Geotechnical Engineering Series - Shallow Foundations

An Online Continuing Education Course for Engineers

Course Number: G-6003

Credit: 6 Hours / 6 PDH / 6 CPD

GEOTECHNICAL ASPECTS OF SHALLOW FOUNDATIONS

Foundation design is required for all structures to ensure that the loads imposed on the underlying soil will not cause shear failures or damaging settlements. The two major types of foundations used for transportation structures can be categorized as "shallow" and "deep" foundations. This course first discusses the general approach to foundation design including consideration of alternative foundations to select the most cost-effective foundation. Following the general discussion, the course then concentrates on the topic of shallow foundations.

1. GENERAL APPROACH TO FOUNDATION DESIGN

The duty of the foundation design specialist is to establish the most economical design that safely conforms to prescribed structural criteria and properly accounts for the intended function of the structure. Essential to the foundation engineer's study is a rational method of design, whereby various foundation types are systematically evaluated and the optimum alternative selected. The following foundation design approach is recommended:

1. Determine the direction, type and magnitude of foundation loads to be supported, tolerable deformations and special constraints such as:

    a. Underclearance requirements that limit allowable total settlement.
    b. Structure type and span length that limits allowable deformations and angular distortions.
    c. Time constraints on construction.
    d. Extreme event loading and construction load requirements.

    In general, a discussion with the structural engineer about a preliminary design will provide this information and an indication of the flexibility of the constraints.

2. Evaluate the subsurface investigation and laboratory testing data with regard to reliability and completeness. The design method chosen should be commensurate with the quality and quantity of available geotechnical data, i.e., **don't use state-of-the-art computerized analyses if you have not performed a comprehensive subsurface investigation to obtain reliable values of the required input parameters.**

3. Consider alternate foundation types where applicable as discussed below.

1.1 Foundation Alternatives and Cost Evaluation

As noted earlier, the two major alternate foundation types are the "shallow" and "deep" foundations. Shallow foundations are discussed in this course. Proprietary foundation systems should not be excluded as they may be the most economical alternative in a given set of conditions. Cost analyses of all feasible alternatives may lead to the elimination of some foundations that were otherwise qualified under the engineering study. Other factors that must be considered in the final foundation selection are the availability of materials and equipment, the qualifications and experience of local contractors and construction companies, as well as environmental limitations/considerations on construction access or activities.

Whether it is for shallow or deep foundations, it is recommended that foundation support cost be defined as the total cost of the foundation system divided by the load the foundation supports in tons. Thus, the cost of the foundation system should be expressed in terms of **dollars per ton load** that will be supported. For an equitable comparison, the total foundation cost should include all costs associated with a given foundation system including the need for excavation or retention systems, environmental restrictions on construction activities, e.g., vibrations, noise, disposal of contaminated excavated spoils, pile caps and cap size, etc. For major projects, if the estimated costs of alternative foundation systems during the design stage are within 15 percent of each other, then alternate foundation designs should be considered for inclusion in contract documents. If alternate designs are included in the contract documents, both designs should be adequately detailed. For example, if two pile foundation alternatives are detailed, the bid quantity pile lengths should reflect the estimated pile lengths for each alternative. Otherwise, material costs and not the installed foundation cost will likely determine the low bid. Use of alternate foundation designs will generally provide the most cost effective foundation system.

A conventional design alternate should generally be included with a proprietary design alternate in the final project documents to stimulate competition and to anticipate value engineered proposals from contractors.

1.2 Loads and Limit States for Foundation Design

Foundations should be proportioned to withstand all anticipated loads safely including the permanent loads of the structure and transient loads. Most design codes specify the types of loads and load combinations to be considered in foundation design, e.g., AASHTO. These load combinations can be used to identify the "limit" states for the foundation types being considered. A limit state is reached when the structure no longer fulfills its performance requirements. There are several types of limit states that are related to maximum load-carrying capacity, serviceability, extreme event and fatigue. Two of the more common limit states are as follows:

- An **ultimate limit state** (ULS) corresponds to the maximum load-carrying capacity of the foundation. This limit state may be reached through either structural or geotechnical failure. An ultimate limit state corresponds to collapse. The ultimate state is also called the **strength limit state** and includes the following failure modes for shallow foundations:
  - bearing capacity of soil exceeded,
  - excessive loss of contact, i.e., eccentricity,
  - sliding at the base of footing,
  - loss of overall stability, i.e.,, global stability,
  - structural capacity exceeded.

- A **serviceability limit state** (SLS) corresponds to loss of serviceability, and occurs before collapse. A serviceability limit state involves unacceptable deformations or undesirable damage levels. A serviceability limit state may be reached through the following mechanisms:
  - Excessive differential or total foundation settlements,
  - Excessive lateral displacements, or
  - Structural deterioration of the foundation.

  The serviceability limit state for transportation structures is based upon economy and the quality of ride. The cost of limiting foundation movements should be compared to the cost of designing the superstructure so that it can tolerate larger movements, or of correcting the consequences of movements through maintenance, to determine minimum life cycle cost. More stringent criteria may be established by the owner.

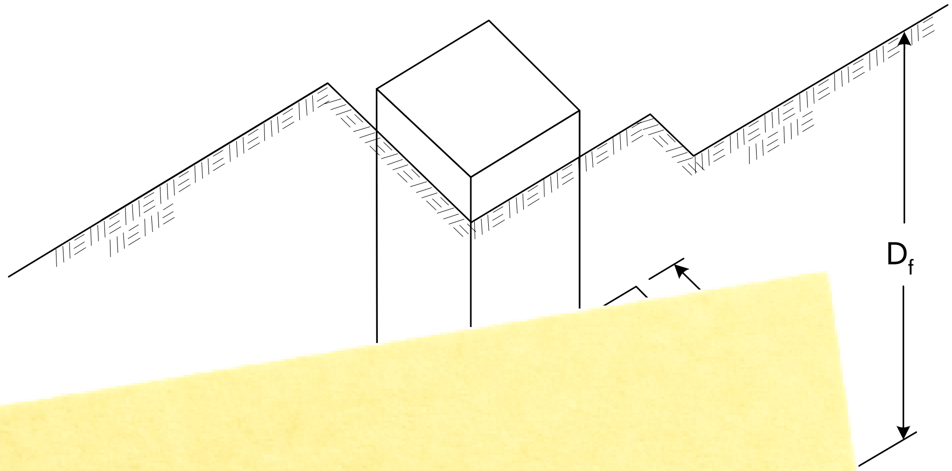
All relevant limit states must be considered in foundation design to ensure an adequate degree of safety and serviceability. Therefore, all foundation design is geared towards addressing the ULS and the SLS. In this course, the allowable stress design (ASD) approach is used.

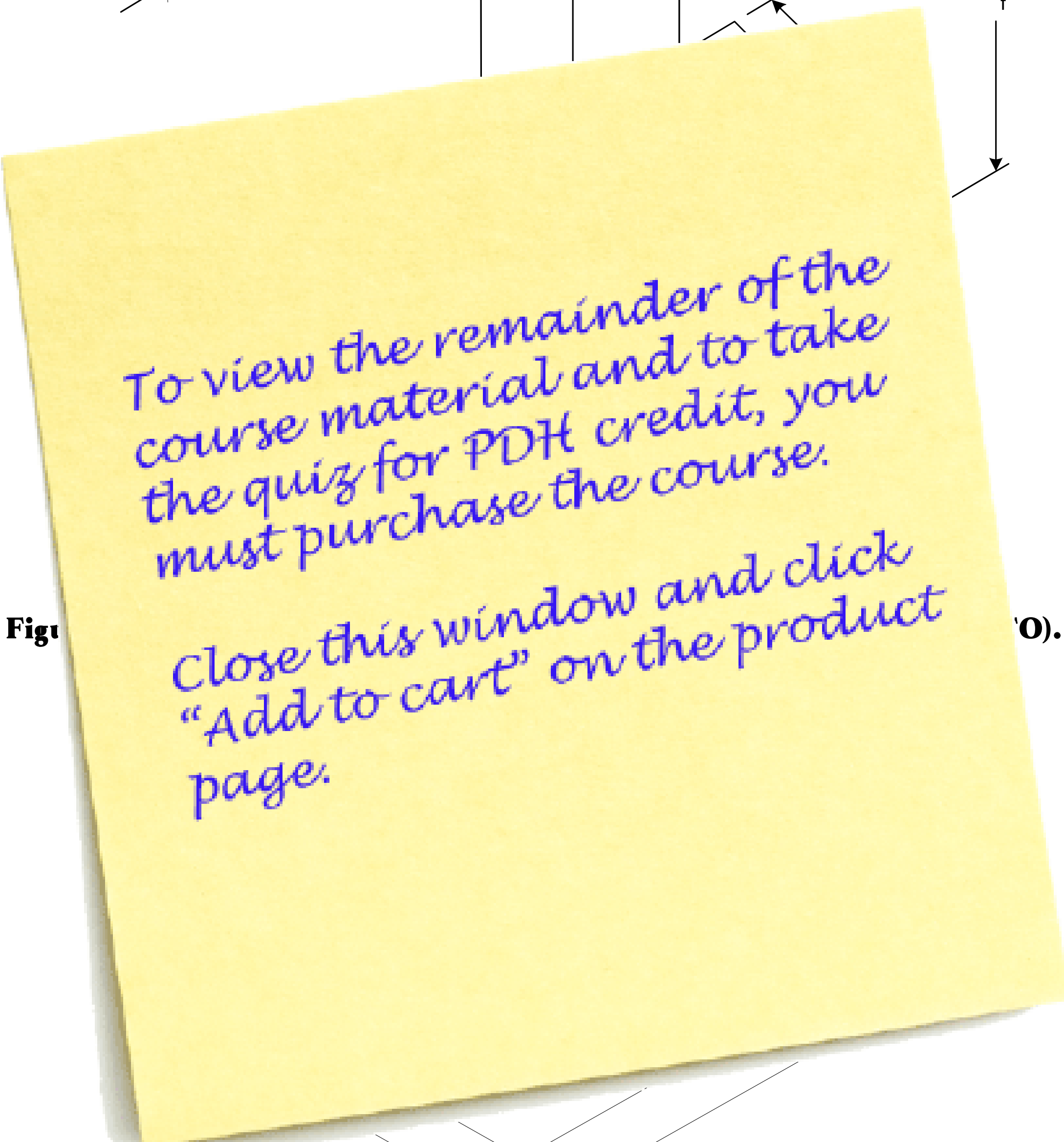
2. TYPES OF SHALLOW FOUNDATIONS

The geometry of a typical shallow foundation is shown in Figure 1. Shallow foundations are those wherein the depth, D_f, of the foundation is small compared to the cross-sectional size (width, B_f, or length, L_f). This is in contradistinction to deep foundations, such as driven piles and drilled shafts, whose depth of embedment is considerably larger than the cross–section dimension (diameter). The exact definition of shallow or deep foundations is less important than an understanding of the theoretical assumptions behind the various design procedures for each type. Stated another way, it is important to recognize the theoretical limitations of a design procedure that may vary as a function of depth, such as a bearing capacity equation. Common types of shallow foundations are shown in Figures 2 through 9.

2.1 Isolated Spread Footings

Footings with L_f/B_f ratio less than 10 are considered to be isolated footings. Isolated spread footings (Figure 2) are designed to distribute the concentrated loads delivered by a single column to prevent shear failure of the soil beneath the footing. The size of the footing is a function of the loads distributed by the supported column and the strength and compressibility characteristics of the bearing materials beneath the footing. For bridge columns, isolated spread footings are typically greater than 10 ft by 10 ft (3 m by 3 m). These dimensions increase when eccentric loads are applied to the footing. Structural design of the isolated footing includes consideration for moment resistance at the face of the column in the short direction of the footing, as well as shear and punching around the column.





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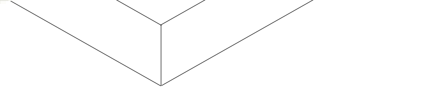

Figure 2. Isolated spread footing (FHWA, 2002c).