

## Integration of Optimum, High Voltage Transmission Line Foundations

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**Published By:** American Society of Civil Engineers (ASCE)

**Date:** February 17, 2009

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## Abstract

High voltage electric power transmission lines span various regions and geology, and with these variations in venue and subsurface conditions, comes the need for efficient foundation designs to control construction costs. In most locations conventional deep foundations prove to be economical for design and construction, and thus an optimum foundation system. In some locations, however, site conditions make conventional foundations too expensive or impractical, and micropile foundations become the prime solution.

Micropiles are often thought of as an emerging technology, even though they were conceived over 50 years ago and have been used in the United States for more than 30 years. The electric power transmission industry has recently discovered this "emerging technology" and is beginning to take advantage of it. As the need to transfer electricity from more remote locations continues to expand, the use of micropile foundations will become more common as a practical solution for the challenges encountered.

This paper will introduce and illustrate the basic advantages and disadvantages of both conventional and micropile foundations in this industry and how they are being integrated to provide design solutions. A brief history of the introduction of micropiles into this industry will also be discussed.

## Introduction

The paths of transmission lines include varying geographies: varying in terrain, subsurface conditions, environmental sensitivity, and accessibility. Approximately one third of the cost of each transmission tower/structure is beneath the ground surface and is never seen. The value of these foundations is of tremendous importance because remediation of a failed structure foundation incurs far greater cost than any other type of single-structure failure. Conventional deep foundations, which are cast-in-place drilled piers, are still the most economical solution for many structures, but when certain obstacles are encountered, micropile foundations become the most economical solution. These high costs, high values, and different foundation options elicit a closer look at this invisible portion of the structure.

## Obstacles

Efficient foundation design and construction are the major topics that will be discussed in this paper. One key to efficient design of proper foundations is the acquisition of accurate and adequate geotechnical and geological information of the tower sites, as this information greatly influences the foundation design requirements for each tower. An accurate geological survey requires quality survey data and supporting geotechnical information. A proper geotechnical investigation requires, among many things, access to critical locations on the site with small investigatory drills and associated equipment. Gaining such access is often an obstacle that can be very difficult and involve much more than will be discussed in this paper. It should be noted, however, that such access and permitting challenges will be similar or more stringent in the construction phase of the project, and the foundation design team should be aware of such obstacles.

Building transmission lines in remote areas brings about many constructability issues. Limited access can cause problems with getting equipment and material to the sites, which can increase time and cost. Some areas can be restricted such that no vehicular traffic is allowed to the structure sites at all. This can result in the need for hand digging foundations and/or blasting with explosives. This is where safety concerns increase tremendously in traditional construction techniques. Traditional foundations for deadend structures can extend to depths of 20 to 30 feet below grade. This introduces many safety concerns for hand-dug foundations. A typical 500-kV single circuit deadend structure can require up to 15 yards of concrete per leg. This requires approximately 60 helicopter trips with a single-yard concrete bucket. Clearly, this is both lengthy and expensive.

## Investigation

Geological and geotechnical investigation programs involve the study of the local terrain for stability and drainage, insitu tests such as standard penetration tests (SPTs), collection of disturbed and undisturbed soil samples, and pertinent laboratory tests. Foundation design parameters are then estimated from the collected test data. The types of foundations chosen

depend upon these geologic and geotechnical conditions identified, the tower loading, and various other factors, such as access constraints and environmental restrictions.

A limitation of typical geotechnical investigation programs is the number of locations that can be practically and economically explored during the design phase of the project. Typically, geotechnical borings are obtained at deadend locations and at least one per mile. This seems to be a commonly accepted practice, but leads to interpretation and conservatism in geotechnical properties to account for possible variations between boring locations.

After proper geological and geotechnical investigation programs have been performed and the respective reports and associated recommendations have been conveyed to the foundation designer, the final foundation design process begins. The final design considers the many different requirements and limitations, and finally produces foundations that satisfy all such controlling factors.

## Conventional Foundations

The design of conventional foundations (also called traditional foundations) often involves drilled-shaft-type deep foundations of sufficient size to support the specified structure loading in the worst expected geologic and geotechnical conditions identified or suspected in the geological and/or geotechnical reports and recommendations. These types of foundations are referred to as "conventional" (or "traditional") foundations for good reason: they have been effectively used for transmission structure foundations for the last century, and will continue to do so. Where both access is reasonable and subsurface conditions are favorable, conventional deep foundations are the optimum choice. An excepted limitation of a traditional foundation is that the loads supported by the foundation are usually too large to economically perform insitu testing to verify adequacy of the design. This causes additional factors of safety to be applied to the design to insure an adequate foundation. It also impedes the ability to streamline the design if soil conditions are better than expected.

## Introduction To Micropiles

Before discussing the benefits of micropile transmission structure foundations, the following is a brief introduction to micropile technology, which is still not well-understood by many and thus continues to be labeled as an "emerging technology."

Micropiles were conceived in Italy in the early 1950's, by Dr. Fernando Lizzi (Armour, T., et al., 2000). They were introduced into the eastern United States nearly 20 years later and have continued to grow in applicability and versatility for the last 30 years. A micropile is a small (about 4- to 12-inch-diameter) replacement pile - drill (weighing 15- to 40-thousand pounds) and can be installed in virtually any geotechnical condition, from soft silts and clays to hard, igneous bedrock. During the drilling, the hole is stabilized (when necessary) using high grade steel tubing (casing), which is

often extended behind the drill bit to the bottom of the hole. The drill steel and bit are then completely withdrawn from the fully-cased hole, a string of continuously-threaded rebar is inserted which extends the full length of the hole, and the hole is then tremie-filled with neat cement grout. The casing is withdrawn, exposing a portion of the micropile grout to the soil (this portion is called the bond zone), and leaving a portion of the casing in place around the upper portion of the micropile for connections and flexural performance. Figure 1 is an illustration of a typical composite micropile.

A typical composite micropile consists of these three main elements: a single strand of continuously-threaded rebar (bar) that extends the full length of the micropile in the center of the micropile; a design-specified length of steel tubing (casing) around the circumference that extends from the top of the micropile to a critical depth (about half the length of the micropile in Figure 1); and neat cement grout, encasing the bar, and bonding the micropile components together and to the geotechnical strata. Other ancillary components of the micropile include items such as couplers, which connect segments of bar to form a continuous element, and pvc centralizers, which position the bar in the center of the drill hole. Typical sizes of bar (nominal diameters) range from 1 to 3 inches, and typical strengths of such bar are 75,000 to 120,000 psi, minimum yield. Typical sizes of casing (outer diameter by wall thickness) range from 5 inches by 0.375 inches to 8-5/8 inches by 0.500 inches, with minimum yield strengths ranging from 45,000 to over 100,000 psi. Typical neat cement grout is composed of two primary elements: Portland cement and water, with 28-day unconfined compressive strengths ranging from 3,000 psi to more than 5,000 psi.

A single typical micropile can exhibit a capacity ranging from as little as 25 kips up to and exceeding 500 kips. While the lateral capacity of a single micropile is understandably limited, groups of appropriately arranged micropiles can support tremendous loading - both axially and laterally. The size, length, and configuration of micropiles are designed to accommodate the magnitudes and proportions of the different loading (axial loading, base shear, and overturning moment) on a project- specific basis.

Micropiles are not inexpensive foundation elements, nor is their cost as volatile as that of traditional foundations when limitations are imposed on access and/or construction procedures. Such limitations highlight the clearest benefit that micropiles can provide. The construction techniques for micropile installation are refined and controlled enough to satisfy many environmental concerns and still retain flexibility to meet higher, project-specific construction demands or limitations.

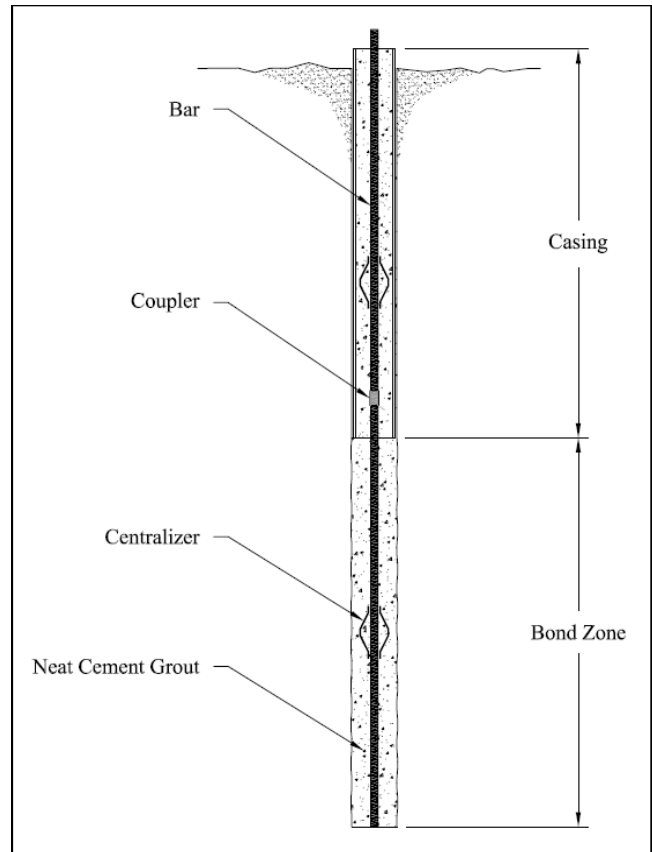


Figure 1: Typical Composite Micropile

## Micropile Foundations

When factors such as access constraints and environmental restrictions become substantial obstacles, the advantages micropile foundations have over all other deep foundations, which are mostly construction-related, have significant effects on schedule and cost.

Micropiles can be installed through virtually any subsurface condition, from soft sediments and clays to hard, competent rock. This may seem counterintuitive to many, but in harder and more competent rock, the penetration rate for micropile installation typically becomes noticeably faster than in granular soils or less competent rock formations. Different subsurface conditions pose different obstacles, which will be highlighted in a few case histories.

Drill rigs used for micropile installation are small and light-weight (typically 15- to 40-thousand pounds). Specialized rigs are modular and sometimes even smaller, so mobilization of these rigs to limited access locations with medium-lift helicopters has become standard practice.

When subsurface conditions vary from those expected, the installation procedures for micropiles are flexible enough and have become streamlined to accommodate such variance by modifying the lengths, number, and/or configuration of the micropiles at each site. Such modification is part of design contingencies outlined in

the construction documents in something called a decision tree or flow chart. With such a guidance tool, drill operators and inspectors have clear directives to follow in the event of such variant subsurface conditions.

Another unique quality of micropiles, because of their size and geometry, is their ability to be economically tested to validate their capacity. This ability reduces the need for additional conservatism and increased Factors of Safety - which are used to accommodate uncertainties in foundations that are not tested.

Health and safety are concerns in any type of construction, but the hazards present during micropile construction, while they do exist, are minor and are managed through regular, simple safety training protocols.

Other benefits of micropiles (which are not typically important in this industry) are the compact sizes of many micropile drills for use in restricted access and head space, as well as low noise and vibration emission.

Again, micropile foundations are not an inexpensive system, so they are not beneficial when a traditional foundation can be easily constructed, but the cost of micropile foundations do not escalate as rapidly as traditional foundations when various constraints and restrictions are imposed or adverse ground conditions are encountered.

### **Micropiles In This Industry**

The first micropile foundations for transmission structures in this industry involved triangular and rectangular micropile configurations with steel or concrete pile caps. The advent of radial micropile arrays has revealed numerous design and construction advantages. Radial-arrayed micropile configurations, installed with specialized equipment, can be completed with surprising accuracy and efficiency. In completely helicopter-supported site conditions, micropile foundation elements for all four legs of a 500-kV suspension tower have been installed in less than a day. In the same conditions, the same accomplishment for a 500-kV deadend tower has been achieved in under three days.

Both steel and concrete pile caps have been utilized for non-lattice structures. Concrete pile caps are currently the preferred choice for lattice towers, but advancements are continually being investigated and implemented for improved design and construction efficiency.

Even today, as constraints and restrictions grow and impede project advancement, micropile design and construction techniques continue to evolve to accommodate these increasing limitations. Some of these interesting evolutions and solutions will be illustrated in a few case histories.

The current state of practice for micropile foundations in the electric transmission industry is still developing as the industry leaders gain familiarity and comfort with this technology.

### **Integration Of The Different Foundations**

**Kangley-Echo Lake Transmission Line (500-kV).** One of the first major attempts to implement micropiles as lattice transmission tower foundations was in part of the Kangley-Echo Lake 500-kV transmission line that extends through a protected watershed east of Seattle, Washington (Mathieson, W.L., et al., 2004). At that time (15 years ago), micropile construction techniques and efficient environmentally sensitive practices were still advancing, and only one tower was constructed using micropiles on this project.

**Swan-Tyee Intertie (138-kV).** This 138-kV line connects the Four Dam Pool Power Agency's hydroelectric facilities at Swan Lake and Lake Tyee. This 57-mile segment of line includes more than 250 structure locations with more than 350 foundations, all of which are supported by micropile foundations with steel pile caps. These structures consist of guyed single-shaft structures, guyed and un-guyed Y-structures, guyed H-structures, guyed 3-pole structures, and guyed A-frame structures for major water crossings. Lateral structure loading was supported via battered foundation micropiles and guy wires. Figure 2 is an example of one of these micropile foundations. This was the first micropile transmission line foundation project of this size, and micropiles were chosen because of the remote, mountainous terrain of the structure sites. This project was completely helicopter-supported. Another major variable encountered from site-to-site was the subsurface condition, ranging from 3- blow-count silt to 25,000-psi rock. With a foundation construction schedule of directions to follow, dependent on structure type and subsurface conditions encountered, micropile foundations were the only feasible approach to complete this project within the narrow seasonal window available.



**Figure 2 - Swan-Tyee Intertie Micropile Foundation**

**Miguel to Mission Transmission Line (230-kV).** The construction of a new 230-kV transmission line on single-shaft self-supporting structures was proposed to address current and

future overloads on existing 138-kV and 69-kV transmission lines. Several of these structures utilized micropile foundations, the construction of which satisfied various constraints, such as restricted access, environmental restrictions, and strict noise control requested by the community, which could not be efficiently satisfied with conventional foundations. Micropile foundations (with steel caps and concrete caps) were the solution. Figures 3 and 4 are photos of two such pile caps.



Figure 3 - Miguel to Mission Micropile Foundation with Steel Cap



Figure 4 - Miguel to Mission Micropile Foundation with Concrete Cap

**Ebey Slough (230-kV).** The rebuild of this 2.5-mile section of transmission line consisted of the replacement of 80 old wood poles with 15 new steel, single-shaft, self-supporting structures, carrying two 230-kV circuits. Of these 15 structures, the foundation construction for 10 was possible only with micropiles. These 10 structures are located in a sensitive estuary, having strict environmental restrictions, and silty, organic geotechnical material that simply could not support more than about 500 psf on the surface. Blow counts (N-values) for the first 50 to 75 feet of this material were between about 0 and 5 blows per foot. Directly beneath this material was the bearing unit of dense granular material. Because of these rare subsurface conditions, micropile lengths ranged from

70 to 120 feet. Special transportation vehicles, drilling equipment, and construction techniques were utilized to accommodate these unique challenges. High-capacity marsh buggies were assembled and used for transporting equipment, material, and crews to the structure sites; unique construction platforms were designed, assembled, and placed; and modular drill rigs were customized to drill these micropile foundations in a controlled, precise, and efficient manner. The suspension structures required 10 to 16 micropiles per structure, with a 9- to 10-foot-diameter concrete cap, and the one deadend structure in this section required 36 micropiles with an 18-foot-diameter concrete cap. This deadend foundation was designed to support a 15,000-kip-foot moment, and to exhibit less than three degrees of rotation. Figure 5 is a photo of this deadend foundation.



Figure 5 - Ebey Slough Micropile Deadend Foundation

**Tehachapi Renewable Transmission Project (TRTP) (500-kV).** This line is designed to carry 500-kV single-circuit bundled 2156 kcmil "Bluebird" conductor. The first 14 miles of Segment 1, Section 2 of this line traverses the Angeles National Forest, in which no new road construction was permitted. Most of the tower sites were, therefore, accessible only by helicopter. This portion of the section consisted of 60 lattice towers, 4 towers of which were accessible by existing road, and are supported by drilled shafts; the remaining 56 towers were accessible only by helicopter, and are supported by micropile foundations. The pile caps for these micropile foundations are of reinforced concrete, which accept the standard drilled-shaft stub angles. Construction techniques were understandably restricted, and a major influence on construction schedule was weather. Workable days were controlled by temperature, humidity, and wind, and their impact on assessed fire danger. The efficiency of micropile installation was unexpected by those new to micropile technology, and the short schedule was maintained. These footings consisted of between 3 and 8 micropiles, in a radial array ranging from 3 to 4 feet in diameter, all battered at 10 degrees out from the center of the array. Tangent towers had footings with as few as 3 micropiles each, and deadend towers had footings with as many as 8

micropiles each. Reinforced concrete pile caps for these footings ranged in diameter from 4.5 to 6.5 feet, and cap heights were between 4 and 6 feet. Figure 6 is a typical micropile suspension tower footing on this project.



**Figure 6 - TRTP Micropile Suspension Tower Leg Foundation**

### **Conclusion**

In this industry, traditional foundations are practical, trusted, and often the most economical choice for transmission structures; however, when varying obstacles and restrictions present themselves, threatening budget and schedule, micropile foundations can provide solutions that are being realized by the industry.

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