Deep Foundations

An Online Continuing Education Course for Engineers

Course Number: G-8002

Credit: 8 Hours / 8 PDH / 8 CPD

Deep Foundations

Chapter 1

Introduction

1. Purpose

This course presents data, principles, and methods for use in planning, design, and construction of deep foundations. Deep foundations are literally braced (supported) column elements transmitting structure loads down to the subgrade supporting medium.

2. Scope

General information with respect to the selection and design of deep foundations is addressed herein. Single and groups of driven piles and drilled shafts under axial and lateral static loads are treated. Some example problems are introduced. This course is not intended for hydraulic structures; however, it does provide the following:

a) Guidance is provided to assist the efficient planning, design, and quality verification of the deep foundation.

b) Guidance is not specifically provided for design of sheet piles used as retaining walls to resist lateral forces or for the design of stone columns.

c) Guidance for construction of deep foundations is provided only in minor detail.

3. References

Appendix A contains a list of references used in this course.

4. General Design Methodology

A single drilled shaft or a group of driven piles is typically designed to support a column load. The number of driven piles in a group is determined by dividing the column load by the design load of a single pile. The piles should be arranged in the group to provide a spacing of about three to four times the pile diameter B up to $6B$. The diameter of the piles may be increased to reduce the size of the pile cap if appropriate. Table 1-1 describes a general design methodology. Other design methodology aspects are the following:

a. Load factor design. This course applies load factors for design (LFD) of the structural capacity of deep foundations. The sum of the factored loads shall not exceed the structural resistance and the soil resistance. The LFD, the structural resistance, and the soil resistance are all related to the load factors as follows:

1. Definition. The LFD may be defined as a concept which recognizes that the different types i of loads Q_i that are applied to a structure have varied probabilities of occurrence. Examples of types of loads applied to a structure include the live load Q_{LL}, dead load Q_{DL}, wind load Q_{WL}, and earthquake load Q_{EL}. The probability of occurrence of each load is accounted for by multiplying each Q_i by a load factor $F_i > 1.0$. The value of F_i depends on the uncertainty of the load.

Table 1-1
General Design Methodology for Deep Foundations

Step	Evaluate	Description
1	Soil profile of selected site	Develop depth profiles of water content, liquid and plastic limits, unit weight and overburden pressure, and unconsolidated-undrained shear strength to a depth of a least twice the width of a pile group or five times the tip diameter of drilled shafts. Estimate shear strength and elastic soil modulus from results of in situ and laboratory triaxial tests. Determine water table depth and extent of perched water. Perform consolidation/swell tests if soil is potentially expansive or collapsible and plot compression and swell indices and swell pressure with depth. Evaluate lateral modulus of subgrade reaction profile. Compare soil profile at different locations on the site. See Chapters 1-6 for further details.
2	Group similar soils	Group similar soils and assign average parameters to each group or strata.
3	Depth of base	Select a potentially suitable stratum that should support the structural loads such as a firm, nonswelling, and noncollapsing soil of low compressibility.
4	Select type of deep foundation	Select the type of deep foundation such as driven piles or drilled shafts depending on requirements that include vertical and lateral load resistance, economy, availability of pertinent construction equipment, and experience. Environmental considerations include allowable noise level, vibrations, overhead clearance, and accessibility of equipment to the construction site. Soil conditions such as potential ground rise (heave) or loss and expansion/collapse also influence type of foundation. See Chapter 1 for further information on type and selection of deep foundations.
5	Check Q_a with structural capacity	Allowable pile or shaft load Q_a shall be within the structural capacity of the deep foundation as described by methodology in Chapter 2.
6	Design	The design procedure will be similar for most types of deep foundations and requires evaluation of the ultimate pile capacity $Q_u = Q_{su} + Q_{bu}$ where Q_{su} = ultimate skin friction resistance and Q_{bu} = ultimate end bearing capacity. Reasonable estimates of vertical and lateral displacements under the probable design load Q_d are also required. Q_d should be within levels that can be tolerated by the structure over its projected life and should optimize operations. $Q_d \leq Q_a$ where Q_a = allowable pile capacity. $Q_a = Q_u/FS$ = factor of safety. A typical $FS = 3$ if load tests are not performed or if the deep foundation consists of a group of driven piles. $FS = 2$ if load tests are performed or 2.5 if wave equation analyses of the driven piles calibrated with results of pile driving analyzer tests. Design for vertical loads is given in Chapter 3, lateral loads in Chapter 4, and pile groups in Chapter 5.
7	Verify the design	The capability of the deep foundation to support the structure shall be verified by static load and dynamic tests. These tests are usually nondestructive and allow the tested piles or drilled shafts to be used as part of the foundation. See Chapter 6 for further details.
8	Addition to existing structure	Calculate displacements of existing deep or shallow foundations to determine the ability to carry existing and additional loads and to accommodate new construction.
9	Effect on adjacent structure	Evaluate changes in bearing capacity and groundwater elevation and effect of any action which can result in settlement or heave of adjacent structures.

2. Structural resistance. The sum of the factored loads shall be less than the design strength

$$\Phi_{pf}\, Q_{cap} \geq \Sigma\, F_i\, Q_i \qquad (1\text{-}1)$$

where

Φ_{pf} = performance factor for structural capacity

Q_{cap} = nominal structural capacity, kips

F_i = Load factor of type *i*

Q_i = applied load of type *i*

Guidance for analysis of structural capacity is given in Chapter 2.

3. Soil resistance. The sum of the factored loads shall be less than the ability of the soil to resist the loads. This evaluation may be determined by factors of safety *(FS)* or by load factors. Factors of safety are often empirical values based on past experience and may lead to a more conservative design than the LFD concept. The *FS* and the LFD are presented as:

a. Global *FS*. The allowable load may be evaluated with global *FS*

$$Q_a = \frac{Q_u}{FS} \geq \Sigma\, F_i\, Q_i \qquad (1\text{-}2a)$$

where

Q_a = allowable load that can be applied to the soil, kips

Q_u = ultimate pile capacity, kips

FS = global factor of safety

The approach taken throughout this course is to select a global *FS* for analysis of soil resistance rather than partial *FS* or load factors. Chapters 3 through 5 provide guidance for design of deep foundations to maintain loads within the allowable soil bearing capacity and displacement. Chapter 6 provides guidance for design verification.

b. Load factor design. Analysis of soil resistance may also be determined by the LFD concept using performance factors

$$\Phi_{pfq}\ Q_u \geq \Sigma\, F_i\, Q_i \qquad (1\text{-}2b)$$

where Φ_{pfq} = performance factor appropriate to the ultimate pile capacity. Performance factors Φ_{pfq} depend on the method of evaluating Q_u and the type of soil resistance, whether end bearing, skin friction, uplift, or a group capacity. Values for Φ_{pfq} and examples of load factor analysis are available in National Cooperative Highway Research Program Report No. 343, "Manuals for the Design of Bridge Foundations" (Barker et al. 1991). Load factors and factors of safely taken in combination can lead to an uneconomical foundation design. The design should be verified by guidance in Chapter 6.

b. Unusual situations. Consideration should be given to obtaining the services and advice of specialists and consultants in foundation design where conditions are unusual or unfamiliar or structures are economically significant. Some unusual situations for deep foundations, discussed below, include expansive clay, underconsolidated soil, and coral sands.

1. Expansive clay. The swell of expansive clay can cause an uplift force on the perimeter area of deep foundations that can force the foundation to move up and damage the structure connected to the deep foundation.

2. Underconsolidated soil. The settlement of underconsolidated soil can cause negative skin friction on the perimeter area of the deep foundation that can increase the end-bearing load, which results in an increase in settlement of the foundation.

3. Coral sands. Piles in coral sands may indicate low penetration resistance during driving and an apparent low bearing capacity, but the penetration resistance often increases over time as a result of the dissipation of excess pore pressure. Driving of piles into cemented, calcareous sands can crush the soil and lower the lateral stress, which results in a low value for skin friction and bearing capacity.

5. Types of Deep Foundations

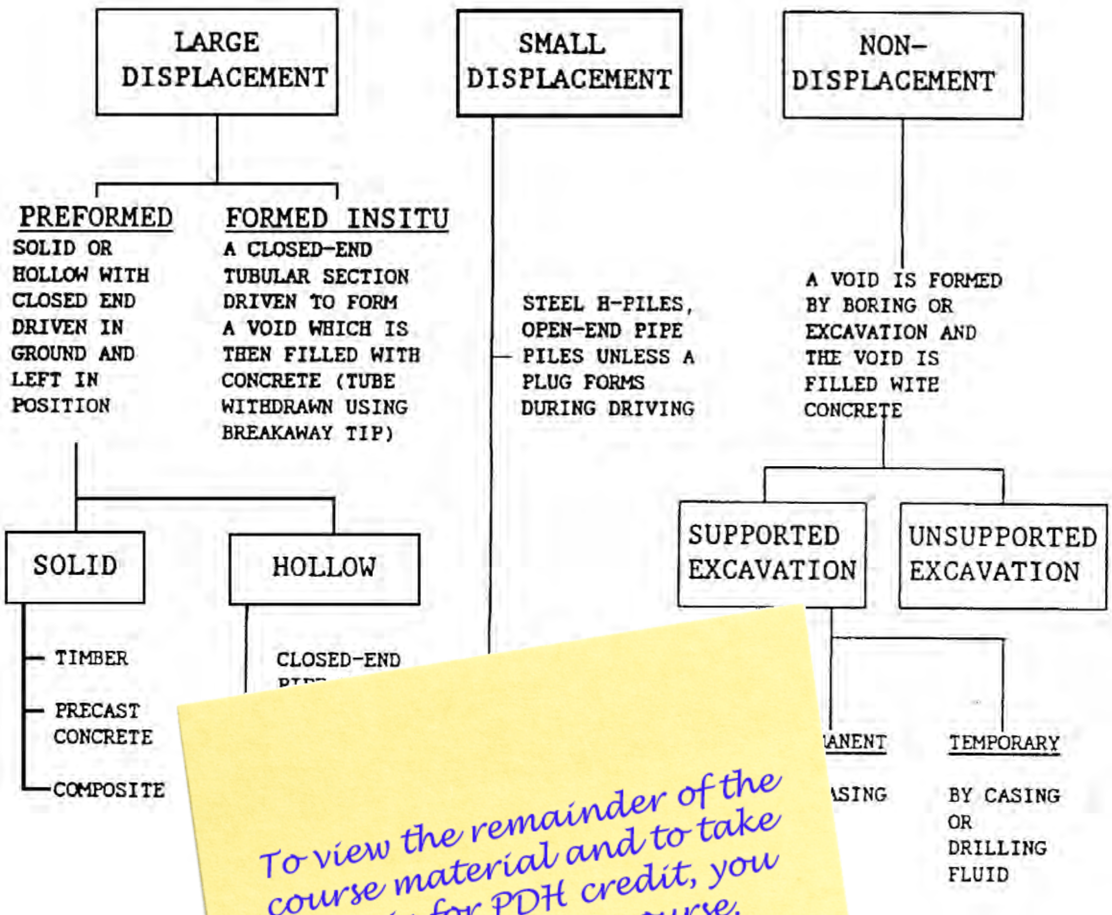
Deep foundations are classified with respect to displacements as large displacement, small displacement, and nondisplacement, depending on the degree to which installation disturbs the soil supporting the foundation (Table 1-2). Large displacement and small displacement piles are fabricated prior to installation and driven into the ground, while nondisplacement piles are constructed in situ and often are called drilled shafts. Augured cast concrete shafts are also identified as drilled shafts in this course.

a. Large displacement piles. Driven piles are classified by the materials from which the pile is constructed, i.e., timber, concrete, or filled or unfilled steel pipe.

1. Timber piles. These are generally used for comparatively light axial and lateral loads where foundation conditions indicate that piles will not be damaged by driving or exposed to marine borers. Overdriving is the greatest cause of damage to timber piles. Pile driving is often decided by a judgment that depends on the pile, soil condition, and driving equipment. Overdriving typically occurs when the dynamic stresses on the pile head exceed the ultimate strength of the pile. Timber piles can broom at the pile tip or head, split, or break when overdriven. Such piles have an indefinite life when constantly submerged or where cut off below the groundwater level. Some factors that might affect the performance of timber piles are the following:

a. Splicing of timber piles is expensive and time-consuming and should be avoided. The full bending resistance of timber pile splices may be obtained by a concrete cover (Figure 1-1a) (Pile Buck Inc. 1992). Other transition splicers are available to connect timber with cast concrete or pipe piles.

Table 1-2
Types of Deep Foundations



b. Tips of timber piles ca

c. Timber piles are norma onmental attack.

d. American Society for T cal specifications of round timber piles.

2. Precast concrete piles. oncrete piles and prestressed concrete pile with an internal reinforcement cage consisti ties, individual hoops, or a spiral. Prestressed concrete steel rods or wire strands under tension as reinforcement. Since the co under continuous compression, transverse cracks tend to