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Shallow Post and Pier Foundation Design

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Shallow Post and Pier Foundation Design

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Keywords: Foundation, Post, Shallow, Structures

1 Purpose and scope

1.1 Purpose. The purpose of this Engineering Practice is to present a procedure for determining the adequacy of shallow, isolated post and pier foundations in resisting applied structural loads. This Engineering Practice will help ensure that soil and backfill are not overloaded, foundation elements have adequate strength, frost heave is minimized, and lateral movements are not excessive.

1.2 Scope. This engineering practice 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.

1.2.1 Limitations. Application of this Engineering Practice is limited to post and pier foundations with the following characteristics:

- vertically installed in relatively level terrain;
- concentrically-loaded footings;
- minimum post or pier foundation spacing equal to the greater of 4.5 times the maximum dimension of the post/pier cross-section, or three times the maximum dimension of a footing or attached collar.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies unless noted. For undated references, the latest approved edition of the referenced document (including any amendments) applies.

2.1 Structural design specifications

ACI 318, Building Code Requirements for Structural Concrete and Commentary

ANSI/AWC NDS, National Design Specification (NDS) for Wood Construction with Commentary

ANSI/ASAE EP484, Diaphragm Design of Metal-Clad, Wood-Frame Rectangular Buildings

ANSI/ASAE EP559, Design Requirements and Bending Properties for Mechanically Laminated-Wood Assemblies

ASCE/SEI 7-10, Minimum Design Loads for Buildings and Other Structures

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SEI/ASCE 32, Design and Construction of Frost-Protected Shallow Foundations

2.2 Laboratory soil testing standards

ASTM D422, Standard Test Method for Particle-Size Analysis of Soils

ASTM D854, Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

ASTM D2166, Standard Test Method for Unconfined Compressive Strength of Cohesive Soil

ASTM D2435, Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

ASTM D2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

ASTM D2850, Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils

ASTM D3080, Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions

ASTM D4318, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

ASTM D4643, Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating

ASTM D4767, Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils

ASTM D7181, Standard Test Method for Consolidated Drained Triaxial Compression Test for Soils

2.3. In-situ soil testing standards

ASTM D1586, Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils

ASTM D2573, Standard Test Method for Field Vane Shear Test in Cohesive Soil

ASTM D3441, Standard Test Method for Mechanical Cone Penetration Tests of Soil

ASTM D4719, Standard Test Method for Prebored Pressuremeter Testing in Soils

ASTM D1194, Standard Test Method for Bearing Capacity of Soil for Static Load and Spread Footings (withdrawn 2003)

ASTM D4750, Standard Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)

ASTM D5778, Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils

2.4 Preservative-treated wood standard

AWPA U1, Use Category System: User Specification for Treated Wood

2.5 Nomenclature standard

ANSI/ASABE S618, Post-Frame Building System Nomenclature

3 Definitions

3.1 Foundation types and components

3.1.1 backfill: Material filling the excavation around a post or pier foundation. See Figure 5.

3.1.2 collar: Foundation component attached to a post or pier, and that moves with it to resist lateral and vertical loads. See Figure 5.

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3.1.3 driven pier or post: A pier or post that is pounded or turned into the ground. A pier or post foundation not requiring prior soil excavation. Also referred to as a displacement pier or post. See Figure 2.

3.1.4 footing: Foundation component at the base of a post or pier that provides resistance to vertical downward forces. When properly attached to the post/pier, a footing aids in the resistance of lateral and vertical uplift forces, and embedment depth is measured to the base of the footing instead of to the top of the footing. See Figures 1 through 5.

3.1.5 helical pier: A pier comprised of a steel pipe or tubing with an attached helix or helices. See Figure 2. Helices are also known as auger flighting. A helical pier is a type of driven pier that is turned into the soil in a manner that minimizes soil movement/displacement.

3.1.6 pedestal: A relatively short column that can support vertical forces, but is not designed to transmit horizontal shear, and bending moments. This engineering practice is not applicable to the design of pedestals.

3.1.7 pier: 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. See Figures 2 through 4.

3.1.8 pier foundation: An assembly consisting of a pier and all below-grade elements, which may include a footing, uplift resistance system, and collar. See Figure 3.

3.1.9 pile: A relatively long and slender column driven, screwed, jacked, vibrated, drilled or otherwise installed into soil to provide lateral and vertical support for a structure. Generally used to carry loads through weak layers of soil to those capable of supporting such loads. This engineering practice is not applicable to the design of piles.

3.1.10 pole: A round post.

3.1.11 post: 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. See Figures 1 and 5.

3.1.12 post foundation: An assembly consisting of an embedded post and all below-grade elements, which may include a footing, uplift resistance system, and collar. See Figure 1.

3.1.13 screw anchor: A helical pier primarily designed to handle uplift or tension forces.

3.1.14 shallow foundation: A foundation for which deformation under load is small, so foundation movement approximates rigid body motion. Foundation deformation is kept small by selection of foundation depth, d, and post/pier bending stiffness, $E_p I_p$.

3.1.15 uplift resistance system: Elements attached to an embedded post or pier, generally near the base, to increase the uplift resistance of a foundation system. See Figures 1 through 5.

3.2 Foundation geometry and constraints

3.2.1 constrained post (or pier): A post or pier foundation that is restrained from significant horizontal movement at the ground surface, typically by a concrete slab.

3.2.2 foundation depth, d_F: Vertical distance from the ground surface to the bottom of a post or pier foundation. Typically the vertical distance from the ground surface to the base of the footing.

3.2.3 non-constrained post (or pier): A post or pier foundation that is not restrained from moving horizontally at or above the ground surface.

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3.2.4 post (or pier) embedment depth, *d*: Vertical distance from the ground surface to the bottom of the embedded post or pier. Includes the thickness of the footing when the footing is rigidly attached to the post/pier or is cast integrally with the post/pier.

3.2.5 post (or pier) width, *B*: The cross-sectional dimension that is perpendicular to the direction of lateral post/pier movement. This width defines the area of contact between the foundation and soil that resists lateral post/pier movement. The width of a round post or pier is its diameter.

3.3 Material properties and characteristics

3.3.1 cohesion of soil, *c*: Component of soil shear strength due to cementation or bonding at particle contacts resulting from ionic bonds, hydrogen bonds, and gravitational attraction.

3.3.2 controlled low-strength material (CLSM): A self-leveling and self-compacting, cementitious material with an unconfined compressive strength of 8 MPa (1200 psi) or less. Other terms used to describe controlled low-strength material (CLSM) include flowable fill, unshrinkable fill, controlled density fill, flowable mortar, flowable fly ash, fly ash slurry, plastic soil-cement and soil-cement slurry.

3.3.3 constant of horizontal subgrade reaction, n_h: Soil property used in the calculation of horizontal soil stiffness. When divided by post/pier width *b*, the constant of horizontal subgrade reaction establishes the rate at which the modulus of horizontal subgrade reaction increases with depth.

3.3.4 dry bulk density of soil, ρ_D: Oven-dried mass of a soil divided by its in-situ volume. Also known as dry unit weight.

3.3.5 effective stress: Net stress across points of contact of soil particles, generally considered as equivalent to the total stress minus the pore water pressure.

3.3.6 frost heave: Surface distortion caused by volume expansion within the soil when water freezes and ice lenses form.

3.3.7 moist bulk density of soil, ρ: Mass of a soil divided by its in-situ volume. Also known as wet unit weight.

3.3.8 Poisson's ratio, *v*: Transverse (lateral) strain divided by the corresponding axial (longitudinal) strain that occurs when a uniformly distributed axial load is applied to a soil sample whose transverse expansion is not restricted during load application.

3.3.9 soil friction angle, ϕ: Slope angle of Mohr-Coulomb shear strength criterion for soils, where shear strength = $\sigma \tan \phi + c$.

3.3.10 swelling soil: A soil material, particularly clays, that exhibit expansion with increasing moisture content, and shrinkage with decreasing moisture content. Also referred to as an expansive soil.

3.3.11 total stress: Total pressure exerted in any direction by both soil and water.

3.3.12 undrained shear strength, S_U: Shear strength of soil sheared such that pore water pressure is not allowed to dissipate (i.e., undrained condition). Shear strength criterion typically used for short-term loading of soil with significant clay content.

3.3.13 Young's modulus for soil, E_S: Uniaxial compressive stress divided by the corresponding uniaxial strain of a soil sample whose transverse (lateral) expansion is not restricted during load application.

3.4 Structural loads and analysis

3.4.1 allowable stress design: A method of proportioning structural members such that elastically computed stresses produced in the members by nominal loads do not exceed specified allowable stresses. Also called "working stress design".

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3.4.2 bearing pressure, *q*: Pressure applied normal to the base of the foundation by the soil in response to all downward forces acting on the foundation.

3.4.3 modulus of horizontal subgrade reaction, *k*: Ratio of the load per unit area on a vertical soil surface to the corresponding lateral displacement of the surface. Also known as the coefficient of horizontal subgrade reaction. It is a function of soil properties, surface area over which the pressure is applied, depth below grade at which the pressure is applied, and the magnitude of the lateral displacement.

3.4.4 modulus of vertical subgrade reaction, k_V: Ratio of the load per unit area on a horizontal soil surface to the corresponding vertical displacement of the surface. Also known as the coefficient of subgrade reaction or subgrade modulus.

3.4.5 lateral loading: Any horizontally-directed forces applied to the foundation.

3.4.6 lateral soil pressure, *p*: Net soil pressure acting normal to the sides of the foundation in response to horizontal displacements of the foundation.

3.4.7 load combination: A combination of nominal loads that can reasonably be expected to act on a structure. Loads in a particular combination will be reduced by load factors where there is a low probability of them simultaneously acting at their full value. Load factors in load combinations for strength design also account for uncertainties in structural analyses, and uncertainties surrounding nominal load calculations.

3.4.8 load factor: A factor that accounts for deviations of the actual load from the nominal loads, for uncertainties in the analysis that transforms the load into a load effect, and for the probability that more than one extreme load will simultaneously occur.

3.4.9 nominal loads: The magnitudes of loads specified in ASCE 7 for dead, live, wind, snow, rain, earthquake, etc.

3.4.10 required soil strength: Equal to the product of the nominal load and a load factor.

3.4.11 resistance factor: A factor that accounts for deviations of the actual strength from the nominal strength and the manner and consequences of failure. Also called “strength reduction factor”.

3.4.12 spring constant, K_H: A value assigned to the stiffness of a spring used to model the resistance provided by a soil layer with thickness, *t*, to the lateral movement of a foundation element with thickness, *b*. Numerically equal to the product of *t, b* and the modulus of horizontal subgrade reaction *k.*

3.4.13 strength design: A method of proportioning structural members such that the computed forces produced in the members by the factored loads do not exceed the member design strength. Also called “load and resistance factor design”.

3.4.14 structural analysis: Any analysis used to determine the distribution of applied structural loads to various structural elements.

3.4.15 vertical loading: Any upward or downward force applied to the foundation.

3.4.16 uplift resistance: Resistance provided by the soil to the vertical force acting to withdraw the foundation.

4 Nomenclature (Symbols)

4.1 Abbreviations

ASD	allowable stress design
CPT	Cone Penetration Test
LRFD	load and resistance factor design
SPT	Standard Penetration Test

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4.2 Variables and Constants. The units shown after the description of each term are suggested units. Other units that are consistent with expressions being evaluated may be used.

A footing bearing area, m^2 (in^2)

A_E linear increase in Young's modulus with depth z below grade, kPa/m (lbf/ in^2/ in). When A_E is multiplied by depth z, Young's modulus E_S at depth z (or $E_{S,Z}$) is obtained

A_P cross-sectional area of post/pier, m^2 (in^2). For helical piers, A_P is the cross-sectional area of the shaft (it does not include the area of the attached helix)

b width of the face of the post/pier, footing, or collar that applies load to the soil when the foundation moves laterally, m (in)

b_G post/pier face width at the ground surface, m (in)

B diameter of a round footing or side length of a square footing, m (in)

B_U diameter of a circular uplift resisting system or the smaller of the two dimensions characterizing a rectangular uplift resisting system, m (in)

c cohesion of soil, kPa (lbf/ in^2)

C_{CPT} constant relating CPT blow counts to bearing resistance, kPa (lbf/ in^2)

C_{PB} empirical bearing capacity coefficient for adjustment of pressuremeter readings, dimensionless

C_{SPT} constant relating SPT blow counts to bearing resistance, kPa (lbf/in^2)

C_{w1} correction factor for effect of ground water location on the ultimate bearing strength of cohesionless soils, dimensionless

C_{w2} correction factor for effect of ground water location on the ultimate bearing strength of cohesionless soils, dimensionless

d post/pier embedment depth, m (in)

d_c depth factor for ultimate bearing strength of a cohesive soil based on the general bearing capacity equation, dimensionless

d_q depth factor for ultimate bearing strength of a cohesionless soil based on the general bearing capacity equation, dimensionless

d_R depth from ground surface to point of post/pier rotation, m (in)

d_{RU} depth from ground surface to point of post/pier rotation at ultimate load, m (in)

d_F foundation or footing depth, m (ft)

d_U distance between soil surface and top of the foundation uplift resisting system, m (in)

d_W distance between soil surface and top of the water table, m (in)

E_P Young's modulus for the post/pier material, kPa (lbf/in^2)

E_S Young's modulus for soil which may or may not vary with depth z, kPa (lbf/in^2)

$E_{S,B}$ Young's modulus for backfill soil which may or may not vary with depth z, kPa (lbf/in^2)

$E_{S,U}$ Young's modulus for unexcavated soil which may or may not vary with depth z, kPa (lbf/in^2)

$E_{S,Z}$ Young's modulus for unexcavated soil that is assumed equal to zero at grade and increases linearly with increasing depth z below grade, kPa (lbf/in^2)

f_B ASD factor of safety for bearing strength assessment, dimensionless

f_L ASD factor of safety for lateral strength assessment, dimensionless

f_U ASD factor of safety for uplift strength assessment, dimensionless

F_C breakout factor for soil uplift, dimensionless

F_S force in a horizontal spring used to model lateral soil resistance, kN (lbf)

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F_{ASD} F_S induced by an ASD load combination, kN (lbf)

F_{LRFD} F_S induced by an LRFD load combination, kN (lbf)

F_{ult} soil spring ultimate strength, kN (lbf)

g gravitation acceleration constant, 9.81×10^{-3} kN/kg (1.0 lbf/lbm)

h vertical extent of the uplift soil failure surface, m (in)

I_P moment of inertia of post/pier around axis of rotation, m^4 (in^4). Equal to $w^3b/12$ for a solid rectangular post/pier

I_S strain influence factor, dimensionless

k modulus of horizontal subgrade reaction which may or may not vary with depth z, kN/m^3 (lbf/in^3)

k_c modulus of horizontal subgrade reaction that is constant with depth z, kN/m^3 (lbf/in^3)

k_B modulus of horizontal subgrade for backfill soil which may or may not vary with depth z, kN/m^3 (lbf/in^3)

k_U modulus of horizontal subgrade reaction for unexcavated soil which may or may not vary with depth z, kN/m^3 (lbf/in^3)

k_V modulus of vertical subgrade reaction, kN/m^3 (lbf/in^3)

K_H stiffness of a horizontal spring used to model the resistance to lateral post/pier movement provided by a soil layer with thickness t in contact with a foundation element of width b, kN/m (lbf/in)

K_P coefficient of passive earth pressure, dimensionless

K_U nominal uplift coefficient of earth pressure on a vertical plane, dimensionless

L_U length of a rectangular uplift resisting system with a width B_U, m (in)

M bending moment in post/pier, kN-m (lbf- in)

M_F foundation mass, kg (lbm)

M_G bending moment in post/pier at the ground surface (at grade), kN-m (lbf- in)

M_{ASD} M_G due to a ASD load combination, kN-m (lbf-in)

M_{LRFD} M_G due to a LRFD load combination, kN-m (lbf-in)

M_U ultimate groundline bending moment capacity of the foundation as limited by soil strength, kN-m (lbf-in)

n_h constant of horizontal subgrade reaction, kN/m^3 (lbf/in^3)

N_C bearing capacity factor that accounts for cohesion in the general bearing capacity equation, dimensionless

N_γ bearing capacity factor that accounts for soil unit weight in the general bearing capacity equation, dimensionless

N_q bearing capacity factor that accounts for surcharge pressures in the general bearing capacity equation, dimensionless

N_{SPT} SPT blow count as recorded during test, Blows per 300 mm (Blows per 12 in.)

N_{60} N_{SPT} blow count corrected for field procedures and equipment, Blows per 300 mm (Blows per 12 in.)

$(N_1)_{60}$ N_{60} blow count normalized with respect to vertical effective stress, Blows per 300 mm (Blows per 12 in.)

p lateral soil resistance, kPa (lbf/in^2)

p_A atmospheric pressure, 100 kPa (2090 lbf/in^2)

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p_L limit pressure from a prebored pressuremeter, kPa (lbf/in^2)

p_U ultimate lateral soil resistance, kPa (lbf/in^2)

$p_{U,z}$ ultimate lateral soil resistance at depth z, kPa (lbf/in^2)

p_z lateral soil resistance at a depth z, kPa (lbf/in^2)

P axial load in post/pier, kN (lbf)

P_{LRFD} P due to a load and resistance factor load combination, kN (lbf)

P_{ASD} P due to an allowable stress design load combination, kN (lbf)

q_B ultimate soil bearing capacity, kPa (lbf/ in^2)

q_{cr} average cone penetration resistance measured over a specified depth during a CPT test. Cone penetration resistance is equal to the vertical force applied to the cone divided by its horizontally projected area, kPa (lbf/in^2)

q_0 total overburden pressure at footing depth d_F, kPa (lbf/in^2)

r radius of uplift resisting system (e.g. concrete collar), m (in)

R_B LRFD resistance factor for bearing strength assessment, dimensionless

R_L LRFD resistance factor for lateral strength assessment, dimensionless

R_U LRFD resistance factor for uplift strength assessment, dimensionless

s_c shape factor for ultimate bearing strength of a cohesive soil based on the general bearing capacity equation, dimensionless

s_q shape factor for ultimate bearing strength of a cohesionless soil based on the general bearing capacity equation, dimensionless

s_γ shape factor for ultimate bearing strength of a cohesionless soil based on the general bearing capacity equation, dimensionless

s_F shape factor for uplift resistance in cohesionless soils, dimensionless

S_{LU} increase per unit depth in the ultimate lateral force per unit depth that is applied to a foundation by a cohesionless soil, kPa (lbf/in^2)

S_u undrained shear strength, kPa (lbf/in^2). Numerically equal to cohesion, c, for a saturated clay soil

t thickness of a soil layer that is represented with a soil spring with stiffness K_S, m (in)

u_z pore water pressure at depth z, kPa (lbf/in^2)

U ultimate uplift resistance due to soil mass, kN (lbf)

V shear force in post/pier, kN (lbf)

V_G V at the ground surface (at grade), kN (lbf)

V_{ASD} V_G due to a ASD load combination, kN (lbf)

V_{LRFD} V_G due to a LRFD load combination, kN (lbf)

V_U ultimate groundline shear capacity of the foundation as limited by soil strength, kN (lbf)

y lateral deflection of post/pier, m (in)

w dimension of a post/pier measured parallel to the direction of applied lateral load. Equal to width b for a round pier/pole; m (in)

z depth below the ground surface, m, (in)

γ moist unit weight of soil = $\rho\, g$, kN/m^3 (lbf/ in^3)

γ_D dry unit weight of soil = $\rho_D\, g$, kN/m^3 (lbf/ in^3)

Δ lateral deflection of post/pier at ground surface, m (in)

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ε	strain, mm/mm (in/in)
θ	below grade rotation of post/pier with infinite flexural rigidity, radians
v	Poisson's ratio, dimensionless
ρ	moist bulk density of soil, kg/m^3 (lbm/in^3)
ρ_D	dry bulk density of soil, kg/m^3 (lbm/in^3)
σ	stress, kPa (lbf/in^2)
σ_v	total vertical stress, kPa (lbf/in^2)
σ'_v	effective vertical stress, kPa (lbf/in^2)
σ_{0h}	total horizontal stress at rest, kPa (lbf/in^2)
σ'_{0h}	effective horizontal stress at rest, kPa (lbf/in^2)
ϕ	effective friction angle of soil, degrees

5 Soil and backfill properties

5.1 General. This clause addresses soils that should be avoided during post/pier construction (clause 5.2) and appropriate backfill materials (clause 5.3). It also contains provisions for establishing Young's modulus (clause 5.5), undrained shear strength (clause 5.6), and friction angle (clause 5.7) of soils from applicable soil tests. Clause 5.8 addresses presumptive soil properties.

5.1.1 Drained versus undrained. When establishing soil properties, assume that all cohesive soils will be loaded undrained, even under long-term static loadings, and that all cohesionless soils will be loaded drained, even under rapid loadings such as those resulting from earthquakes and wind forces.

5.2 Poor soils. Building in organic silts, soft clays and peat soils is never recommended as these soils are either weak or inherently unstable. Extra caution should be taken when evaluating strength properties of soils with variable characteristics, composition, and moisture content.

5.2.1 Expansive soils. A soil with an expansion index greater than 20, as determined in accordance with ASTM D482, is considered expansive and should be avoided. A soil is also considered expansive if it meets both of the following criteria:

1. Plasticity index (PI) of 15 or greater, determined in accordance with ASTM D4318;
2. More than 10% of the soil particles are less than 5 micrometers in size, determined in accordance with ASTM D422.

5.3 Backfill materials. Backfill properties can have a significant impact on post/pier foundation behavior. Appropriate backfill materials include:

5.3.1 Excavated soil. Except as excluded in clause 5.2, excavated soil can generally be used for backfill. In the special case where holes are drilled in clay, it may be preferable to backfill with the excavated clay instead of a coarse-grained material (clause 5.3.2) for reasons explained in clause 13.2.3. In all cases, excavated material used as backfill should be compacted to at least its pre-excavation density and should be free of organic material and construction debris.

5.3.2 Coarse-grained soils. Replacing excavated material with a gravel or well-graded sand may be necessary where greater soil strength and stiffness are needed. Compact all backfill by tamping layers that do not exceed a thickness of 0.2 m (8 in.).

5.3.3 Concrete and CLSM. Cast-in-place concrete and controlled low-strength material (CLSM) can significantly enhance the lateral strength and stiffness of a post/pier foundation. This is because the width, *b*, of the pier/post foundation for lateral strength analysis is equated to the diameter of the concrete or CLSM backfill. Concrete and CLSM placed against soil may affect frost heaving; see clause 13 on frost heaving.

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5.4 Soil tests. Obtaining soil properties by laboratory or in-situ testing reduces uncertainty and enables the application of lower factors of safety relative to those associated with ultimate strength values based on presumptive soil properties.

5.4.1 Sampling locations. For uplift and lateral strength assessments, soil sampling and in-situ soil tests should cover the distance between one-third and 100% of the anticipated foundation depth. For bearing strength assessment, in-situ soil tests should be taken at a location between the anticipated footing base and a distance *B* below the anticipated footing depth.

5.5 Young's modulus for soil, E_S. Young's modulus is used to calculate modulus of horizontal subgrade reaction (clause 8.2) for backfill and the surrounding soil. In order to use the Simplified Method f*or determination of foundation and soil forces* (clause 8.4), E_S must increase linearly with depth or be constant with depth.

5.5.1 E_S from laboratory tests. Young's modulus can be determined for any soil using a triaxial compression test in accordance with ASTM D2850. E_s for most cohesive soils can also be determined using an unconfined compression test in accordance with ASTM D2166. E_s can also be determined from a one-dimensional consolidation test in accordance with ASTM D2435. Where horizontally applied loads are primarily due to forces that fluctuate with time (e.g., wind, stored materials), define E_S as the secant modulus associated with a major principle stress of approximately one-fourth of the soil's ultimate strength at the location being modeled.

5.5.2 E_S from prebored pressuremeter test (PMT) results. For all soils:

$$E_S = (E_O + E_R) / 2$$

where E_O is the pressuremeter first load modulus and E_R is the pressuremeter reload modulus calculated in accordance ASTM D4719.

5.5.3 E_S from cone penetration test (CPT) results. For sandy soils:

$E_S = 1.5\ q_{cr}$ for silts, sands and silty sands;

$E_S = 2\ q_{cr}$ for young, normally consolidated sands;

$E_S = 3\ q_{cr}$ for aged, normally consolidated sands;

$E_S = 4\ q_{cr}$ for sand and gravel.

where q_{cr} is average cone resistance in kPa (lbf/in.^{2}) determined in accordance with ASTM D3441.

5.5.4 E_S from standard penetration test (SPT) results.

For silts, sandy silts, slightly cohesive soils:

$$E_S\ (\text{kPa}) = 380\ (N_1)_{60}$$

$$E_S\ (\text{lbf/in}^2) = 56\ (N_1)_{60}$$

For clean fine to medium sands and slightly silty sands:

$$E_S\ (\text{kPa}) = 670\ (N_1)_{60}$$

$$E_S\ (\text{lbf/in}^2) = 97\ (N_1)_{60}$$

For coarse sands and sands with little gravel:

$$E_S\ (\text{kPa}) = 960\ (N_1)_{60}$$

$$E_S\ (\text{lbf/in}^2) = 140\ (N_1)_{60}$$

For sandy gravel and gravels:

$$E_S\ (\text{kPa}) = 1150\ (N_1)_{60}$$

$$E_S\ (\text{lbf/in}^2) = 170\ (N_1)_{60}$$

and

$$(N_1)_{60} = N_{60}\ (p_A / \sigma'_v)^{0.5}$$

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where:

$(N_1)_{60}$ is the N_{60} blow count normalized with respect to vertical effective stress;

N_{60} is the N_{SPT} blow count corrected for field procedures and equipment;

p_A is atmospheric pressure (100 kPa or 2090 lbf/ft^2 or 14.5 lbf/in^2); and

σ'_v is vertical effective stress.

5.5.5 E_S from undrained shear strength, S_U

For soft sensitive clay: E_S ranges from 400 S_U to 1000 S_U

For medium stiff to stiff clay: E_S ranges from 1500 S_U to 2400 S_U

For very stiff clay: E_S ranges from 3000 S_U to 4000 S_U

where S_U is undrained shear strength, kPa (lbf/in^2).

5.6 Constant of horizontal subgrade reaction, n_h

$$n_h = 2.0\ E_{S,Z} / z = 2.0\ A_E$$

and

$$E_{S,Z} = A_E\ z$$

where:

n_h is the modulus of horizontal subgrade reaction, kN/m^3 (lbf/in^3);

z is depth below grade, m (in);

$E_{S,Z}$ is a Young's modulus for soil that is assumed equal to zero at grade and to increase linearly with increasing depth z below grade (e.g., a cohesionless soil), kN/m^2 (lbf/in^2); and

A_E is the increase in Young's modulus per unit increase in depth z below grade, kN/m^3 (lbf/in^3).

5.7 Undrained shear strength, S_U. Is used to calculate bearing capacity, uplift resistance and lateral strength in cohesive soils.

5.7.1 S_U from laboratory tests. Determine S_U for a cohesive soil using an unconfined compressive strength test in accordance with ASTM D2166 or an unconsolidated-undrained triaxial compression test in accordance with ASTM D2850.

5.7.2 S_U from prebored pressuremeter (PBPMT) test results

$$S_U = 0.67\ p_L^{0.75} \quad \text{for } S_U \text{ and } p_L \text{ in kPa}$$

$$S_U = 0.41\ p_L^{0.75} \quad \text{for } S_U \text{ and } p_L \text{ in lbf/in}^2$$

where p_L is limit pressure determined in accordance with ASTM D4719.

5.7.3 S_U from cone penetration test (CPT) results

$$S_U = 0.037\ q_{cr}$$

where q_{cr} is average cone resistance determined in accordance with ASTM D3441.

5.7.4 S_U from field vane tests. Determine S_U of cohesive soils directly from the torque applied to a four-bladed vane shear device in accordance with ASTM D2573.

5.8 Soil friction angle, ϕ. Is required in clause 12.5.1 to calculate the uplift resistance, U, provided by a cohesionless soil. When ultimate bearing capacity, q_B, is not determined via in-situ tests, ϕ is used in the general bearing capacity equation (clause 10.4.1) to determine q_B of cohesionless soils. Likewise, ϕ is used to calculate the ultimate lateral resistance pressure, p_U, where p_U has not been determined by in-situ testing.

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5.8.1 Friction angle ϕ from laboratory tests. For cohesionless soils determine the friction angle ϕ using a direct shear test in accordance with ASTM D3080 or a consolidated-drained (CD) triaxial compression test in accordance with ASTM D7181.

5.8.2 Friction angle ϕ from standard penetration test (SPT) results. For sandy soils:

$$\phi = [20\ (N_1)_{60}]^{0.5} + 20$$

and

$$(N_1)_{60} = N_{60}\ (p_A / \sigma'_v)^{0.5}$$

where:

$(N_1)_{60}$ is the N_{60} blow count normalized with respect to vertical effective stress;

N_{60} is the N_{SPT} blow count corrected for field procedures and equipment;

p_A is atmospheric pressure (100 kPa or 2090 lbf/ft^2 or 14.5 lbf/in^2); and

σ'_v is vertical effective stress.

5.8.3 Friction angle ϕ from cone penetration test (CPT) results. For sandy soils:

$$\phi = 17.6 + 11.0 \log [q_{cr} / (p_A\ \sigma'_v)^{0.5}]$$

where:

q_{cr} is average cone resistance;

p_A is atmospheric pressure (100 kPa or 2090 lbf/ft^2 or 14.5 lbf/in^2); and

σ'_v is vertical effective stress.

5.9 Presumptive values. In the absence of satisfactory soil test data or specific building code requirements, presumptive soil characteristics in Table 1 may be used.

6 Foundation material properties

6.1 General. This clause contains material requirements for post and pier foundation elements. Elements not specifically addressed by the following requirements shall be designed in accordance with applicable normative references, building codes, standards, and good engineering judgment.

6.2 Minimum concrete compressive strength. All concrete used in footings, posts and piers must have a minimum 28-day compressive strength of 3000 lbf/in^2.

6.3 Cast-in-place concrete footings

6.3.1 Minimum nominal thickness. The minimum nominal thickness of an unreinforced (plain) footing that is cast-in-place on a compacted base shall be 20 cm (8 in). The minimum thickness of a reinforced cast-in-place footing shall be such that the concrete provides a minimum cover of 7.5 cm (3 in) above and below the reinforcement. Load-induced forces may dictate a thicker footing.

6.3.2 Reinforcement. Cast-in-place concrete footings do not require steel reinforcement when the actual maximum distance from a footing edge to the nearest post/pier edge is less than the nominal thickness of the footing. Where this requirement is not met, the need for reinforcement shall be determined in accordance with ACI 318 Chapter 15.

6.4 Precast concrete footings

6.4.1 Minimum actual thickness. The minimum actual thickness of unreinforced (plain) precast footing that is placed on a flat, compacted base shall be 10 cm (4 in). The minimum thickness of a reinforced precast footing shall be such that the concrete provides a minimum cover of 4 cm (1.5 in) above and below the reinforcement. Load-induced forces may dictate a thicker footing.

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6.4.2 Reinforcement. Precast concrete footings do not require steel reinforcement when the actual maximum distance from a precast footing edge to the nearest post/pier edge is less than 1.25 times the actual thickness of the footing. Where this requirement is not met, the need for reinforcement shall be determined in accordance with ACI 318 Chapter 15.

6.5 Concrete piers

6.5.1 Longitudinal reinforcement. The location and size of longitudinal reinforcement shall be determined in accordance with ACI 318 Chapter 10. The cross-sectional area of longitudinal reinforcement shall not be less than 1.0% of the gross cross-sectional area of the concrete. The minimum number of longitudinal bars shall be 4 for bars within rectangular or circular ties, 3 for bars with triangular ties and 6 for bars enclosed with spirals.

6.5.2 Shear reinforcement. The location and size of shear reinforcement shall be determined in accordance with ACI 318 Chapter 11. Shear reinforcement is not required where tests show that the required bending strength and shear strengths can be developed when shear reinforcement is omitted.

6.5.3 Cover on reinforcement. When a concrete pier is formed by casting concrete directly against earth, a minimum concrete cover of 7.5 cm (3 in) shall be provided on all steel reinforcement. When concrete is cast on site but not directly against the earth (e.g., the concrete is cast into cardboard forming tubes), the minimum concrete cover on steel reinforcement can be reduced to 5 cm (2 in) for bars 19 mm or greater in diameter (No. 6 or larger bars) and 3.8 cm (1.5 in) for bars 13 mm or smaller in diameter (No. 5 or smaller bars). Minimum concrete cover on reinforcement in precast concrete piers (i.e., piers manufactured under plant control conditions) shall be 3.8 cm (1.5 in) for bars 19 mm or greater in diameter (No. 6 or larger bars) and 3.2 cm (1.25 in) for bars 13 mm or smaller in diameter (No. 5 or smaller bars).

6.6 Embedded wood posts and piers

6.6.1 Preservative treatment. Wood used for embedded posts and piers shall be preservative treated in accordance with AWPA U1 Use Category UC4B.

6.6.2 Size. Mechanically-laminated wood posts and piers shall be sized in accordance with ASAE EP 559. All other wood posts and piers shall be sized in accordance with ANSI/AWC NDS.

6.6.3 Mechanical Fasteners. Fasteners used below grade in mechanically-laminated wood posts and piers shall meet the requirements of ASAE EP 559.

6.7 Anchor attachments. Fasteners used below grade to attach collars, footings and other devices to resist uplift forces shall have a durability equal to the service life of the structure.

6.8 CLSM base for precast concrete and wood footings. A controlled low-strength material (CLSM) placed between the bottom of a precast concrete or wood footing and the underlying soil can be used to increase the effective bearing area of the footing when its unconfined compressive strength exceeds the ultimate bearing capacity of the underlying soil.

7 Structural load combinations

7.1 General. Loads applied to the above-grade portion of a structure, shall be considered to act in the combinations specified in clause 7.2 for allowable stress design, and in clause 7.3 for strength design. More than one combination may control the design of the same structural element. Consideration shall be given to one or more loads in the same combination not acting.

7.1.1 Nominal loads. The following nominal loads shall be calculated in accordance with ASCE 7.

D nominal dead load

E nominal earthquake load

F nominal load due to fluids with well-defined pressures and maximum heights

H nominal pressure of bulk materials

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L nominal live load

L_r nominal roof live load

R nominal rain load

S nominal snow load

T self-straining force

W nominal wind load

7.1.2 Combinations including wind and earthquake loads. The most unfavorable effects from both wind and earthquake loads shall be considered, where appropriate, but need not be assumed to act simultaneously.

7.1.3 Ice, wind-on-ice, flood, and self-straining loads. Ice, wind-on-ice, flood and self-straining loads shall be calculated in accordance with ASCE 7, and shall be used in load combinations as specified in ASCE 7.

7.1.4 Snow loads. In load combinations in which the full force of companion load S is not assumed to be acting (i.e., combinations 4 and 6 in clause 7.2 and combinations 2, 4 and 5 in clause 7.3), S shall be taken as either the flat roof snow load (p_f) or the sloped roof snow load (p_s). In combinations in which the full force of companion load S is assumed to be acting (i.e., combination 3 in clause 7.2 and combination 3 in clause 7.3), S shall account for adverse effects of partial, unbalanced, drift and sliding loads where applicable.

7.1.5 Loads due to lateral earth pressure, ground water pressure, or pressure of bulk materials. Load H shall be included with an ASD load factor of 1.0 (clause 7.2 combinations) and an LRFD load factor of 1.6 (clause 7.3 combinations) when the effect of H adds to the primary variable load effect. Where H is a permanent load and its effect resists the primary variable load effect, include H with an ASD load factor of 0.6 in clause 7.2 combinations and with a LRFD load factor of 0.9 in clause 7.3 combinations. Use a load factor of 0 when H resists the primary load variable but is not a permanent load.

7.1.6 Fluid loads. Where fluid loads F are present, they shall be included in ASD (clause 7.2) combinations 1 through 6 and 8 and in LRFD (clause 7.3) combinations 1 through 5 and 7. Assign fluid loads the same factors as used in the combination for dead load.

7.2 Load combinations for allowable stress design (a.k.a. working stress design)

1. D
2. $D + L$
3. $D + (L_r \text{ or } S \text{ or } R)$
4. $D + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$
5. $D + (0.6W \text{ or } 0.7E)$

6a. $D + 0.75L + 0.75(0.6W) + 0.75(L_r \text{ or } S \text{ or } R)$

6b. $D + 0.75L + 0.75(0.7E) + 0.75S$

7. $0.6D + 0.6W$
8. $0.6D + 0.7E$

7.3 Load combinations for load and resistance factor design (a.k.a. strength design)

1. $1.4D$
2. $1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
3. $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W)$
4. $1.2D + W + L + 0.5(L_r \text{ or } S \text{ or } R)$
5. $1.2D + E + L + 0.2S$
6. $0.9D + W$
7. $0.9D + E$

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7.3.1 The load factor on *L* in LRFD load combinations 3, 4, and 5 is permitted to equal 0.5 for all occupants in which the uniformly distributed live load is less than or equal to 100 psf, which the exception of garages or areas occupied as places of public assembly.

8 Structural analysis

8.1 General. Structural analysis is the determination of the forces induced in a post/pier foundation by applied structural loads. Two methods are outlined in this clause. The Universal Method (clause 8.3) can be used to analyze any post/pier foundation. Application of the Simplified Method (clause 8.4) is limited by assumptions inherent in its development which are outlined in clause 8.4. In order to complete the calculations in clauses 8.3 and 8.4, the modulus of horizontal subgrade reaction must be established in accordance with clause 8.2.

8.1.1 Alternative analyses. Structural analyses of post and pier foundations are not restricted to the procedures outlined here. Other analytical procedures along with laboratory and field testing are available that can provide more accurate analyses. In all cases, sound engineering judgment should guide selection and application of the design procedure.

8.2 Modulus of horizontal subgrade reaction, *k*. The modulus of horizontal subgrade reaction *k* is the ratio of average contact pressure (between the foundation and soil) to horizontal foundation movement, and is equated to twice the effective Young's modulus for the soil divided by foundation face width. In equation form:

$$k = p_Z / \Delta_Z = 2.0\ E_{SE} / b$$

where:

k is modulus of horizontal subgrade reaction at depth z;

p_z is average contact pressure between the foundation and soil at depth z;

Δ_Z is horizontal movement of the foundation at depth z;

E_{SE} is effective Young's modulus for the soil at depth z from clause 8.2.1 or 8.2.2; and

b is face width of foundation at depth z.

8.2.1 Effective Young's modulus of soil, E_{SE}, for portions of the foundation backfilled with soil.

$$E_{SE} = \frac{1}{I_S / E_{S,B} + (1 - I_S) / E_{S,U}} \qquad \text{for } 0 < J < 3b$$

$$E_{SE} = E_{S,B} \qquad \text{for } J \geq 3b$$

$$E_{SE} = E_{S,U} \qquad \text{for } J = 0$$

where $$I_S = [\ln(1 + J/b)] / 1.386 \qquad \text{for } 0 < J < 3b$$

and:

$E_{S,B}$ is E_S for backfill at depth z;

$E_{S,U}$ is E_S for the unexcavated soil surrounding the backfill at depth z;

I_S is strain influence factor, dimensionless;

b is width of the face of the foundation component (post/pier, footing, or collar) at depth z; and

J is distance (measured in the direction of lateral foundation movement) between the edge of the backfill and the face of the foundation component at depth z (see Figure 9).

The condition of $J = 0$ would apply to a driven pier/post for which the foundation is entirely surrounded by unexcavated soil.

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8.2.2 Effective Young's modulus of soil, E_{SE}, for portions of the foundation backfilled with concrete or CLSM

At any depth below grade where concrete or CLSM backfill is present, face width b is equal to the width of the concrete backfill or CLSM backfill, respectively, and effective Young's modulus of the soil at that depth is equal to E_S for the unexcavated soil surrounding the concrete or CLSM backfill.

8.3 Universal Method for determination of foundation and soil forces. The Universal Method refers to any structural analysis utilizing a 2-dimensional structural analog that uses conventional frame elements to model the below grade portions of a post/pier foundation, and horizontal spring elements to model the resistance to lateral movement provided by backfill and soil (Figures 6, 7 and 8). Soil spring stiffness values are calculated in accordance with clause 8.3.1. Recommendations for soil spring and support placements are given in clauses 8.3.2 and 8.3.3, respectively. Soil spring forces provided by the subsequent structural analysis are converted to soil pressures in accordance with clause 8.3.4.

8.3.1 Soil spring stiffness. The stiffness of a horizontal soil spring, K_H, located at depth, z, is given as:

$$K_H = t\,k\,b = 2.0\,t\,E_{SE}$$

where:

t is thickness of the soil layer represented by the spring;

b is width of the post/pier, footing, or collar upon which soil represented by the spring is acting; and

k is modulus of horizontal subgrade reaction at depth z from clause 8.2.

E_{SE} is effective Young's modulus for soil at depth z from clause 8.2.1 or 8.2.2

8.3.2 Soil spring placement. A closer spring spacing enables more accurate estimation of post/pier forces and soil pressures and is most important where such forces and pressures change rapidly. In general, soil spring spacing, t, should not exceed $2w$ where w is the face width of a rectangular post/pier and diameter of a round post/pier.

8.3.3 Support placement. Where a post is constrained from moving laterally by a concrete slab or other rigid structure, place a vertical roller support at the point of likely contact between the post and constraining component (Figure 8a). Do not constrain post/pier movement with a roller support if the post/pier is not directly connected to the structure and will move away from it when loaded (Figure 8b). Model the interface between the base of the foundation and the soil with a horizontal roller support (Figure 8).

8.3.4 Lateral soil pressures. Lateral soil pressure at a depth z below the ground surface, p_z, is given as:

$$p_z = F_S / (t\,b)$$

where F_S is the force in a horizontal spring located at depth z that represents a soil layer with thickness t and width b. In this case, b is the width of the post/pier, footing, or collar upon which the soil represented by the spring is acting.

8.4 Simplified method for determination of foundation and soil forces. The Simplified Method assumes the following:

1. At-grade pier/post forces are not dependent on below-grade deformations.
2. The below-grade portion of the foundation has an infinite flexural rigidity ($E_P I_P$).
3. Unexcavated soil and backfill are each homogeneous for the entire embedment depth.
4. Young's modulus for soil is either constant for all depths below grade or is zero at grade and then 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.

The Simplified Method can be used if the condition in clause 8.4.1 is met. The procedure uses a fixed-based structural analog described in clause 8.4.2 to determine the bending moment, axial, and shear forces induced in the post/pier near the ground surface. These forces are then substituted in the appropriate equations in

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clause 8.4.3 to determine lateral soil pressures as well as the ground surface displacement and rotation of the post/pier.

Equations in clause 8.4.3 utilize the sign convention shown in Figure 10. Note: V_G and M_G have the same sign if they independently rotate the foundation in the same direction.

8.4.1 Depth requirements. For soils whose modulus of horizontal subgrade reaction k increases linearly with depth, the Simplified Method can be used if:

$$d \leq 2(E_P I_P / n_h)^{0.20} = 2[E_P I_P / (2A_E)]^{0.20}$$

For soils whose modulus of horizontal subgrade reaction k is constant with depth, the Simplified Method can be used if:

$$d \leq 2[E_P I_P / (k_c b)]^{0.25} = 2[E_P I_P / (2E_{SE})]^{0.25}$$

8.4.2 Fixed base analog. The fixed base analog refers to any 2-dimensional structural analog that replaces an embedded post/pier foundation with fixed supports. For a constrained foundation (i.e., a post/pier constrained from moving laterally by a concrete slab or other rigid structure located at grade), place a vertical roller support at the point of likely contact between the post/pier and constraining component, and place a fixed support at the ground surface. For a non-constrained post/pier, place the fixed support a distance w below the ground surface, where w is the face width of a rectangular post/pier and diameter of a round post/pier (Figure 11a). The shear force, V, and bending moment, M, resisted by the fixed support shall be used in the equations of clause 8.4.3. for V_G and M_G, respectively. Note that:

$V_{LRFD} = V_G$ for LRFD

$M_{LRFD} = M_G$ for LRFD

$V_{ASD} = V_G$ for ASD

$M_{ASD} = M_G$ for ASD

8.4.3 Lateral soil pressures. For calculation of lateral soil pressures use clauses 8.4.3.1 and 8.4.3.3 for *non-constrained* posts/piers and clauses 8.4.3.2 and 8.4.3.4 for *constrained* posts/piers. The effective Young's modulus for soil E_{SE} is not required in this clause to calculate lateral soil pressures, which is one advantage of using the Simplified Method. However, the effective Young's modulus for soil is required in the following clauses for calculation of post/pier displacement parameters θ and Δ.

8.4.3.1 Non-constrained posts/piers with linearly increasing soil stiffness. The following equations for non-constrained post/pier foundations assume the effective Young's modulus for soil E_{SE} increases linearly with soil depth, and is numerically equal to $A_E z$ (Figure 12).

$$d_R = \frac{d(3\ V_G d + 4\ M_G)}{4\ V_G d + 6\ M_G} \qquad \text{for } 0 \leq d_R \leq d$$

$$\theta = \frac{12\ V_G d + 18\ M_G)}{d^4 A_E}$$

$$\Delta = \frac{9\ V_G d + 12\ M_G)}{d^3 A_E}$$

$$p_z = 6z(6M_G z/d + 4V_G z - 3dV_G - 4M_G)/(d^3 b)$$

8.4.3.2 Constrained posts/piers with linearly increasing soil stiffness. The following equations for post/pier foundations constrained at grade assume the effective Young's modulus for soil E_{SE} increases linearly with soil depth, and is numerically equal to $A_E z$ (Figure 13).

$$\theta = \frac{2\ M_G}{d^4 A_E}$$

$$p_z = 4z^2 M_G / (d^4 b)$$

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8.4.3.3 Non-constrained posts/piers with constant soil stiffness. The following equations for non-constrained post/pier foundations assume the effective Young's modulus for soil E_{SE} remains constant with depth (Figure 14).

$$d_R = \frac{d(2\ V_G d + 3\ M_G)}{3\ V_G d + 6\ M_G}$$

$$\theta = \frac{3\ V_G d + 6\ M_G}{d^3 E_{SE}}$$

$$\Delta = \frac{2\ V_G d + 3\ M_G}{d^2 E_{SE}}$$

$$p_z = (12 M_G z/d + 6 V_G z - 4 d V_G - 6 M_G)/(d^2 b)$$

8.4.3.4 Constrained posts/piers with constant soil stiffness. The following equations for post/pier foundations constrained at grade assume the effective Young's modulus for soil E_{SE} remains constant with depth (Figure 15).

$$\theta = \frac{1.5\ M_G}{d^3 E_{SE}}$$

$$p_z = 3 z M_G/(d^3 b)$$

9 Resistance and safety factors

9.1 Tabulated values. Tables 2, 3, 4 and 5 contain resistance factors for LRFD design and corresponding safety factors for ASD design. Table 2 values apply to bearing strength assessment, Table 3 values apply to lateral strength assessment involving the Universal Method of analysis, Table 4 values apply to lateral strength assessment involving the Simplified Method of analysis, and Table 5 values apply to uplift strength assessment.

9.2 Adjustments. For buildings and other structures that represent a low risk to human life in the event of a failure, Tables 2, 3, 4, and 5 resistance factors may be increased 25% (multiplied by 1.25), and Tables 2, 3, 4, and 5 safety factors may be reduced 20% (multiplied by 0.80). In all cases, the adjusted resistance factor is limited to a maximum value of 0.93 and the adjusted safety factor is limited to a minimum value of 1.50.

10 Bearing strength assessment

10.1 General. Clauses 10.2 and 10.3 contain equations for checking adequacy of the foundation's bearing capacity under ASD and LRFD load combinations, respectively. Clause 10.4 contains equations for calculating ultimate soil bearing capacity, q_B, a variable in the equations of clauses 10.2 and 10.3. The quantity q_0 in clauses 10.2 and 10.3 is the pressure applied by the soil overburden at the foundation base (i.e., at a depth, d_F) and is equal to γd_F for soils with a uniform unit weight γ between the soil surface and depth d_F.

Assuming that the difference is negligible between the moist unit weight γ of the soil and the average unit weight of the foundation elements, the net ultimate bearing capacity can be approximated as the difference between q_B and q_0. When the net ultimate bearing capacity is calculated in this fashion, the values of P_{ASD} and P_{LRFD} should not include the weight of foundation elements located below grade.

10.2 Allowable stress design. Bearing area is sufficient if the following inequality is met.

$$(q_B - q_0)/f_B \geq P_{ASD}/A$$

or

$$A \geq f_B\ P_{ASD}/(q_B - q_0)$$

where f_B is the allowable stress design factor of safety for bearing strength assessment from Table 2.

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