Chapter 15

SHALLOW FOUNDATIONS

Final

SCDOT GEOTECHNICAL DESIGN MANUAL

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CHAPTER 15

SHALLOW FOUNDATIONS

15.1 INTRODUCTION

This Chapter presents the design and analysis requirements for shallow foundations that will be used for projects designed both within and for SCDOT. According to the *Bridge Design Manual* 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, earth retaining structures (ERS) (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 *Bridge Design Manual* lists the following prohibitions to the use of shallow foundations:

- at stream crossings where (shallow foundations) may be susceptible to scour,
- on fills, and
- beneath bents that are located within the reinforced soil mass associated with MSE walls.

In addition, shallow foundations shall not be used to support bridges or building structures if the potential for liquefaction is indicated, unless approved in writing by the PCS/GDS. For these structures the magnitude of displacement shall be determined using the procedures provided in Chapter 13 of this Manual and shall conform to the requirements of Chapter 10 of this Manual.

Geotechnical Engineering Circular No. 6 – Shallow Foundations indicates that a strip footing has a length dimension (L_f) at least five times larger than the width dimension (B_f). Spread footings have a ratio of L_f/B_f less than five. Mat foundations according to Bowles (1996) are very large spread footings that have thickenesses ranging from 2-1/2 to 6-1/2 feet and have negative moment steel. 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.

15.2 DESIGN CONSIDERATIONS

The design of shallow foundations consists of two components, the bearing (resistance to shear) capacity and settlement (performance limits). According to Bowles (1996) 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). 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 shearing failure. Shallow foundations shall be designed for service (settlement), strength (bearing capacity) and extreme event (bearing capacity) loading states as required by LRFD. All shallow foundation designs will be governed by the basic LRFD equation:

$$\boldsymbol{Q} = \sum \eta_i \gamma_i \boldsymbol{Q_i} \leq \varphi \boldsymbol{R_n} = \boldsymbol{R_r} \qquad \textbf{Equation 15-1}$$

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 loading is applied to the foundation and the performance limit of the foundation is not exceeded. Further, the affect 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 used to support bridges shall be determined in accordance with the latest edition of the *Bridge Design Manual*.

15.2.2 Bearing Depth – Other Structures

The bearing depth of shallow foundations used to support structures (i.e. buildings, ERSs other than MSE walls, signs, 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. 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 PCS/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 and MSE walls shall be determined from the existing ground surface (i.e. d = 0). 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 Strength limit state in accordance with the procedures published in the latest version of the AASHTO

LRFD Bridge Design Specifications (Section 10.6 – Spread Footings). The size of the foundation shall be determined using the factored resistance. This proportionally sized foundation shall be used in the determination of settlement (Service limit state). In addition, the proportionally sized foundation shall also be used to check for sliding of the foundation due to inclined and shear loads. The nominal bearing capacity of foundations placed within slopes shall also be determined in accordance with the latest version of the AASHTO LRFD Bridge Design Specifications (Section 10.6 – Spread Footings). Further, the proportionally sized foundation shall be checked for the Extreme Event limit state. Both bearing and settlement shall be determined for the Extreme Event. The bearing determined for the Extreme Event shall be compared to and not exceed the nominal resistance. The settlement determined (Chapter 13) for the Extreme Event 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 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. The AASHTO LRFD Bridge Design 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 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 two points) should 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) should 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. The amount (total and differential) of settlement and the rate of settlement shall conform to the limits presented in Chapter 10 of this Manual.

Typically for shallow foundations founded on 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 quiet 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 one-half of the factored bearing resistance required. Under this condition additional settlement will occur and should be determined, as should the time for this settlement to occur. According to AASHTO LRFD Bridge Design Specifications three-dimensional affects should be considered if the following criteria 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 = Three-dimensional reduction factor (see Figure 15-1)

$S_{c(3D)}$ = Reduced total primary consolidation accounting for three-dimensional effects

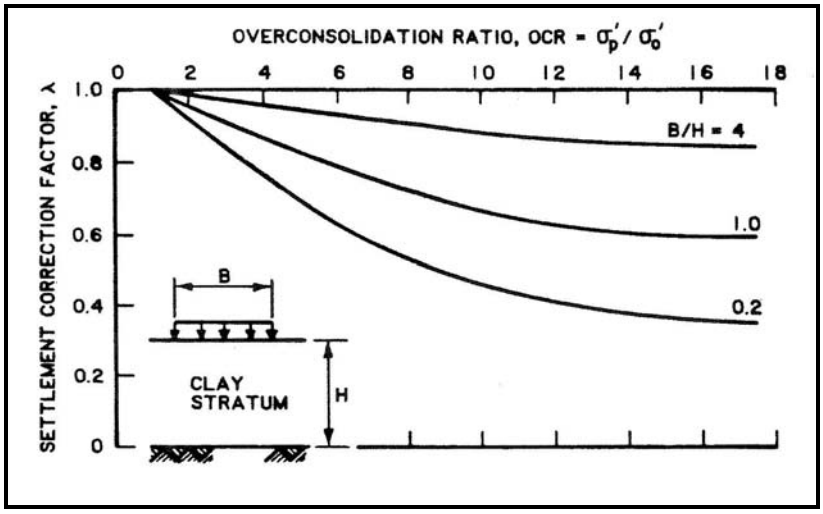

Figure 15-1, Three-Dimensional Reduction Factors (Settlement Analysis – 1990)

15.5 REFERENCES

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