IMPLEMENTATION OF MICROPILES BY THE FEDERAL HIGHWAY ADMINISTRATION

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Abstract

FHWA implementation of micropiles in the highway industry dates back nearly 30 years to when a reticulated micropile (pali radice) wall was used in northern California near Mendocino to stabilize the shoulder of a roadway. Since then FHWA has used micropiles on several projects for bridge pier and abutment foundations, slope retention, and retaining wall foundations. In addition, FHWA has worked with several State Departments of Transportation in their implementation of micropiles for bridge foundations, slope stabilization and seismic retrofit.

Micropile technology was originally introduced in the United States in 1973. FHWA recognized the potential for this technology and starting in 1993, set about to establish guidelines for their use in the highway industry. This effort resulted in a four volume document, *Drilled and Grouted Micropiles*, *State-of-Practice Review*, published in 1997. FHWA followed this with an implementation manual, *Micropile Design and Construction Guidelines*, published in 2000. FHWA through its training arm, the National Highway Institute, has recently completed an effort to develop a two-day training course. As part of the training course development the 2000 micropile document was revised to reflect current technology and to include a chapter on Design of Micropiles for Soil Slope Stabilization, *Micropile Design and Construction*. FHWA has also supported research efforts through its research branch at Turner-Fairbanks including Seismic Behavior of Micropile Systems.

After 30 years of Micropile research, training and implementation, many State DOTs still consider micropiles an emerging technology. Through efforts by FHWA such as the new NHI micropile training course and activities by the International Society for Micropiles, it is hoped that will begin to be perceived as not an experimental or emerging technology but a mainstream practice and part of our regular bag of tools we use to address geotechnical challenges in transportation engineering.

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The Early Years

Federal Highway Administration (FHWA) implementation of micropiles in the highway industry dates back nearly 30 years to 1978 when a reticulated (CASE 2) micropile (pali radice) wall was used in northern California on Forest Highway 7 in the Mendocino National Forest to stabilize a 94-m long section of the shoulder of a roadway. The site geology was primarily meta-sediments consisting mainly of phyllite with mica quartzschist and slate. The wall was designed to provide additional shear capacity along the slide plane that cut through re-brown clay with rock fragments, to increase the factor of safety to an acceptable level. A total of 721, 15- to 24-m long, 127-mm diameter, Type A (gravity grouted) micropiles were placed with a pile density of 8.25 piles per linear meter of retaining structure, Figure 1. Drilling was advanced by open-hole method and air flushing to depths of 12 to 24 m. The piles were tied together at the top using a concrete cap, 0.9-m thick by 1.8-m wide. Seventeen piles were instrumented with strain gauges and showed that the piles were acting in compression with a maximum compressive force of 6 kN. The completed structure performed well, despite a subsequent failure of the slope below the wall that exposed the micropiles.

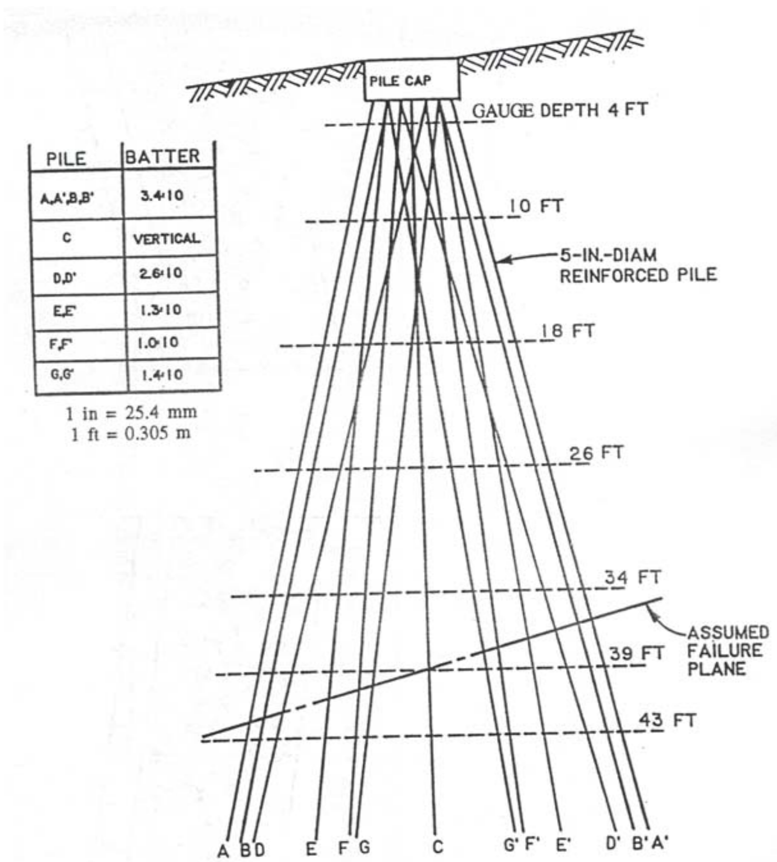

Figure 1. Cross-Sectional View of Micropile Network, Mendocino, California (Palmerton, 1984)

Early on, FHWA also used micropiles for structural support of bridges on two projects. The first was in 1980, the Linn Cove Viaduct located along the Blue Ridge Parkway in northwestern North Carolina. The viaduct was constructed from the top down to minimize disturbance to the natural environment. This method eliminated the need for a "pioneer road" and heavy equipment on the ground. The only construction that occurred at ground level was the drilling of foundations for the seven permanent piers on which the Viaduct rests. Exposed rock was covered to prevent staining from concrete, epoxy, or grout. The only trees cut were those directly beneath the superstructure. The seven piers and two abutments that were designed to be supported on micropiles, although at the time, FHWA referred to them as “root piles” or “microshafts”. The site presented difficult drilling conditions because of the large sized talus material near the surface and restricted access due to the environmentally sensitive nature of the area. The micropiles were 230 mm in diameter and reinforced with three 51-mm diameter steel reinforcing bars bundled together with a 25-mm diameter steel pile in the center and then wrapped with spiral wire. The lengths varied from 3 meters to 30 meters and supported loads that varied from 1100 kN in compression to 450 kN in tension, Figure 2.

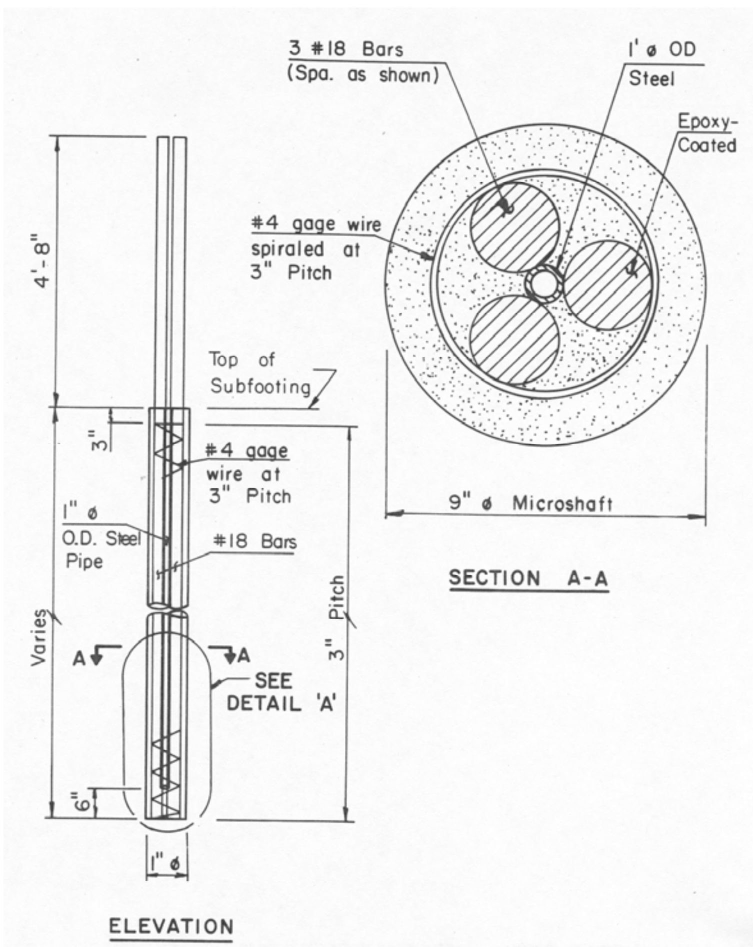

Figure 2. Elevation and Section Views of Micropile Used for Linn Cove Viaduct

In 1992, FHWA utilized micropiles for an abutment of the Marble Fork Bridge in Sequoia National Park in central California. The abutment was originally design as a spread footing but when poor bearing conditions were encountered along two sides of the abutment the designed was modified to include micropiles for abutment support. On this project the micropiles were called "pinpiles". The eight micropiles, of which 3 were battered at 3:1 (V:H), were 300 mm in diameter and 6 meters long and reinforced with 180-mm O.D. casing.

Micropiles were used 1994 to support the abutments of the single span Chilnualna Bridge which provides access to the Chilnualna Falls trailhead in Yosemite National Park in central California. This time the plans referred to the 180-mm diameter micropiles a "drilled shafts". Each abutment was supported on five (5) 7-inch diameter micropiles, 5.0 to 6.5 meters long. The design load for each micropile was 330 kN.

Establishing the State of the Practice

Up to this point in time, FHWA was either designing the micropiles in-house using standard drilled shaft design methods or hiring consultants to design the micropiles. It had become evident that micropiles offered advantages over other foundation systems in certain circumstances and they were going to be used more in the future, yet our understanding of their design and construction was limited. FHWA recognized the potential for this technology and, starting in 1993, set about to establish guidelines for their use in the highway industry. The first step in this effort was to document the state of the practice, and toward this end, FHWA produced a four volume document, "Drilled and Grouted Micropiles: State-of-Practice Review", published in 1997. This document presented the comprehensive engineering knowledge at that time, available analytical models and design methods for single micropiles, groups of micropiles and networks of reticulated micropiles, and construction specifications. This report also identified future research needs. Based on the information in this document, FHWA began in 1997 to prepare an implementation manual, "Micropile Design and Construction Guidelines" published in 2000. This document presented a definition for micropiles as well as recommendations for design, construction, quality control and contracting methods. It also offered a classification system based on design intent and construction method, specifically the grouting procedure. Based on design intent micropiles were referred to as either CASE 1 where the micropiles are load directly in either tension or compression or CASE 2 where the micropile elements circumscribe and reinforce the soil to create a soil-structure composite. Based on grouting procedure micropiles are either: Type A – gravity grouting; Type B - pressure grouting through the casing; Type C – single global post grouting; or Type D – multiple repeatable post grouting. FHWA commonly constructs Case I micropiles utilizing a Type A, Type B or rarely Type D grouting procedure. Type C grouting is only utilized in France.

Later Utilization of Micropiles

With this guidance in hand, FHWA has utilized micropiles on several projects for structure support, retaining wall extension and retaining wall rehabilitation.

Micropiles were used in 1998 on Bridge 10 on the Foothills Parkway project, in the Great Smoky Mountains National Park in eastern Tennessee for structure support. This project was similar to the Linn Cove Viaduct in that it was located in an environmentally sensitive area. The reason for selecting micropiles was due to the site conditions on the Foothills Parkway. Steep terrain and minimal work space prevented the use of large equipment required for other foundation types such as drilled shafts or driven piles. The drill and support equipment for the micropiles were relatively compact and maneuverable. The drill was small enough to be placed in the foundation with a crane if necessary. Micropiles were not used under all the substructure elements. Three of the four abutments and one of the four piers were founded on micropiles. The remaining foundations were spread footings on competent rock. The micropiles were designed using the FHWA recommended design methodology including substructure connection details, plunge length, and material and construction specifications. The micropiles were 225 mm in diameter with 200-mm diameter casing and a 55-mm diameter central reinforcing bar, Figure 3.

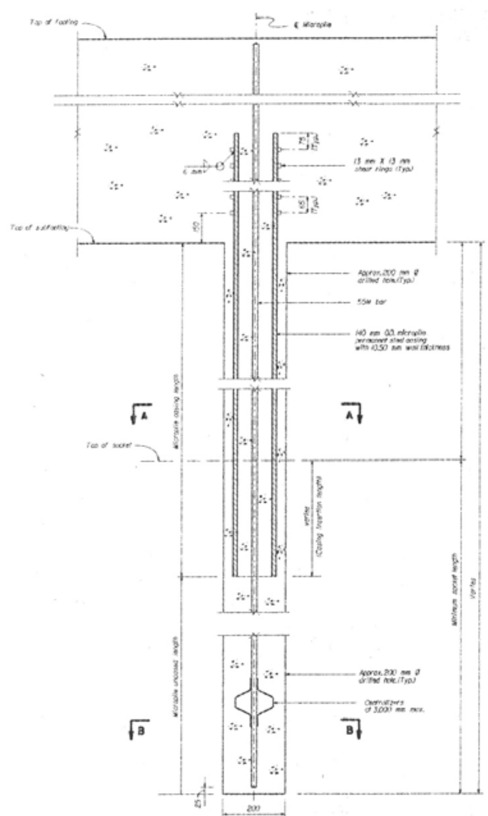

Figure 3. Cross-Sectional View of Micropile Used for Bridge 10, Foothills Parkway

In 2000, FHWA used micropiles to extend a retaining wall on the 75-year old, marginally stable Madrone Dam in California. The micropiles were battered in either direction and no load testing was conducted.

In 2002 FHWA used micropiles to support guard walls along the Going-to-the-Sun Road in Glacier National Park in Montana. The Going-to-the-Sun Road, with much of its 80 kilometers carved out of steep mountainsides, poses some interesting dilemmas relative to maintenance, safety and visitor use. Much of the high elevation roadside is lined with approximately 11 kilometers of stone masonry guardwalls and over 130 stone masonry retaining walls. During winters, avalanches take their toll on the roadway and primarily inflict damage to the stone masonry guardwalls that lie within their path. Historically, within known avalanche chutes, a removable timber rail was erected and removed annually resulting in rather significant maintenance costs in dollars and time. A lack of safety appurtenances in these locations also presented significant hazards to park employees including maintenance forces that are required to traverse the road prior to the reinstallation of the rail. The solution was a pile-supported slab that translates the avalanche forces into the ground behind and below the guard wall. The pile supported slab approach used micropiles because they are able to penetrate most ground conditions. This system is ideal for the mixed soil and rock ground conditions that can be encountered in Glacier Park.

In 2003 FHWA used micropiles to underpin an abutment of the Deer Canyon Bridge on a US Forest Highway project to address differing site conditions where bedrock was not encountered at the elevation shown in the plans. Drilled shafts were considered but were determined impractical because of the presence of large boulders. Spread footings were not considered feasible because of the possibility of differential settlement. The work required the drilling and grouting of 10 micropiles, 6 m in depth (3 m in decomposed granite and 3 m in granite bedrock). The upper 4.5 m of the pile will be cased with 13 mm thick, 550-MPa steel having an outside diameter of 175 mm. The full length of the pile shall be grouted with a neat cement grout and shall be reinforced with one No. 44, Grade 410 threaded bar.

In 2004 FHWA used micropiles to rehabilitate an historic, dry-stacked stone masonry wall at Gibbons Falls in Yellowstone National Park in Wyoming. An approximately 8-m wide section of the south end of the wall lost its foundation support due to a shallow sliding failure. The bottom two rows of stone masonry collapsed. As a result the south end was overhanging and in immanent risk of failure. Drilling was done using high rotational speed (1000 rpm), and low down pressure to help maintain the 16 degree drill angle. During drilling the drill rod angle was checked at least every 1.5 m. The recovered core was examined for voids, soft zones or anything that could cause drill rod deviation. The wall face was watched for indications that drill rods were close to the surface, and for air/cuttings exiting through voids. Areas where air and cuttings were escaping were marked visually and with digital pictures. Drilling progressed without problems through the 8-m wall, through 3.5 m of soils, gravels and cobbles, and through

3 m of highly to moderately weathered rhyolitic tuff. Drill string was pulled and permanent casing inserted. A 25-mm threaded Williams bar with centralizers was the grouted inside the casing. The casing was pressure grouted at 3.5 MPa with a cement grout having an anticipated yield of 30 MPa.

FHWA and Micropiles in the Future

FHWA, through its training arm, the National Highway Institute, has recently completed the development of a two-day training course called "Micropile Design and Construction". The primary goal of this course is to provide the target audience with guidance on when and where it is appropriate to use micropiles, and with the state-of-the-practice in the design and construction of micropiles. Stepwise procedures for the design of micropiles for structural support and for slope stability applications are presented. Construction, inspection and integrity testing aspects and issues are discussed. Classroom presentations include exercises that will lead participants through the technical and cost feasibility evaluation aspects for structural support and slope stability design with micropiles. Each participant will receive a participant workbook and micropile reference manual containing detailed micropile design examples for various applications. As part of the development of this training course, the 2000 Micropile Implementation Manual was revised to reflect current technology and to include a chapter on Design of Micropiles for Slope Stabilization. FHWA has also supported research efforts through its research branch at Turner-Fairbanks where recently completed research efforts in this area are being expanded to investigate use in seismic retrofit situations and for slope stabilization purposes. According to a survey, the popularity of micropiles is increasing, with more proprietary systems being developed for both foundations and earth retention. In addition, three recent failures of micropile systems on design-build projects have caused concern among the FHWA engineers, their partners, and customers about current design practice. Both vertical (compression and tension) and lateral resistance (structurally and geotechnically) of micropile systems have been investigated.

FHWA has plans to use micropiles on several projects for bridge pier and abutment foundations, slope retention, and retaining wall foundations. In addition, FHWA has worked with several State Departments of Transportation in their implementation of micropiles for bridge foundations, slope stabilization and seismic retrofit.

Conclusion

After 30 years of micropile research, training and implementation, many State DOTs still consider micropiles an emerging technology. Through efforts by FHWA such as the new NHI micropile training course and manual, and activities by the International Society for Micropiles, micropiles are beginning to be perceived not an experimental or emerging technology, but as a mainstream practice and part of our regular bag of tools we use to address geotechnical challenges in transportation engineering.

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