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Shallow Post Foundation Design

American Society of Agricultural Engineers

STANDARD

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Shallow Post Foundation Design

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1 Purpose and scope

1.1 Purpose. The purpose of this Engineering Practice is to present a design procedure for shallow post foundations that resist moments and lateral and vertical forces acting on them. The design procedure provides necessary definitions, material requirements, and design equations for post foundations. A commentary on the practice is also included.

1.2 Limitations. Precedence of applicable building codes or other enforced requirements.

2 Normative references

ACI 318 1999. Building Code Requirements for Structural Reinforced Concrete and Commentary.
ACI 318.1 1999. Building Code Requirements for Structural Plain Concrete.
AWPI. Patterson, D. 1969. Pole Building Design.
BOCA 1999. The BOCA National Building Code.
ICBO 1999. The ICBO Uniform Building Code (UBC).

3 Definitions

3.1 post: A post or a pole.

3.1.1 post: A structural column partly embedded in the soil to provide lateral and vertical support for a building. Posts include members of any material with assigned structural properties such as solid or laminated wood, steel, or concrete.

3.1.2 pole: A round, naturally tapered, unsawn, wood post. The above ground portions of poles are sometimes slabbed to aid in fastening framing members.

3.2 post foundation: The post foundation includes the post, collar, and footing. Foundation depth, *d*, for a specific load is the vertical distance from the ground surface to the bottom of the foundation-soil contact area resisting that specific load.

3.3 shallow post foundation: A post foundation for which foundation deformation under load is small, so foundation movement approximates rigid body motion. Foundation deformation is kept small by selection of foundation depth, *d*, and stiffness, *EI*.

3.4 Foundation loads and constraints

3.4.1 lateral loading: The foundation is loaded by forces and moments that cause horizontal displacements and rotation about a horizontal axis.

3.4.1.1 non-constrained case: Post foundation rotation and horizontal displacement (horizontal movement of entire foundation) is resisted by reactive soil pressures only. Without collars, the point of rotation is between two-thirds and three-fourths of the total foundation depth.

3.4.1.2 constrained case: The post foundation rotates about a restraint (point of insignificant horizontal movement) at or above the ground surface. Post foundation rotation is resisted by reactive soil pressures, and applied shear forces are resisted by the restraint.

3.4.2 vertical loading: The foundation is loaded by upward or downward forces (such as from wind, snow, live and dead loads) causing vertical movement of the foundation.

3.5 collar: Foundation component attached to the post that moves with the post to resist lateral and vertical loads.

3.6 footing: Foundation component below the post and collar (when present) but not attached to the post or collar and not included in foundation depth. Footings provide resistance to vertical downward forces.

3.7 backfill: Material filling the excavation around the post foundation.

4 Material requirements

4.1 General. Design posts, collars, footings, and backfill in accordance with the design standards accepted for each material used, such as listed in normative references.

4.2 Soil. Variable characteristics, composition, and moisture content require caution in evaluating soil strength properties. Lateral soil strength is assumed to increase linearly with depth.

4.2.1 Organic silt, soft clay, and peat soils do not have adequate bearing strength or stability for post foundation design.

4.2.2 In the absence of satisfactory soil test data or specific building code requirements, presumptive soil characteristics may be used (table 1).

4.2.2.1 Allowable lateral pressure increase for isolated posts. Allowable lateral soil pressure may be doubled for isolated posts that are spaced at least six times their width apart. The increase is due to the expanded volume of soil support for the post (clause 7).

4.2.2.2 Allowable lateral pressure increase for wind loading. Allowable lateral soil pressure may be increased one-third for wind forces acting alone or in combination with vertical loads. Wind increases are cumulative with other pressure increases for constrained and non-constrained cases.

4.2.3 The allowable vertical and lateral pressures for the soil can be determined by soil tests. The angle of internal friction, soil cohesion, and soil bulk density from soil tests can be used to predict allowable vertical and lateral pressure.

4.2.3.1 Increases in allowable pressures. Increases for isolated post and for wind loading are dependent on the soil test performed and should be recommended by the testing laboratory.

4.2.3.2 Soil test samples. Soil test samples are to be taken at the depth where soil strength is assumed to be critical: at one-third of foundation depth for lateral loading of non-constrained foundations, at foundation depth for lateral loading of constrained foundations, and at the foundation depth for vertical loading.

4.2.3.3 Soil test results. Convert soil test results for allowable lateral soil pressure to allowable unit soil pressure increase per unit of depth below the ground surface in Pa/m ($lbf/ft^2 \cdot ft$).

4.2.3.4 If soil data are used, include a safety factor. A safety factor of 3.0 is recommended. Consider a safety factor as low as 2.5 if greater foundation movement is acceptable.

4.3 Backfill. Backfill with one of the following materials:

4.3.1 Granular aggregate from class 3 and 4 materials in table 1 and compacted by tamping layers of not more than 0.2 m (8 in.) deep.

4.3.2 Excavated soil, except as excluded in clause 4.2.1, compacted to at least its pre-excavation density.

4.3.3 Placed concrete: Concrete as backfill that bonds to the post becomes part of the foundation, thereby increasing the post effective width *b* to the diameter of the excavation. Concrete placed against soil may affect frost heaving; see clause 5 on frost heaving.

Table 1 – Presumed soil properties for post foundation design (for use in absence of codes or tests)

Class of materials	Density or consistency[1]	Lateral pressure per unit depth[2], S		Lateral sliding coefficient[3], k_{cs}	Vertical Pressure[4], Sy		Friction angle[5], ϕ	Density[6], w		Estimated Constant of Lateral Soil Reaction[8], n_h S_v	
		kPa/m	lb/ft^2·ft		kPa	lb/ft^2	degree	kg/m^3	lb/ft^3	kPa/m^2	lb/ft^4
1. Massive crystalline bedrock	—	180	1200	0.79	200	4000	–	–	–	–	–
2. Sedimentary and foliated rock	—	60	400	0.35	100	2000	–	–	–	–	–
3. Sandy gravel and/or gravel (GW and GP)	firm	45	300	–	–	–	38	2000	120	6285	40000
	loose	30	200	0.35	100	2000	32	1500	90	1570	10000
4. Sand, silty sand, clayey sand, silty gravel, and clayey gravel (SW, SP, SM, SC, GM, and GC)	firm	30	200	–	–	–	30	1750	105	1570	10000
	loose	22.5	150	0.25	75	1500	26	1400	85	1180	7500
5. Clay, sandy clay, silty clay, and clayey silt (CL, ML, MH, and CH)	medium	20	130	6(130)[7]	–	–	15	2000	120	785	5000
	soft	15	100	–	50	1000	10	1500	90	160	1000

[1] Firm consistency of class 4 and the medium consistency of class 5 can be molded by strong finger pressure, and the firm consistency of class 3 is too compact to be excavated with a shovel.

[2] The hydrostatic increase in lateral pressure per unit depth has been included in the equations of this Engineering Practice. Source: Table 18-1-A UBC modified with the addition of firm and medium values from Hough.

[3] Sliding resistance source: Table 18-1-A UBC.

[4] Allowable foundation pressures are for footings at least 300 mm (1 ft) wide and 300 mm (1 ft) deep into natural grade. Pressure may be increased 20% for each additional 300 mm (1 ft) of width and/or depth to a maximum of three times the tabulated value. Source: Table 18-1-A UBC.

[5] Soil friction angle varies from soft to medium density of clay materials, and from loose to firm for sand and gravel materials. Source: Merritt.

[6] Soil density varies from soft to medium density for clay materials and from loose to firm for sand and gravel materials. Source: Hough.

[7] Multiply an assumed lateral sliding resistance of 6 kPa (130 lb/ft^2) by the contact area. Use the lesser of the lateral sliding resistance and one-half the dead load.

[8] Values estimated from following references: Langer *et al.* (1984), Parkash and Sharma (1990), and Poulos *et al.* (1980).

5 Frost heaving

5.1 Frost heaving mechanism: Frozen soil expanding below the foundation or pushing upward on rough foundation vertical surfaces causes frost heaving. As soil water freezes, capillary action moves more water into the frozen area, causing ice lenses to grow. Ice lenses expand the soil and raise foundations if they form under the foundation or if there is sufficient friction between the foundation and the soil. Melted ice lenses saturate and weaken the soil adjacent to the foundation. For frost heaving to occur there must be freezing soil temperatures, ground water close to the frozen soil, and soil that supports rapid capillary water movement.

5.2 Reducing frost heaving. Suggestions to reduce the probability of post foundation frost heaving are as follows:

5.2.1 Extend foundations to below maximum frost penetration.

5.2.2 Direct surface water away from the building by sloping ground surface away from the building, move roof water away from the building with gutters and roof drains, and raise the building elevation above surrounding area.

5.2.3 Interrupt vertical water movement in the soil and lower the water table by placing a tile or coarse granular channel below maximum frost depth with drainage to an outlet.

5.2.4 Use coarse granular backfill to reduce frozen soil uplift on vertical foundation surfaces.

5.2.5 Place concrete floor around posts such that vertical movement of floor and post is independent. Post and/or concrete shrinkage may break post–concrete bond and can allow independent movement.

5.3 Concrete backfill against irregular soil surfaces, or in holes with diameter decreasing with depth, can increase the probability of frost heaving (clause 5.1).

6 Design for lateral loads

6.1 Applied forces and foundation resistance

6.1.1 Applied forces. Foundation design is based on the moment and lateral shear transferred from the above-ground structure to the foundation at the ground surface or the lateral restraint.

6.1.2 Frictional resistance. Friction between the soil and the foundation and between the collar and footing is neglected in design for lateral loads.

6.1.3 Soil resistance assumptions. The design equations in clause 6 utilize two soil assumptions. First, it is assumed that the soil resistance to deformation is proportional to displacement for the range of deformations used in design. Secondly, it is assumed that the resistance to deformation increases linearly with depth below the ground surface. This increasing resistance to deformation is due to the confining pressure of the soil overburden. For each case, the maximum soil pressure is limited to the allowable lateral pressure. These assumptions, along with failure criteria and equations of statics, determine the equations in clause 6.

6.2 Shallow post foundation. In addition to the soil assumptions in clause 6.1.3, equations in clause 6 also assume shallow post foundations.

6.3 Restraint. Two lateral foundation design cases are considered in this Engineering Practice, constrained and non-constrained. Constrained foundations are prevented from horizontal movement at the constraint that is assumed to be at the ground surface or some distance above the ground surface.

6.3.1 Restraint requirements (see clause 6.6.6).

6.4 Collars. Collars develop lateral bearing forces near the bottom of the post, where lateral soil bearing strength is relatively high. These forces add resistance to foundation rotation, provided they retain material and structural integrity.

6.5 Non-constrained case. Without restraint at or just above the ground surface, rotation is resisted by soil reactive pressures and the post rotates about an axis a distance d_0 below the ground surface. For non-constrained foundations without collars, as in figure 1, d_0 varies from $0.67d$ when only moment is applied to $0.75d$ when only shear is applied.

6.5.1 Post without collar. Figure 1 illustrates the post foundation free-body diagram for a non-constrained post without a collar. The equations below determine the minimum foundation depth that will support the applied loads at a maximum soil pressure, S, and the maximum depth for a shallow foundation. Solve for d by iteration. Foundation depth, d, must be less than d_{max} from the equation below or table 2.

$$d=\sqrt{\frac{6V_a+\frac{8M_a}{d}}{Sb}},$$

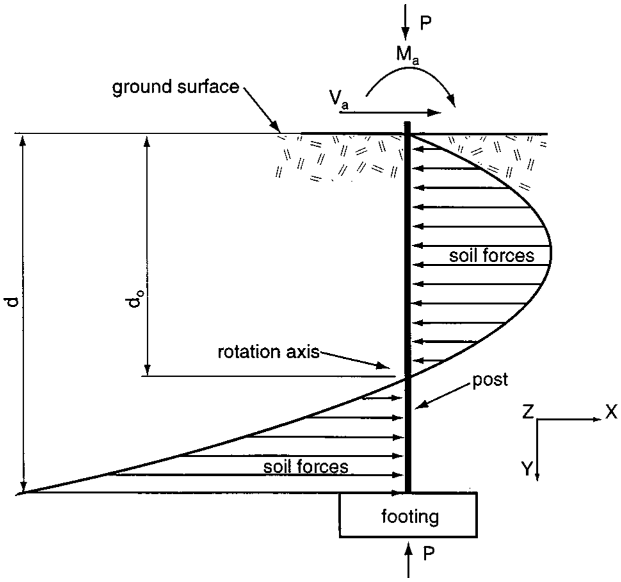

Figure 1 – Free body diagram for a non-constrained post foundation

$$d_{max}=\sqrt[5]{\frac{6EIN(4M_a+3V_ad_{max})}{n_hb\left(\frac{2M_a}{5}+\frac{V_ad_{max}}{12}\right)}},$$

where

Table 2 – Maximum embedment depths permitted for selected shallow post foundation sizes and consistent with assumptions in this Engineering Practice[1),2)], m(ft).

Soil class [3)] Constant of Lateral Soil Reaction, n_h [4)], Pa/m^2 (lbf/ft^4)	5-Soft 500 (1000)	5-Med 2550 (5000)	4-loose 3850 (7500)	4-firm or 3-loose 5100 (10000)	3-firm 20600 (40000)
Constrained case[5)]					
89 mm×89 mm (3.5 in.×3.5 in.); 4 in.×4 in. nominal	1.2 (4.1)	0.9 (3.0)	0.8 (2.8)	0.8 (2.6)	0.6 (2.0)
89 mm×140 mm (3.5 in.×5.5 in); 4 in.×6 in. nominal	1.6 (5.4)	1.2 (3.9)	1.1 (3.6)	1.0 (3.4)	0.8 (2.6)
140 mm×140 mm (5.5 in.×5.5 in.); 6 in.×6 in. nominal	1.5 (5.1)	1.1 (3.7)	1.0 (3.4)	1.0 (3.2)	0.7 (2.4)
140 mm×191 mm (5.5 in.×7.5 in.); 6 in.×8 in. nominal	1.8 (6.1)	1.4 (4.5)	1.2 (4.1)	1.2 (3.9)	0.9 (2.9)
191 mm×191 mm (7.5 in.×7.5 in.); 8 in.×8 in. nominal	1.8 (6.1)	1.4 (4.5)	1.2 (4.1)	1.2 (3.9)	0.9 (2.9)
Unconstrained case[5)]					
89 mm×89 mm (3.5 in.×3.5 in.); 4 in.×4 in. nominal	1.7 (5.5)	1.2 (4.0)	1.1 (3.7)	1.1 (3.5)	0.8 (2.6)
89 mm×140 mm (3.5 in.×5.5 in.); 4 in.×6 in. nominal	2.0 (6.6)	1.5 (4.8)	1.3 (4.4)	1.3 (4.2)	1.0 (3.2)
140 mm×140 mm (5.5 in.×5.5 in.); 6 in.×6 in. nominal	2.0 (6.6)	1.5 (4.8)	1.3 (4.4)	1.3 (4.2)	1.0 (3.2)
140 mm×191 mm (5.5 in.×7.5 in.); 6 in.×8 in. nominal	2.4 (7.9)	1.8 (5.8)	1.6 (5.3)	1.5 (5.0)	1.2 (3.8)
191 mm×191 mm (7.5 in.×7.5 in.); 8 in.×8 in. nominal	2.4 (7.9)	1.8 (5.8)	1.6 (5.3)	1.5 (5.0)	1.2 (3.8)

[1)] To use this table, first calculate the required embedment depth to resist applied moment and shear. If the calculated depth is greater than the maximum depth from table 2, the post is too flexible for the required depth. Selecting a larger post will reduce the calculated depth due to increased post width and increase the maximum depth due to the higher moment of inertia.

[2)] The maximum design moment for the post and zero shear are the applied loads. Post foundation deformation assumed to be 20% of maximum rigid body movement, $N=0.20$.

[3)] Refer to table 1 for soil class.

[4)] Value of n_h from table 1.

[5)] Wet service conditions, No. 1 or 2 So. Pine or No. 1 or 2 Douglas Fir-Larch.

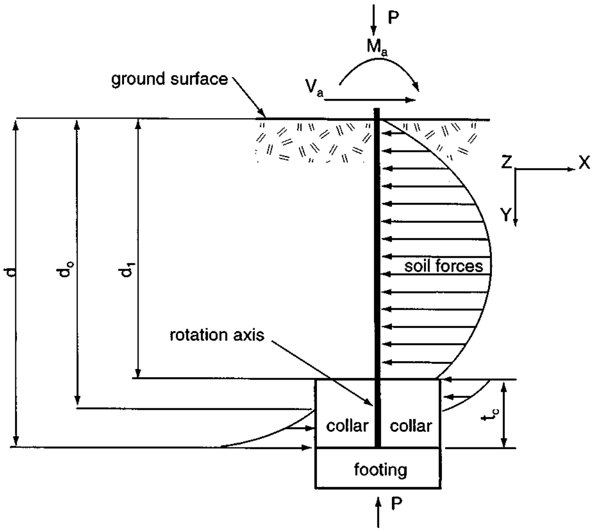

Figure 2 – Free body diagram for a non-constrained post foundation with a collar

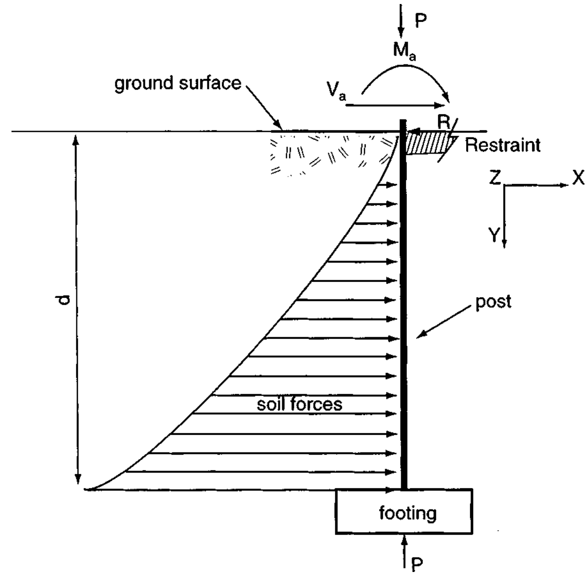

Figure 3 – Free body diagram for a post foundation constrained at the ground surface

b = effective width of the post in the soil perpendicular to the direction of movement, m (ft) (clause 7)
d = minimum post embedment depth to resist applied forces with a maximum soil pressure of S, m (ft)
d_{max} = maximum post embedment depth for shallow foundation, m (ft)
E = post modulus of elasticity, N/m^2 (lbf/ft^2)
I = post moment of inertia about axis perpendicular to lateral force, m^4 (ft^4)
n_h = constant of horizontal soil reaction, N/m^4(lbf/ft^4), see table 1
M_a = moment applied to foundation at ground surface, kN·m (lbf·ft)
N = post deformation at d divided by the maximum post movement (at ground surface for nonconstrained post), dimensionless
S = allowable lateral bearing soil pressure, per unit of depth including increases, kPa/m (lbf/ft^2·ft), see clause 4.2 and table 1
V_a = shear force applied to foundation at ground surface, kN (lbf)

6.5.2 Post with collar. Figure 2 shows the free-body diagram for a non-constrained foundation with collar. Collars lower the rotation axis and increase resisting moment.

The equations that relate the foundation geometry, soil strength, and applied forces are given below. Solve for d by iteration.

$$d_1 = d - t_c,$$

$$V_a = \frac{Sb}{2}\left(\frac{2d^3}{d_0} - 3d^2\right) + \frac{S(w-b)}{2}\left[\frac{2(d^3-d_1^3)}{d_0} - 3(d^2-d_1^2)\right],$$

$$V_a d + M_a = -\frac{Sb}{4}\left(\frac{d^4}{d_0} - 2d^3\right) - \frac{S(w-b)}{4}\left[\frac{d^4-3dd_1^3+3d_1^4}{d_0} - 2d^3 - 6dd_1^2 + 4d_1^3\right],$$

where

d_0 = depth to the rotation axis, m (ft)
d_1 = distance from ground surface to top of collar, m (ft)
t_c = collar dimension in y direction, m (ft)
w = collar dimension in z direction, m (ft)

All other variables have been defined previously.

6.6 Constrained case. Foundation horizontal movement is zero at or a distance "a" above the ground surface because of a restraint. The post foundation rotates about this restraint. The resisting moment is provided by reactive soil pressures that increase parabolically with depth. Reactive soil pressures act on one side of the post.

6.6.1 Post foundations must be designed for all combinations of force, direction, and constraint in that direction. See clause 6.6.6 for restraint requirements.

6.6.2 Ground surface restraint. The post rotates about a rigid restraint at ground surface. Figure 3 illustrates the lateral forces in this case. The following equations express the minimum depth, restraint reaction, and maximum depth in terms of foundation geometry, allowable soil pressure, and foundation stiffness. Solve for d and d_{max} directly. The equation for R is available for checking bearing adequacy. Minimum foundation depth must be less than d_{max} from the equations below or table 2.

$$d = \sqrt[3]{\frac{4M_a}{Sb}},$$

$$d_{max} = \sqrt[5]{\frac{180EIN}{13n_h b}},$$

$$R = V_a + \frac{Sbd^2}{3},$$

where

N = post deformation at d divided by the maximum post movement (at $y = d$ for constrained post), dimensionless
R = reaction at constraint, kN (lbf)

All other variables have been defined previously.

6.6.3 Ground surface restraint with collar (figure 4) illustrates the forces associated with this case.

The following equations express the moment resistance and restraint reaction in terms of foundation geometry and allowable soil pressure. Design by selecting a combination of b, d, t_c, t_f, and w for which $M_r > M_a$. The equation for R is available for checking bearing adequacy.

$$M_r = \frac{Sbd^3}{4} + \frac{S(w-b)(d^4-d_1^4)}{4d},$$

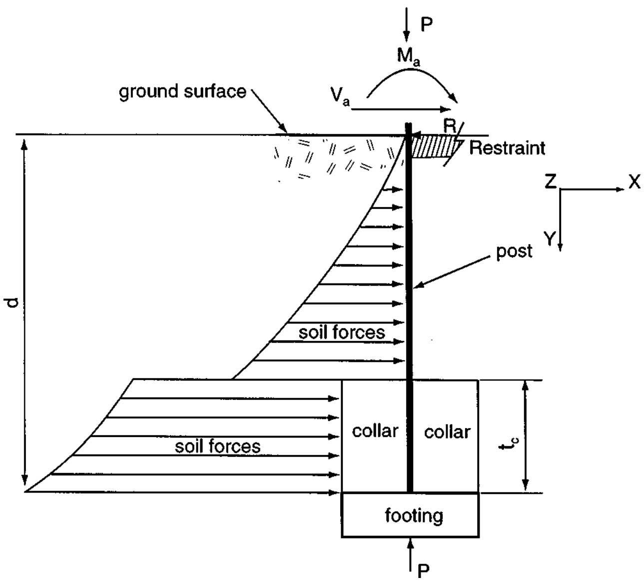

Figure 4 – Free body diagram for a post foundation constrained at the ground surface and with a collar

$$R=V_a+\frac{Sbd^2}{3}+\frac{S(w-b)(d^3-d_1^3)}{3d},$$

where

d_1 = distance from ground surface to top of collar, m (ft)
M_r = moment resistance of post foundation, Nm (lbf·ft)
t_c = collar dimension in y direction, m (ft)
w = collar dimension in z direction, m (ft)

All other variables have been defined previously.

6.6.4 Restraint above ground surface. The post rotates about a constraint distance "*a*" above the ground surface. The longer lever arm increases the soil supporting moment. Figure 5 illustrates the forces for this case. This case does not include a collar. The following equations express the resisting moment and restraint reaction in terms of foundation geometry and allowable soil pressure. Set M_a equal to M_r and solve for d by iteration. The equation for R is available for checking bearing adequacy.

$$M_r=\frac{Sbd^2}{12(a+d)}(6a^2+8ad+3d^2),$$

$$R=\frac{V_a+Sbd^2(3a+2d)}{6(a+d)},$$

where

a = distance to constraint above ground surface, m (ft)

Other variables as previously defined.

6.6.5 Restraint above ground surface and with a collar. Figure 6 illustrates the forces associated with a post foundation with collar. The following equations express the resisting moment and restraint reaction in terms of foundation geometry and allowable soil pressure. Design by selecting a combination of b, d, t_c, and w for which $M_r > M_a$.

$$M_r=\frac{Sbd^3}{12(a+d)}(4a+3d)+\frac{S(w-b)}{12(a+d)}[4a(d^3-d_1^3)+3(d^4-d_1^4)],$$

$$R=V_a+\frac{Sbd^2(3a+2d)}{6(a+d)}+\frac{S(w-b)}{6(a+d)}[3a(d^2-d_1^2)+2(d^3-d_1^3)],$$

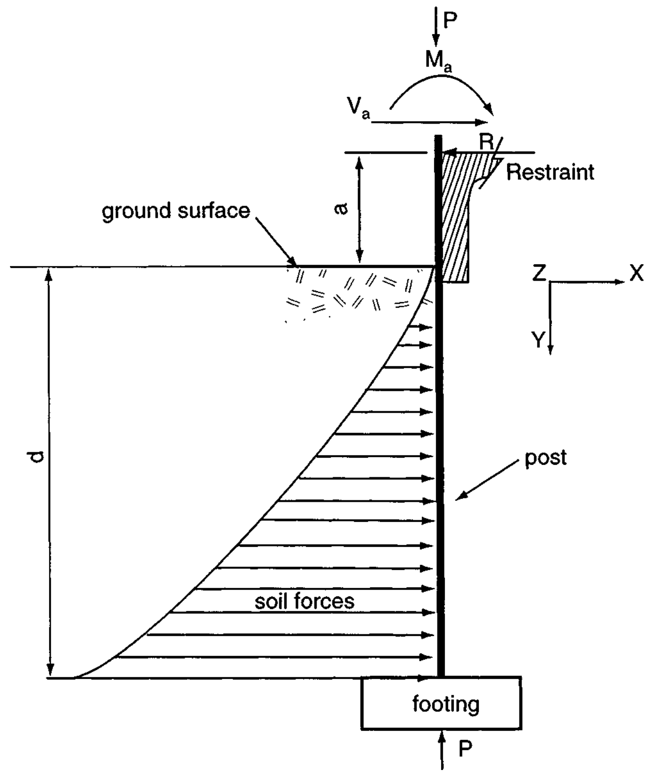

Figure 5 – Free body diagram for a post foundation constrained above the ground surface

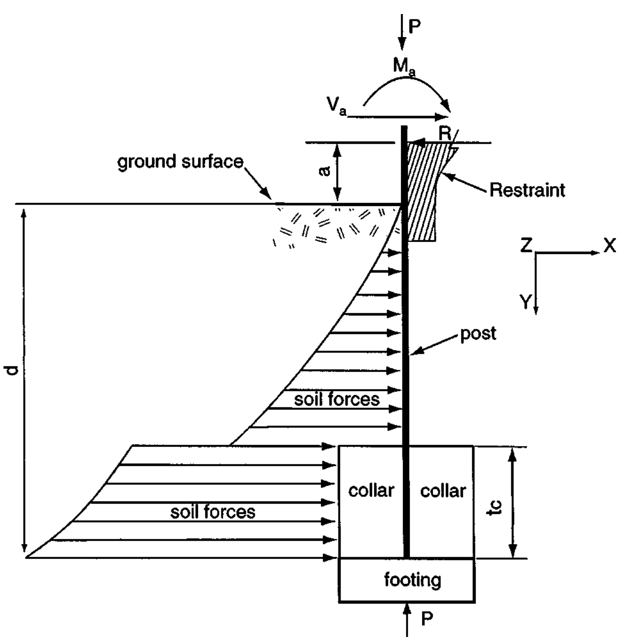

Figure 6 – Free body diagram for a post foundation constrained above the ground surface and with a collar

where all terms have been previously defined.

6.6.6 Restraint requirements. For a post foundation to be constrained, the restraint must provide the necessary lateral resistance with horizontal movement small enough to be considered fixed in that direction. Cast rectangular or circular concrete slabs provide restraint through sliding resistance and lateral bearing. Preservative-treated wooden beams, located just below grade and fastened to the post, provide restraint through lateral bearing only. To prevent frost heaving, do not connect the surface restraint to the post. Figures 7a and 7b illustrate surface restraint.

Calculate the lateral resultant, R_r, with the following equations:

6.6.6.1 Concrete slab:

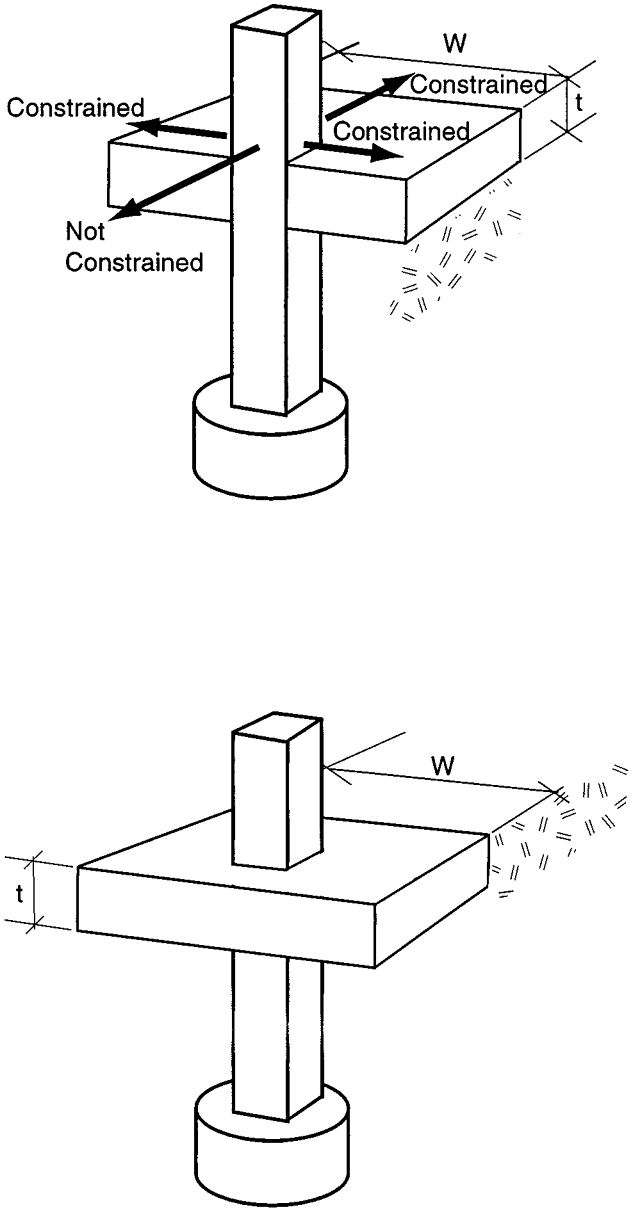

Figure 7a – Concrete surface support to provide constrained conditions

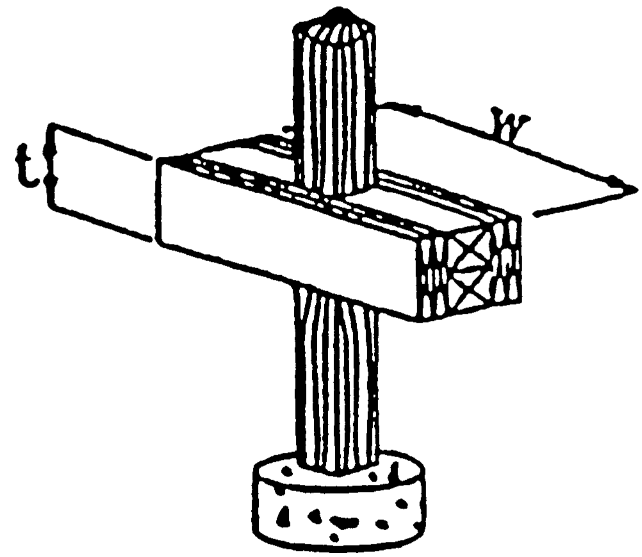

Figure 7b – Wood surface support to provide constrained conditions

$$R \leq R_r = k_{cs} W_d + 0.5 S w t^2$$

where

R = reaction, kN (lbf)

R_r = lateral resistance of constraint, kN (lbf)

k_{cs} = lateral sliding coefficient, concrete on soil, dimensionless (table 1)

W_d = dead weight of concrete slab, kN (lbf)

S = allowable lateral bearing soil pressure per unit of depth including increases, kPa/m (lbf/ft^3), see clause 4.2 and table 1

t = slab or beam bearing depth, m (ft)

w = slab or beam bearing width, m (ft)

6.6.6.2 Wooden beam:

$$R \leq R_r = 0.5 S w t^2$$

where definitions in clause 6.6.6.1 apply.

6.6.6.3 Bearing plate restraint. When a floor does not constrain a post in one direction, a bearing plate at the floor level may provide sufficient restraint to allow constrained case analysis. Design the plate with sufficient area to prevent post crushing under the reaction, *R*. Anchor the bearing plate to the concrete floor with adequate connectors to sustain the reaction, *R*. If frost heaving can occur, this connector must allow independent vertical movement between the post and concrete floor.

7 Effective post bearing width

7.1 Post bearing. The soil pressure diagrams shown in figures 1 through 6 are soil pressure diagrams in the vertical plane through the post foundation centerline. The soil–post foundation interaction also varies in any horizontal plane as shown in figure 8a. This horizontal plane pressure distribution is accounted for in the effective post width, *b*.

7.1.1 Post. The effective post width, *b*, is defined for a rectangular post as $B\sqrt{2}$, where the x dimension of the post foundation is *B*, m (ft).

7.1.2 Pole. The effective post width, *b*, is defined for a pole as the pole diameter, m (ft). If the pole is tapered, use the pole diameter at the ground surface.

7.2 Bearing on the backfill and undisturbed soil. Figure 8a illustrates constant pressure lines in the soil in the same direction as the pressure *q* acting on the post foundation surface. To determine the pressure acting on the backfill–undisturbed soil interface, calculate the distance from the post face moving into the backfill to the backfill–undisturbed soil interface, *J*, and divide by *B*. Use J/B and figure 8b to determine *C*. The pressure at the backfill–undisturbed soil interface is *C* times *q*. The

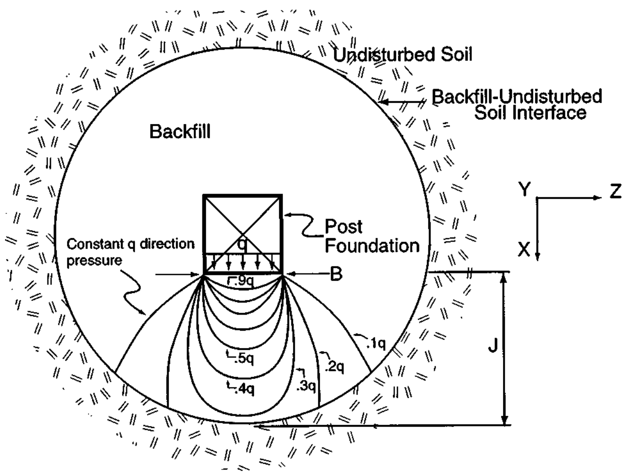

Figure 8a – Constant pressure lines in the soil

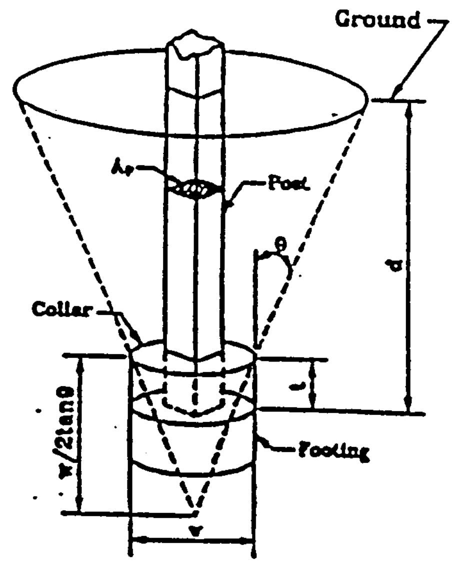

Figure 9 – Concrete uplift resistance

pressure on the backfill and the undisturbed soil must be less than the allowable lateral pressure, *S*, for each material.

8 Vertical foundation design

8.1 General. Post foundations resist vertical upward and downward forces, including upward forces from wind and downward forces from dead and live loads.

8.2 Gravity foundation designs. The vertical bearing area required to support gravity loads or vertical wind forces is:

$$A = \frac{P}{S_v}$$

where

A = required footing area, m^2 (ft^2)

P = vertical foundation load, kN (lbf)

S_v = allowable vertical soil pressure, including increase, kPa (lbf/ft^2), see clause 4, Material Requirements.

8.2.1 Minimum depth. Determine minimum depth by applicable codes, frost heave prevention, overturning, and uplift resistance.

8.2.2 Minimum thickness of footings. For reinforced concrete footings provide concrete cover of 0.075 m (0.25 ft) above and below the reinforcement. Provide sufficient depth to prevent the post punching through the footing. A minimum of 0.2 m (0.67 ft) is recommended.

8.2.3 Post hole preparation. Assure that soil in the bottom of holes is level and has the density of undisturbed soil.

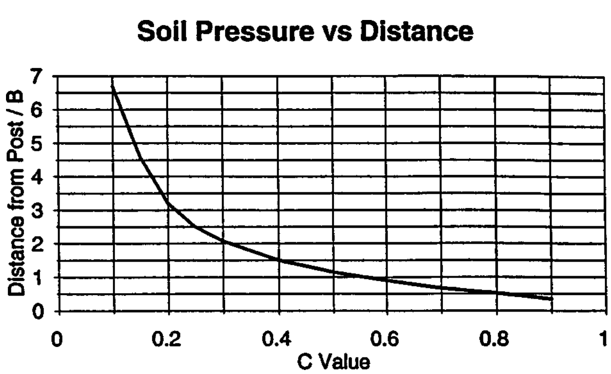

Figure 8b – Ratio of soil to backfill allowable pressure, *C*

8.2.4 Presumed allowable foundation pressure. In the absence of soil test data or applicable building codes, allowable foundation pressures may be presumed from table 1.

8.3 Uplift foundation design. Foundation mass and soil mass lifted by the foundation resist uplift loads on posts.

8.3.1 Post uplift design. Design the post to resist withdrawal from the soil under wind uplift forces. Below grade, use mechanical fasteners with durability equal to the service life of the building.

8.3.1.1 Friction. Do not include the frictional resistance between soil and post.

8.3.1.2 Poles. Tapered poles, when embedded large-end down, may have some resistance to vertical withdrawal from a wedging effect.

8.3.1.3 Concrete backfill. Concrete cast against undisturbed soil and mechanically fastened to the post adds vertical resistance because of the mass of concrete and skin friction between concrete and soil. Frost heaving could be a problem with concrete backfill (see clause 5).

8.3.1.4 Concrete paving. When adequately mechanically fastened to posts, paving adds vertical resistance equal to the mass of concrete that remains connected to the post. See clause 5 for frost heaving considerations to be included in the concrete pavement design.

8.3.2 Enlarged post bottom. The size of the soil cone above a foundation element depends on the soil friction angle. In the absence of soil test data or applicable building codes, allowable friction angles and soil density may be presumed from table 1.

8.3.2.1 Concrete collars. Circular cast-in place concrete collars displace a conically shaped wedge of soil as illustrated in figure 9. Calculate the potential resistance of a circular collar, including soil and attached concrete, from the following equation. In practice, the mass is usually limited to the strength of the collar-to-post connection.

$$U = \alpha G\Big[0.33\pi\{[(d-t)+0.5w/\tan\theta]^3(\tan\theta)^2 - 0.125w^3/\tan\theta\} - A_p(d-t)\Big] + 0.25C\pi w^2 tG$$

where

U = soil and foundation uplift resistance, kN (lbf)

α = soil density, kg/m^3 (lb/ft^3), see table 1

C = presumed concrete density, 90 kg/m^3 (150 lb/ft^3)

G = gravity acceleration, constant 9.8 x 10^{-3} $kN \cdot m/N_s^2$ (1.0 lbf/lb)

d = embedment depth, m (ft)

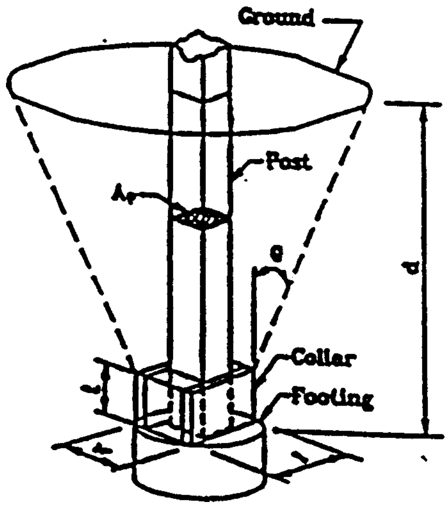

Figure 10 – Wood uplift resistance

t = collar thickness, m (ft)
w = collar width, m (ft)
θ = soil friction angle, deg, see table 1
A_p = post cross sectional area, m^2 (ft^2)

8.3.2.2 Wood collars. Rectangular pressure-treated wood beams which are fastened to the post displace a rounded corner, truncated prismatic wedge of soil radiating above that wood surface as illustrated in figure 10. The mass of the soil which can be lifted is usually limited to the strength of the beam-to-post connection. Calculate the uplift resistance from the mass of the truncated prismatic volume with the following equation:

$$U=\alpha G[(wl-A_p)(d-t)+(w+l)(d-t)^2\tan\theta+0.33\pi(d-t)^3\tan^2\theta]$$

where

U = soil uplift resistance, kN (lbf)
α = soil density, kg/m^3 (lb/ft^3); see table 1
G = gravity acceleration constant, 9.8×10^{-3} $kN\cdot m/N\cdot s^2$ (1.0 lbf/lb)
w = width of collar, m (ft)
l = length of collar, m (ft)
A_p = post cross sectional area, m^2 (ft^2)
d = embedment depth, m (ft)
t = wood collar thickness, m (ft)
θ = soil friction angle, deg; see table 1

Annex A
(informative)
Commentary

A1 Refers to clause 1, Purpose and scope

1.1 General. This Engineering Practice has been developed to assist engineers to improve the quality of post frame building foundations. These foundations are assumed to be shallow, that is, to deform very little compared to the total foundation rotation and/or translation. The sources for this Engineering Practice are the standards and references cited and listed. Assumptions involving soil, embedment conditions, and the performance of embedded posts and their structural collars and footings are part of this practice and are discussed in this commentary.

This Engineering Practice presents constrained and non-constrained lateral design cases including collars, constraint at or above the ground surface, and post foundation depth/flexibility limits. These options help the engineer meet design requirements. Generally, the engineer will first analyze the "post-only case" for required embedment depth and then modify the backfill or add collars if needed to achieve the required resistance. Finally the foundation maximum depth and flexibility are checked.

A2 Refers to clause 3, Definitions

3.1 post: The post definition includes any cross section shape and structural material.

3.2 post foundation: Foundation depth has been synonymous with the post length in the soil, however in this document, foundation depth is the greatest distance from the ground surface to any part of the foundation resisting the applied load. For example, foundation depth for lateral loads will be the distance from the ground surface to the bottom of the post or to the bottom of the collar, if present and below the bottom of the post.

3.4.1 Loads that cause horizontal displacement and rotation of post foundations are often wind, stored granular materials, or earth pressures.

3.5 collars: Collars are attached to the post to increase bearing area. The post and collar move together to resist lateral loads, vertical upward loads, and vertical downward loads if a footing is not present. Attachment must be sufficient to resist reactive forces. Equations only consider bottom collars (collars that extend to the foundation depth for lateral loads) because collars that do not extend to that depth may be subject to frost heaving.

3.6 footing: The footing is placed below the post and collar (if present) to increase the bearing area resisting vertical downward loads.

A3 Refers to clause 4, Material requirements

4.2 Soil. Presumptive soil strength values tend to be conservative because they are the lowest strength for a broad classification of soils each at their minimum strength condition. Site specific soil tests may increase allowable soil pressure.

The lateral soil strength increase with depth has been incorporated in all embedment equations; therefore, the allowable pressure, S, should not be increased for depth.

4.2.2 Presumed pressures from table 1 may be adjusted for the conditions of design that include wind load, isolated post location, and deflection tolerance if permitted by applicable building codes.

4.2.2.1 The allowable soil pressure increase for isolated posts results from the soil pressure distribution in a horizontal plane. The ultimate resistance depends upon the post bearing on the soil and the pressure in the soil expanding beyond the post width as shown in figure 8a. The soil resistance per unit area of foundation–soil interface depends upon foundation width (figure 9). For isolated posts with widths of 315 to 720 mm and depths of 0.94 to 2.83 m, the ultimate load (at 20 mm deflection 355 mm above ground surface) has been found to be 2.2 to 3.4 times the design load (figure 9). Deflection at design load was 2 mm at 355 mm above the ground surface (figure 9).

4.2.3 Site specific soil tests produce the most accurate allowable pressures. The allowable lateral pressure per foot of depth can be estimated from soil data by the following equation:

$$S=wy\tan^2\left(45+\frac{\phi}{2}\right)+2c\sqrt{\tan\left(45+\frac{\phi}{2}\right)}$$

where

S = allowable lateral bearing soil pressure, per unit of depth without increases, kPa/m (lbf/ft^2·ft), see clause 4.2 for increases
w = soil bulk density, kg/m^3 (lbm/ft^3)
ϕ = soil angle of internal friction, degrees
y = depth where soil allowable pressure is calculated, taken as 1, m (ft)
c = soil cohesion, Pa (lbf/ft^2)

The allowable bearing pressure for a round or square footing can be estimated by the Terzaghi-Meyerhoff equation as follows:

$$N_q = e^{\pi \tan\phi} \tan^2\left(45 + \frac{\phi}{2}\right)$$

$$S_v = (N_q + N_q \tan\phi - 1)\left(\frac{c}{\tan\phi} + wy\right) + 0.6wb(N_q + 1)\tan\phi$$

where
b = footing diameter or length of one side, m (ft)
S_v = allowable vertical soil pressure, including increases, kPa (lbf/ft^2)

A4 Refers to clause 6, Design for lateral loads

6.1.1 Applied forces. In many publications the load is a force applied at some distance above the ground surface. In this Engineering Practice the loads are the moment and shear in the post at the ground surface or at the restraint if above the ground surface.

6.1.2 Frictional resistance. The friction between the soil and the foundation and between the collar and footing is unpredictable and cannot be counted upon to resist lateral or vertical loads. This is due to soil variability and interaction of simultaneous lateral and vertical loading.

6.3 Post foundation restraint is often provided by a concrete floor. Restraint may be in one direction only. Posts in an exterior wall and abutting an interior concrete floor may be constrained only against loads tending to tip the post inward, such as wind, and not constrained against outward forces, such as stored grain.

6.5 Non-constrained case

6.5.1 Post without collar. The soil pressure, q, on the post foundation as a function of the vertical coordinate, y, is given by the equation below.

$$q = 3S\left(\frac{y^2}{d_0} - y\right)$$

The equations in clause 6.5.1 result from statics and the integration of the soil pressure function (figure 8b). If the soil properties or the foundation width change between the ground surface and foundation depth, the equations of static equilibrium can be written in terms of the integral of q and solved for the required geometrical properties of the foundation.

The point of rotation equation shown below is also determined by the soil pressure equation and statics.

$$d_0 = \frac{d^4}{2d^3 - \frac{4V_a d}{Sb} - \frac{M_a}{Sb}}.$$

The d_{max} equation, which sets a shallow foundation limit, was derived by calculating the bending of the post (deformation of post, not the post rigid body rotation or translation) and setting that deformation equal to N times the maximum post movement, see figure 11. That maximum movement is at the ground surface for non-constrained foundations and at the depth d for constrained foundations. An N of 0.2 appears to be reasonable for wood, steel, and concrete posts.

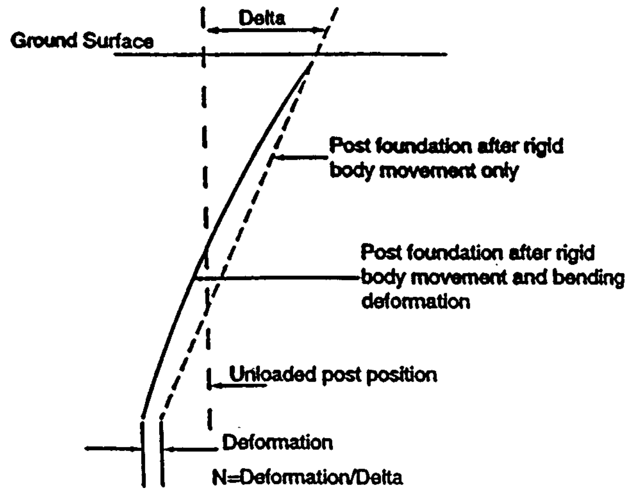

Figure 11 – Definition of "*N*" for non-constrained foundations

6.5.2 Post with collar. Solve for d by iteration by assuming d_0/d and solve for d in each of the equations for V_a and $V_a d + M_a$. Assume other d_0/d values until the d for both equations are the same. The d_0/d ratio will probably be less than 0.67 because of the collar.

The equation for d_{max} has not been derived.

Notice that the equations for post with collar reduce to the equations for a post without collar when $w = t_c = 0$.

6.6 Constrained case

6.6.1 Examine all possible force directions and the directions in which constraint is provided. For example, when post foundations are constrained by a floor, that constraint might not be effective when the wind force is away from the floor. In that case, the post foundation is constrained when loaded in one direction and non-constrained when loaded in another direction.

6.6.2 Ground surface constraint. The equation for soil pressure on the post foundation constrained at the surface and without or with a collar as a function of the vertical coordinate, y, is given as

$$q = S\frac{y^2}{d}.$$

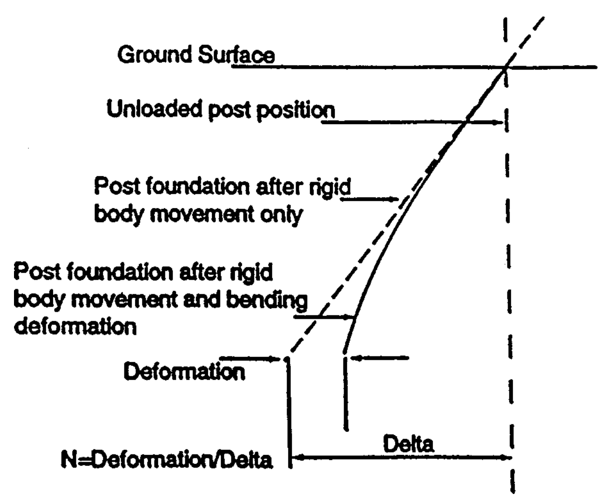

Figure 12 – Definition of "*N*" for groundline constrained foundations

See Annex A4 6.6.1 for a discussion on how this equation can be used to apply to cases other than those addressed in this Engineering Practice.

The d_{max} equation, which sets a shallow foundation limit, was derived as described in Annex A4 6.6.1.

6.6.4 The equation for soil pressure on the post foundation constrained at a distance "*a*" above the ground surface and without or with a collar as a function of the vertical coordinate, *y*, is given as

$$q=\frac{S}{a+d}(hy+y^2).$$

See Annex A4 6.6.1 for a discussion on how this equation can be used to apply to cases other than those addressed in this Engineering Practice.

A5 Refers to clause 7, Effective post bearing width

7.1.1 Research has shown that square posts have the same soil resistance as poles (round cross section) with a diameter equal to the diagonal of the square pole. Since the original work used poles, other shaped posts have been referenced to poles. Since soil–post foundation friction on the post sides have been assumed to be zero, rectangular posts have the same resistance as square posts. Therefore, a square root of two multiplier of the face dimension is used for square and rectangular posts.

Annex B
(informative)
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