Bridge Design - Deep Foundations

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Module 16: Deep Foundations

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the specific conditions under which driven piles or drilled shafts are selected over shallow foundations.
- **Calculate** axial force distributions and resistance capacities for pile groups in competent and soft/liquefiable soils.
- **Evaluate** constructability requirements for CIDH shafts, including concrete cover, inspection pipe layouts, and reinforcement spacing.
- **Design** large-diameter column-shafts (Type I and Type II) for seismic stability and shear capacity.

Executive Summary: This chapter provides an exhaustive technical framework for the design and analysis of deep foundations, emphasizing driven piles and Cast-in-Drilled-Hole (CIDH) shafts. It details the structural and geotechnical procedures required for foundations in diverse soil profiles, including competent, marginal, and liquefiable layers. Key focus areas include the rigid cap assumption, seismic overstrength force transfer, and the specialized detailing required for Large Diameter Column-Shafts to ensure ductile performance and ease of post-earthquake inspection.

Introduction

Deep foundations consist of pile and shaft units embedded in the ground to support bridge bents or piers. A **pile** is typically installed by driving or vibration, while a **drilled shaft** is constructed by placing concrete in a pre-drilled hole. In Caltrans terminology, "pile" is often used generically, but AASHTO LRFD specifically distinguishes **Driven Piles** (Article 10.7) and **Drilled Shafts** (Article 10.8).

Deep foundations are essential when:

- Competent soil strata are significantly below ground level.
- Liquefaction or lateral-spreading risks are present.
- Scour depth is large.
- Space constraints or contaminated soil removal prevent spread footing use.

Types of Piles and Shafts

Standard Plan Piles (Class Piles) are structurally predesigned units used in groups. Common driven piles include steel H-Pile (HP), pipe piles, and Cast-in-Steel Shell (CISS) piles. **Drilled shafts (CIDH)** are often recommended to mitigate noise/vibration or avoid utility interference.

Constructability Issues

⚠️ **Safety Constraint:** If groundwater is anticipated, drilled shafts must be at least **24 in. in diameter** to facilitate cleaning and Gamma-Gamma Logging (GGL).

Table 16.1-1: Minimum Cover Requirement for Drilled Shafts

Diameter of Drilled Shaft, D	Concrete Cover
16 in. and 24 in. Standard Piles	See Standard Plan B2-3
24 in. $\leq D \leq$ 36 in.	3 in.
42 in. $\leq D \leq$ 54 in.	4 in.
60 in. $\leq D <$ 96 in.	5 in.
96 in. and larger	6 in.

General Design Considerations – Pile/Shaft Group

Pile/Shaft Spacing

Table 16.1-2: Pile/Shaft Group Spacing

Type of Piles or Shafts	Minimum center-to-center spacing of piles/shafts	Minimum spacing between face of the pile/shaft to face of the cap (for edge/corner piles/shafts)
Driven Piles	36 in. or $2D$ (whichever greater)	9 in. or $0.5D$ (whichever greater)
Drilled Shafts	$2.5D$	12 in.

Scour Protection

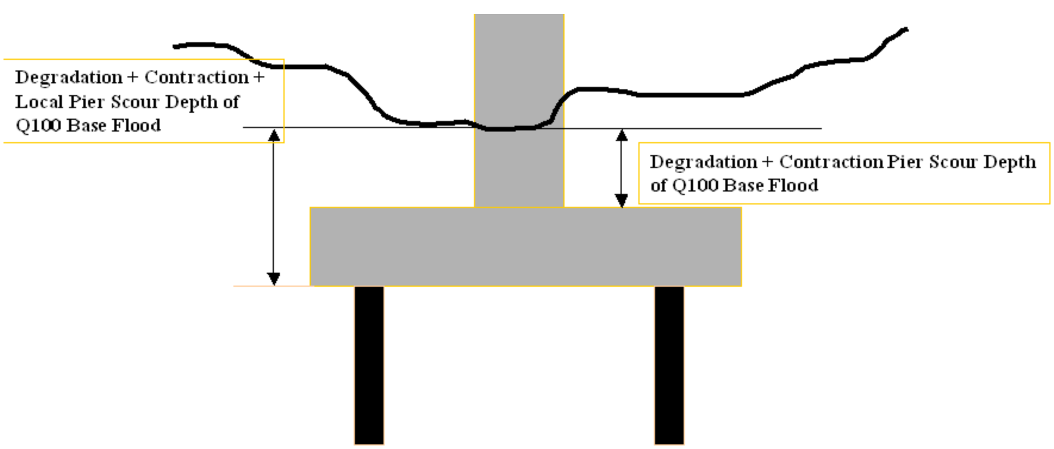

Figure 16.1-1: Required Embedment Depth for Scour Protection

Table 16.1-3: Percentage of Scour Used in Design for Different Limit States

Limit State	Maximum Aggradation/Degradation and Contraction Scour to be considered for footing design, shown as a % of total	Maximum Local Scour to be considered for footing design, shown as a % of total
Service	100	100
Strength	100	50
Extreme Event	100	0

Standard (Class) Piles

Standard piles (Class 90, 140, 200) have pre-calculated structural capacities. LRFD Nominal Resistance in compression is twice the class value (e.g., Class 200 = 400 kips).

General Design Assumptions

A pile cap is assumed rigid if the length-to-thickness ratio is **<= 2.2**. In competent soil, a pin connection is assumed between piles and the cap.

Analysis for Service and Strength Limit State Loads

🧮 **Calculation Note:** Calculate max compression (Cmax) and tension (Tmax) in a symmetrical group:

Equation 16.1.3.5-1: $C_{max} = \frac{P}{N} + \frac{M_x C_y}{I_x} + \frac{M_y C_x}{I_y}$

Where:

- **Cmax** = maximum compression in the symmetrical group
- **P** = total axial load
- **N** = total number of elements in the group
- **Mx** = moment about the x-axis
- **Cy** = distance from the centroid to the element along the y-axis
- **Ix** = moment of inertia about the x-axis
- **My** = moment about the y-axis
- **Cx** = distance from the centroid to the element along the x-axis
- **Iy** = moment of inertia about the y-axis

Equation 16.1.3.5-2: $T_{max} = \frac{P}{N} - \frac{M_x C_y}{I_x} - \frac{M_y C_x}{I_y}$

Where:

- **Tmax** = maximum tension in the symmetrical group
- **P** = total axial load
- **N** = total number of elements in the group
- **Mx** = moment about the x-axis
- **Cy** = distance from the centroid to the element along the y-axis
- **Ix** = moment of inertia about the x-axis
- **My** = moment about the y-axis
- **Cx** = distance from the centroid to the element along the x-axis
- **Iy** = moment of inertia about the y-axis

Analysis for Extreme Event (Seismic) Loads

Design for column overstrength moment ($M_o = 1.2M_p$) and associated shear transferred to the bottom of the pile cap.

Design Process

The process requires coordination between the Structural Designer (factored loads, lateral tip) and Geotechnical Designer (tip elevations for compression/tension).

Analysis/Design of Pile/Shaft Groups in Competent Soil (Design Example)

Pile Cap Geometry and Spacing

A standard layout for a symmetrical group typically utilizes a grid (e.g., 4 rows of 4 shafts). Per Caltrans and AASHTO specifications, the following geometric constraints must be maintained:

- **Minimum Spacing (Drilled Shafts):** 2.5 times the diameter (2.5D).
- **Minimum Spacing (Driven Piles):** 36 in. or 2D, whichever is greater.
- **Minimum Edge Distance:** 12 in. clear for drilled shafts; 9 in. or 0.5D for driven piles.

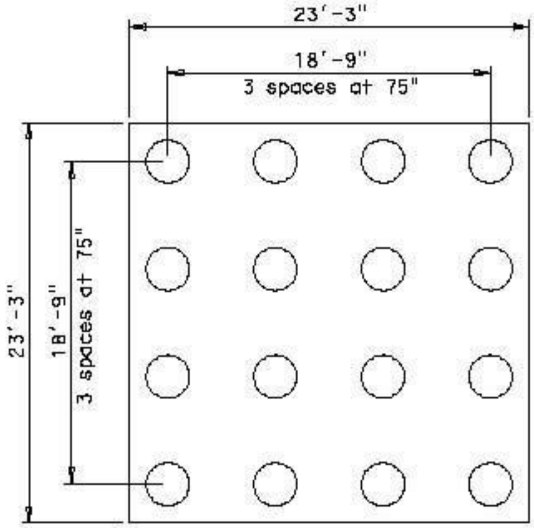

Figure 16.2-1: Shaft Group Layout

Determining Minimum Cap Depth

To ensure the full moment capacity of a column is developed, the depth of the pile cap must accommodate several vertical components:

1. Minimum clearance from the bottom of the pile cap to the bottom reinforcement mat (typically 6 in.).
2. Diameters of the bars used for the bottom reinforcement mat.
3. The required development length of the main column reinforcement.

Calculation Note: Use the following equation to establish the minimum depth ($D_{ftg,min}$): $D_{ftg,min} = clr + 2d_{bd} + l_d$

Where:

- **Dftg,min =** minimum depth of footing
- **clr** = clear cover
- **dbd =** diameter of the longitudinal bar
- **ld =** development length of the reinforcement

Purchase this course to see the remainder of the technical materials.