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Bridge Design - Shallow Foundations

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SHALLOW FOUNDATIONS

1.1 INTRODUCTION

Shallow foundations (spread footings) are advantageous to pile foundations considering lower cost, easier construction, and fewer environmental constraints. However, weak soil and seismic considerations may limit use of spread footings and impact the foundation type selection.

In general, size of the spread footing is determined based on bearing resistance of the supporting soil or rock and also permissible level of settlement. Design of spread footings requires constant communication between the Structural Designer (SD) and the Geotechnical Designer (GD) throughout the design process. Factored loads are provided by the SD and factored resistance for the supporting soil and rock, that is permissible net contact stress q_{pn} and factored gross nominal bearing resistance q_R are calculated and reported by the GD. The structural design is performed by the SD. Consistency between the SD and the GD in the use of required gross or net stresses is important. Caltrans *Memo to Designers* (*MTD*) 4-1 (Caltrans, 2014b) provides general guidance on design process and also the minimum level of required communications between the SD and the GD. The analysis and design of a spread footing based on the 6th Edition of the *AASHTO LRFD Bridge Design Specifications* (AASHTO, 2012) and the *California Amendments* (Caltrans, 2014a), and *Seismic Design Criteria* (*SDC*) Version 1.7 (Caltrans, 2013), will be illustrated through an example.

1.2 COMMON TYPES OF SPREAD FOOTINGS FOR BRIDGES

Spread footings can be used as isolated footings to support single columns or as combined footings to support multi-columns when columns are closely spaced. Elongated spread footings under abutments and pier walls act as strip footings where moments act only in the short direction. Strip footings under abutments or piers can be analyzed and designed similar to column footings, with moments acting in one direction only.

1.3 PROPORTIONING AND EMBEDMENT OF FOOTINGS

The designer should consider several parameters such as axial force and biaxial moment acting on the footing, right of way, existing structures, and also depth of footing when selecting size and location of the footing. Although square footings are more common for footings supporting pinned columns, rectangular shapes may be more efficient when column is fixed at the base, since moments acting on the footing in two directions may be very different. Considering various load combinations specified in *AASHTO* (2012) and *Caltrans* (2014a), and variation of geotechnical resistances with eccentricities of loads acting on the footing any type of optimization can be rigorous.

1.3.1 Sizing of Spread Footings

The trial minimum size of the spread footing can be selected based on footings of similar conditions and past experience. Size of a spread footing is usually governed by the column size, magnitude of loads acting on the footing, and resistances of the substrate. The effective length to effective width (L'/B') ratio is commonly 1.0 ~ 2.0. The GD should be consulted for selection of the ratios. The allowable settlement will be assumed as 1 in. or 2 in. according to *MTD* 4-1 (Caltrans, 2014b) and based on continuity of the superstructure. Larger limits can be used if structural analysis shows that the superstructure can tolerate such settlement without adverse serviceability impacts (Caltrans, 2014a).

The footing size is usually proportioned based on "***permissible net contact stress***" at the service limit state and checked for "***factored gross nominal bearing resistance***" at strength and extreme event limit states.

These stresses are functions of the effective width as well as the effective length to effective width ratio, therefore they are presented by a family of curves and also a table as shown in the design example. The SD needs to use double interpolation to extract the information required for design under different load combinations using corresponding effective dimensions. If necessary, the GD may be contacted to revise the information and provide a new set of curves and tables to avoid extrapolation.

1.3.2 Embedment and Depth of Footings

The footing embedment shall be carefully determined for degradation and contraction scour for the base (100 year) flood, as well as short term scour depth. The embedment depth of the footing should be adequate to ensure the top of the footing is not exposed when total scour has occurred, as shown in Figure 1.3-1. If the footing is not in water and freezing is not of concern, a minimum cover of 2 to 3 ft is recommended.

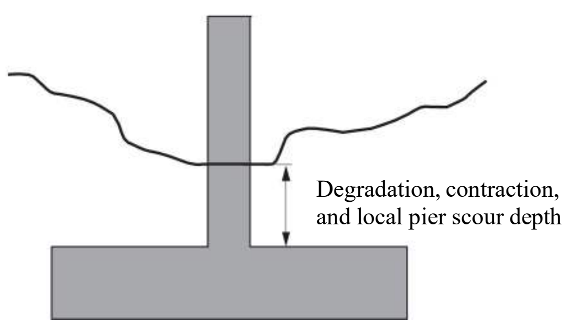

Figure 1.3-1 – Minimum Embedment for Scour Protection

The depth (thickness) of the footing is preliminary selected based on the required development length of the column reinforcement and then designed for flexural and shear strength.

1.4 DESIGN LOADS

The factored shear forces (V_x and V_y), column axial force (P) and bending moments (M_x and M_y) resulting from structural analysis are usually reported at the base of the column and must be transferred to the bottom of the footing in order to calculate contact bearing stresses. Therefore, the resultant moment at the base of the columns must be modified to include the additional moment caused by shear force transfer. The modified moment in a generic format can be written as $M + (V \times d_{footing})$, where $d_{footing}$ is the actual footing depth.

1.5 BEARING STRESS DISTRIBUTION

The sign convention shown in *MTD* 4-1 (Caltrans, 2014b) is to avoid mistakes in communications between the SD and the GD. The footing local X axis is defined along the longer dimension of the footing (L), and the Y axis along the short dimensions (B) as shown in Figure 1.5-1. Forces and moments resulting from superstructure analysis acting at the column base are resolved in the directions of local axes if local axes do not coincide longitudinal and transverse directions of the bridge.

Bearing stress distribution depends on relative stiffness of the footing and supporting soil and rock. For determination of the footing size based on the bearing resistance and settlement requirements, the bearing stress is assumed to be uniformly distributed for footings on soil and linearly distributed for footings on rock. For structural design of the footing, bearing stress is assumed to be linearly distributed.

For eccentrically loaded footings on soil, the effective footing dimensions (B' and L') specified in *AASHTO* Article 10.6.1.3 (AASHTO, 2012) shall be used for design of settlement and bearing resistance. Bearing stress distribution over effective footing area is assumed to be uniform. The effective dimensions for a rectangular footing are shown in Figure 1.5.1 and shall be taken as follows:

$$B' = B - 2e_y$$
$$L' = L - 2e_x$$
(AASHTO 10.6.1.3-1)

where:

$B,\ L$ = actual dimensions of the footing (ft)
e_y, e_x = eccentricities parallel to dimensions B and L, respectively (ft)
A' = reduced effective area of the footing $= B' \times L'$ (ft^2)
q = uniform bearing stress $= P/A'$ (ksf)