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SHALLOW POST AND PIER FOUNDATION DESIGN

Major revision of standard completed

In October 2012 the latest version of the American Society of Agricultural and Biological Engineers' engineering practice (EP) for the design of shallow post foundations was approved by ANSI. The official designation of this new document is ANSI/ASAE EP486.2 *Shallow Post and Pier Foundation Design*, published more than five years after work on the revision began. The lengthy revision process can be attributed to an almost total rewriting of the document, the heart of which are new calculation methods for foundation bearing strength, uplift strength and lateral strength.

The revised EP contains 14 main clauses and a commentary. As a way to introduce this revised EP, an overview of each clause follows.

1 PURPOSE AND SCOPE

The purpose of ASAE EP486 is to help designers determine the adequacy of shallow, isolated post and pier foundations. This includes ensuring that soil and backfill are not overloaded, foundation elements have adequate strength, frost heave is minimized and lateral movements are not excessive.

This EP contains safety factors and other provisions for allowable stress design (ASD), which is also known as working stress design, and for load and resistance factor design (LRFD), which is also known as strength design. It also contains properties and procedures for modeling soil deformation for use in structural building frame analyses.

Application of the EP is limited to post and pier foundations that (1) have been vertically installed in relatively level terrain, (2) have concentrically loaded footings and (3) have a minimum spacing equal to the greater of 4.5 times the maximum dimension of the post or pier cross-section, or three times the maximum dimension of a footing or attached collar. The third limitation addresses the fact that the shorter the distance between isolated pier/post foundations, the greater the overlap between the "pressure bulbs" surrounding the foundations, and the less applicable will be the equations contained in the EP for estimating maximum uplift, bearing and lateral capacities for isolated pier/post foundations.

This EP applies to piers and posts that are driven into soil, as well as those that are placed into pre-excavated holes and then backfilled. Driven (or displacement) piers consist primarily of steel helical piers (e.g., screw anchors) that are turned into the ground. Driven (or displacement) posts include the short wood posts used to support highway guardrails. Interestingly, helical piers are primarily used to resist bearing and uplift forces, and driven wood posts are primarily used to resist lateral forces.

2 NORMATIVE REFERENCES

References for documents that are indispensable for the application of the standard are given in Clause 2. This includes six structural design specifications, 10 laboratory soil testing standards, seven in-situ soil testing standards, a preservative-treated wood standard (AWPA U1) and the post-frame building systems nomenclature standard (ANSI/ASABE S618).

3 DEFINITIONS

Clause 3 contains 49 definitions. These are categorized under headings of: foundation types and components; foundation geometry and constraints; material properties and characteristics; and structural loads and analysis.

With respect to foundation types and components, the primary definitions of interest are those for post, pole, pier, post foundation and pier foundation.

A *post* is defined as "a structural column that functions as a major foundation element by providing lateral and vertical support for a structure when it is embedded in the soil. Posts include members of any material with assigned structural properties such as solid or laminated wood, steel, or concrete." A *pole* is simply defined as "a round post."

A *pier* is defined as "a relatively short column partly embedded in the soil to provide lateral and vertical support for a building or other structure. Piers include members of any material with assigned structural properties such as solid or laminated wood, steel, or concrete. Piers differ from embedded posts in that they seldom extend above the lowest horizontal framing element in a structure, and when they do, it is often only a few centimeters."

A *post foundation* is defined as "an assembly consisting of an embedded post and all below-grade elements, which may include a footing, uplift resistance system, and collar." Likewise, a pier foundation is defined as "an assembly consisting of a pier and all below-grade elements, which may include a footing, uplift resistance system, and collar."

Figures 1–4 from the revised EP are reproduced here and provide examples of a preservative-treated wood post foundation, a helical pier foundation, a precast concrete pier foundation and a cast-in-place concrete pier foundation, respectively.

4 NOMENCLATURE

The fourth EP clause contains a list of 110 variables with a symbol, description, and where applicable, a suggested set of units given for each variable. One of the primary objectives when selecting

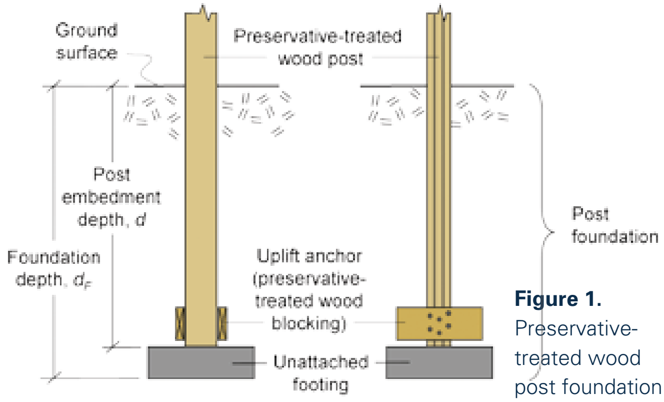

Figure 1. Preservative-treated wood post foundation

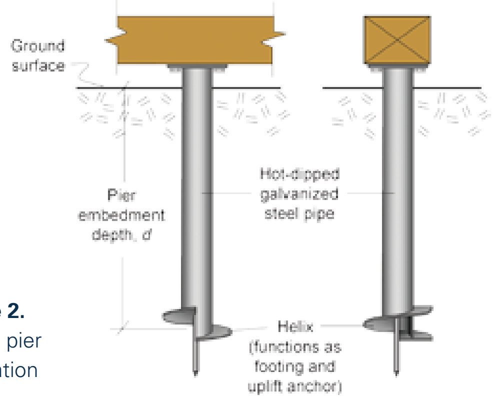

Figure 2. Helical pier foundation

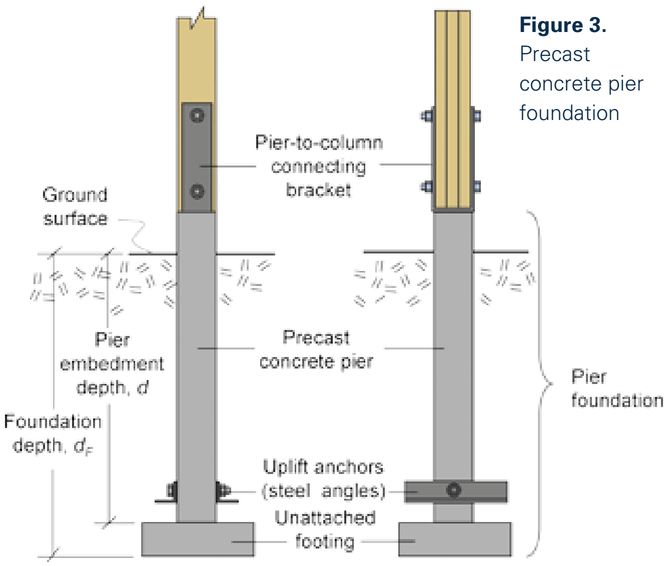

Figure 3. Precast concrete pier foundation

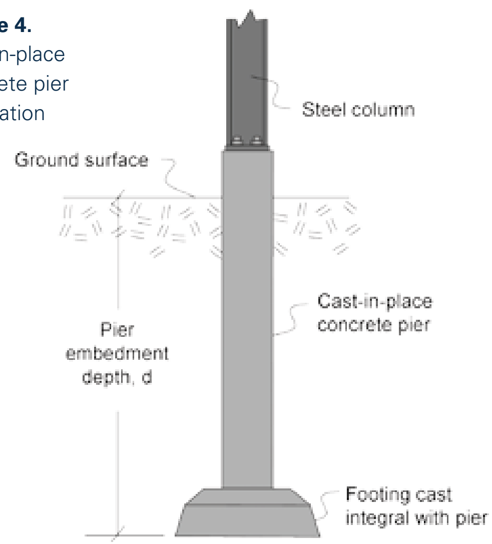

Figure 4. Cast-in-place concrete pier foundation

nomenclature was to align verbiage and symbols with those commonly used in geotechnical circles. In two cases, meeting this objective resulted in a switch from what was used in previous versions of the EP.

5 SOIL AND BACKFILL PROPERTIES

This clause contains provisions for establishing Young's modulus, undrained shear strength, and friction angle of soils from applicable soil tests. Either laboratory or in-situ testing or a combination of laboratory and in-situ testing can be used to obtain all information needed for post or pier foundation design. Soil tests remove uncertainty associated with the use of presumptive soil properties, and thus lower factors of safety are associated with calculations where soil characteristics have been ascertained through testing.

Clause 5 also addresses soils that should be avoided during post and pier construction. It also addresses appropriate backfill materials, and it contains a table of presumptive soil properties that can be used in the absence of soil test data.

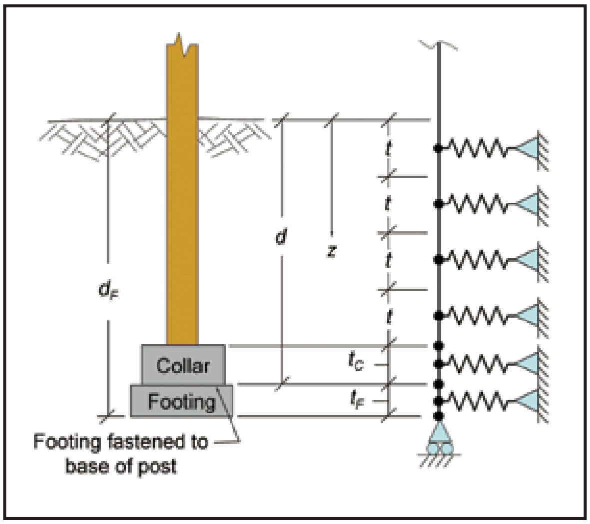

Figure 5. Two-dimensional structural analog for a post or pier foundation. Different soil springs are used to model soil acting on the collar, attached footing, and post or pier because of the difference in width of the three foundation elements.

6 FOUNDATION MATERIAL PROPERTIES

This clause contains material requirements for post and pier foundation elements, including: minimum concrete compressive strengths; minimum thicknesses and reinforcement requirements for both cast-in-place and precast concrete footings; longitudinal reinforcement, shear reinforcement and concrete cover requirements for concrete piers; and preservative treatment, size and mechanical fastener requirements for embedded wood posts and piers. With respect to precast concrete footings, a thickness as thin as four inches is allowed, provided the footing is placed on a flat compacted base and load-induced forces do not dictate a thicker footing.

As long as the unconfined compressive strength of controlled low-strength material (CLSM) exceeds the ultimate bearing capacity at the base of a post hole, it can be placed between the bottom of a precast concrete (or wood) footing and the underlying soil to increase the effective bearing area of the footing. In lieu of using a CLSM base for footings, some builders have compacted a non-hydrated (i.e., dry) concrete mix in the base of holes. The EP commentary notes that nonhydrated concrete mixes that are compacted within a soil mass and allowed to self-hydrate should obtain unconfined compressive strengths that more than double the 8 MPa limit for classification as a CLSM. Implied by this statement is that the practice of using nonhydrated concrete mixes in this manner is sound.

7 STRUCTURAL LOAD COMBINATIONS

Clause 7 contains both ASD and LRFD load combinations from ASCE-7. These load combinations are included in the EP to ensure consistency between soil resistance factors introduced in the EP and the ASCE 7 load factors.

All ASCE-7 nominal loads are included in the EP with the exception that loads due to lateral earth pressure and those due to ground water pressure have not been included. Loads due to lateral earth pressure are not included because soil is treated and modeled as a structural element and not as an applied load (i.e., it is on the resistance side of the equation). Ground water pressure is not included because it is assumed that ground water pressure acts equally on all sides of an embedded post or pier foundation and thus has no net effect on the behavior of embedded elements.

8 STRUCTURAL ANALYSIS

Structural analysis is the determination of the forces induced in a post or pier foundation by applied structural loads. Two methods for accomplishing this are outlined in the EP: the Universal Method and the Simplified Method. Alternative methods not covered in the EP are available and may be able to provide more accurate analyses. In all cases, sound engineering judgment should guide selection and application of the design procedure.

The Universal Method can be used to analyze any post or pier foundation. It involves the use of a series of horizontal soil springs to model the interaction between a foundation and the surrounding soil (see Figure 5). The stiffness of an individual spring, K_H, located at depth, z, is given as $K_H = t\,k\,b$ where: t is thickness of the soil layer represented by the spring; b is width of the post or pier, footing, or collar upon which soil represented by the spring is acting; and k is modulus of horizontal subgrade reaction at depth z. The modulus of horizontal subgrade reaction is the ratio of average contact pressure (between foundation and soil) and the horizontal movement of the foundation and is equated to two times Young's modulus (at the depth in question) divided by width b.

The Simplified Method uses a fixed-based structural analog to determine the bending moment, axial, and shear forces induced in the post or pier near the ground surface. These forces are then substituted in the appropriate equations to determine lateral soil pressures as well as the ground surface displacement and rotation of the post or pier. During the development of these equations it was assumed that (1) at-grade pier and post forces are not dependent on below-grade deformations, (2) the below-grade portion of the foundation has an infinite flexural rigidity, (3) soil is homogeneous for the entire embedment depth, (4) modulus of horizontal subgrade reaction k is either constant for all depths below grade or linearly increases with depth below grade, (5) width b of the below-grade portion of the foundation is constant (this generally means that there are no attached collars or footings that are effective in resisting lateral soil forces), and (6) groundline shear, V_G, and groundline bending moment, M_G, would not independently cause post rotation in opposite directions.

These assumptions collectively turn a highly indeterminate structural analysis problem into a determinate analysis. The second assumption (i.e., that the post or pier has an infinite bending stiffness) sets a foundation depth limit on use of the Simplified Method. When this depth is exceeded, the Universal Method must be used to calculate lateral soil pressures and foundation forces. There is no depth limit on use of the Universal Method.

The Simplified Method has the advantage that it does not require estimates of soil stiffness or bending stiffness of the post or pier to determine soil forces. However, relative to the Universal

Method, the Simplified Method is associated with higher factors of safety to account for the simplifying assumptions associated with its use.

9 RESISTANCE AND SAFETY FACTORS

In previous versions of EP486, safety factors were incorporated into presumptive soil properties and design values, and thus designers had no measure of the actual magnitude of the safety factors associated with their designs. In addition, there were no adjustment factors or recommendations to account for more accurate methods of analyses or to enable higher levels of risk in design.

The revised version includes ASD safety factors and LRFD resistance factors. Tabulated safety (and resistance) factors differ depending on the strength property (i.e., lateral, uplift or bearing strength) being calculated, on the test methods used to determine soil properties, and on general soil type (i.e., cohesive versus cohesionless). In addition, safety and resistance factors for lateral strength assessment also depend on whether the Universal or Simplified Method of analysis was used to determine soil pressures, and in the case of cohesionless soils, safety and resistance factors are also a function of soil friction angle.

For buildings and other structures that represent a low risk to human life in the event of a failure, resistance factors may be increased 25 percent (multiplied by 1.25), and safety factors may be reduced 20 percent.

10 BEARING STRENGTH ASSESSMENT

Under previous editions of EP486, bearing strength was exclusively based on presumptive allowable vertical soil pressures. Actual tabulated values were applicable for footings one foot wide and one foot deep. However, it was permissible to increase the tabulated values by 20% for each additional foot of width and/or depth to a maximum of three times the tabulated value.

In the revised EP, bearing strengths are based on ultimate bearing capacities obtained from in-situ measurements or calculated using the general bearing capacity equation. In-situ measurements that can be used to determine ultimate bearing capacity include the standard penetration test (SPT), the cone penetration test (CPT) and the pressuremeter test (PMT). Correction factors are included in equations for cohesionless soils to account for water table depth relative to foundation depth.

In the end, the methods for determination of foundation bearing strength embodied in the new EP provide more realistic design values than the previous editions, and in most cases, these values will enable assignment of greater bearing strengths to the typical post or pier foundation.

11 LATERAL STRENGTH ASSESSMENT

In the revised EP, the lateral strength of pier and post foundations is dictated by the ultimate lateral resisting pressure of the soil, p_U. This resisting pressure can be determined directly from cone penetrometer or PMT data or can be calculated from soil properties (soil friction angle and cohesion) using equations given in the EP. The equations used to calculate p_U from soil properties will provide a p_U that is three times the Rankine passive pressure.

When the Universal Method is used, the designer simply checks that at every spring location p_U is greater than $f_L F_S /(t\ b)$ for ASD (or that p_U is greater than $F_S /(R_L t\ b)$ for LRFD), where f_L is the ASD factor of safety for lateral strength assessment; R_L is the LRFD resistance factor for lateral strength assessment; F_S is the force in the spring at depth z due to the applied structural loads; t is thickness of the soil layer represented by the spring; and b is width of the post or pier, footing, or collar upon which soil represented by the spring is acting.

When the Simplified Method is used, the designer checks that M_U is greater than $f_L M_G$ for ASD (or that M_U is greater than M_G /R_L for LRFD), where M_U is the ultimate moment that can be applied to a post or pier foundation at its groundline without causing a soil failure, and M_G is the moment induced in the post or pier foundation at its groundline by applied structural loads. A series of equations for calculating M_U are compiled in the EP for different soil types and constraint conditions. The manner in which these equations are solved guarantees that $V_U \geq V_G /R_L$ for LRFD and that $V_U \geq f_L V_G$ for ASD, where: V_U is the shear force that can be applied to a post or pier at its groundline without causing a soil failure, and V_G is the shear force induced in the post or pier at groundline by the applied structural loads.

12 UPLIFT STRENGTH ASSESSMENT

Foundation uplift strength is due to the combination of foundation mass and resistance to uplift provided by soil mass. Attaching a footing, collar, uplift blocking or any other device that effectively enlarges the foundation's base can significantly increase resistance to upward foundation displacement. This resistance is provided by the weight of the soil mass located above the anchorage system plus the resistance to movement of this soil mass.

To move the soil mass located above the anchorage system requires that a failure plane form in the soil. This failure plane extends upward and outward from the edges of the anchorage system. Unlike previous editions of the EP, the revised EP recognizes the fact that this failure plane may or may not reach the ground surface (what actually happens depends on soil properties and the depth and width of the anchorage system). A *shallow foundation under uplift* is a foundation associated with a failure plane that reaches the ground surface. Conversely, a *deep foundation under uplift* is a foundation associated with a failure plane that does not extend to the ground surface. It follows that the first step in uplift calculations is to determine whether a foundation is shallow or deep under uplift. When this has been done, the appropriate EP equation can be used to determine the overall resistance to uplift provided by the soil mass.

In addition to calculation of uplift strength this clause also contains requirements for anchorage system attachment and backfill compaction.

13 FROST HEAVE CONSIDERATIONS

An entire clause in the revised EP is dedicated to minimizing the effects of frost heave. This includes recommendations for footing location, water drainage, working with fine-grained soils, concrete backfill and concrete floors.

14 INSTALLATION REQUIREMENTS

The last clause in the revised EP covers two construction-related factors that can significantly affect structural performance: soil compaction and component placement. In short, all disturbed soil at the base of a hole must be compacted to a magnitude consistent with the soil bearing capacity assumed in design, and soil upon which a precast concrete footing will be placed must be flat and level. In addition, the installed depth of a post or pier foundation must not be less than 90% of the specified depth. Precast concrete footings must be placed so that the center of the footing is within a distance $b/2$ of the center of the post or pier it supports, where b is the width of the post or pier. Cast-in-place concrete footings must be placed so that distance from the center of the post or pier to the nearest edge of the footing is not less than half the specified width of the footing.

SUMMARY

The newly released version of ASAE EP486 is significantly different from the version it replaces. It contains completely different methods for calculating bearing, lateral and uplift strengths of both pier and post foundations, and unlike previous versions, it contains safety and resistance factors as well as many methods for obtaining soil properties from on-site soil tests. The advantage of on-site soil testing is that it reduces uncertainty in design. The revised EP enables designers to take advantage of this reduced uncertainty with the use of lower factors of safety. It is important to note that the new EP does not require soil testing; it simply enables the use of lower safety factors when and where soil tests have been performed.

Because the revision is so extensive, parts of it are bound to cause confusion among designers as they work through them for the first time or two. An obvious way to clarify some of the new procedures, and thus give designers more confidence in the numbers they generate, is to develop example analyses. This project has been discussed by the NFBA Technical and Research Committee and is something that end users should expect to see in the not-too-distant future.

NFBA members may download the standard for free by logging in at www.nfba.org, going to the ASABE Code Library and searching for document number EP486. Those who are not NFBA members can download the EP for a fee from the ASABE Technical Library (https://elibrary.asabe.org/). The price is $38 for ASABE members and $55 for non-ASABE members. ***FBN***

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