Bridge Design - Shallow Foundations

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PDH: 3

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Module 1: Shallow Foundations

Learning Objectives

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

- **Select** appropriate footing dimensions and embedment depths based on scour, settlement, and bearing resistance constraints.
- **Calculate** factored loads, bearing stresses, and eccentricities to verify the adequacy of a spread footing design.
- **Evaluate** structural requirements for flexure and shear to ensure the integrity of the footing thickness and reinforcement.

Executive Summary: Shallow foundations (spread footings) provide a cost-effective alternative to pile foundations but require rigorous interdisciplinary coordination between structural and geotechnical designers. The design process balances geotechnical limits—such as settlement and bearing resistance—with structural requirements for flexural strength and shear capacity, often utilizing iterative trial sizing to meet AASHTO LRFD and seismic criteria.

Introduction

Shallow foundations, or spread footings, are often advantageous over pile foundations due to lower costs, simplified construction, and reduced environmental constraints. However, their application may be limited by weak soil conditions or significant seismic considerations.

The sizing of a spread footing is governed by the bearing resistance of the substrate and the permissible settlement level. This process demands constant communication between the Structural Designer (SD), who provides factored loads, and the Geotechnical Designer (GD), who reports factored resistances like permissible net contact stress (qpn) and factored gross nominal bearing resistance (qR).

Common Types of Spread Footings for Bridges

- **Isolated Footings:** Used to support single columns.
- **Combined Footings:** Used to support multi-columns when spacing is close.
- **Strip Footings:** Elongated footings under abutments or pier walls where moments act primarily in the short direction. These are analyzed similarly to column footings but with one-dimensional moment action.

Proportioning and Embedment of Footings

Designers must account for axial forces, biaxial moments, right-of-way, and existing structures. While square footings are standard for pinned columns, rectangular shapes are often more efficient for fixed-base columns where moments in two directions differ significantly.

Sizing of Spread Footings

Initial trial sizes are based on past experience and similar conditions.

- **Aspect Ratio:** Effective length to effective width (L' / B') is commonly between 1.0 and 2.0.
- **Settlement:** Allowable settlement is typically 1 in. or 2 in., unless structural analysis justifies larger limits.
- **Design Interpolation:** Footing size is proportioned based on "permissible net contact stress" for service limits and checked against "factored gross nominal bearing resistance" for strength/extreme limits. The SD uses double interpolation from GD-provided data to determine specific resistances.

Embedment and Depth of Footings

Embedment must protect against degradation, contraction, and local pier scour. Embedment depth should ensure the top of the footing remains unexposed following total scour.

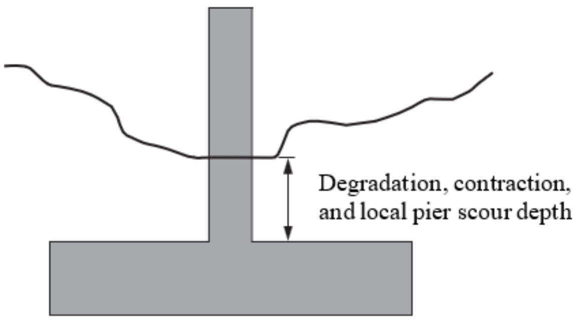

Figure 1.3-1 – Minimum Embedment for Scour Protection

Design Loads

Factored shear (Vx, Vy), axial force (P), and moments (Mx, My) from the column base must be transferred to the bottom of the footing.

Modified Moment Formula

$$M_{modified} = M + (V \cdot d_{footing})$$

Where:

- **Mmodified =** Resultant moment at the bottom of the footing.
- **M =** Moment at the column base.
- **V =** Shear force.
- **dfooting =** Actual footing depth.

Bearing Stress Distribution

The local X-axis is defined along the footing length (L) and the Y-axis along the width (B).

- **On Soil:** Bearing stress is assumed uniform for sizing/settlement and linear for structural design.
- **On Rock:** Bearing stress is assumed linear for all design phases.

Effective Dimensions for Soil (AASHTO 10.6.1.3-1):

$$B' = B - 2e_y$$

$$L' = L - 2e_x$$

Where:

- **B, L** = Actual dimensions of the footing (ft).
- **ey, ex** = Eccentricities parallel to B and L, respectively (ft).
- **A'** = Reduced effective area = B' * L' (ft2).
- **q** = Uniform bearing stress = P / A' (ksf).

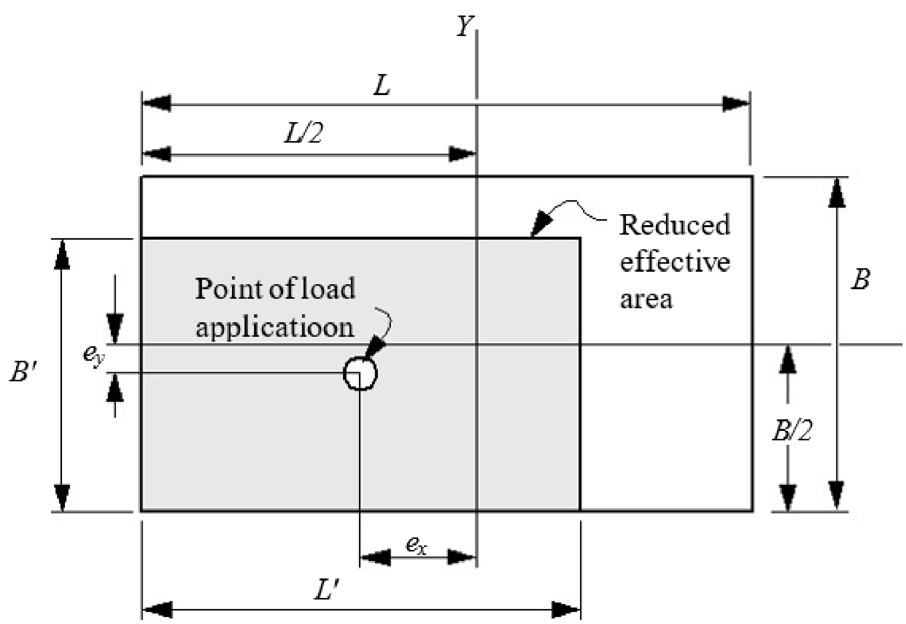

Figure 1.5-1 Effective Footing Area

Maximum Bearing Stress for Rock (Equation 15.5-1):

$$q_{max} = \frac{P}{A} + \frac{M_x}{S_x} + \frac{M_y}{S_y}$$

Where:

- **P =** Vertical force at the CG of the bottom of footing (kip).
- **Mx, My =** Moments at bottom of footing about X and Y directions (kip-ft).
- **Sx, Sy =** Section modulus of footing area (ft3).
- **A =** Actual footing area = B * L (ft2).

General Design Requirements

Settlement Check

Service-I limit state requirements:

Soil: $q_{n,u} \leq q_{pn}$

Where:

- **qn,u** = Applied net uniform bearing pressure.
- **qpn** = Net allowable bearing pressure for settlement (Service-I limit state).

Rock: $q_{n,max} \leq q_{pn}$

Where:

- **qpn** = Permissible net contact stress (ksf).
- **qn,max** = Maximum net bearing pressure on rock.

Bearing Check

Strength and Extreme Event limit state requirements:

Soil: $q_{g,u} \leq q_R$

Rock: $q_{g,max} \leq q_R$

Where:

- **qR** = Factored gross nominal bearing resistance = resistance factor (φ_b) * gross nominal resistance (qn).

Eccentricity Limits

Table 1.6-1 AASHTO (2012) Eccentricity Limits

Limit State	Footing on Soil	Footing on Rock	AASHTO Article Number
Service	*B*/6 or *L*/6	*B*/4 or *L*/4	10.5.2.2
Extreme Event (Seismic) $\gamma_{EQ}=0$	*B*/3 or *L*/3	*B*/3 or *L*/3	10.6.4.2 and 11.6.5.1
Extreme Event (Seismic) $\gamma_{EQ}=1.0$	2*B*/5 or 2*L*/5	2*B*/5 or 2*L*/5	10.6.4.2 and 11.6.5.1

Note: Seismic forces should be applied in all directions per *SDC* (Caltrans 2013). It is not necessary to include live load (design or permit truck) in Extreme Event Limit State load combinations therefore $\gamma_{EQ} = 0$.

Sliding Check

Factored nominal sliding resistance (AASHTO 10.6.3.4-1): $R_R = \phi R_n = \phi_\tau R_\tau + \phi_{ep} R_{ep}$. If passive pressure is negligible, $R_R = \phi_\tau R_\tau$. For cohesionless soil (AASHTO 10.6.3.4-2): $R_\tau = V\tan(\delta)$

Structural Design of Footings

Structural design includes selecting thickness for rebar development, flexural reinforcement design, and shear checks.

Table 1.7-1 – AASHTO (2012) and Caltrans (2014a) Requirements for Structural Design of Footings

Topic	AASHTO Articles	Application
Strut & tie Applicability	5.6.3	Requirement check
Flexural design	5.7.3.2	Reinforcement design
Direct shear design	5.8.3.3	Footing depth and reinforcement design
Shear friction	5.8.4	Shear key design
Reinforcement spacing	5.7.3.3, 5.7.3.4 5.10.3, 5.10.8	Design and detailing
Reinforcement development	5.11.2	Structural design of footings
Concrete cover	5.12.3	Footing depth and detailing
Footings	5.13.3	Footing depth

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