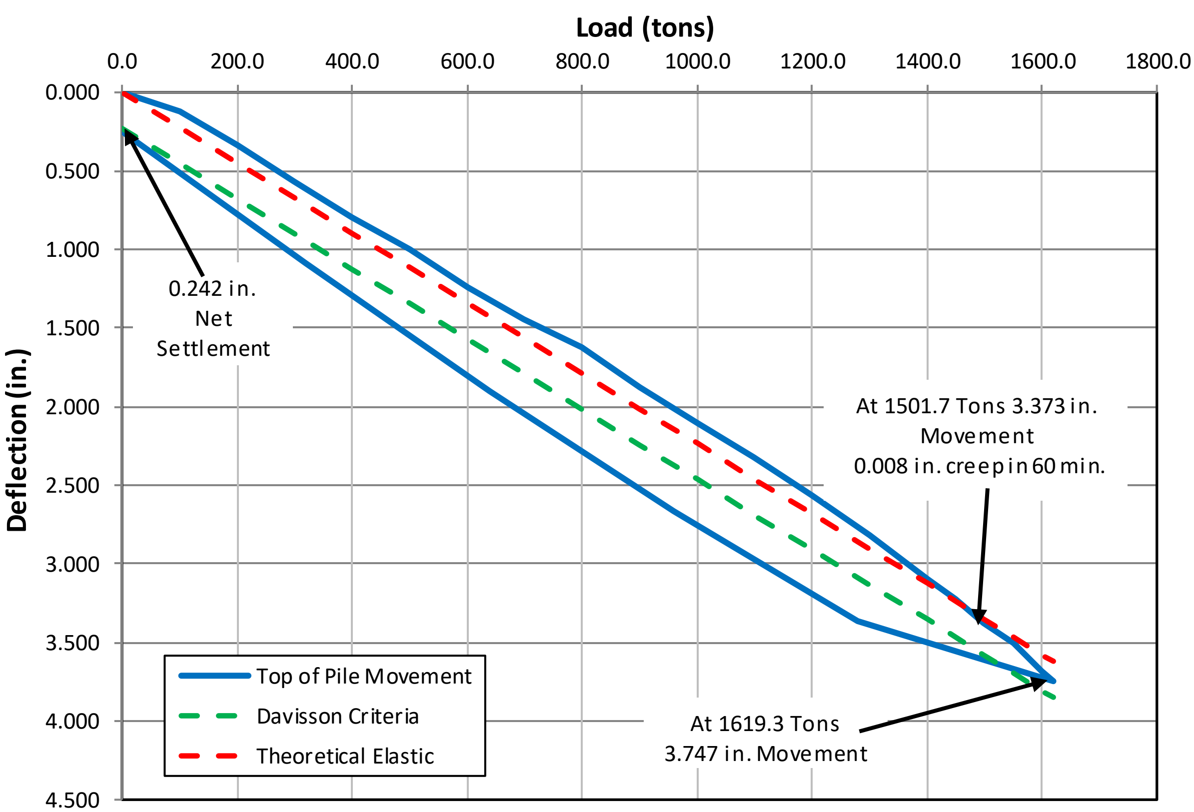

Figure 5: 1619 Ton Settlement v Load Graph

Figure 5 provides the settlement v load plot for the last cycle to 1619.3 tons. The total settlement was 3.747", with a 10 minute creep rate of 0.001" and net settlement of 0.242". The pile settlement was essentially parallel to the theoretical compression and the settlement of only 0.242" shows minor plastic deformation. This test could have documented an 800 ton allowable design load.

One of the points that the authors made in the paper presented at the Vancouver ISM is that the majority of the test loads are transferred in the upper 5 feet of the rock socket. Figures 6 and 7 provide a detailed view of the load distribution of the 699.7 ton and 1619.3 ton cycles within the upper portion of the rock sockets. For both cycles, approximately 100 to 120 tons of the test load was transferred at the bottom of the casing. Approximately 310 to 519 tons were transferred 1 foot below the casing for the 699.7 ton and 1619.3 ton cycles, respectively. At 4 feet below the casing, approximately 549 to 847 tons were transferred for each cycle respectively. This is 52% to 78% of the maximum test loads.

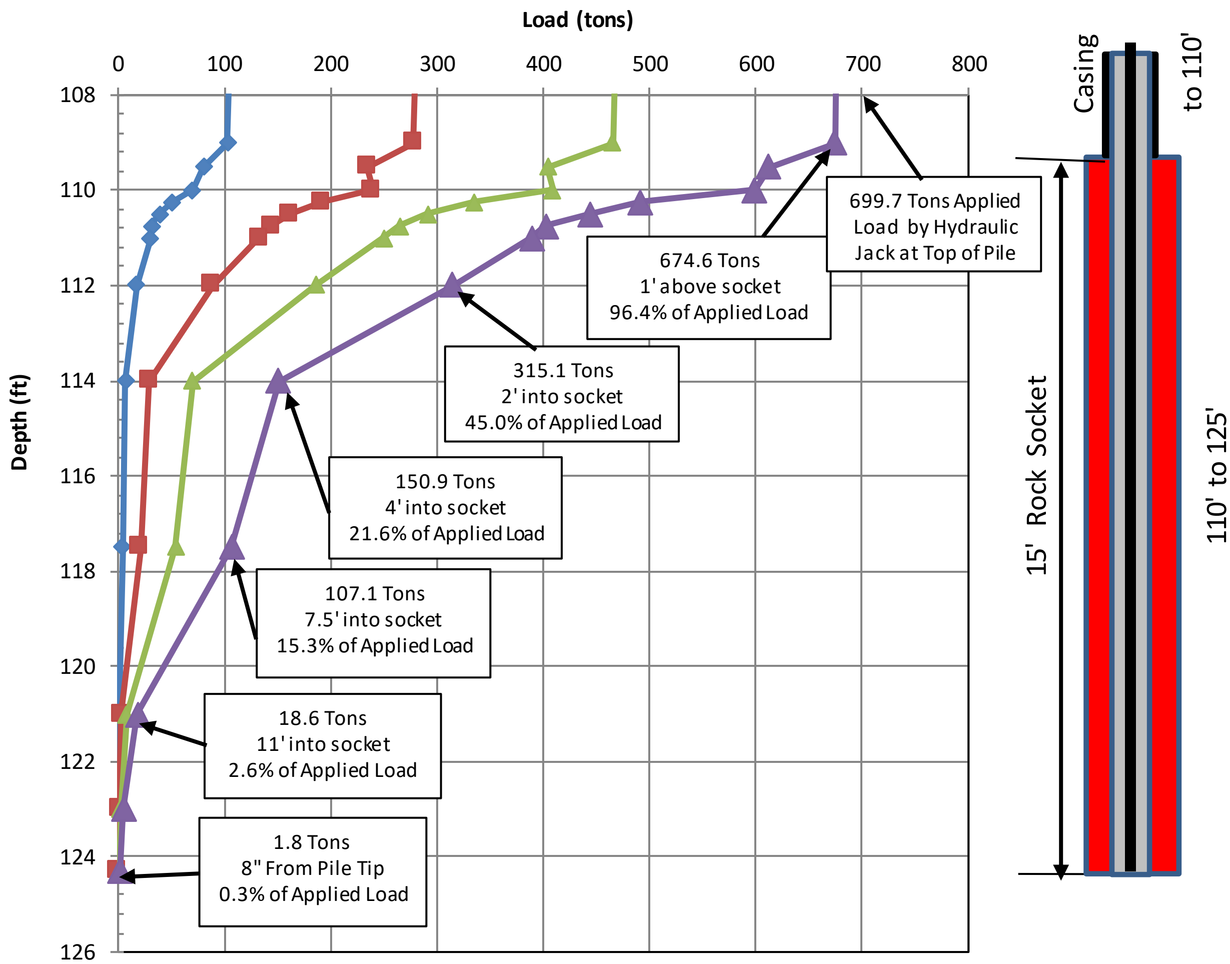

Figure 6: 700 Ton Load Distribution Graph

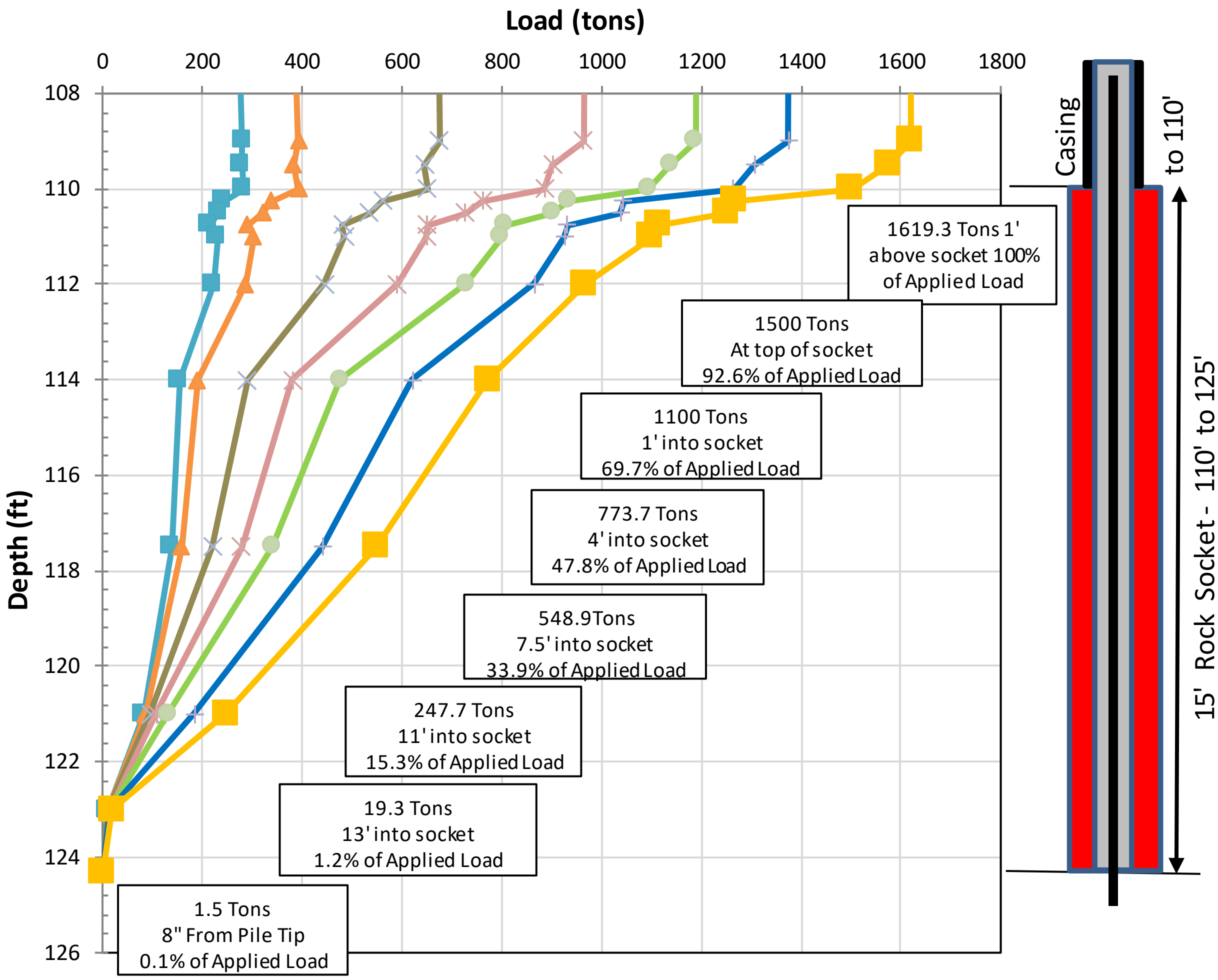

Figure 7: 1619 Ton Load Distribution Graph

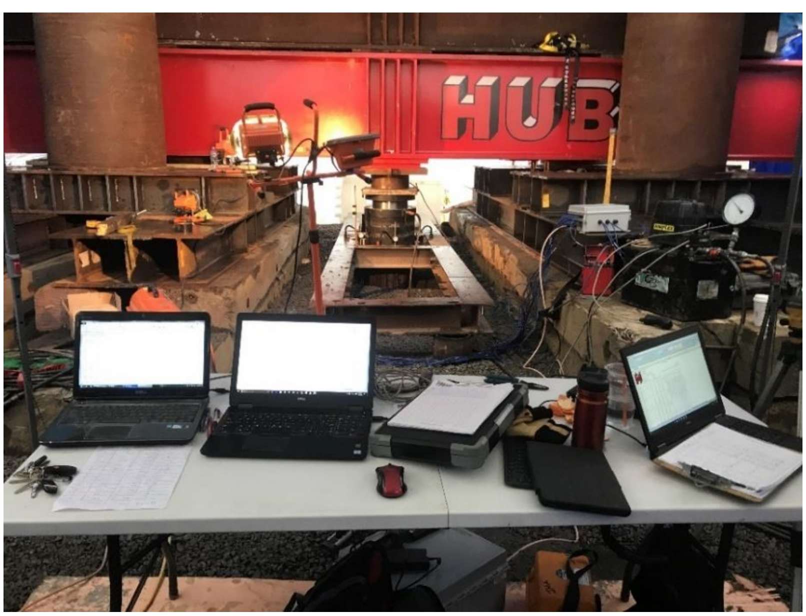

Photo 5: 1000 Ton Test

Photo 5 shows the test during the 1000 ton test cycle. During the testing, all the instrumentation was monitored and analyzed to provide a complete real time picture of settlement and load distribution within the test pile.

Photo 6: 1619 Ton Test

Photo 6 shows the test during the final cycle which resulted in the final test load of 1619.3 tons. Note the cage that was constructed to house the triple jack setup. It is critical when testing at extremely high loads to identify any and all hazards and provide additional measures to mitigate the hazards. And in the event that a failure of some sort occurs, to have safety measures to protect the people and equipment close to the test.

PRODUCTION PILES

A total of 224 micropiles were required to support the foundations for the new structure. The design capacities ranged from 37 to 362 tons in compression. Some of the piles had tension loads up to 85 tons and lateral loads of up to 6 tons.

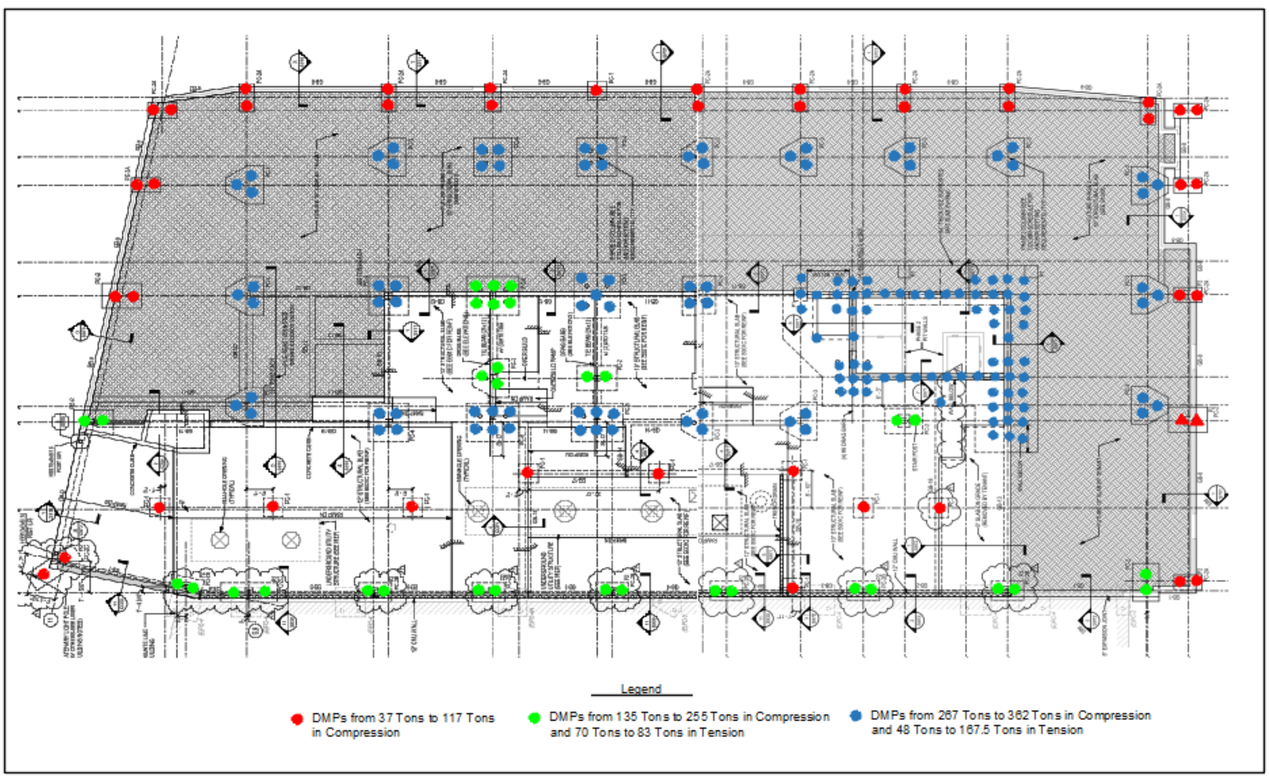

Figure 8: Foundation and Micropile Layout

Figure 8 shows the plan layout of the micropiles. Note that 15 different designs were developed to meet the variety of loading conditions that the structural engineers deemed necessary. Three different outer drill casings were utilized: 7.0 inch, 9.625 inch and 9.875 inch. The reinforcement within the casing and rock sockets varies for each of the 15 design loadings. Figure 9 presents a detailed design sketch for the highest loaded condition in both axial and lateral loads.

The production piles were installed from 6/28/18 to 11/9/18. The piles were installed with two drill rigs. A separate crew was utilized to set the reinforcement and grout the micropiles. Photo 7 shows a Casagrande C-12 installing the highest capacity piles in the building core. The core area was excavated and benched to a depth of approximately 6 feet below the normal working grade. Care was taken to setup the work so that the service crane and Lull could support the drill operation and install the piles. Record breaking precipitation in the fall months flooded the site which made keeping the excavation dry and the drill rigs from floating away a challenge.

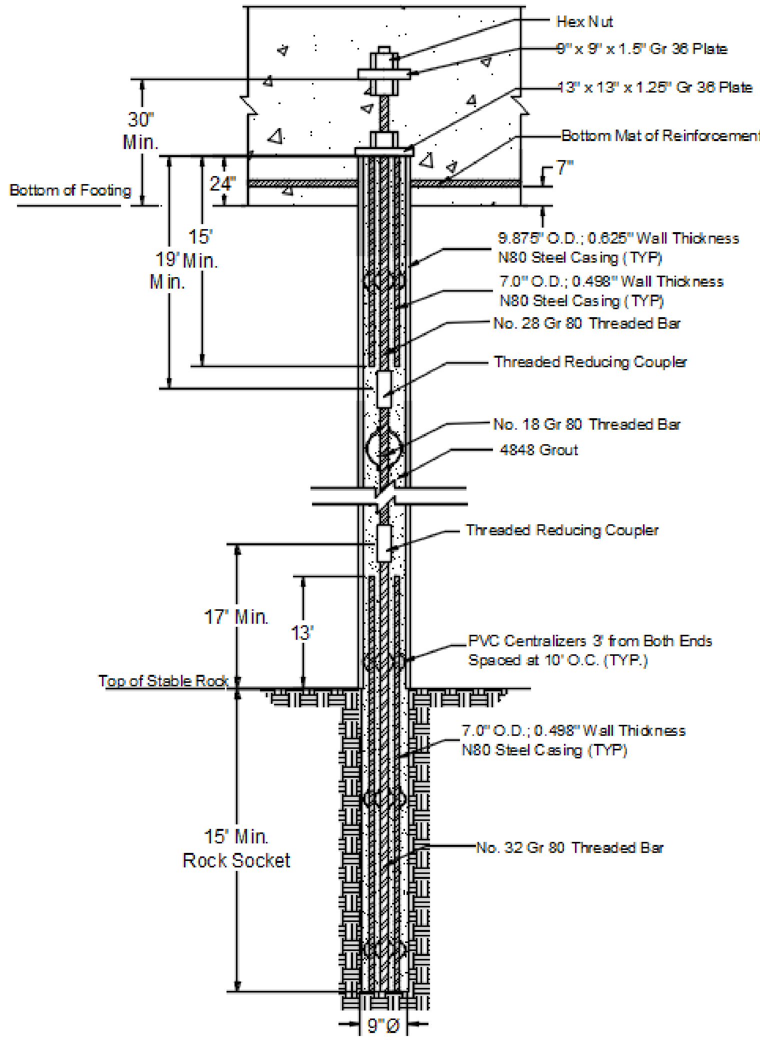

Figure 9: Micropile Design Sketch for the Highest Loading Condition

Along side the C-12, a Casagrande C-16 was used to install the micropiles. Both machines performed the drilling seamlessly and a skilled installation crew was deployed to do the rest. Having 15 different designs with 15 very different reinforcing conditions was a challenge. Yet, the crew, with meticulous attention to detail, installed all 224 micropiles correctly. There were no doovers! Photo 8 shows the drilling crew working side by side with the installation crew. Care was taken to ensure that there were no issues with communication between piles and the grouting of the micropiles was coordinated with the drilling of adjacent micropiles. The end result was the completion of the project within the target schedule.

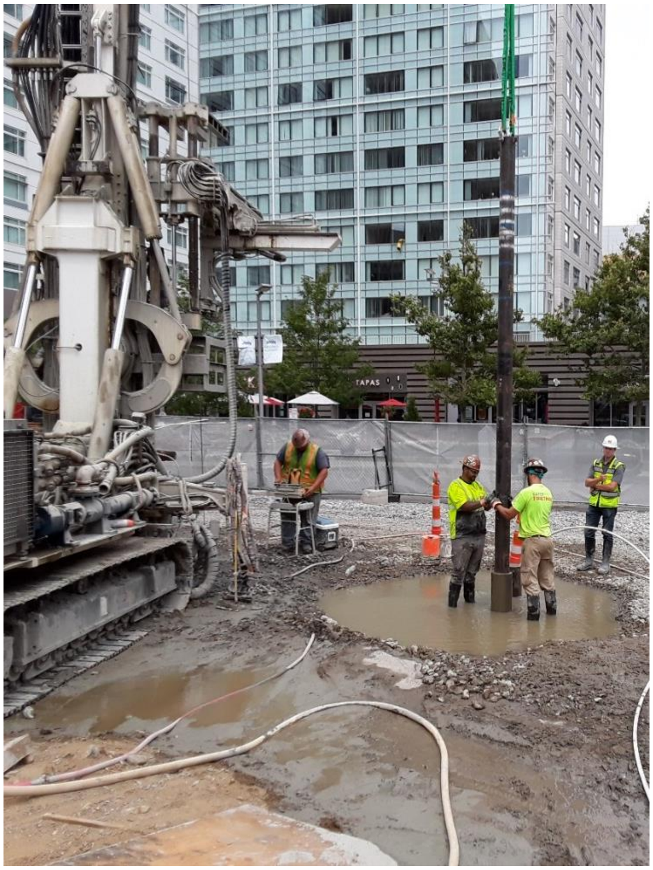

Photo 7: Installing Micropiles in the Core

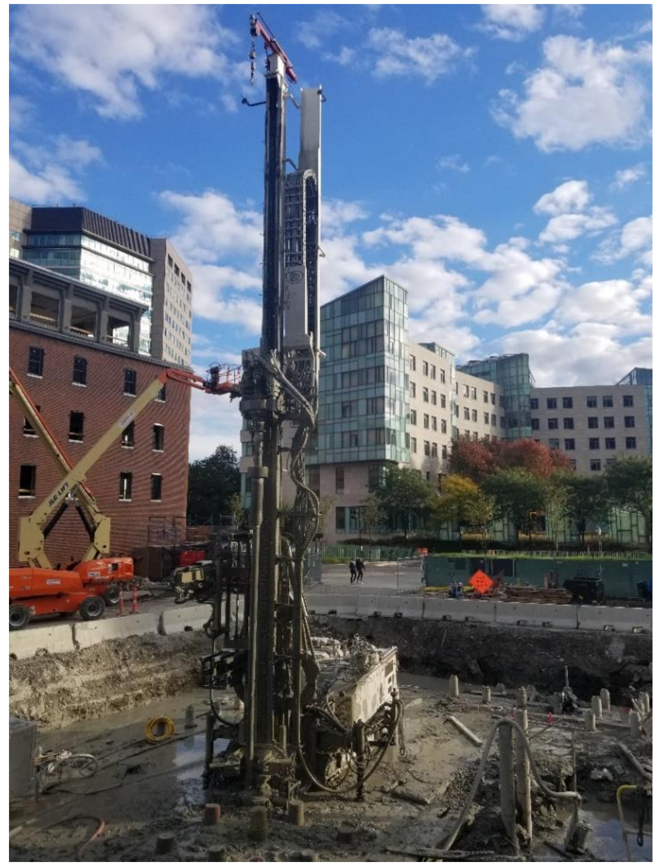

Photo 8: Drilling and Installing working Side by Side

CONCLUSION

The pile load test that was performed on this project clearly indicates that very high capacities can be achieved in rock. Note that the rock on this site, Cambridge Argillite, is a relatively soft sedimentary rock. Hence, these results can be duplicated or improved on for any rock formation. It is important to note that by incorporating a test program during the design phase of the project, the results were used to reduce the project overall cost and schedule. The end result was a total savings which far exceeded the cost of the early testing.

These high capacities can be utilized to replace driven piles (as was done on this project) which will minimize noise, damage to nearby structures and the potential for costly litigation. At these high capacities, depending upon the various schedule of column and core loads, it may be possible that micropiles can be substituted for driven piles with little or no financial penalty. Likewise, it is possible to utilize these high capacity micropiles in lieu of drilled shafts and load bearing elements (LBEs). The drawback for micropiles in these applications is lateral load capacity. Hub has developed different design concepts to enhance the lateral capacity of micropiles. Hub has installed micropiles at the core of a structure with lateral loads of 14 tons. This capacity can be increased, if necessary with larger diameter micropiles.

It is noteworthy, as shown in Photos 9 and 10, to highlight one of the established and highly praised views within the specialty foundation drilling industry of the dedication of Hub Foundation to enhance and innovate our industry. The 1969 photo shows a record-setting pile load test on a driven H pile at a site in Springfield Massachusetts. The 2018 photo, taken at this site, shows the continuation of this tradition to advance our industry and to take our products to the highest limits possible and safely.

Photo 9: Pile Load Test on a Driven H-Pile in year 1969

Photo 10: 1619 Ton Pile Load Test on Micropile Performed on Site