Micropiles

Versatile Foundation Alternative for Challenging Projects

By Andrew F. Brengola, P.E.

Figure 1: Typical mini-drill

Figure 2: Mini-drill moving to micropile locations

Micropiles are small diameter (generally less than 12 inches), cast-in-place drilled or driven piles, which are composed of grout and steel reinforcement. Installable in almost any type of ground where piles are required, micropile design loads range from 3 tons to 500+ tons (*See Figure 4 on page 20*).

Micropiles can offer a viable alternative to conventional piling techniques, particularly in restricted access or low headroom (*Figures 1* & *2*), vibration-sensitive areas, where subsurface obstructions may result in premature refusal or where other pile types require expensive installation. Also know as minipiles, pin piles, needle piles or root piles, micropiles were pioneered in the early 1950s by Fernando Lizzi of Italy. Micropile technology spread to the United Kingdom, West Germany and Switzerland in the early 1960s and into North America in the early to mid 1970s.

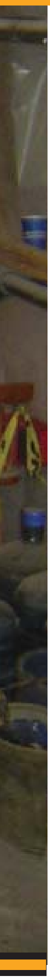
Composition

Steel reinforcement may consist of a permanent steel casing, central reinforcing bar(s), and/or a steel reinforcing cage. The steel pipes used for a permanent casing are the same high-grade steel pipes used as casings for oil wells. These pipes are usually API N80, with a yield strength of 80,000 psi. The pipe out-side diameters range from 5.5-inches to $11\frac{7}{8}$-inches, with five common increments between those sizes. Wall thicknesses generally are in the range of 0.4 to 0.6-inches. Special high-strength machined flush joint threads are typically used to join the pipe sections. Reinforcing bars used inside the pipes are high-strength steel, grade 75, 95 or 150, with diameters from 0.5 to 3.5 inches. Grout generally consists of water and cement with a ratio ranging from 0.40 to 0.50 by weight. Sand is sometimes added to increase strength and reduce cost. Other additives may consist of water reducers, plasticizers, and/or initial set retarding agents.

Micropile Installation

Installation of micropiles are typically performed by drilling or driving a hole through overburden soils and into rock or naturally deposited soils capable of providing adequate frictional bonding capacity (*Figure 3*). The two most common forms of advancing the borehole are rotary drilling or rotary percussive drilling. Rotary drilling uses air and/or water as a flushing medium to remove drill cuttings from the drill hole. As the drill hole is advanced, air/water is pumped through the drill string and exits at the drill bit, flushing drill cuttings to the ground surface. Rotary percussive drilling advances the drill hole by driving a steel casing into the ground. Rotary percussive drilling can be a displacement method whereby a drive point is used at the bottom of the casing, or a non-displacement method whereby air is used as a flushing medium.

After advancing the borehole to the bottom of the bond zone, grout is tremie-placed from



the bottom of the drill hole. For piles founded in soils, the drill casing is then retracted from the bond zone and the pile continually topped off with grout. For high-capacity piles founded in rock, the pipe's penetration depth may be either to the top of the rock or full length into a drilled rock socket. If the pipe terminates at the top of the rock, a drill string is advanced through the center of the pipe to drill the rock bond zone to a diameter less than the inside diameter of the pipe. If the pipe penetrates for the full length into a drilled socket, a permanent drill bit, with a diameter larger than that of the pipe, is fitted to the end of the pipe to advance the casing into the rock. Grout ports in the bit allow for the tremie process, and thus, more grout can be pumped in if needed. Additional concentric steel pipes and/or all-thread bars may be placed in the drill hole together, providing additional steel for increased capacity.

Down The Hole Hammers (DTHH) are air-powered percussion tools capable of penetrating the hardest types of rock found in the United States. These hammers are placed at the bottom of the drill string and require compressed air to actuate the drill percussion and flush cuttings up to the surface. A replaceable high-strength carbide button bit is fitted to the bottom of the hammer. The DTHH allows drilling at a rate of approximately 1 foot per minute, as opposed to 1 foot per 10 minutes with other hammers. DTTHs are suitable for use on projects that require the pile to penetrate obstructions such as rubble, debris, boulders, granite blocks, or concrete.

Classification of Micropiles

Traditional micropiles are tremie grouted from the bottom of the drill hole up and are classified by the method by which the pile is grouted (*Figure 4*). Type A micropiles are placed under gravity head only. Therefore, the grouting of a Type A pile is complete after tremie grouting. Type B micropiles are pressure grouted after initial tremie grouting is performed, and as the drill casing is removed from the bond zone of the pile. Type C micropiles use a pre-installed sleeve port pipe within the pile to apply a single global injection of grout before hardening of the primary tremie grout. Type D micropiles use a pre-installed sleeve port pipe within the pile for multiple injections of grout at specific intervals within the pile bond zone. There are a variety of other micropile types which have been utilized in unique applications (*Figure 4*). These include: pushed or driven, compaction grouted, jet grouted, and drilled end bearing micropiles.

Micropile Design

Micropiles typically derive their axial load carrying capacity from the soil-grout or rock grout bond within the pile bond zone. The geotechnical capacity is essentially equal in tension or compression. In granular soils, typical ultimate bond values can range from 10 to 100 psi. In clay soils, typical bond values can range from 5 to 55 psi. Rock to grout bond values can range from 25 to 450 psi or greater. Guidelines for bond strengths can be found in the Post-Tensioning Institute's *Recommendations for Prestressed Rock and Soil Anchors*. Various formulas for estimating bond capacity can be found in Volume II of the Federal Highway Administration document *Drilled and Grouted Micropiles: State of the Practice Review*, publication No. FHWA-RD-96-016.

The internal structural design of a micropile is a function of pile geometry, the unconfined compressive strength of the grout and the yield capacity of the reinforcing steel. Factors are applied to the material properties to limit working stresses, to account for variations in material properties and to account for strain compatibility between the grout and high strength steel. These factors vary slightly between various codes and manuals. A commonly used equation for determining the allowable compressive capacity of a micropile is:

$$Q_{allowable} = 0.33\, f'_c\, A_c + 0.4\, f_y\, A_s$$

Where,
f'_c = 28-day unconfined compressive strength of cement grout
A_c = Cross sectional area of pile grout
f_y = Yield strength of reinforcing steel
A_s = Area of steel reinforcement

Some specifications and building codes require that a minimum of 40 percent of the design load be carried by the reinforcing steel. Some building codes limit the unconfined compressive strength of the grout and the yield strength of steel in design calculations.

The allowable tensile capacity of a micropile is commonly determined by the following:

$$Q_{allowable} = 0.6\, fy\, A_s$$

In determining the area of steel to use for calculating the axial capacity of micropiles, appropriate allowances for corrosion may be provided if the steel is not otherwise protected by a suitable coating or encapsulation.

Micropiles resist lateral deflections due to their structural integrity and to the resistance derived from the adjacent soils. The lateral load carrying capacity of vertically drilled micropiles is limited by the physical size of the pile, the limited size of reinforcing steel and the bending strength of threaded joints on the exterior steel casing. A steel pipe of sufficient length to span downward from pile cutoff past the first or second casing joint is sometimes

Figure 3: Micropile installation procedures

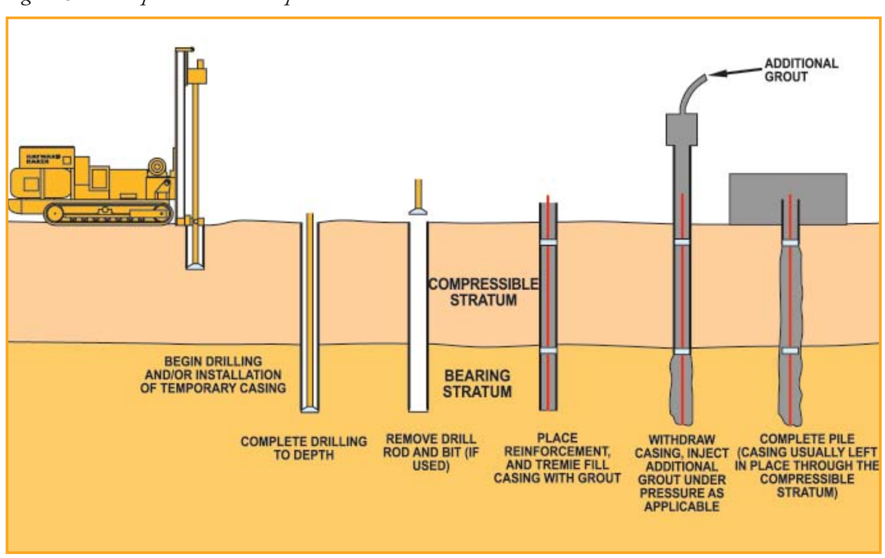
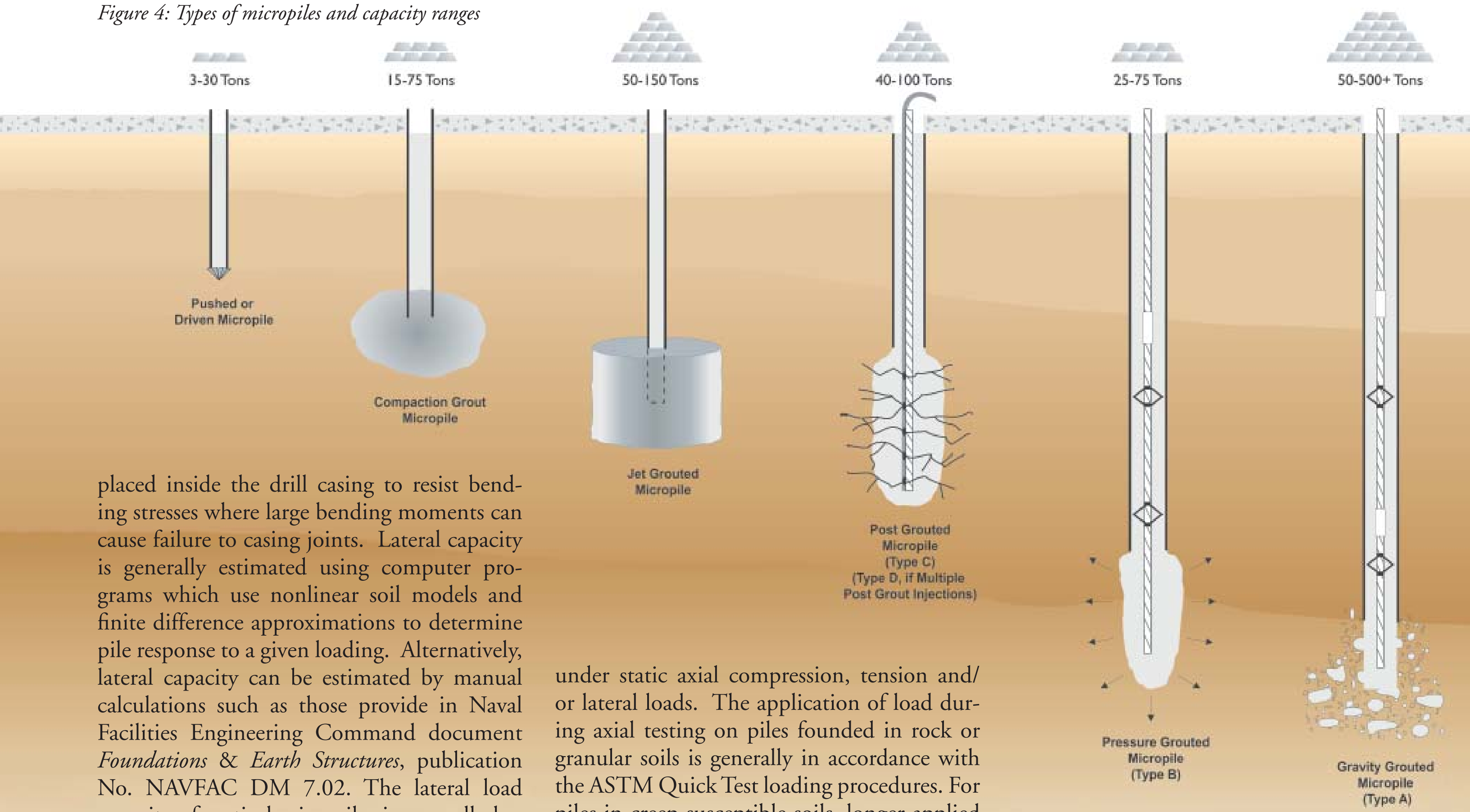


Figure 4: Types of micropiles and capacity ranges



placed inside the drill casing to resist bending stresses where large bending moments can cause failure to casing joints. Lateral capacity is generally estimated using computer programs which use nonlinear soil models and finite difference approximations to determine pile response to a given loading. Alternatively, lateral capacity can be estimated by manual calculations such as those provide in Naval Facilities Engineering Command document *Foundations* & *Earth Structures*, publication No. NAVFAC DM 7.02. The lateral load capacity of vertical micropiles is generally between 5 and 15 tons; however, this resistance can be increased by battering the piles.

Many options exist for pile to pile cap connections. In some cases the reinforcing steel bar(s) are extended into the pile cap and a bearing plate is secured to it between two full capacity hex nuts. The bar(s) alone may provide adequate development length to transfer the load into the pile. In other cases the casing is extended into the pile cap to transfer the load. Pile top attachments such as steel plates may be welded to the casing. However, special welding procedures may be required as the carbon equivalency (CE) of the N80 pipe can be high.

QA/QC

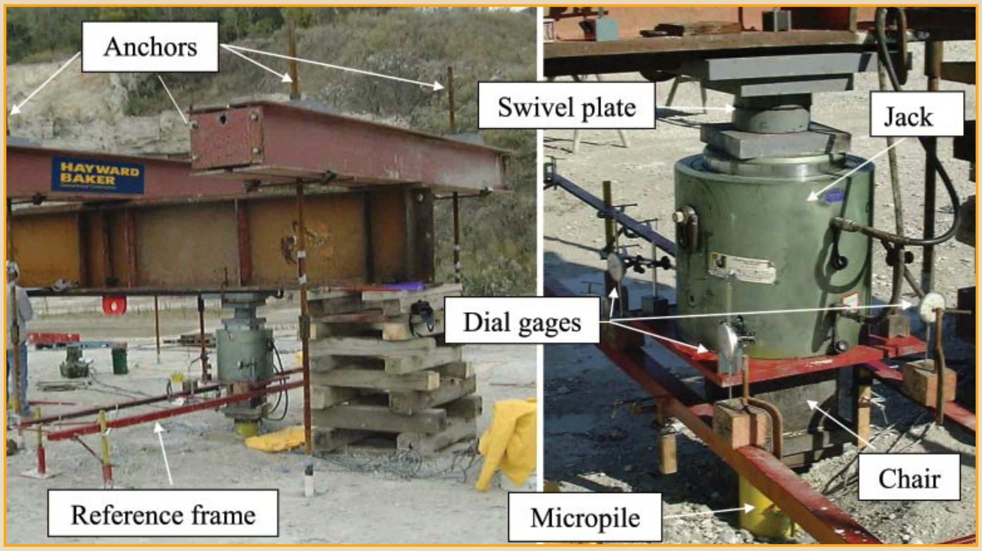
A load test is generally performed to verify a micropile design on a project. A compression or tension test can be performed to verify the axial capacity of a micropile (*Figure 5*). Instrumentation such as strain gauges or tell tales can be installed in test piles to verify that the applied test load is transferred to the bond zone and to calculate actual ultimate bond capacity. For laterally loaded piles, a free or fixed head lateral load test can be performed. Micropile load tests are performed in accordance with the American Society for Testing and Materials (ASTM) standards for piles loaded under static axial compression, tension and/or lateral loads. The application of load during axial testing on piles founded in rock or granular soils is generally in accordance with the ASTM Quick Test loading procedures. For piles in creep susceptible soils, longer applied test loads, particularly at the maximum load increment, are required to verify pile capacity.

Quality control and quality assurance procedures should be implemented on every micropile project to confirm that the production piles are installed in accordance with project specifications and pile design, and that they are consistent with the means, methods and materials used on the test pile. Grout cubes and specific gravity measurements should be taken to monitor grout quality. Installation records should be maintained to document all pile installation aspects. A joint micropile committee of the Deep Foundations Institute and the International Association of Foundation Drilling has published the *Guide to Drafting a Specification for Micropiles*. This publication is helpful in preparing a project specification which includes quality control and quality assurance procedures and is available at **www.dfi.org**.

The Increase in Micropile Usage

Successful installation under difficult constraints is the primary reason for the growth

Figure 5: Left - typical compression test setup; Right - loading apparatus and dial gages



of micropile use in recent years. Site logistics and equipment access may prohibit the installation of other deep foundation methods, leaving micropiles as the only feasible choice. At many sites, micropiles can be the most economical choice.

The popularity of micropiles has resulted in more competition and thus, lower prices. Similarly, as workers have gained experience with micropile use and improved installation methods have been developed, productivity has increased resulting in further cost reduction. Acceptance of higher capacity micropiles has led to fewer piles installed on individual projects, lowering the overall project cost. Over the past decade, costs have decreased by approximately 25 percent.

Figure 6: Hydraulic track drill installing battered micropiles

Applications

Micropiles work in a wide range of challenging conditions in both soil and rock. They can carry loads in numerous difficult ground conditions, whether for new loads being added to an existing structure, for arresting structural settlement, for resisting uplift and dynamic loads, for seismic retrofits or for underpinning and slope stabilization.

Micropiles are used in rehabilitation projects or in new construction with physical constraints, such as limited headroom and restricted access, and in vibration or settlement sensitive areas. They have been installed directly through existing shallow foundations. A typical application might involve foundations placed close to existing footings, columns, walls, or other impediments (*Figure 6*). Difficult ground conditions suitable for micropiles include: karstic limestone geology with voids, mined rock geology with voids (including rubble-filled voids), glacial tills, profiles with "floating" boulders, sites with high water tables, random urban fills, and other difficult geological characterizations.

Conclusion

Micropiles have proved successful at solving problems at a wide range of difficult sites. Installation costs are decreasing while productivity is increasing. Both will encourage the method's wide use. Higher load capacities will further their benefits and enhance their use. Many new applications for this advancement in construction techniques can be expected, both in new projects and for rehabilitation work.▪

See Mt. Storm Power Station Case History on next page....

Andrew F. Brengola is the New England Area Manager of G. Donaldson, a division of Hayward Baker, based in Cumberland, RI. He has 12 years experience in micropiles, earth support, jet grouting, and various ground improvement methods.
afbrengola@haywardbaker.com

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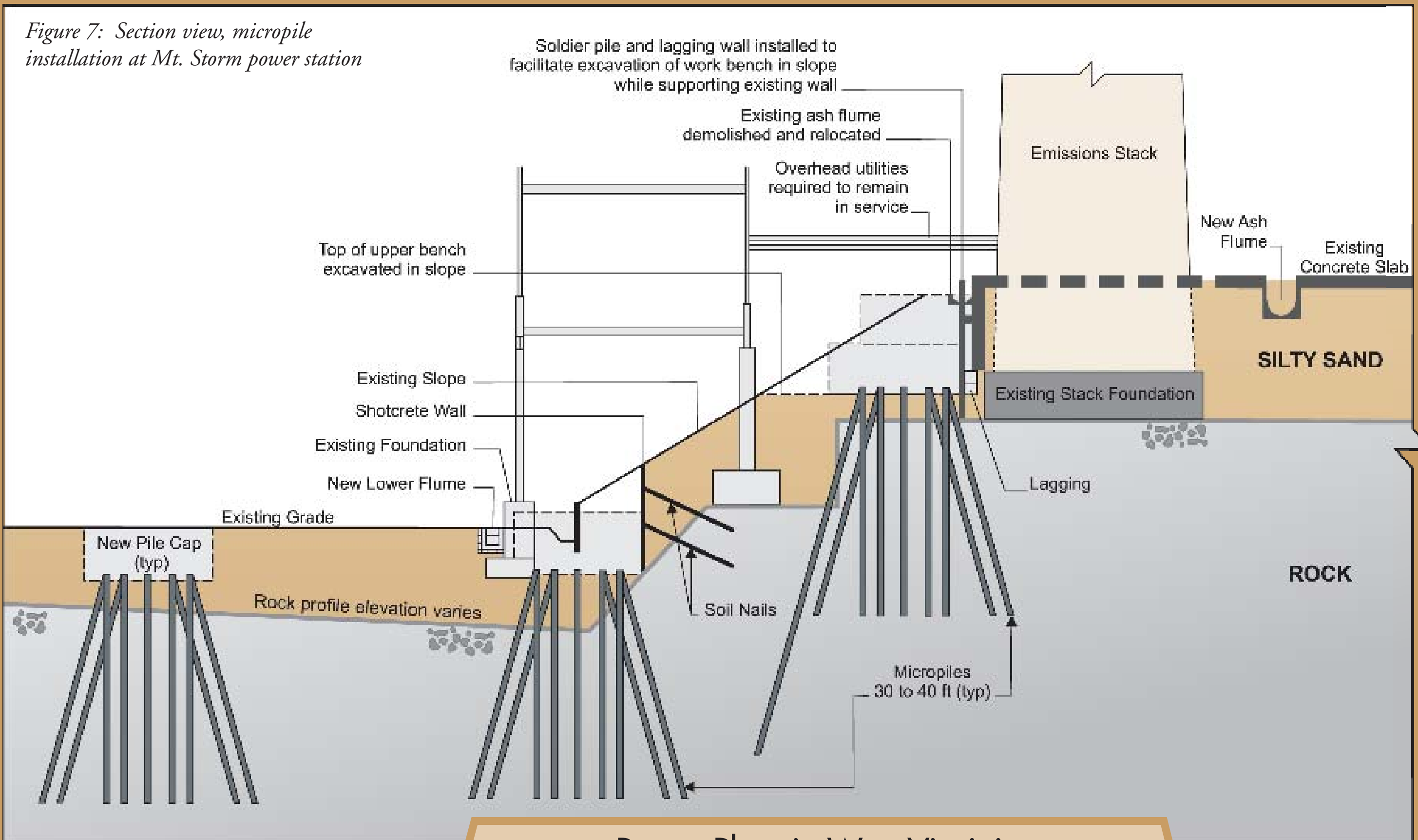

Figure 7: Section view, micropile installation at Mt. Storm power station

Power Plant in West Virginia

Mt. Storm power station is founded on the shores of Mt. Storm Lake in northeastern West Virginia. Selective Catalytic Reduction (SCR) units were slated for installation on the emission stacks. Because the power plant is over 3,500 feet above sea level and is frequently exposed to high wind loads, large steel structures were designed to support the SCR units, requiring new foundations to resist high compressive, uplift and lateral loads. Micropiles fixed into the side of the steep hill were designed to support these foundations.

Crews were required to work around the existing plant foundations situated through a steep hill, and to alter the existing conditions to provide access. Nearly half of the work was done in either low or restricted headroom. A mini-rig was used to install 28, 10¾-inch battered piles in a low headroom area inside a diesel generator room.

The micropiles consisted of a 10 ¾-inch surface casing and a 20 to 30-foot rock socket.

The first installation area was situated at the toe of a 2H:1V slope (*Figure 7*). The geotechnical contractor excavated bays into the slope at the pile cap locations and installed a soil nail and shotcrete wall to support the faces of the cut.

The second area was approximately mid-way up the slope. The geotechnical contractor drilled 60, 22-inch diameter holes, while working from the top of an existing precast retaining wall and from a 7.5-foot wide bench.

Once a bench was excavated at the top of the slope, the geotechnical contractor installed 432 battered micropiles for the new pile caps.

Two load tests were performed to two times the design load. The micropiles were tested in tension to verify that all axial loads were resisted by friction only, and strain gauges were used to accurately compute load transfer from the pile to the rock. Net pile displacement after unloading of a 600 kip test load was 0.10 and 0.21 inches for the two test piles, respectively.