

IEEE Guide to Installation of Foundations for Transmission Line Structures

IEEE Power & Energy Society

Sponsored by the
Transmission and Distribution Committee

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IEEE Guide to Installation of Foundations for Transmission Line Structures

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IEEE Power & Energy Society**

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Abstract: Various approaches to good construction practices that could improve the installation of transmission line structure foundations are presented. Spread foundations, drilled shaft foundations, pile foundations, and anchors are treated. This guide is intended to be used as a reference source for those involved in the ownership, design, and construction of transmission structures.

Keywords: anchor, foundation, pile, transmission line structure

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Introduction

This introduction is not part of IEEE Std 977-2010, IEEE Guide to Installation of Foundations for Transmission Line Structures.

This guide is one of several documents, covering all aspects of overhead transmission line construction, that are being prepared by the Working Group on Construction of Overhead Lines of the Towers, Poles, and Conductors Subcommittee of the Transmission and Distribution Committee of the IEEE Power & Energy Society. This guide presents, in one document, the considerations necessary for the installation of foundations for transmission line structures. This guide is intended to be used as a reference source for parties involved in the ownership, design, and construction of transmission lines.

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1. Overview

1.1 Scope

This guide presents various approaches to good practice that could improve the installation of transmission line structure foundations. This guide covers only the construction aspects of the installation of the foundations.

1.2 Purpose

The purpose of this guide is to present, in one document, the construction considerations necessary for the installation of transmission line structure foundations.

1.3 Application

This guide is intended to be used as a reference source for parties involved in the ownership, design, and construction of transmission structures. Since installation methods will be influenced strongly by the nature of each project, various methods that have been employed successfully are presented.

If any of the recommendations contained within this guide are to be adopted, they should be stated specifically in the owner's design and construction specifications. Any legal requirements of national, state, provincial, or local regulations must, of course, be observed.

1.4 Legal disclaimer

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2. General considerations

2.1 Introduction

Transmission lines are linearized engineering systems that are composed primarily of the following three components:

- a) Overhead lines, including the conductors, overhead ground wires, insulators, hardware, etc.
- b) Structures that support the overhead lines at discrete points
- c) In situ soil and/or rock that supports each structure through a foundation

Considerable interaction occurs among these three components during the planning, analysis, and design of a transmission line. This process is necessary to optimize the design and result in an efficient and economical system.

In recent years, a number of useful documents have been published that address overall line planning and design (see RUS Bulletin [B41]]¹ and *Transmission Line Design Manual* [B45]), loadings (EPRI EL-0643 [B15], *Guidelines for Transmission Line Structural Loading* [B25], and Loading and Strength of Transmission Line Systems, Parts 1 through 6 [B31]), structural design (*Design of Steel Transmission Pole Structures* [B13], *Guide for the Design of Aluminum Transmission Towers* [B23], *Guide for the Design of Steel Transmission Towers* [B24], and Rodgers, Anderson, and Chang [B39]), and foundation analysis and design (EPRI EL-2197 [B16], EPRI EL-2870 [B17], and EPRI EL-3771 [B18]). This document records construction practices for the installation of foundations of electrical transmission line structures. In the remainder of Clause 2, the overall problem is introduced, and general items are discussed that are pertinent to all foundation types. Much of this clause is extracted from EPRI EL-2870 [B17]. Clause 3 through

¹The numbers in brackets, when preceded by the letter B, correspond to those in the bibliography in Annex A.

Clause 6 address the specific issues involved for each major foundation type used for transmission line structures.

2.2 Structure functions and types

2.2.1 Structure functions

From a functional standpoint, there are three primary categories of transmission line structures as follows:

- a) Suspension
- b) Strain
- c) Dead-end

The differentiation between these categories is made principally on structure function in the line, the line angle at the structure, and the insulator configuration.

2.2.1.1 Suspension structures

Suspension structures are used in line sections between strain or dead-end structures. The conductors are supported by suspended insulator assemblies that permit the equalization of conductor tensions in the longitudinal direction. The line angles for these structures are typically light to perhaps medium. Normally, these structures are the lightest, least expensive, and most common in a line.

2.2.1.2 Strain structures

In a strain structure, the conductors are terminated and attached on both sides of the structure by a dead-end or strain assembly, where the insulators are in mechanical series with the conductors and therefore must carry the total conductor tensions. These structures are commonly designed to be loaded on two sides, except for the temporary, one-sided loading during construction. These structures normally are used for medium or heavy line angle positions, where wind span to weight span ratios are excessive, or to separate line segments.

2.2.1.3 Dead-end structures

A dead-end structure is used most commonly at a line termination, where the conductors are terminated and attached on one side only. These structures are designed for loading on one side. Therefore, they are often the heaviest, most expensive, and least common structures in a line.

2.2.2 Structure types

Transmission line structures also can be grouped on the basis of structure type in the following manner:

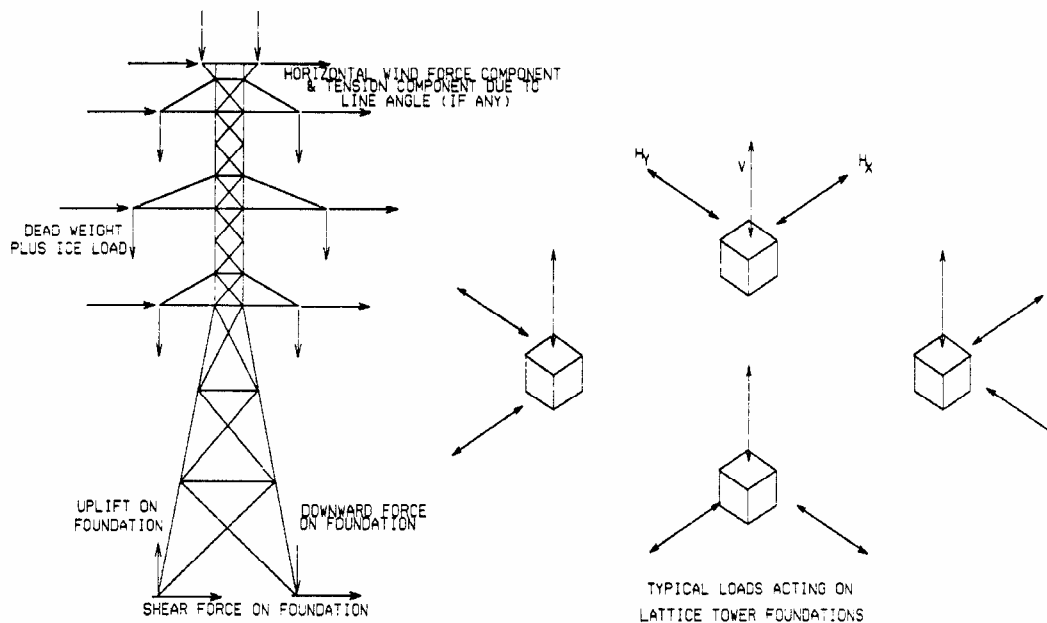
- a) Self-supporting lattice towers
- b) Single poles
- c) Frames

d) Guyed structures

This grouping is convenient because it also differentiates the structures in terms of foundation loading mode.

2.2.2.1 Self-supporting lattice towers

Lattice towers (Figure 1) essentially are four-legged pinned structures. Thus, the foundation loads consist of vertical uplift or compression and horizontal shear.



LATTICE TOWER (FOUR LEGGED) STRUCTURES

Figure 1—Lattice tower structure and foundation loads

2.2.2.2 Single poles

Single shaft or pole structures (Figure 2) are single element systems, below the cross-arm level, that have one foundation to be designed for vertical and horizontal loads and for large overturning and torsional moments.

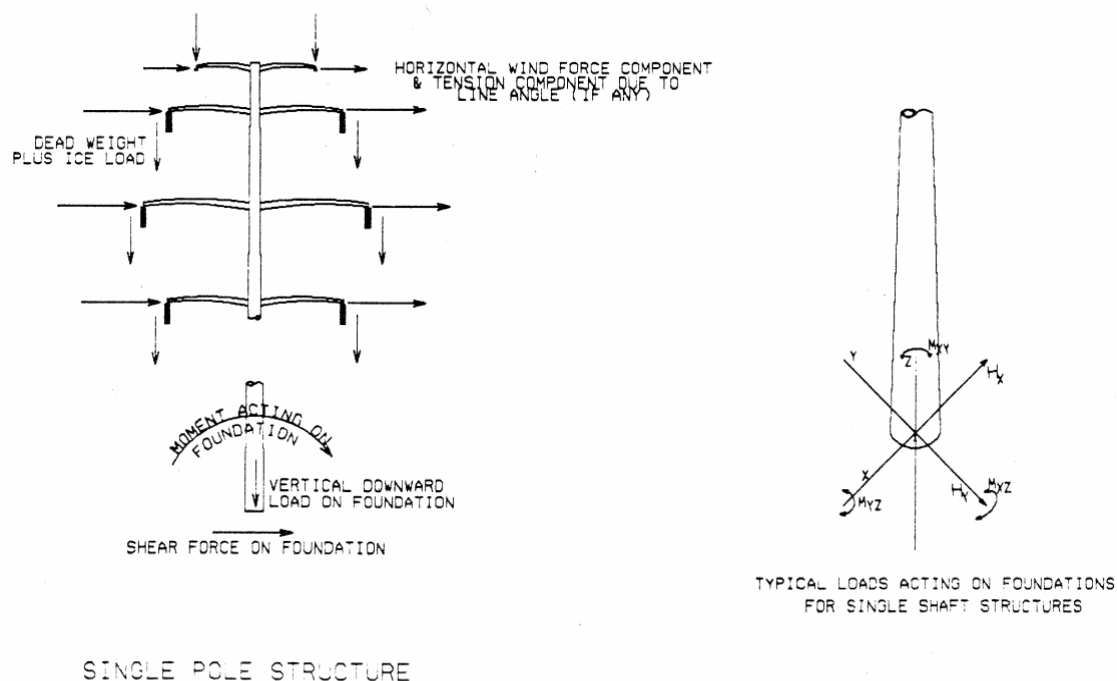


Figure 2—Single pole structure and foundation loads

2.2.2.3 Frames

Framed structures (Figure 3) derive their stability, in part, from the moment-resisting capabilities of one or more joints. The foundations must be designed for vertical and horizontal loads, in addition to overturning moments. However, one or more foundation connections may be pinned to eliminate the transverse moments.

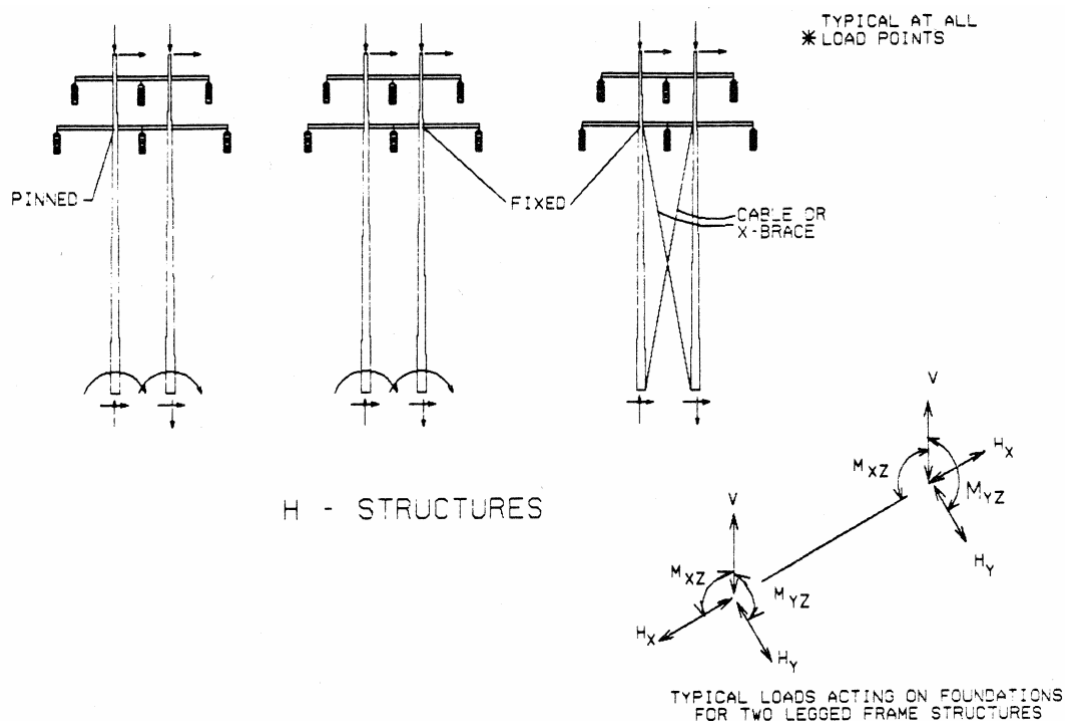


Figure 3—Framed structures and foundation loads

2.2.2.4 Guyed structures

Guyed structures (Figure 4) derive their stability from tensioned guy wires supporting one or more rigid structural shafts. The shaft foundation connection can be pinned, so that the foundation is designed for vertical compression and horizontal loads only. The guy foundations are designed for axial tension.

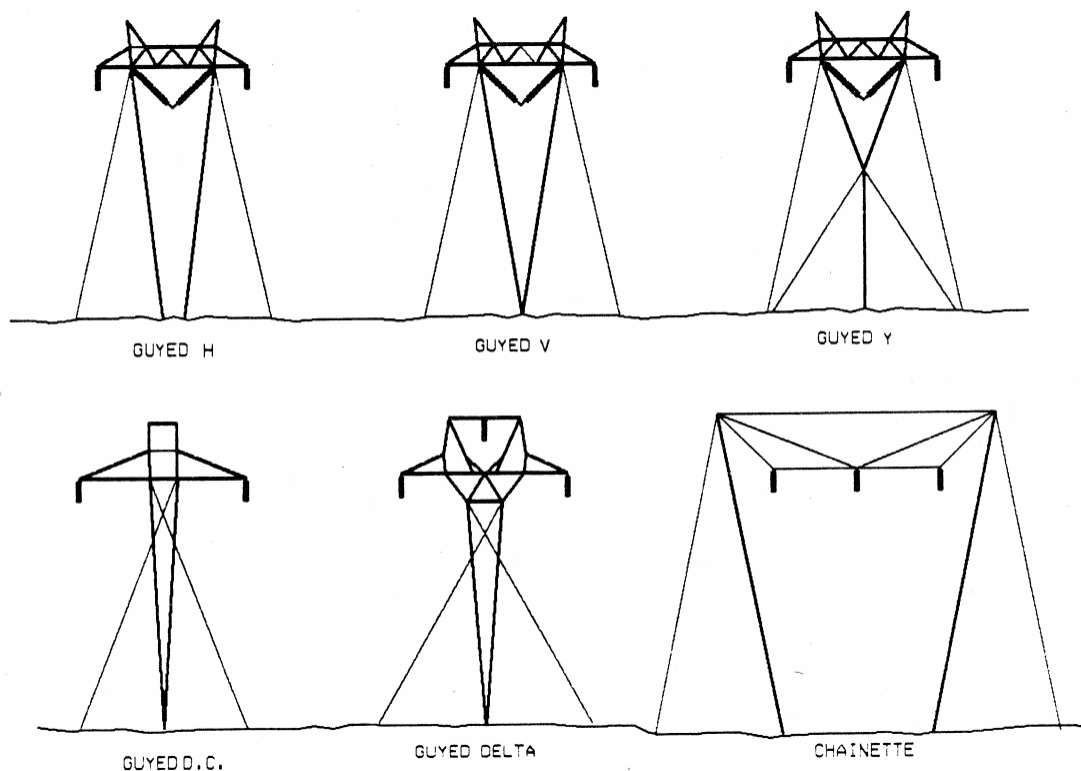


Figure 4—Guyed structures

2.3 Loading

The loads for which the foundations must be designed separate into four major categories. These categories are as follows:

- a) Steady-state loads that act for long periods of time, resulting from dead weight, guy pre-tension, differential conductor tensions, line angles, uplift, and steady wind loads.
- b) Transient loads that act for short periods of time, such as wind loads, unbalanced loads from ice shedding, etc.
- c) Construction loads imposed during structure erection and line installation.
- d) Temporary loads imposed during line maintenance.

Considerable care and engineering judgment must be exercised during the design process when these loads are applied to the structures and foundations. With the typically large number of loading cases and line angles to consider, different combinations may control the design for different structures or foundations.

2.4 Foundation types and functions

The foundation is the transition between the transmission line structure and the in situ soil or rock, and it has to be designed for a variety of loadings, on the basis of site-specific characteristics. These site-specific characteristics often are difficult to define.

Many factors have to be considered in designing a foundation that will perform satisfactorily. These factors include the following:

- a) Geologic environment, which describes the subsurface conditions and locally available materials
- b) Loading characteristics, including the loading types and directions, as well as the magnitude, rate, duration, and frequency of loading
- c) Foundation characteristics, including the size, shape, and weight
- d) Foundation response to load, or how the load is transferred to the soil or rock in side resistance, tip resistance, etc.
- e) Soil or rock response to loads, which is a direct function of their strength and deformation properties for the loading type imposed
- f) Construction procedure, which ultimately may control the foundation system performance

2.4.1 Foundation types

In response to the many variables involved, a number of foundation types have evolved. These can be categorized into the following five groups:

- a) Spread foundations
- b) Drilled shafts
- c) Direct embedment
- d) Piles
- e) Anchors

Most of these foundation types are versatile, and thus can be used for several different loading conditions. Economics, geology, load magnitude, structure type, and construction ease generally dictate the final selection of foundation type. Each type is described briefly in 2.4.1.1 through 2.4.1.5.

2.4.1.1 Spread foundations

A spread foundation has large rectangular plan dimensions. It is placed in a shallow excavation and then is backfilled. The two main variations are concrete and prefabricated-steel foundations. One foundation commonly is used for each structure leg.

2.4.1.2 Drilled shafts

Drilled shafts are constructed by augering a cylindrical hole into the ground, placing reinforcing steel, and backfilling the hole with concrete. A single shaft normally constitutes the foundation for a structure leg.

2.4.1.3 Direct embedment

With single and H-frame pole-type structures, especially the smaller ones, the pole may be directly embedded to serve as the foundation. A hole is excavated, the pole is placed, and then the annulus around the pole is backfilled with various materials.

2.4.1.4 piles

Piles are long, slender, structural elements of steel, concrete, or wood that are installed into the soil by mechanical means, such as driving or vibrating. When two or more piles are installed to create a closely-spaced group, they are commonly integrated structurally, through a pile cap, to form a single foundation.

2.4.1.5 Anchors

Anchors are long, slender, structural members that are installed in soil or rock. Plate anchors consist of long rods with bearing surfaces at various levels that are placed in excavated holes and backfilled. Helical anchors effectively are augers that are screwed directly into the soil. Grouted anchors are long rods that are placed in excavated holes and grouted to fill the annulus. Anchors may be installed in a group and tied together through a cap to form a foundation. Many variations, however, are employed for specific situations.

2.5 Geotechnical factors in construction

Geotechnical factors influence both the foundation design process and the method of foundation construction. The main variables involved are the basic site geology, soil and/or rock types and physical properties, ground water conditions, and in situ state of stress in the ground.

The geotechnical issues must be kept in mind during exploration, analysis, design, and construction. If disregarded, the foundation performance capabilities will be affected.

2.5.1 Rock factors

Setting the design issues aside, geotechnical factors also can control the foundation construction process. Consider first the important question of whether “rock” is within the anticipated foundation depth. If it is not, then only soil factors remain. However, if rock is encountered, then the following questions must be answered:

- a) Where is the sound, unweathered bedrock?
- b) What is the bedrock profile under each structure?
- c) What is the depth of weathering in the bedrock?
- d) Is the bedrock cavernous or void-filled?
- e) Are there detached rock ledges or shelves?
- f) Are there boulders or similar materials above the bedrock surface?

These rock questions have obvious implications in the selection of foundation types, the choice of excavation equipment and/or drilling tools, the possible need for hand excavation, the development of rock anchorages, and the development of rock-concrete bond.

2.5.2 Soil factors

Once the rock factors are resolved, the soil factors are addressed. For a spread foundation or anchor, the main geotechnical concerns are whether a backhoe excavation can be made readily and where the ground water is located, because these foundation systems are not constructed easily below the water table. For driven piles, the soil stiffness is needed to develop pile-driving criteria. It is also important to know of any obstructions to installation by driving, such as boulders, rock ledges, etc. For drilled shafts, direct embedment poles, and grouted anchors, it is important to know whether a hole can be excavated using conventional drilling equipment or whether it must be excavated by alternate means, whether obstructions or “running” soil layers are to be encountered in the hole, and where the ground water table is located. For helical anchors, the questions again are whether the anchor can be augered into the soil without difficulty, or whether boulders or other obstructions will be encountered.

2.5.3 In situ state of stress in the ground

The last geotechnical factor to consider is the in situ horizontal state of stress in the ground. If it is high, greater than the vertical stress, then there will be a tendency to close, to some degree, any excavation made. This phenomenon often is called “loss-of-ground.” This inward movement must be minimized for two very important reasons. First, construction difficulties are minimized when the “as-built” hole size is maintained; otherwise, the hole may have to be redrilled. Second, the horizontal stress controls the foundation side resistance. If it is allowed to relax, the side resistance, and therefore overall foundation capacity, will be reduced.

2.6 Construction influences on foundation performance

The construction practices employed during foundation installation can influence the performance of the foundation in a very significant manner. In general, progressively “poorer” practices result in progressively lower capacities and higher displacements of the foundations. However, these practices can be controlled by the engineer. In fact, foundation performance can be improved by controlling the construction variables through a comprehensive construction specification and construction quality surveillance.

2.6.1 Excavation

For any type of foundation system requiring an excavation, two important rules should be followed. First, support any excavation that is questionable and, second, always minimize the amount of time that any excavation is left open. If these rules are not followed, soil degradation will occur and, in the extreme, the foundation capacities can be reduced by a third or more (EPRI EL-3771 [B18]).

2.6.2 Backfill

When either soil, concrete, or grout backfill is used, two simple rules should be followed to improve foundation performance. For the concrete or grout, the use of non-shrink or expanding cements should be considered, as compared with conventional cements that shrink, when the side resistance capacity dominates the foundation design. Side capacity increases of a third or more can result from the simple change from conventional to expanding cements. In a similar manner, any soil backfill should be well-compacted to develop a good foundation system. Uplift capacity increases of more than 100% are readily achievable by well-compacted backfill, in contrast with just “dumping” it into the excavation (EPRI EL-3771 [B18]). Dumping should never be allowed.

2.6.3 Adverse construction influences

The following comments are of use in minimizing particular adverse construction influences. First, when patented systems are being used, every reasonable effort should be made to follow the manufacturer's recommendations. The manufacturer has, by far, the most experience with the system involved and should have developed an optimal installation procedure that maximizes capacity and minimizes displacements. Second, when piles are to be driven, reasonable hammer and driving criteria should be developed during design, not construction. Different hammers and different driving criteria will result in different capacities. These need to be specified, within reasonable limits, for a proper design. Third, when it is necessary to minimize the displacements of anchor foundations, pre-stressing should be considered.

2.6.4 Human factors

The last issue to consider, which probably is the most important of all, is the human issue that establishes the job attitude and, therefore, the quality of the final product. This issue applies equally to the owner, the design engineer, and the contractor. It consists of three parts: competence, cooperation, and communication. If these three C's are maintained and followed through an entire project, there should be no major foundation “surprises.” However, if one or more of the three C's is ignored, problems may occur.

2.7 Applicable codes and standards

Numerous codes and standards are applicable to transmission line structures. Perhaps the best known is the National Electrical Safety Code® (NESC)®,² which contains safety rules for the design, installation, and maintenance of transmission line systems. Some states have similar safety codes. Contained within these codes are minimum specified loading conditions for wind, ice, and construction loads. However, foundation construction is rarely addressed in these documents.

² The NESC is available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

The following lists, generically, the most applicable codes and standards for the foundations of transmission line structures:

- a) Steel design—American Institute of Steel Construction (AISC) Code
- b) Concrete design—American Concrete Institute (ACI) Code
- c) IEEE Guide for Transmission Structure Foundation Design and Testing—IEEE and ASCE
- d) Material performance and installation—American Society for Testing and Materials (ASTM) Standards
- e) Foundation design criteria—American Society of Civil Engineers (ASCE) standards for driven piles and drilled shafts that are being developed, plus manufacturer's guidelines
- f) Installation criteria—Association of Drilled Shaft Contractors (ADSC) guidelines, manufacturer's guidelines, owner guidelines
- g) Safety practices—Occupational Safety and Health Administration (OSHA) rules, plus those associated with item a) through item e) above

Finally, it must be remembered that the periodic issue of these codes, standards, guidelines, etc. reflects advances in the state-of-the-art, as well as accumulated experiences. Therefore, they should all be considered as recommended criteria that must be adapted to the necessary local conditions and experiences.

3. Spread foundations

3.1 Introduction

This clause reviews the various types of spread foundations that are used commonly for electrical transmission line structures and the basic procedures to install these foundations. The following will not describe the construction procedures in detail, but will only review each step and some of the factors that must be addressed in the construction of this type of foundation.

3.2 Types of spread foundations

Spread foundations, shown in Figure 5, typically consist of a buried rectangular or square pad with a “leg-stub” or “stub angle” column connecting the foundation to the tower body. The typical foundation depth-to-width ratio is between 1 and 3, with the maximum depth often limited to 4.5–6 m (14–20 ft) because of construction equipment limitations. The foundation usually is set horizontally, with a leg-stub battered to the same slope as the tower legs. Steel or concrete, or a combination of both, usually are used for the foundation. On cast-in-place concrete pad and pier spread foundations, a concrete pier or column is used instead of a stub angle.

The basic types of spread foundations are as follows:

- a) Steel foundations
 - 1) Pressed plate (single or multiple)
 - 2) Grillage
- b) Concrete foundations
 - 1) Cast-in-place
 - 2) Precast
- c) Concrete encased grillage

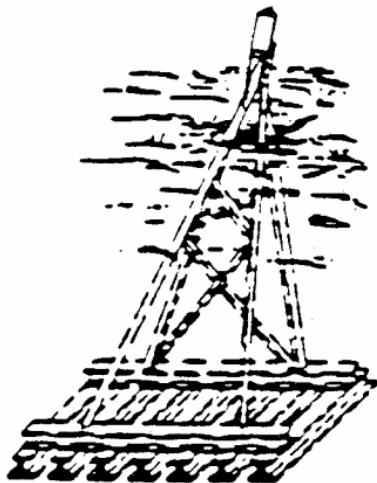
The connection between the spread foundation and the leg stub is, most often, a bolted connection. Most steel foundation connections can be assembled simply and bolted together. Concrete foundations may have anchor bolts embedded in the concrete and a base plate or base shoe connection tying the leg stub to the foundation. Leveling nuts and base plate/base shoe leveling grout often are necessary with this connection detail.



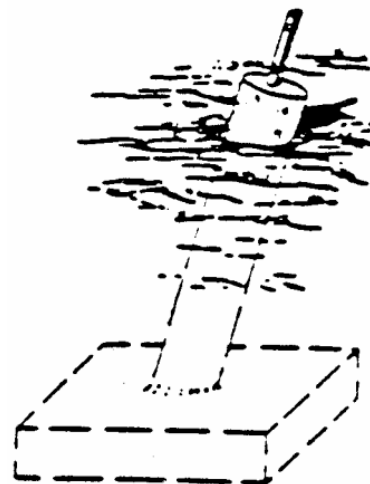
a)—Single Pressed Plate



b)—Double Pressed Plate



c)—Grillage type



d)—Pad and Pier type

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Figure 5—Types of spread foundations

3.3 Site plan outline

A site plan, or a tower site construction layout plan, can serve as a basis for an informal discussion between the contractor and the owner, or it may be the basis for a formal signed document on how the foundations will be installed at a given site. The three basic parts of this outline would be as follows:

- a) Tower site information
- b) Tower foundation construction survey
- c) Foundation site information

3.3.1 Tower site information

The tower site information would include all the limitations and restrictions on the mobilization, operation, and demobilization of the equipment required to install a spread foundation. Some of the factors that would need to be addressed would be as follows:

- a) Restrictions on points of entry to tower site
- b) Equipment limitations on site
- c) Underground and overhead utilities
- d) Existing structures on site
- e) Clearing restrictions
- f) Presence of surface water
- g) Environmental restrictions

3.3.2 Tower foundation construction survey

The tower foundation construction survey establishes the foundation center hub, reference hubs, elevations, and required depth of excavation. Before excavation can begin, the tower foundations must be marked (staked), and the depth of excavation must be computed. Ground staking includes establishing a reference point (RP) hub to the pit center (PC) for each foundation. The elevation of the RP hub is established, and the depth of cut from this hub is computed. The hub will be used during excavation to control the depth of the excavation.

During the staking process, a PC stake and depth of cut at PC is established. The four corners of large excavations also should be staked. The dimensions used to establish these corners are the dimensions of the grillage or pressed plate foundation to be set, plus 300 mm (12 in) on all four sides. For cast in-place concrete foundations, where the concrete is placed against native material, the corner dimensions should match the foundation excavation dimensions.

3.3.3 Foundation site information

Foundation site information would include the following:

- a) Access to foundation sites
- b) Foundation assembly site
- c) Spoil pile management
- d) Erosion control measures

Access to the foundation sites, and the sequence of excavating each foundation, must be planned to avoid

undercutting other sites. This planning is especially critical for steep slopes or tower sites with limited working space. Access limitations may require that only one spread foundation at a time be excavated, assembled, set, and backfilled.

Many steel spread foundations, especially high-capacity grillage foundations, require a large level area to assemble the foundation prior to setting. This area needs to be planned for. Large excavations often are required for spread foundations, which require a spoil pile management plan. This excavated material usually is used for backfill. The organic topsoil and fines often need to be separated so that they can be replaced as top soil and be used adjacent to the foundation. On steep slopes, this spoil pile must be restrained from sliding down the slope. This spoil pile also must be protected from wind or water erosion. During heavy rains, the backfill material needs to be covered to control the moisture content, within allowable limits, to ensure proper compaction.

3.4 Excavation

The equipment and techniques that are used for excavation depend on the type of material encountered at the excavation site. When soil, loose or fractured rock, boulders, or any combinations thereof are encountered, the excavation usually is done with a track-mounted or rubber-tired backhoe. When the terrain is so steep that the backhoe equipment cannot be used for excavation, it may be necessary to incorporate the use of specialized digging machines that have the capability of maneuvering and excavating on hill-side slopes in excess of 45° . Another method is to use a drag line bucket and crane. Hand excavation also is used at difficult sites.

Drilling and blasting may be required whenever machine digging alone cannot proceed because of the hardness of the material being excavated. It is common to run into successive layers of soil and rock that cannot be removed with soil excavators alone. In such cases, drilling and blasting the rock will be necessary. A rock-drilling machine must be brought in to drill holes for blasting. Typically, such drilling would be to the full depth of the excavation in materials that are stable.

3.4.1 Drilling and blasting precautions

Inspection of the drilling and blasting activity should include monitoring to ensure that survey controls, such as tower center monuments, survey hubs, reference points, and benchmarks, are not distorted or lost. A distorted tower center monument could result in an incorrect setting. Precautions required during blasting should conform to applicable state and local codes and requirements.

All personnel on the site should be aware of blasting hazards and procedures and must be warned properly prior to the actual blasting. When constructing a new line parallel to an existing line, or near inhabited or environmentally sensitive areas, a “heave mat” should be placed over the blast area prior to blasting. This mat prevents or minimizes the danger of rocks, wood debris (when blasting to remove stumps), and/or lead-in wires being thrown into the conductors on the existing line, resulting in conductor damage or electrical outages, as well as other property damage. Parallel lines should be de-energized prior to blasting whenever possible. In no event should lead-in wires be allowed to be placed under energized conductors when blasting. Non-electrical and nonconventional electrical detonation methods are recommended near transmission lines. If conventional electrical detonation methods must be employed, there are specific precautions that can be practiced to minimize hazards to the blaster and transmission line.

If rock is encountered during hand excavations on steep hillsides, small portable compressors and jackhammers can be used to loosen the rock material. Excavated material can be removed from hand-dug excavations using a bucket and rope.