308

FOUNDATION INSTALLATION

AN OVERVIEW

Working Group
B2.07

December 2006

Study Committee B2 – Overhead Lines

Working Group 07 – Foundations

Foundation Installation – An Overview



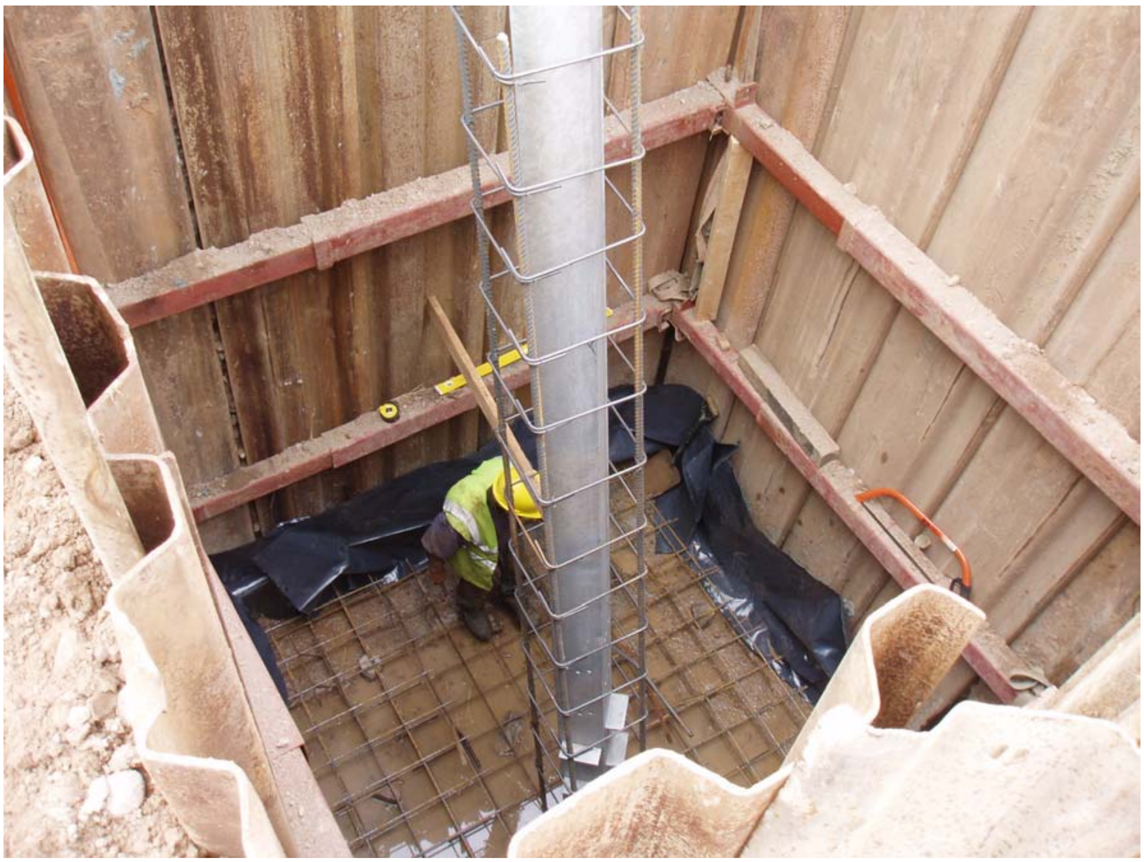


May 2006

Study Committee B2 – Overhead Lines

Working Group 07 – Foundations

Foundation Installation – An Overview



May 2006

During the preparation of this report, WG07 comprised the following members:

N R Cuer (Convenor), E O’ Connor (secretary), M B Buckley (IE), J P Chouteau (CA), W Combrinck (SA), J Dufour (FR), E Dembicki (PL), A M DiGioia Jr (USA), A Haldar (CA), M Leva (IT), G Paterson (AU), M Pietske (DE), J-P Sivertsen (NO) and B Zadnick (SI).

Keywords

Overhead line support, foundations, Foundation design, Foundation installation, Interaction between design and installation, Quality assurance, Health and safety, Environmental impacts and mitigation measures, Foundation costs, Method of measurement and payment.

Executive Summary

Introduction

Overhead line foundations are the interlinking component between the support and the in-situ soil and/or rock. However, unlike the other major components of an overhead line, they are constructed wholly or partly in-situ, in a natural medium whose characteristic properties may vary between support locations and possibly between adjacent footings. Consequently, both the design and the subsequent performance of the foundations, and hence to a degree that of the complete overhead line, is significantly influenced by the methods and practices used during the installation process.

Aim of the Brochure

The aim of the Brochure is to provide an overview of the methods and procedures adopted for the installation of the different types of support foundations. To achieve this overall aim, an extensive literature review has been undertaken to identify how the influences described above interact with the installation process.

Factors influencing foundation installation

There are many factors which potentially influence the installation of overhead line support foundations: support type, base size and applied loadings; foundation type; geotechnical conditions; permanent or temporary installation; primary installation, refurbishment or upgrading of existing foundations; environmental factors, e.g. topography; resources; constraints due to environmental impact; health and safety requirements and quality management requirements.

Although for convenience the design of overhead line support foundations has been considered in Cigre technical brochure 206 [Cigré 2002], there should not be any artificial boundaries between the design and installation process, i.e. the design and installation activities should be seamless, with a continuous exchange of information between all parties. In addition to the obvious interaction between the design and installation process, the interaction with respect to: environmental constraints, health and safety, quality and resource management, must all be taken into account and continuously evaluated throughout the design and installation process.

The serious consequences of failing to verify the assumed geotechnical design parameters during foundation installation are shown in Figure 1.

Reasons for Failure
▸ Failure due to a combination of circumstances:
▸ Tower failure precipitated by high Santa Ana wind prior to commissioning of the line;
▸ Based on geology of line route the foundation designer assumed cohesive soil and decided to use drilled shaft foundation with an under-ream (bell) at the base;
▸ No inspection undertaken during construction and no one noticed the soil was granular;
▸ During concreting the side walls of the shaft collapsed, especially at the bottom;
▸ Installation contractor did not measure quantity of concrete poured, therefore no check against theoretical volume of concrete.

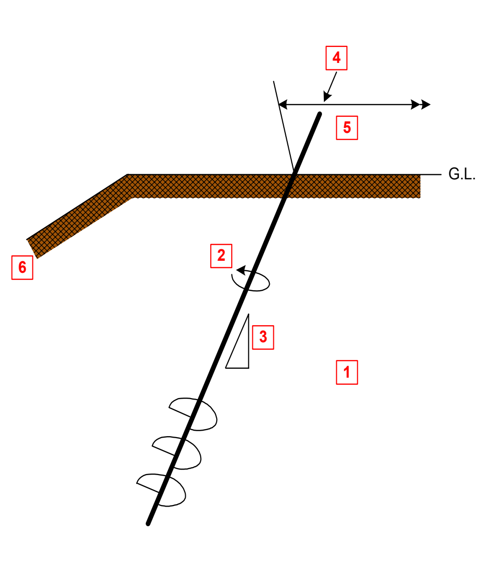
Figure 1 – Failure of a 500 kV Suspension Tower Drilled Shaft Foundation

Interaction with the design process

As previously stated, the foundation design process and the foundation installation activities cannot be considered in isolation, but are mutually dependant on each other. Section 2 of the Brochure considers how the foundation installation activities can have an adverse effect on the design process, taking into consideration not only changes in the actual geotechnical conditions, but also errors or mistakes during the actual foundation installation.

For the principal types of foundations considered, the site activities that are likely to affect the foundation design can be summarised as: failure to recognise changes in the geotechnical conditions, inappropriate installation, concreting and backfilling techniques, and variations in foundation dimensions**.**

For each of the foundation types considered an interaction diagram and associated table detailed the relationship between the installation activities and their potential effect on the foundation design has been prepared. A typical interaction diagram for a helical screw anchor foundation and associated table is shown in Figure 2.



Key	Parameter	Installation activities	Effect on foundation design
1	Soil/rock properties and/or ground water level	Actual soil/rock properties or ground water level encountered during foundation excavation differs from design assumptions.	Change in foundation geotechnical design may affect foundation design strength and/ or long term durability.
2	Installation torque	Failure to use correct installation torque and maintain constant rotational speed.	Reduction in anchor design strength.
3	Alignment	Misalignment of the anchor shaft.	Possibly increase in foundation design loading and/or reduction in foundation design strength.
4	Downthrust	Excessive downthrust.	Torsional buckling failure of anchor shaft.
5	Foundation setting	Incorrect anchor setting.	Increased foundation loading.
6	Ground profile	Changes in ground profile adjacent to foundation.	Reduction in foundation design strength.

Figure 2 – Helical screw foundations interaction between installation and design

Foundation installation activities

Section 3 of the Brochure provides an overview of accepted good practice with respect to foundation installation, such that the adverse effects can be eliminated or at least reduced to a minimum. Foundation installation can be considered as a series of discreet interrelated activities, which for convenience can be divided between the pre-site activities i.e. the activities that are undertaken prior to the commencement of the contract foundation installation and those undertaken as part of the main works. The pre-site activities including the preparation of foundation installation drawings, the concrete mix design, the preliminary foundation design tests and the preparation of the foundation installation criteria schedule which lists the type of foundation to be installed for each support location.

Of particular importance is the concrete mix design, which must ensure that the fresh concrete has the required workability, to enable a, dense, void-free concrete to be placed, such that the hardened concrete has the required strength and durability for the intended service life of the foundations. Further details of the factors to be considered in achieving these aims are given in the Brochure, together with the effects of changing the mix proportions on the properties of the concrete.

The main works activities encompass: setting out of the foundations, excavation including the control of ground water, the installation of drilled shafts and piles, stub setting, concrete production, delivery and placing, backfilling of the excavation, and site reinstatement. Although details of all these activities are given in the Brochure, particular emphasis is placed on the key activities, i.e. excavation, stub setting and concrete placing and subsequent curing.

All excavations should be adequately supported on forming to ensure the stability of the sides, prevent damage to the surrounding ground or adjacent structures and ensure the safety of all personnel; a typical close sheeted excavation is shown in Figure 3.

To ensure the support structure can be erected without inducing additional stresses, the stub steelwork should be accurately set within the permitted tolerance level; Figure 4 shows the lower portion of a lattice steel tower utilized in setting the foundation stubs.

Of crucial importance in ensuring that the concrete achieves its intended service life is the curing regime adopted after placing. The setting and hardening of cement depends on the presence of water, drying out, if allowed to take place to soon, results in low strength and porous concrete. The curing regime should ensure that: premature drying particularly due to solar radiation or wind is prevented; rapid cooling does not occur in the first few days after placing, the concrete is protected against low temperatures, high internal thermal gradients, vibration and impacts do not occur.

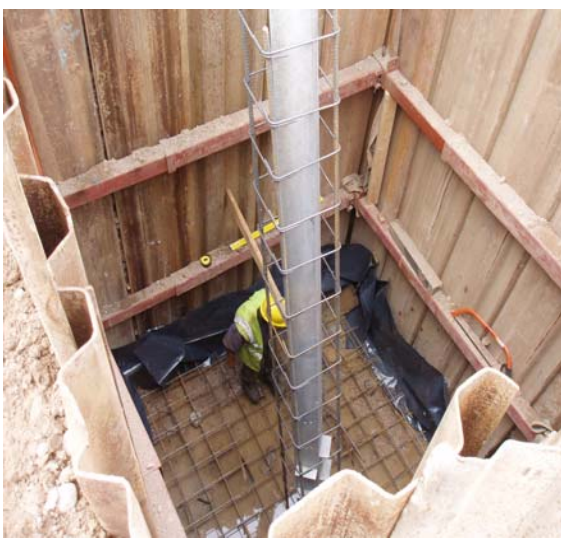


Figure 3 - Foundation excavation

Figure 4 – Stub setting

Quality management

Overhead transmission line construction is undertaken effectively on a long linear site with isolated areas of activity. Since the overhead line support foundations are installed in a variable natural medium, quality management should form an integral part of the construction activities. The common European Standard for the design of overhead lines requires that ‘The systems and procedures, which the designer and/or installation contractor will use to ensure that the project works comply with the project requirements, shall be defined in the designer’s and/or installation contractor’s quality plan for the project works’. Section 4 of the Brochure considers various aspects of the quality management activities undertaken during the foundation design and installation, together with the associated Hold and Notification points.

For simplicity the quality management requirements have been divided between pre-project foundation installation activities and project foundation installation activities. Pre-project foundation installation activities include the foundation design process, the concrete mix design, the quality auditing of proposed suppliers and/or subcontractors and, the installation and full-scale testing of any test foundations. A diagrammatic representation of this process, together with an indication of the documentation required and the corresponding hold and notification points is shown in Figure 5.

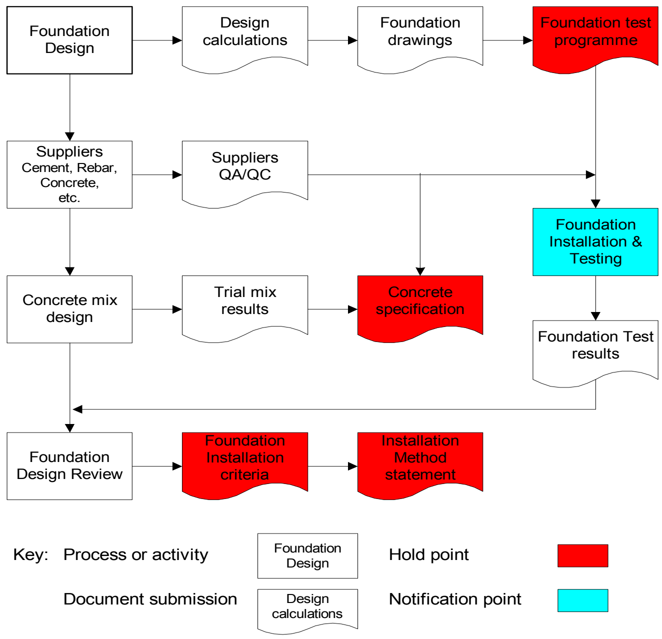


Figure 5 – Diagrammatic representation of pre-project foundation QA & QC arrangements

Project foundation installation activities include setting out of the foundations, verification of the foundation geotechnical design parameters, inspection prior to concreting, concrete placing, concrete identity tests, foundation setting dimensions, foundation proof and integrity tests.

While this section of the Brochure mainly concentrates on the Quality Assurance activities, it is an inherent responsibility of the installation contractor to instigate his own internal quality control procedures and verification methods.

Health and safety

Foundation installation can be a hazardous operation both to the site operatives and members of the general public, if due care and attention is not paid to the health and safety (H&S) aspects of the work. Consequentially, there is a need to consider H&S aspects of foundation installation activities; since the H&S legislation varies between countries, the information contained in Section 5 of the Brochure is indicative only and is based on current UK practice.

Within this section of the Brochure consideration is given both to the initial design assessments and on-site risk assessments, whereby the foundation design or the installation process are reviewed for their inherent hazards and by a process of hierarchical risk control the risks are eliminated or at least reduced to an acceptable level. Preparation of health and safety plans both at the pre-tender and construction phases are also considered, together with the associated method statements and checklists.

The foundation designers should apply a hierarchy of risk control, i.e. the designers need to identify the hazards inherent in undertaking the construction work and where possible alter the design to eliminate them. If the hazards cannot be removed by design changes, the designers should minimise the risks and provide information about the risks that remain. Information regarding these residual risks is then contained in the pre-tender health and safety plan. Possible mitigation measures considered are the use of alternative foundation types, which require smaller and shallower excavations and the use of driven piles on brownfield (contaminated) sites.

Good health and safety practices can be summarised as: the adoption of good working practices; provision of adequately trained and motivated site operatives; ensuring that design assessments and pre-tender health and safety plans concentrate on the hazardous operations that a competent contractor could not foresee; that for hazardous operations site specific risk assessments and method statements are prepared; the site is kept tidy, simple checklists are used and adequate inspections are undertaken; there is effective communication between all parties to the work and that timely action is taken if the assumptions made in the design regarding the ground conditions are not found on-site.

Environmental impacts and mitigation measures

Section 6 of the Brochure deals specifically with the environmental impacts and the associated mitigation measures related to installation of support foundations and the affect of the access route construction on the environment.

Potential environmental impacts, which may occur, during access construction and foundation installation activities include: increase in traffic on local roads; impact of access tracks on the environment; disturbance of land and vegetation management; vegetation and tree removal; noise, dust and vibrational pollution; soil erosion and pollution of water courses; disturbance to birds and fauna and the dispersion of contaminated soil or ground water.

While it is not possible to completely remove all of the potential impacts, described above, it is possible to at least reduce their impact and therefore to a degree, the public's and/or landowners perception of the affect of overhead transmission line construction on the environment.

Irrespective of whether it is new build, the refurbishment and/or upgrading of existing overhead transmission lines an initial desk-top study and site assessments should be undertaken to establish which of the support sites and associated access tracks are likely to be affected by environmental and/or archaeological constraints.

Support sites, which are located in designated areas of importance under international conventions or by national regulations, will require specific studies to be undertaken in consultation with the appropriate statutory bodies. Once the studies outlined above have been completed and depending on their outcome in terms of the environmental and archaeological impacts, it may be necessary to prepare a site environmental plan, detailing the mitigation measures required.

With regards to the actual design of the foundation, mention has been previously made of the use of alternative foundation types, which may lessen the overall environmental impact. Where foundations are located in contaminated sites, there will be a need to control the migration of pollutants to the surrounding area and particularly aquifers, especially when piled foundations are being considered.

As alternative to the use of existing access tracks consideration should also be given to the use of special temporary access systems, i.e. aluminium track way panels or temporary stone roads, (see Figure 6.1). Other potential methods of alleviating the environmental impact are the use helicopters to transport materials, equipment and site operatives, (see Figure 6.2). The use of helicopters may be a condition of the planning consent of the overhead transmission line route, if the route crosses sensitive ecological areas or as an economic alternative to the construction of long and expensive access tracks from the nearest public highway.

Figure 6.1 - Aluminium track way panels

Figure 6.2 – Transportation of concrete by helicopter

Foundation costs

The support foundations represents between 14 and 23 percent of the total cost of an overhead line, with an average value of 19 percent [Cigré 1991]. This average value remains reasonably constant and is not affected by changes in the transmission line voltage, circuit configuration and support type. Similarly, the percentage breakdown between material supply and installation also remains reasonably constant at 65 percent to 35 percent.

The factors which have the greatest influence on the foundation cost are: the support type, the magnitude of the applied loadings, the foundation type and the geotechnical conditions.

With respect to support foundation costs there are no universal rules that can be developed and this to a degree is a reflection of the difference in costs in relation to different foundation types which in itself is a reflection of the variability of the ground conditions. Other factors which may influence the selection of foundation type and hence its cost are: environmental, resource limitations and health and safety requirements.

The price or rate for the foundation will in addition to the factors described above, depend on the method of measurement and payment plus the allocation of risk between the client and the installation contractor. Details of typical methods of measurement and payment are given in the section 7 of the Brochure.

Conclusions

The installation of overhead line support foundations can not be viewed in isolation but must be considered as on going process, with a seamless transition between design and construction, if the adverse effects outlined in section 2 of this Brochure are to be avoided. Similarly, to ensure that the intended service life is achieved, quality management requirements must also be integrated within the installation process. Since foundation installation is also hazardous both to site operatives and the environment, mitigation measures must also be considered from the outset of the project.

References

Cigre [1991], 'An International Survey of Component Costs of Overhead Transmission Lines', Cigre, Electra No.137, August 1991.

Cigre [2002], Technical Brochure No.206 'The Design of Transmission Line Support Foundations - An Overview', Cigre WG 22-07.

Foundation Installation – An Overview

Contents

Acknowledgements:

Acknowledgements are given to the Danish representative of SC B2 and the Convenor of WG06, for their time in reviewing this report and for helpful comments and suggestions.

Acknowledgements are also are given to the following organisations:

Westpile Ltd. for permission to reproduce Figure 1.7;

NorPower Limited for permission to reproduce Figures 3.5, 3.9 and 3.11.

AMEC Power Ltd. for permission to reproduce Figures 3A.1, 3A.2 and 3A.3;

Eve Transmission for permission to reproduce Figure 3A.4;

1 Introduction

1.1 General

Overhead line foundations are the interlinking component between the support and the in-situ soil and/or rock. However, unlike the other major components of an overhead line, they are constructed wholly or partly in-situ, in a natural medium whose characteristic properties may vary between support locations and possibly between adjacent footings. Consequently, both the design and the subsequent performance of the foundations, and hence to a degree that of the complete overhead line, is significantly influenced by the methods and practices used during the installation process.

This report is a guide to the methods and procedures adopted for the installation of the common types of overhead line support foundations used in practice.

There are many factors which potentially influence the installation of overhead line support foundations:

- Support type, base size or diameter and applied loadings;
- Foundation type, e.g. drilled shaft, pad and chimney, direct embedment, steel grillages, etc.;
- Geotechnical conditions, e.g. soil or rock type, ground water level, etc.;
- Permanent or temporary installation;
- Primary installation, refurbishment or upgrading of existing foundations;
- Environmental, e.g. topography, climatic, contamination, etc.;
- Resources, e.g. foundation materials, labour, construction plant, programme and financial;
- Constraints, e.g. environmental impact, client requirements, third parties with respect to access, use of the surrounding land, etc.;
- Health and safety requirements;
- Quality management requirements.

The interaction between the primary influences, i.e. design, installation, environmental, resources, quality and health and safety, is discussed further in section 1.3 of this report.

1.2 Aims and Objectives

The aim of this report is to provide a guide/overview of the methods and procedures adopted for the installation/construction of the different types of overhead line support foundations. To achieve this overall aim, an extensive literature review has been undertaken to identify how the influences described in Section 1.1 of this report interact with the installation process.

Section 2 of this report considers the influence of the installation process on the design of the foundation, i.e. how changes in the design geotechnical conditions, use of inappropriate installation techniques or mistakes during construction can adversely effect the foundation design strength and/or the long term durability of the foundation and hence its design life.

The actual installation process, e.g. site access, setting out, excavation, concreting, backfilling, etc., for various types of foundation is discussed in Section 3, while Section 4 considers the associated quality assurance issues including the quality control test requirements both on the foundation's constituent materials and the complete foundation.

Section 5 of the report considers the health and safety issues related to the foundation installation process

The environmental impacts of the foundation installation process together with possible mitigation measures are discussed in Section 6; while, Section 7 provides a brief review of the relative cost of the foundation and the associated foundation price and the factors which influence them. An overall summary of the report is given in Section 8 and Section 9 contains a comprehensive bibliography.

For details of the life cycle assessment for overhead line foundations, reference should be made to Cigré Technical Brochure No. 265 [Cigré 2004].

1.3 Interaction

Although for convenience the design and installation of overhead line support foundations have been considered in two separate Cigre technical brochures, there should not be any artificial boundaries between the design and installation process, i.e. the design and installation activities should be seamless, with a continuous exchange of information between all parties, e.g. the client, the foundation designer and the installation contractor. In addition to the obvious interaction between the design and installation process, the interaction with respect to: environmental constraints, site access, health and safety, quality and resource management, must all be taken into account and continuously evaluated throughout the design and installation process. The overall interaction is shown diagrammatically in Figure 1.1, while a detailed diagrammatic representation of the foundation design and installation process is shown in Figure 1.2.

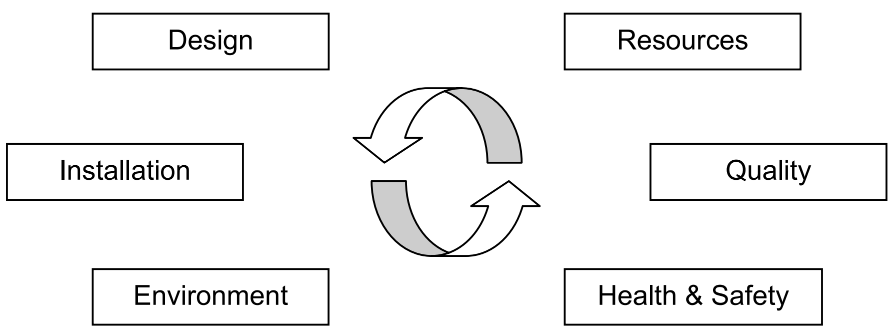


Figure 1.1 - Interaction Process

As stated above, good communications between the respective parties to contract, i.e. the client, the client's representatives, the foundation designers and the installation contractor form an essential part of the overall design and installation process and will have a marked influence on the successful outcome of the project, in terms of quality, safety and the environmental impact.

The client and/or his representatives should ensure that their technical requirements are clearly stated in the specification and that for any work on existing support foundations the existing foundation drawings, calculations and associated health and safety information (pre-tender health and safety plan) are made available at the earliest opportunity to both the foundation designers and the installation contractor.

The foundation designers should ensure that all the information used in the design and especially any assumptions made regarding the installation contractor's method of working are made available to the client, the client's representative and the foundation installation contractor. The information should include the foundation design calculations, installation drawings, the geotechnical report and the initial design risk assessment.

The foundation installation contractor should ensure that all the appropriate information is considered in the preparation of his construction health and safety plan, site risk assessment and proposed foundation installation method statements. Critically, the foundation installation contractor's site staff and operatives should ensure that if there are any changes in the ground conditions from those assumed in the foundation design, e.g. variations in ground water level or soil properties, the foundation designers are immediately informed and, if necessary, work on-site suspended until a reassessment of the design has been made and, if appropriate, a revision to the method statement undertaken.

The serious consequences of failing to verify the assumed geotechnical design parameters during foundation installation are shown in Figure 1.3; which emphasis the need for effective communications between the foundation designer and the installation contractor.

For specific details of the foundation design process, reference should be made to Cigré Technical Brochure No.206 [Cigré 2002].

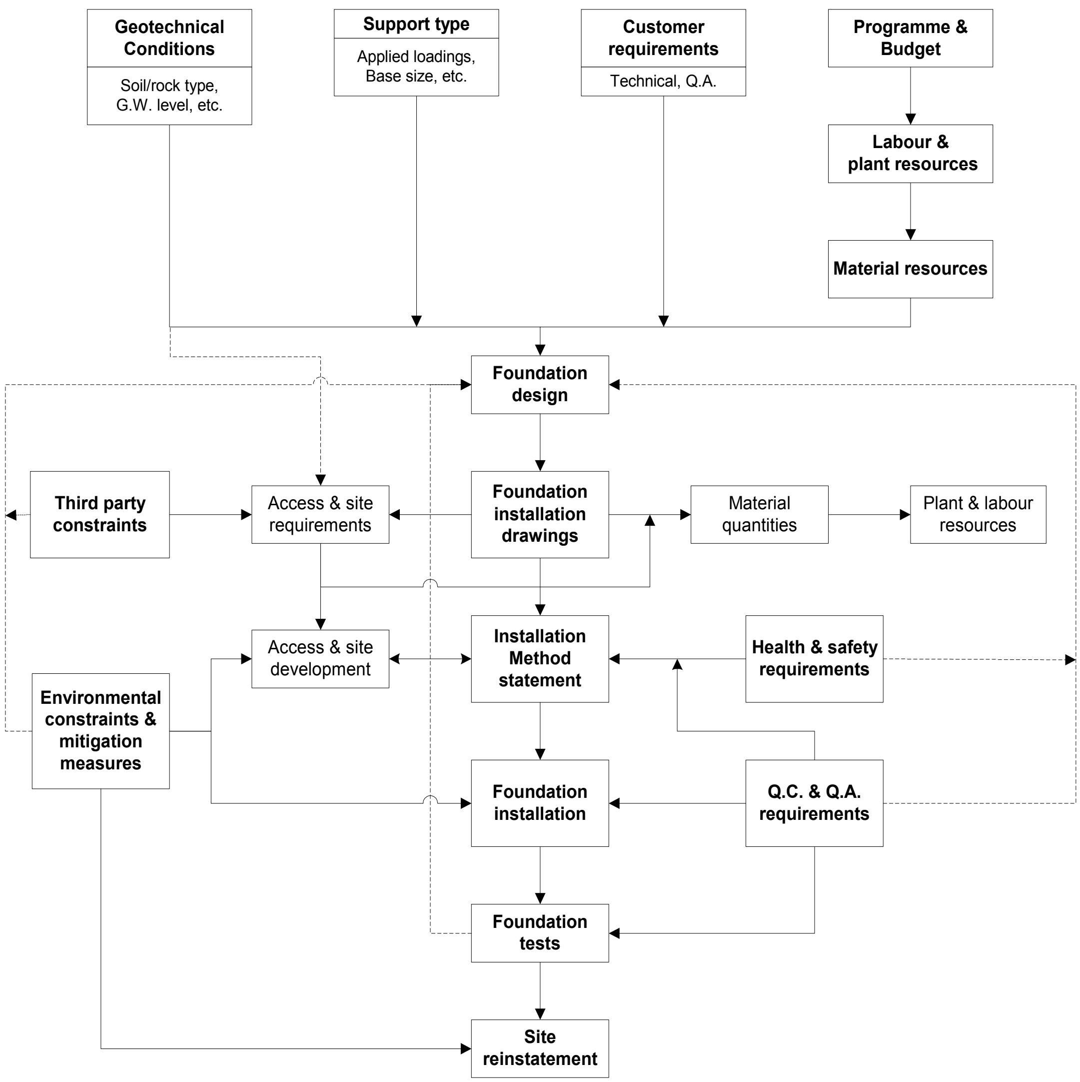


Figure 1.2 – Diagrammatic representation of Foundation Design / Installation Process

Figure 1.3 – Failure of a 500 kV Suspension Tower Drilled Shaft Foundation

Failure due to a combination of circumstances:	▸ Tower failure precipitated by high Santa Ana wind prior to commissioning of the line;
	▸ Based on geology of line route the foundation designer assumed cohesive soil and decided to use drilled shaft foundation with an under-ream (bell) at the base;
	▸ No inspection undertaken during construction and no one noticed the soil was granular;
	▸ During concreting the side walls of the shaft collapsed, especially at the bottom;
	▸ Installation contractor did not measure quantity of concrete poured, therefore no check against theoretical volume of concrete.

1.4 Foundation categories

1.4.1 General

For simplicity three basic categories of foundation are considered in this report, i.e. spread, anchor and compact foundations. The use of any particular category of foundation, and specifically an individual foundation type, will depend to a degree on both the support type and the geotechnical conditions present. This subsection of the report considers the relationship between the support type and foundation category, and between the foundation type and the geotechnical conditions: the geotechnical conditions influencing both the foundation design and the foundation installation. A diagrammatic representation depicting the relationships between the support type, the basic foundation category, the foundation type and the geotechnical conditions, is shown in Figure 1.4.

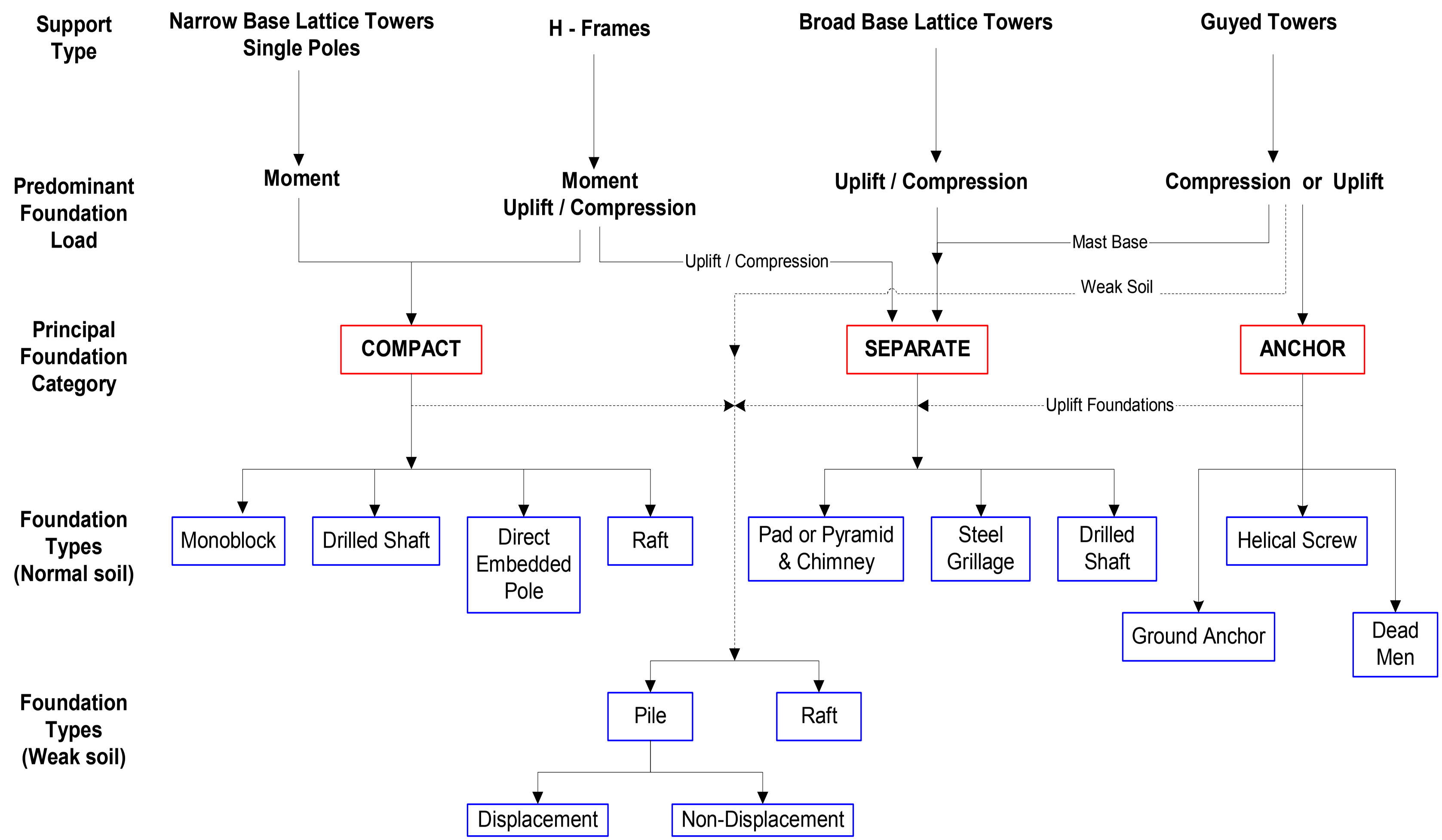


Figure 1.4 Diagrammatic Representation of Interrelationship between Support Type and Principal Foundation Category

Note: Weak Soil defined as soil with an SPT value of less than 10 blows per 300 mm, or an undrained shear strength of less than 35 kN/m ^{2}

1.4.2 Applied foundation loadings

Prior to describing the various foundation types, a resume of the principal support types and their primary applied foundation loadings is given below:

a) Single poles and narrow base lattice towers
The foundation loads for single poles and narrow base lattice towers with compact foundations consist of overturning moments in association with relatively small horizontal, vertical and torsional forces.

b) H–Frame supports
H–Frame supports are basically structurally indeterminate. The foundation loads may be determined either by making assumptions that result in a structurally determinate structure, or by using computerised stiffness matrix methods. The foundation loads for H-frame supports consist of overturning moments in association with relatively small horizontal, vertical forces and torsional moments. If the connection between the supports and foundations are designed as pins or universal joints, theoretically, the moments acting upon the foundations will be zero.

c) Broad base lattice towers
Lattice tower foundation loads consist principally of vertical uplift (tension) or compression forces and associated horizontal shears. For intermediate and angle towers with small angles of deviation, the vertical loads may either be in tension or compression. While, for angle towers with large angles of deviation and terminal towers under normal climatic loadings, two legs will normally be in uplift with the other two legs in compression. Under all loading combinations, the distribution of horizontal forces between the individual footings will vary, depending on the bracing arrangement of the tower.

d) Externally guyed supports
For all types of externally guyed supports, the guy anchor will be in uplift, while the mast foundations will be in compression with relatively small horizontal forces.

1.5 Foundation types

1.5.1 Separate foundations

Separate foundations may be defined as those specifically designed to withstand the loads transmitted by each leg of a support. Generally, separate foundations are used for lattice towers or H-frame structures when the face width exceeds 3 m, provided that the geotechnical conditions are suitable, or where there are no specific requirements to limit the differential settlement between adjacent foundations. The connection between the leg of the support and the foundation is normally provided by stubs encased in the foundations or by the use of anchor bolts.

Under the classification ‘separate’, the following types of foundations have been considered:

- spread footings;
- drilled shafts;
- piles.

a) Spread footings
Spread footings considered in this report are: concrete pad and chimney foundations including stepped block foundations, concrete pyramid and chimney including normal non reinforced concrete pyramids, shallow reinforced pyramids and pyramids with extended

pads, and steel grillage foundations. A diagrammatic representation of the various types of spread footings is shown in Figure 1.5 and a typical grillage foundation in Figure 1.6.

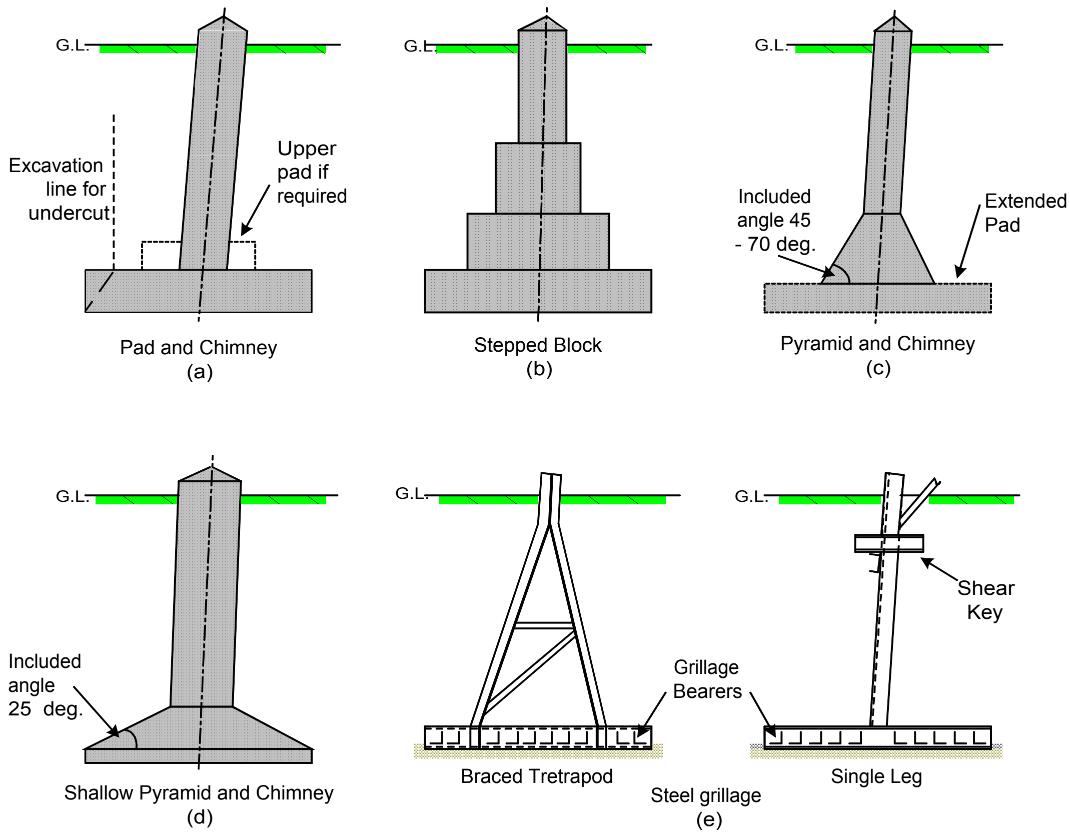


Figure 1.5 – Spread footings

Figure 1.6 – Typical grillage foundations

b) Drilled shaft foundations

A drilled shaft or augered foundation is essentially a cylindrical excavation formed by a power auger and subsequently filled with reinforced concrete. The shaft may be straight or the base may be enlarged by under-reaming or belling. Although this type of foundation is effectively a bored pile, the American Concrete Institute [ACI 1993] defines them as drilled shafts (piers) when their diameter is greater than 760 mm.

For broad base lattice towers drilled shafts may be installed vertically or inclined along the hip slope of the leg as shown in Figure 1.7. The shaft shear load is greatly reduced for drilled shafts inclined along the tower leg hip slope. For H-frame supports the shaft would be installed vertically.

Under-reaming of the base can be undertaken in non-caving soils to increase both the bearing and uplift capacities of the drilled shaft.

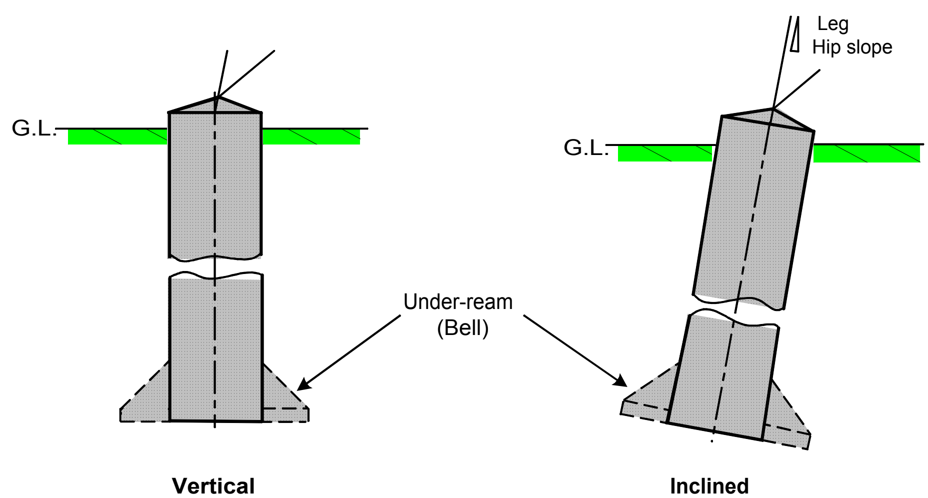


Figure 1.7 - Drilled shaft foundations

c) Piled foundations

Pile foundations can comprise either a single pile or a group of piles connected at or just below ground level by a reinforced concrete cap, i.e. a piled foundation.

Piles may be classified as 'driven' (displacement) where the soil is moved radially as the pile enters the ground, or 'bored' (non-displacement) when little disturbance is caused to the soil as the pile is installed. Driven displacement piles may comprise a totally preformed section from steel, pre-cast concrete or timber. Alternatively, where hollow steel or pre-cast concrete sections are used these are normally subsequently filled with concrete, or for steel H-sections post grouted. Non-displacement piles are cast-in-situ using either concrete or grout; the pile section is formed by boring or drilling.

Typical driven pre-cast concrete and steel tube piles, and bored and continuous flight auger piles are shown in Figure 1.8.

Micropiles are defined as non-displacement piles with a diameter of 300 mm or less and for the purpose of this report have been included within the section related to anchors and anchor foundations.

Driven pre-cast concrete piles

Driven steel tube piles

Bored piles

Continuous flight auger piles

Figure 1.8 – Typical pile types

1.5.2 Anchor foundations

Anchors may be used to provide tension resistance for guys of any type of guyed support and to provide additional uplift resistance to spread footing type foundations in which case various types of anchors can be used.

a) Ground anchors

Ground anchors and micropiles consist of a steel tendon (either reinforcing steel, wire or steel cable) placed into a hole drilled into rock or soil which is subsequently filled with a cement or resin based grout usually under pressure (Figure 1.9a)

Ground anchors can be grouped together in an array and connected by a concrete cap at or below ground level to form a spread footing anchor foundation (Figure 1.9b).

b) Block anchors

Block anchors comprise a pad and chimney spread type footing whereby the concrete is cast directly against the face of the excavation possibly with an undercut at the base (Figure 1.9c).

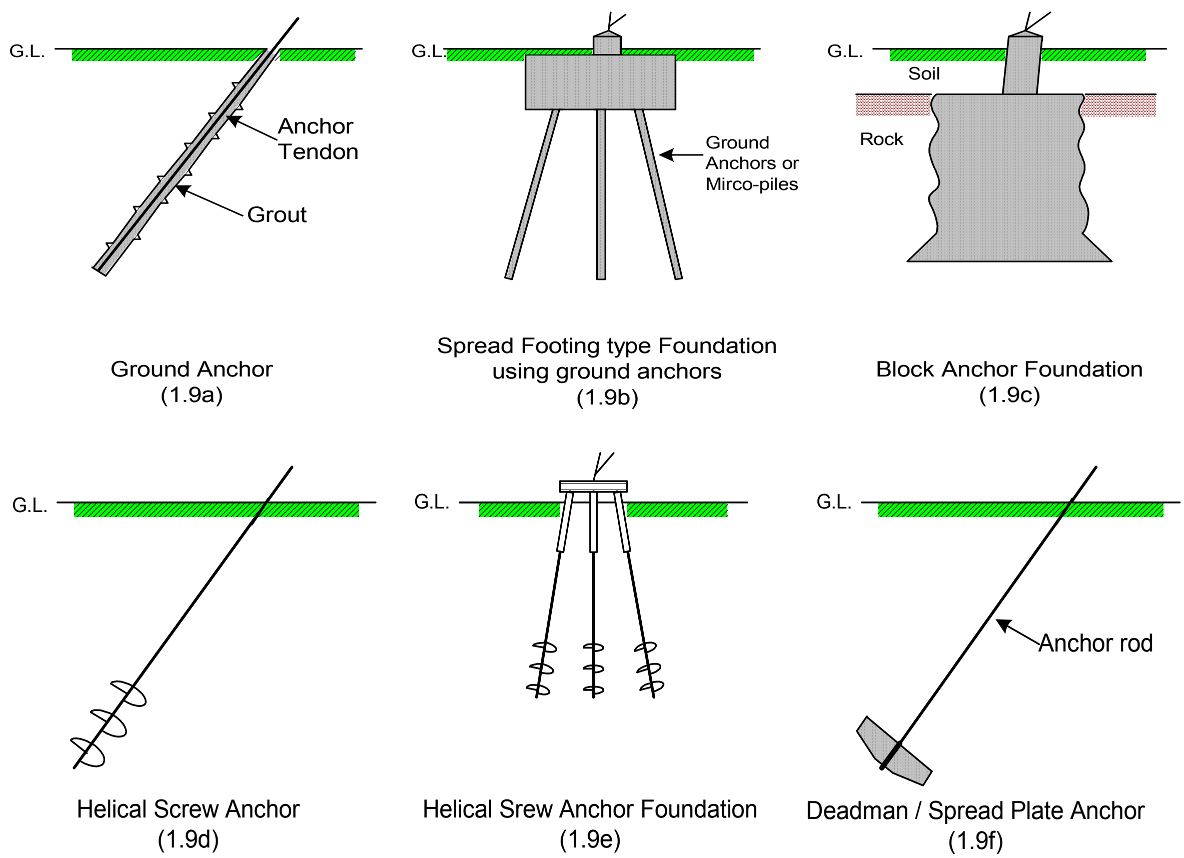


Figure 1.7 – Anchor foundations

c) Helical screw anchors

A helical screw anchor comprises a steel shaft which is screwed into the ground (Figure 1.9d). Helical screw anchors can also be connected together at or above ground level by a steel grillage or concrete cap to form a helical screw anchor foundation (Figure 1.9e).

d) Deadman/Spread anchors
Typically these anchors consist of a timber baulk, a pre-cast concrete block/pad or deformed steel plate installed in the ground by excavating a trench or augering a hole, placing the anchor against undisturbed soil and backfilling the excavation (Figure 1.9f). The anchor rod may be installed by cutting a narrow trench or drilling a small diameter hole.

1.5.3 Compact foundations

Compact foundations have been defined as those specifically designed to resist the applied overturning moment from the support. Generally this type of foundation is used for single poles, for lattice towers with narrow base widths (less than 3 m) and for H-frame supports with a predominant moment loading. In addition, they may be used to replace separate footings for wide base lattice towers when there is a specific need to limit the differential settlement between adjacent footings, i.e. raft foundations. The connection between the support and the foundation is normally provided by anchor bolts, by a section of the pole directly encased in the foundation, or by stubs encased in the foundation.

Under the classification of ‘compact’, the following types of foundations have been considered: Monoblock, Drilled shaft, Direct Embedded Pole, Raft and Piled. Both drilled shaft and piled foundations for compact foundations are similar to those described for separate foundations.

a) Monoblocks
Concrete monoblock foundations in their simplest form, comprises a cast-in-situ reinforced concrete block. A typical one for a single pole is shown in Figure 1.10a. A monoblock foundation for a narrow base width tower is shown in Figure 1.10b; alternatively they can be cast in-situ using prefabricated formwork or pre-cast, Figure 1.10c.

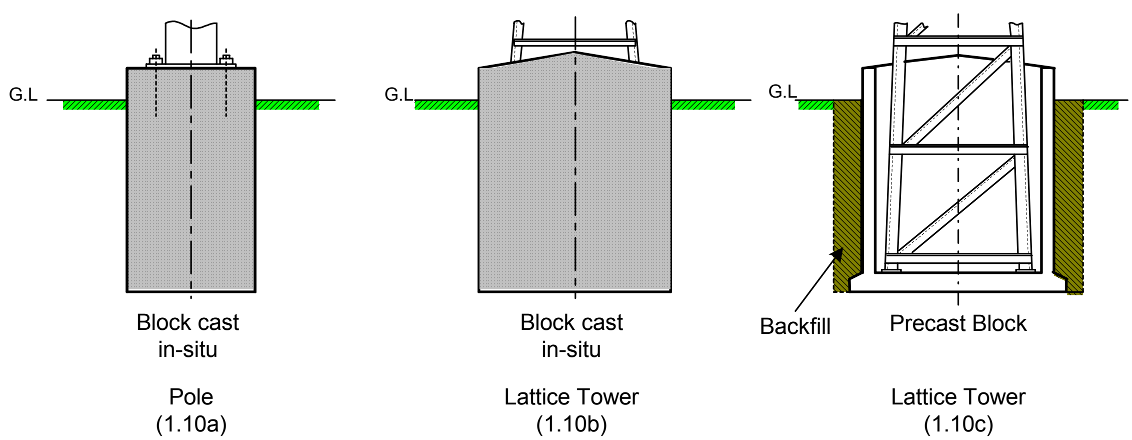


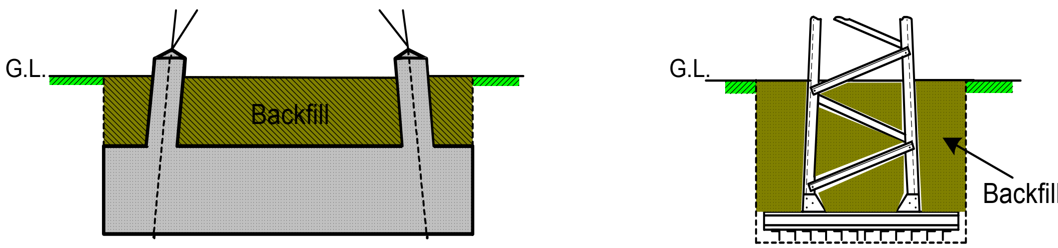
Figure 1.10 – Monoblock foundations

b) Direct embedment
Originally used for the direct embedment of relatively lightly loaded wood poles, this type of foundation is now also used for steel and concrete poles subjected to high overturning moments. However, for steel and concrete poles the size of the excavation, the type of backfill material, e.g. imported granular or weak mix concrete and the compaction of the backfill material are carefully controlled.

c) Raft foundations
Under the general classification of raft foundations, the following types of foundations have been considered: concrete raft foundations and steel grillage raft foundations.

Concrete raft foundations in their simplest form comprise a cast-in-situ reinforced concrete pad at or below ground level as shown in Figure 1.11a and Figure 1.12.

Steel grillage raft foundations as shown in Figure 1.11b, are normally only used for narrow base lattice steel towers, and basically consist of steel angle section grillage members which are connected to two steel angle or channel section bearers orientated at 90° to the grillage members. Depending on the fabrication process used, the grillage members are either bolted to, or slotted in the bearers. In the latter case it is common practice to 'spot' weld the grillage members to the bearers prior to installation. The connection of the grillage to the support is by means of an extension of the tower body.



Concrete
(1.11a)

Steel Grillage
(1.11b)

Figure 1.11 – Raft foundations

Figure 1.12 – Reinforced concrete raft (slab) foundation for a 110 kV lattice steel tower

1.6 Liability

This report is not intended to be a standard nor a textbook but only a guide to good practice. The material presented has been collected from a number of sources and is based on recognized engineering practices. The information contained in this report should not be used without first securing competent advice with respect to its suitability and application for any general or specific use. This is especially important in respect of complying with any statutory requirements relating to health and safety and/or the environment.

2 Interaction with the Design Process

2.1 General

The foundation design process and the foundation installation activities cannot be considered in isolation, but are mutually dependant on each other. This section of the report considers how the foundation installation activities can have an adverse effect on the design process, taking into consideration not only changes in the actual geotechnical conditions, but also errors or mistakes during the actual foundation installation.

Although environmental and third party constraints and the effect of resource constraints can influence both the foundation design process and the foundation installation activities, these have been dealt with separately.

For simplicity, the interaction has been considered for each major type of foundation separately.

2.2 Separate foundations

2.2.1 Spread footings

Spread footings as previously stated in section 1.5; include concrete pad and chimney foundations, concrete pyramid foundations and steel grillage foundations. To illustrate how the foundation installation activities interact with the foundation design process a composite concrete pad/pyramid and chimney foundation is shown in Figure 2.1.

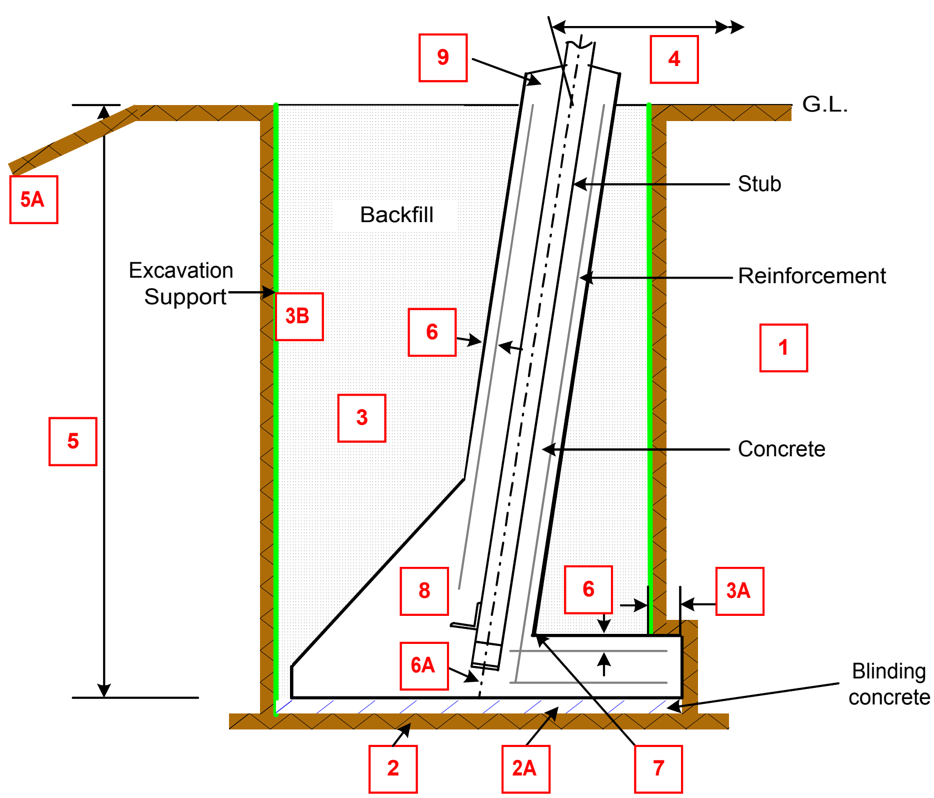


Figure 2.1 – Spread foundations – interaction diagram

Detailed in Table 2.1 are the relevant construction activities and the affect they have on the overall foundation design:

Table 2.1 – Interaction installation activities and foundation design – Spread footings

Key	Parameter	Possible changes during installation activities	Adverse effect on foundation design
1	Soil/rock properties and/or ground water level	Actual soil/rock properties or ground water level encountered during foundation excavation differs from design assumptions.	Changes in foundation geotechnical design may affect foundation design strength and/ or long term durability.
2	Soil/rock beneath base of foundation	Failure to remove 'soft spots' below setting level of foundation or premature removal of bottom layer of cohesive soil prior to placing blinding concrete.	Possible reduction in foundation design bearing pressure and/or the cause of differential settlement of adjacent footings.
2A	Blinding concrete	Failure to place blinding concrete.	In cohesive soils possible reduction in bearing capacity due to softening of the soil. In soils with high concentration of sulfates or chlorides, reduction in the long term durability.
3	Backfill	Backfill bulk density lower than assumed in design calculations.	Reduction in foundation design uplift strength. Reduction in foundation design lateral resistance to shear loads.
3A	Undercut	No undercut or reduced undercut.	Reduction in foundation design uplift strength.
3B	Excavation support	Failure to remove excavation support.	Change in design basis for foundation uplift resistance.
4	Stub setting	Incorrect stub setting dimensions or stub alignment.	Increase in foundation loading.
5	Foundation dimensions	Foundation dimensions smaller than design values.	Reduction in foundation design strength.
5A	Ground profile	Changes in ground profile adjacent to foundation	Reduction in foundation design uplift and shear strength.
6	Reinforcement cover	Reinforcement cover less than specified.	Reduction in foundation design strength and/or long term durability.
6A	Stub cover	Stub cover less than specified.	
7	Construction joint	Inadequate construction joint.	
8	Concrete strength, workability and compaction	Reduced concrete strength and/or poor workability – insufficient compaction.	
9	Concrete curing	Inappropriate concrete curing.	

In addition, to the parameter outlined in Table 2.1, the following additional considerations are also applicable in respect of spread footings:

- Key 3 Backfill, failure to adequately compact the backfill may also result in either ponding of rainwater above the foundation or a change in backfill densities from dry to partially or fully saturated, both likely to result in a potential reduction in the foundation design strength and /or long term durability;
- Key 3A Undercut, failure to provide an undercut, or failure to cast the foundation directly against the side of the excavation for a specified height, will again alter the basic design principles of the foundation uplift resistance;
- Key 5 and 6A Foundation dimensions and Stub cover, failure to install the foundation at the correct depth could either result in the stub cleats being located in foundation chimney

and not in pyramid/pad (as required) if the foundation is set too deep, or the stub may project below the base of the foundation with insufficient punching shear resistance for the cleats and without the required concrete cover to the embedded steel, if the foundation is set shallower than required.

- With respect to spread foundations in rock, formed foundations, i.e. those cast in formwork should not be used without additional anchoring to the rock, because under uplift conditions there is effectively no shear resistance developed between the backfill material and the sides of the rock excavation.
- Although not shown in the Figure 2.1, the failure to adequately restore any in-situ drainage or, if appropriate, to improve the overall site drainage during the reinstatement activities could lead to the foundation excavation acting as a sump, with the consequential reduction in both the soil strength properties and the foundation strength.

Similar construction activities would also be applicable for both non-reinforced concrete stepped block foundations and steel grillage foundations. For the former, key points 1, 2, 2A, 3, 3B, 4, 5, 5A, 6A, 7, 8 and 9 would apply, while for the latter, key points 1, 2, 3, 3B, 4 and 5A would apply and, if appropriate, the failure to provide a non-cohesive bedding layer.

Figure 2.2 – Separate foundations poor compaction of concrete at the chimney – pyramid joint (Key 8)

2.2.2 Drilled Shaft foundations

Within the overall category of separate foundations are drilled shaft or augered foundations, which essentially consist of cylindrical excavations with or without an under-ream (bell) formed by a power auger and subsequently filled with reinforced concrete. To illustrate how the foundation installation activities interact with the foundation design process a composite drilled shaft (with and without an under-ream) is shown in Figure 2.3.

If short, relatively shallow, drilled shaft foundations are installed with the stub projecting to the base of the foundation, then reference should be made to section 2.2.1 regarding the location of the stub relative to the base of the foundation. In addition, failure to adequately restore any in-situ drainage or, if appropriate, to improve the overall site drainage during the reinstatement activities could lead to a change in the soil properties and a consequential reduction in the foundation strength.

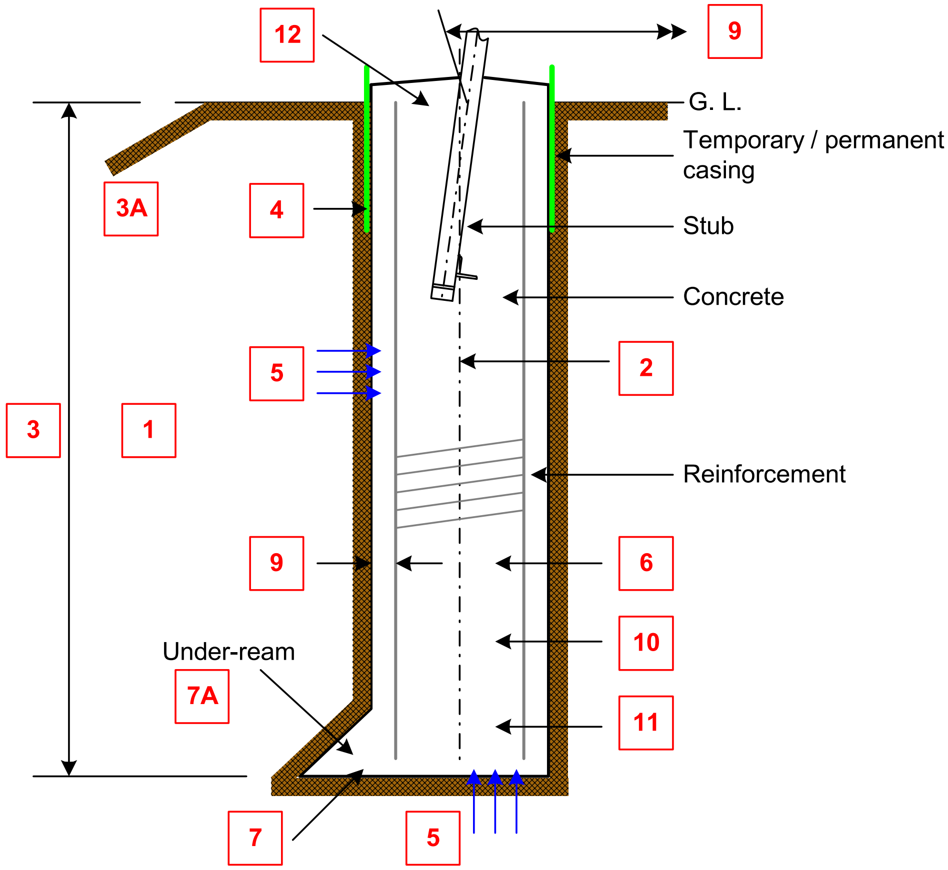


Figure 2.3 – Drilled shaft foundation – interaction diagram

Table 2.2 – Interaction installation activities and foundation design – drilled shafts

Key	Parameter	Possible changes during installation activities	Adverse effect on foundation design
1	Soil/rock properties and/or ground water level	Actual soil/rock properties or ground water level encountered during foundation excavation differs from design assumptions.	Change in foundation geotechnical design may affect foundation design strength and/ or long term durability.
2	Alignment of shaft	Misalignment of shaft.	Possibly increase in foundation loading and/or reduction in strength.
3	Foundation dimensions	Incorrect depth and/or diameter, under-ream and/or insufficient penetration into bearing stratum.	Reduction in foundation design strength.
3A	Ground profile	Changes in ground profile adjacent to foundation	Reduction in foundation design strength.
4	Temporary/permanent casings	Incorrect installation techniques with respect to temporary and/or permanent casing. Incorrect length of permanent casing.	Reduction in foundation design strength and/or long term durability.
5	Ground water penetration	Incorrect installation techniques with respect to the control of ground water penetration causing shaft instability, reduction in c.s.a. or contaminated concrete.	

Key	Parameter	Possible changes during installation activities	Adverse effect on foundation design
6	Stabilizing fluids or drilling muds	Incorrect installation techniques with respect to the use of stabilizing fluids or drilling muds, causing shaft instability, reduction in c.s.a. or contaminated concrete.	Reduction in foundation design strength and/or long term durability.
7	Base cleaning or forming	Failure to remove loose or disturbed soil from shaft base causing inadequate bearing material or contaminated concrete.	
7A	Under-ream	Incorrect dimensions and/or partial collapse of under-ream.	
8	Reinforcement alignment and/or cover	Misalignment of reinforcement and/or reinforcement cover less than specified.	
9	Stub setting	Incorrect stub setting or alignment.	Increase in foundation loading.
10	Concrete placing	Inappropriate concreting techniques causing concrete to segregate, concrete contamination, voids, etc. Delays in placing concrete after completion of excavation, failure to check actual against theoretical concrete volumes.	Reduction in foundation design strength and/or long term durability.
11	Concrete strength and/or workability	Reduced concrete strength and/or poor workability.	
12	Concrete curing	Inappropriate concrete curing techniques.	Reduction in long term durability.

Figure 2.4 – Drilled shaft foundations failure to adequately remove all of excavation material during concrete placing (Key 7 & 10)

2.2.3 Piled foundations

Although, piled foundations are included in the general category of both separate and compact foundations, for simplicity they have been included in this section of the report. Pile foundations can either comprise a single pile or a group of piles connected at or just below ground level by a reinforced concrete cap, i.e. a piled foundation.

The following types of piles have been considered in this section of the report:

- Bored cast in-situ piles;
- Continuous flight auger piles (CFA-pile);
- Driven cast-in-place piles;
- Pre-cast reinforced and pre-cast reinforced concrete segmental piles;
- Steel bearing piles.

Bored piles can be constructed ‘dry’ employing temporary casing to seal the pile bore through water-bearing or unstable strata overlying suitable stable material. Upon reaching the design depth a reinforcing cage is introduced, and concrete is placed in the bore to the required level. The casing is then withdrawn. ‘Wet’ boring also employs a temporary casing through unstable ground and is used when the pile bore cannot be sealed against water ingress. Boring is then undertaken using a digging bucket to drill through the underlying soils to the design depth. The reinforcing cage is lowered into the bore and the concrete placed by tremie pipe and subsequent removal of the temporary casing. In some cases there may be a need to employ drilling fluids to maintain a stable shaft.

Continuous flight auger piles (CFA-pile) are formed by screwing a continuous auger into the ground to the required depth. Concrete is then pumped under pressure down the hollow stem of the auger to the bottom of the bore. Once pumping starts the auger is progressively withdrawn bringing the excavated soil to the surface. Once the auger is finally removed the reinforcement is placed in the concrete pile.

Pre-cast reinforced piles are normally manufactured off-site, the use of mechanical interlocking joints means that the individual units can be rapidly coupled together during the driving.

Steel bearing piles can either H-section or tubular steel piles, the latter now being extensively used for overhead transmission line support foundations. Prefabricated stub connectors can be cast into the top of the tubes for direct connection of the tower leg.

Although, timber piles have been used previously for transmission line support foundations, their current use is not extensive and as such they have not been included in this report.

Because of the variety of pile types considered and the fact that the piles can be installed singularly or in a group, it has not been possible to produce a piled foundation interaction diagram; consequentially, only a review of the installation activities and their affect on the overall foundation design is given in Table 2.3.

Note: The following key has been used to identify the different piles types, B - Bored cast in-situ, C - Continuous flight auger, D - Driven cast-in-place, P – Pre-cast reinforced and pre-cast reinforced concrete segmental piles and S - Steel bearing piles.

Unless noted otherwise, details pertaining to the use of bored cast in-situ piles are covered in the preceding subjection for drilled shaft foundations.

Table 2.3 - Interaction installation activities and foundation design - piled foundations

Pile type	Parameter	Possible changes during installation activities	Adverse effect on foundation design
All	Soil/rock properties and/or ground water level	Actual soil/rock properties or ground water level encountered during foundation excavation differs from design assumptions.	Change in foundation geotechnical design may affect foundation design strength and/ or long term durability.
All	Alignment of pile	Misalignment of pile.	Possibly increase in pile design loading and/or reduction in strength.
All	Pile dimensions	Incorrect depth and/or diameter, and/or insufficient penetration into bearing stratum.	Reduction in pile design strength.
All	Ground profile	Changes in ground profile adjacent to foundation.	Reduction in foundation design strength.
All	Adjacent piles	Insufficient distance between piles or time elapse before installation of adjacent piles.	Damage to or increased loading of adjacent piles.
B, C & P	Pile trimming	Inappropriate pile trimming/cutting techniques causing pile cracking.	Reduction in pile design strength and/or long term durability.
B, C & D	Placing of reinforcement	Inadequate construction of reinforcement cage.	
B, C & D	Reinforcement alignment and/or cover	Misalignment of reinforcement and/or reinforcement cover less than specified.	
B, C & D	Concrete placing	Inappropriate concreting techniques causing concrete segregation.	
B, C & D	Concrete strength and/or workability	Reduced concrete strength and/or poor workability.	Reduction in pile design strength and/or long term durability.
B, C & D	Concrete curing	Inappropriate concrete curing techniques.	Reduction in long term durability.
C	Pile construction monitoring system	Failure of automated monitoring system.	Reduction in pile design strength and/or long term durability.
C	Non-cohesive soils	Inappropriate installation techniques with respect to the advance and rate of rotation of the auger.	
C	Concreting	Misalignment between the rate of removal of the auger and the rate of supply of concrete, causing changes in c.s.a. or contaminated concrete.	
D, P & S	Pile driving	Inappropriate installation techniques with respect to pile driving.	Damage to pile and reduction in pile design strength.
D, P & S	Pile joints	Misalignment of pile joints.	Reduction in pile design strength.
D, P & S	Pile set	Inappropriate techniques used to measure pile set.	
D & S	Stub setting or anchor bolt placing*	Incorrect stub setting or alignment.	Increase foundation loading.
D	Temporary casing	Incorrect techniques with respect to removal of temporary casing.	Reduction in pile and hence reduction foundation design strength and/or long term durability.
P & S	Pile transportation, lifting and pitching	Inappropriate techniques with respect to pile transportation, lifting and pitching.	Damage to pile and hence reduction in foundation design strength.

Note: Stub setting or anchor bolt placing* - only applicable to single piles with no pile cap.

Where pile caps and ground (tie) beams are required, the interaction between the construction activities and the design process will be similar to that described in section 2.2.1 for spread footings. In particular, key points 1, 2, 2A, 3, 4, 5, 5A, 6, 6A, 7, 8 and 9 will apply. For pile caps and/or ground beams constructed above ground level, additional interaction between the strength of the formwork and the overall foundation design will also apply.

2.3 Anchor foundations

2.3.1 Micropiles and ground anchors

Since there are a variety of different types of micropiles and ground anchors and corresponding installation techniques, the parameters identified in figure 2.5 and described in Table 2.4, have been generalised and may not be applicable to a specific type and/or method of installation. The parameters described in the following table are equally applicable to ground anchors.

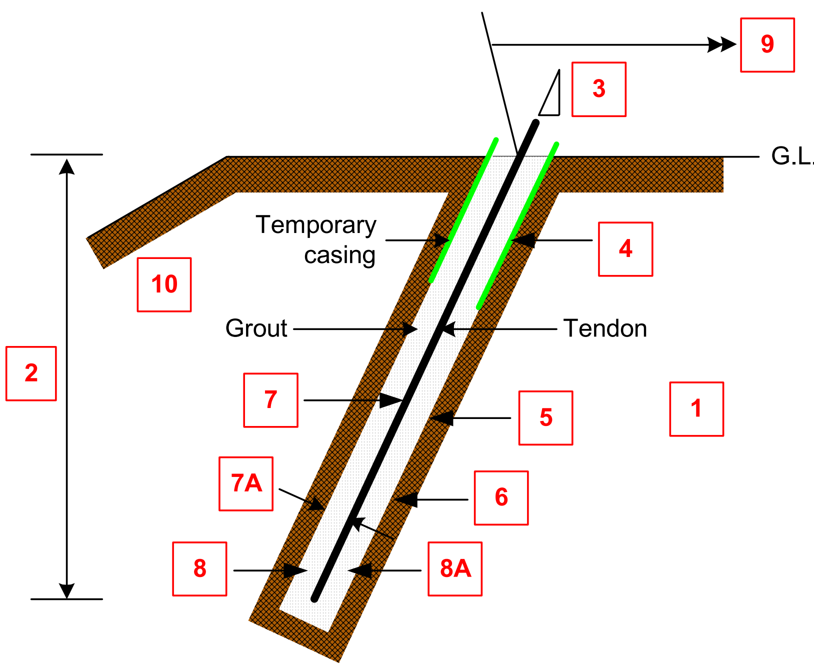


Figure 2.5 – Micropiles and ground anchors – interaction diagram

Table 2.4 – Interaction installation activities and foundation design – micropile & ground anchors

Key	Parameter	Possible changes during installation activities	Adverse effect on foundation design
1	Soil/rock properties and/or ground water level	Actual soil/rock properties or ground water level encountered during foundation excavation differs from design assumptions.	Change in foundation geotechnical design may affect foundation design strength and/ or long term durability.
2	Micropile dimensions	Incorrect depth and/or diameter and/or insufficient penetration into bearing stratum.	Reduction in micropile design strength.
3	Alignment	Misalignment of micropile.	Possibly increase in foundation design loading and/or reduction in foundation design strength.

Key	Parameter	Possible changes during installation activities	Adverse effect on foundation design
4	Temporary/permanent casings	Incorrect installation techniques with respect to temporary and/or permanent casing. Incorrect length of permanent casing.	Reduction in micropile design strength and/or long term durability.
5	Drilling and hole stabilisation	Inappropriate drilling techniques, hole collapse.	
6	Hole flushing	Inappropriate hole flushing techniques, failure to remove all soil/rock particles.	
7	Tendon placement (homing)	Inappropriate tendon handling technique, causing damage to tendon.	
7A	Tendon alignment and/or cover	Misalignment of tendon and/or cover less than specified.	
8	Grout strength and/or workability	Reduced grout strength and/or poor workability.	
8A	Grouting	Delay between hole drilling and/or incorrect grouting techniques.	
9	Foundation setting	Incorrect micropile setting.	Increased foundation loading.
10	Ground profile	Changes in ground profile adjacent to foundation.	Reduction in foundation design strength.

For details with respect to the micropile and ground anchor caps, reference should be made section 2.2.3.

2.3.2 Block anchors

For details of the interaction between installation activities and the foundation design strength for block anchors, reference should be made to section 2.2.1 for spread footings.

2.3.3 Helical screw anchors

Although helical screw anchors are relatively simple to install, there are a number of key installation activities which have a direct influence on the foundation design strength; these are shown diagrammatically in Figure 2.6 and described in Table 2.5.

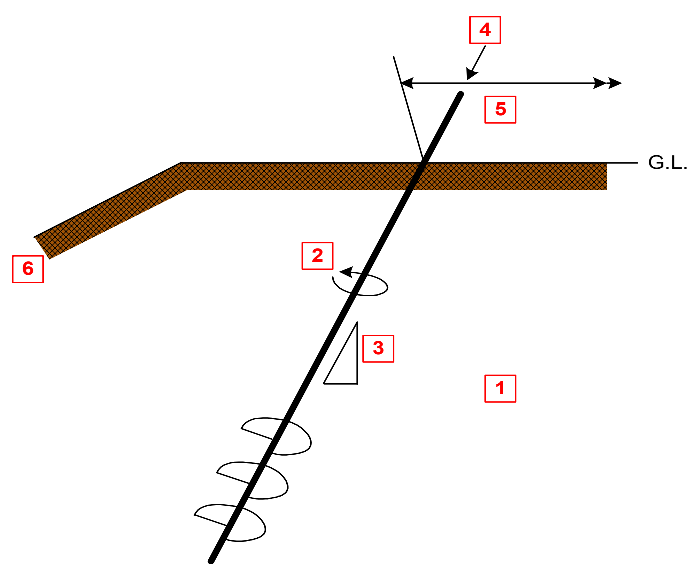


Figure 2.6 – Helical screw anchors – interaction diagram

Table 2.5 – Interaction installation activities and foundation design – helical screw anchors

Key	Parameter	Possible changes during installation activities	Adverse effect on foundation design
1	Soil/rock properties and/or ground water level	Actual soil/rock properties or ground water level encountered during foundation excavation differs from design assumptions.	Change in foundation geotechnical design may affect foundation design strength and/ or long term durability.
2	Installation torque	Failure to use correct installation torque and maintain constant rotational speed.	Reduction in anchor design strength.
3	Alignment	Misalignment of the anchor shaft.	Possibly increase in foundation design loading and/or reduction in foundation design strength.
4	Downthrust	Excessive downthrust.	Torsional buckling failure of anchor shaft.
5	Foundation setting	Incorrect anchor setting.	Increased foundation loading.
6	Ground profile	Changes in ground profile adjacent to foundation.	Reduction in foundation design strength.

If multiple helical screw anchors are interconnected with a reinforced concrete cap, similar interactions to those described in section 2.2.3 for pile caps would apply.

2.3.4 Deadman and spread plate anchors

Deadman and spread plate anchors can be used as alternative to helical screw anchors, especially in soils which contain boulders. A diagrammatic representation of the interaction between the installation activities and the foundation design is shown in Figure 2.7 and described in Table 2.6

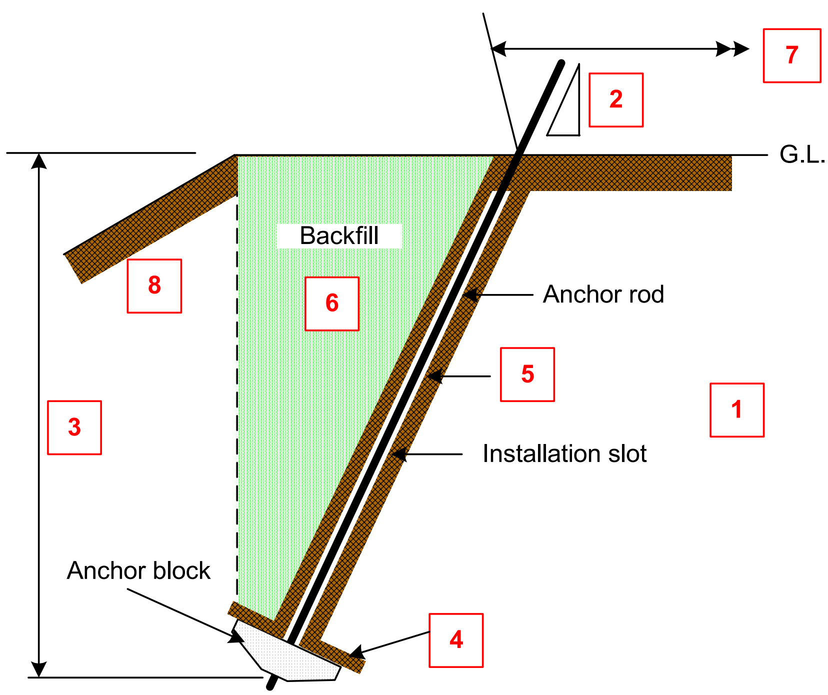


Figure 2.7 – Deadman anchors- Interaction diagram

Table 2.6 – Interaction installation activities and foundation design – deadman anchors

Key	Parameter	Possible changes during installation activities	Adverse effect on foundation design
1	Soil/rock properties and/or ground water level	Actual soil/rock properties or ground water level encountered during foundation excavation differs from design assumptions.	Change in foundation geotechnical design may affect foundation design strength and/ or long term durability.
2	Alignment	Misalignment of the anchor rod.	Possible increase in foundation design loading and/or reduction in foundation design strength.
3	Anchor depth	Incorrect anchor depth.	Reduction in anchor design strength.
4	Block installation	Failure to locate anchor block against undisturbed soil.	
5	Rod installation	Inappropriate techniques used to install anchor rod.	
6	Backfill	Backfill density lower than assumed in design calculations.	Reduction in foundation design uplift strength.
7	Foundation setting	Incorrect anchor setting.	Increased foundation loading.
8	Ground profile	Changes in ground profile adjacent to foundations.	Reduction in foundation design strength.

2.4 Compact foundations

2.4.1 General

The interaction between the installation activities and the foundation design process for both monoblock and raft foundations is similar to that described for spread footings, and reference should be made to sections 2.2.1. For raft foundations constructed above ground level, additional interaction between the strength of the formwork and the overall foundation design will also apply.

For drilled shafts and piles used as compact foundations, similar interactions to those described in sections 2.2.2 and 2.2.3, respectively will apply.

2.4.2 Direct embedment

The installation activities associated with the direct embedment of monopoles are similar in certain respects to those for drilled shaft foundations; the major difference is the absence of concrete and the presence of a backfill material. Both the width of the annulus between the pole and the surrounding soil/rock and the degree of compaction of the backfill will have a major influence on the foundation design strength. In addition, the key points 1, 2, 3, 3A, 5 and 7 for drilled shaft foundations, will also apply.

2.5 Conclusions

This section of the report has considered how the foundation installation activities can potentially influence both foundation design strength and its long term durability. For the principal types of foundations considered, the site activities that likely affect foundations can be summarised as:

- Failure to recognise changes in the geotechnical conditions;
- Inappropriate installation techniques;
- Variations in foundation dimensions;
- Inappropriate concreting methods;

- Inappropriate backfilling techniques.

The consequences of these failings in the foundation installation activities has been shown in Figure 1.3, but in a less dramatic manner in figure 2.8, which illustrates the reduction in the long term durability of the foundation due to a failure to provide an adequate construction joint between the foundation and muff concrete.

Section 3 of the report outlines the recommended site installation methods and procedures that should be employed to ensure that the deficiencies described in this section of the report do not occur.

Figure 2.8A – Corrosion of stub & tower bracing member

Note poor compaction of muff concrete and failure to effectively seal between double angle bracing members, thereby permitting ingress of aggressive agents.

Figure 2.8B – Corrosion of tower bracing member after removal of the muff concrete.

3 Foundation Installation Activities

3.1 General

The previous section of this report has considered how the foundation design can be adversely influenced both by changes in the geotechnical properties and the use of inappropriate foundation installation techniques. This section of the report provides an overview of accepted good practice with respect to foundation installation, such that the adverse effects can be eliminated or at least reduced to a minimum.

Foundation installation can be considered as a series of discreet interrelated activities commencing with the initial foundation design and associated installation drawings, site access preparation, setting out, excavation, etc., through to the site reinstatement, although completion of the latter does normally occur until after the end of construction activities. A diagrammatic flow chart of the foundation installation activities is shown in Figure 3.1.

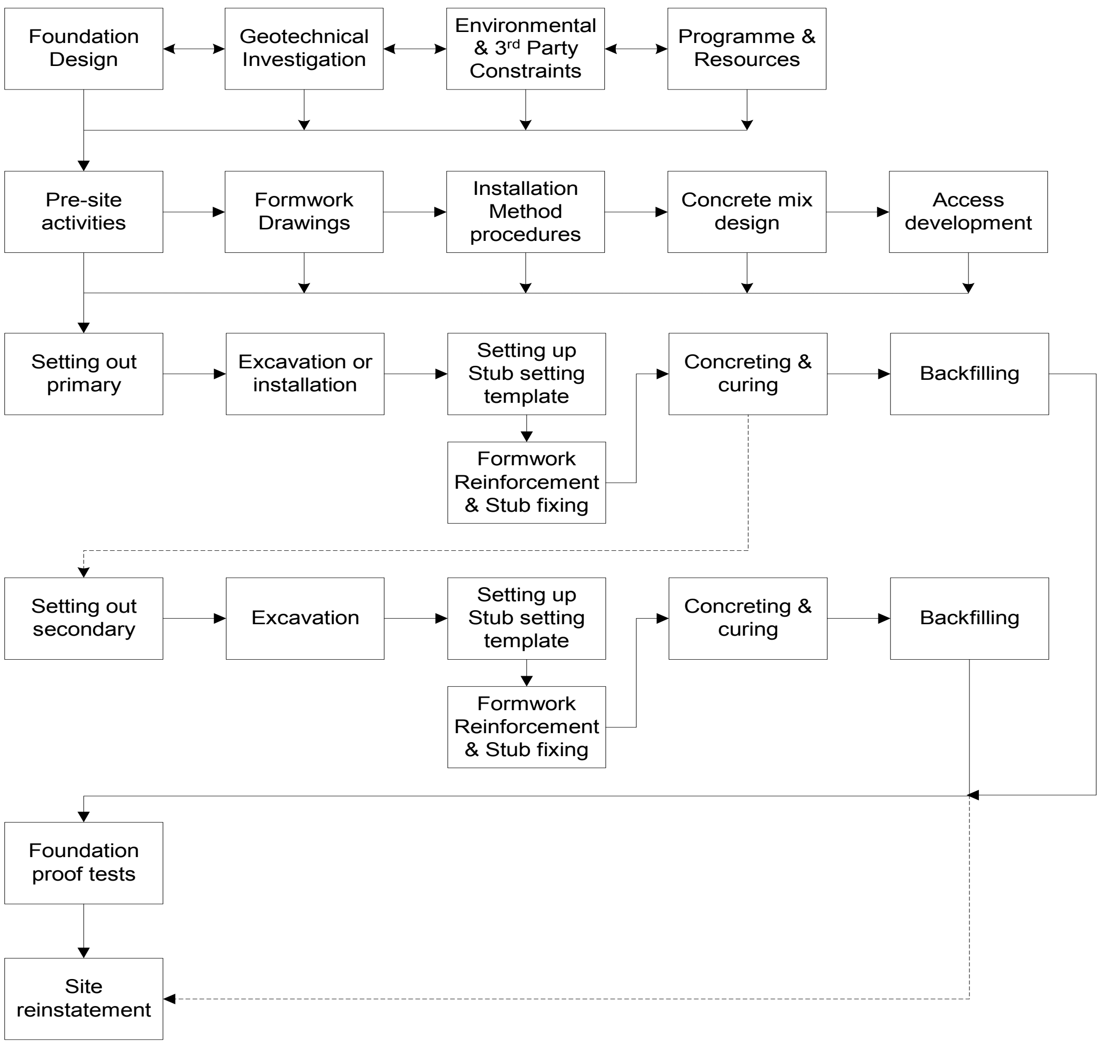


Figure 3.1 - Diagrammatic representation of foundation installation activities

Note: Primary activities refer to main foundation installation, i.e. for piled foundations the installation of the piles themselves, while the secondary activities refer to the construction of the pile cap.

3rd Parties include Landowners, Grantors, Regulatory Agencies, etc.

This section of the report does not cover the specific requirements for foundation installation in areas subject to mining subsidence caused by the extracting of coal and other minerals by shallow, deep or opencast mining. For details of procedures to be adopted reference should be made to CIRIA Report 32 [CIRIA 1984] and to Jones, Deal and Paisley [1988].

For details of the quality control and quality assurance, and health and safety activities associated with foundation installation, reference should be made to sections 4 and 5 of this report respectively.

3.2 Pre-site activities

3.2.1 General

For the purpose of this report, pre-site activities are defined below and assume that the foundation design and associated geotechnical investigation have already been undertaken, that any client, environmental and/or third party constraints have been considered and the requirements of both the programme and financial budgets have been taken into account.

- Preparation of the foundation installation drawings;
- Manufacture of the foundation formwork (shuttering) and the stub or anchor bolt setting templates. If the lower portion of a lattice tower is used to set the stubs, then the associated erection and rigging drawings also must be available;
- Preparation of the foundation installation method statement and associated hazard identification/risk assessment;
- If the excavation method proposed differs from the installation contractor's normal practice, consideration should be given to the preparation of foundation excavation support drawings and associated calculations (if appropriate);
- Site access development (accommodation works) has been undertaken, taking into consideration any client, environmental and/or third party constraints, the size and weight of the installation equipment, the transportation of site personnel and materials. If the use of helicopters is required for the transportation of equipment/materials/site personnel, all the appropriate planning and off-site activities have been completed.
- The concrete mix(es) has been finalised and approved, if appropriate;
- Details of the support type, extension and location have been agreed/approved and the support centre peg fixed on site;
- Any preliminary foundation design tests have been undertaken, unless the tests are going to be undertaken on working foundations and subsequently incorporated into the final work;
- The foundation installation criteria schedule has been prepared and approved, if appropriate.

Although, not stated above, it is assumed that all materials, installation plant/equipment and personnel, site offices/welfare facilities and stores are available.

3.2.2 Foundation installation drawings

Foundation installation drawings may include some or all of the following:

- Foundation general arrangement / construction drawings
- Concrete reinforcement bar bending and cutting schedules;
- Foundation formwork (shuttering) drawing;
- Stub setting or anchor bolt assembly template drawings.

a) Foundation general arrangement / construction drawings

Foundation installation drawings should typically show the elevation, plan and cross sections (if appropriate) of the foundation complete with all the appropriate dimensions. Stub details or holding down bolt assembly details, excavation dimensions, concrete mix design details, concrete reinforcement details, bar bending schedule, stub or anchor bolt assembly setting dimensions, installation tolerances and cross-references to all the appropriate foundation design documentation including the Site Investigation (SI) report, should also be included. As a minimum and where appropriate, the key foundation design data should be included on the general arrangement / construction drawing e.g. soil/rock profile, ground water level, assumed bearing pressure, frustum angle, density of backfill, etc. Typical foundation general arrangement/construction drawings for a reinforced concrete spread footing (pyramid and chimney); single driven steel tube pile foundation and a multiple driven steel tube piled foundation complete with a reinforced concrete pile cap are shown in Figures 3A.1, 3A.2 and 3A.3 respectively.

For the reinforcement bar bending and cutting schedule, care should be taken to ensure that both bending and cutting tolerances are taken into consideration when determining the overall bar length and that the specified concrete cover is not infringed. The clear spacing between the reinforcement should take into consideration both the maximum aggregate size and the diameter of the vibrator. In addition, the location of concrete spacers, especially chairs to support the upper layers of reinforcement, should be clearly shown on the foundation construction drawing.

b) Formwork

The following parameters should be considered in the design of formwork:

- The formwork should be sufficiently rigid and tight to prevent the loss of grout or mortar from the fresh concrete;
- The formwork and its supports should maintain their correct position and ensure the correct shape and profile of the concrete;
- The design of the formwork should take into account any safety considerations applicable, including manual handling;
- The formwork should be capable of being dismantled and removed from the cast concrete without shock, disturbance or damage;

If ‘standard’ foundations are required for a specific geotechnical condition for a range of different support types, e.g. suspension, light, medium and heavy angle, and terminal, normal UK practice is to undertake the design and manufacture of a standard range of steel formwork (shutters). The key requirement is to achieve the highest interchangeability between different support types, without compromising the foundation design. A typical steel shuttering general arrangement drawing is shown in Figure 3A.4 and the actual shutters in Figure 3.10; an alternative arrangement using disposal shuttering is shown in Figure 3.11. The use of timber formwork is shown in Figures 3A.11 and 3A.12.

c) Stub setting and anchor bolt assembly templates

Stub setting or anchor bolt assembly templates may be provided by the support manufacturer or by the foundation installation contractor. Stub setting templates may comprise a complete frame such that all four stubs can be set at once or alternatively a single template such that individual stubs are set in turn. The critical features are, that the stub setting template should be accurate such that the setting tolerances can easily be met, support the weight of the stub without causing the frame to distort, easily extendable for different support extensions and capable of setting hillside leg extensions. A typical stub setting template is shown in Figures 3.9 and, an alternative approach in Figure 3A.7c and an anchor bolt template in Figure 3A.5.

3.2.3 Concrete mix design

a) General

The primary objective of the concrete mix design is to ensure that the fresh concrete has the required workability, to enable a dense, void-free, concrete to be placed such that the hardened concrete has the required strength and durability for the intended service life of the foundation. For the majority of overhead line support foundations, the durability of the concrete and not the strength is the key requirement.

To achieve these aims, the concrete mix design, should take into account the following factors:

- The design strength in terms of the 28-day characteristic strength, strength grade or compressive strength grade;
- The durability required, taking into consideration the intended service life of the foundation, the chemical aggressiveness of the surrounding soil or ground water (static or mobile), whether the site is a greenfield or a brownfield location and whether the concrete is prone to freeze-thaw attack;
- The workability required, taking into consideration the delivery time to site from the batching plant, the proposed method of transporting and placing the concrete, the method of compaction, environmental conditions, e.g. cold or hot weather, etc.;
- The type of cement available and whether a combined cement, e.g. Portland cement combined with pulverised fly ash (pfa) or ground granulated blast furnace slag (ggbs), can be used,
- The type and size of the coarse aggregate, taking into account the proposed method of placing, e.g. rounded aggregates are preferred for concrete placed by tremie or pumping, the clear spacing between reinforcement and the diameter of the concrete vibrator;
- The permitted use of admixtures;
- Whether a design mix or a standardised mix in accordance with a national standard is required;
- The relevant requirements of the client's technical specification and/or national/international standards;
- Whether the concrete is going to be supplied from an external ready-mix supplier or batched on-site;
- Whether the external supplier is accredited to an approved quality assurance scheme;
- For site batched concrete, the source and types of aggregates and the quality of water.

Note: A brownfield site is defined as a site or part of a site that has been subject to industrial development, storage of chemicals or deposition of waste, and which may contain aggressive chemicals in residual surface materials or ground penetrated by leachates. [BRE 2001]

Similar details to those listed above will also need to be considered in respect of the design of cementious grouts for anchor foundations.

With regards to durability, the concrete and especially the cover to the reinforcement undertakes a series of functions, i.e.:

- Provides a high alkaline environment which passivates the reinforcement, thereby inhibiting corrosion;
- Provides a low permeability physical barrier (of sufficient depth) to the chemical agents that would otherwise promote corrosion in embedded steel items, e.g. chloride attack on concrete reinforcement;
- Forms an outer shell to protect the foundation from physical attack, e.g. freeze-thaw damage.

The achievement of the desired level of durability requires the correct cover to the reinforcement, the appropriate concrete mix, good compaction (i.e. reduction of voids and low permeability), correct curing, and possibly the use of admixtures in appropriate applications and quantities.

The effect of altering (increasing) the proportions and/or properties of the concrete mix constituents, i.e. cement, aggregates and water, on the workability, cohesiveness and stiffening time of the mix, are shown in Table 3.1.

Table 3.1 - Effect of increasing the proportions and/or properties of the mix constituents

Mix constituents	Effect on		
	Workability	Cohesiveness	Stiffening time*
Water	Increase	N / A	N / A
Portland cement	N / A	Increase	Reduce
pfa	Increase	Increase	Increase
ggbs	Increase	Increase	Increase
Aggregate			
max. aggregate size	Increase	Reduce	N / A
angularity	Reduce	N / A	N / A
fine aggregate content	Reduce	Increase	N / A

Notes: * Stiffening time is time beyond which reworking the concrete would be detrimental. Details taken from Table 4.6 of CIRIA report R165 [CIRIA 1977a].

For further information reference should be made to the appropriate standards, e.g. EN 206-1 [BSI 2000a], BS 8500 [BSI 2002]. Reference should also be made to section 3.6 of this report, for specific requirements for concrete mixes for drilled shaft foundations and piles.

b) Aggressive ground or ground water conditions

Concrete in the ground is prone to attack by a variety of different chemicals either in the soil and/or the ground water, with a corresponding reduction in both its long term strength and durability. The chemical constituents of aggressive ground and groundwater are: sulfates and sulfides, acids, magnesium ions, ammonium ions, aggressive carbon dioxide, chloride ions and phenols. For further details regarding concrete in aggressive ground conditions and recommendations regarding the design of resistant concrete mixes, reference should be made to BRE Special Digest 1 [BRE 2001]. In addition, details of reinforced concrete construction in hot-wet and hot-dry environments are given in CIRIA Report C577 [CIRIA 2002a].

Concrete can also suffer from internal degradation from alkali-aggregate reaction, normally in the form of alkali-silica reaction, for further details reference should be made to BS 8500 [BSI 2002].

c) Combined cements

Portland cement combined with either pfa or ggbs can provide adequate protection against sulfate attack and enhanced protection against chloride attack, and these combinations are suitable alternatives to Sulfate-resisting Portland cement, when this is not available. Care should be taken when using a ggbs combination due to its slower rate of gain of strength and tendency to bleed more than concrete made from Portland cement.

d) Admixtures

Admixtures are a useful way of modifying or improving the concrete mix in respect of the workability or durability. All admixtures should be used in accordance with the manufacturers' instructions, especially where multiple admixtures are used in combination for their compatibility and in accordance with the relevant standard, e.g. EN 934 [BSI 2001a]. The range of admixtures available includes: accelerators, retarders, air-entraining agents, water reducers, plasticisers and pumping aids.

- Accelerators — reduce the setting/stiffening time and increase the rate of strength gain;
- Retarders — retains workability thereby offsetting the effects of high ambient temperatures, slower/strength time response and hence prevention of cold joints between pours;
- Air-entraining agents — increase the durability of concrete to resist freeze-thaw attack; however, the use of this admixture can cause a reduction in the concrete strength and may require a change in the mix design;
- Water reducers & plasticisers — higher workability for a given water content hence denser concrete, higher strength for a reduced water content at a maintained workability therefore stronger concrete, same strength at a reduced cement content whilst maintaining the same w/c ratio hence lower permeability;
- Superplasticisers — very high workability at given water content thereby assisting placing in difficult situations, time and energy saving no compaction necessary, non-shrink/non-bleed grouts.

The effect of altering (increasing) the admixture proportions on the workability, cohesiveness and stiffening time of the concrete mix are shown in Table 3.2.

Table 3.2 - Effect of increasing the admixture proportions on the mix properties

Admixture	Effect on		
	Workability	Cohesiveness	Stiffening time
Accelerators	N / A	N / A	Reduce
Retarders	N / A	N / A	Increase
Water reducers / plasticisers	Increase	Increase	N / A
Air-entrainer	Increase	Increase	N / A
Superplasticisers	Increase	Increase	N / A
Pumping aids	Increase	Increase	N / A

For further details regarding concrete technology for cast in-situ foundations, reference should be made CIRIA Report C569 [CIRIA 2002b].

3.2.4 Preliminary foundation design tests

Full-scale foundation design tests are normally undertaken in advance of the main site activities and are usually carried out on specially installed foundations, with one or more of the following objectives:

- To verify design parameters or methodologies;
- To verify installation procedures;
- To establish geotechnical design parameters and/or design methodologies for a specific application;

- To verify compliance of the foundation design(s) with the client's specification;
- To determine the average failure load and coefficient of variation of the foundation design in specified geotechnical conditions.

A typical full-scale foundation uplift loading test arrangement is shown in Figure 3.2. For further details regarding full-scale foundation design requirements, reference should be made to IEC 61773 [IEC 1996] and Cigre Brochure No. 81 [Cigre 1994].

Figure 3.2 – Full-scale foundation uplift loading test arrangement

3.2.5 Foundation installation criteria

Foundation installation criteria are detailed in a schedule which categorises for each support location, the soil and/or rock type, ground water level, the type of foundation to be installed and the concrete mix to be used. The schedule is prepared by the foundation designer and should demonstrate the basis for the selection, taking into account the following items:

- The results of the site investigation;
- The results of any preliminary foundation design tests;
- The design criteria, i.e. a summary of the design parameters including the theoretical basis for the design, the applicable design standards or codes of practice used, etc.

3.3 Setting out

Prior to commencing any work on-site apart from site clearing, main and auxiliary line pegs both transverse and longitudinal to the direction of the overhead line should be established, such that, the centre peg of the support can be re-established, if necessary. The pins used, should be of steel with a minimum length of 300 mm and a minimum diameter of 12 mm, located outside the proposed area of working and driven to ground level.

Pins used for marking out the foundation excavation should be of a similar type. Setting out pins for piles should be similar and for raking piles due account should be taken of the horizontal offset required, to allow for any difference in elevation between the piling platform and the cut-off level of the pile. In addition, for raking piles an alignment pin will be required to indicate the direction of the rake. If appropriate, the pins should be clearly tagged with the pile reference number.

Permitted installation tolerances for piles are given in both EN 1536 [BSI 2000b] and the ‘Specification for Piling and Embedded Retaining Walls’ [ICE 1996].

3.4 Excavation

Excavations should be adequately supported or formed to ensure stability of the sides, prevent any damage to the surrounding ground or adjacent structures and ensure the safety of all personnel. Where sheet piling and/or timbering is used for the support of the foundation excavation, this should be in accordance with a recognised standard or code of practice, e.g. BS 8004 Section 5 [BSI 1984] or HSG185 [HSE 1999].

Unless the excavation is battered or stepped, excavations in non-cohesive loose sand and gravel, soft clays and silts will require close sheeting to prevent ground movement. The use of steel trench sheeting or timber boards driven prior to excavation commencing may be necessary in many cases. For details of safe slope angles for battered back sides of excavations reference should be made to HSG185 [HSE 1999]. Typical excavations with side support are shown in Figures 3.3, 3.4, 3.5 and 3.6.

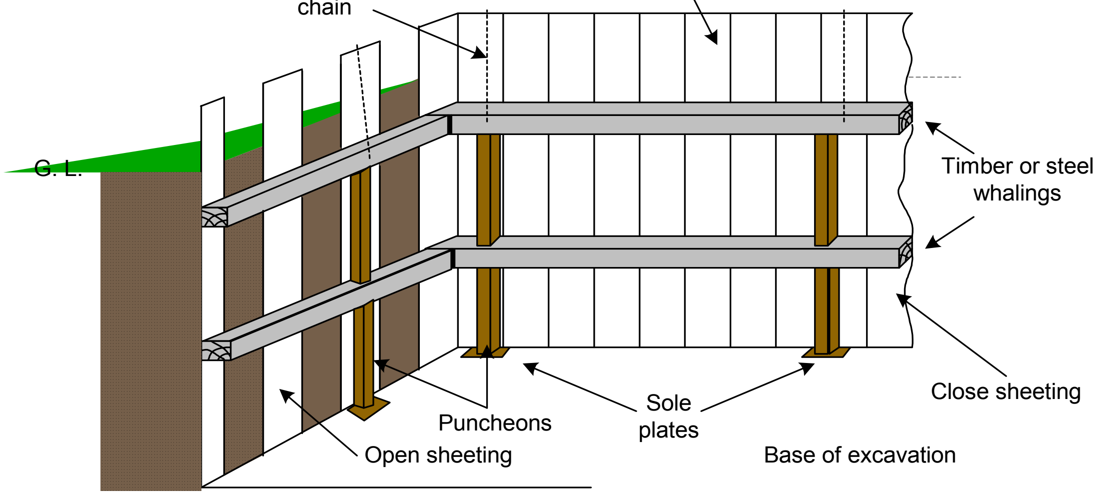


Figure 3.3 - Typical foundation excavation

Note: Safety barriers and/or guard rails, stop blocks omitted for clarity.

Excavations in cohesive soil and weak rock may stand unsupported; however, there is always a risk that excavations in these ground conditions will collapse without warning. Cohesive stiff or very stiff clays may be adequately supported by open trench sheeting where alternate sheets/boards are omitted. Care is necessary when excavating rock which may fracture, to ensure that loose blocks do not fall from the excavation face.

The risk of the collapse of the excavation side is influenced by the following factors:

- Loose uncompacted soils, especially fill materials or made-up ground;
- Excavations through different strata;

- Presence of groundwater or surface water running into the excavation;
- Proximity of earlier excavations;
- Loose blocks of fractured rock;
- Weathering, rain and freeze/thaw effects;
- Vibration from plant and equipment;
- Surcharging by spoil;
- Proximity of loaded foundations.

Excavated material suitable for reuse as a backfill should be stored within the working area, but in such a location so as not to cause an increase in loading (surcharge) on the face of the excavation (minimum distance from excavation face of 1.5 m or the depth of the excavation, if greater). Excavated top soil should be stored separately.

For excavation in cohesive soil, the final 150 mm above the formation level should only be removed prior to placing the blinding concrete, thereby preventing softening of the exposed formation layer. Normal practice is to use a concrete blinding layer 75 mm thick, although in chemically aggressive soils it may be necessary to use an impermeable membrane between the blinding concrete and the soil. Similar requirements may be required for certain weak rocks that deteriorate due to the presence of moisture, e.g. uncemented mudstones.

No water should be permitted to accumulate in the excavation; any water arising from the excavation or draining into it, should be drained to an approved location, clear of the excavation area and in a manner that does not cause erosion, silting or contamination of existing drains and watercourses. Adequate steps should be taken to prevent the adjacent ground being adversely affected by the loss of fines in any groundwater control process. The water removal system may include conventional pumping from a sump in the corner of the excavation or alternatively in soils with a high permeability using well pointing de-watering techniques. For further details regarding groundwater lowering, e.g. de-watering, reference should be made to BS 8004 [BSI 1984]. The design of the groundwater control system should ensure that any upward flow of water is not sufficient to cause ‘piping’ at the base of the excavation, whereby the soil cannot support any vertical load.

Figure 3.4 – Foundation excavation open sheeting

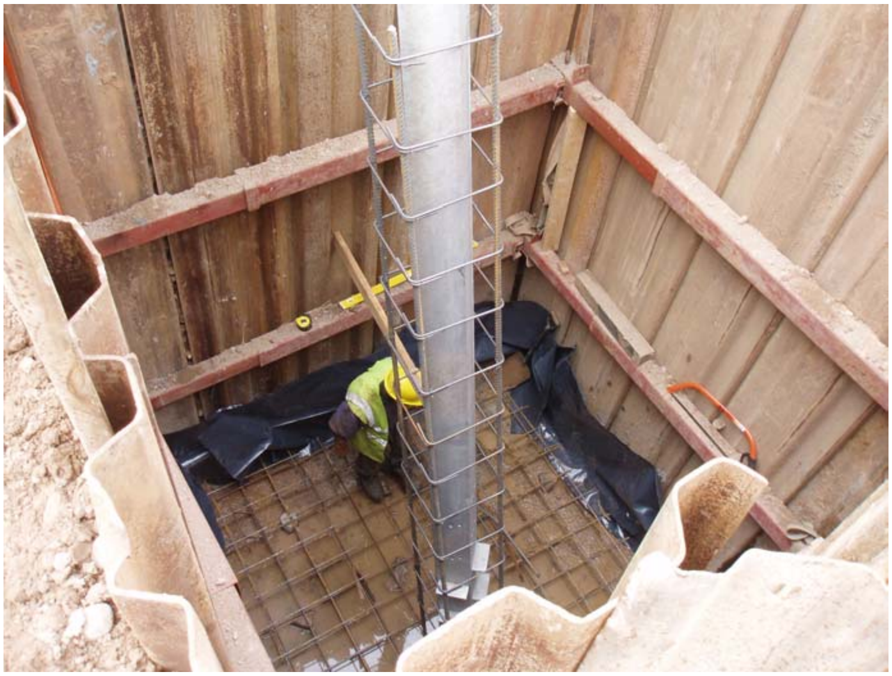


Figure 3.5 – Foundation excavation close sheeting using steel trench sheeting

Figure 3.6 – Foundation excavation side support using netting frame

3.5 Reinforcement

The necessity for adequate concrete cover has been previously discussed in section 3.2.3 with respect to the overall durability of the foundation. With regards to the storage, cutting, bending, fixing and site bending of the reinforcement, the following points should be taken into consideration:

- All reinforcement should be adequately stored to prevent contamination or damage.
- Cutting and bending should be undertaken in accordance with the appropriate standard, e.g. BS 8666 [BSI 2000c] and should be clearly identified with securely fixed durable tags.
- The welding of reinforcement cages or the welding of handling steelwork to the cage should be undertaken in accordance with appropriate standards. Care should be taken to ensure that the reinforcement is of 'weldable' quality.
- The reinforcement should be property supported and maintained in position by the adequate use of chairs, concrete block spacers, plastic wheel spacers and tying wire (see Figures 3.7, 3.8, 3A.7 and 3A.8).
  BS 7973 [BSI 2001b], requires that spacers and chairs for horizontal mat reinforcement, e.g. for pile caps should be spaced at 50 x reinforcement diameter, but not exceeding 1000 mm and should be staggered in plan. Similarly, spacers for vertical reinforcement should be positioned at similar spacings.
- The reinforcement should be free of all loose rust, scale or contamination of any kind.
- Site bending of reinforcement, or bending and subsequent straightening of reinforcing bars projecting from existing concrete, should be undertaken at a reinforcing bar temperature greater than 6°C and in accordance with recognised practices.
- Where heating is required, the heat should be applied as uniformly as possible over a length of bar equal to 10 x reinforcement diameter. The centre of the heated length should be at the centre of the completed bend. The temperature should be maintained constant during bending and straightening operations and should not exceed 100°C. Temperature measuring crayons or a contact pyrometer should be used to determine the temperature. Care should be taken to prevent quenching of the heated bars either by application of water, or by a high volume of air.
- Straightened bars should be visually inspected before and after straightening to determine whether they are cracked or otherwise damaged.

Where possible the site bending of reinforcement should be avoided by the use of bar couplers.

For further details regarding the care and treatment of steel reinforcement on site, reference should be made to CIRIA Report 147 [CIRIA 1995]. ISO 14654 [BSI 1999] contains guidelines on site practice with respect to the use of epoxy-coated steel reinforcement.

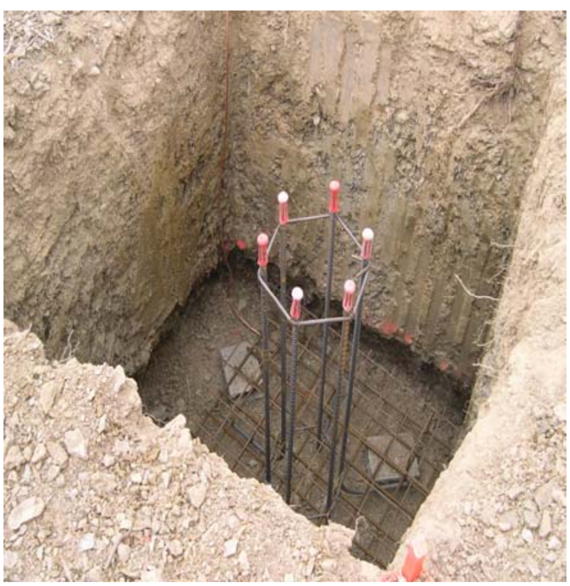


Figure 3.7 – Foundation reinforcement showing concrete block spacers

Figure 3.8 - Foundation reinforcement complete with plastic wheel spacers

3.6 Drilled shaft and pile installation

To avoid the problems and their effect on the foundation design outlined in section 2 of this report, all drilled shaft foundations and piles should be installed in accordance with the appropriate standards or recognized codes of practice.

Details of the design requirements, installation techniques including methods of excavating or forming the pile, methods of dealing with unstable ground conditions or ground water infiltration, use of temporary and/or permanent casings or other means of excavation support, e.g. use of stabilizing fluids, concrete mix design, placing of reinforcement and concrete or grout, installation tolerances, inspection requirements and associated records, and testing requirements are contained in the following standards and codes of practice:

- ACI 543-74 [ACI 1974] - Concrete piles;
- ACI 336.3R-93 [ACI 1993] - Drilled shaft foundations;
- EN 1536 [BSI 2000b] - Drilled shaft foundations, Bored cast in-situ piles and c.f.a piles;
- EN 12699 [BSI 2001c] - Displacement piles;
- Specification for Piling and Embedded Retaining Walls [ICE 1996] - All pile types, for drilled shaft foundations see bored cast in-situ piles.

Further information regarding pile installation is contained in the following reports:

- CIRIA Report PG2 [CIRIA 1977b] - Cast-in-place piles;
- CIRIA Report PG3 [CIRIA 1977c] - Use and influence of bentonite in bored pile construction;
- CIRIA Report SP12 [CIRIA 1979] - Piling in chalk;
- CIRIA Report PG8 [CIRIA 1980] - Problems associated with the installation of displacement piles.
- IEEE Guide to Installation of Foundations for Transmission Line Structures [IEEE 1991]

3.7 Micropile and ground anchor installation

To avoid the problems and their effect on the foundation design outlined in section 2 of this report, all micropiles and ground anchors should be installed in accordance with the appropriate standards or recognized codes of practice.

Details of the design requirements, installation techniques including methods of drilling or forming the micropile/ground anchor, methods of dealing with unstable ground conditions or ground water infiltration, use of temporary and/or permanent casings or other means of excavation support, e.g. use of grout, grout mix design, placing of reinforcement and grout, installation tolerances, inspection requirements and associated records, and testing requirements are contained in the following standards and codes of practice:

- BS 8081 [BSI 1989] - Ground anchors relevant in part to micropiles;
- EN 1537 [BSI 2000d] - Ground anchors;
- EN 14199 [BSI 2005] – Micropiles.

For a general introduction on the use of micropiles for overhead line support foundations, reference should be made to Cigre Brochure 281 [Cigre 2005].

3.8 Stub setting

The key points for consideration in respect of stub setting or holding down bolt assemblies are:

- Stubs should be held firmly in position by a stub setting template (see Figures 3.9 and 3.14) or other device including the bottom panel of a tower (see Figure 3.10), while the concrete is placed.
- The support should be maintained until backfilling of the foundation is complete, or for drilled shaft, anchor and pile caps, compact and raft foundations until a minimum period of 48 hours have elapsed after concreting.
- Where individual templates are used (i.e. per footing), as opposed to an overall frame template, additional care should be taken to ensure the stub setting dimensions and the level, rake and orientation of the stubs are correct and within any specified setting tolerance.
- Where the lower section of the support is used, as an alternative to a stub setting template, adequate measures should be taken to ensure the stability of the support;
- When large heavy stubs are used, care should be taken to ensure the effect of the suspended stubs does not cause the stub setting template to distort. The use of concrete blocks to support the lower end of the stub and assist in the leveling of the stubs will overcome this. Where concrete blocks are used, they should have similar strength and durability to the surrounding concrete;
- Where holding bolt assemblies are used for separate foundations, setting templates should be used and retained in position for a minimum of 48 hours after concreting.

Figure 3.9 – Stub setting template,

Note only two foundations being excavated at one time.

Figure 3.10 – Stub setting using the bottom panel of the tower

3.9 Concrete production, delivery and placing

3.9.1 General

The following recommendations with respect to the production, delivery both to and on site, and placing are for guidance only and reference should be made to the applicable standards, e.g. BS 5328 Part 3 [BSI 1990a], EN 206-1 [BSI 2000a], BS 8500 [BSI 2002], for specific requirements.

3.9.2 Concrete production

a) Material storage

The key requirements for material storage are:

- Provision of separate storage for cement, ggbs, pfa and each nominal size and type of aggregate;
- Silos used for bulk storage of cement, ggbs and pfa should be weatherproof and control dust pollution;
- Bagged cement should be stored to prevent it becoming damp and used in the same order as delivered;
- Cement that is adversely affected by damp should not be used;
- Aggregate storage areas should have adequate drainage;
- Water should be protected against contamination.

b) Batching

Concrete batching should be undertaken taking into account the following points:

- Cement, ggbs and pfa should be measured by mass, using a separate weighing device from that provided for the aggregates;
- For bagged cement use whole bags;
- Aggregate(s) should be measured by mass, using a weighing device, with due allowance

for the mass of the water in the aggregate(s);

- Water may be measured by volume or mass;
- The accuracy of the measuring equipment should be within ±3% for all constituent materials, except admixtures where ±5% is acceptable;
- The weighing devices should be zeroed daily, checked for accuracy monthly and calibrated every 3 months;
- In cold weather, the mixing plant, aggregates and mixing water should be free from snow, ice and frost. If steam heating of aggregates is used, allowance for the increased moisture content should be made;
- In cold weather if the water and aggregates are heated, the water should not be heated above 80°C, and if the water is heated above 60°C, it should be mixed with the aggregate before coming into contact with the cement;
- In hot weather, the most effective means of reducing the concrete temperature is the addition of crushed ice to the mix water [BRE 1971]. However, the mass of crushed ice or ice chips should not exceed 50% of the total mass of water [BSI 2000b].

3.9.3 Concrete transportation

Concrete should be transported from the mixer to the point of placing as rapidly as practicable, by methods that will maintain the required workability and will prevent segregation, loss of any constituents or ingress of foreign matter, significant loss or gain of water and loss of air entrainment. No additional water should be added to the mix before placing, unless where required to permit the correct mixing of admixtures just before placing; however, no changes to the design water-cement ratio are permitted. In addition, the mode of transportation should take into consideration the terrain and the required rate of supply.

3.9.4 Concrete placing

Normally, concrete should be placed within two hours after the initial loading in a truck mixer or agitators, or within one hour if non-agitating equipment is used. These periods may be extended or shortened, depending on climatic conditions and whether ggbs, pfa, accelerating admixtures or retarding admixtures have been used.

Concrete chutes suitable for high workability concrete should have an adequate constant slope to permit continuous flow without segregation and should be fitted with end baffle plates to prevent segregation or impact with the reinforcement or other embedded items.

Where it is intended to place the concrete by pumping, careful attention should be paid to the concrete mix design, i.e. the workability, with particular reference to the fine aggregate grading, type and size of coarse aggregate, the use of replacement cementious material (pfa), the water cement ratio and the use of suitable admixtures, to ensure that segregation and bleeding does not occur.

Before the concrete is placed, all rubbish should be removed from the formwork and the faces of the forms in contact with the concrete should be cleaned and treated with a suitable release agent. The release agent should be applied to provide a uniform coating to the forms without contaminating the reinforcement. Figure 3.10 illustrates the setting up of steel formwork prior to concreting, while Figures 3.13, 3.14, 3A.6 and 3A.13 all show concrete being placed.

For further details regarding the placing of concrete in general and especially the use of tremie pipes, reference should be made section 3.6 of this report and CIRIA report R165 [CIRIA 1997a].

Figure 3.11 – Steel formwork
Concreting using chutes

Note timber props to resist uplift force of wet concrete

Figure 3.12 – Disposable formwork

Figure 3.13 – Concreting using chutes

Figure 3.14 – Placing of concrete in a drilled shaft foundation.

Note: The use of an alternative type of stub setting template

3.9.5 Construction joints

Although, it is preferable to have an integrally cast foundation, this may not be possible due to the foundation type or connection between the tower bracings and the stub member. To ensure that the joint between the two concrete pours are acceptable the following procedure is recommended:

- The surface of the first pour should be roughened to increase the bond strength and to provide aggregate interlocking;
- For horizontal joints, this can be achieved by spraying the joint surface approximately 2 to 4 hours after the concrete is first placed with a fine spray of water and/or brushing with a stiff brush;
- If it is not possible to roughen the joint surface until the concrete has hardened, the large aggregate particles near the surface should be exposed by sand blasting;
- The joint surface should be cleaned immediately before the fresh concrete is placed and if necessary the surface should be slightly wetted to prevent excessive loss of mix water by absorption.
- Particular care should be taken in placing the fresh concrete close to the joint to ensure it has adequate fines content and is fully compacted and dense.

3.9.6 Compaction

Unless a self-compacting concrete mix is used, all concrete should be thoroughly compacted by vibration, or other means, and worked around the reinforcement, embedded items, e.g. stubs and into corners of the formwork to form a solid void-free mass. When vibrators are used, vibration should be applied until the expulsion of air has practically ceased and in a manner that does not promote segregation. Over-vibration should be avoided to minimize the risk of forming a weak surface layer or excessive bleeding.

3.9.7 Curing

The setting and hardening of cement depend on the presence of water; drying out, if allowed to take place too soon, results in low strength and porous concrete. At the time of concrete placing, there is normally an adequate quantity of water present for full hydration; however, it is necessary to ensure that this water is retained so that the chemical reaction continues until the concrete has thoroughly hardened. Correspondingly, curing and protection should start immediately after compaction of the concrete and should ensure adequate protection from:

- Premature drying out, particularly by solar radiation and wind;
- Leaching out by rain and flowing water;
- Rapid cooling during the first few days after placing
- Low temperatures or frost until the concrete has reached an adequate maturity;
- High internal thermal gradients;
- Vibration and impact which may disrupt the concrete and interfere with its bond to the reinforcement or other embedded items.

Although, normal formwork, e.g. steel shutters for concrete spread footings, provides adequate protection to the concrete in normal climatic conditions, extra measures may be required during cold or hot weather conditions. As an approximate guide, for concrete with a characteristic strength of between 25 N/mm² and 35 N/mm², a minimum period before stripping of 24 hours should be allowed for Portland cement or combined cements, except for combined cements containing ggbs when a minimum period of 48 hours should be allowed. For further information regarding minimum curing periods, reference should be made to BS 8110 section 6 [BSI 1997].

For horizontal surfaces, e.g. upper surfaces of pile caps or raft foundations, effective curing can be achieved by covering the surface with an impermeable membrane, e.g. polyethylene, which should be well sealed and fastened, or by using a sprayed curing membrane.

3.9.8 Working in cold weather

The concrete setting time and gain in strength are delayed at low temperatures and if the partly set concrete is allowed to freeze, serious damage can occur. Consequentially, in cold weather consideration should be given to:

- Prevention of freezing of the immature concrete, e.g. by insulating the fresh concrete using thermal blankets, etc. (see Figure 3.15);
- The extended stiffening times of fresh concrete, which lead to increased formwork pressures and finishing times;
- The low rate of concrete strength development, which can lead to delays in subsequent operations;
- Increasing the cementious content of the mix, thereby increasing the heat of hydration and early strength gain;
- Using admixtures that reduce the setting time and/or increase the rate of strength gain;
- Specifying a minimum temperature of fresh concrete higher than the norm of 5°C.

The key requirement of winter working is planning, taking into consideration weather forecasts, and keeping records of maximum and minimum temperatures, thereby assisting in the assessment of the concrete maturity and formwork striking times.

The rate of gain of strength is related to the concrete maturity, which is the product of the concrete temperature above -10°C and the number of hours at that temperature. For concrete with a characteristic strength of 25 N/mm², the requisite pre-hardening period is 52 hours if the concrete temperature is 5°C reducing to 26 hours at 20°C. For further details reference should be made to 'Concrete Practice' [C & CA 1975].

For conventional reinforced concrete spread footings, the early backfilling of the foundation will assist in the prevention of damage to the concrete by frost action, provided that the backfill material is not frozen.

Figure 3.15 – Cold weather concreting, note use of thermal insulation

3.9.9 Working in hot weather

In hot weather the main difficulties in concreting are caused by reductions in the working life of fresh concrete due to loss of mix water by evaporation and accelerated hydration, and early-age thermal cracking arising from a high temperature rise in the concrete. Consequentially, in hot weather consideration should be given to:

- Using admixtures to retard the hydration and/or to increase the initial workability;
- Using a cement or cement combination that has a low heat evolution;
- Specifying a maximum temperature of fresh concrete lower, than the norm of 30°C.

As previously noted, the key requirements for concreting in hot weather are planning and the need to protect the fresh concrete from drying out by sun and/or wind action.

3.10 Backfilling

As previously mentioned in section 2 of this report, failure to adequately compact the backfill is one of the prime reasons for a foundation's actual uplift strength, being less than its theoretical design strength. Correspondingly, the following recommendations should be taken into consideration:

- Backfilling should be compacted in 300 mm layers to achieve a bulk density equivalent to that assumed in the geotechnical design model;
- Backfilling should be undertaken progressively over the whole foundation plan area, with particular emphasis on the area adjacent to the inner face of the chimney (see Figure 3.16);

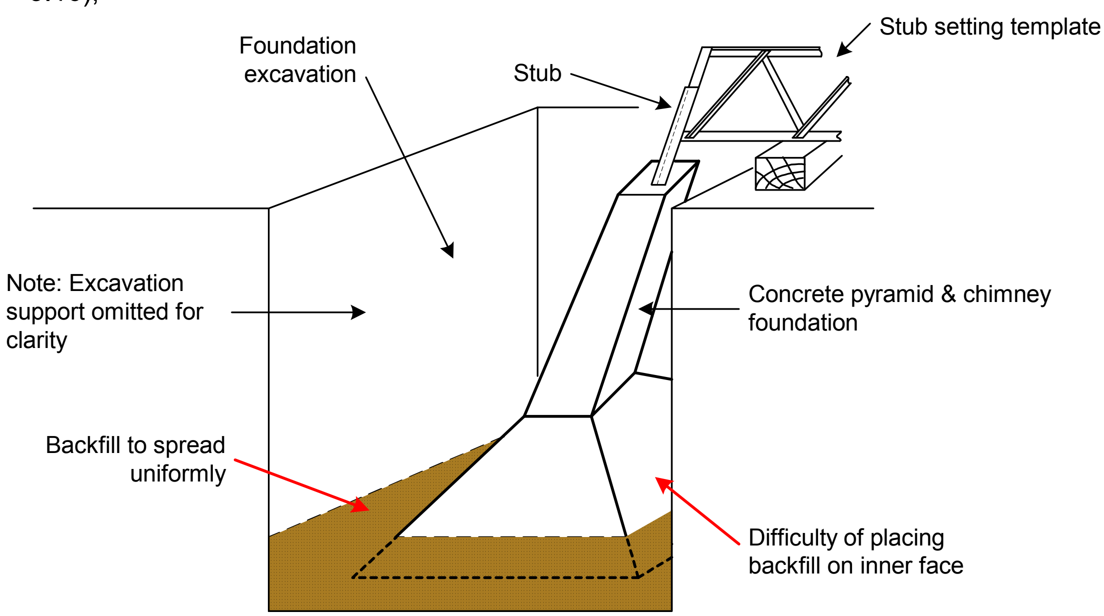


Figure 3.16 - Foundation backfilling

- During backfilling, the side support sheeting to the excavation should, wherever possible, be progressively withdrawn such that the toe of the sheeting is never more than 600 mm below the surface of the compacted material;
- Extreme care should be taken during compaction to ensure that the foundation is not damage nor displaced out of position;
- The compaction plant should be selected to achieve the required bulk density. The actual

method of compaction selected will depend on the type of material to be compacted, the difficulty in accessing areas within the excavation and the safety of the site operatives.

For spread footing foundations in soils subjected to permafrost and frost forces, consideration should be given to backfilling with non frost susceptible materials, e.g. granular fill with less than 8% silt content and passing through a 200 sieve. For further recommendations regarding the use of insulating materials and the application of a lubricant to steel foundation members, reference should be made to Cigre Brochures No.141 [Cigre 1999a] and No. 206 [Cigre 2002].

Compaction of the backfill around steel grillage foundations is shown in Figure 3A.9.

3.11 Protective coatings

Where appropriate, consideration should be given to the application of protective coatings to the foundation or foundation components, e.g. steel bearing piles, guy anchor rods, etc., to improve their long term durability.

Normal practice is to coat, as a minimum, all exposed concrete surfaces above ground level and 300 mm below ground level, although in very aggressive conditions, it may be necessary to coat all concrete surfaces below ground level. Similarly, all support steelwork should be treated for a minimum distance of 300 mm above the top of the concrete. Where steel bearing piles or driven cast-in-situ piles with permanent casings are used, a combination of sacrificial steel and protective coatings, may be used as alternative to a pure protective coating system.

Coatings may take the form of waterproof membranes or surface coatings. Surface coatings include cementious mortars, polysulphides, resins and silicones, silanes and siloxanes for concrete and coal tar epoxy paint for steelwork. Although, historically two coats of heavy duty bituminous paint (with a density of 1 kg/litre and applied at a rate of 1.7 to 2.1 m^2/litre) has performed satisfactorily in the UK, care should be taken in its use owing to its tendency to crack under high temperature conditions. Coal tar epoxy coatings to buried steelwork should have a minimum dry film thickness of 300 μm.

Prior to the application of any external coating, the concrete should be allowed to cure for at least 28 days and all surface laitance, dirt and other contaminants should be removed. Where applicable, the concrete surface should be treated with a proprietary filling compound, compatible with the coating system.

If it is necessary to bury the support steelwork (excluding directly embedded steel poles), consideration should be given to protecting the buried steelwork using an approved medium, e.g. mastic impregnated tape or coal tar epoxy coating. The use of concrete to protect buried support steelwork, especially lattice tower bracing members is not recommended, due to the difficulty of ensuring a homogenous concrete covering and the possibility of damaging or distorting the steelwork.

3.12 Installation activities

Reference should be made to section 3A, where photographs of both foundation installation equipment and sequences in the installation of different types of foundations are shown.

3.13 Summary

The foundation installation activities considered in this section of the report have encompassed the general pre-site activities, e.g. preparation of foundation installation drawings, concrete mix design, preliminary foundation design tests, the foundation setting out, excavation, the placing of the reinforcement, concrete production, delivery and placing, backfilling, and protective coatings.

To ensure that activities described in this section are performed satisfactory such that the foundation achieves its intended service life, the next section of the report considers the quality management requirements in respect of foundation installation.


Figure 3A.7a – Auger-pile foundations before concreting of the individual auger-piles


Figure 3A.7b – Auger-pile foundations after concreting of the individual auger-piles

Figure 3A.7c – Auger-pile foundations before concreting of the pile cap

Note: The use of a cast-in-situ concrete block to support the stub vertically and the use of a simple adjustable prop system to form the stub setting template.

Figure 3A.8 - Foundation Installation - Driven steel tube piles - pile cap

Note: Pile cap ready for concreting, concrete cast directly against the surrounding soil, use of pre-cast concrete block below stub and reinforcement welded to steel tube piles (starter bars).

Figure 3A.9a – Assembly of steel grillage foundations for 230 kV OHL - Newfoundland

Figure 3A.9b – Compaction of the backfill around the steel grillage foundations

Figure 3A.9c – Completion of the backfilling for the nearest tower legs and excavation for the far two legs.

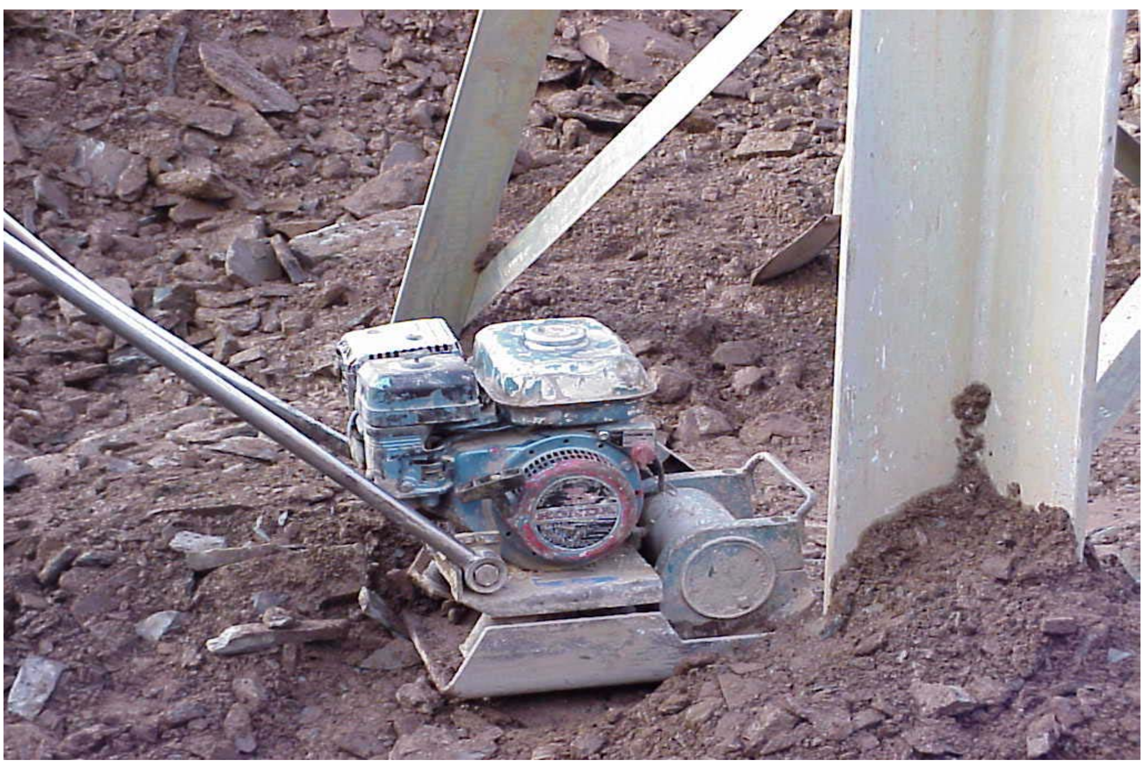


Figure 3A.9d – Detail of the plate vibrator used for the backfill compaction

Figure 3A.10 – Details of bored pile installation equipment ~ 1.3 m diameter piles Germany

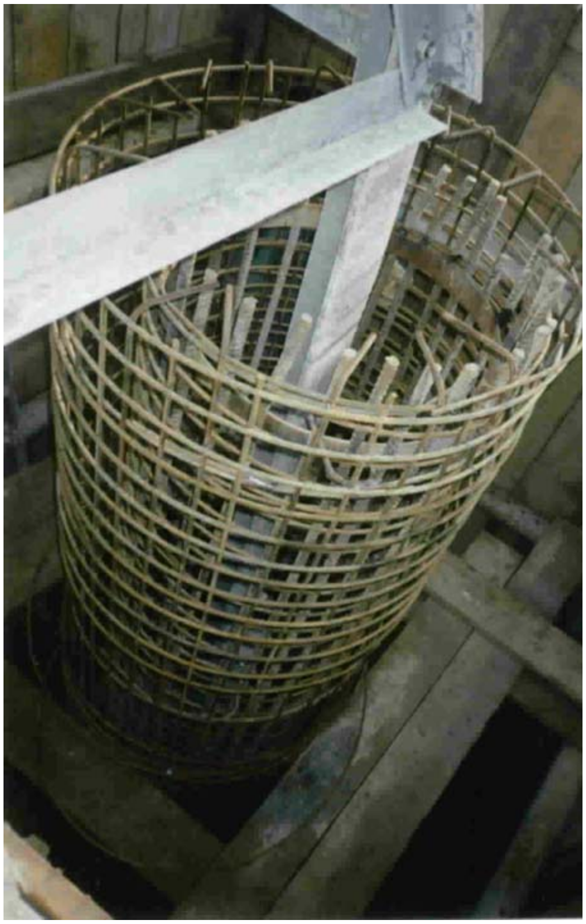


Figure 3A.11a – Bored pile 1.3 m diameter single pile per leg 380 kV lattice steel tower

Figure 3A.11b – Bored piles 2 x 1.3 m diameter per leg, detail of pile cap and chimney.

Figure 3A.11c – Bored pile 2 x 1.2 m diameter per leg, details of pile cap and chimney extension 110 kV lattice steel towers ~ Germany

Figure 3A.12 – Details of cruciform foundation for 330 kV lattice steel tower located in Hunter Valley coalfield, N.S.W. Australia

Note: Cruciform foundation used instead of a raft foundation to ensuring no differential settlement between footings in the event of subsequent subsidence due to deep mining activities.

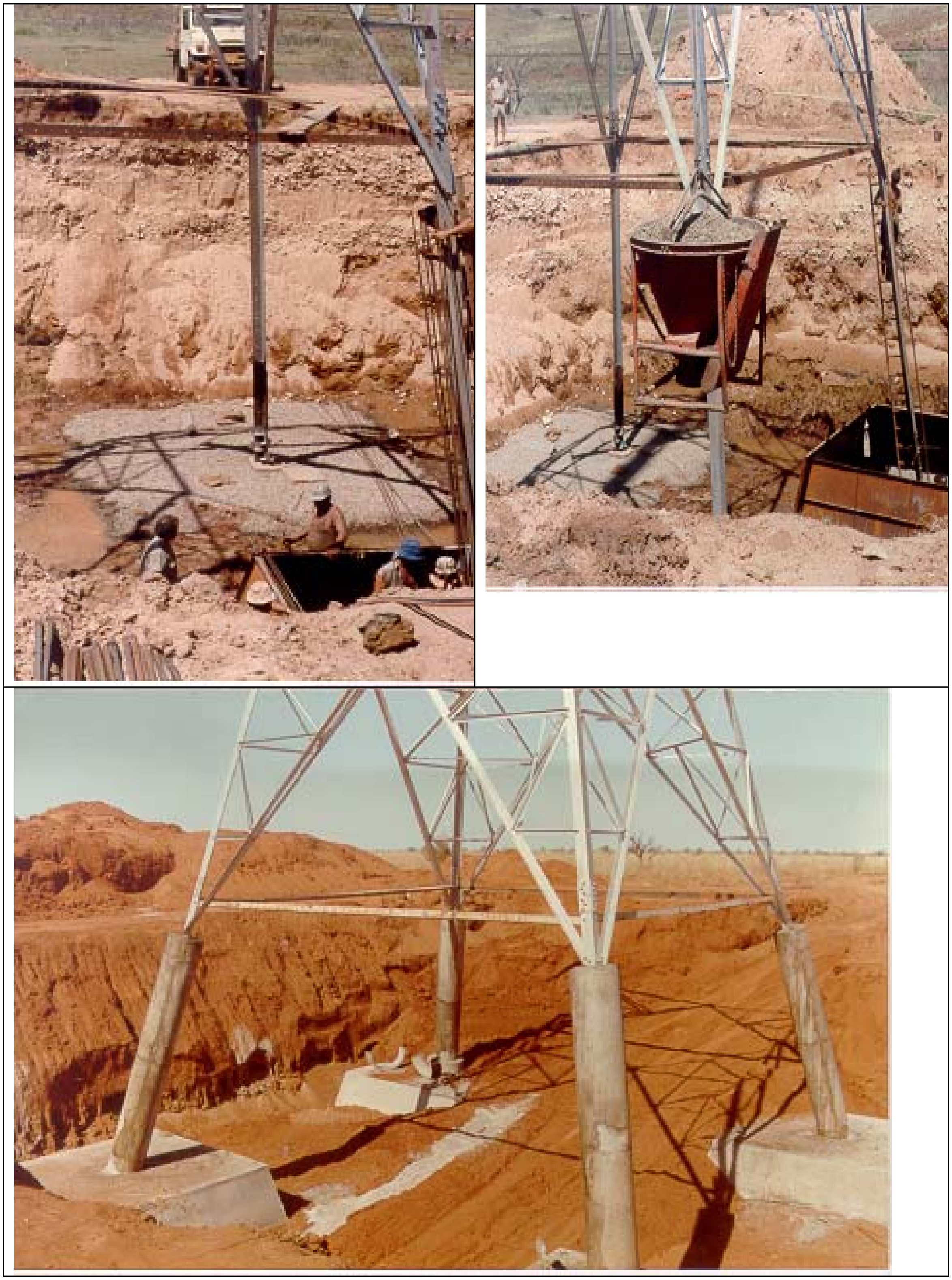


Figure 3A.13 – Installation of pad and chimney foundations for 220 kV lattice steel tower Western Australia

Note: The overlapping of adjacent footings prevent individual excavations, resulting in a major excavation and backfilling operation.

4 Quality Assurance and Quality Control

4.1 General

Overhead transmission line construction is undertaken effectively on a long linear site with isolated areas of activity. Since overhead line support foundations are installed in a variable naturally occurring medium, quality assurance and quality control should form an integral part of the construction activities. Consequentially, the majority of overhead line technical specifications or design standards require that all activities are undertaken in accordance with the relevant requirements of ISO 9001 [BSI 2000e]. The common European Standard EN 50341-1 [BSI 2001d], requires that 'The systems and procedures, which the designer and/or installation contractor will use to ensure that the project works comply with the project requirements, shall be defined in the designer's and/or installation contractor's quality plan for the project works'.

This section of the report considers various aspects of the quality assurance and quality control activities undertaken during the foundation design and installation.

The following definitions are used throughout this section of the report:

- **Quality Assurance** - 'Part of the quality management, focussed on providing confidence that quality requirements are fulfilled'. Quality Assurance has both internal and external aspects, which in many instances may be shared between the contractor (1st party), the customer (2nd party) and any regulatory body (3rd party) that may be involved.

- **Quality Control** - 'The operational techniques and activities that are used to fulfil requirements for quality'. Quality control is considered to be the contractor's responsibility.

- **Hold Point** - 'A stage in the material procurement or workmanship process beyond which work shall not proceed without the documented approval of designated individuals or organisations'.

- **Notification Point** - 'A stage in the material procurement or workmanship process for which advance notice of the activity is required to facilitate the witnessing of the activity'.

Normally, the client's written acceptance is required to authorise work to proceed beyond a Hold Point. With regards to notification points, if the client does not attend after receiving document notification, the work may normally proceed. Note that the term 'client' includes his representative, if appropriate.

For simplicity sake, the quality requirements have been divided between pre-project foundation installation activities, i.e. the design phase including the foundation type testing, (if appropriate, of the proposed project foundations) and project foundation installation activities.

Within the pre-project activities consideration has been given to possible Hold and Notification points, concrete mix design and specification, foundation installation criteria and foundation installation method statements. For the project foundation installation phase of the work, consideration has again been given to possible Hold and Notification points, setting out tolerances for the support and the actual foundations, verification of the foundation geotechnical design parameters, inspection prior to concreting, concrete identity tests, foundation proof and/or identity tests and foundation installation records.

4.2 Quality control

While this section of the report mainly concentrates on the Quality Assurance activities, it is an inherent responsibility of the installation contractor to instigate his own internal quality control procedures and verification methods. Without these procedures and activities including the appropriate level of internal auditing in-place, the overall quality assurance requirements of the project will be difficult to achieve.

Identified below are examples of quality control activities that may be applicable during the foundation installation:

- Verification of all foundation installation drawings, technical specifications for sub-contracted goods and services, e.g. concrete, foundation test programmes, installation method statements, concrete mix design, etc.;
- Auditing of proposed material supplier(s) or sub-contractor(s);
- Verification of the concrete trial mix results;
- Verification of the foundation type test results;
- Verification of the support and foundation setting out;
- Verification of the foundation geotechnical design parameters during the foundation installation process, if this is not undertaken as part of the project quality assurance activities;
- Verification of concrete identity test results and concrete returns;
- Verification of the backfill density;
- Verification of the foundation setting dimensions;
- Verification of the proof and integrity test results;
- Verification of the ‘as constructed’ foundation drawings and associated records.

4.3 Pre-project foundation installation

4.3.1 General

Pre-project foundation installation activities include the foundation design process, the concrete mix design, the quality auditing of proposed suppliers and/or subcontractors, the installation and full-scale testing of any test foundations and the preparation of the foundation installation criteria and the associated foundation installation method statement(s). A diagrammatic representation of this process, together with an indication of the documentation required and the corresponding hold and notification points is shown in Figure 4.1.

4.3.2 Suppliers

All materials used in the foundation installation should, where possible, be purchased from a supplier operating a quality management system in accordance with a recognised standard; where this is not possible, the installation contractor should instigate his own quality control requirements with respect to the materials purchased, e.g. all materials should be regularly tested in accordance with the appropriate standards. Similar comments would also apply to any subcontractor engaged for the foundation installation.

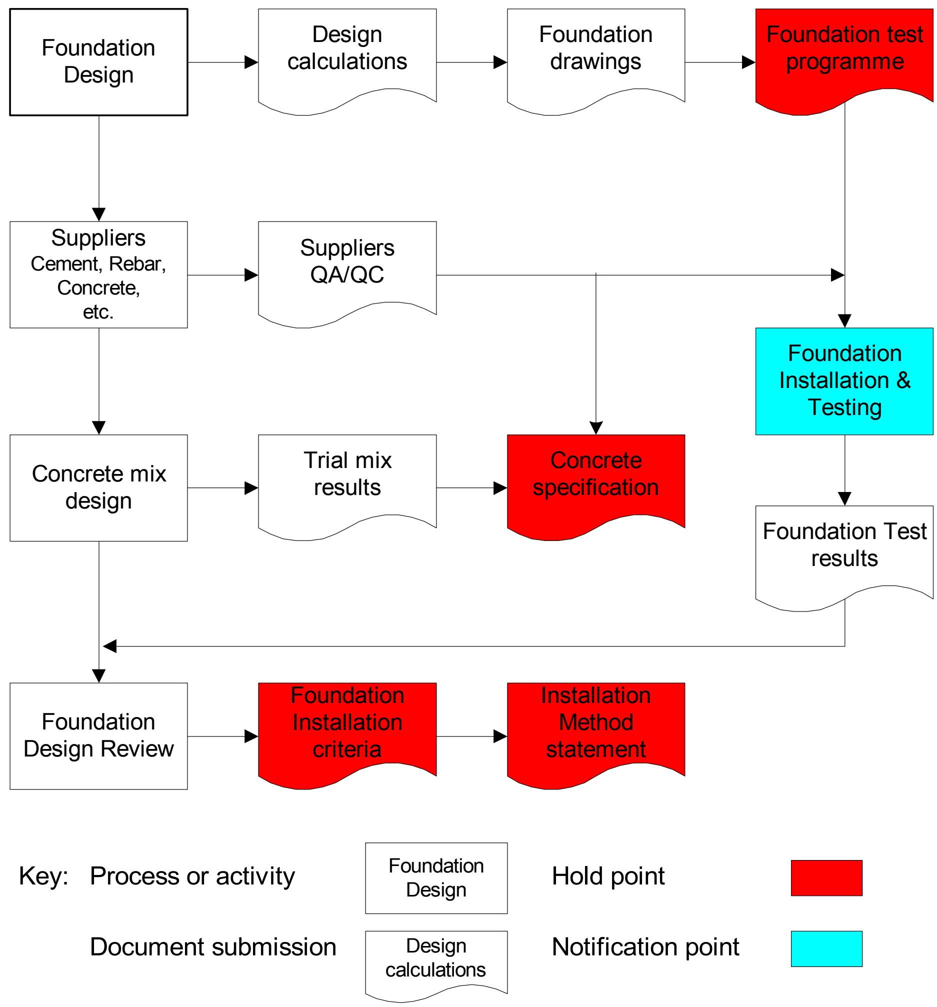


Figure 4.1 - Diagrammatic representation of pre-project foundation installation QA & QC

4.3.3 Concrete mix design

Before any concrete is supplied (assuming off-site ready mix), the recommended procedure is for the purchaser (the foundation installation contractor) to request the proposed producer to provide the following information:

- The nature and source of all constituent materials, including water and admixtures;
- The proposed quantity of each constituent, per cubic metre of fully compacted concrete;
- Evidence of the suitability of the proposed mix proportions to meet the specified requirements;
- The supplier's quality assurance certification.

Where evidence is requested of the adequacy of the proposed mix proportions to meet the specified strength, this generally can be obtained from previous productions of concrete using similar materials and equipment to that proposed or using trial mixes.

Where concrete is produced on-site, the constituent materials should be obtained from a recognised source and the relevant quality control test undertaken. The evidence of the suitability of the mix design would be based on the results from trial mixes.

Acceptance of the trial mix is usually based on the results of both workability and compressive strength tests, in accordance with the appropriate standards. Typically, for the compressive strength test, three concrete cubes or cylinders would be made from each batch of concrete and tested at twenty-eight days, with the average compressive strength of the three cubes tested exceeding the specified characteristic strength by a stated value, normally 10 N/mm².

In certain cases, where standardised mixes are used and are supplied from plants having a product conformity certificate, the certification body is responsible for checking the suitability of the mix proportions.

Typical details on specifying concrete, together with the respective quality assurance requirements are given in BS 5328 [BSI 1990b], EN 206-1 [BSI 2000a], BS 8500 [BSI 2002].

4.3.4 Concrete specification

Once the source of supply of the concrete has been decided and the adequacy of concrete mix proportions agreed, it is frequently a requirement that the installation contractor should submit to the client, a concrete specification detailing:

- Details of the proposed mix proportions and the relevant standards used;
- The source of supply, including if necessary all the constituent materials;
- Detail of the trial mixes undertaken and work's test results;
- Quality assurance and quality control procedures instigated.

The submission of this specification is normally a Hold Point.

4.3.5 Foundation design tests

Prior to undertaking any full-scale foundation design tests, it would be normal practice for the installation contractor to submit his proposed foundation test programme, e.g. test arrangement, loading regime, etc., to the client for agreement. This again would be Hold Point, although the actually testing of the foundation would usually only be a Notification Point.

4.3.6 Foundation installation criteria and method statement

The final, two written submissions that are normally required before work can commence on-site are the foundation installation criteria and the foundation installation method statement(s). For details of the foundation installation criteria, reference should be made to section 3.2.5 of this report.

The foundation installation method statement(s) should include, as appropriate, the following:

- The proposed method of foundation installation (for all foundation types), including proposals regarding the removal of water from the excavation and methods of verifying the foundation soil / rock parameters assumed in the foundation design (e.g. soil type, depth and ground water level) ;
- The proposed method of site bending or welding of concrete reinforcement;
- The proposed method of placing concrete, including grouting;
- The proposed method of installing permanent casings, including backfilling or grouting behind the casings;
- The proposed method of backfilling the excavation and backfill compaction;
- Quality assurance and quality control procedures;
- Risk assessments including cross-reference to design checks undertaken on the foundations under temporary construction loadings or during refurbishment and/or upgrading activities.

Both of these submissions would constitute Hold Points, i.e. as a general requirement no foundation installation could commence before agreement is given by the client.

4.4 Project foundation installation

4.4.1 General

Assuming that agreement has been given for the installation contractor to commence work on-site, the relationship between the various foundation installation activities and the associated QA/QC requirements can be represented diagrammatically, as shown in Figure 4.2.

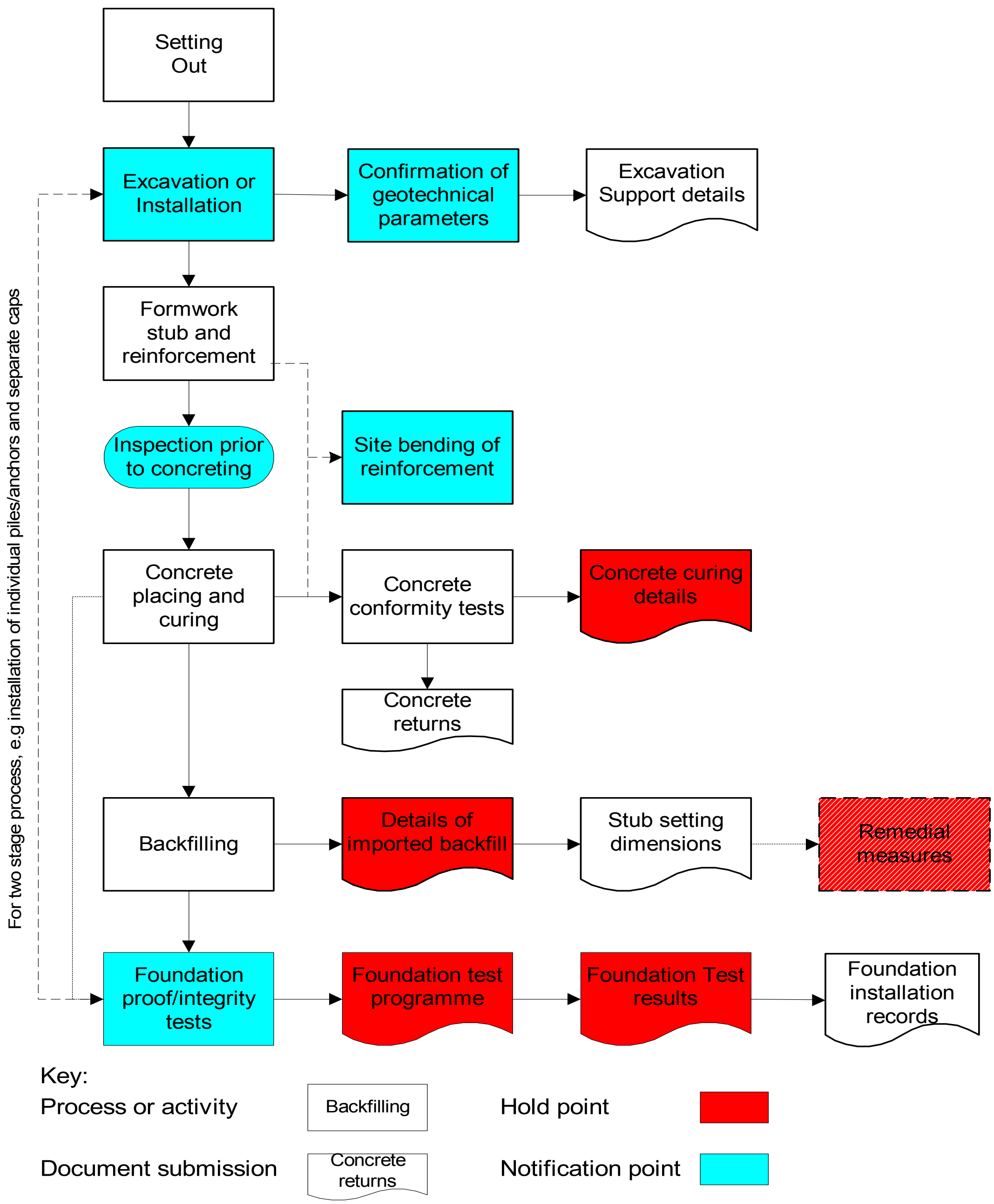


Figure 4.2 - Diagrammatic representation of project foundation installation QA & QC

Note: The actual sequence of installation activities will depend on the foundation type and whether it is a one or two-stage process. The installation of spread footings is normally a one stage process, while piled foundations are normally a two-stage process; with the piles installed first and the pile cap constructed subsequently.

4.4.2 Setting out

Typical requirements would be for the centre-peg of the support to be located along the line route within 2000 mm of the location shown on the overhead line profile. The perpendicular displacement transverse to the line route would be 50 mm relative to a theoretical route centre-line joining the adjacent angle support points.

Where angle supports have asymmetrical length crossarms, the route centre line and the support centre-peg will not be coincident (see Figure 4.3) and this should be taken into account when setting out the foundations.

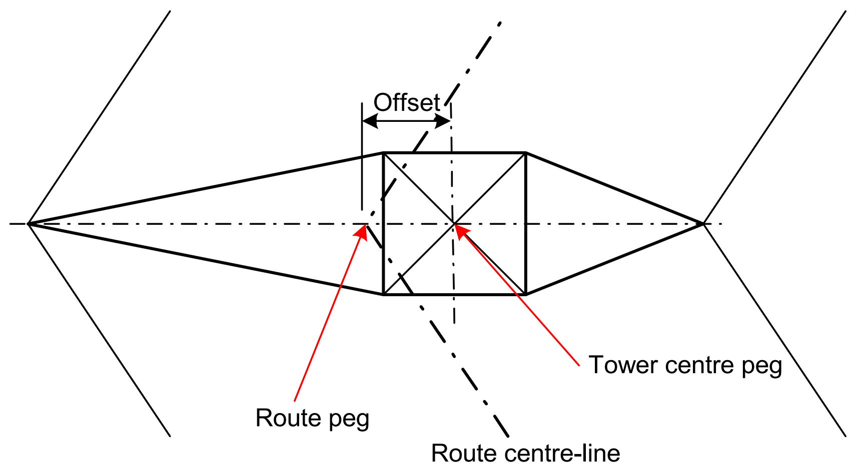


Figure 4.3 - Angle support setting out

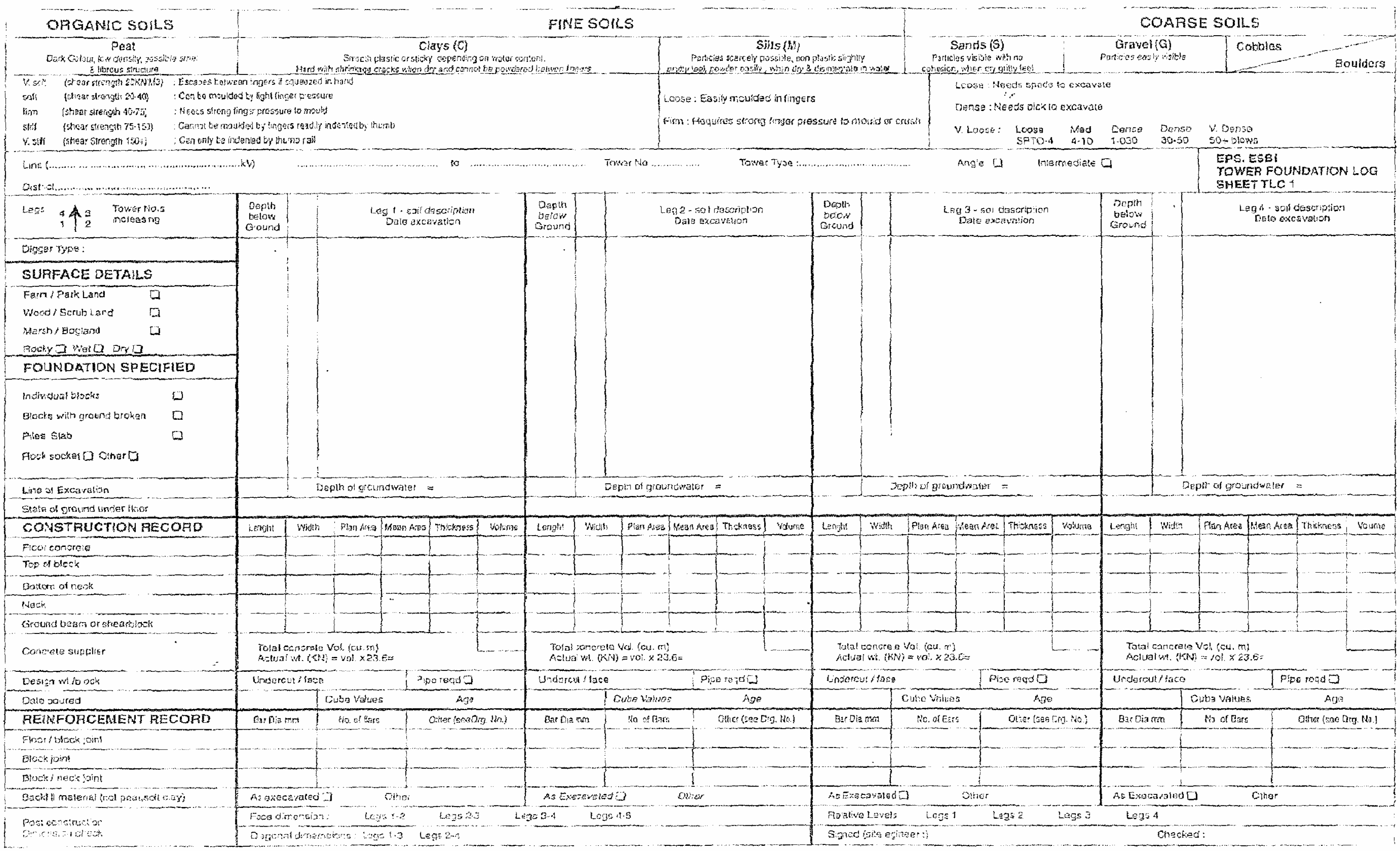
4.4.3 Verification of foundation design soil / rock parameters

The serious consequence of failing to verify the assumed foundation geotechnical design parameters during the foundation installation is shown in Figure 1.3. This sub-section of the report considers what practical methods / techniques are available to verify the geotechnical parameters assumed in the foundation design.

The on-site verification process obviously assumes that the basic design parameters are shown on the foundation installation drawing (reference section 3.2.2(a)) or that a copy of SI report is available on-site. Details of common geotechnical design parameters and possible verification methods are given in Table 4.1 and Figure 4.4 shows a typical foundation installation record sheet.

Table 4.1 - Verification methods – geotechnical design parameters

Geotechnical parameter	Verification method
Soil strata	Visual during excavation
Soil type	Visual / tactile
Ground water level	Visual / measurement
Base resistance	Penetrometer / Shear vane



ORGANIC SOILS	FINE SOILS		COARSE SOILS		
Peat Dark Colour, low density, possible smell & fibrous structure	Clays (C) Smooth plastic or sticky depending on water content. Hard with shrinkage cracks when dry and cannot be powdered between fingers	Silts (M) Particles scarcely possible, non plastic slightly gritty feel, powder easily, when dry & disintegrate in water	Sands (S) Particles visible with no cohesion, when dry gritty feel	Gravel (G) Particles easily visible	Cobbles / Boulders

V. soft (shear strength ≤20KN/M3) : Escapes between fingers if squeezed in hand
soft (shear strength 20-40) : Can be moulded by light finger pressure
firm (shear strength 40-75) : Needs strong finger pressure to mould
stiff (shear strength 75-150) : Cannot be moulded by fingers readily indented by thumb
V. stiff (shear Strength 150+) : Can only be indented by thumb nail

Loose : Easily moulded in fingers
Firm : Requires strong finger pressure to mould or crush

Loose : Needs spade to excavate
Dense : Needs pick to excavate

V. Loose :	Loose	Med	Dense	Dense	V. Dense
	SPTO-4	4-10	1-030	30-50	50+ blows

Line (..................kV) .... to .... Tower No .... Tower Type :.................. Angle ☐ Intermediate ☐

District..................

EPS. ESBI TOWER FOUNDATION LOG SHEET TLC 1

Legs 4 3 / 1 2 Tower No.s increasing	Depth below Ground	Leg 1 - soil description Date excavation	Depth below Ground	Leg 2 - soil description Date excavation	Depth below Ground	Leg 3 - soil description Date excavation	Depth below Ground	Leg 4 - soil description Date excavation
Digger Type :								
SURFACE DETAILS								
Farm / Park Land ☐								
Wood / Scrub Land ☐								
Marsh / Bogland ☐								
Rocky ☐ Wet ☐ Dry ☐								
FOUNDATION SPECIFIED								
Individual blocks ☐								
Blocks with ground broken ☐								
Piles Slab ☐								
Rock socket ☐ Other ☐								
Line of Excavation		Depth of groundwater =		Depth of groundwater =		Depth of groundwater =		Depth of groundwater =
State of ground under floor								

CONSTRUCTION RECORD	Lenght	Width	Plan Area	Mean Area	Thickness	Volume	Lenght	Width	Plan Area	Mean Area	Thickness	Volume	Lenght	Width	Plan Area	Mean Area	Thickness	Volume	Lenght	Width	Plan Area	Mean Area	Thickness	Volume
Floor concrete																								
Top of block																								
Bottom of neck																								
Neck																								
Ground beam or shearblock																								

	Leg 1			Leg 2			Leg 3			Leg 4		
Concrete supplier	Total concrete Vol. (cu. m) Actual wt. (KN) = vol. x 23.6=			Total concrete Vol. (cu. m) Actual wt. (KN) = vol. x 23.6=			Total concrete Vol. (cu. m) Actual wt. (KN) = vol. x 23.6=			Total concrete Vol. (cu. m) Actual wt. (KN) = vol. x 23.6=		
Design wt./b ock	Undercut / face		Pipe reqd ☐	Undercut / face		Pipe reqd ☐	Undercut / face		Pipe reqd ☐	Undercut / face		Pipe reqd ☐
Date poured		Cube Values	Age		Cube Values	Age		Cube Values	Age		Cube Values	Age
REINFORCEMENT RECORD	Bar Dia mm	No. of Bars	Other (see Drg. No.)	Bar Dia mm	No. of Bars	Other (see Drg. No.)	Bar Dia mm	No. of Bars	Other (see Drg. No.)	Bar Dia mm	No. of Bars	Other (see Drg. No.)
Floor / block joint												
Block joint												
Block / neck joint												
Backfill material (incl peat,soil clay)	As excavated ☐	Other		As Excavated ☐	Other		As Excavated ☐	Other		As Excavated ☐	Other	

Post construction Dimensions of stub
Face dimension : Legs 1-2 Legs 2-3 Legs 3-4 Legs 4-5
Diagonal dimensions : Legs 1-3 Legs 2-4
Relative Levels Legs 1 Legs 2 Legs 3 Legs 4
Signed (site engineer) Checked :

Figure 4.4 – Foundation Installation Record Sheet

Details of visual / tactile identification of soil types are given in ASTM D2488 [ASTM 1984] and BS 8004 [BSI 1984].

For details of the Norwegian practice in respect of on-site verification of the suitability of rock for transmission tower foundations, reference should be made to Appendix 4A of this report.

4.4.4 Inspection prior to concreting and site bending of reinforcement

Common practice is for the installation contractor to inform the client of his intention to commence concreting; thus allowing the client to undertake an inspection if so desired (Notification Point). Similarly, if the installation contractor needs to undertake site bending of reinforcement, e.g. the bending of the pile reinforcement into a pile cap, this activity would also be a Notification Point.

Points to be considered in the inspection prior to concreting:

- Cleanliness of the foundation, e.g. ensuring that any rubbish has been removed and the formwork is coated with a release agent;
- Stub or anchor bolt setting dimensions;
- Rigidity of the stub setting or anchor bolt template;
- Reinforcement cover and rigidity of any reinforcement cage or mat;
- Fixity of formwork to ensure it had adequate stiffness and support to prevent movement or displacement during concreting;
- Availability of stand by vibrators;
- Site health and safety aspects as appropriate (see Section 5).

The failure by both the installation contractor and the client to undertake an adequate inspection prior to concreting is shown in Figure 4.5.

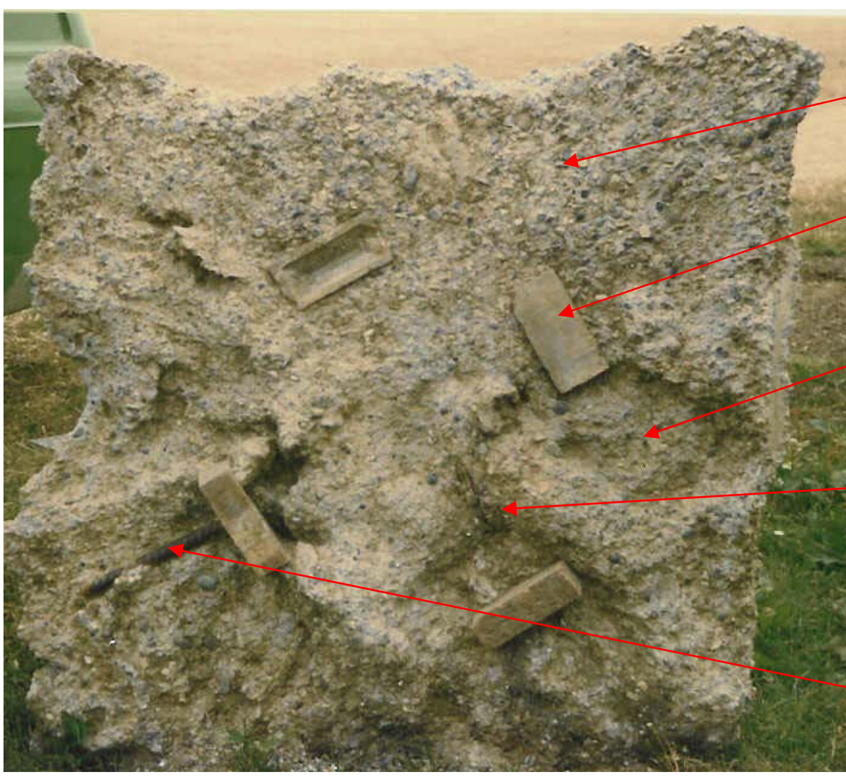


Figure 4.5 – Base of concrete pyramid foundation

4.4.5 Concrete placing

Although this is a quality control activity, it is imperative to ensure that the concrete is placed strictly in accordance with the specified requirements, thereby insuring that the problems identified in section 2, e.g. concrete segregation, honeycombing, formation of cold joints, 'necking' of cast-in-situ piles, etc., do not occur.

Figure 4.6, illustrates potential segregation of concrete due to the failure to use adequate concrete chutes.

Figure 4.6 – Concrete placing

4.4.6 Concrete identity tests

Concrete identity tests normally comprise workability, air content (if appropriate) and compressive strength tests.

Workability tests either slump or flow tests, as appropriate, should be undertaken on spot samples obtained after the initial discharge of 0.3 m³ of concrete, from the producer's delivery vehicle or alternatively at the point of placing into the foundation. Slump and flow tests should be undertaken in accordance with the appropriate standards, e.g. EN 12350-2 [BSI 2000f] and EN12350-5 [BSI 2000g], with the acceptance criteria in accordance with BS 8500 [BSI 2002].

Air content identity tests should be undertaken on composite samples and tested in accordance with the appropriate standards, e.g. EN12350-7 [BSI 2000h], with the acceptance criteria in accordance with BS 8500 [BSI 2002].

Compliance with the specified characteristic strength is normally based on tests made on cubes or cylinders (test specimens) at twenty-eight days. Normal practice is for four test specimens to be taken from each pour or footing. If the footing requires more than one pour, a set of test specimens should be taken from each pour. Samples should be taken in a similar manner to that described for workability tests. Test specimens should be made, cured and details recorded in accordance with the appropriate standard, e.g. EN 12390-2 [BSI

2000j] and compressive strength or density in accordance with EN 12390-3 [BSI 2000k] and EN 12390-7 [BSI 2000m] respectively. Usually, the following procedure is adopted:

- One specimen is tested at seven days to provide an early indication as to whether the twenty-eight day strength is likely to be achieved;
- Two specimens are tested at twenty-eight days;
- One specimen held in reserve for further testing if required.

Should the twenty-eight day compressive strength criteria fail to be met, then there are a number of actions that could be undertaken, e.g.:

- Validating the sampling procedure adopted;
- Validating the testing procedure adopted;
- Establishing the location and the extent of non-conformity;
- Considering the degree of non-conformity and its influence on the required strength and durability of the foundation;
- Considering the scope and the consequences of the proposed remedial action;
- Implementation of measures to prevent reoccurrence of the non-conformity.

The determination of the location and extent of the non-conformity may involve undertaking either some or all of the following tests:

- Penetration resistance or surface hardness tests;
- The drilling of test cylinders in the suspect concrete and testing of the samples to destruction by compression.

All testing should be undertaken in accordance with the appropriate standard.

However, the usual cause of failure of a test specimen(s) is poor workmanship in the making, curing and transporting the test specimen: it should also be noted that in the majority of cases, the characteristic strength is not the most important feature of the concrete but its durability, e.g. cement content and the water-cement ratio. Since it is difficult to determine either the cement content or the water-cement ratio directly, reliance has to be placed on an indirect measure, i.e. the compressive strength of the concrete.

4.4.7 Concrete returns

The installation contractor should maintain and when requested make available to the client, a record of the daily returns of the quantity, concrete mix, location and identity test results for all of the concrete placed.

4.4.8 Concrete curing compounds

Where the installation contractor proposes to use a proprietary concrete curing compound to protect exposed surfaces of the concrete from solar radiation or to improve moisture retention, normal practice is for agreement to be requested from the client for its use, e.g. a Hold Point.

4.4.9 Imported backfill

If it is necessary to import backfill material either due to the unsuitability of the existing soil, e.g. large boulders or lumps of clay, or where it is necessary to use a flowable material for directly embedded steel poles, the installation contractor should submit details of his proposed backfill material, source of supply, the relevant standard(s), if appropriate, and if necessary his proposed method of backfilling / compaction. This would normally be a Hold Point.

Checks on the backfill soil bulk density to ensure that the minimum value assumed in the design is achieved, could be undertaken using a lightweight dynamic penetrometer or by undertaking in-situ density tests, in accordance with the appropriate standard, e.g. BS1377-9 [BSI 1990c].

4.4.10 Foundation setting dimensions

The relevant stub setting or anchor bolt dimensions, e.g. back to back of the stubs (face and diagonal), stub levels and rakes, should be measured prior, during and after concreting. Records of these measurements should be retained by the installation contractor and made available to the client upon request.

Where the dimensions, levels or rakes are outside the permitted tolerance values, the installation contractor should propose the relevant remedial measures to the client. These might vary from redesign of the splice connection between the stub and the support leg to removal and reinstallation of one footing. This would normally be a Hold Point.

For details of permitted stub setting tolerances, reference should be made to table 4.2 of this report.

For guyed supports, typical permitted installation tolerances would be:

- Guy anchor foundations' nominal distance from the support centre line ± 15 mm or 0.15% of the guy lane dimension (whichever is greater);
- Guy anchor alignment ± 2.5° of the specified guy angle;
- H-poles nominal centre to centre dimensions ± 0.1 % of the nominal centre to centre dimensions.

4.4.11 Foundation proof and integrity tests

Foundation proof tests are undertaken on project foundations or individual elements of a foundation, e.g. individual piles or ground anchors.

Proof tests should be undertaken on all foundations where the resistance of the foundation is dependant upon the geotechnical properties of the soil, or where there is doubt of the reliability of the theoretical design model used. The number of foundations subject to proof testing will depend on the soil type, the extent of the ground investigation, the heterogeneity of the subsoils, the type of the foundation and the reliability of the design. Where proof tests are considered necessary, it is recommended that a least 5 percent of the relevant number of foundation types or foundation elements should be proof tested. For further details, reference should be made to IEC 61773 [IEC 1996] and EN 1537 [BSI 2000d].

For drilled shaft, bored cast-in-situ, continuous flight auger or similar types of piled foundations, low-strain integrity tests should be undertaken on all piles to ensure a satisfactory level of workmanship is achieved especially during concreting. For further details reference should be made to ICE 'Specification for Piling and Embedded Retaining Walls' [ICE 1996], CIRIA Report 144 [CIRIA 1997] and ASTM D 5882 [ASTM 1996].

4.4.12 Early age concrete strength assessment

Occasionally it may be necessary to erect a support on the foundations earlier than the normal time allowance of seven days after placing. Reliance on cube testing for early-age strength assessment is usually unsatisfactory because:

- Generally the results come too late;
- The test specimens taken are not necessarily representative of the concrete in-situ;
- The making, storing, transporting, testing of test specimens is non-productive, liable to

error and is usually impractical for very early-age strength assessment.

In these circumstances, consideration should be given to the use of pull-out inserts cast into the concrete. The principle behind the test method is that the force required to pull out an insert cast into the concrete can be correlated with the concrete's compressive strength. For further details, on the use of the 'Lok-test', reference should be made BCA report 'Early age strength assessment on site' [BCA 2000].

4.5 Foundation installation records

As part of the overall quality management requirements a foundation installation record sheet should be prepared for each support location by the foundation installation contractor and, where appropriate, should be agreed and signed by the client.

The installation report sheet should contain the following information, as appropriate:

- Project and overhead line route reference;
- Support type and number;
- Foundation type;
- Details of the verification of the support location setting out;
- Details of the confirmation of the basic geotechnical parameters;
- Excavation check dimensions;
- Details of the inspections undertaken prior to concreting;
- Concrete identity test results, including details of the concrete mix design, slump or flow test results, cubes or cylinders taken, compressive test results, etc.;
- Backfilling, giving details of any tests undertaken of the backfill density;
- Stub or guy setting out dimensions after the foundation installation;
- Results of any foundation proof or identity tests undertaken;
- Any other pertinent information, including any changes or modifications made to the foundation;
- Date and appropriate weather conditions over the foundation installation period.

A typical foundation record sheet is shown in Figure 4.4.

Where it is necessary to distinguish individual footings, an agreed nomenclature should be used; a typical nomenclature based on UK practice is shown in Figure 4.7.

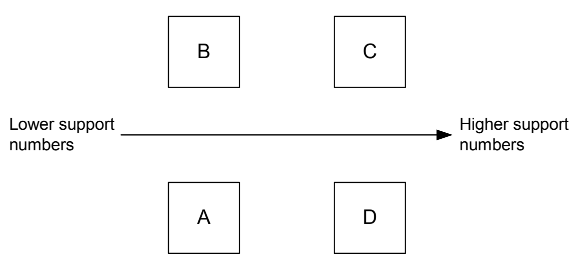


Figure 4.7 – Footing nomenclature

4.6 Final records

Final as-constructed drawings form a vital part of the quality assurance requirements for a construction contract. In addition to the as-constructed foundation drawings, the foundation design calculations, the geotechnical report, foundation installation criteria schedule, foundation test reports, concrete mix design, etc., should all form part of the final records.

Care should be taken as regards the choice of the storage medium, to ensure long durability and that any computer generated records can be retrieved and read in the future.

4.7 Conclusions

The quality assurance principles outlined in this section of the report cannot be considered in isolation, but must be considered in the overall context of quality, safety and environmental impact. Correspondingly, the next two sections of this report considers both of these issues in detail.

Table 4.2 – Foundation Setting Tolerances

Country	Face Dimensions	Diagonal Dimensions	Rake of Stub	Stub Levels	Twist of Stub in plan
Belgium (Elia)	Linearly from ± 0 to 10 mm for 0 to 5 m face or diagonal dimensions, then ± 10 to 15 mm for 5 to 15 m face or diagonal dimension.		≤ 5 mm / m	Max. difference between highest and lowest stub ≤ 2 to 5 mm varying linearly between 0 and 12 m face dimensions.	≤ 5 mm / m
France (EDF)	± 10 mm	± 15 mm	Angles ≤ 100 mm 10 mm / m Angles > 100 mm 5 mm / m	Max. difference between each pair of stubs 10 mm.	-0.01< tgα < + 0.02 + towards centre of tower.
Ireland (ESB)	± 5 mm	± 10 mm	Nil – Bottom panel of tower used as stub setting template.	Max. difference in level between all 4 stubs 3 mm; Max. difference between mean level of pairs of diagonally opposite stubs 3 mm.	Nil – Bottom panel of tower used as stub setting template.
Italy (ABB)	± 12 mm or ± 0.2% of face or diagonal dimension.		0.3°	Difference in levels between one stub and a plane passing through other 3 stubs ± 3 mm or 0.1%.	0.5°
Norway (Stanett)	Use of Holding Down Bolts with holes 8 to 10 mm larger than bolt diameter, horizontal tolerance ± 4 / 5mm, vertical maximum difference 3 mm.				
Spain (Red Electrica) (Iberdrola)	± 0.1% of face dimension	± 0.15% of diagonal dimension	± 5 mm /m	Max. difference in level between all 4 stubs ± 0.01% of diagonal; Max. difference between mean level of pairs of diagonally opposite stubs ±.0.15%.	Not defined
	± 6 mm or ± 0.1% of face dimension	± 6 mm or ± 0.1% of diagonal dimension	± 5 mm /m	Max. difference in level between all 4 stubs 3 mm or ± 0.01% of diagonal; Max. difference between mean level of pairs of diagonally opposite stubs 3 mm or ±.0.1%.	1% of width of steel frame
UK (NGT)	± 10 mm or ± 0.1% of face dimension	± 15 mm or ± 0.1% of diagonal dimension	1:100 from hip slope	Max. difference in level between all 4 stubs 10 mm or ± 0.05% of diagonal; Max. difference between mean level of pairs of diagonally opposite stubs 6 mm.	1° about longitudinal axis
USA (GAI)	± 0.1% of face dimension	± 0.1% of diagonal dimension	± 1.6 mm / 300 mm	Max. tolerance from the top of each stub 0.1% of face or diagonal dimension; Max. difference between mean levels of diagonally opposite stubs 0.1% of diagonal dimension.	Not defined

Annex 4A
Verification of Rock Suitability – Based on Norwegian practice

A4.1 Introduction

To ensure that the rock will have sufficient strength to withstand the applied foundation uplift forces it is necessary to categorize the quality of the bedrock into quality classes thereby ensuring that the appropriate type of foundation is installed.

The rock can for convenience be divided into four categories or classes, where the fourth class represents completely weathered rock which can be treated as equivalent to soil.

The rock quality classes and corresponding foundation types are:

	Rock Quality	Foundation type
1	Good (homogenous)	Bolt anchor type A
2	Medium (some fractures)	Bolt anchor type B
3	Poor (highly fissured)	Bolt anchor type C
4	Very poor, highly weathered similar to soil	Soil foundation

A4.2 Rock quality classes

The rock qualities and typical anchorage details are given below:

a) Good rock ~ Bolt anchor type A

The rock is homogeneous without fractures. The anchorage length for ribbed reinforcement with a diameter of 25 mm is 1.3 m, while that for 32 mm diameter is1.6 m.

b) Medium rock ~ Bolt anchor type B

The rock has some fractures, but it is not faulted. The anchorage length for ribbed reinforcement with a diameter of 25 mm is 2.0 m for 50% of the bolts and 1.3 m for the remaining 50%; for 32 mm diameter the anchoring length is 1.6 m. Bolts with different anchorage lengths shall be used alternately.

c) Poor rock ~ Bolt anchor type C

The rock is of poor quality, highly fissured and faulted. The anchorage length for ribbed reinforcement with a diameter of 25 mm is between 2.0 m to 3.0 m for 50% of the bolts (depending on the degree of weathering of the rock) and 1.3 m for the other 50%; for 32 mm diameter the anchorage length is 1.6 m. Bolts with different anchorage lengths shall alternate. In addition, it may be necessary to strengthen the area around the foundation using rock bolts or equivalent; the anchorage length of the rock bolts, depending on the degree of weathering, should be between 2.0 m to 3.0 m.

d) Very poor rock ~ Soil foundation

The rock is of very poor quality, highly fissured and strongly weathered. In these circumstances a soil type foundation is installed.

For details of typical rock foundations, reference should be made to Figure 3A.6.

A4.3 Rock quality classification

The main parameters for a simple rock quality classification are the Block size (B) and the fracture characteristics and the degree of weathering (S). The grading of the rock type parameters used in the selection of the appropriate foundation types are shown in table A4.1.

Table A4.1 - Grading of rock type parameters

Parameter	Description	Grading
Block size (B)	> 5 m	5
	1m to 5 m	4
	0.5 m to 1.0 m	3
	100 mm to 500 mm	2
	100 mm	1
	Very weak rock, soil	0
Fracture characteristics (S)	Rough, without filling	5
	Plane, without filling	4
	Rough, open or with clay filling	3
	Plane, open or with clay filling	2
	Loose, like soil	1

Classes which are defined as number in table A4.1 are of course strongly dependent on rock type and the geological conditions.

Examples of the application of table A4.1 to different rock and foundation types are given below.

For classification of the rock qualities determine the sum of the rock type parameters (B+S).

Suitable rock types for the different types of foundations are given in table A4.2. The illustrations show examples of typical rock types, together with the appropriate foundation type. However, it must be emphasized that the classification of rock type and the choice of foundation type will be highly influenced by the surrounding terrain.

Table A4.2 - Example of rock types and foundation types

Sum B+S	Description	Type of foundation	Example of rock types
8 -10	Good rock (class I)	Bolt anchor A	Compact rock types with some fractures, e.g. Gneiss, Granite, Gabbro, Amphibolite, crystalline Shale.
6 - 7	Medium rock (class II)	Bolt anchor B	Medium fractured rock types, e.g. Gneiss, Granite, Gabbro, Amphibolite, crystalline Shale. Good, homogeneous and unweathered Sandstone, Limestone and Phyllites.
4 - 5	Poor rock (class III)	Bolt anchor C	Highly fissured, but little weathered rock types, e.g. Gneiss, Granite, Gabbro, Amphibolite. Little fractured and little weathered Sandstones, Limestone, Phyllites and clay Shale.
1 - 3	Very poor rock, similar to soil (class IV)	Soil foundation	Highly fissured and strongly weathered rock types, Phyllit, black Shale, clay Shale. Alum Shale (caution - aggressive to concrete!).

The classification shown in table A4.2 is applied to all the following figures (B+S = class I, II, III or IV).

Figure 4A.1 - Bedrock Gneiss

Bedrock Gneiss	B+S = 5 + (3 or 5) = 8 -10	Class I (good rock)

Figure 4A.2 - Compact non-weathered Phyllite (Hallingskarvet)

Compact non-weathered Phyllite (Hallingskarvet)	B+S = (3 or 4) + (4 or 5) = 7 - 9	Class I – II (good – medium rock)

Figure 4A.3 - Typical thick-bedded and fissured Gneiss

Typical thick-bedded and fissured Gneiss	B+S = 2 or (3 + 3) = 5 - 6	Class II – III (medium – poor rock)

Figure 4A.4 - Typical thick-bedded Quartzite

Typical thick-bedded Quartzite	B+S = 3 + 3 = 6	Class II (medium rock)

Figure 4A.5 - Layered and weathered Gneiss

Layered and weathered Gneiss (“dagfjell”)	B+S = (2 or 3) + (2 or 4) = 4 -7	Class II – III (medium – poor rock quality)

Figure 4A.6 - Alum Shale

Alum Shale (Hallingskarvet) highly fissured and weathered	B+S = (1 or 2) + (1 or 2) = 2 - 4	Class III - IV (poor rock – soil foundation)

5 Health and Safety

5.1 General

Foundation installation can be a hazardous operation both to the site operatives and members of the general public, if due care and attention is not paid to the health and safety (H&S) aspects of the work. The information contained in this section of the report is indicative only and is based on current UK practice. However, it should not be considered as being complete, nor fully satisfying the requirements of the relevant statutory or approved codes of practice of the readers' own country.

One of the guiding principals of the UK's H&S legislation, is the principle of 'so far as reasonably practicable'. In other words, an employer (or designer) does not have to take measures to avoid or reduce the risk if they are technically impossible or if the time, trouble or cost of the measure would be grossly disproportionate to the risk [HSE 2003]. However, in strict Health and Safety terms 'so far as reasonable practical' are not measured against cost and benefit but refer to any means, which are technically possible irrespective of cost.

A diagrammatic representation of the development of health and safety procedures in shown in Figure 5.1

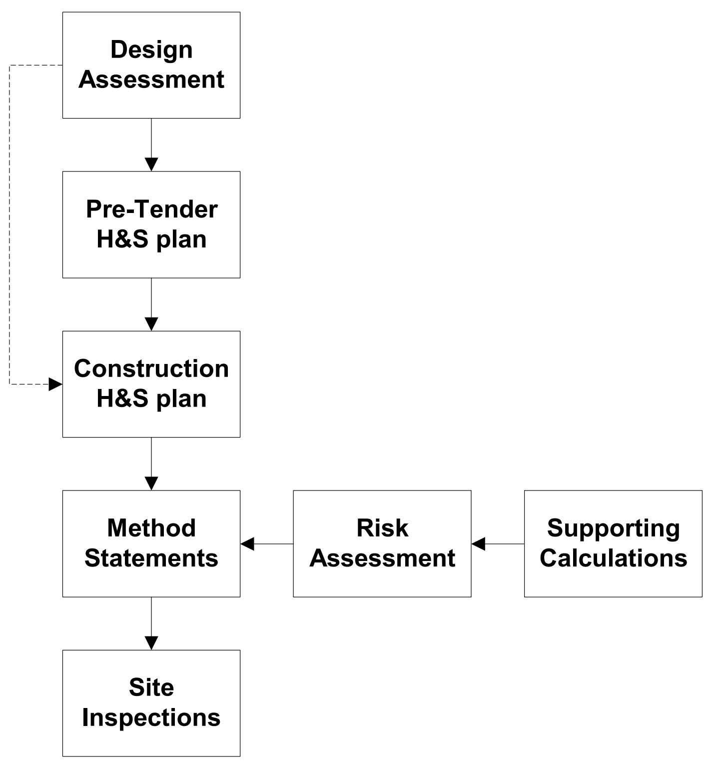


Figure 5.1 - Diagrammatic representation of development of H&S procedures

Within this section of the report consideration is given both to the initial design assessments and on-site risk assessments, whereby the foundation design or the installation process are reviewed for their inherent hazards and by a process of hierarchical risk control the risks are eliminated or at least reduced to an acceptable level. Preparation of health and safety plans both at the pre-tender and construction phases are also considered, together with the associated method statements.

The health and safety aspects of securing the site from the general public and the need for an excavation checklist are also outlined in this section.

5.2 Design assessments

Under the UK's Construction (Design and Management) Regulations [HMSO 1994], there is a requirement for all designers to ensure that when they design for construction work they consider foreseeable H&S risks during the construction, maintenance and eventual removal of the structure and, that they are in balance with other design considerations, e.g. aesthetics and costs.

The designers should apply a hierarchy of risk control, i.e. the designers need to identify the hazards inherent in undertaking the construction work and where possible alter the design to eliminate them. If the hazards cannot be removed by design changes, the designers should minimise the risks and provide information about the risks that remain. Information regarding these residual risks is then contained in the pre-tender health and safety plan. This point is of particular importance when overhead line support foundations are being refurbished or upgrading with the support in place, or during any preliminary investigations to ascertain the condition of existing foundations.

For foundation installation, the following factors may need to be considered:

- Previous use of the site;
- Location of adjacent properties and services;
- The types of soil and/or rock present and their characteristics;
- The level of the ground water and the permeability of the soils;
- Ground or ground water contamination;
- A suitable scheme for temporary support of the excavation and the prevention of falls into the excavation.

Mitigation measures that could be considered are the use of alternative foundation types, which require smaller and shallower excavations, e.g. replacing reinforced concrete spread foundations by driven steel tube piles or micropiles with a small reinforced concrete cap. The use of driven piles on brownfield (contaminated) sites instead of bored piles eliminates the need for the removal of contaminated spoil.

For further details regarding risk assessments, please refer to section 5.4 of this report.

5.3 Health and safety plan

5.3.1 General

The H&S plan develops with the project and has two distinct phases; the first is associated with the design and planning of the project before tendering, the second is associated with the construction phase. The purpose of the plan is to ensure information relevant to health and safety is passed on to those who need it. For further details, reference should be made to 'Health and Safety in Construction' [HSE1996].

5.3.2 Pre-tender health and safety plan

The pre-tender H&S plan may include:

- A general description of the works and details of the project timescale;

- Details of the H&S risks as they are known, including information provided by designers about specific project risks they were unable to eliminate and assumptions in broad terms they have made about precautions which will be taken by the installation contractor to combat these risks;
- Information required by the potential principal contractor, to allow them to identify the H&S competences and resources they will need for the project;
- Information on which to base a construction phase H&S plan.

Often the necessary information will already be contained within existing documents, e.g. the tender documents and design drawings. In these cases the plan can be simply an index to where the necessary information can be found.

The plan only needs to contain information which is specific to the project and is necessary to assist in the development of a safe system of working; it does not need to repeat information which a competent contractor would already know.

5.3.3 Construction phase health and safety plan

For the construction phase the principal contractor (i.e. the contractor appointed by the client to plan, manage and control H&S during the construction phase of the project), develops the H&S plan so that it addresses issues which are relevant to health, safety and welfare matters of the project. Issues which may need to be considered in the plan are:

- How the H&S will be managed during the construction phase, including how information will be passed to other contractors and how their activities will be coordinated;
- Information about welfare arrangements;
- How the views of site operatives and their representatives on H&S issues will be coordinated;
- Information on the necessary levels of H&S training required;
- Arrangements for monitoring compliance with H&S law;
- Site H&S rules, e.g. permits to work, and relevant H&S standards where appropriate;

The extent to which a particular item needs to be addressed within the plan will depend on the degree of risk associated with the project and how much coverage has been given to the issues in other documentation. Where the risk is low and the issues are covered in the principal contractor's health and safety policy, a simple reference to the safety policy arrangements may be sufficient.

5.4 Method statements and risk assessments

5.4.1 Risk assessments

a) General

Risk assessments are required during the design phase of the project and prior to undertaking any hazardous operations on-site. A risk assessment is a systematic determination of what the hazards are, the probability of harm occurring and the possible consequences of the harm and its severity. A hazard is the potential for harm, whereas a risk is the chance or probability that somebody will be harmed by the hazard.

Risk =	Hazard effect (Severity)	X	Likelihood of occurrence

b) Design risk assessments
During the design phase of the project the designer should undertake a risk assessment, to ascertain whether their design can be constructed, maintained and eventually dismantled without causing harm to the site operatives or members of the general public.

A precise estimate of risk is not required, under most conditions a qualitative method could be selected, provided its limitations are recognized. For example three categories of severity could be assumed, e.g. High (fatality, major illness, etc.), Medium (injury causing short-term disability) and Low (minor injury). Similarly, the designers need to consider whether the hazard and the worker will coincide and again only a crude, qualitative judgement need be made, e.g. High (certain or near certain to occur), Medium (reasonably likely to occur) or Low (very seldom or never occurs).

The product of the severity and the occurrence will then give some measure of the assessed risk, which can in turn provide an indication of the action required, i.e. does the designer need to change his design or can it be accepted without modifications.

As an alternative to a design risk assessment, the designer could produce a 'Hazard Elimination and Management list', this list could than be passed to installation contractor on completion of the design phase of the work. A typical example is shown in Figure 5.2.

Hazardous Activity	Residual Hazard	Information provided for hazard control
Foundation Installation	Electric shock overhead power line	Note: 11 kV overhead power line crosses the access track approximately 50 m from site. (See Drg. No xxx)

Figure 5.2 – Hazard Elimination and Management List

c) Hazardous on-site operations
Under the UK's 'Management of Health and Safety at Work Regulations' [HMSO 1992], an employer must identify the hazards involved with their work, assess the likelihood of any harm arising and deciding on adequate precautions.

The associated risk assessment is usually undertaken in five steps:

- Consider how the job or process will be undertaken, where it is done and what equipment, materials and chemicals will be used;
- Decide who might be harmed, e.g. employees, or other workers on the site, members of the general public;
- Evaluate the risks and decide on the action, i.e. is somebody likely to be harmed?
- Record the results;
- Review the findings.

Where there is a risk, the hierarchy of safety controls described in sub-section (d) should be invoked.

d) Basic hierarchy of safety controls and precautions
The basic hierarchy of safety controls and precautions are:

- Eliminate - Remove the hazard;
- Isolate or contain - Create a barrier between the hazard and people;
- Safe system of work - Use a defined system of working, following safety procedures designed to reduce risk;
- Training, instruction and information - This should be combined, where appropriate, with

supervision. Information may include warning signs or notices;
- Personal protective equipment and/or clothing.

e) Typical risk assessment for foundation installation

A typical risk assessment for foundation installation for a concrete pyramid and chimney foundation is shown in Table 5.1. For convenience, it has been assumed that risk assessments for material delivery to site, storage of material on site, safe use of lifting gear and the effect of handling cement / concrete or other substances hazardous to health have already been undertaken.

Table 5.1 - Foundation installation typical risk assessment

Risk	Method of controlling risk
Complete collapse of excavated hole with persons working in excavation.	All excavations over 1.2 m deep are close sheeted and framed.
Persons falling into excavation when not working above open excavation.	All excavations are fenced or side sheeting extended above ground level.
Spoil stacked by hole falls into excavation onto persons working below.	Material to be stacked a minimum of 1.5 m from edge of excavation.
Mechanical excavator too close to excavation edge causing partial collapse and or excavator falling into excavation.	Stop boards positioned 1m from edge of excavation.
Objects falling on persons working in excavation.	Safety helmets to be worn at all times.
Persons falling during access / egress to excavation.	Ladders to be used for access and to be adequately secured.
Instability of excavation arising from high ground water table and or accumulation of water in excavation.	Use of pumps or de-watering plant installed.
Risk of foot medical problems	Use of personal protective equipment.
Back strain due to handling stub setting template, etc.	Use of mechanical lifting plant.
Risk of falling when working on chimney section of formwork.	Ladders and use of safety harness.
Poured concrete forces bottom foundation formers upwards and dislodges whalings resulting in collapse of sheeting.	Formers are prevented from upward movement by use of timber sprags to sides of excavation. Wedges driven into upper side of whalings prevent upward movement.

5.4.2 Method statements

The H&S method statement sets out how a hazardous job or process will be carried out, including all the control measures which will be applied; this will assist in planning the work and identifying the health and safety resources required. In addition, it is an effective and practical way of providing information to the site operatives about how the work is expected to be done and the precautions to be taken.

Method statements should include details of safe means of access and egress from the site, arrangements for a safe place of work on site, plant and equipment to be used, training and competence, specific hazards to be expected, measures to control the hazards, routine inspections to be undertaken, precautions or limitations on the activities of others in the vicinity and a cross-reference to the associated risk assessment. For further information, reference should be made to ‘Health and Safety for Engineers’ [Thomas Telford 1996].

5.4.3 Supporting calculations

As part of the risk assessment or the preparation of the method statement, supporting calculations may be necessary. Typical examples would be if a foundation is subject to a reversal of loadings, e.g. a spread footing designed for compression is required to take uplift under a temporary loading condition, or an existing foundation is being partially uncovered as part of a preliminary investigation or during refurbishment/upgrading activities with the support and conductors still in place.

5.5 Site access

One of the major safety issues connected with site access and/or work on-site, is that associated with working adjacent to, or underneath live overhead lines. For site access normal procedure is to use a height barrier as shown in Figure 5.3.

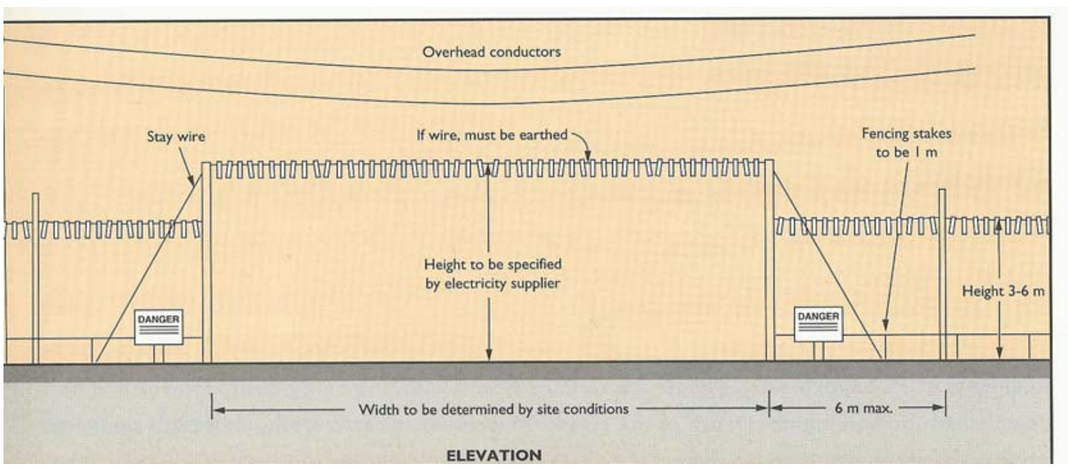


Figure 5.3 - Typical overhead line height barrier

5.6 Foundation installation

5.6.1 General

All construction sites should be fenced-off from the general public and/or from other site activities. The types of fencing will reflect the degree of risk involved and whether the site is enclosed in an overall protected area. Typical fencing would be timber paling with a suitable lockable gate, ensuring that in agriculture areas the site is fully stock proof at all times. In areas adjacent to public areas or highways, it may be necessary to use 2.0 m high steel link fencing. In addition, warning notices and lighting may need to be provided.

Sites should be kept clean and tidy, with materials safely stored and all working areas should be free from obstructions. In addition, there should be proper arrangements for collecting and disposal of waste and, if appropriate, additional lightning should be provided if it is envisaged that work will be undertaken in poor natural lighting or in the dark.

5.6.2 Excavation health and safety checklist

The following checklist identifies some of the hazards most commonly found on a foundation installation site:

- Has the site been checked for utility services, e.g. gas, water, electricity, telecommunications, etc;
- If appropriate, has the site been checked for unexploded ordinance;
- Is there an adequate supply of timber, trench sheets, props or other supporting material available before excavation works start;
- Is the material strong enough to support the sides of the excavation, see Figures 5.4 and 5.5;
- Is a safe method used for putting in the excavation supports, i.e. one that does not rely on people working within an unsupported excavation;
- Is there a suitable method statement covering the use of explosives for excavation purposes;
- If the sides of the excavation are sloped back or battered, is the angle of batter sufficient to prevent collapse;
- Is there an adequate method available to deal with any ground water entering the excavation, including ensuring that existing field or temporary drains are in working order, see Figure 5.6.
- Is there safe access to the excavation, e.g. by a sufficiently long, secured ladder;
- Are there guard rails or is there other equivalent protection to stop people falling in;
- Are properly secured stop blocks provided to prevent vehicles falling in;
- Does the excavation effect the stability of neighbouring structures, this in particularly important if groundwater control processes are used;
- Are stacked materials, backfill, spoil or plant stored near the edge of the excavation likely to cause a collapse of the sides;
- Is the excavation inspected by a competent person at the start of each shift: and after any accidental collapse or an event likely to have affected its stability.

If it is proposed to use explosives for excavation purposes, their use and storage must be undertaken strictly in accordance with all appropriate civil and, if appropriate, military requirements.

Figure 5.4 – Inadequate support of sides of excavation

Figure 5.5 – Failure of surrounding soil

Figure 5.6 - Failure of an excavation support system

The cause of the failure was due to water from broken field drains being allowed to soften the ground behind the excavation, thereby causing a complete rotational slip of the supported material and failure of the excavation support system. The steel trench sheeting had been driven to a minimum of 1 m below the depth of the excavation.

5.7 Summary

Good health and safety practices can be summarised as follows:

- The adoption of good working practices, ensuring that unofficial and unsafe systems of working are eliminated by site inspections and H&S audits;
- Provision of adequately trained and motivated site operatives;
- Ensure that design assessments and pre-tender health and safety plans concentrate on the hazardous operations that a competent contractor could not foresee;
- Ensure that, where applicable, site specific risk assessments and method statements are prepared for hazardous operations;
- Ensure the site is kept tidy, simple checklists are used and adequate inspections are undertaken;
- Ensure that there is effective communication between all parties to the work, i.e. the designers, site engineers and site operatives is in place;
- Ensure that timely action is taken if the assumptions made in the design regarding the ground conditions, e.g. ground water level, soil and/or rock strength etc., are not found on-site.

While this section of the report has concentrated on specific health and safety aspects in relation to foundation installation, the general H&S requirements in respect of the control of substances hazardous to health, noise, manual handling, provision of personal protective equipment, etc., should not be overlooked.

6 Environmental Impact and Mitigation

6.1 General

This section of the report deals specifically with the environmental impacts and the associated mitigation measures related to overhead transmission line support foundations. For details regarding the overall issue of environmental impacts of overhead transmission lines, reference should be made to Cigre Technical Brochure 147 [Cigre 1999b].

Since the installation of the foundations is the first major activity associated with the construction of an overhead transmission line, the affect of the access route construction on the environment is also considered in this section of the report.

Potential environmental impacts caused by the foundation installation process including the provision of site access are reviewed in this section of the report. Possible mitigation measures, e.g. the use of temporary access systems or alternatively the use of helicopters are considered, together with means to reduce the impact caused by the actual foundation installation process.

6.2 Environmental impact

Both the local environment and the communities adjacent to the route of the overhead transmission line are affected by the construction activities, with access construction and foundation installation having a major impact. Consequentially, the adoption of the appropriate mitigation measures can significantly reduce the environmental impact of an overhead transmission line during the construction phase.

Potential environmental impacts, which may occur, during access construction and foundation installation activities include:

- Increase in traffic on local roads, especially as regards the delivery of plant, equipment and materials, e.g. excavation or piling equipment, supply of ready-mix concrete;
- Impact of access tracks on the environment;
- Disturbance of land and vegetation management;
- Vegetation and tree removal;
- Noise, dust and vibrational pollution;
- Soil erosion and pollution of water courses;
- Disturbance to birds and other fauna;
- Foundation installation, including the dispersion of contaminated soil or ground water.

Other impacts that may occur are:

- Disturbance to farming, agriculture and other business or leisure activities;
- The client's relationships with landowners, grantors, local authorities and other statutory or public agencies;
- Disturbance of archaeological remains.

While it is not possible to completely remove all of the potential impacts, described above, it is possible to at least reduce their impact and therefore to a degree, the public's and/or landowners/grantors perception of the affect of overhead transmission line construction on the environment.

6.3 Environmental mitigation

6.3.1 Design phase

As an integral part of the planning and consent process, the majority of new overhead transmission lines are subject to an environmental assessment, e.g. ‘The Electricity Works (Environmental Impact Assessment) (England and Wales) Regulation 2000' [HMSO 2000]. This requirement has also been extended to cover the constructional activities associated with the refurbishment and/or upgrading of existing overhead transmission lines. Both an initial desk-top study and site assessments would be undertaken to establish which of the existing support sites are likely to be affected by environmental and/or archaeological constraints. The area to be considered would possibly extend to include a buffer zone 500 m wide either side of the route centre line and including the access roads/tracks.

Overhead transmission line support sites, which are located in designated areas of importance under international conventions or by national regulations, will require specific studies to be undertaken in consultation with the appropriate statutory bodies, within the UK these would be:

- Wetlands of International Importance under the Convention of Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar Convention 1976);
- Classified under European Community Directive 79/409 on the Conservation of Wild Birds;
- Classified under European Directive 92/43/EEC on the Conservation of Natural Habitats of Wild Fauna and Flora;
- UK Sites of Special Scientific Interest or National Nature Reserve.

In conjunction with the environmental studies, a separate study is usually undertaken in respect of determining whether any support site, or the area adjacent to any site, may have an archaeological interest.

Once the studies outlined above have been completed and depending on their outcome in terms of the environmental and archaeological impacts, it may be necessary to prepare a site environmental plan, detailing the mitigation measures required.

Mitigation measures that can or may, need to be taken are:

- Commencement of early consultations with the appropriate statutory or voluntary bodies, to ensure that necessary notifications, agreements, consents etc., are made and/or received prior to proposed commencement of site activities;
- Removal of any bird nests in the proposed or existing support location during the non bird nesting period prior to commencing site work;
- Vegetation management, e.g. tree lopping and/or hedge trimming and/or removal, before the commencement of any site work;
- Translocation of any protected species of fauna from the working area;
- Working outside the bird nesting period, over-wintering period of migratory birds or fauna breeding period;
- Adoption of special access procedures, or installation techniques;
- Use of low emission equipment, use of ‘silent’ or equipment with a low noise profile;
- Minimizing the number of trips to the site or reduced working periods.

Archaeological mitigation measures might include the necessity for a watching brief during the foundation installation.

With regards to the actual design of the foundation, mention has been previously made of the use of alternative foundation types, which may lessen the overall environmental impact, e.g. the use of micropiles, driven steel tube piles, helical screw anchors, etc., as an alternative to conventional reinforced concrete spread foundations. However, this may have to be counterbalanced against the possible temporary increase in environmental impact during the installation phase from the use of larger plant and equipment.

Where foundations are located in contaminated sites, there is a need to control the migration of pollutants to the surrounding area and particularly aquifers, especially when piled foundations are being considered. For further information, regarding piling and other ground improvement methods on contaminated land, reference should be made to the National Ground Water and Contaminated Land Centre Report NC/99/73 [EA 2001]. An example of a solution to overcome the problems associated with installing support foundations in contaminated ground is detailed below:

"The ground conditions at the support sites under consideration had a 2 m clay cap, 6 m depth of landfill, and 2 to 3 m of virgin clay above layers of sand and peat, above the Keuper Marl. The sand and peat layers acting as a minor aquifer. The particular problem was that Tritium from a university physics laboratory experiments had dissolved into the leachate. The other waste included incinerator ash, some food waste and low level radioactive waste from the local hospital X-ray facility. The latter had decayed to background radioactive levels and was simply re-buried.

The landfill was excavated down to the virgin clay over an area which was at least 1.5 m in length and width greater than the footprint of the piles. Clay of low permeability was used to fill the excavations up to ground level, was compacted in layers with a swing machine, and the steel tubular piles were then driven through the new clay - in effect each tower is standing on a clay island. The environmental agency responsible subsequently monitored the local groundwater, and no rise in contamination was found. No problems were encountered due to settlement of the clay, but the method adopted is not considered to be applicable with raked concrete piles. The additional cost (circa 1998) was approximately £15,000 for each tower site, compared to £6,000,000 to underground the 6 circuits around the landfill.

Leachate flooding the excavations was a problem; however, this could be overcome by spraying it over the site and allowing it to evaporate, once consent had been obtained from the owner and the weather was suitable. When the work commenced, the weather was cold and wet, and the installation contractor had to transport the leachate away to a licensed disposal site at considerable expense. Subsequentially, the installation contractor kept two excavations open all the time, and pumped from the one which was to be backfill into the other. For the final excavation the installation contractor was able to spray the remaining leachate over the site."

Other environmental mitigation measures, which could be considered at the design stage (in the widest environmental context), are the use instead of Portland cement of alternative cementious materials, which in themselves are waste by-products from other industrial processes, e.g. use of pulverised fly ash or blast furnace slag. In the same context, consideration should also to given to the use reclaimed aggregates, EN 206 [BSI 2000a], permits the use of both recycled aggregates or recycled crushed concrete in the production of concrete.

6.3.2 Site access

The successful planning and construction of site access roads or tracks, modifications to field fences and/or hedges, gateways, etc. (accommodation works), will obviously make a significant contribution to the overall impact of the project, both in terms of the environmental impact and the relationship with landowners, grantors and the general public, and where appropriate the environmental protection agencies. The need to commence early negotiations with landowners, grantors, civic authorities, environmental protection agencies, etc., is highly recommended.

Consideration will also be required in respect of the use of public roads by site traffic, with particular reference to road width, weight limits on bridges, clearance to structures or overhead lines, location of schools or other areas where there is a concentration of children, etc. Any traffic management scheme will need to be agreed with the responsible authorities.

Wherever possible use should be made of existing tracks as access roads/tracks, although they may need to be upgraded, depending on the existing wearing surface, drainage conditions, general ground conditions and the anticipated volume and size/weight of site traffic using the proposed access. Consideration may also need to be made in the respect of provision of temporary bridging of water courses or drainage systems. The removal of hedges, fences, widening of gateways and possible insertion of new entrances from the public highway, will all need control and agreement with the appropriate parties. In addition, the landowner/grantor should not be put to any inconvenience in gaining access to his land/property by the installation contractor’s use of the access route.

Where new access tracks are required, these should wherever possible, follow the natural contours of the terrain to minimise cut and fill quantities. Care should also be taken to minimise the effect of erosion caused by water runoff and siltation of water courses. For further details regarding the control of water pollution reference should be made CIRIA report C648 [CIRIA 2006].

Consideration should also be given to the use of special temporary access systems, i.e. aluminium track way panels or temporary stone roads (i.e. crushed imported stone laid on a geotechnical membrane), see Figure 6.1. The effect of failing to install a temporary access system is shown in Figure 6.2.

Aluminium track way panels **Temporary stone roads**

Figure 6.1 - Temporary access system

As an alternative to the use of special temporary access systems, consideration should be given to the use of low ground pressure vehicles, thereby preventing excessive soil compaction or damage.

Figure 6.2 – The consequences of failing to provide a temporary access system

The cost and temporary environmental impacts (increase in local traffic and noise level etc.), must be weighed against the benefits, i.e. protection of environmental sensitive areas, reduction in soil compaction and reduction in avoidable land damage. In addition, consideration should also be given to extending the temporary access system to provide a working-platform at the tower site for plant and equipment; although the benefits in reduction in land damage, etc., may have to be weighed against the detrimental effects of extended seasonal working periods and hence temporary environmental impacts. Other benefits that will accrue from the use of special temporary access systems will be a reduction of soil deposited on the public highway and may lessen the possibility of the spread of soil borne diseases in agricultural crops, e.g. Rhizomania in Sugar Beet.

6.3.3 Helicopters

As an alternative to the use of access tracks, it may be necessary to consider the transportation of materials, equipment and site operatives by helicopter, see Figure 6.3. The use of helicopters may be a condition of the planning consent of the overhead transmission line route, because the route passes through sensitive ecological areas or as an economic alternative to the construction of long and expensive access tracks from the nearest public highway.

One of the key features of the use of helicopters is the need for careful planning prior to commencing the work, taking into consideration payload limitations, duration and altitude limit of the helicopter, downtime for helicopter maintenance, weather conditions, possible need to ‘breakdown’ installation equipment into manageable units, the establishment of strategically placed depots for the transfer of materials, equipment and personnel from road to air and possibly changes in the concrete mix design to allow for longer periods of workability.

Figure 6.3 - Transportation of foundation concrete by helicopter

6.3.4 Foundation installation

Potential mitigation measures that the foundation installation contractor can undertake are:

- Removal of the topsoil and vegetation for subsequent reinstatement;
- Where it is necessary to bench the site, because of excessively steep hillsides or cross-falls, ensuring that this does not become a cause of future soil erosion;
- Keeping the top soil separate from the subsoil during on-site storage prior to backfilling. Note top soil should not be stock piled to a height greater than 2 m to prevent damage to the soil structure;
- Fencing off the site working area to prevent injury to farm livestock or wild animals;
- Preventing the contamination and/or siltation of water courses arising from removal of water from the excavation or surround area, e.g. well point dewatering;
- Ensuring that the removal of any ground water, does not affect adjacent land or properties;
- Controlled disposal of contaminated soil or materials used in the installation process, e.g. excavation stabilizing fluids (bentonite), or the use of polymer based drilling aids which can be broken down with an oxidizing agent for safe disposal;
- Prevention of fuel, oil, concrete or grout spillages;
- Use of synthetic (biodegradable) oil for hydraulic lubrication as opposed to mineral oil;
- Ensuring all material wrappings, general site litter, etc., are removed off-site on a daily basis;
- Possible restriction in the hours of working and control of noise, dust and vibration pollution;
- Use of wheel washing facilities or regular sweeping of public roads;
- Ensuring that site is secured against vandalism, all plant and equipment are immobilised when not in use and that all chemicals are correctly stored, etc.;
- Having a contingency/emergency plan ready, in the case of an environmental accident on-

site.

Although, not strictly an environmental mitigation measure, it may be necessary for an archaeologist to be present on-site, if the preconstruction archaeological survey has indicated the site to be of potential historical interest.

For further information regarding environmental good practice on-site in the UK, reference should be made to CIRIA Report C 502 [CIRIA 1999].

6.3.5 Site reinstatement

Site reinstatement should include, as appropriate, the following actions:

- Reinstatement of site drainage and/or provision of new site drainage;
- Controlled spreading of excessive spoil from the foundation;
- Reinstatement of hedges, etc.;
- Replanting of removed flora;
- Removal of access roads/tracks.

The sequence of the reinstatement will obviously depend on the construction activities and to a degree will not be completed until all site work has been finished.

6.4 Conclusions

This section of the report has considered the potential environmental impacts arising from both the site access accommodation works and the actual foundation installation. The actual environmental impact will obviously depend on the environment of the transmission line route and the type and size of the support foundations being installed.

Possible mitigation measures include the initial environmental assessment, the preparation of a site environmental plan, the use of temporary access systems or alternatively the use of helicopters for the transportation of plant, material and site operatives. Since any mitigation measure will, to a degree, have an impact on the foundation installation and possibly the actual design of the foundation; it can not be considered in isolation, but must be considered as part of the overall interaction between the foundation installation, foundation design, the associated quality management, and health and safety requirements for the scheme.

7 Foundation Costs

7.1 General

The support foundations represents between 14 and 23 percent of the total cost of an overhead line, with an average value of 19 percent [Cigré 1991]. This average value remains reasonably constant and is not affected by changes in the transmission line voltage, circuit configuration (single or double circuit) and support type. Similarly, the percentage breakdown between material supply and installation also remains reasonably constant at 65 percent to 35 percent.

The factors which have the greatest influence on the foundation cost are:

- The foundation type which is to a degree dependant upon the support type;
- The magnitude of the applied loadings;
- The geotechnical conditions of the in-situ soil and/or rock.

The Cigre foundation cost study [Cigre 1996], indicated that:

- Foundation costs were a linear function of the load capacity for a given foundation type per soil condition and location;
- That for compact foundations for a 10 percent change in load, there was a 2 to 8 percent change in cost;
- For spread footings with an initial 'high' uplift resistance, for a 10 percent change in load, there was a 9 to 10 percent change in the cost.

From the above, it can be seen that there are no universal rules that can be developed for support foundation costs and this to a degree is a reflection of the difference in costs in relation to different foundation types which in itself is a reflection of the variability of the ground conditions.

Other factors which may influence the selection of foundation type and hence its cost are:

- Environmental, e.g. topography, climate, contamination and access requirements, e.g. the predominate use of steel grillage foundations in Canada;
- Resource limitations;
- Health and safety requirements.

The price or rate for the foundation, in other words 'what the foundation installation contractor gets paid by the client', will in addition to the factors described above, depend on the method of measurement and payment plus the allocation of risk between the client and the installation contractor. Details of typical methods of measurement and payment are given in the following sections of this report.

7.2 Allocation of risk

With regards to the allocation of risk between the client and the installation contractor, for the foundation installation this specifically relates to the question of the in-situ geotechnical conditions. Either, the foundation installation contractor carries the majority of the risk, based on a fixed all-inclusive rate with limited geotechnical information at the time of tendering or whether the risk is shared, based on a re-measured fixed rate with extras payments for changes in the assumed ground conditions. Obviously, there are intermediate levels of risk allocation, whereby the client undertakes the geotechnical investigation prior to the tender stage or undertakes the actual foundation design. Other factors which need to be considered are the question of foundation testing and the risk of a test failure, whether environmental assessments (impacts) have been undertaken and the associated mitigation measures agreed with the relevant authorities before the tender stage.

In respect of the geotechnical risks, it is interesting to note that the final warning in the paper by Littlejohn, Cole and Mellors entitled ‘Without site investigation ground is a hazard’ [ICE 1994], states ‘That you pay for site investigations whether you have one or not, and you are likely to pay considerably more if you do not, or if it is inadequately designed, executed or interpreted’. Consequentially, it is preferable if the client undertakes a reasonable extensive geotechnical investigation prior to going out to tender.

7.3 Methods of measurement and payment

During the past twenty to thirty years, there has been a noticeable change in the method of measurement and payment for OHL support foundations, from a re-measured fixed rate with extras payments for changes in the assumed ground conditions, to one of inclusive prices based on a fixed rate with no re-measure apart from piled foundations, and this only in respect of pile length.

Typically in the UK until the early 1980's, foundation contract prices were based on:

- A fixed unit rate for a ‘standard’ foundation per tower type (inclusive of all tower extension); based on normal ground conditions, irrespective of access conditions, ground slope, subsoil conditions or the presence of water, unless the Engineer certified the conditions as ‘abnormal’. The rate of a ‘standard’ foundation to include the supply of all materials and all site work in respect of the foundation installation, e.g. setting-out, excavation, excavation support, stub setting, concreting, backfilling, site reinstatement, etc.

If the Engineer certified the conditions as ‘abnormal’, additional payments, based on fixed rates, would be made in respect of the following items, all subject to re-measured quantities:

- Additional excavation, related to the difference in ground level between any two stub positions exceeding 1.5 m, after taking into consideration the use of differential leg extensions. Note that an allowance was made with regards to the excavation plan area being 0.45 m wider than the foundation base area.
- Close timbering (support) of the foundation excavation due to poor soil conditions was required, based on the assumption that for normal ground conditions only 50% of the excavation sides would be timbered. Additional payment, based on the difference in cost between close timbering and the cost of 50% timbering.
- Additional pumping was necessary in excess of that required to remove overnight accumulation of water in the excavation: payment based on the pump size and the hours of pumping.
- Rock was encountered in the excavation, which could not be removed by pick and shovel and was unsuitable for a rock foundation.
- Piling was required. Payment based on piling sub-contractor’s cost plus a percentage to cover main contractor’s on-costs.

Standard foundations suitable for normal ground conditions, were spread footings either reinforced concrete pyramid and chimney foundations or drilled shaft (augered) foundations. Normal ground conditions were defined in terms of the maximum allowable bearing pressure of the foundation in conjunction with an assumed frustum angle for, use in uplift resistance calculations.

Taking into consideration the need to have a stricter control of the final contract price, especially when the overhead transmission line is being financed by an international aid agency or a private bank loan and the reduction in client's site supervisor staff, there has been a change from a fixed rate re-measured method of pricing to an all-inclusive approach.

A typical method of measurement and payment for support foundations based on an inclusive cost approach would be:

- The rates for foundation supports shall include for site clearing, geotechnical investigation (assuming that this has not already been undertaken by the client), excavating in any material and by any means, manual or mechanical, and for ensuring stability and natural drainage inside the working area including pumping and well-point dewatering, excavation support, concrete work, formwork, concrete reinforcement, stub steelwork, stub cutting, routine testing, for all backfilling, compacting and disposal of surplus material, site restoration and all other work required to complete the foundation in accordance with the technical specification.
- In addition, the rate shall include for the use of any type of cement or density of concrete required to ensure the durability of the foundation, the supply of weak-mix concrete or the importation of any backfill material necessary due to the excavated material being unsuitable as backfill.
- The rate for foundations shall include all stub steelwork installation and setting out, including the use of templates, setting to any level and any excavation necessary for setting out. The protective treatment to defined concrete faces or support steelwork, provision of site protective barriers and foundation earthing as necessary.
- Design tests to prove the foundation design shall be paid for at the rates quoted and shall include for the removal of the foundation to a defined depth below ground level.

Support foundations would be defined in terms of permitted types of foundations, e.g. spread footings, anchor or piled for a range of soil categories. Soil categories are usually described in terms of soil and backfill density, the internal angle of friction of the soil, allowable bearing and lateral earth pressures, etc., and the correlation with geotechnical investigation, e.g. standard or cone penetration tests.

Even if this approach is adopted, additional work in respect of the provision of access development or the use of helicopters for the transportation of materials and plant would be paid for as an extra.

7.4 Conclusions

Irrespective of the method of measurement and payment adopted for the foundation design and installation, the actual total cost of the foundation, i.e. the design, supply of material and installation and hence the total cost of the project, can be reduced if sufficient time is spent in the preparation of the work prior to the actual commencement of the installation. This effectively means reducing the risk due to geotechnical uncertainties, environmental impacts, access development, quality, health and safety, and especially effective communications between the client, foundation design and foundation installation contractor.

8 Summary

8.1 General

Although the support foundations typically only represents nineteen percent of the total cost of an overhead transmission line [Cigre 1991]: the actual installation process differs from that of all the other transmission line components, in that it is undertaken in a variable medium which can rapidly change not only between support locations but also between adjacent footings on the same support site. This variability of the in-situ soil or rock and the ground water level, can have a marked influence not only on the long term performance of the foundation, but also on the short term success of the scheme, unless the interaction between the foundation design and installation is carefully controlled. The failure to control this interaction has been demonstrated in Figures 1.3 and 2.6, and is further illustrated in Figure 8.1.

Figure 8.1 ~ Failure of the Tully Falls – Townsville 132 kV OHL, Queensland, Australia

Failure due to a combination of circumstances:	▸ Foundation installed in dry season with no consideration given to potential change in ground water level, i.e. standard non-buoyant foundation ;
	▸ General reduction in ground level (0.5 m to 0.75 m) due to adjacent agriculture activities and subsequent soil erosion;
	▸ High ground water table after heavy rain (at or near ground level) in conjunction with cyclonic winds

This report has attempted to demonstrate that to achieve both the intended performance and service life of the support foundations, the installation process cannot be viewed in isolation, but must be considered as an evolving process that has a continuous interaction with the foundation design. Furthermore, the interaction with respect to the environmental impact of the actual foundation installation and associated access, the health and safety of the site operatives and general public must also be taken into consideration.

8.2 Foundation design

To provide initial guidance to the readers of this report, the relationship between the support types, i.e. broad based lattice towers, externally guyed supports, monopoles or narrow based lattice towers and H-framed supports, the primary applied foundation loading, e.g. vertical uplift and compression forces for broad base lattice towers or overturning moments for monopoles and the principal foundation types, e.g. separate, anchor and compact, has been provided in section 1 of this report and is shown diagrammatically in Figure 1.4.

To assist the readers further, a description of individual foundation types within each of the three principal categories of foundations considered has also been given in that section, i.e.:

▸ Separate	Spread footings, e.g. pad or pyramid and chimney, grillage; Drilled shafts; Piled, i.e. driven (displacement) and bored (no-displacement).
▸ Anchor	Ground, Block, Helical screw, Deadman.
▸ Compact	Monoblock, Direct embedment and Raft

8.3 Interaction with the design process

The interaction between the foundation installation activities and the foundation design process has been considered in section 2, for each of the individual types of foundation described above. This interaction has been portrayed by the use of interaction diagrams and descriptive tables, which for each foundation type highlights the key design parameter, the associated installation activity and the effect on the foundation design.

The effect on the foundation design can, as has already been stated, be summarised as a potential reduction in the foundation's geotechnical design strength and a reduction in the long term durability of the foundation and hence its service life. The major causes of these potential effects can be ascribed to the following foundation installation activities:

- Changes in the assumed geotechnical conditions during the foundation installation;
- Incorrect foundation excavation or installation techniques;
- Poor dimensional control of the foundation overall size or in the stub and/or holding bolt setting;
- Inappropriate concreting techniques, e.g. placing, compacting or curing;
- Inappropriate techniques or controls during the backfilling of the foundation.

8.4 Foundation installation activities

To ensure that the foundations are correctly installed and the effects described in section 2 do not occur, section 3 of this report provides an overview of the accepted good practice with respect to the foundation installation activities.

Foundation installation can be considered as a series of discreet interrelated activities, which for convenience can be divided between the pre-site activities i.e. the activities that are undertaken prior to the commencement of the contract foundation installation and those undertaken as part of the main works. The pre-site activities including the preparation of foundation installation drawings, the concrete mix design, the preliminary foundation design tests and the preparation of the foundation installation criteria schedule detailing for each support location the type of foundation to be installed. The main works activities encompass: setting out of the foundations, excavation including the control of ground water, the installation of drilled shafts and piles, concrete production, delivery and placing, backfilling of the excavation, and site reinstatement.

To provide further guidance to the reader, a selection of photographs illustrating different sequences in the installation process has been provided in section 3A.

8.5 Quality management

The need to ensure the that the project works comply with project requirements has been considered in section 4 of this report, with respect to the quality assurance and quality control requirements associated with foundation installation activities.

The pre-project activities relate to the foundation design process, the vetting of proposed suppliers or sub-contractors, the concrete mix design, the foundation design tests and the foundation installation criteria and associated method statements. The project foundation installation activities encompassing: setting out, verification of the foundation design soil /rock parameters, concrete placing and identity tests, backfilling, foundation proof and integrity tests.

While it is not restricted to foundation installation the question of the final as-installed records, is also considered in this section of the report.

8.6 Health and safety

The health and safety of the foundation installation contractor's site operatives and members of the general public in respect of foundation installation activities, has been outlined in section 5. This has been based on current UK practice and may not be completely applicable to the readers' own local statutory requirements or accepted local practice.

One of the guiding principals of UK's H&S legislation is the principle of 'so far as reasonable practical'; in others words an employer does not have to avoid or reduce the risks if they are technically impossible or if the time, trouble or cost of the measure would be grossly disproportionate to the risk. However, in strict Health and Safety terms 'so far as reasonable practical' are not measured against cost and benefit but refer to any means, which are technically possible irrespective of cost.

Health and safety stems from the designer ensuring that this proposed design can be safely built, maintained and eventually removed. Where the designer identifies a hazard, he should if possible eliminate, or minimise the risk or where this is not possible identify the residual risks.

The need for employers to undertake risk assessments of hazardous on-site operations, preparation of method statements and excavation health and safety checklists are also considered in this section of the report.

8.7 Environmental impact and mitigation

The environmental impacts associated with the foundation installation and the associated accesses considered in section 6, can be summarised as: increase in traffic on local roads, impact of access tracks, disturbance of land and vegetation management, noise, dust and vibrational pollution, soil erosion and pollution of water courses, disturbance to birds and other fauna, and the effect on the flora surrounding the support site.

Mitigation measures described include undertaking an environmental (ecological) impact assessment, use of temporary access systems or helicopters (see Figure 8.3) and controls during the foundation actual installation, e.g. removal of top soil and vegetation for subsequent reinstatement, prevention of spillages on sites, restrictions in working hours etc.

Figure 8.3 – Transportation of foundation concrete by helicopter

8.8 Foundation cost

The support foundations represents between 14 and 23 percent of the total cost of an overhead line, with an average value of 19 percent [Cigré 1991]. This average value remains reasonably constant and is not affected by changes in the transmission line voltage, circuit configuration and support type. Similarly, the relative percentage breakdown between material supply and installation also remains reasonably constant at 65 percent to 35 percent.

The factors which have the greatest influence on the foundation cost are: the support type, the magnitude of the applied loadings, the foundation type and the geotechnical conditions.

With respect to support foundation costs there are no universal rules that can be developed and this to a degree is a reflection of the difference in costs in relation to different foundation types which in itself is a reflection of the variability of the ground conditions. Other factors which may influence the selection of foundation type and hence its cost are: environmental, resource limitations and health and safety requirements.

The price or rate for the foundation will in addition to the factors described above, depend on the method of measurement and payment plus the allocation of risk between the client and the installation contractor. Details of typical methods of measurement and payment are given in the section 7 of the Brochure.

8.9 Conclusions

The installation of overhead line support foundations can not be viewed in isolation but must be considered as on going process, with a seamless transition between design and construction, if the adverse effects outlined in section 2 of this Brochure are to be avoided. Similarly, to ensure that the intended service life is achieved, quality management requirements must also be integrated within the installation process. Since foundation installation is also hazardous both to site operatives and the environment, mitigation measures must also be considered from the outset of the project.

9 Bibliography

ACI [1974] 543-74 ‘Recommendations for Design, Manufacture and Installation of Concrete Piles’, American Concrete Institute, Detroit, MI, USA.

ACI [1993], 336.3R-93 ‘Design and Construction of Drilled Piers’, American Concrete Institute.

ASTM [1984], D2488 ‘Description and Identification of Soils (Visual – Manual Procedures). American Society for Testing and Materials, 100 Barr Harbour Drive, West Conshohocken, PA 19428, USA.

ASTM [1996], D5882 ‘Standard Test Method for low Strain Integrity Testing of Piles.
BCA [2000], ‘Early age strength assessment on site’, British Cement Association, Century House, Telford Avenue, Crowthorne, Berkshire, RG45 6YS. www.bca.org.uk

BRE [1971], ‘Problems of Concrete Production in Arid Climates’, Overseas Building Note 139, Building Research Establishment, August 1971. BRE publications are available from CRC, 151 Rosebery Avenue, London EC1R 4GB, UK.

BRE [2002], Special Digest 1, ‘Concrete in aggressive ground conditions’. Note revised in 2005.

BSI [1984], BS 8004 ‘Code of practice for foundations’. BSI, 389 Chiswick High Road, London W4 4AL, UK. www.bsi-global.com/bsonline

BSI [1989], BS 8081 'Ground anchorages’.

BSI [1990a], BS 5328:Part 3 ‘Specification for procedures to be used in producing and transporting concrete’.

BSI [1990b], BS 5328 ‘Concrete’.

BSI [1990c] ,BS 1377-9 ‘Methods of tests for soils for civil engineering purposes, In-situ tests’.
BSI [1997], BS 8110-1 ‘Structural use of concrete - Part 1 : Code of practice for design and construction’.

BSI [1999], ISO 14654 ‘Epoxy-coated steel for reinforcement of concrete’.

BSI [2000a], EN 206-1 ‘Concrete - Part 1: Specification, performance, production and conformity’.

BSI [2000b], EN 1536 ‘Execution of special geotechnical work - Bored piles’.

BSI [2000c], BS 8666 ‘Specification for scheduling, dimensioning, bending and cutting of steel reinforcement for concrete’.

BSI [2000d], EN 1537 ‘Execution of special geotechnical work - Ground anchors’.

BSI [2000e], ISO 9001 ‘Quality management systems. Requirements’.

BSI [2000f], EN12350-2 ‘Testing fresh concrete - Part2: Slump tests’.

BSI [2000g], EN12350-5 ‘Testing fresh concrete - Part5: Flow table tests’.

BSI [2000h], EN 12350-7 ‘Testing of fresh concrete - Part7: Air content - Pressure methods’.

BSI [2000j], EN 12390-2 ‘Testing hardened concrete - Part2: Making and curing specimens for strength tests'.

BSI [2000k], EN 12390-3 'Testing hardened concrete - Part3: Compressive strength of test specimens'.

BSI [2000m], EN 12390-7 'Testing hardened concrete - Part7: Density of hardened concrete'.

BSI [2001a], EN 934 'Admixtures for concrete, mortar and grout'.

BSI [2001b], BS 7973-2 'Spacers and chairs for steel reinforcement and their specifications. Fixing and application of spacers and chairs and tying of reinforcement'.

BSI [2001c], EN 12699 'Execution of special geotechnical work - Displacement piles'.

BSI [2001d] EN 50341-1 'Overhead electrical lines exceeding AC 45kV - Part1: General requirements - Common specification'.

BSI [2002], BS 8500 'Concrete - Complementary British Standard to BS EN 206-1'.

BSI [2005], EN 14199 'Execution of special geotechnical works – Micropiles'.

C&CA [1975], 'Concrete Practice', Cement and Concrete Association, Wrexham Springs, Slough, SL3 6PL, UK, 1975.

Cigre [1991], 'An International Survey of Component Costs of Overhead Transmission Lines', Cigre, Electra No.137, August 1991. Cigré, 21, rue d 'Artois - F -75008 Paris, France.

Cigre [1994], Special Publication No.81 'Foundation Testing', Cigre WG 22-07,

Cigre [1996], Foundation Cost Study, Cigre, Electra No. 165, April 1996.

Cigre [1999a], Technical Brochure No. 141, Refurbishment and Upgrading of Foundations', Cigre WG 22.07.

Cigre [1999b], Technical Brochure No. 147, High Voltage Overhead Lines Environmental Concerns, Procedures, Impacts and Mitigations, Cigre WG22.14.

Cigre [2002], Technical Brochure No.206 'The Design of Transmission Line Support Foundations - An Overview', Cigre WG 22-07.

Cigre [2004], Technical Brochure No.265 'Life Cycle Assessment (LCA) for Overhead Lines', Cigre WG B2-15.

CIRIA [1977a], Report R165 'Concrete mixes - planning and design for transporting, placing and finishing. Construction Industry Research & Information Association, Classic House, 174-180 Old Street, London, EC1V 9BP, UK. www.ciriabooks.com

CIRIA [1977b], DOE/CIRIA Report PG2 'Review of problems associated with construction of cast-in-place concrete piles',

CIRIA [1977c], Report PG3, 'The use and influence of bentonite in bored pile construction'.

CIRIA [1979], Report SP12, 'Piling in Chalk'.

CIRIA [1980], DOE/CIRIA Report PG8, 'Survey of problems associated with the installation of displacement piles'.

CIRIA [1984], DOE/CIRIA Special Publication 32, ‘Construction over abandoned mine workings’.

CIRIA [1995], Report 147, ‘Care and treatment of steel reinforcement and the protection of starter bars’.

CIRIA [1997], Report R144, ‘Integrity testing in piling practice’.

CIRIA [1999], Report C502, ‘Environmental good practice on site’.

CIRIA [2002a], Report C577, ‘Guide to the construction of reinforced concrete in the Arabian Peninsular’.

CIRIA [2000b], Report C569, ‘Concrete technology for cast in-situ foundations’.

CIRIA [2006], Report C648, ‘Control of water pollution from Linear construction projects’. See also associated guide C649.

ICE [1994], ‘Without site investigation ground is a hazard’, Littlejohn G, Cole K, Mellors T, Civil Engineering Proceedings 102, Paper 10373. The Institution of Civil Engineers, 1 Great George Street, Westminster, London, SW1P 3AA UK.

ICE [1996], ‘Specification for Piling and Embedded Retaining Walls’, The Institution of Civil Engineers, Thomas Telford Ltd. Thomas Telford House, 1 Heron Quay, London E14 4JD, UK. www.thomastelford.com

IEC [1996], IEC 61773, ‘Overhead lines - Testing of foundations for structures’

IEEE [1991], Std 977-1991 ‘Guide to Installation of Foundations for Transmission Line Structures, IEEE, 345 East 47th Street, New York, NY 10017, USA.

HMSO [1992], ‘Management of Health and Safety at Work Regulations 1992’.

HMSO [1996], ‘The Construction [Design and Management] Regulations 1994'.

HMSO [2000], ‘The Electricity Works (Environmental Impact Assessment) (England and Wales) Regulation 2000'.

HSE [1996], ‘Health and Safety in Construction’, Health & Safety Executive, HSE Books, PO Box 1999, Suffolk, CO10 6FS, UK.

HSE [1999] , ‘Health and safety in excavations’, Health & Safety Executive, HSE Books.

HSE [2003], ‘Health and Safety regulations - a short guide’, HSC13(rev1), 08/03.

Jones A, Deal J A and Paisley D F [1988], ‘The design and construction of a 132 kV double circuit line over a route containing extensive uncharted mineworkings’, IEE Conference Publication No.297.

Thomas Telford [1996], ‘Health and Safety for Engineers, Edited by M J Barnard, Thomas Telford Ltd.