Chapter 15

SHALLOW FOUNDATIONS

GEOTECHNICAL DESIGN MANUAL

January 2019

Table of Contents

Section **Page**

List of Figures

CHAPTER 15

SHALLOW FOUNDATIONS

15.1 INTRODUCTION

This Chapter presents the design and analysis requirements for shallow foundations that will be used to support SCDOT structures. According to the BDM a shallow foundation "distributes the loads…to suitable soil strata or rock at relatively shallow depths (less than 10 feet)". Shallow foundations are used not only to support bridges, but also to support building structures, ERSs (see Chapter 18), box and floorless culverts and other ancillary structures. Shallow foundations are not limited to spread footings, but may also include strip footings, mat foundations and thickened (turned-down) edge slabs. The type of shallow foundation to be used will be based on the structure to be supported. The BDM includes the use of pile/drilled shaft supported footings; however, since the footing (shallow foundation) is supported by deep foundations see Chapter 16 for the design and analysis of the deep foundation. For these types of foundations the footing is not anticipated to transmit any load directly to the soil beneath the footing.

The use of shallow foundations shall conform to the requirements of Chapter 14. In addition, shallow foundations shall not be used at any location where scour beneath the bottom of the shallow foundation (i.e., the bearing stratum) is anticipated. The exception to this is if scour prevention measures are used to mitigate scour. This exception shall be approved in writing by the PCS/GDS, PCS/HDS, and PCS/SDS.

Samtani and Nowatzki (2006) indicate that a strip footing has a length dimension (L_f) at least 10 times larger than the width dimension (B_f). Spread footings have a ratio of L_f/B_f less than 10. Mat foundations according to Bowles (1996) are very large spread footings that have thicknesses ranging from 2-1/2 to 6-1/2 feet and have negative moment steel. A mat foundation should be used in a pile/drilled shaft supported footing. A thickened edge slab is a variation of a mat foundation, where the interior of the slab is typically thin, 4 to 6 inches in thickness, while at the locations of columns and at the edge the thickness is at least 18 inches. Thickened edge slabs are typically used to support buildings and shall not be used to support bridges, ERSs, culverts or other ancillary structures (i.e., signal mast arms or light poles).

15.2 DESIGN CONSIDERATIONS

The design of shallow foundations consists of 2 components, the bearing (resistance to shear) capacity and settlement (performance limits). According to Samtani and Nowatzki (2006) most shallow foundation problems occur because of settlement, while true bearing failure is limited. Typically, the factored resistance (R_r) will be dictated by the settlement (performance limits, see Chapter 10). Therefore, the initial footing dimensions (B_{fi} and L_{fi}) should be based on the results of the settlement analysis. The effect of footing width on bearing capacity and settlement is shown conceptually in Figure 15-1. For narrow footings with high bearing capacity shear will typically control. However, structural considerations usually limit tolerable settlements. As the footing width increases, the bearing capacity is limited by the settlement of the soil within the Depth of Significant Influence (DOSI). Using elastic theory, the DOSI is the finite depth below which there are no significant strains in the soil mass due to the loads imposed at the surface (bearing pressure induced by structure). At stress reductions of 10 to 15 percent of the applied bearing pressure (stress), the strains induced in the soil column become insignificant. For strip footings the DOSI is 4 to 6 times the footing width (i.e., $4B_f$ to $6B_f$), while for spread footings the DOSI is 1-1/2 to 2 times the footing width (i.e., 1-1/2B_f to $2B_f$) (see Figure 15-2).

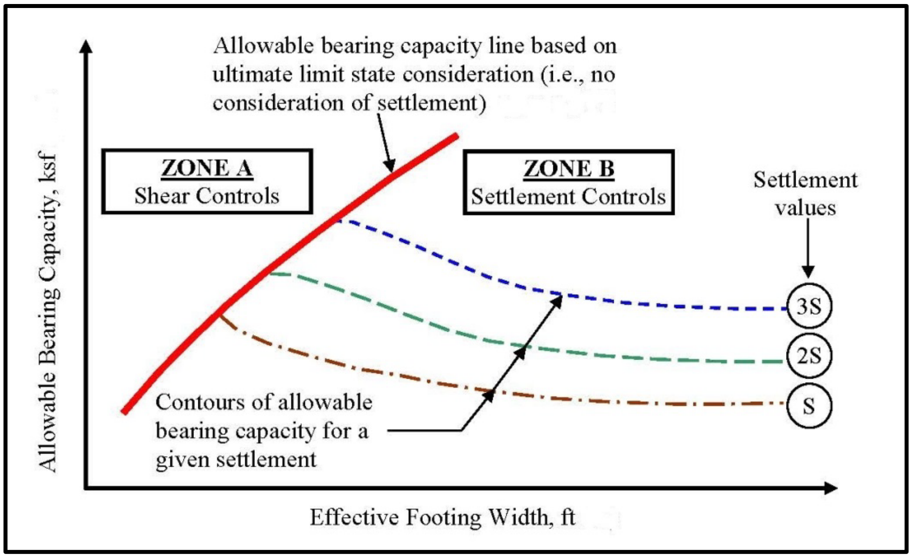

Figure 15-1, Footing Width vs Bearing Capacity on What Controls Footing Size (Samtani and Nowatzki (2006))

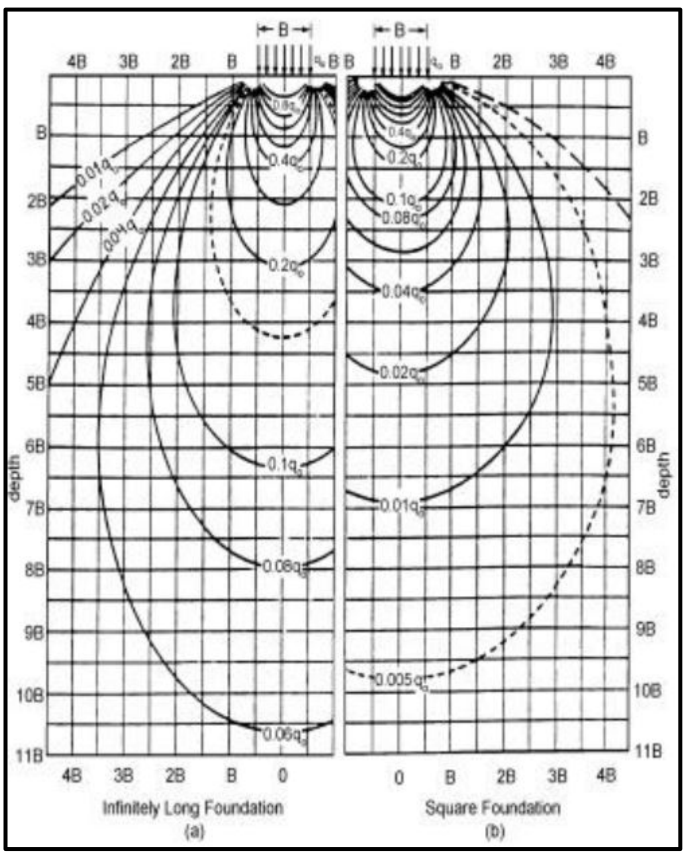

Figure 15-2, Depth of Significant Influence (DOSI) (FHWA-NHI-132084 (2014))

Roadway embankments do not typically have a structural foundation element; however, either settlement or global stability (Chapter 17) will govern the design and acceptability of the embankment. Therefore, it is not required or necessary to determine the bearing capacity of the soil beneath embankments, unless there is a question of localized (punching) shearing failure. Shallow foundations shall be designed for Service (displacement), Strength (bearing capacity), EE I and EE II (bearing capacity and displacement) limit states as required by LRFD. All shallow foundation designs will be governed by the basic LRFD equation:

$$Q = \sum \eta_i \gamma_i Q_i \leq \varphi R_n = R_r$$ **Equation 15-1**

Where,

Q	=	Factored load
Q_i	=	Force effect
η_i	=	Load modifier
γ_i	=	Load factor
R_r	=	Factored Resistance (i.e., allowable capacity)
R_n	=	Nominal Resistance (i.e., ultimate capacity)
φ	=	Resistance Factor

Shallow foundations shall be proportioned so that the factored resistance is not exceeded when the factored (nominal) loading is applied to the foundation and the performance limit (e.g., settlements at the Service limit state loading) of the foundation is not exceeded. Further, the effect of inclined loads that cause the reduction of the net bearing area shall also be considered. The bearing depth of shallow foundations depends on the type of structure being built. The bearing depths for shallow foundations are discussed in greater detail in the following sections.

15.2.1 Bearing Depth – Bridge Foundations

The bearing depth of shallow foundations, referred to as Spread Footings in the BDM, used to support bridges shall be determined in accordance with the latest edition of the BDM.

15.2.2 Bearing Depth – Other Structures

The bearing depth of shallow foundations used to support structures (i.e., buildings, signs, ERSs other than MSE walls, etc.) shall account for the presence of groundwater and frost penetration. Shallow foundations should not be placed beneath the groundwater table since this will require additional effort in construction, unless approved in writing by the PC/GDS. To prevent frost from affecting shallow foundations, shallow foundations shall be placed beneath the frost penetration depth, which according to the Building Code Council for South Carolina is between 1 and 2 inches. The bottom of shallow foundations shall be placed no shallower than 18 inches unless the depth to the groundwater table is shallower than this depth. If the depth to the groundwater table is shallower than 12 inches, contact the PC/GDS with recommendations for installing the shallow foundations prior to completing foundation design plans.

15.2.3 Bearing Depth – Embankments and MSE Walls

The bearing capacity for embankments (if necessary) shall be determined from the existing ground surface (i.e., d = 0). The bearing depth of an MSE wall is the top of the leveling pad and shall meet the requirements contained in Chapter 18 and Appendix C for the leveling pad depth. The leveling pad of an MSE wall is not a shallow foundation and does not have to meet the requirements of this Chapter.

15.3 BEARING CAPACITY DETERMINATION

The nominal bearing capacity of a shallow foundation shall be determined using the procedures published in the AASHTO LRFD Specifications (Section 10.6 – Spread Footings). The size of the foundation shall be determined using the factored resistance. This proportionally sized foundation shall be compared to the initial footing dimensions to determine which footing is larger (i.e., does settlement or bearing control footing design). The nominal bearing capacity of foundations placed on top of or within slopes shall also be determined in accordance with the AASHTO LRFD Specifications (Section 10.6 – Spread Footings). Further, the proportionally sized foundation shall be checked for the EE I and II limit states. Both bearing and settlement shall be determined for the EE I and II limit states. The bearing determined for the EE I and II limit states shall be compared to and not exceed the nominal resistance. The settlement determined (Chapter 13) for the EE I and II limit states shall be compared to the performance limits provided in Chapter 10. The resistance factors provided in Chapter 9 are for shallow foundations with vertical loads. The AASHTO LRFD Specifications allow for the use of plate load tests to determine the bearing capacity of soil; however, the use of plate load tests to determine bearing capacity is not allowed by SCDOT.

15.4 SLIDING RESISTANCE

The nominal sliding resistance of a shallow foundation shall be determined using the appropriate limit state in accordance with the procedures published in the AASHTO LRFD Specifications (Section 10.6 – Spread Footings). In addition, the proportionally sized foundation shall also be used to check for sliding due to inclined and shear loads. The effect of inclined loads on the resistance factor is not well known or understood; therefore caution should be used when applying the resistance factors of Chapter 9 to shallow foundations with inclined loads.

15.5 ECCENTRICITY

The eccentricity of a shallow foundation shall be determined using the appropriate limit state in accordance with the procedures published in the AASHTO LRFD Specifications (Section 10.6 – Spread Footings). In addition, the proportionally sized foundation shall also be used to check for eccentricity due to inclined and shear loads. The effect of inclined loads on the resistance factor is not well known or understood; therefore caution should be used when applying the resistance factors of Chapter 9 to shallow foundations with inclined loads.

15.6 SETTLEMENT

As indicated previously, settlement normally governs the size and capacity for shallow foundations. The total settlement as well as the differential settlement (the difference in settlement between 2 points) shall be considered when sizing a shallow foundation. Further, the time for settlement to occur as well as the rate of settlement (amount per unit of time) shall also be considered in shallow foundation design. The amount and time for settlement to occur shall be determined using the methods described in Chapter 17. Settlement shall be determined for the Service limit state. The amount (total and differential) and the rate of settlement at the Service limit state shall conform to the limits presented in Chapter 10. Depending on the requirements of the particular project, the use of the Construction-Point Concept may be used. Unlike traditional settlement calculations which assume the bridge is instantaneously placed, the Construction-Point Concept determines the settlement at specific critical construction points (see Figure 15-3).

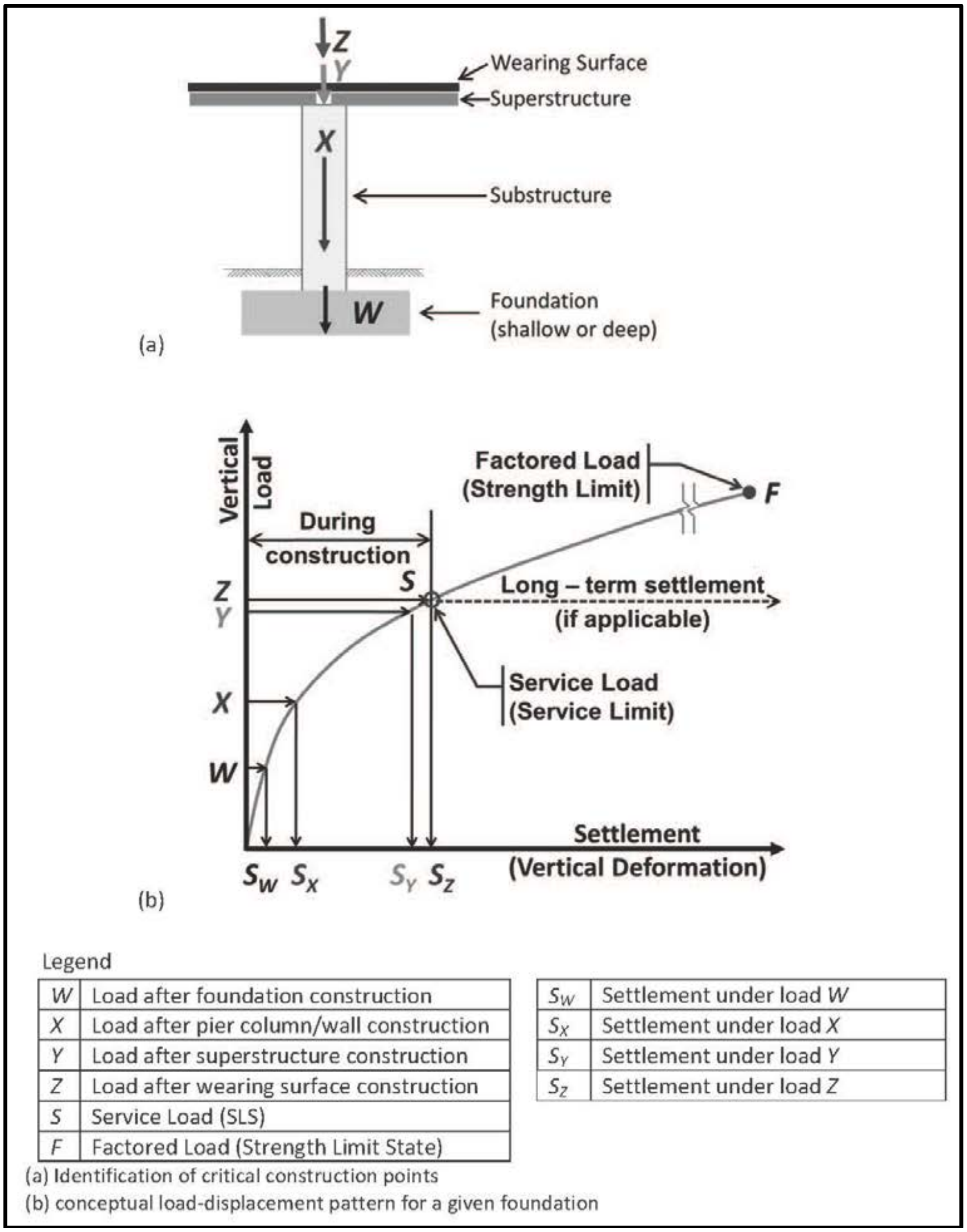

Figure 15-3, Construction-Point Concept
(DeMarco, Bush, Samtani, Kulicki and Severns (2015))

If the differential settlement is, according to the AASHTO LRFD Specifications determined to be "…extreme values…" then the settlement determination should be determined using the procedure recommend by Abu-Hejleh, Alzamora, Mohamed, Saad, and Anderson (2014). This procedure determines settlement to account for construction sequencing, since the amount of settlement determined at various stages of construction will affect the overall performance of the bridge. Settlement should be determined upon completion of the footing, pier and cap for interior bents and footing, abutment and wing walls and any earth fill behind the abutment for end bents prior to the installation of the superstructure. Typically, live loads are not included in the loads for determining this settlement. This settlement is termed S_{t-1} for use in this Manual. The next settlement to be determined is after the placement of girders on to the caps and is termed S_{t-2}. These settlements will not affect the bridge deck since these settlements will occur prior to the placement of the bridge deck. S_{t-1} and S_{t-2} include immediate settlement as well as any consolidated settlement that may occur during construction. The final settlement to be determined is S_{t-3} which account for the loads induced by placement of the bridge deck as well as the appropriate live loads used to determine the Service limit states. Both immediate settlement, induced by application of the bridge deck, and any consolidation settlement that will occur after the completion of construction should be included in S_{t-3}. S_{t-3} settlement should be used to determine the performance of the bridge. The acceptable performance of the bridge shall be determined by the SEOR. These settlements should be determined not only in the longitudinal direction but also in the transverse direction if the conditions indicate the potential for differential settlement in the transverse direction.

Typically for shallow foundations founded on dense cohesionless materials the amount of settlement will be relatively small and will typically occur during construction. For cohesive soils the amount of settlement can be quite large and can take a long time to occur. Therefore, preloading may be used to reduce or remove the anticipated settlement amount prior to installation of the shallow foundations. If preloading is performed, the pressure applied by the preload should achieve at least 1/2 of the factored bearing resistance required. Under this condition additional settlement will occur after preloading and shall be determined, as well as the time for this settlement to occur. According to AASHTO LRFD Specifications 3-dimensional effects should be considered if the following criterion is met.

$$\frac{B_f}{H_o} \leq 4 \qquad \textbf{Equation 15-2}$$

Where,

B_f = B = Foundation width
H_o = H = Total thickness of consolidating layer

Then the settlement should be reduced using the following equation

$$S_{c(3D)} = \lambda S_{c(1D)} \qquad \textbf{Equation 15-3}$$

Where,

$S_{c(1D)}$ = Total primary consolidation
λ = 3-dimensional reduction factor (see Figure 15-4)
$S_{c(3D)}$ = Reduced total primary consolidation accounting for 3-dimensional effects

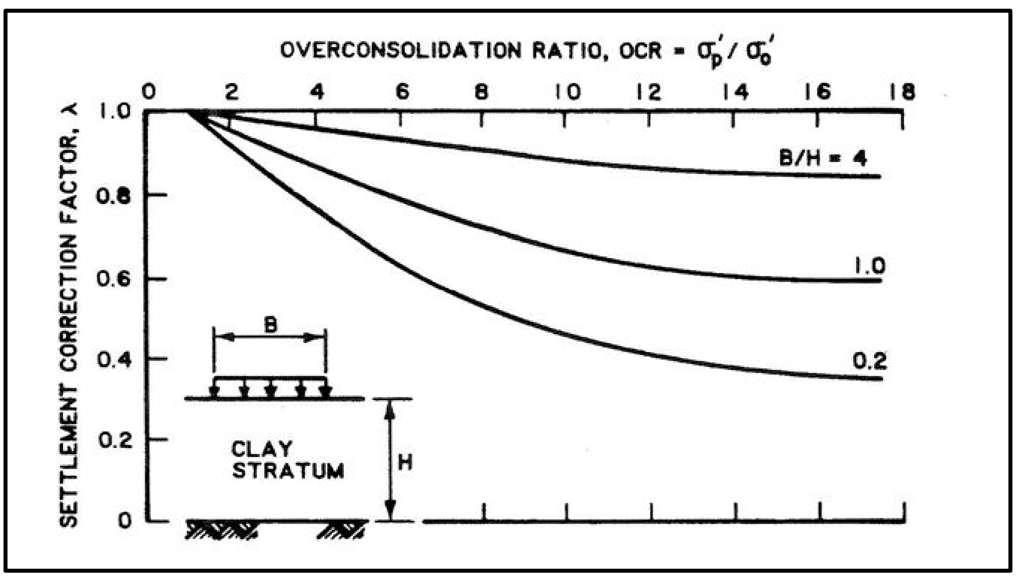

Figure 15-4, Three-Dimensional Reduction Factors
(EM 1110-1-1904 (1990))

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