High Capacity Minicaissons in NYC

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Figure 1: Bauer Rig.

The construction of tall and slender high rises in Manhattan results in large lateral loads and overturning moments. Rock socketed micropiles and caissons are often designed to resist these loads. Using high strength reinforcing bar cages, contractors can construct 18- and 24-inch diameter rock-socketed "minicaissons" to support service loads of up to 3400 kips. This "new" technology results from the marriage of several established methods including rotary duplex drilling, high capacity micropiles and high capacity reinforced concrete building columns.

Drilling Equipment

Specialized drilling equipment is required to install this foundation element, which is intermediate between micropiles and caissons. The minicaissons for the four projects described herein were installed with either a Barber DR-24 rig or a Bauer BG-15 rig (*Figures 1* and *2*). It is a dual rotary rig; it has independent drives for both the minicaisson casing and the inner drill string, which removes the soil and rock from the hole within or in advance of the minicaisson casing. The uniqueness of the system over other dual head systems is that the lower drive casing of the rig chucks around the minicaisson casing (i.e. it does not attach to the top of the casing). This allows the machine to grab the casing at any point, and provides flexibility in regards to the casing shoe to bit distance. This facilitates adjustments to soil conditions, such as advancing the inner string forward to deal with dense materials or pulling it back to develop a soil plug in running conditions. One disadvantage is that the large lower drive increases the clearance needed from vertical obstructions, such as walls.

The contractor modified the BG-15 rig by replacing the Kelly bar with a duplex rotary. The duplex rotary allows the drill string to rotate independent of the casing. A Kelly bar is a long, square drive shaft to which augers and drilling bits can be attached. The casing is installed similar to a single head micropile, by installing the permanent casing as the hole is drilled. The rig has a 40-foot stroke, allowing it to drill long sections of casing.

Cage Assembly

Until recently, core steel used in caissons almost exclusively consisted of steel sections. The replacement of the steel section with multiple high strength reinforcing bars significantly increases the compressive strength of the minicaisson. For example, the rebar cage used in the first case history consisted of 15 Grade 75 #20 bars, for which the New York City Building Code (NYCBC) provides an allowable compressive stress of 30 ksi. The total compressive capacity of the steel is 2210 kips. The reinforcing cage has an outside diameter of 19 inches, which complies with the NYCBC required 1.5 inches clearance for a 22-inch diameter rock socket. In contrast, the NYCBC limits H-pile sections to 18 ksi. The largest H-pile section that can fit into a 22-inch rock socket with the required 1.5 inch clearance is a HP12x84. The total compressive capacity of the HP12x84 is 443 kips, which is significantly less than the 2210 kips compressive capacity for the reinforcing bars.

In the early 2000s, SAS Stressteel developed a high strength reinforcing cage for building columns. It utilized spacer plates and centralizers to assure full bond for a large number of bars. When SAS learned of a similar need for minicaissons, the cage was easily adapted for this use.

Figure 2: Barber Rig.

Figures 3 and *4* show the assembly of the reinforcing cage for the 2800 kip compression capacity rock socket at Project #3. The 19 inch diameter cage included 15 Grade 75 #20 bars. Twelve bars were wrapped around short lengths of 14-inch diameter centralizer pipes, while the inner three bars were similarly attached to short lengths of 2.875-inch diameter centralizer pipes. Spacer plates were inserted along the cage to maintain the proper perimeter spacing of bars around the centralizer pipes. Sometimes inner centralizer pipes are made continuous for use as tremie pipes.

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Cages are fabricated at the SAS facility in Fairfield, New Jersey and trucked in maximum 60-foot lengths to the New York City (NYC) job sites. Where longer cages are required, cages are extended with staggered couplers.

Design

The caisson section of the current NYCBC provides allowable stress values of 0.25 f′c for concrete (or grout), 0.35 Fy for the casing with Fy limited to 36 ksi, 0.4 Fy for reinforcing steel with Fy limited to 75 ksi, 0.5 Fy for core steel with Fy limited to 36 ksi, and 200 psi for concrete-to-rock bond stress based on NYC Class 3-65 bedrock (see below), or better. The code allows the use of end bearing in combination with side friction; however, this is seldom used for small diameter drilled piles because the pile bottoms cannot be inspected. The NYCBC has no upper limit for caisson loads and does not require static load tests, provided that the design grout-to-bedrock bond stress does not exceed 200 psi. It does require field verification that each socket is embedded into suitable bedrock.

Figure 3: Centralizer Pipe.

Figure 4: Spacer Plate.

The NYCBC defines Class 3-65 bedrock as those that include local gneiss, diabase, schist, marble, serpentine, cemented shale and sandstone. The rock's characteristics are as follows: it gives a dull sound when struck with a pick or bar; it does not disintegrate after exposure to air or water; it contains broken pieces that may show weathered surfaces; it may contain fractures and weathered zones up to one inch wide but is filled with stiff soil; and its core recovery with a double tube, diamond core barrel is generally 35% or greater for each five foot core run.

Typically for caissons, it is assumed that the compressive stress in the casing is transferred directly to bedrock, thereby reducing the design load for the rock socket. Obviously, the critical condition for this assumption is the seating of the casing into the bedrock. For large diameter caissons, this can be verified by visual inspection. For minicaissons, borehole cameras can be used to evaluate the condition of the seating, as well as to verify that the casing is into the bedrock rather than into a boulder.

Using the current code values, which will not change with the new code, the load reduction in the rock socket, due to the assumption of casing load being transferred directly to bedrock, is 346 kips for a 0.5-inch wall, 18-inch diameter Grade 36 or higher steel casing, and 465 kips for a 0.5-inch, 24-inch diameter Grade 36 or higher steel casing. *Table 1* compares three methods of computing the structural capacity of the rock socket with the reduced socket load. It shows that using the current code, with the casing load reduction, provides a rock socket design that is very close to that obtained using Federal Highway Administration (FHWA) guidelines (FHWA, 2000).

The new NYCBC code is expected to be adopted in the near future. It will increase the allowable stress for concrete to 0.33 f′c, in-crease the allowable stress for reinforcement to 0.5 Fy, with no stated limit on Fy, and require that all caissons be inspected by direct observation, video methods or a rock core taken prior to the drilling of the socket. Static load tests may be substituted for inspection. Most projects are being designed on the basis of the current building code. On some projects, waivers have been obtained from the Building Official to use the pending code.

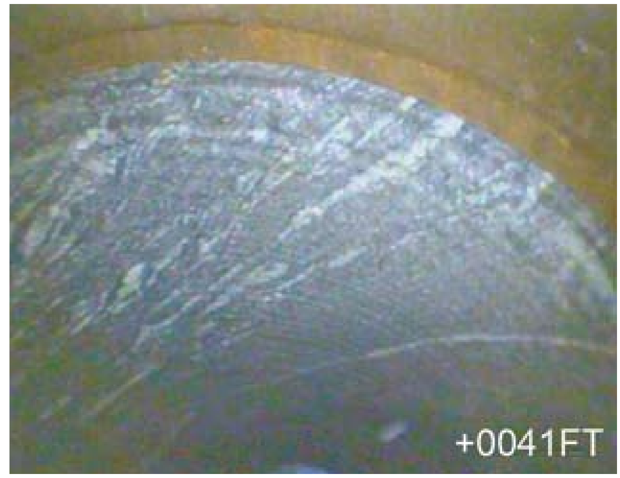

Figure 5: Weathered rock with large void.

Load Capacity Verification

Video inspection has become more prevalent as a replacement for static load testing in the years since the pending code was written.

During video inspections, several aspects of the pile can be evaluated, including the casing joints, the seating of the casing into the bedrock and the quality of the bedrock. The seating of the casing into competent bedrock can be particularly important if the design is based on the casing load being taken directly by the bedrock.

Good video images cannot be obtained if the hole contains muddy water. Even if the seepage through the bedrock is minimal and clean, the casings can quickly fill with muddy water during a heavy rain. As a practical matter, this is best accomplished by either pumping the hole dry or flushing the hole with clean water. Although holes can generally be video inspected in a half hour, the tight constraints of a typical NYC site significantly reduce production rates.

A video inspection report commonly includes a narrative of the day's inspection activities and a CD containing the full inspections of each minicaisson. The CD is typically reviewed by both the caisson designer and the owner's design team. If the casing is observed to be not seated into competent bedrock, typically the casing will be re-seated. *Figures 5* and *6* show video images of casings seated in competent bedrock. *Figure 5* was taken above water, and *Figure 6 (page 12)* was taken below water.

Table 1

Case History #	Caisson Load	Casing Capacity	NYC Current	Socket Capacity NYC Pending	FHWA
1	2800 k	465 k	2637 k	3326 k	3280 k
2	1200 k	346 k	1203 k	1521 k	1521 k
3	2800 k	465 k	2481 k	3151 k	3218 k
4	3400 k	465 k	2946 k	3724 k	3713 k

Case Histories

1- Chelsea Arts Tower, 543 West 25th Street, Manhattan, New York

This slender 78-foot wide, 22 story building was determined to develop significant overturning moments due to the applied design wind loads. The foundation was originally designed for driven pipe piles. A redesign to minicaissons was chosen to reduce cost and to reduce the possibility of vibration damage to adjacent structures.

The building was constructed in a filled-in portion of Manhattan that was originally under the Hudson River. The subsurface profile consisted of 20 to 23 feet of earth and rubble fill, 10 to 12 feet of organic silt, 15 to 50 feet of sand, and schist bedrock at depths of 48 to 78 feet below ground surface.

The foundation was redesigned to be supported on 2 minicaissons of 24-inch diameter, 14 minicaissons of 18-inch diameter and 11 minicaissons of 12.75-inch diameter. Maximum design loads were 2800 kips compression and 450 kips tension on the 24-inch diameter minicaissons, 1800 kips compression and 200 kips tension on the 18-inch minicaissons, and 1100 kips compression on the 12.75-inch minicaissons. The 24-inch minicaissons were reinforced with 15 #20 SAS Grade 75 reinforcing bars. Twelve of the bars were attached to a 14-inch diameter centralizer pipe, and the remaining three were bundled around a small diameter tremie pipe. Grout had a 5000 psi compressive strength. The socket design was based on the casing load being transferred directly to the bedrock.

The load transfer in the rock sockets was designed on the basis of an allowable grout-to-bedrock bond stress of 200 psi. The quality of the bedrock was verified by inspection of the drilling operation and comparison with the rock cores from test borings. No static load tests were performed.

2- 13-15 Jackson Avenue, Queens, New York

The project is a 13-story residential condominium. The foundation was originally designed for minipiles in order to reduce vibrations transmitted to adjacent buildings and to a nearby subway. Additionally, the Transit Authority required the foundation loads to be transmitted via rock sockets into bedrock located below the influence line of the subway. The contractor redesigned the project for minicaissons to reduce cost.

Subsurface conditions consisted of 7 feet of miscellaneous earth and rubble fill over medium dense to dense, fine to medium sand that extended to bed-rock at depths of 42 to 52 feet. Bedrock was classified as granodiorite.

The 72-foot square building was designed to be supported on 29 minicaissons of 18-inch diameter. The design compressive loads were 1200 kips on 10 minicaissons and 1000 kips on the remaining 19 minicaissons. The reinforcing cages included 5 #20's and 1 #24. Grout strength was 5200 psi.

Rock sockets were verified by borehole camera inspections. No static load tests were performed. Sockets were designed on the basis of an allowable bond stress of 150 psi. The socket was designed to take the full compressive load of the minicaisson with no reduction for the casing load being transferred to the bedrock.

3- 22 East 23rd Street, Manhattan, New York

The project is a 50 story commercial/residential building on a 50- x 100-foot site. The foundation was originally designed for minicaissons in order to reduce vibrations transmitted to adjoining row houses of brick and masonry construction that abutted the property lines. The excavation for a basement required underpinning the adjacent buildings, which further reduced access to the small site. The contractor was able to reduce the cost by redesigning the minicaissons for higher capacities. Due to the small size and limited access to the site, larger drilling equipment was not feasible.

The subsurface profile below cellar level consisted of medium dense sand and gravelly sand to 20 to 25 feet, decomposed rock to 35 to 45 feet, and mica schist.

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The building was designed to be supported on 31 minicaissons of 24-inch diameter. The maximum design compressive load was 2800 kips. The minicaissons were reinforced with 12 #20 reinforcing bars. Grout strength was 8000 psi. The socket design was based on the casing load being transferred directly to bedrock. All minicaissons were inspected with a borehole camera.

No static load tests were performed. The geotechnical capacity of the rock socket was based on a 150 psi bond stress.

4- 123 Washington Street, Manhattan, New York

The project is a 65-foot wide, 59 story combined hotel and residential use building. The project was originally designed for 96 minicaissons. The contractor was able to reduce the number of minicaissons to 69 by redesigning the rebar cage.

The maximum design compressive load was 3400 kips. The rock socket was reinforced with 16 Grade 75 #20 bars and was filled with 7000 psi grout. The design was based on the casing load being transferred directly to bedrock.

Bedrock was mica schist. The geotechnical capacity of the rock socket was based on a 200 psi bond stress and a 20 ton per square foot allowable end bearing capacity. All minicaissons were inspected with a borehole camera. No load tests were performed.

Figure 6: Casing on bedrock.

Conclusions

1) Most of the lessons learned on these four projects relate to avoiding the extremely high cost and complicated logistics of redrilling a 24-inch diameter minicaisson on a very confined site. First, develop and follow a detailed plan of sequence for installing the minicaissons. Second, drill rock sockets deeper than the minimum if there is any question regarding the quality of the bedrock. Third, take the time to measure correctly when cutting the reinforcing cage.
2) The assumption that the casing load is transferred directly to competent bedrock is reasonable for New York City due to the general quality of the bedrock, and the very specific classification system required by the NYCBC. This assumption would not be valid in areas of poor quality bedrock.
3) A rock socket design using the current NYCBC, in which the casing load is assumed to be transferred directly to bedrock, will be very similar to a rock socket design using FHWA guidelines.
4) The development of this "new" technology resulted from a contractor's desire to create a niche in the local foundation market. He did so by marrying several existing technologies, some of which were developed many decades ago.▪

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Finally, we would be remiss if we did not acknowledge the pioneering contributions of Mark Ziegenfuss, Thomas Begley and others who used the Barber rigs to install minicaissons of lesser capacity in NYC in the 1980s and 1990s.

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