IEEE Std 977-1991

IEEE Guide to Installation of Foundations for Transmission Line Structures

IEEE Standards Board
Approved March 21, 1991

Sponsor
Transmission and Distribution Committee
of the
IEEE Power Engineering Society

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.

The Institute of Electrical and Electronics Engineers, Inc. 345 East 47th Street, New York, NY 10017-2394, USA

Library of Congress Cataloging in Publication Data will be found on the following page.

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Foreword

(This Foreword is not a part of IEEE Std 977-1991, 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 Engineering 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.

This guide was developed by a task force of the Working Group on Construction of Overhead Lines. At the time that this guide was approved, the task force had the following membership:

T. E. Rodgers, Jr., ***Chair***

D. E. Bobbitt
F. H. Kulhawy
R. C. Latham
R. R. Melcher
C. C. Perigo
W. O. Reeside

The balloting group that balloted and approved this guide for submission to the IEEE Standards Board had the following membership:

J. J. Burke
M. L. Charest
V. L. Chartier
A. G. Davidson
J. C. Engimann
L. H. Fink
I. S. Grant
G. Karady
H. Lam
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S. Nilsson
R. G. Oswald
R. L. Patterson
W. E. Reid
R. L. Retallack
F. A. M. Rizk
B. R. Shperling
J. M. Van Name

We wish to thank A. B. Chance for the use of the sketches and text from the A. B. Chance Encyclopedia of Anchoring and photos in Figs 6-4, 6-5, 6-9, 6-10, 6-11, and 6-12.

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IEEE Guide to Installation of Foundations for Transmission Line Structures

1. Introduction

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

The support data for this guide were collected from a great number of sources, and are believed to be reliable and true. Care has been taken during the compilation and writing to prevent error or misrepresentations. The authors make no warranty with respect to the accuracy, completeness, or usefulness of the information contained in this guide, nor assume any liabilities with respect to the applicability or use of any information, method, or process presented herein. The use of trade names is for the information and convenience of the user of this guide and does not constitute an endorsement by the authors.

2. General Considerations

2.1 Overview

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

1) Overhead lines, including the conductors, overhead ground wires, insulators, hardware, etc.
2) Structures that support the overhead lines at discrete points
3) 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 [B5][1] and [B12]), loadings ([B1], [B9], and [B10]), structural design ([B6], [B7], [B8], and [B11]), and foundation analysis and design ([B2], [B3], and [B4]). This document records construction practices for the installation of foundations of electrical transmission line structures. In the remainder of Section 2, the overall problem is introduced, and general items are discussed that are pertinent to all foundation types. Much of this section is extracted from EPRI EL-2870 [B3]. Sections 3 through 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:

1) Suspension
2) Strain
3) 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.

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[1] The numbers in brackets, when preceded by the letter B, correspond to those in the bibliography at the end of the section.

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:

1) Lattice towers
2) Single poles
3) Frames
4) Guyed structures

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

2.2.2.1 Lattice Towers

Lattice towers (Fig 2-1) essentially are four-legged pinned structures. Thus, the foundation loads consist of vertical uplift or compression and horizontal shear.

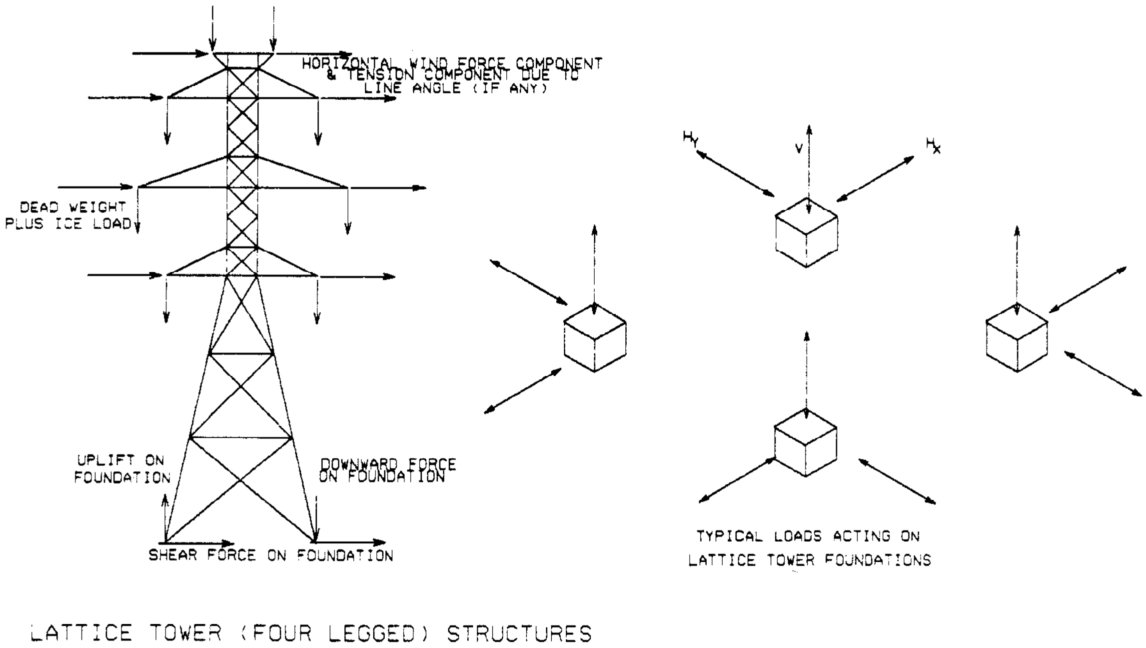
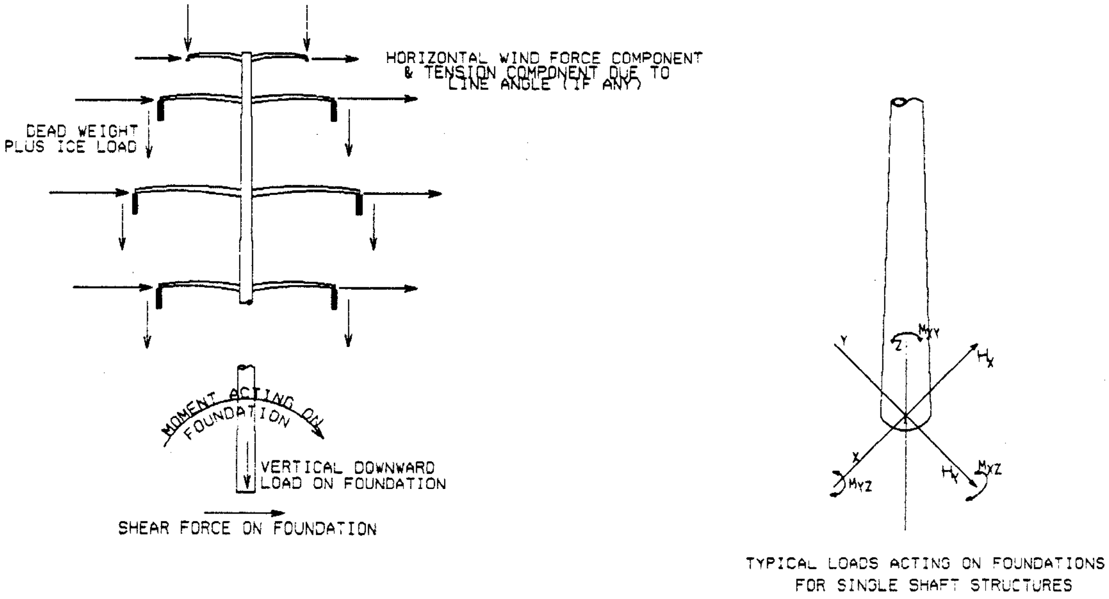


Figure 2-1 — Lattice Tower Structure and Foundation Loads

2.2.2.2 Single Poles

Single shaft or pole structures (Fig 2-2) 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.



TYPICAL LOADS ACTING ON FOUNDATIONS FOR SINGLE SHAFT STRUCTURES

SINGLE POLE STRUCTURE

Figure 2-2 — Single Pole Structure and Foundation Loads

2.2.2.3 Frames

Framed structures (Fig 2-3) 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. But, one or more foundation connections may be pinned to eliminate the transverse moments.

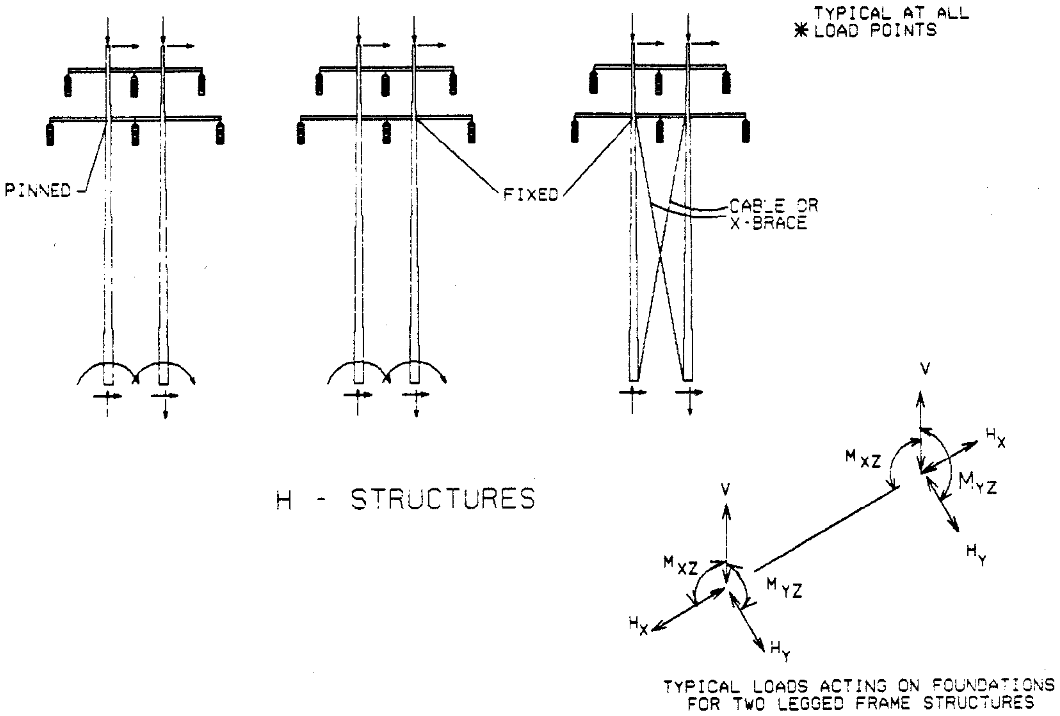


Figure 2-3 — Framed Structures and Foundation Loads

2.2.2.4 Guyed Structures

Guyed structures (Fig 2-4) 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.

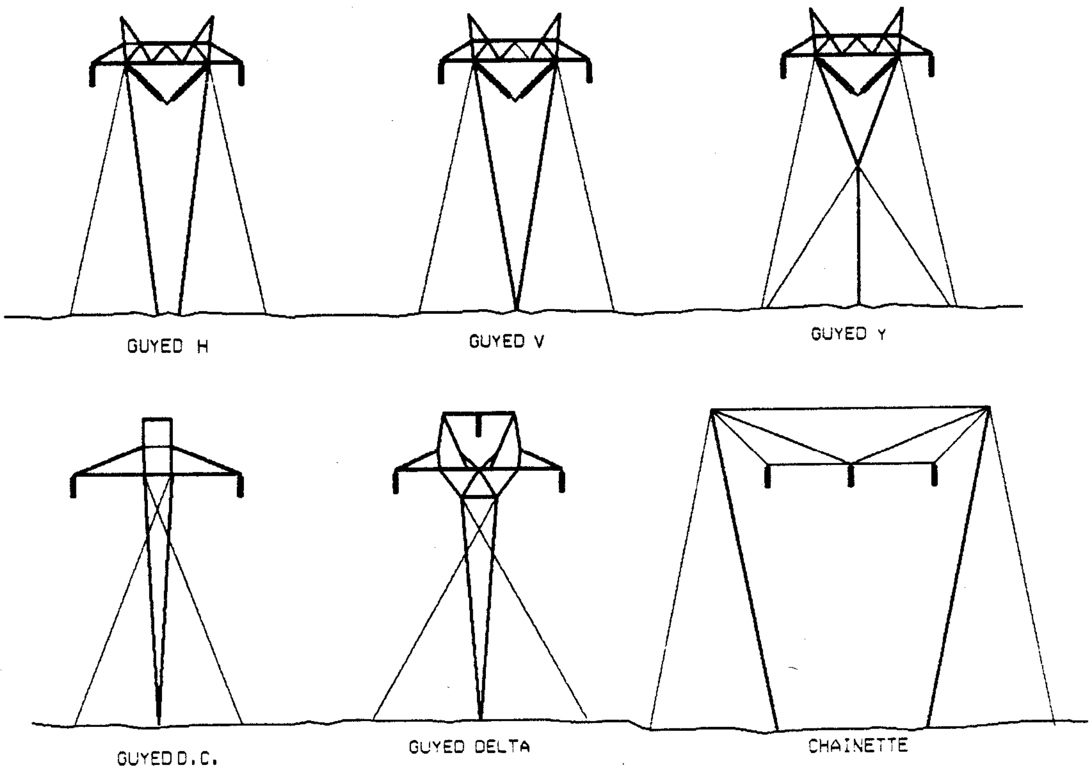


Figure 2-4 — Guyed Structures

2.3 Loading

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

1) Steady-state loads that act for long periods of time, resulting from dead weight, guy pretension, differential conductor tensions, and line angles
2) Transient loads that act for short periods of time, such as wind loads, unbalanced loads from ice shedding, etc.
3) Construction loads imposed during structure erection and line installation
4) 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

1) Geologic environment, which describes the subsurface conditions and locally available materials
2) Loading characteristics, including the loading types and directions, as well as the magnitude, rate, and frequency of loading
3) Foundation characteristics, including the size, shape, and weight
4) Foundation response to load, or how the load is transferred to the soil or rock in side resistance, tip resistance, etc.
5) Soil or rock response to loads, which is a direct function of their strength and deformation properties for the loading type imposed
6) 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 five groups:

1) Spread foundations
2) Drilled shafts
3) Direct embedment
4) Piles
5) 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 below.

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 Hock 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:

1) Where is the sound, unweathered bedrock?
2) What is the bedrock profile under each structure?
3) What is the depth of weathering in the bedrock?
4) Is the bedrock cavernous or void-filled?
5) Are there detached rock ledges or shelves?
6) 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 augered 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 [B4].

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 [B4]. 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), 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.

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

1) Steel design — American Institute of Steel Construction (AISC) Code
2) Concrete design — American Concrete Institute (ACI) Code
3) Material performance and installation — American Society for Testing and Materials (ASTM) Standards
4) Foundation design criteria — American Society of Civil Engineers (ASCE) standards for driven piles and drilled shafts that are being developed, plus manufacturer's guidelines
5) Installation criteria — Association of Drilled Shaft Contractors (ADSC) guidelines, manufacturer's guidelines, owner guidelines
6) Safety practices — Occupational Safety and Health Administration (OSHA) rules, plus those associated with (1) through (5) 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.

2.8 Bibliography

[B1] EPRI EL-0643, *Longitudinal Unbalanced Loads on Transmission Line Structures*, Aug. 1978, Mozer, J. D.

[B2] EPRI EL-2197, *Laterally Loaded Drilled Pier Research — Volume 1: Design Methodology*, Jan. 1982, Davidson, H. L.

[B3] EPRI EL-2870, *Transmission Line Structure Foundations for Uplift-Compression Loading*, Feb. 1983, Kulhawy, F. H., Trautmann, C. H., Beech, J. F., O'Rourke, T. D., McGuire, W., Wood, W. A., and Capano, C.

[B4] EPRI EL-3771, *Critical Evaluation of Design Methods for Foundations Under Axial Uplift and Compression Loading*, Nov. 1984, Stas, C. V. and Kulhawy, F. H.

[B5] REA Bulletin 62-1, Design Manual for High Voltage Transmission Lines, US Dept. of Agriculture, Aug. 1980.

[B6] *Design of Steel Transmission Pole Structures*, ASCE Manual No. 72, 2nd ed. Task Committee on Steel Transmission Poles Structures of the Structural Division of the American Society of Civil Engineers, 1990.

[B7] "Guide for the Design of Aluminum Transmission Towers," *Journal of the Structural Division*, ASCE, Vol. 98, No. ST12, Dec. 1972, pp. 2785–2801.

[B8] *Guide for the Design of Steel Transmission Towers*, 2nd ed., American Society of Civil Engineers Task Committee on Updating Manual 52, ASCE Manuals and Reports on Engineering Practice, No. 52.

[B9] *Guidelines for Transmission Line Structural Loading*, American Society of Civil Engineers Committee on Electrical Transmission Structures, 1990.

[B10] "Loading and Strength of Transmission Line Systems, Parts 1 through 6," Conference Papers A77 228-0, A77 229-8, A77 230-6, A77 2314, A77 232-2, A277 233-0, IEEE Power Engineering Society Winter Meeting, New York, NY, Jan.-Feb. 1977.

[B11] Rodgers, T. E., Jr., Anderson W. C., and Chang, D. R. "Guide for Design and Specification for Concrete Pole Structures," Transactions Paper T75-170-6, IEEE Power Engineering Society Winter Meeting, New York, NY, Jan. 1975, pp. 1248–1257.

[B12] *Transmission Line Design Manual*, Farr, H., US Dept. of the Interior, Denver, CO, 1980.

3. Spread Foundations

3.1 Introduction

This section 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 Figs 3-1 through 3-4, typically consist of a buried rectangular or square pad with a “leg-stub” or 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 15–20 ft (4.5–6 m) 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

1) Steel foundations
    a) Pressed plate (single or multiple)
    b) Grillage
2) Concrete foundations
    a) Cast-in-place
    b) Precast
3) 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.

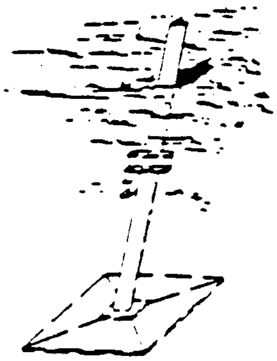


Figure 3-1 — Single Pressed Plate

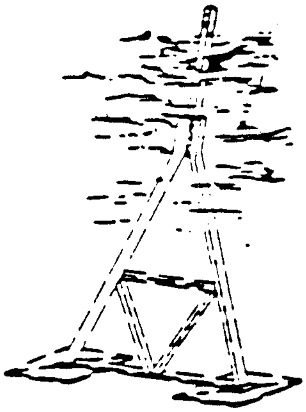


Figure 3-2 — Double Pressed Plate

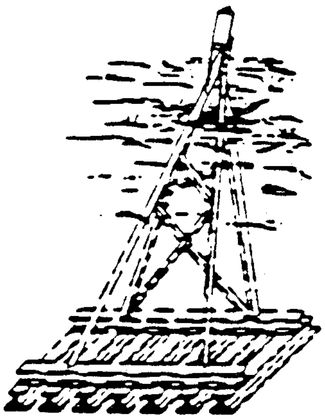


Figure 3-3 — Grillage Type

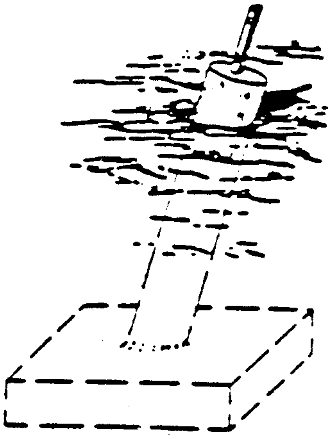


Figure 3-4 — Pad and Stem Type permission from [B3]

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

1) Tower site information
2) Tower foundation construction survey
3) 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

1) Restrictions on points of entry to tower site
2) Equipment limitations on site
3) Underground and overhead utilities
4) Existing structures on site
5) Clearing restrictions
6) Presence of surface water
7) 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 12 in (300 mm) 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:

1) Access to foundation sites
2) Foundation assembly site
3) Spoil pile management
4) 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 locate specialized digging machines. One such machine is the spiderlike “Mensi Muck,” which has 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.

3.4.2 Dewatering

Often, a high water table will require dewatering of the excavation. Depending on the site-specific conditions, open pumping, cutoff trenches, or predrainage with wells may be necessary to remove the water. If water continues to run into or seep in from the walls or bottom of the excavation after the initial dewatering, a sump hole can be dug at one or more corners of the foundation bottom, and small portable suction pumps can be used in these pumping points to keep the excavation dry during the foundation installation.

3.4.3 Safety Hazards

Whenever personnel are in the excavation, safety hazards must be considered. There must be a good means of ingress into and egress from the excavation. Excavated material should be stockpiled away from the edge of the excavation. Round rocks and boulders must be placed in a location and manner that will not allow them to roll back into the excavation. Side walls should be backsloped or shored to prevent caving and sloughing of material. The degree of backsloping depends upon the type, soundness, and stability of material being excavated.

3.4.4 Inspection

Inspection of the excavation activity should include all of the above items, in addition to the checking of the staking for each tower by the contractor's survey crew prior to excavation.

3.5 Subgrade Preparation

After excavation, the stability of the foundation bottom must be checked to insure adequate bearing capacity. If soil conditions exist that lead to inadequate load bearing capacity caused by water or poor soil properties, additional excavation below the foundation, to a depth of 1–4 ft (300–1200 mm) (depending on the subgrade soil), is needed to remove these soils. The excavation will be backfilled with select soil or rock materials to improve the bearing capacity of the foundation bottom. After compaction of such material and final subgrade preparation, the excavation is ready for foundation placement. Care should be taken to avoid saturation of the foundation bottom during periods of heavy rain. This condition can create instability in open excavations. Whenever the water table is at or above foundation bottom elevations, the excavation must be kept free of water.

One way to mitigate water problems is to time the excavation closely with the foundation installation. The excavation may be left 6± ft (2 m) above the bottom of the foundation until just before the foundation is to be placed. After pumping out any water, the final 6± ft (2 m) of excavation (to grade) can be done, which should leave a firm and stable foundation bottom. Otherwise, the foundation bottom is likely to become saturated and unstable, requiring overexcavation, and select backfill material will have to be used to bring it back to final grade.

Pressed plate foundations must be placed on a “formed” bearing surface such as a fine sand. The entire area of the foundation bottom should be covered with a minimum 4 in (100 mm) layer of sand. A metal frame template, shaped like the pressed plate foundation, is placed at the foundation bottom elevation and also is filled with sand. Following tamping, the template is removed, leaving a sand mound in the shape of the pressed plate. The pressed plate foundation then is lowered into the excavation and is placed on this mound.

Grillage and precast concrete spread foundation subgrades often need only fine grading of the subgrade. A layer of sand, pea gravel, or small crushed stone under the foundation often will aid in the setting of the foundation.

3.6 Foundation Assembly

All steel spread foundations and, to a lesser degree, concrete precast foundations need to be assembled before setting them on the prepared subgrade. During the transport and handling of the steel, care should be taken not to damage the galvanizing or to deform members. Steel should not be dumped, dragged, rolled, or dropped. It should be loaded, unloaded, and stored carefully.

A check of the assembled grillage also must be made to insure that all bolts are tightened, lock-nuts are installed, and the steel is not warped or twisted. Grillages must be assembled on a smooth level surface. On uneven surfaces, the assembled grillages should be blocked properly. If assembled on uneven ground and left there for a period of time, the steel beams of the grillage can eventually settle to conform to an uneven surface, making proper level setting of the grillage difficult in the excavation.

3.7 Setting Foundations

After all the foundations have been excavated and fine-graded, and their subgrade elevations have been established to be within allowable tolerances, the excavation with the highest elevation is set first. The remaining foundations can be set using the first foundation as a reference for elevation and angular placement. This procedure allows the remaining foundations to be adjusted in elevation with subgrade fill instead of further excavation. Adding fill is easier than having to excavate and fine-grade the remaining foundation holes. For foundations with rock excavation, it will eliminate the necessity of chipping off the high points of rock projecting into the foundation.

In setting any tower foundation, the first consideration is to check both the position of the tower center hub for alignment and the line angle, if any. Vertical control also should be checked before proceeding with the actual setting of the foundations.

3.7.1 Templates

Templates normally are used to ensure correct setting dimensions and to reduce the time required to set foundations. Templates also are used to shape the sand subgrade base for pressed plate footings and to help ensure that proper compaction exists under the plate footing.

3.7.2 Placing Foundations

In placing a foundation, there are five major items to be considered (Fig 3-5).

1) Batter
2) Working point elevation
3) Horizontal or “A” distance
4) Transverse location or “B” distance
5) Twist

Generally, these items should be considered in order. Some foundation crews, however, establish the “C” distance, or center of the foundation assembly at the bottom of the excavation, and set the foundation to the “C” dimension first. In this case, the order of consideration should be

1) “C” distance
2) Batter
3) Working point elevation
4) Horizontal or “A” distance
5) Transverse location or “B” distance
6) Twist

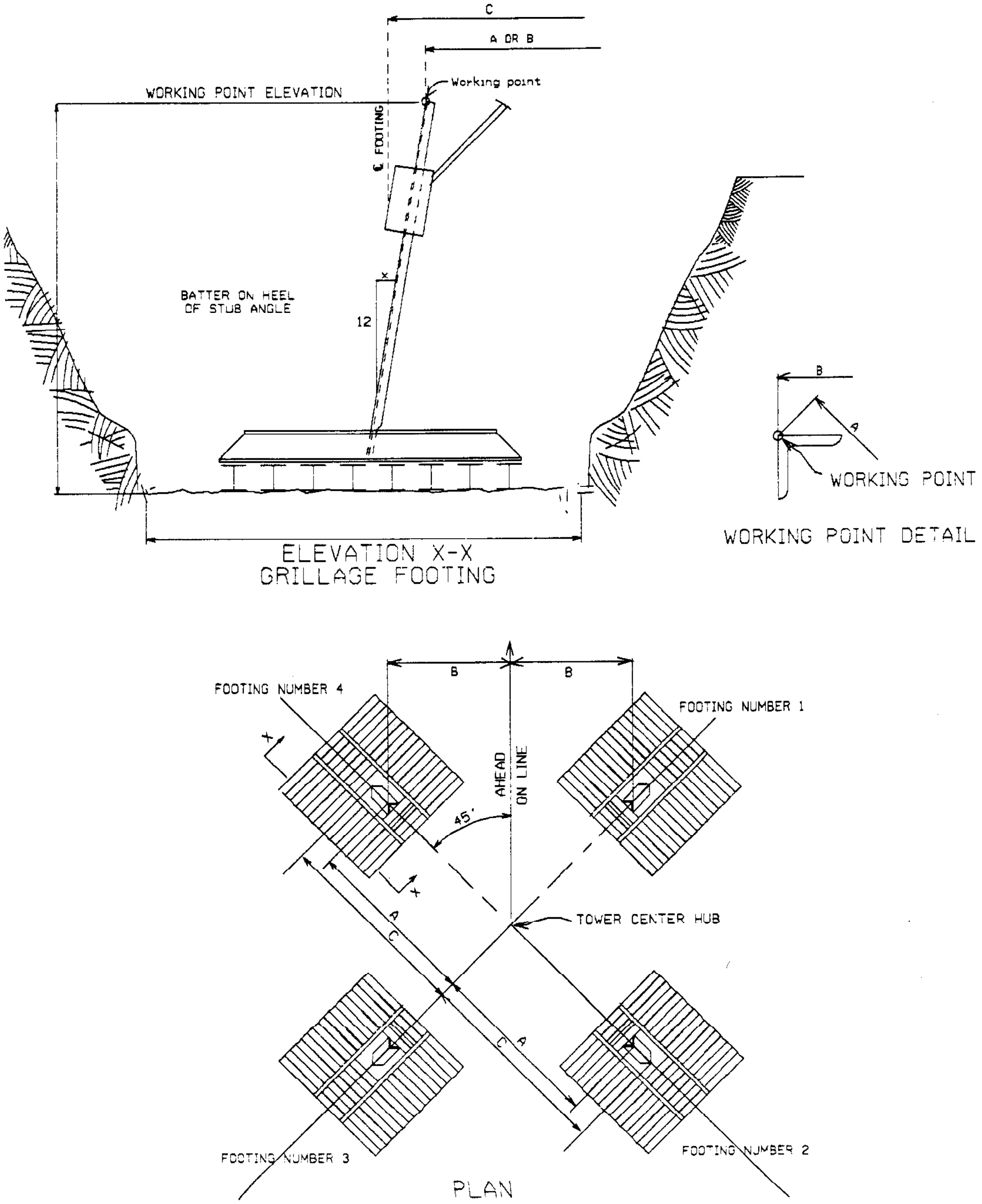


Figure 3-5 — Grillage Setting

3.7.3 Construction Setting Tolerances

Construction setting tolerances for the above items should only be necessary and sufficient to ensure that the tower can be assembled without adverse effects. Improperly set footings can result in tower erection difficulties and built-in stresses that will reduce the design load-carrying capacity of the tower legs. These assembly difficulties can result from an improperly set footing (i.e., improper batter, twist, working point elevation, horizontal distance, or angular orientation), from one footing being out-of-plane of the other three (i.e., warping), or from the complete tower foundation being out-of-square (i.e., improper angular orientation or improper working point elevation). Computer simulations and field experience indicate that warping is often the critical factor in ease of erection and built-in stresses. Many factors are involved in selecting the required construction setting tolerances. Several factors to consider are size and framing of the lattice structure, tower leg length and stiffness, bolt slippage, steel footing fabrication and assembly tolerances, footing subgrade condition, and backfill compaction stresses on the tower leg.

Using a transit, chain, and level rod, the foundation setting supervisor checks all the control factors to bring all points of control into tolerance. For example, for a pressed plate foundation, if the elevation is too high, the supervisor would call for a "hit" (tamping) or "hits" on the pressed plate. This hitting is done by a worker in the excavation who strikes the top of the pressed plate on both sides of center with a heavy iron device, appropriately called a beater. This device is padded on its striking face to protect the pressed plate galvanized surface. If the stub angle is out of plumb or batter, a hit is made on the pressed plate on the side opposite the one out of tolerance. If the foundation is out of twist, a turn of the front of the pressed plate is needed to bring the stub into proper twist alignment.

If the foundation is too low in elevation, it can be raised high enough to permit workers to add sand to the mound, or it can be removed from the excavation to permit a complete grading of the excavation base.

Specifications often require that, after the foundation is set in the correct position, the backfill be brought up to 12 in (300 mm) above the foundation assembly by hand and be tamped thoroughly in the process. Tolerances set forth in the specifications must be observed.

3.8 Backfill

Backfill is an extremely important operation and should only be done when an inspector is present. Improperly backfilled spread foundations can lead to tower failure. Proper backfill over the foundation does five things:

1) Provides weight and shearing resistance above the foundation for resisting uplift
2) Minimizes foundation movement in uplift
3) Provides passive resistance to horizontal shear forces
4) Brings ground back to grade
5) Reduces water entry

Before the backfill is started, the inspector should check to see that the horizontal shear plates are on, all bolts are tight, and the below ground assembly is ready to be backfilled. All water, snow, or ice should be removed, and surface drainage should be diverted from the excavation before backfilling. During backfilling, the location of the foundation steel (i.e., the setting dimensions) should be monitored to maintain its position within permissible setting tolerances. Material used for backfill should meet the construction specification requirements.

The excavated material commonly is reused as backfill unless it does not meet specifications. If this is the case, select backfill must be used. Backfill material should be close to optimum moisture content and should be free of frozen soil, snow, ice, refuse, debris, vegetation, or other foreign matter. The backfill and compacting done close to the assembly is most critical. This backfill material should be placed by hand (not machine) and should be tamped thoroughly until it is 12 in (300 mm) above the foundation assembly. The rest of the backfill material should be placed in layers on all sides of the foundation by a front loader, backhoe, clamshell, or other lifting equipment. Each layer must be compacted by tamping. Bulldozing or otherwise pushing the material into the excavation must be avoided.

When backfilling around a stub angle, the pressed plate, or the grillage beams, care must be taken to prevent rocks from being placed against the steel. Fine material should be used when backfilling the grillage beams and should be tamped in with a small tamping tool. The area immediately inside of the foundation stub angle must be hand-tamped as the backfill level increases, because machine tampers will not fit into this area because of the batter of the stub angle. Compaction specifications are typically either a performance specification or a method specification. A performance specification requires a minimum backfill density. The inspector would test the backfill to ensure achievement. A method specification would specify a layer thickness, type of tamper, number of passes of the tamper, etc. The inspector should watch to ensure this method is followed and should also test the backfill density. Whatever methods are used, it is important that the backfill be compacted to the required design criteria.

3.9 Site Restoration

The site restoration around a tower should be done after the final backfilling is complete. On foundations with a steel stub angle, the backfill should be built up around the leg and out to the limits of the excavation, to a height of approximately 12 in (300 mm) above original grade to counteract settling and resulting depression. On concrete pad and pier foundations, the backfill usually is not brought higher than the top of concrete. In cultivated land, the final backfill should be the original topsoil, which will require special care during excavation to separate the soils.

3.10 Installation Problems

Installation problems during the construction of a spread foundation can arise for a number of reasons. Since construction is the last step in the sequence of steps that includes foundation investigation, selection of foundation types, and the preparation of construction drawings and specifications, any oversights during these previous steps will show up and will need to be corrected during construction. The successful installation of a spread foundation will depend on how the factors outlined in the previous sections of this chapter are addressed.

3.10.1 Geotechnical Problems

Some of the geotechnical problems that can cause installation problems, if not identified early in the design process or dealt with in a timely manner, are sites with one or more of the following conditions:

1) High water table
2) Unstable soils
3) Unanticipated rock
4) Steep slopes
5) Permafrost
6) Frozen ground
7) Collapsible soil
8) Expansive soils
9) Very soft soils
10) Flowing soils
2) Previous fills

3.10.2 Construction-Related Problems

Construction-related installation problems often arise from having to deal with the unexpected geotechnical conditions listed above or from an inadequate quality assurance/quality control program. Some of the more common construction problems are as follows:

1) Improper backfill material and compaction
2) Improper concrete batching, delivery, placement, or testing
3) Inadequate construction equipment
4) Inexperienced construction personnel

3.11 Bibliography

[B1] EPRI EL-2870, *Transmission Line Structure Foundations for Uplift Compression Loading*, Feb. 1983, Kulhawy, F. H., Trautmann, C. H., Beech, J. F., O'Rourke, T. D., McGuire, W., Wood, W. A., and Capano, C.

[B2] "Blasting Near High Voltage Transmission Lines," Report DE-AP79-84B816328, Bracken, T. D., Bonneville Power Administration, Portland, OR, Oct. 1985.

[B3] "Footing Tests For Transmission Line Towers: A Collection of Data," Technical Report SA-9, Logan, C. E., Bureau of Reclamation, Denver, CO, Nov. 1976.

[B4] Kulhawy, F. H., Trautmann, C. H., and Nicolaides, C. N. "Spread Foundations in Uplift: Experimental Study," *Foundations for Transmission Line Towers* (GSP8), Ed. J. L. Briand, New York: ASCE, Apr. 1987, pp.96–109.

[B5] Trautmann, C. H. and Kulhawy, F. H., "Uplift Load-Displacement Behavior of Spread Foundations," Journal of *Geotechnical Engineering*, ASCE, Vol. 114, No. 2, Feb. 1988, pp. 168–184.

4. Drilled Shaft Foundations

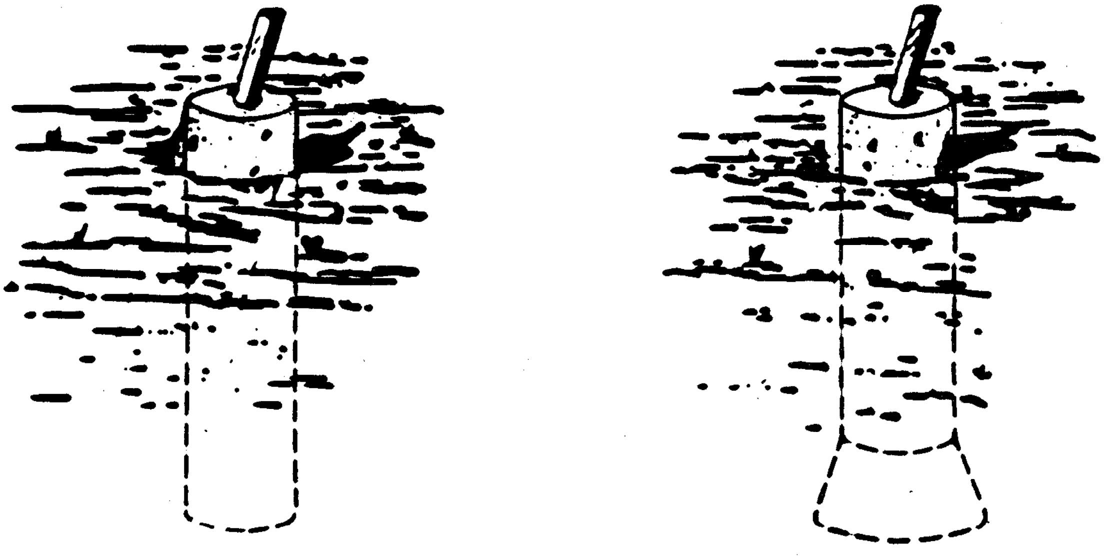
4.1 Introduction

For definition purposes, a drilled shaft (Fig 4-1) is a cylindrical excavation from which all of the soil or rock has been removed. The diameters of drilled shafts for transmission structures are controlled by the size of the anchor bolt circle or the stub angle geometry, and thus can be from 2 ft (0.6 m) to 10 ft (3 m), or larger.

A drilled shaft should be excavated to the required depth with equipment that gives a true dimensional hole with straight walls. Where rock is near the ground surface, drilled shafts that penetrate the rock are common. This excavation can be done by methods that will be discussed herein.

Auger-type drilling rigs are available in a wide variety of mounting and driving arrangements. The choice normally is the contractor's preference, based on experience and the capability of the machine. The equipment should be suitable to complete the job.

In addition to the auger-type drilling rigs, there are rotary rigs that use circulating drilling fluid to carry the cuttings out of the excavation (see 5.4). These rigs can be used in wet-hole construction to drill large diameter, uncased foundations.



Drilled Shaft **Belled Drilled Shaft**

Figure 4-1 — Drilled Shaft

4.2 Construction — Dry-Hole Method

In noncaving soils where a drilled hole stands open readily, straight holes are drilled quickly, usually with an open-helix auger having two or three turns of a single flight. In these areas, the concrete is placed with few, if any, problems.

When a hole is being drilled in stable soil and a soft stratum of clay or organic silt is encountered, this stratum tends to squeeze in and reduce the diameter of the hole. A casing should be inserted to limit this action and to protect the hole. The casing can be advanced by driving or drilling ahead of the excavation through the squeezing zone.

Cohesionless soils, sandy silts, and gravels usually will cave when drilled by auger, either above or below the water table. The usual and direct way of coping with a caving soil is to install casing as the hole proceeds through the caving formation. In some caving soil, it is possible to drill the hole quickly and insert the casing freely before caving starts.

4.2.1 Placement of Concrete.

Immediately prior to the placement of concrete, the bottom of the drilled shaft should be clean and dry. If the bottom of the hole contains a few inches of water or mud, enough cement or gravel-cement mix must be added to absorb the water and form a paste or soil-cement mix so rich that it will protect the concrete as it is placed in the bottom of the foundation.

Past experience has shown that freely-falling concrete does not segregate, but concrete discharged into the drilled shaft from the chute of the transit mixer invariably will strike the reinforcing and the side of the hole as it falls. This type of placement should be avoided. A hopper centered over the hole with a section of elephant trunk attached to its bottom is necessary to take the concrete from the chute of the truck or the concrete bucket and concentrate it in a small stream to the bottom of the excavation.

Concrete slump and maximum aggregate size should be controlled so that the concrete will flow freely around the reinforcing bars and completely fill the area outside the cage. The slump should be between 4–6 in (100–150 mm). The concrete should be vibrated in the top 10–15 ft (3–4.5 m) so that it makes complete contact with the reinforcing and anchor bolts. This vibration also prevents voids in the part of the foundation where the hydrostatic pressure of the wet concrete is the lowest. Vibration should not be done until the casing has been removed, because it could cause packing and wedging of sand and gravel outside the casing, resulting in considerable difficulty in pulling the casing.

Although not always possible, the placement of concrete in the drilled shaft should be continuous. When a partially-filled drilled shaft is allowed to stand until the concrete has taken its initial set, the exposed surface will require cleaning before more concrete can be placed to ensure a good bond between the old and new concrete. The scum or laitance that settles on the top of the newly-set concrete should be removed, and the surface should be roughened. Just before the pour is resumed, a slush of cement grout should be spread over the top of the old concrete. All reinforcing bars should be cleaned of old cement grout.

4.2.2 Casing

When a hole has been cased to seal out water, the casing must not be disturbed until enough concrete has been placed to produce a higher concrete pressure at the level of the casing seal than the water pressure outside the casing at that level. If this procedure is not followed, water can enter the concrete column, causing voids or zones where aggregate is washed clean of cement. Also, the concrete level in the casing must be maintained at a high level as it is pulled because voids outside the casing will cause concrete to flow from the casing to fill them.

When telescope casing is used, it is necessary to place enough concrete in the casing section so that the surface of the concrete does not fall below the bottom of the next larger casing. This surface will depend on the relative positions of the top of the bottom casing, the bottom of the next section, the level of groundwater outside the bottom section, and the volume of water to be displaced outside the lower casing and below the bottom of the next sections. If there has been extensive caving during drilling, or if the lower formation is cavernous, the concrete level should be watched carefully as the bottom section is lifted. More concrete should be added if it appears the concrete level is about to fall below the bottom of the next section to prevent inflow of groundwater. Casing should always be pulled in an axial direction as slowly and steadily as possible. The concrete level must be maintained so that it never falls below the bottom of the casing until the top of the foundation has been reached.

4.3 Construction — Wet-Hole Method

4.3.1 Construction Methods

In areas of high ground water level, sand and granular silt cannot be removed to extend the hole past the bottom of the casing without causing soil run-in. This run-in could result in loss of soil outside the casing and a settlement of the ground around the excavation. However, this problem can be handled by one of the three methods described below.

4.3.1.1 Water Head

The first method is to keep a positive head of water in the drilled shaft so that the hydrostatic pressure is enough to prevent soil run-in at the shaft bottom.

4.3.1.2 Casing

A second method is to advance the casing ahead of the excavation with a vibratory pile driver attached to the casing. The agitation of the cohesionless soil below water reduces the skin friction between the soil and casing so that the casing can be sunk below the excavation level. Once the soil is removed and the concrete is placed, the casing can be removed by the vibratory driver without damaging the concrete.

4.3.1.3 Slurry

A third method is to stabilize the excavation by mud slurry (Fig 4-2). The use of slurry allows a hole with straight walls to be drilled in dry, moist, or saturated sand. This procedure requires an experienced driller who understands slurry construction procedures. The drilling equipment can be either rotary or auger type. The mud slurry is premixed in a sump adjacent to the foundation areas. Water and bentonite or attapulgite (clay) are mixed to the proper consistency, which could have a unit weight of 65–75 lb/ft^3 (10–12 kN/m^3). Drilling with an auger or mudding bit of the same diameter as the required shaft is started with the mud slurry circulating from the sump to the excavation. With a rotary drilling machine, the slurry is circulated through the hollow drill stem into the bottom of the shaft. The slurry is mixed with the soil cuttings as the bit advances and is pushed back up and into the sump where the cuttings are screened out before the mud is returned to the excavation. With an auger machine, the slurry is pumped into the excavation and circulated by action of the auger bit. If the slurry mix is not stirred, it will turn into a gel and hold the excavation wall in place and the cuttings in suspension. Some of the larger diameter shafts are drilled by reverse circulation. The mud slurry is placed in the top of the excavation as the bit is advanced, and the slurry mixed with soil cuttings is pumped from the bottom back into the sump. Before the reinforcing steel is placed, the slurry should be stirred vigorously and circulated to remove the soil cuttings that have settled to the bottom of the excavation.

After the hole has been excavated, prompt placement of steel reinforcement and anchor bolts is necessary to prevent caving, water entry, and difficulty in pulling the casing.

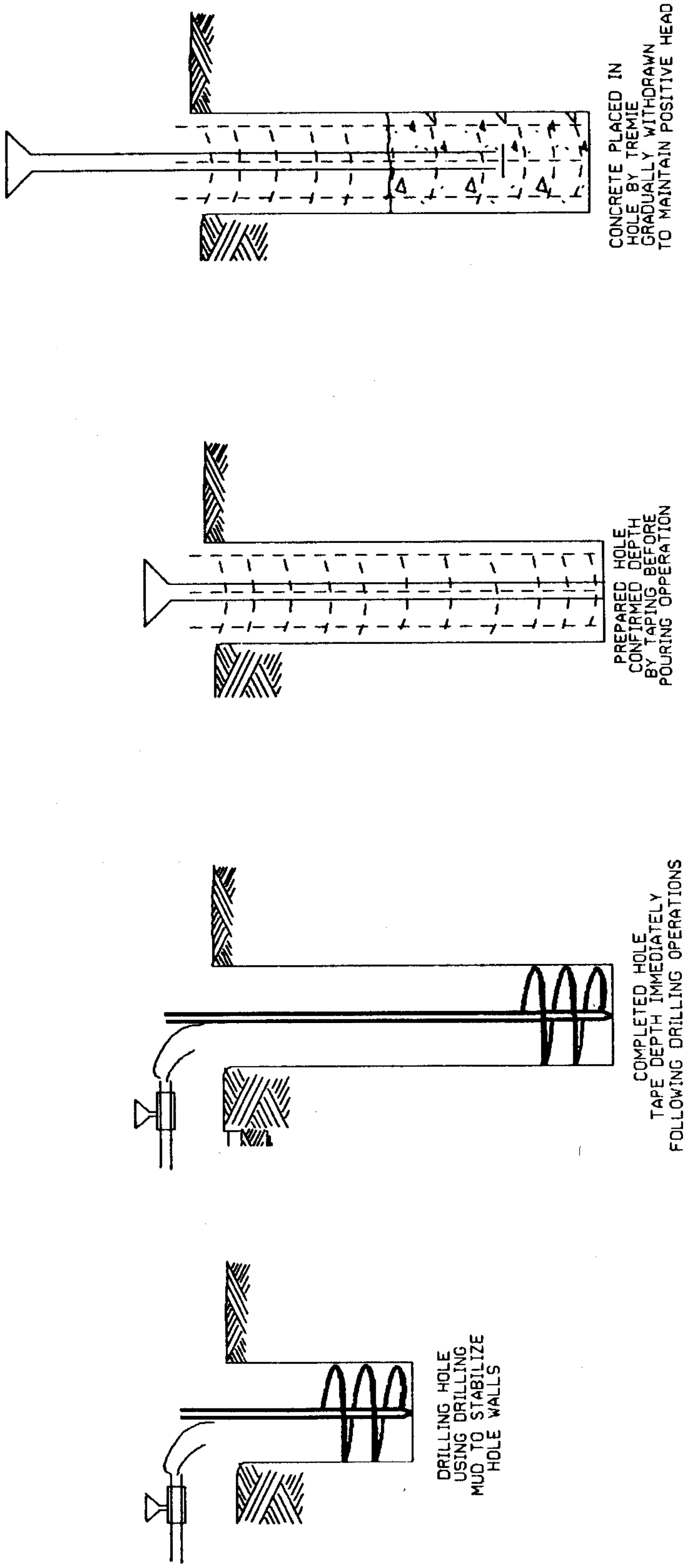


Figure 4-2 — Typical Procedure for Installation by Wet-Hole Method

4.3.2 Concrete Placement by Tremie

Tremie methods are used to place concrete under the following conditions:

1) When the water flow into the drilled shaft is too rapid to be pumped down to allow the placement of the concrete in a dry excavation
2) In a static water table condition where the hydrostatic head is required to prevent a blow-out at the base of the excavation,
3) Where the shaft has been drilled by the mud slurry method.

The drilled shaft should be full of mud slurry, or the water should have reached its stabilized elevation, before concrete is placed. The concrete used in the tremie method should have a high slump of 7–10 in (180–250 mm) and be rich in cement with 7.5 bags/yd^3. (One bag is 94 lb [418 N]). A tremie pipe of 8 in (200 mm) or larger, with a temporary closure applied to the bottom to make it watertight, is lowered to the bottom of the shaft.

When the concrete in the pipe has reached a level where the concrete pressure exceeds the water pressure at the bottom, the pipe is raised slightly to allow the seal to come off. The discharge end of the tremie should be raised slowly, but it must be kept submerged in the concrete at a sufficient depth to maintain an adequate seal during underwater placement. If the seal is broken, the tremie must be withdrawn immediately from the shaft, resealed, and lowered below the surface of the concrete. Then the pouring operation is restarted.

Once started, the tremie operation must proceed without interruption until the concrete has reached the ground surface. It is then continued until all foreign materials have been flushed from the top of the pour. Vibration of the tremie concrete usually is not required, but it is permissible to vibrate the tremie pipe under certain conditions when the flow of concrete becomes sluggish.

4.3.3 Concrete Placement Using Pumps

In lieu of the tremie method, concrete pumps are gaining wide use for placement of concrete under water. Pumping is especially useful for large volume pours and sites where unsuitable terrain make it difficult to locate delivery trucks and placement equipment efficiently. Coordination is required between the contractor, concrete supplier, and pumper to ensure that a proper mix is used, and that a machine with adequate capacity is used. The concrete pump should be capable of pumping a minimum of 60 yd^3/hr (46 m^3/hr) to a vertical height of 200 ft (60 m), and the conductor pipe should not be less than 5 in (130 mm) inside diameter. All the requirements and procedures for placement by the tremie method discussed above apply to placement by pumping. If the contractor chooses to pump concrete, a back-up pump should be available during concrete operations, or a suitable hopper and tremie pipe should be on site.

4.4 Excavation — Rock

Where rock is near the surface, drilled shafts that penetrate the rock are common. The depths and diameters of the rock sockets are determined by the load requirements and the characteristics of the soil and rock. For excavating the shaft, one of the following tools or techniques usually is employed:

1) Core barrel
2) Rock auger
3) Blasting

Where the rock is weathered, rock augers can be very effective. Core barrels (Fig 4-3) with replaceable carbide teeth are used frequently in sandstone and limestone formations. However, if the rock is extremely hard (such as unweathered granite or basalt), it can be pre-drilled from the surface, a blasting charge can be set off, and the shattered rock then can be removed with a rock auger and/or a core barrel.

If sound rock is very near the surface, the most economical foundation may be a design in which the vertical reinforcing bars are placed in 2.5 –3.5 in (64–90 mm) diameter holes drilled into the rock at the base of a drilled shaft, and the annular space around each steel bar is filled with non-shrink grout (Fig 4-4).

Where the rock is so near the surface that anchor bolts cannot be placed in the drilled shaft above the rock, anchor bolts may be grouted directly into the rock. The design load may or may not require additional rock anchors to be grouted in as well.

Figure 4-3 — Core Barrel for Rock Drilling

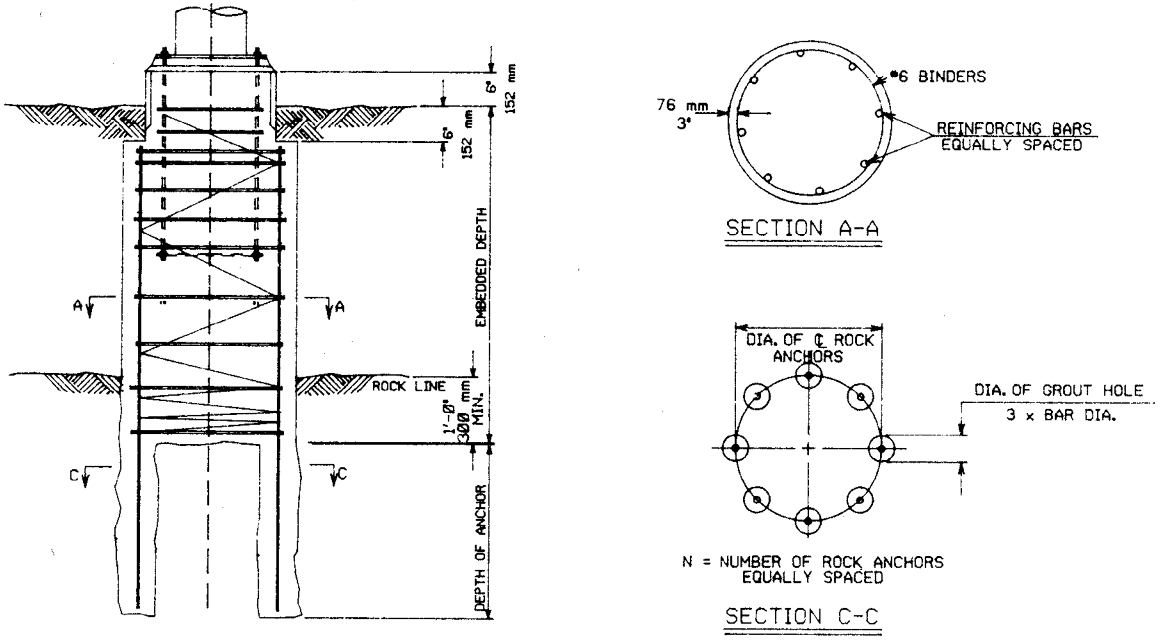


Figure 4-4 — Typical Rock Anchor Foundation

Subsurface conditions that make the installation of rock anchors very difficult can be present. At times, rock anchors are specified in areas where the rock is fractured, jointed, layered, etc. Instead of the air drill blowing the cuttings out of the hole, they are blown into an adjacent hole previously completed. Consequently, it is nearly impossible to place and grout the bars in clean holes. This problem can be solved, at times, by increasing the length of the rock anchor into sound rock and grouting each bar in place before air drilling the next hole. This is often the more time-consuming and expensive solution to the problem. All things considered, the result is usually a design change to full shaft rock sockets (Fig 4-5).

The presence of ground water with an artesian head can result in a substantial flow of water up the drilled hole. Such a condition can make the grouting of rock anchors difficult, if not impossible.

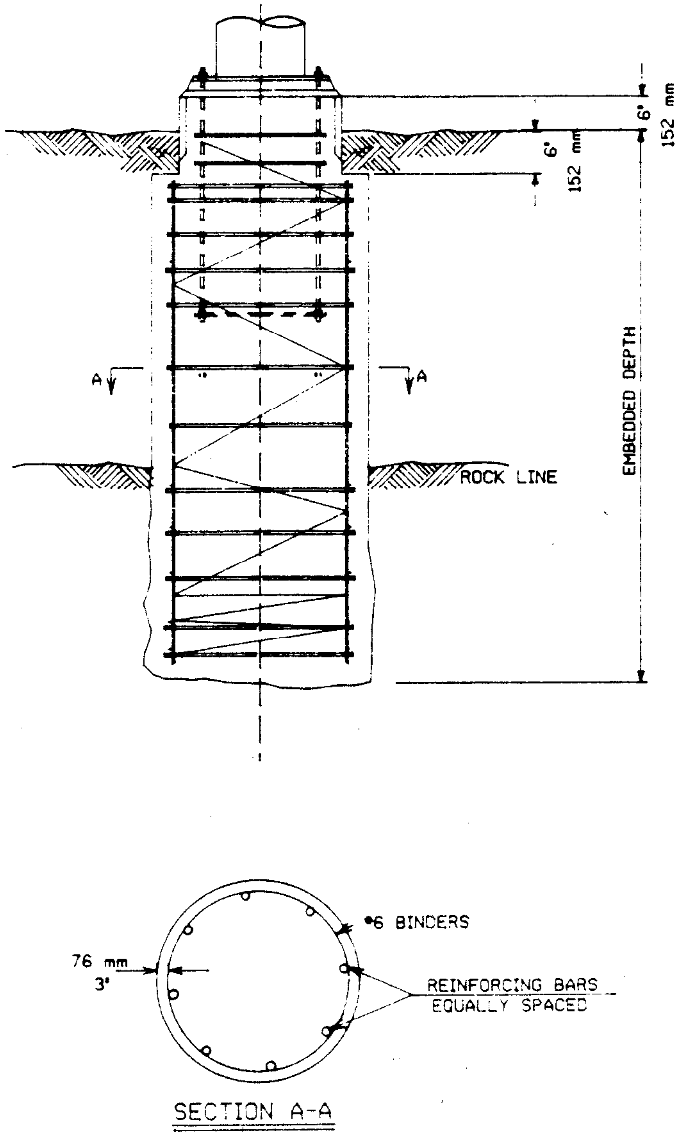


Figure 4-5 — Typical Rock Socket Foundation

4.5 Direct Embedment

A direct-embedded pole foundation (Fig 4-6) is constructed in a drilled shaft that has been excavated by conventional means as previously discussed. The base of the pole is erected in the drilled hole, and is backfilled by compacting specified material (native soil, crushed stone, etc.) to a specified density into the annulus surrounding the pole. This type of foundation is typically used for lighter-loaded structures such as tangent and guyed poles. Construction problems such as high water table and caving soils may prevent or hinder the application of direct embedment.

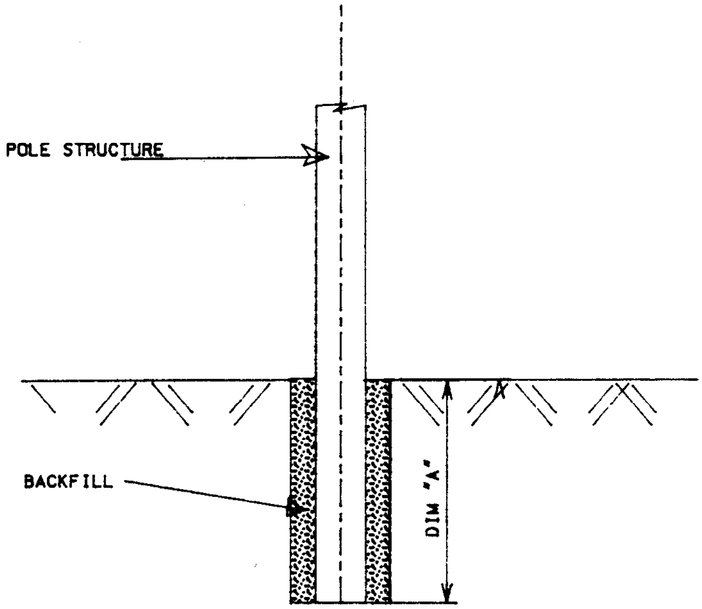


Figure 4-6 — Direct Embedment Foundation

4.6 Noncircular Shaft

It is necessary, at times, for a shaft to be dug by means other than standard drilling equipment. One example is the hand-dug shaft. Occasionally, pick and shovel are chosen as the means of excavation because of environmental concerns, economics, access barriers, etc. The cross-sectional shape of these excavations ranges from square or rectangular to circular.

Square or rectangular shafts are constructed when the designer and contractor decide that a backhoe can be used for excavation. Also, transitional shafts (cylindrical below the surface and formed square at the surface, or vice versa) are used for aesthetics, equipment utilization, etc.

4.7 Hollow Shaft

A hollow shaft foundation is constructed by inserting into the ground a casing (hollow shaft) that is designed to be an integral part of the completed foundation. The construction process is as follows:

1) Vibrate or drive a large diameter, hollow shaft to the specified depth.
2) Remove the soil from inside the hollow shaft by conventional means.
3) Construct the standard concrete foundation or the standard direct-embedded foundation inside the hollow shaft.

This type of drilled shaft is used where deep shafts are required in unstable and/or wet soils and soil data indicate that casings can be inserted with relative ease by a vibratory hammer. Common casings used with this type of foundation are either fabricated steel or precast-prestressed concrete shafts. The concrete hollow shafts are utilized typically as foundations for large poles (Fig 4-7).

Hollow shaft casings usually are inserted 2–3 ft (0.6–0.9 m) below the design depth of the shaft to provide a seal against entry of groundwater under hydrostatic head. If, during excavation, the seal is broken, the excavation must proceed under the naturally resulting hydrostatic head, and the concrete must be placed under water either by pumping or by the tremie method described earlier. Attempts at dewatering must be avoided unless the source is known to be from the surface.

Permanent casings (hollow shafts) in poor soil conditions allow construction of the foundations with ease, and remove the possibility of disturbance to the reinforcing cage, anchor bolts, or stub angle during extraction. However, disadvantages of permanent casing are the cost of the casing, the extra time for construction, and the extra cost if casing insertion stalls because of obstructions or stiff layers of soil. On larger-diameter holes, a 2–3 ft (0.6–0.9 m) pilot hole facilitates passing the casing through such obstructions.

Other considerations regarding the use of very large-diameter casings are

1) Special routes may be needed from the fabricator to the job site to accommodate over-width and over-height loads.
2) Shipping brackets or “spiders” must be used to avoid damage to the section. These are removed once the casing is in a vertical position suspended from the hammer.
3) Significant crushing loads are developed at the design depths on large-diameter casings by hydrostatic pressure acting on the evacuated tube. Wall thickness requirements must be developed for the depth, diameter, and density of the external fluids at the specific installation site.

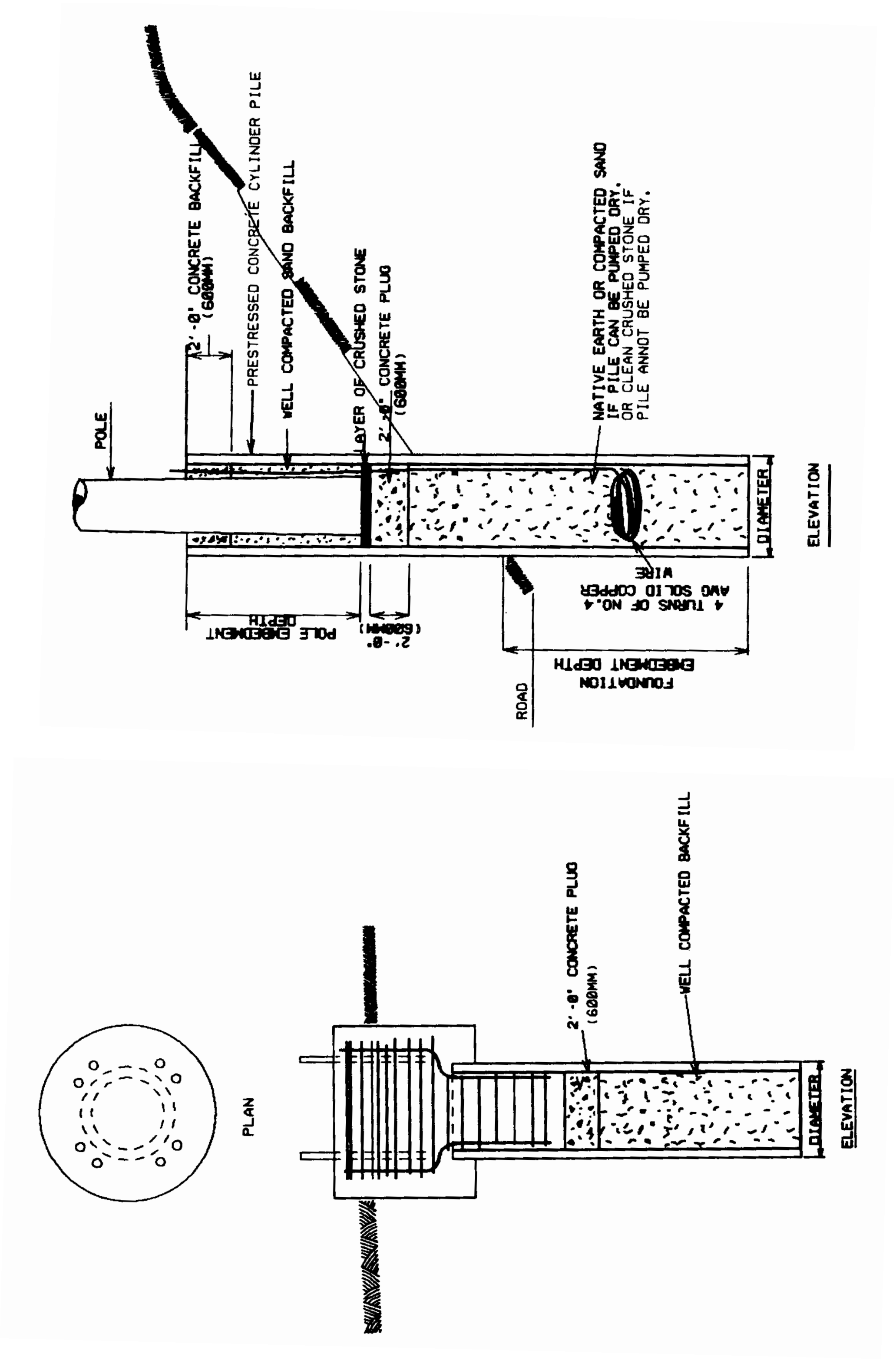


Figure 4-7 — Concrete Cylinder Foundation Types

4.8 Installation Problems — Geotechnical

Installation difficulties that occur during the construction of drilled shaft foundations can be divided into geotechnical problems and construction problems. The geotechnical problems will be discussed first.

The first issue relates to rock. It is necessary to know where it is, how solid it is, and how deep the weathering profile is. It is also necessary to clarify whether boulders are present and how they are differentiated from the local rock.

It is also important to know:

1) Whether a hole can be augered or must be excavated by other means
2) Whether obstructions or “running” soil layers are to be encountered in the hole
3) Where the groundwater table is located

Groundwater, in combination with a sand or silt stratum, is a geotechnical problem that is often encountered. As discussed previously, several construction methods are commonly used when coping with these difficulties. These methods are

1) Keeping a positive head of water in the drilled shaft
2) Advancing the casing ahead of the excavation
3) Stabilizing by mud slurry

Important factors to be considered when groundwater is a possible problem are the periodic variations of the water table, permeability of the soil, artesian groundwater flow, stratification of the soil, and thickness of soil layers.

4.9 Installation Problems — Construction

Installation difficulties that fall in the class of construction problems and occur most often can be listed as follows:

1) Improperly cleaned hole
2) Improperly placed reinforcing steel
3) Concrete not at the proper slump

All holes that are of questionable stability should be cased. The time any hole is left open should be minimized.

In slurry construction, the typical sequence is to auger the hole, remove the cuttings, place the steel reinforcement, insert the tremie, and pour the concrete. While waiting for the concrete to be poured, settlement from the slurry often occurs because of the cuttings not being maintained in suspension. (It is not uncommon in sandy soils for several feet of settlement to occur.) Measurement of the hole depth, immediately after augering and again prior to pouring, determines whether the hole needs to be recleaned.

Construction problems arise when the specific gravity of the slurry is too great, and there is an excessive amount of cuttings from the excavation still in suspension at the time of concrete placement. The solidified soil then has a tendency to be pushed outward from the center of the drilled shaft by the concrete that is flowing upward and outward from the tremie tube. These pockets of soil may be trapped in and around the reinforcing cage (Fig 4-9). The problem intensifies as the pour reaches groundwater level where the buoyancy that the groundwater had given the material being lifted by the concrete disappears. The resulting pressure increase causes solidification of the soil in suspension to intensify. Everywhere that a mass of the resolidified cuttings is trapped in the foundation, a void in the concrete will be formed.

Foundation contractors who use stabilization by the mud slurry method understand the basics of the process and try to prevent voids caused by resolidification of the cuttings from forming in the foundations.

To ensure that this problem does not occur, the slurry must be thinned, after excavation of the hole, by the addition of water. The slurry also must be circulated through the sump to allow as much of the excavated material to settle out as possible. The lower the specific gravity of the slurry just prior to placing the concrete, the lower the chance of any voids developing in the foundation. However, caution must be exercised because a lower specific gravity could increase the chance of a cave-in.

To improve the chances of obtaining good foundation quality from the mud slurry method, it is necessary to first know and understand the parts of the method that are important to the quality of the finished foundation. Second, it is necessary to know the contractor's capabilities and personnel. Third, it is necessary to have an effective inspection program during construction. This program must include inspectors who know when the required quality is not being achieved, and who have the authority to enforce the specifications.

Proper positioning of the reinforcing steel, both vertically and horizontally, is important. Centering the reinforcing cage during construction is necessary to achieve the required concrete cover between the rebars and the side of the hole. Preventing downward slippage of the cage ensures that specified concrete cover will exist at the top and bottom of the shaft.

Proper concrete slump in wet-hole construction is in the range of 7–10 in (180–250 mm) with a high cement content, around 7.5 bags/yd^3. This slump allows rapid placing of the concrete mix and quick displacement of the drilling mud. A high slump mix completely surrounds the rebars without voids.

Other construction problems that may occur are site access restrictions, overhead and underground utilities, environmental concerns, and existing nearby structures.

4.10 Inspection

An effective inspection program can ensure high quality results. An onsite inspector observes the foundation construction and maintains a complete log of events, such as slump measurements and batch plant inspections. The inspector's duties include performing slump tests and rejecting concrete that has slump other than specified. Properly performed batch plant inspections can ensure the following:

1) Correct admixtures and quantities are added
2) Yield is within specified tolerances
3) Water/cement ratio is within tolerance
4) Specified quantity of cement is added
5) Compressive strength test cylinders are molded and tested according to specifications

At the structure site, measurement of the hole depth, immediately after augering and again prior to concrete placement, determines whether the hole needs to be recleaned. The inspector can record these measurements, as well as the time that it takes to complete the construction phases. The inspector's log is used in the selection of foundations that will be cored full-length for quality testing. Acceptance or rejection of the foundation is presented to the contractor on the basis of such an inspection program.

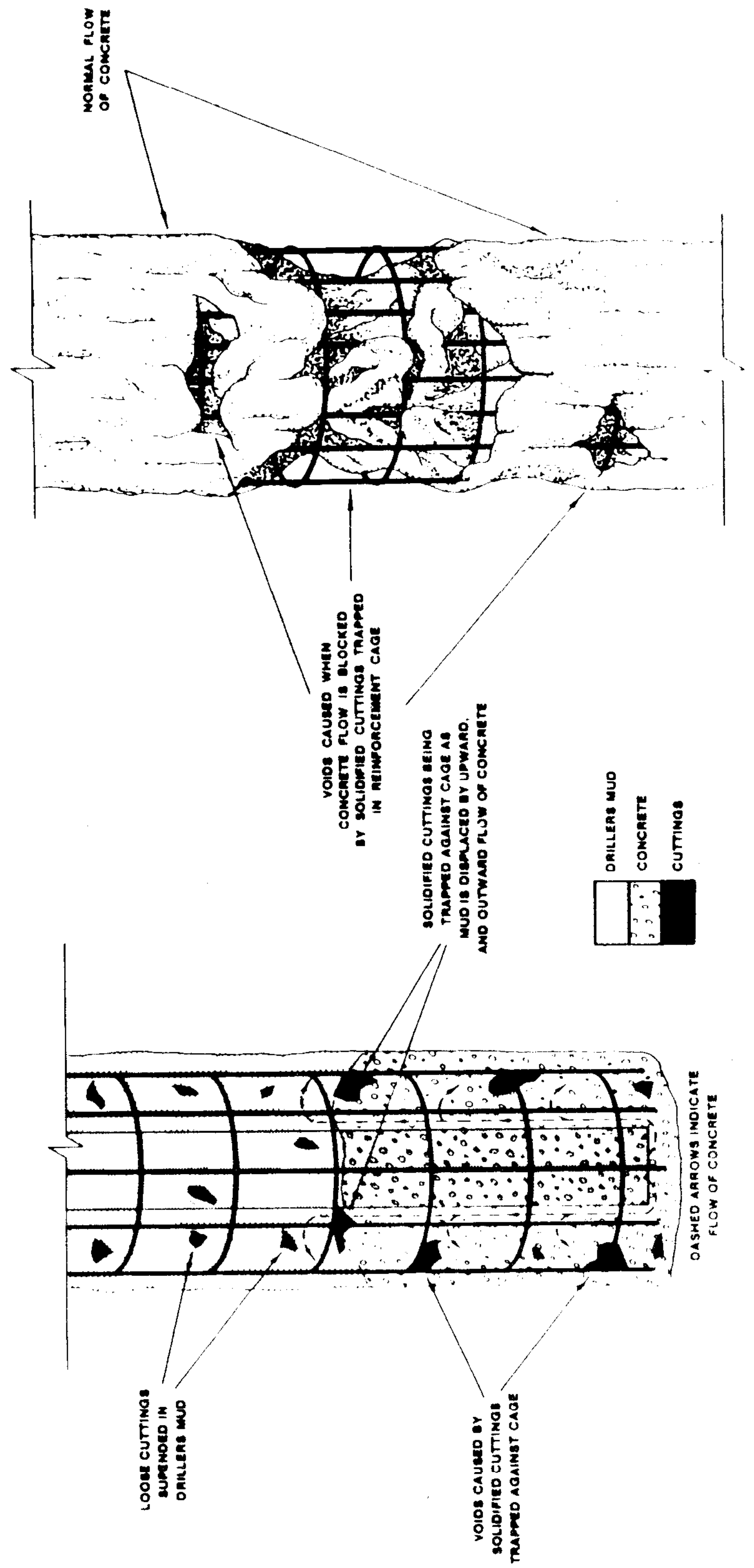


Figure 4-8 — Wet Hole Concrete Placement Problems

4.11 Bibliography

[B1] EPRI EL-5323, *Experimental Study of the Undrained Uplift Behavior of Drilled Shaft Foundations*, Oct. 1987, Kulhawy, F. H. and Beech, J. F.

[B2] Carson, A. B. *General Excavation Methods*, New York: McGraw-Hill Book Company, 1961, pp. 136–145.

[B3] Greer, D. M. and Gardner, W. S. *Construction of Drilled Pier Foundations*, New York: John Wiley and Sons, 1986, 261 p.

[B4] Kemp, J. E. “Investigation and Repair of Defective Steel Pole Concrete Foundation,” *Proceedings of Southeastern Electric Exchange, Engineering and Operating Division Conference*, New Orleans, LA, May 27–29, 1987.

[B5] Reese, L. C. and Tucker, K. L. “Bentonite Slurry in Constructing Drilling Piers,” *Drilled Piers and Caissons II*, Ed. C. N. Baker, New York: ASCE, May 1985, pp. 1–15.

[B6] Rodgers, T. E. Jr. “Construction of Foundations for Transmission Structures Subject to Overturning Forces,” Conference Paper A77255-3, IEEE Power Engineering Society, Winter Meeting, New York, NY, Feb. 1977.

[B7] “Specification for Cast-in-Place Piles Formed Under Bentonite Suspension,” *Ground Engineering*, Vol. 8, No. 2, Mar. 1975, pp. 50–52.

[B8] *Standards and Specifications for the Foundation Drilling Industry*, Association of Drilled Shaft Contractors, Dallas, TX, 1991.

5. Pile Foundations

5.1 Introduction

Piles are long, slender, structural elements utilized most commonly in transmission line engineering to transmit loads through water and very soft soils to denser soils. Piles can be classified broadly according to the material used, such as wood, steel, or concrete. Although there are many special types of piles in use, only the basic types generally used in the United States for transmission line structures will be discussed herein.

Economy with dependability is the proper selection criterion for the type of pile to be used. Often, a type is used because it is known to have been successful in a given area. Engineers agree that certain types of piles are more suitable for different soil conditions, but they do not always agree on specific installations.

5.2 Pile Types

5.2.1 Timber Piles

Round timber piles are furnished in Southern Yellow Pine in lengths up to about 80 ft (24 m), in West Coast Douglas Fir in lengths up to about 125 ft (38 m), and in other species ([B1] [2] and [B4]). They are relatively inexpensive with a high strength-to-weight ratio, and can be used in acidic soils. Only pressure-treated piles should be used. Untreated piles are susceptible to deterioration caused by insects and decay unless they are cut off below the water table. A disadvantage of timber piles is the cost of replacing those that are broken during hard driving.

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[2] The numbers in brackets, when preceded by the letter B, correspond to those in the bibliography in Section 5.9.

5.2.2 Precast Concrete Piles

Precast concrete piles can be either conventionally reinforced or prestressed [B1]. They are manufactured in a casting yard in square, octagonal, or round configurations and may be solid or have a hollow core. Precast concrete piles can be manufactured in any size or length to meet the design requirements, but there are practical constraints such as handling equipment, transporting facilities, or pile driving equipment.

5.2.3 Precast Post-Tensioned Concrete Cylinder Piles

Precast post-tensioned concrete cylinder piles usually are manufactured in sections at a casting yard, and can be assembled and prestressed to the required length either at the casting yard or on the job site. The cylinder pile sections are cast under centrifugal, vibrating, and rolling forces using concrete having essentially zero slump. This process produces an extremely dense and relatively impermeable concrete. Longitudinal holes are cast in the pile walls, into which prestressing steel is inserted when the pile sections are assembled to the required length. The joints between the sections are coated with an epoxy compound before the sections are brought together. The stressed cables are chucked off at one end and jacked at the other end to the required tension. The cable ducts then are grouted under pressure, while the prestressing force is maintained.

The post-tensioned concrete cylinder pile has a high bending strength-to-weight ratio ([B7], [B8], and [B11]), making it well suited for use in structures requiring long unsupported length, such as single transmission pole or H-frame structures in water sites or soft soil conditions.

5.2.4 Cast-in-Place Concrete Piles

Cast-in-place concrete piles, 10–24 in (250–600 mm) in diameter, are installed by placing reinforcing steel and concrete in a drilled hole formed in the ground. This is a nondisplacement-type pile that can be placed with little or no disturbance to the in situ state of the soil. As a nondisplacement pile, the side resistance capacity of the pile will be nearly equal in tension and compression.

5.2.5 Augered Cast-in-Place Piles

Augered cast-in-place piles, or augercast piles, are installed by drilling to the tip of pile elevation with a hollow shaft continuous auger [B15]. When the tip of pile elevation is reached, a ready-mix cement grout is pumped through the auger, forcing out a small plug in the drill head. The grout is pumped under pressure as the auger is withdrawn slowly, forming the pile walls against the soil and providing a good skin friction bond. Reinforcing steel can be inserted into the fresh mortar when the pile is complete. Typical reinforcing steel cages are limited to 30 ft (9 m), since the grout below that depth tends to stiffen quickly, limiting steel placement. For uplift forces, a single bar reinforcement and a reinforcing cage in the top 20–30 ft (6–9 m) is necessary. This pile also is a nondisplacement type.

5.2.6 Steel H-Piles

Steel H-piles are rolled sections designed particularly for use as piles. The width and thickness of both the flange and web usually are the same, and they are rolled in several sizes and weights per linear foot. H-piles often behave as nondisplacement piles. H-piles may, however, behave as displacement piles in certain soil conditions, when a plug of soil may be picked up between the flanges during driving.

5.2.7 Pipe Piles

Pipe piles are driven either open or close-ended. Pipe piles can be manufactured in a variety of standard sizes and wall thicknesses, and they can be fabricated to practically any size and weight per linear foot to meet special conditions. Pipe piles installed open-ended by vibratory means often are considered as nondisplacement piles.

5.3 Orientation

For lattice tower foundations, piles should be driven vertical and/or close to the batter of the tower leg. The batter helps offset the lateral shear load of the tower. If a concrete cap is used, it should be shallow with the resultant force from the tower leg intersecting the center of gravity of the pile group (Figs 5-1 through 5-6).

For a pole structure, the moment load should be transferred through the concrete pile cap to the individual piles as tension or compression loads. If piles are battered, they should be battered to intersect at the centroid of the pole loads (Figs 5-7 through 5-9).

For H-frame or single pole structures, where pipe piles or precast concrete cylinder piles are used, the piles should be driven vertical to the depth required for vertical and lateral loads. (Figs 5-10 and 5-11).

5.4 Installation

Piles generally are installed by driving, vibrating, drilling, or a combination of these methods. Pipe and concrete cylinder piles also can be installed by dead weight, augmented by excavation from the inside. Piles for transmission structures may have to resist uplift forces as well as compression forces. In these cases, the pile should be installed so that the tension capacity is not reduced. *Therefore, none of these piles should be predrilled or jetted during installation.*

The installation of piles requires good quality control combined with experience and judgment. Success depends mainly on the selection of the right hammer, the use of adequate pile cushioning material, a suitable drive-head, leads, etc., all in conjunction with a sufficient knowledge of the soil conditions. Some of the equipment used is as follows.

5.4.1 Mobile Crane

A mobile crane should be of sufficient size and capacity to handle the leads, hammer, and pile. It can be either track or wheel mounted, depending on the terrain and site access requirements.

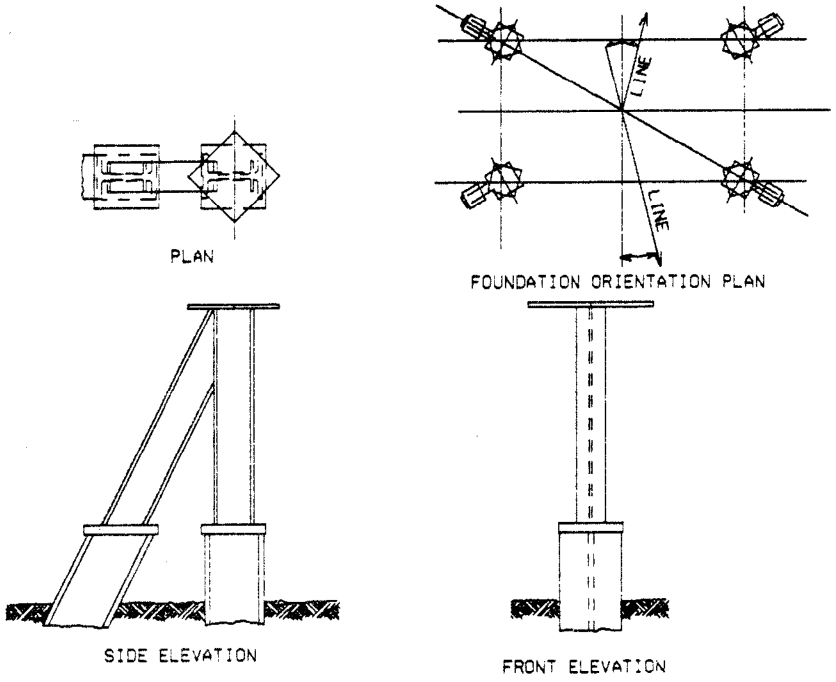


Figure 5-1 — Battered Steel Pile Foundation

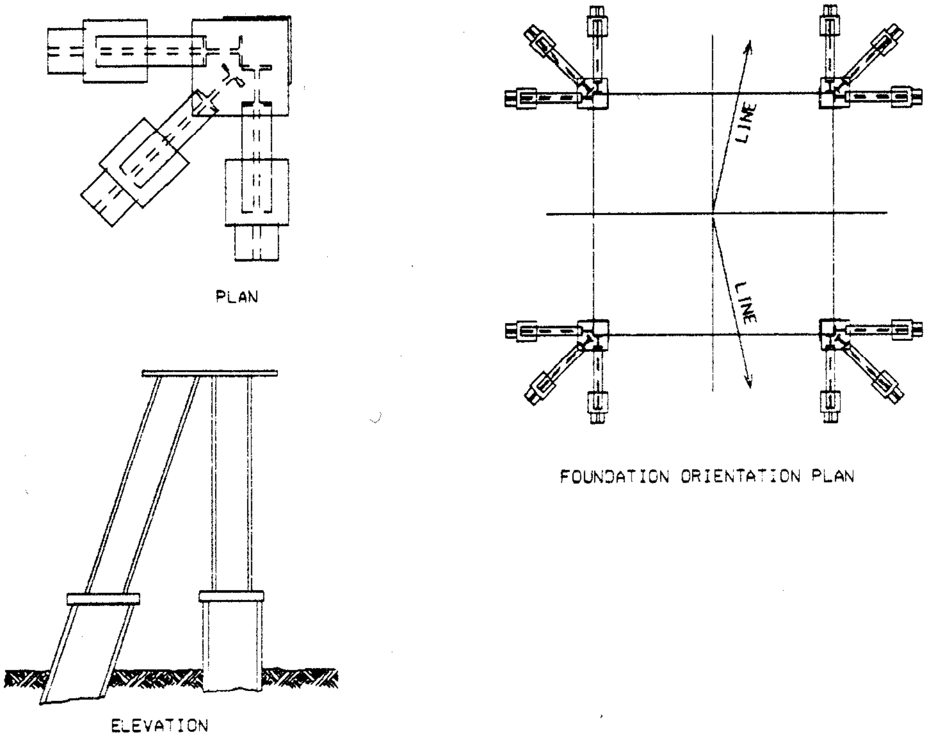


Figure 5-2 — Multi-Battered Steel Pile Foundation

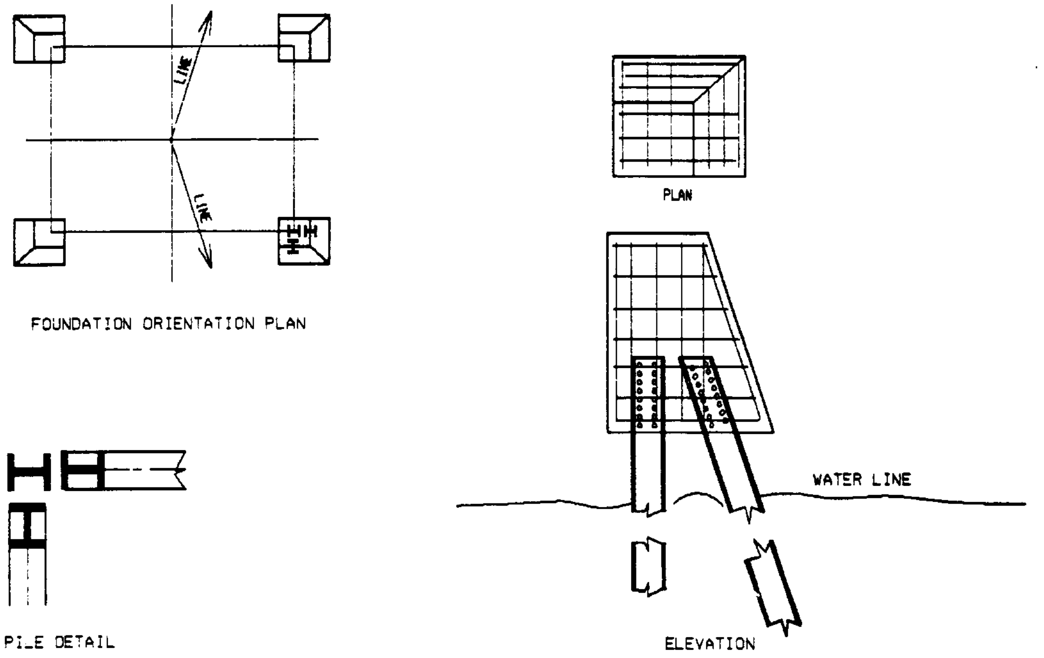


Figure 5-3 — Multi-Battered Steel Pile Capped Foundation

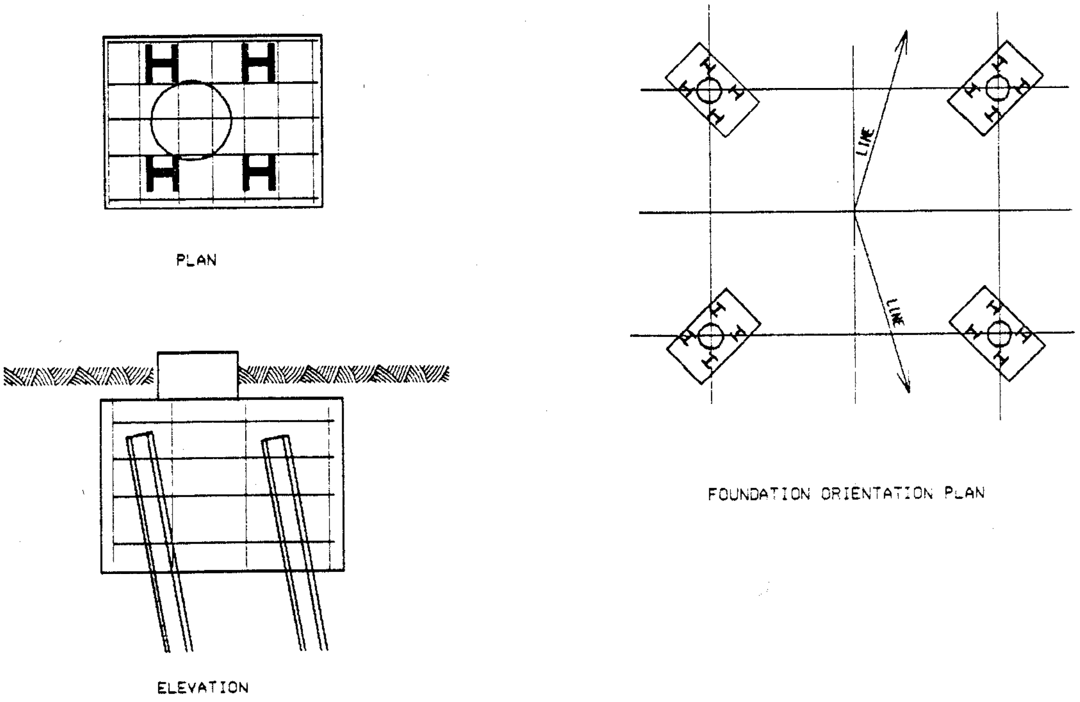


Figure 5-4 — Battered Steel Capped Foundation

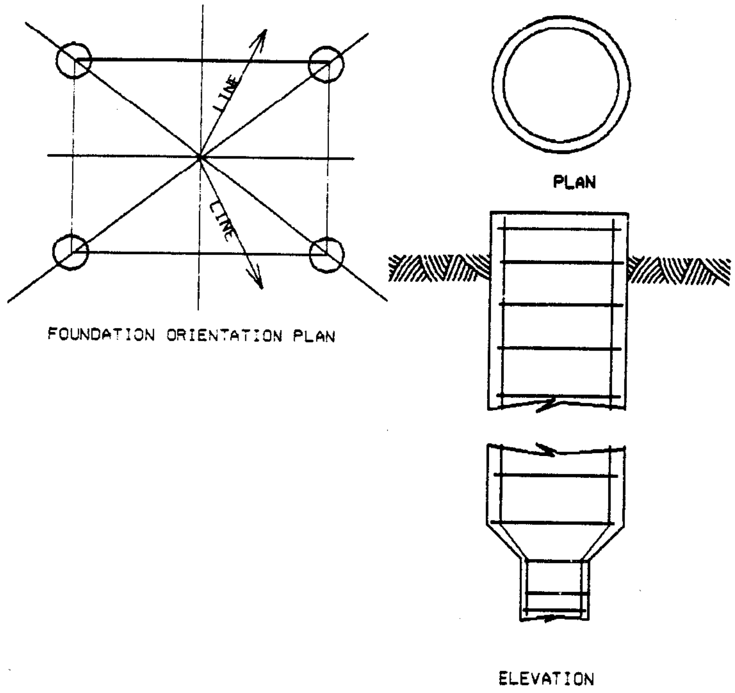


Figure 5-5 — Single Cast-in-Place Concrete Pile Foundation

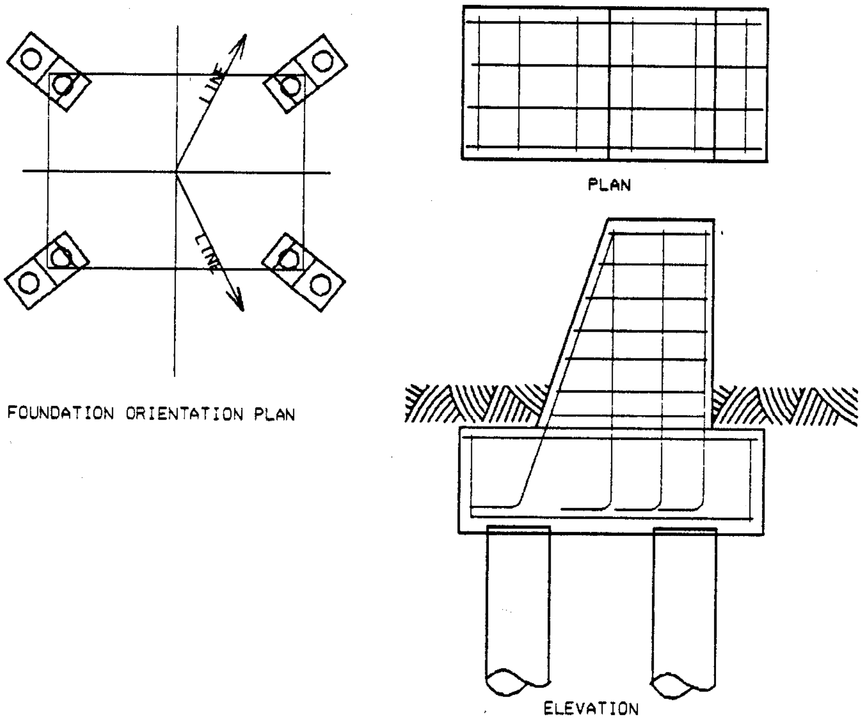


Figure 5-6 — High Reveal Cast-in-Place Concrete Pile Foundation

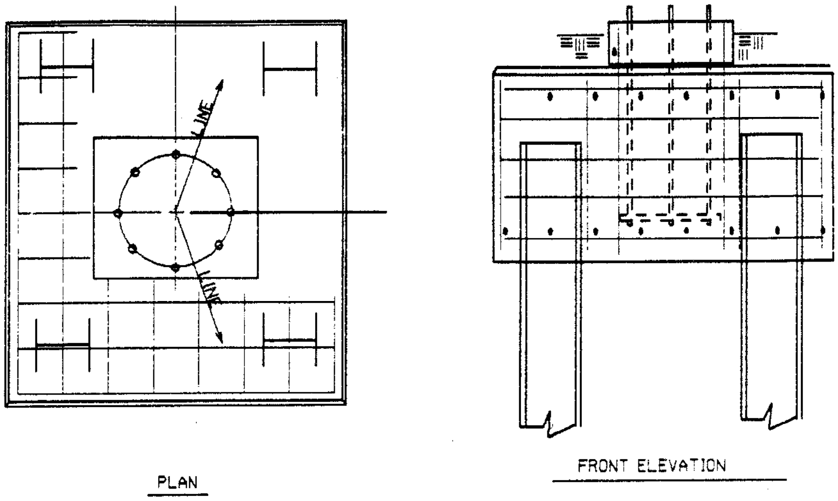


Figure 5-7 — Steel Pile Pole Foundation

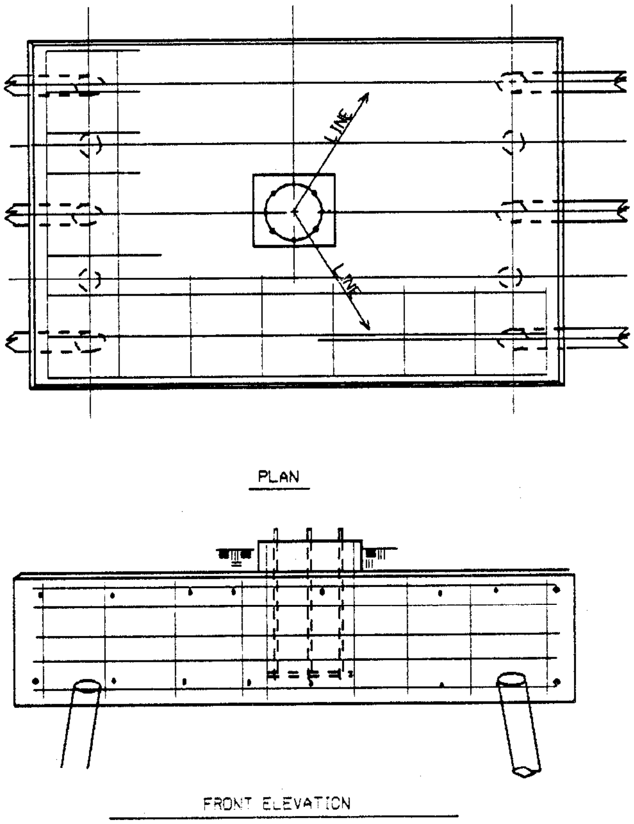


Figure 5-8 — Concrete Pile Pole Foundation

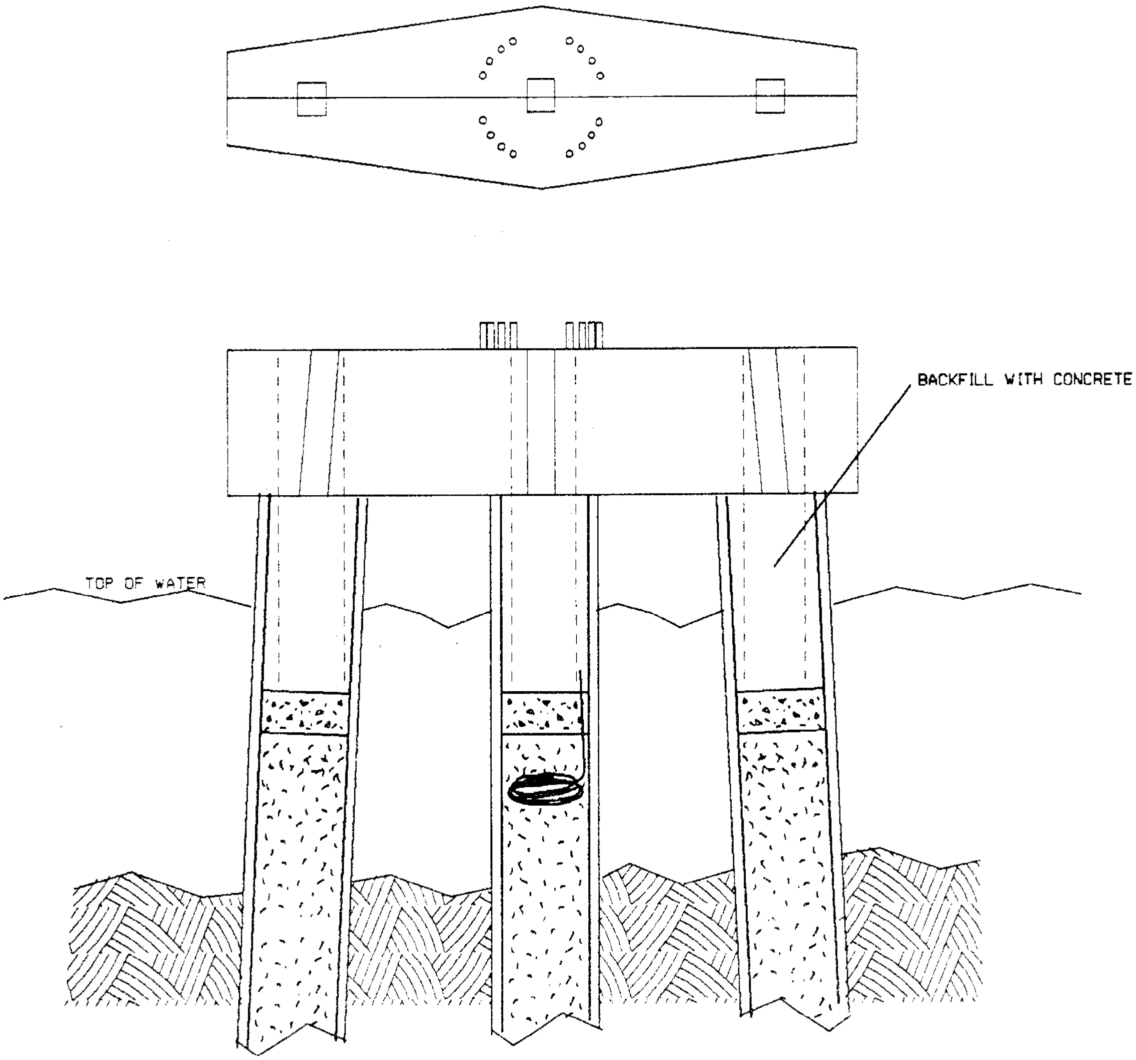


Figure 5-9 — Precast Concrete Cylinder Pile Foundation

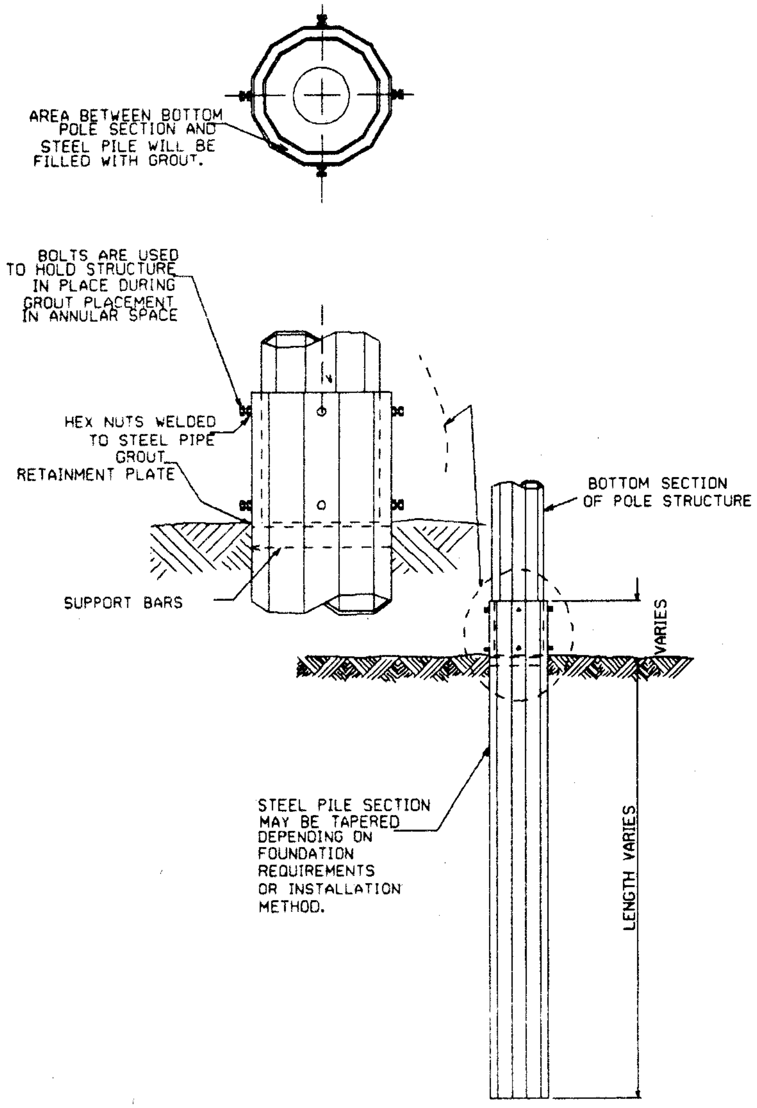


Figure 5-10 — Steel Pipe Foundation

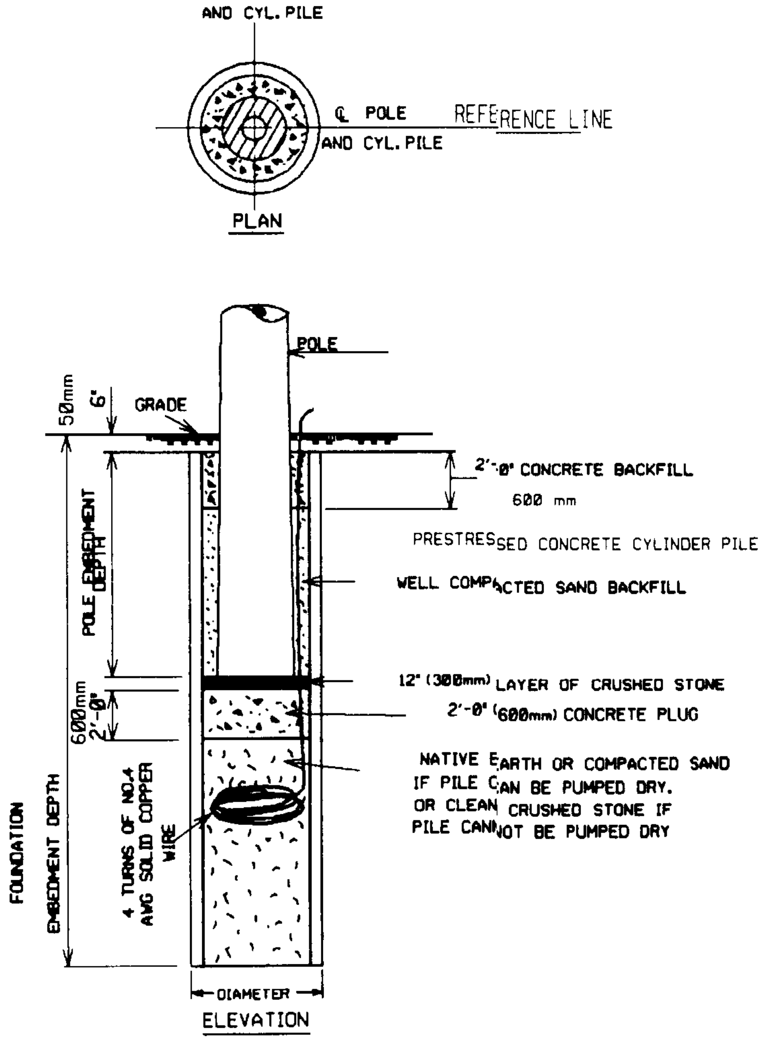


Figure 5-11 — Concrete Cylinder Foundation

5.4.2 Leads

The leads guide the hammer and pile and should be constructed to provide freedom of movement for the hammer. They should be rigged to hold the hammer and pile in alignment at the correct batter during driving.

5.4.3 Pile Hammers

Pile hammers are the source of energy required to drive a pile into the ground. Pile driving hammers are designated by types and sizes, and common types are described below.

5.4.3.1 Drop Hammer

A drop hammer is a heavy metal weight, with or without leads, that is lifted by a cable and is then released and allowed to fall on top of the pile. The energy per blow is figured by the weight times the distance it falls (force-distance).

5.4.3.2 Single-Acting Hammer

A single-acting hammer is a free-falling weight, called a ram, that is lifted by steam or compressed air applied to the underside of a piston that is connected to the ram through a piston rod. When the piston reaches the top of the stroke, the air pressure is released and the ram falls freely to strike the top of the pile. The energy is delivered by a heavy weight striking with a low velocity from the short fall. While a drop hammer may strike 4–8 blows/min, a single-acting hammer can strike 50–60 blows/min, delivering the same energy per blow.

5.4.3.3 Double-Acting Hammer

A double-acting hammer uses steam or air pressure applied to the underside of the piston to raise the ram and, during the downward stroke, applies steam or air to the top side of the piston to increase the energy per blow. With a given weight ram, it is possible to get the desired amount of energy per blow with a shorter stroke than with a single-acting hammer. The number of blows per minute will be twice that of a single-acting hammer with the same energy rating.

5.4.3.4 Diesel Hammer

A diesel hammer is a self-contained driving unit that requires no external source of energy such as steam or air. The complete unit consists of a vertical cylinder, a piston or ram, an anvil, fuel and lubricating oil tank, a fuel pump, injectors, and a mechanical lubricator. After the hammer is placed on top of the pile, the combined piston and ram are lifted to the upper end of the stroke and released to start the unit operating. As the ram nears the end of the downstroke, it activates a fuel pump that injects the fuel into the combustion chamber between the ram and anvil. The continued downstroke of the ram compresses the air and fuel, resulting in heat that is sufficient to ignite the mixture. The resulting explosion drives the pile downward and the ram upward to repeat its stroke. The energy per blow can be controlled by the operator, and may be varied over a wide range.

Diesel hammers develop a maximum energy under hard driving. Under easy driving conditions, the operation of the hammer may not be continuous. The driving force developed by certain types of diesel hammers is maintained over a relatively long period of time, thus giving an effective push to the pile insofar as pile penetration is concerned. A characteristic of the diesel hammer during hard driving is the delivery of high-impact velocity that, for some conditions, is more effective than a low velocity with a heavier ram. These hammers operate at speeds ranging from 40-55 blows/min depending on the stroke.

5.4.4 Hammer Cushion

Hammer cushions (capblocks) (Fig 5-12) are used between the drive-head or cap and hammer ram to control stresses and to protect the pile and hammer from damage that may be caused by direct impact. However, the capblock must transmit the hammer energy to the pile without excessive elastic energy losses. A commonly used capblock is made of a one-piece hardwood block approximately 6 in (150 mm) thick, with grain parallel to the pile axis, and contained in a close-fitting steel sleeve. This type of capblock has the disadvantages of becoming crushed and burned, requiring frequent replacement, and of having variable elastic properties during driving.

Capblocks made up of small pieces of wood or a few coils of wire or other highly elastic material should not be used.

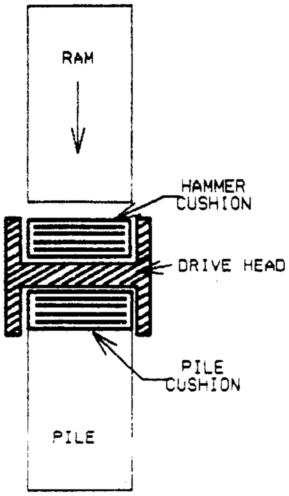


Figure 5-12 — Drive Head Assembly

5.4.5 Drive Head

A drive head (known as a drive cap, bonnet, hood, helmet, or follower) (Fig 5-12) is used to hold the head of a pile in position under the hammer and distribute the force of the hammer blow to the pile head. Drive heads for H sections preferably should be in the shape and size of the pile. Drive heads used for timber and precast concrete piles must not fit so tightly as to restrain the pile from rotating, but they should not be so loose as to prevent proper axial alignment of hammer and pile. Drive heads for steel pipe piles must fit snugly to prevent bulging and distortion of the pile head. A machined surface on the inside of the drive head should provide for uniform and complete bearing contact with the top of the pipe pile. Drive heads for pipe piles often are constructed with multiple steps to fit pipe of various diameters. This type of drive head can be made to fit either inside or outside the pipe.

5.4.6 Pile Cushion

Pile cushions (Fig 5-12) are used between the top of timber and precast concrete piles and the drive head to distribute the hammer blow, protect the pile head, and control driving stresses in the pile. They usually are of laminated construction, consisting of softwood boards that are often combined with plywood. Pile cushions should cover the entire pile head, and they must be designed to prevent spalling of the pile head or to limit excessively high compression or tension stresses in the pile during driving. In addition, they must be effective in transmitting the hammer energy to the pile. The correct balance must be obtained between hammer size, thickness of cushioning, pile size and weight, and driving requirements.

5.4.7 Vibratory Driver

The vibratory driver causes penetration of the pile into the soil by exciting the pile with either nonresonant or resonant longitudinal vibrations. Vibratory drivers are either of the low or high frequency type. The former operate at a frequency under 50 Hz, and the latter operate in the ranges of the resonant frequency of the pile itself, up to about 150 Hz. Vibrations are produced by an oscillator, consisting essentially of pairs of eccentric weights mounted on rotating shafts and phased in their operation so that the centrifugal forces generated in a pair of weights tend to cancel in the horizontal direction and to add in the vertical direction. The oscillator can be powered by electric or hydraulic motors or by gasoline or diesel engines.

The oscillator must be equipped with a suitable connector or clamp to engage the pile effectively to prevent dissipation of energy. Added weight or downcrowd may be required, in addition to the weight of the pile and vibratory drive, to achieve soil penetration during vibration.

5.4.8 Drilling Rig

Drilling rigs are available commercially in a wide variety of mountings and driving arrangements to drill for cast-in-place concrete piles, direct embedment foundations, or large-diameter drilled shaft foundations. This equipment also is used for foundations described in 4.3. They are mounted on trucks, cranes, crawlers, or skids. The drive arrangements fall into three classes: the kelly driven by a mechanically geared rotary table, the kelly driven by a yoke turned by a ring-gear or by hydraulic drive, or a hydraulic motor either mounted at the turntable or on top of the drill stem. Drilling tools vary with the type of drilling, as described below.

1) A mudding bit or auger is used with drilling mud in a wet hole. As the hole is advanced, the cuttings will be mixed with the mud for removal. This type of bit or auger is used with a circulation type of rotary drilling rig.
2) Multi-roller type bits are used to drill holes in soft or medium rock. The cutting parts of the bit are rollers equipped with teeth of hard metal that crush the rock and produce small cuttings that are suspended in drilling fluid and flushed out of the hole. Several of the rollers are arranged over the face of the bit to cover the entire area of the hole as the bit rotates. This type of bit is used with the rotary drilling rig.
3) Drilling buckets have a cutting edge on the bottom, and the spoil is pushed into the bucket as it advances. When the bucket is full, it is lifted out by the kelly through the ring-gear, which is the drive mechanism, and is swung aside and emptied into a spoil pile. If a hole is needed larger than can be pulled through the ring-gear, a hinged hole reamer can be attached to the bucket that will cut the full diameter needed and bring the cuttings back and into the bucket. Drilling buckets are most efficient in soft soils or running sands that are too fluid or loose to be brought out with an open helix auger.

5.4.9 Concrete Placement

For concrete placement of cast-in-place piles, the following equipment is used:

1) *Batch Plant*. A batch plant is a storage plant of cement, aggregates, and water, plus additional mixtures where concrete is produced to the required specifications.
2) *Transit Mixer Truck*. Transit mixer trucks are vehicles in which the concrete is mixed and transported to the construction site.
3) *Concrete Bucket*. A concrete bucket transports concrete from the transit mixer truck to the foundation site when the truck cannot get into position to deliver the concrete directly. The bucket has a bottom gate that opens in such a manner that the concrete will flow downward. It is designed so that the gate can be opened and closed to regulate the flow of concrete. Buckets are available in sizes from 1/2-8 yd^3 (0.766 m^3) for use with cranes. The gates are operated manually or by compressed air.
4) *Tremie Pipe*. A tremie pipe is a closed pipe at least 8 in (200 mm) in diameter that allows the placement of high slump concrete under water.

5.5 Splicing

It is advisable to drive the pile full length without interruption. If splicing in the leads is required, precautions must be taken. Piles for transmission structures normally are required to take both uplift and compression loads, so any splice used will have to develop the full strength of the pile. Spliced Hpiles and pipe piles require full penetration butt welds and splice plates. The sections to be spliced must be held in accurate alignment during the splicing operation.

5.6 Installation Problems — Geotechnical

Other than subsurface obstructions such as boulders and debris that might affect pile driving, the driving itself can introduce the following affects on the soil around the pile.

1) *Subsidence*. Vibration from pile driving in loose sand may cause compaction of sand. Consequently, the area may settle and adjacent structures may be affected. In saturated fine sand and silt, the shock may introduce excessive subsidence.
2) *Heave*. Pile driving in clays commonly is associated with surface heave and lateral displacement. The upheaval may well exceed 12 in (300 mm) in plastic soils. Piles uplifted by ground heave should be redriven. To minimize heave and lateral movement, pile driving should be started from the center of the pile group and proceed outwards.
3) *Compaction*. Sand and gravel within a lateral distance of about 3 diameters of the pile and 2 diameters below the tip is compacted from pile displacement. Consequently, a pile group in sand often behaves as a rigid block of compacted soil.
4) *Disturbance*. Clay soils surrounding the pile are disturbed from the displacement of the pile. This disturbance may extend to a large lateral distance. In ordinary cases, the clay regains its strength and, in 30 to 50 days, 90% or more of its strength may be regained.
5) *Soil Freeze*. When piles are driven through soft clay or loose saturated sand and silt, the disturbance of the soil from pile driving may temporarily reduce the shear strength of the soil, and the dynamic resistance to penetration may be very low because of the generation of excess pore water pressures in the soil. In time, the pore water pressures will dissipate, and the soil will regain some of its shear strength. The time required for this process could range from an hour to more than 30 days. This phenomenon is difficult to evaluate and requires experience and good judgment in utilizing its benefits.

5.7 Installation Problems — Construction

5.7.1 General

The decision to utilize a pile foundation may present unique accessibility problems. Generally, the pile foundation design is selected because of deep surface soft soils. Piles of any material and installation equipment (driving hammers, leads, and cranes) are items of considerable weight. If the foundation soil materials are representative of the soils in the immediate area, an access with adequate bearing capacity must be provided to enable these items to be moved to the structure site. This access may consist of simply adding gravel to stabilize the soil, or it may require the use of mats to reduce the bearing pressure.

5.7.2 Transporting Piles

During transportation to the construction site, care should be exercised in handling to prevent deformation of steel and pipe piles or cracking of wood and concrete piles. For long piles, significant handling stresses can result from the large bending moments developed during pickup, depending on the location of the pickup point. Tensile stresses developed in concrete or wood piles can result in structural damage to the pile (i.e., cracking). Bending moments caused by handling long slender steel piles can cause permanent curvature of the pile, resulting in undesirable bending stresses during and after driving. Since the magnitude of bending moments depends on the location of the pickup points, they should be determined based on allowable stresses and should be clearly marked. Initial alignment of the piles is most important in reducing the subsequent possibility of creating excessive bending stresses.

5.7.3 Driving Piles

Drilling of a pilot hole or spudding may be necessary to remove or displace obstructions near the surface. The use of fixed leads is desirable to eliminate sway at the head and to ensure an axial hammer blow. The use of driving heads to distribute the blow of the hammer, and cap blocks to prevent damage to the pile and hammer, is necessary for impact driving. Overdriving of a pile may cause structural damage and should be avoided.

The selection of the proper hammer for the size, length, and weight of pile, the soil conditions, and the required load capacity or driving requirements should be given the proper analysis. The selection of the hammer should be the contractors responsibility, with the concurrence of the engineer. Considerations also should be given to the drive lead to be used. For precast concrete piles, the type and thickness of pile cushion is selected to avoid excessive stressing during driving.

The installation of piles using a vibratory driver is not applicable to all pile types or soil conditions. It is generally more effective in granular soils and with nondisplacement piles such as H-piles, open-end pipe, and precast post-tensioned concrete cylinder piles. Under suitable conditions, vibratory drivers can install piles quite rapidly. They are equally effective in extracting piles or temporary casings used for various types of uncased cast-in-place concrete foundations.

5.7.4 Problems During Driving

Problems during driving are described below.

5.7.4.1 Timber Piles

To prevent tip damage, timber piles should not be driven to high tip resistance or where frequent obstructions are found. If timber piles must be used under these conditions, steel pile points may be necessary to protect the tip. Such points should be fiat at the bottom to utilize the full tip area. To prevent splitting and brooming of the pile butts, they should be chamfered to accommodate the drive cap and ensure full contact with the top surface of the pile.

If, during driving, penetration resistance suddenly decreases, breakage of the pile should be suspected. In such cases, the pile can be withdrawn for inspection or be abandoned and replaced. If penetration resistance suddenly increases, driving should be stopped. Overdriving is the greatest cause of damage to timber piles. As a guide, timber piles should not be driven to penetration resistances greater than 5 blows/in (25 mm) using hammers with energies equivalent to that of a Vulcan No. 06 (15 000 ft·lb).

5.7.4.2 Steel H-Piles

These piles are relatively flexible, especially about the weak axis. It may be necessary to support long piles at intervals along the lead to prevent buckling under the hammer blows.

During driving, subsurface obstructions, boulders, or hard driving in rock could cause damage to pile tips. This damage generally can be avoided by using tip reinforcement. Steel H-piles also have a tendency to rotate and be deflected readily from axial alignment by boulders or other obstructions.

Overdriving with greater than 12–15 blows/in (25 mm) increases the possibility of damaging the pile (bending, twisting, flange distortion, and tearing) and should be avoided. Steel H-piles should be of sufficient cross-sectional area to provide the necessary stiffness for adequate driveability to achieve the required capacity.

5.7.4.3 Reinforced or Prestressed-Precast Concrete Piles

Damage during driving could be in the form of spalling, cracking, or actual breaking. Spalling could take place either at the tip of the pile because of high tip resistance, at the pile head because of insufficient cushioning material or eccentric hammer blows, or along the pile length because of buckling of long piles inadequately supported. Spalling also could result from manufacturing errors, such as the head of the pile not being a plane surface perpendicular to its longitudinal axis, the projection of reinforcing steel above the concrete surface, the lack of adequate spiral reinforcing at the pile head or tip, the top edges and corners of square piles not being properly chamfered, or the concrete not being sufficiently cured or of poor quality.

Cracking of the pile could be caused by high compressive or tensile stresses or torsional forces. In severe cases, actual breaking of the pile could occur.

For concrete piles that are properly made, spalling at the pile tip can be avoided by not overdriving to greater than 6–8 blows/in (25 mm). Spalling at the pile head can be controlled by the use of a proper pile cushion, drive head, and driving equipment that will hold the hammer and pile in accurate alignment. Long, slender, vertical piles may require guides at intervals along the leads to prevent buckling under the hammer blows. Battered piles may have to be supported at intervals in the leads to reduce the gravity-induced bending to acceptable limits.

When the pile tip encounters little or no soil resistance, high tensile forces could be built up in the pile during driving, resulting in cracking. Under such conditions, the driving energy should be reduced until pile tip penetration resistance is built up, such as by using a diesel hammer with a variable throttle control. High tensile forces also could occur in the pile when the reflected stress wave reaches the top of the pile, and the hammer-capblock-pile cushion system does not have sufficient weight and stiffness to prevent the stress wave from being re-reflected as a tensile wave.

This phenomenon can be prevented by using a driving system of adequate weight and stiffness. Torsional forces can be reduced using drive heads that do not restrain the pile from its tendency to rotate. Much of the possible damage to precast concrete piles can be avoided with proper pile cushions.

5.7.4.4 Precast-Prestressed Concrete Cylinder Piles

Most of the above information on precast concrete piles pertains to concrete cylinder piles also. In addition, when these piles are driven open-ended, care must be taken to avoid high soil or hydraulic pressure from building up inside the pile that can cause longitudinal cracks [B12].

5.7.4.5 Cast-in-Place Concrete Piles

These piles usually are 10–24 in (250–600 mm) in diameter and are drilled with a rotary drill rig using circulating drilling fluid. Cast-in-place concrete piles are installed by the same mud slurry method described in 4.3 (Fig 5-13). They also have the same installation problems described in 4.8 and 4.9. The concrete in each pile should be carried at least 2 ft (600 mm) above the cut-off elevation and either be removed while fresh or by chipping after excavation for the pile cap.

If a casing is used, it should be withdrawn as the concrete is placed, so that sufficient head of concrete will be maintained to prevent extraneous material from entering the concrete pile.

The design mix of concrete for the piles should be a high slump mix of 7–10 in (180–250 mm), be rich in cement with 7 1/2 bags/yd^3 (one bag is 94 lb [418 N]), and have a maximum aggregate size of 3/4 in (20 mm) stone.

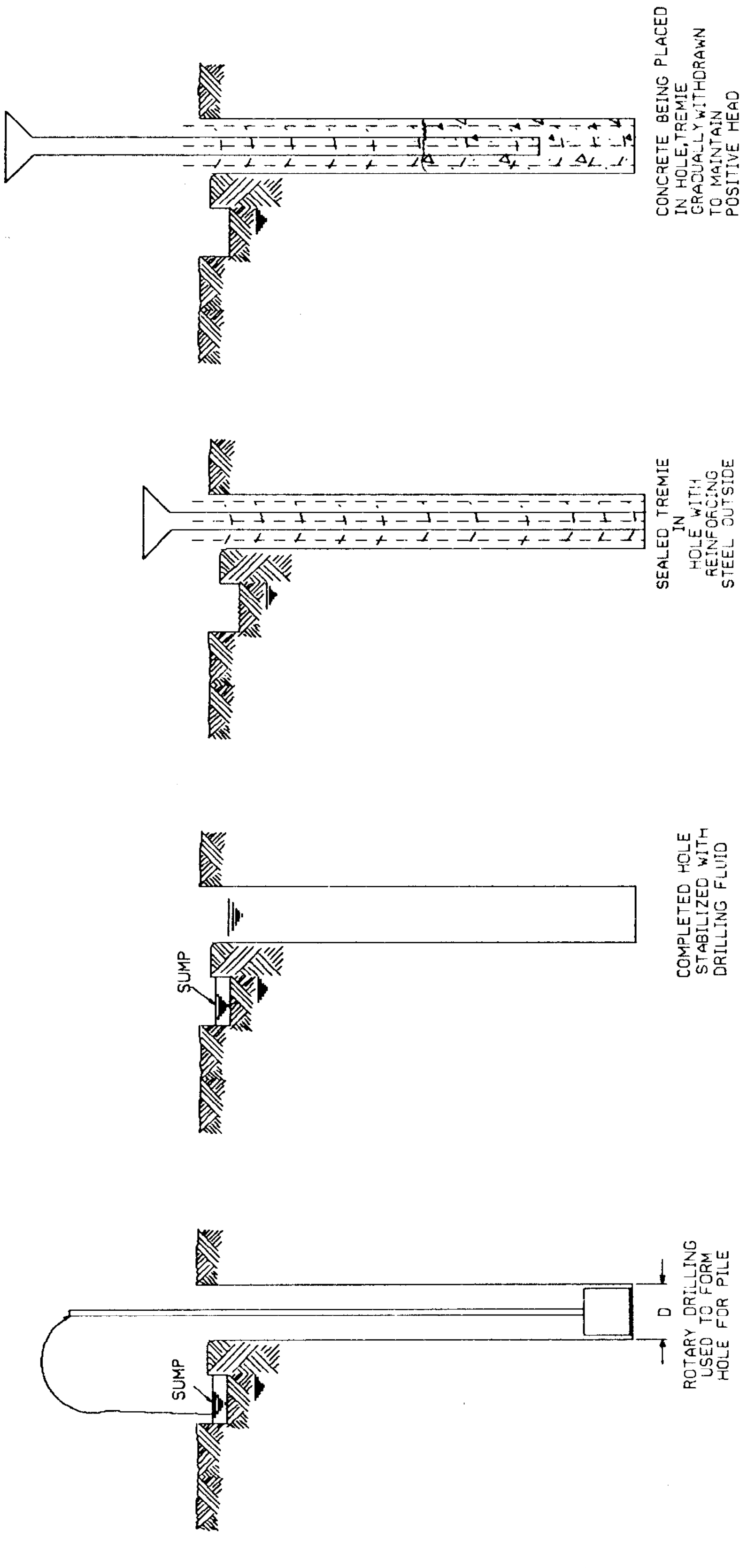


Figure 5-13 — Typical Procedure for Installation of Cast-in-Place Pile

5.8 Inspection

The inspection of the pile installation operations is important in securing safe and economical foundations. A qualified, full-time inspector should be provided for each rig and should continuously observe all operations, record required information, and be aware of conditions requiring the attention of the engineer. The geology of the line should be summarized, and the soil boring logs should be available to the inspector.

Carelessness in handling piles, overdriving, hitting obstructions, driving out of plumb, and retardation of hammer speed or stroke should not be permitted by the inspector.

Piles should be driven continuously in their specified locations, to their specified batter, and to the required depth or penetration resistance. The pile-driving equipment must be in good repair and be operational to perform the required work. No predrilling, except for drilled cast-in-place piles, or jetting is permitted for piles designed for developing uplift resistance. The type, size, and energy rating of the pile-driving hammer is determined and approved by the foundation engineer, based on the length, weight, and type of pile to be driven and design load. A record of each driven pile should be maintained showing

1) Date
2) Time
3) Type and make of hammer and its stroke or rated energy
4) Other driving equipment including driving head, cushion, etc.
5) Pile location, type, size, batter
6) Location of splices
7) Driven length to cutoff elevation
8) Cutoff elevation
9) Continuous record of the blows per foot required for installation.

In addition, the amount of concrete placed, if cast-in-place piles are used, and any unexpected difficulties or obstructions should be recorded, together with the depth encountered and extent of each difficulty.

Upon completion of pile installation for a single foundation, the foundation area may be excavated to the required grade, and the pile tops may be cut off at their required elevation. The pile cap forms, reinforcing steel, and anchor bolts or stub angle should be placed for final inspection and approval before the placement of concrete.

5.9 Bibliography

[B1] ACl 543 R-74 (80), Recommendations for Design, Manufacture and Installation of Concrete Piles, Committee 543, American Concrete Institute.

[B2] ANSI/AWS D1.1-90, Structural Welding Code — Steel.

[B3] ASTM D 25, Specifications for Round Timber Piles.

[B4] *American Wood-Preserver's Association Book of Standards*, AWPA, Stevensville, MD 21666.

[B5] Bastian, C. E. “The Effect of Vibrations on Freshly Poured Concrete,” *Foundation Facts*, Vol. 6, No. 1, 1970, pp. 14–17.

[B6] Chellis, R. D. *Pile Foundations*, 2nd ed. New York: McGraw-Hill Book Co., 1961.

[B7] “Cylinder Pile Bending Test,” *Foundation Facts*, Vol. 11, No. 1, 1976, p. 21.

[B8] Fuller, F. M. "Raymond Cylinder Piles Meet the Challenge of High-Load Tests," *Foundation Facts*, Vol. 12, No.1, 1979. pp. 1–20.

[B9] Gardner, W. S. and Greer, D. M. *Construction Of Drilled Pier Foundations*, New York: John Wiley and Sons, 1986, p. 128.

[B10] Hunt, H. W. *Design and Installation of Driven Pile Foundations*, Associated Pile and Fitting Corp., Clifton, NJ, 1974.

[B11] "Lateral Tests on Uni-Piles," *Foundation Facts*, Vol. 8, No. 1, 1972, p. 7.

[B12] "Machine and Contracts Speed Job," *Engineering New Record*, Vol. 185, No. 8, Aug. 10, 1970.

[B13] *Practical Guidelines for the Selection, Design and Installation of Pile*, American Society of Civil Engineers Committee on Deep Foundation, 1984.

[B14] "Recommended Practice for Design, Manufacture, and Installation of Prestressed Concrete Piling," *Journal of the Prestressed Concrete Institute*, Vol. 22, No. 2, Mar.-Apr. 1977.

[B15] Rodgers, T. E. "Lock-In-Place Piles for Hurricane Proof 115 kV Towers Footing," *Electrical World*, Vol. 165, No. 14, Apr. 4, 1966, pp. 66–70.

6. Anchors

6.1 Introduction

Anchors are long, slender, tension members that interact with the soil to support tension loads. Anchors are installed in several different ways. Plate or spread anchors (Fig 6-1) are bearing-type anchors that are placed in excavated holes and backfilled. Helical anchors (Fig 6-2) are bearing and/or friction-type anchors that are screwed directly into the ground. Drilled anchors (Fig 6-3) are friction-type anchors, consisting of tendons, that are placed in excavated holes and grouted to fill the annulus. Several anchors may be installed in groups and tied together through a cap to form a complete foundation. Many variations are utilized for specific situations.

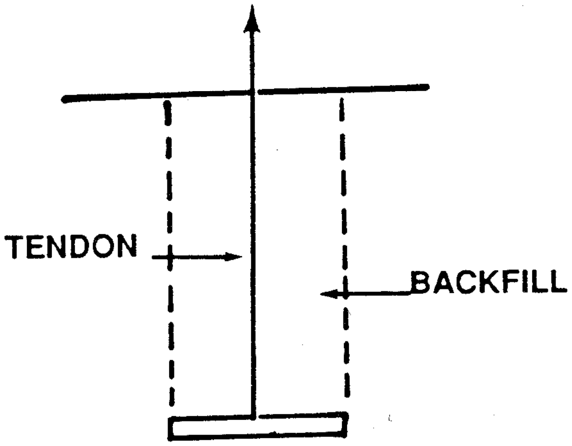


Figure 6-1 — Plate Anchor

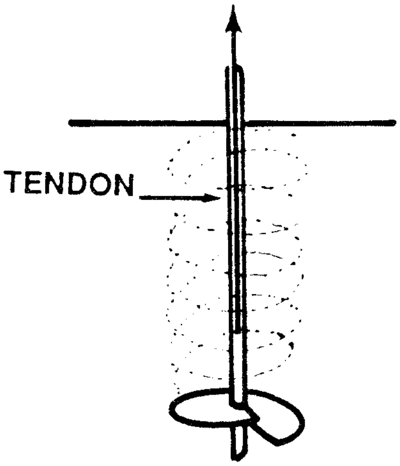


Figure 6-2 — Helical Anchor

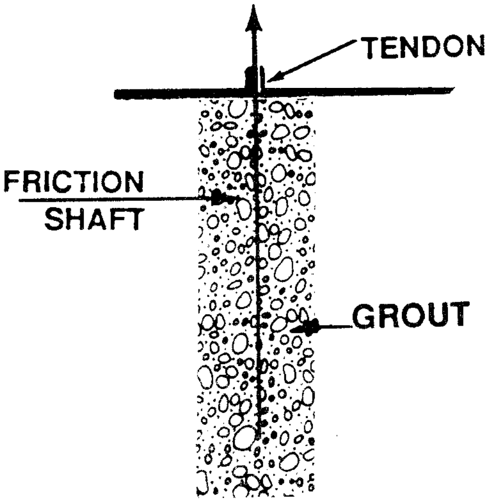


Figure 6-3 — Grouted Anchor

6.2 Excavated Soil Anchors

6.2.1 General

Excavated soil-type anchors have been used for many years and were the original guy anchors used by utilities. This type of anchor is still widely used because the equipment and technical requirements are minimal. Construction practices, especially the backfilling operation, greatly influence the capacity of this type of anchor.

6.2.1.1 Spread Anchors

Spread (expanding) anchors (Fig 6-4) are manufactured devices that are collapsed and installed into the soil by a drill or bored hole. These anchors then are expanded by mechanical means, such as striking or rotating with a special tool and backfilling the drilled hole. The expanded surface then bears against the undisturbed soil adjacent to the backfilled hole. Several factors need to be considered, including

1) *Hole diameter.* The least possible diameter results in better anchor performance.

2) *Full expansion*. Follow manufacturer's instructions to ensure the maximum possible anchor area is in contact with the undisturbed (unexcavated) soil.
3) *Backfill compaction*. Compact well for a minimum of 2 plate diameters above plate. Compact all soil to prevent water saturating the loose backfill more than the surrounding undisturbed soil.
4) *Alignment of predrilled hole with guy angle*. Locate and drill as accurately as possible.

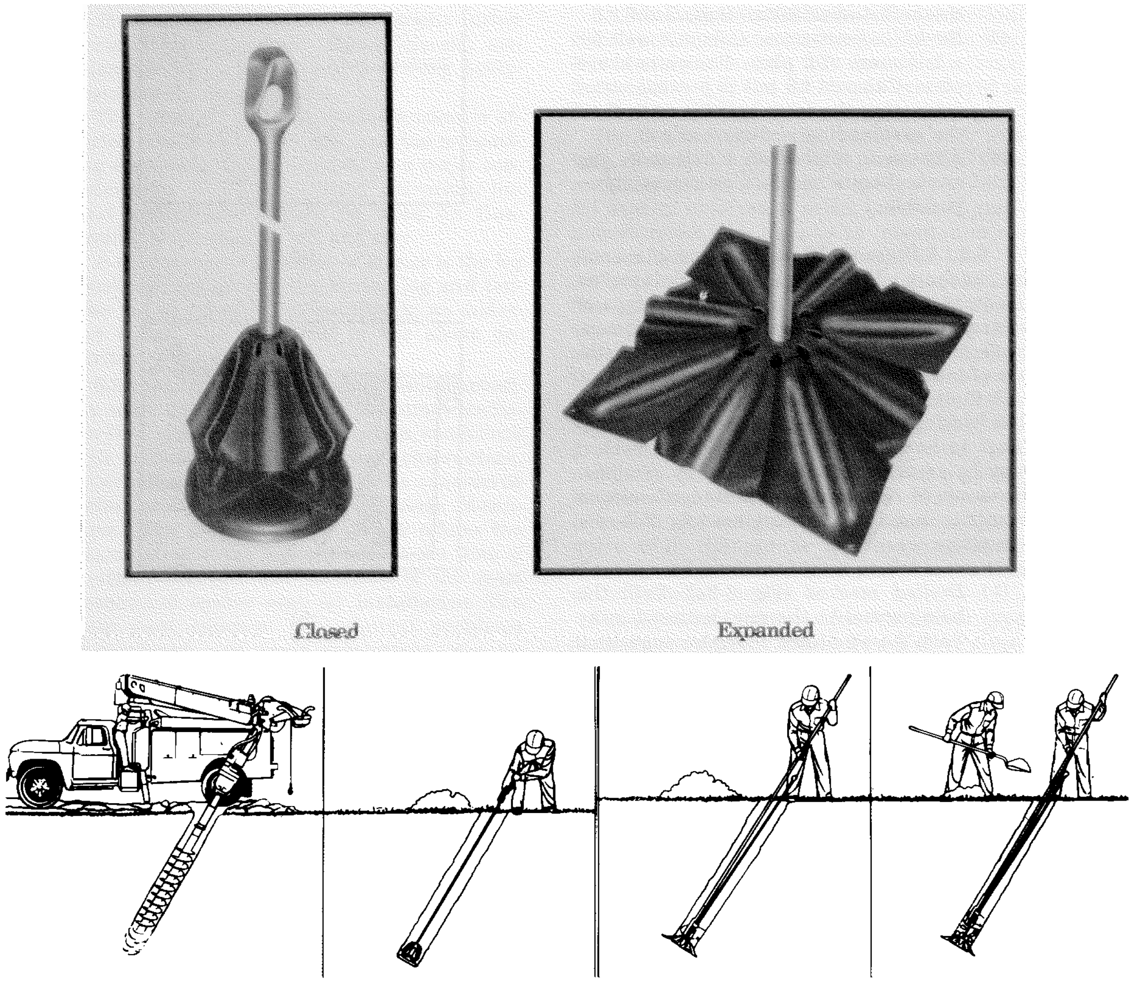


Figure 6-4 — Spread (Expanding) Anchor

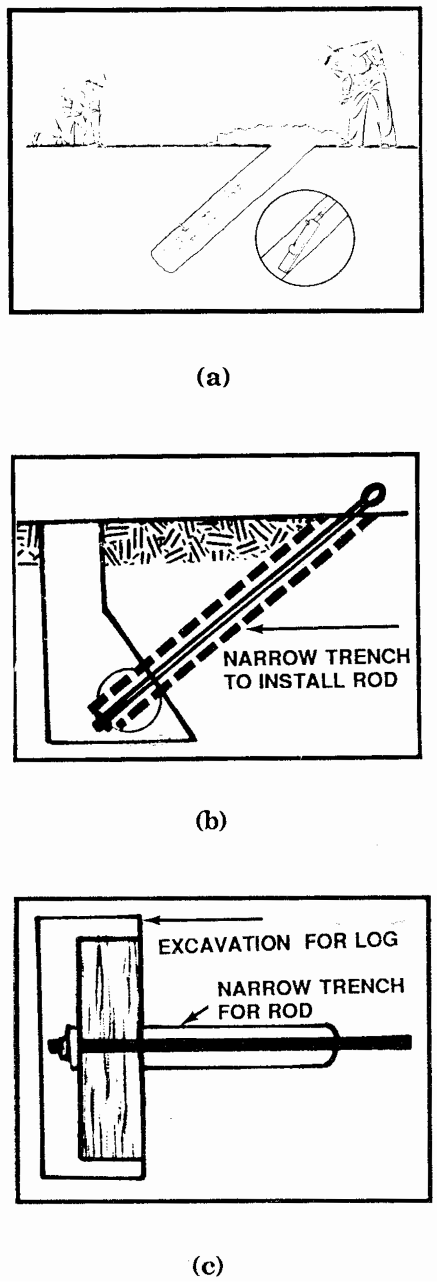
6.2.1.2 Plate and Log Anchors

Plate and log anchors (Fig 6-5) also are known as deadman anchors. They are a passive type of system that is installed to its finished dimensions and backfilled. The two common methods of installation are discussed below.

Both can be achieved using hand labor only. The “drilled” method typically uses only hand labor to backfill, while the “trench” method may be excavated and backfilled by machine. However, in remote sites and underdeveloped countries, hand methods are used for this construction.

1) *Drilled method* (Fig 6-5 a). Drill the hole normal to the guy, battered away from the structure, using an auger that conforms to the curvature of the plate. Drill the rod hole or trench with the minimum possible trench width. After connecting the rod to the plate, backfill the hole and compact well for the entire depth of the hole.

2) *Trench method* (Fig 6-5 b). Excavate the trench with the wall nearest the structure as vertical as practical. Sculpture the trench floor and front wall to permit the plate to rest firmly against the soil "normal" and to the guy plane. If possible, drill the anchor rod hole to intersect the plate (deadman) at the attachment point. If the rod is "trenched in," use a minimum width trench. Backfill and compact the soil to 100% of its original density for two times the plate width above the plate.



(a)

(b)

(c)

Figure 6-5 — Plate and Log Anchors

The trench method is the normal installation utilizing an excavator. The backfilling may be done with larger equipment to achieve higher densities. The capacity of the anchor installed by either of these methods is a function of the backfill density quality. Loose fill placed under or behind the anchor plate permits an unacceptable amount of creep, since the soil has a tendency to flow around the anchor when loaded.

6.2.1.3 Installation Equipment

Equipment required for the excavated-type anchors is the least sophisticated of the various anchor installation equipment. Hand shovels, mechanical excavators, and hole drilling equipment are the most common.

The capacity of the excavated anchor is affected greatly by the backfill, and the compacting equipment therefore becomes a major consideration. In the backfilling operation, impact compactors should be used on finegrained soils, such as silt and clay.

A special case of this type of anchor is the log deadman, consisting of a buried log and tension rod (Fig 6-5 c). It is installed in an undercut trench and backfilled in the above described manner.

6.2.2 Installation Problems — Geotechnical

As with all foundation construction, undiscovered and unknown subsurface conditions will become evident during construction. Alternative procedures should be considered before work commences to minimize "downtime." The excavated-type anchor allows the examination of the bearing soil, at the time of construction, and the selection of the most economical anchor type for installation. The four most common geotechnical problems encountered, and their resolutions, are as follows:

1) *Boulders in excavation, too large to excavate*. Move the anchor location or overexcavate and remove boulder. The latter solution requires greater amounts of compacted backfill.
2) *Bedrock shallower than expected*. If removal by a large core-barrel drill is not practical, change the anchor type to grouted-type anchor.
3) *High water table*. If excavation is possible, backfill with an ungraded granular backfill and vibrate well during compaction with the largest practical vibrating compactor. Dewatering is sometimes practical by placing a sump hole well outside the projected area of the plate anchor. The sump is to be backfilled and compacted after the first several lifts of fill are placed on the plate anchor.
4) *Very loose or lightweight soil*. This condition requires importing select backfill or a mixture of imported and native soil.

6.2.3 Installation Problem — Construction

Construction of excavated soil anchors is similar to construction of spread footings. Sections 3.4, 3.6, and 3.8 should be referred to for further details.

The major construction problem with this type of anchor is the backfill placement. If the anchor installer is unable to achieve the backfill density required, a select backfill of granular material may have to be imported to replace or mix with the native backfill.

The orientation of the anchor with respect to the guy cable may have to be changed. Geotechnical problems may require the anchor to be installed in a different orientation than that specified by the manufacturer or engineer. Deadman anchors typically have keys to prevent them from creeping out of the ground under load. The installer must first notify the designer of his intent to change orientation and then modify or add keys as required by the designer. The designer may require that changes to the drawings/specifications be confirmed by a performance test of the installed anchor.

Construction tolerances for this anchor type are the most flexible. The following three properties should be specified with tolerances given in 6.2.4:

1) Location
2) Anchor rod alignment
3) Backfill

6.2.4 Inspection and Construction Tolerances

The excavated anchor is simply a foundation in tension, and normal foundation construction tolerances should be applied. The obvious difference is the flexibility (should the contractor have to relocate the anchor). Relocating the anchor may cause the guy to load the structure differently than was assumed in the structure design. These changes in structural loading need to be considered before construction begins, so that an alternate location can be made in the field in an expedient manner, by specifying the permissible range of conditions below:

1) Location of the anchor rod should have a tolerance of +2% of the structure height from the staked location. Check for possible electrical conflicts.
2) Anchor rod alignment should be within ±5° to the specified guy angle.
3) Backfill compaction should be expressed in terms of relative density for granular material and Proctor density for cohesive soil. Test methods with ASTM designations should be specified. The density of the backfill should be checked by the sandcone method or nuclear densiometer at angle structures and crossing structures of major transmission lines. The inspection of the backfill is critical.

6.3 Drilled Anchors

The construction of drilled anchors involves rotary and, occasionally, percussion drilling equipment to excavate or bore the shaft to the bearing stratum. Drilled anchors are similar to drilled foundations given in Section 4. One of the appealing aspects of drilled anchors is the ability to install the anchors with a single piece of equipment. The various types of drilled anchors are discussed below.

6.3.1 Installation

The equipment to install drilled anchors must be suitable to the terrain and be able to position itself physically at the proper location to accomplish its intended purpose. The drill holes and anchors may be installed with hand-held equipment (i.e., posthole augers or tripod mounted percussion bit), specialized rotary equipment, or sophisticated “down-hole” equipment. Rotary equipment for installing helical anchors must have sufficient ground clearance under the kelly bar and an installing torque of at least one-tenth the holding capacity required (i.e., a 100 000 lb [445 kN] anchor requires a 10 000 ft.lb [13.5 k N·m] machine and down force of at least 1000 lb [4.5 kN]).

6.3.1.1 Drilled Concrete Anchors

Drilled concrete anchors include all the large-diameter concrete drilled shafts used for high-capacity

loads. The drilled shafts may be aligned vertically or axially with the guy. They may be “belled” or straight (Fig 4-1). The most economical drilled concrete anchor, under normal access conditions, is the vertical, straight shaft, with a “bent anchor eye” (Fig 6-6). The passive soil pressures resist the vertical shaft rotation.

The anchor may be installed using either an open or cased hole. Drilling mud may be used to hold the hole open when the walls or bottom of the hole are unstable.

The drilled concrete anchor is constructed in essentially the same manner as the drilled shaft foundation (see Section 4). The addition of the anchor rod is the only difference.

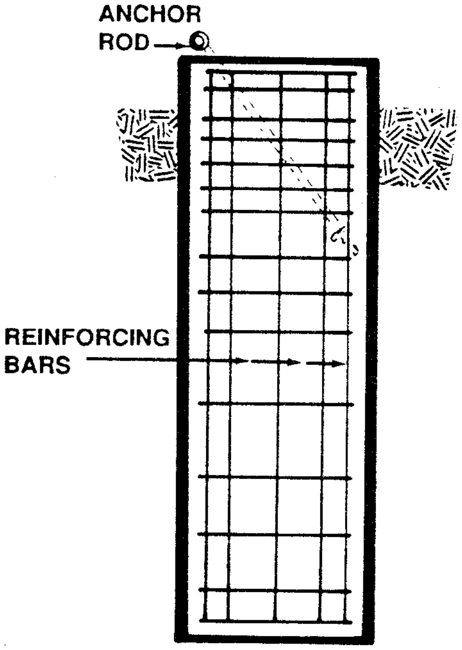


Figure 6-6 — Large Drilled Concrete Anchor

6.3.1.2 Large-Diameter and Low-Pressure Drilled and Grouted Anchors

Large-diameter and low-pressure drilled and grouted anchors (Fig 6-7 b), having a diameter of 12 in (300 mm) or greater, are drilled or bored with a batter or inclination equal to the guy angle (i.e., axially aligned with a guy strand). While they may be cased in unstable soil, their most economical application is in conditions that permit an uncased, uniform-diameter borehole. This anchor type typically is used in unconsolidated soils and low-strength, highly-fractured rock. The use of drilling mud generally is not required.

The boring may be advanced by means of any of the various rotary drilling or percussion machines to the required depth. The tendon, consisting of strand or bar, is inserted into the borehole with the lower end fitting attached, such as a plate. The grout tube or tremie is inserted to the full depth of the bore. Grout or concrete then is placed by gravity feed through the tube. The grout must meet the required specifications with regard to viscosity, maximum aggregate size, etc. The grout/concrete should be placed from the bottom of the hole, and the tube should be kept at least 2–3 ft (600–900 mm) below the top of the pour at all times until completed. The tendon should not be vibrated.

A special case of the low-pressure grouted anchor is the small-diameter grouted anchor (Fig 6-7 a). This type of anchor is installed in rock for anchor capacities of 100 000 lb (445 kN) or less. The tendon is installed as given above. The grout often is mixed manually and injected into the bore by means of a grout tube and funnel. Gravity provides the only pressure for the placement of the grout.

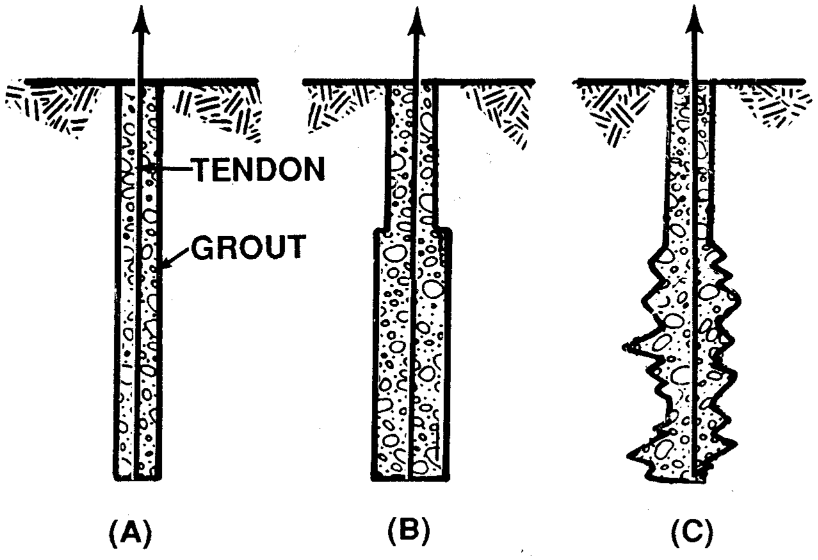


Figure 6-7 — Small Drilled Concrete Anchors

6.3.1.3 Small-Diameter and High-Pressure Drilled and Grouted Anchors

Small-diameter and high-pressure drilled and grouted anchors (Fig 6-7 c and 6-8) have diameters of less than 12 in (300 mm) and tend to be economical in granular soils and rock. If used in rock, they are of straight shaft, and the rock socket is cut 3–5 ft (1–1.5 m) into competent rock. Soil anchors may be belled or straight. After the hole has been drilled with a continuous flight auger, down-hole hammer, pneumatic drill, or tricone rotary bit, the tendon with lower-end fitting is installed to the full depth of the hole.

The grout tube is fixed to the tendon by taping every 5–6 ft (1.5–1.8 m), with its end approximately 4–6 in (100–150 mm) from the end of the tendon. The tube may be plugged with a tapered plug to prevent clogging during insertion. The ground surface of the hole may be covered with a vented plate.

Pressure grouting of the anchor is performed using specifications that consider soil/rock type, depth, and purpose of grouting. Normally, high-pressure grouting does not exceed 300 lb/in^2 (2.1 MN/m^2) in rock. It has been shown that pressures over 450 lb/in^2 (3.1 MN/m^2) are unnecessary for achieving higher capacity. Soil anchors typically are grouted to 1 lb/in^2 per ft (6.9 kN/m^2 per 300 mm) of overburden. The Federal Highway Administration ([B6] and [B8]) gives extensive details of this method of construction and should be referred to.

The small-diameter, high-pressure anchors typically are not used for guy anchors on transmission structures. They have been effectively used to resist the foundation uplift of four-legged towers (Fig 6-8).

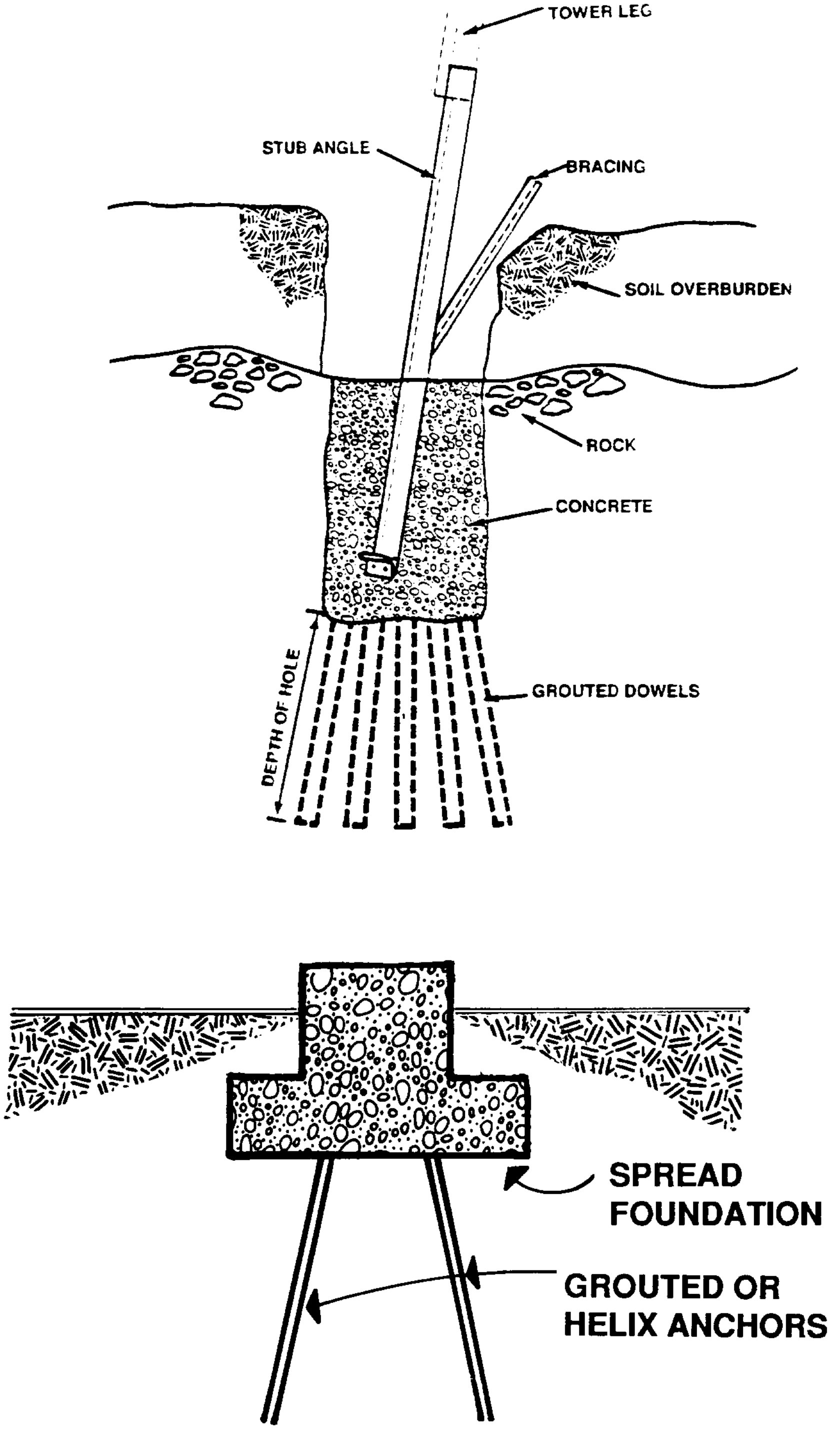


Figure 6-8 — Anchor Assisted Foundations

6.3.1.4 Helical Screw Anchors

Helical anchors (Figs 6-9 through 6-11) are screwed directly into the soil with rotary equipment, causing as little disturbance to the soil as possible. They may be installed with various types of equipment, but rotary drilling equipment modified to generate higher torques with moderate down pressure is generally used. They are most generally applicable in sand and fine-grained soils.

The helical screw anchors are divided into two broad families: wrench (drive tube) installed and shaft driven, or wrenchless. The wrench installed anchor is screwed into the soil using a drive (torque) tube. After installation, the drive tube or wrench is withdrawn and the load is transferred to the plate by means of a tension bar or tendon. The wrenchless anchors are driven into the ground by gripping the uppermost end of the anchor shaft and applying torque to the shaft, driving the helical plates into the bearing strata by adding shaft extensions. The wrenchless type of screw anchor generally is used for anchors greater than 14 ft (4.25 m) overall length and for tension load over 40 000 lb (178 kN).

The procedure for installing helical screw anchors with rotary equipment is somewhat different than normal augering of the drilled shafts. The primary differences are lower rotating speed and allowing the anchor to advance into the ground unimpeded. The helix should advance into the soil at one pitch length each revolution of the shaft. A common practice is to put enough down pressure or “crowd” on the anchor to cause it to penetrate at a proper rate.

The helix anchor is always installed to a depth greater than the minimum specified depth and often to a minimum specified installing torque. The minimum specified depth should be five diameters, or deep enough to get the plate below the seasonal zone of frost and/or moisture variations. The minimum torque requirement is given by the utility for their local service area, based on the manufacturer's data and their own experience.

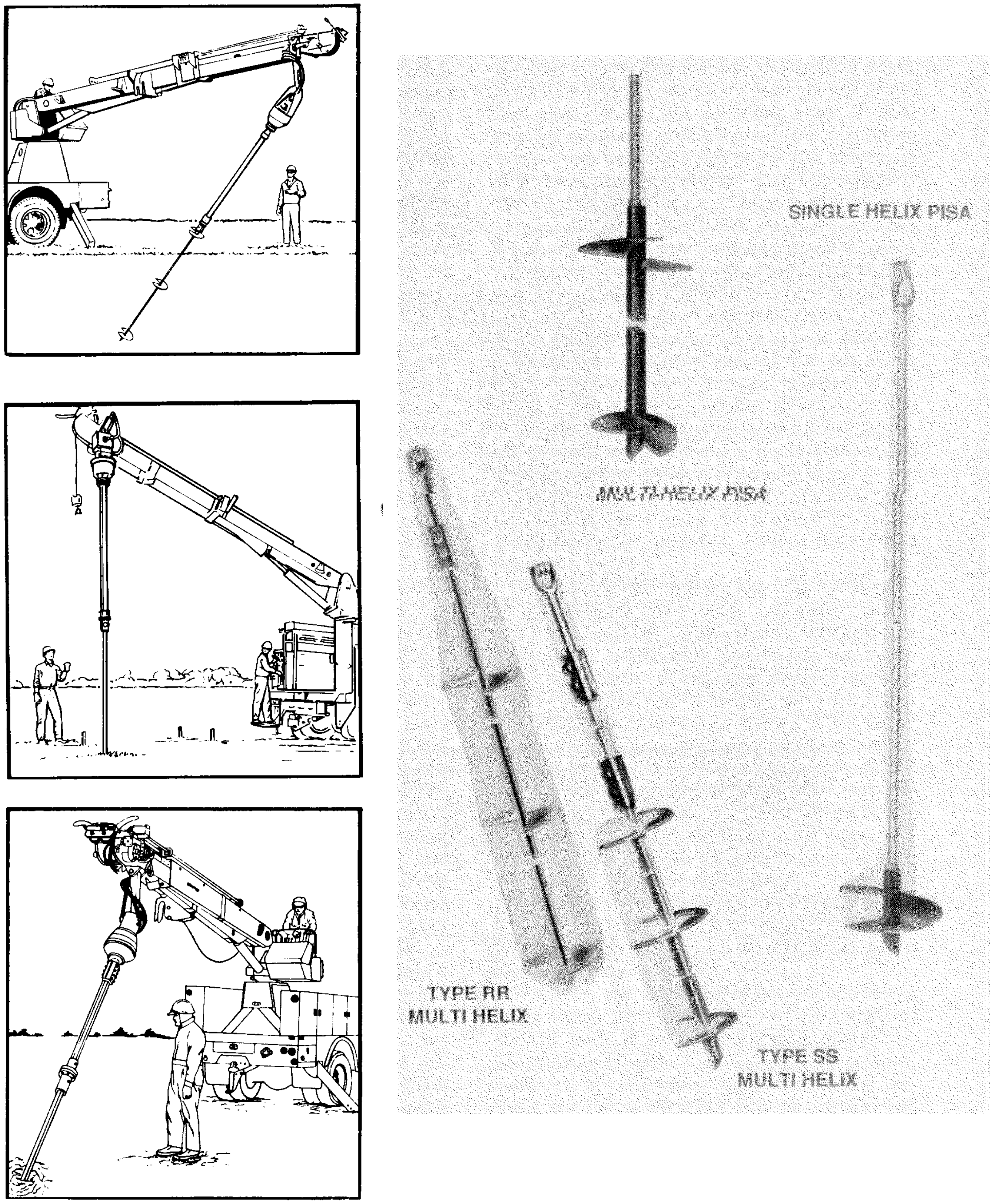
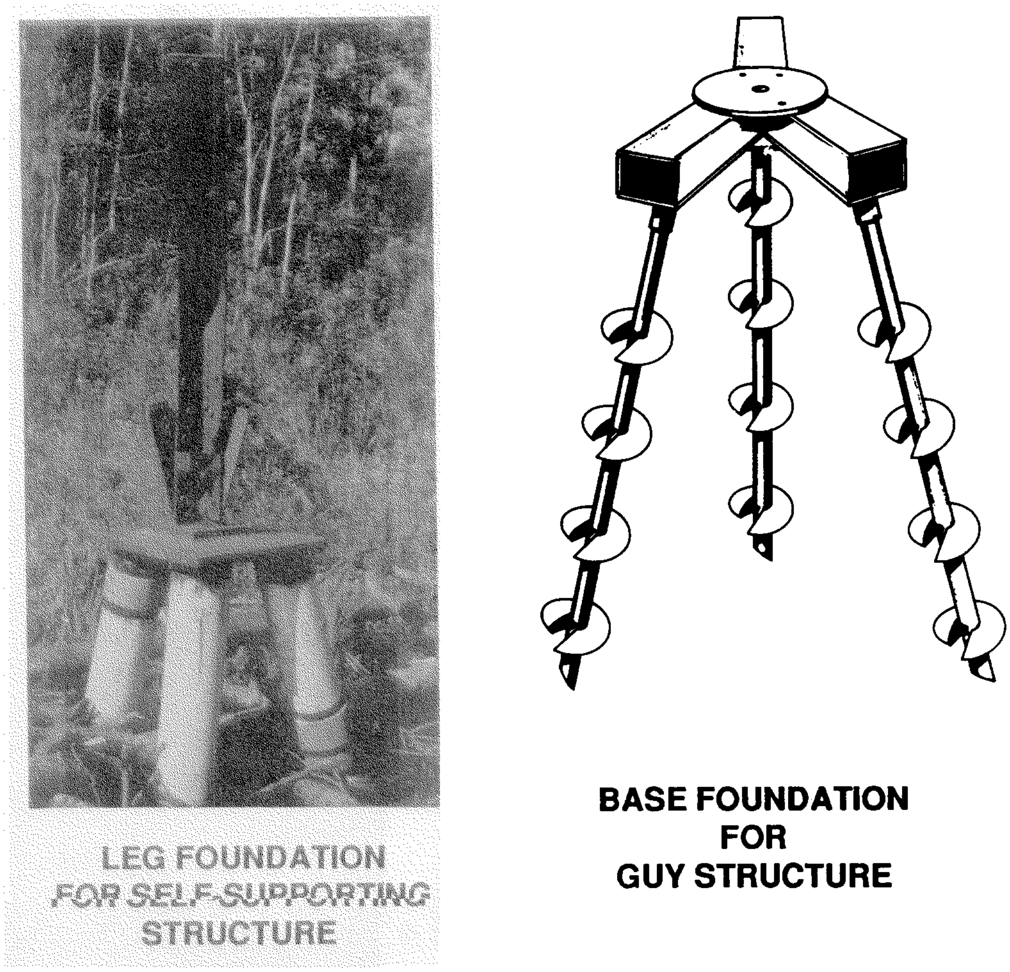


Figure 6-9 — Helix Screw Anchors



LEG FOUNDATION
FOR SELF-SUPPORTING
STRUCTURE

BASE FOUNDATION
FOR
GUY STRUCTURE

Figure 6-10 — High-Capacity Multi-Helix Screw Anchor for Foundations

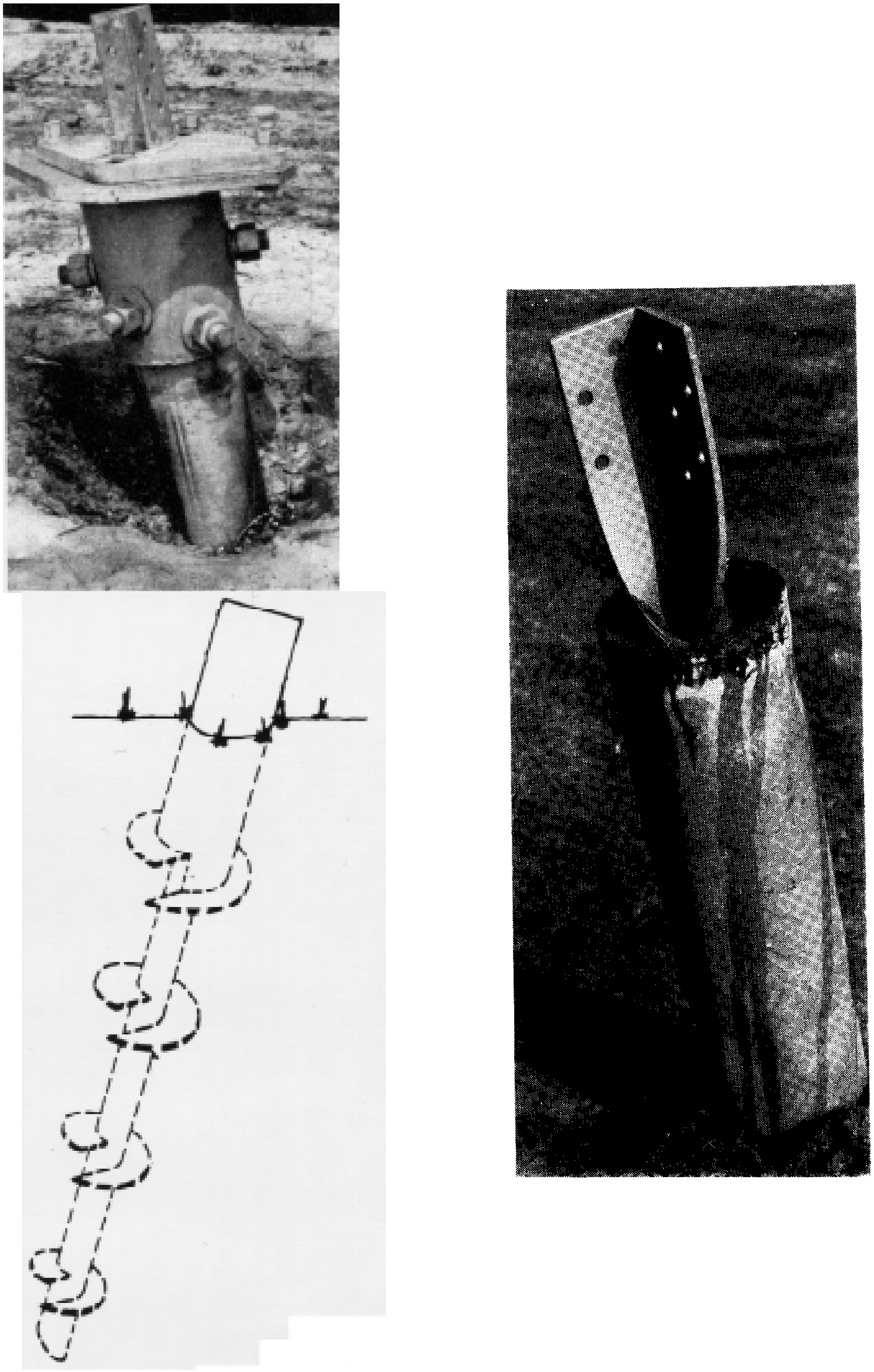


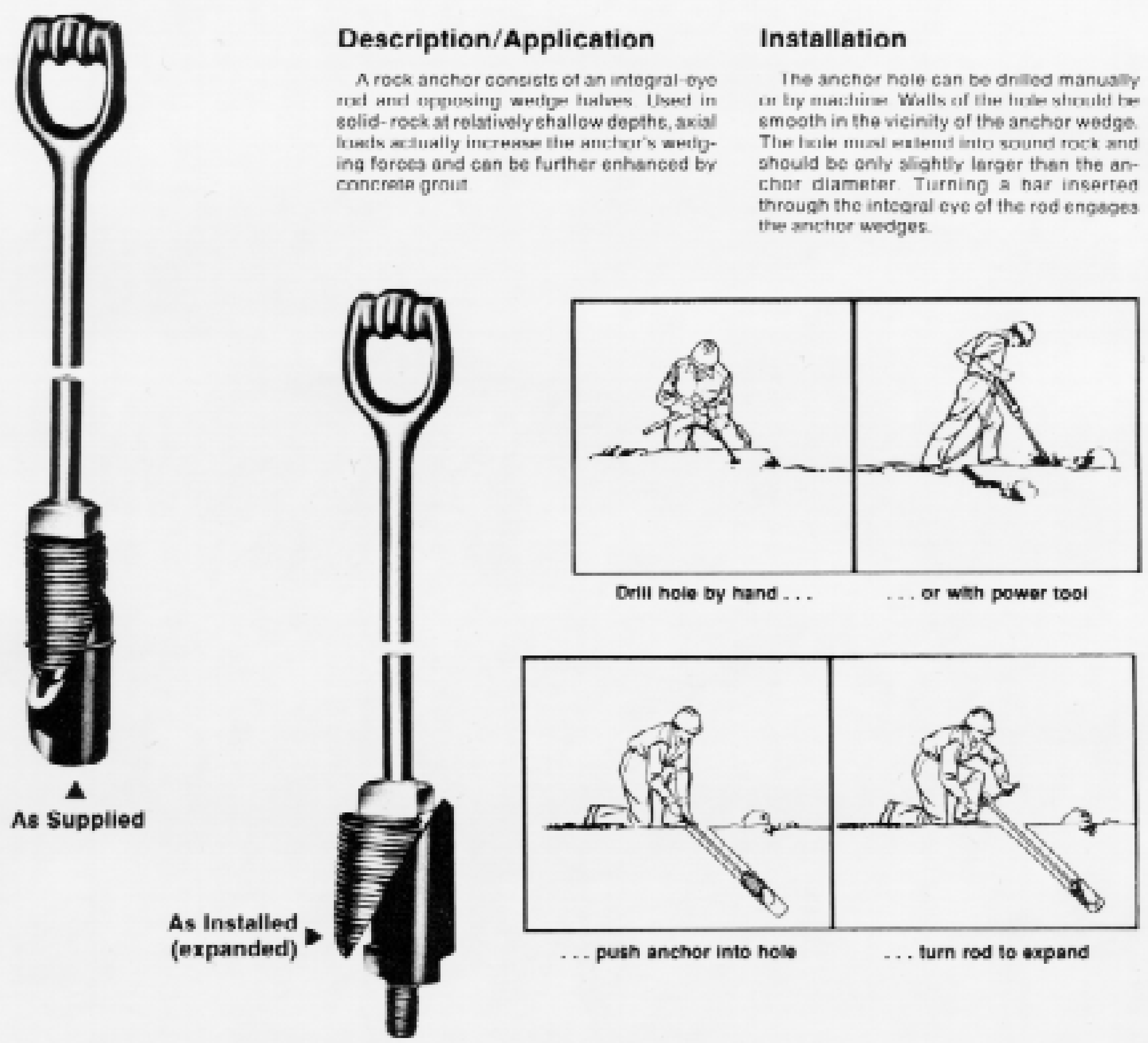
Figure 6-11 — High Capacity Multi-Helix Screw Anchor for Foundations of Self-Supported Transmission Line Structures

6.3.1.5 Rock Anchors

Rock anchors can be divided into two classes: passive (nonexpansive) and active (expansive). The former is a friction installation and depends on relative movement to develop capacity. The latter is also a friction installation, but it is mechanically expanded against the rock at the time of installation, and no relative movement is necessary to mobilize its capacity (Fig 6-12). The expansive-type rock anchor generally is used when movement must be restricted through prestressing/post-tensioning.

Construction of the passive/friction-type rock anchor is similar to the low-pressure, small-diameter grouted anchor described above.

The active-type rock anchor (Fig 6-12) must be installed in competent rock and requires hard rock cutting equipment to advance the drill hole. Down-hole hammers, diamond bits, pneumatic drills, and special carbide augers have been used to drill the bore holes. The anchor is inserted to the specified depth and expanded, generally by rotating or impacting the shaft of the anchor. Expanding rock anchors often are grouted, after installation, by gravity means to prevent weathering of the rock under load. Ungrouted expansive rock anchors may be used in indurated rock that does not weather appreciably.



Description/Application

A rock anchor consists of an integral-eye rod and opposing wedge halves. Used in solid-rock at relatively shallow depths, axial loads actually increase the anchor's wedging forces and can be further enhanced by concrete grout.

Installation

The anchor hole can be drilled manually or by machine. Walls of the hole should be smooth in the vicinity of the anchor wedge. The hole must extend into sound rock and should be only slightly larger than the anchor diameter. Turning a bar inserted through the integral eye of the rod engages the anchor wedges.

Figure 6-12 — Rock Anchors

6.3.2 Installation Problems — Geotechnical

The geotechnical problems for drilled and grouted anchors are the same as those given above in Section 6.2.2.

However, the water table is of less concern as grouting under water is no real problem. Helical anchors may encounter a geotechnical problem in rock. The rock may be cobbles, boulders, or competent bedrock. Helical anchors cannot be installed into the latter, but certain high-strength helical anchors can be installed into soil with rocks and boulders.

These are heat-treated, high-strength alloy anchors.

6.3.3 Installation Problems — Construction

The construction problem most often encountered is misalignment of the axis of the anchor with the line of action of the load.

Particular care should be taken to ensure rod-guy alignment within ±5°, unless otherwise stated. The other potential problems are grout loss, water infiltration to the extent it washes out the grout, tendon or rod sagging in the inclined hole, cracking of the grout around the anchor rod, and inability to install the rock anchor shell into the bearing stratum.

6.3.4 Inspection and Construction Tolerances

The tolerances given in Section 6.2.4 also apply to drilled anchors. Additional requirements for grout volumes, flowability, and strength should be specified. Torque monitoring equipment should be used during the installation of helical anchors to ensure the required bearing stratum is reached, as indicated by achieving the specified torque.

The field engineer and the installer should have the option of testing the completed anchor to the design load as a basis for acceptance or rejection of the anchor.

6.4 Bibliography

[B1] EPRI EL-2870, *Transmission Line Structure Foundations for Uplift Compression Loading*, Feb. 1983, Kulhawy, F. H., Trautmann, C. H., Beech, J. F., O'Rourke, T. D., McGuire, W., Wood, W. A., and Capano, C.

[B2] Adams, J. I. and Radhakrishna, H. S. “Uplift Capacity of Footings and Anchors for Transmission Towers,” *Ontario Hydro Research Quarterly*, Vol. 29, No. 1, Jan. 1977, pp.7–20.

[B3] Clemence, S. P. “The Uplift and Bearing Capacity of Helix Anchors in Soil,” Contract Report TT112-1, Volume 3, Syracuse University, Syracuse, NY, Nov. 1984.

[B4] “Encyclopedia of Anchoring,” Bulletin 47700, A. B. Chance Co., Centralia, MO, 1977.

[B5] Hanna, T. H. *Foundations in Tension*, New York: McGraw-Hill Book Co., 1982.

[B6] “Permanent Ground Anchors,” Report FHWA-DP-68-1, Cheney, R. S., Federal Highway Administration, Washington, DC, Mar. 1984.

[B7] Rodgers, T. E., Jr. “High Capacity MultiHelix Screw Anchors for Transmission Line Foundations,” *Foundations for Transmission Line Towers* (GSP8), Ed. J. L. Briand, New York: ASCE, Apr. 1987, pp.96–109.

[B8] “Tiebacks,” Report FHWA/RD-82/047, Weatherby, D. E., Federal Highway Administration, Washington, DC, Jul. 1982.

[B9] Udwari, J. J., Rodgers, T. E., Jr., and Singh, H. “A Rational Approach To The Design of High Capacity Multi-Helix Screw Anchors,” Conference Paper CH1139, IEEE Power Engineering Society, New York, NY, Apr. 1979.