SIMPLIFIED METHOD FOR SHALLOW POST AND PIER FOUNDATION DESIGN DETAILS

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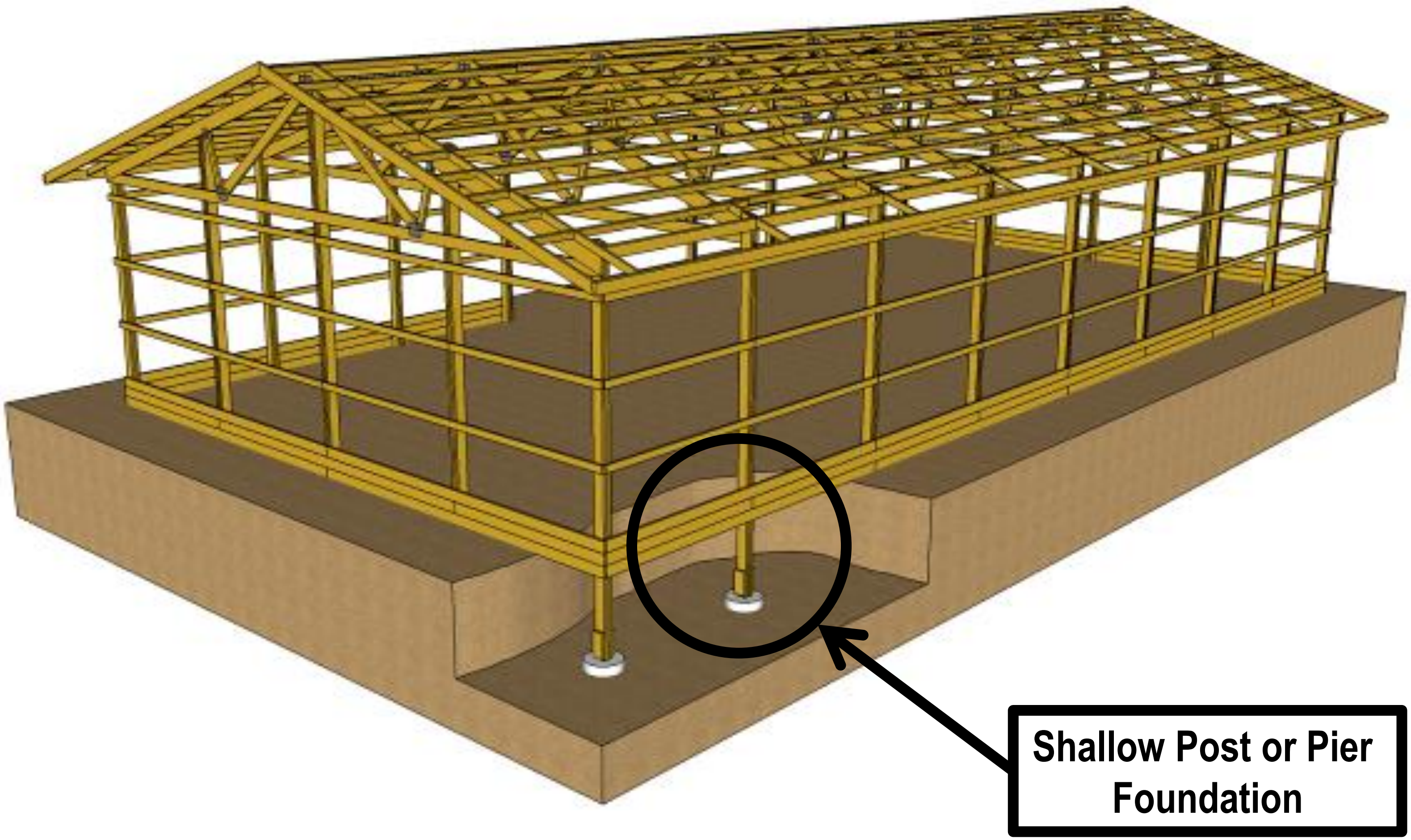
NFBA
POST-FRAME ADVANTAGE

LEARNING OBJECTIVES

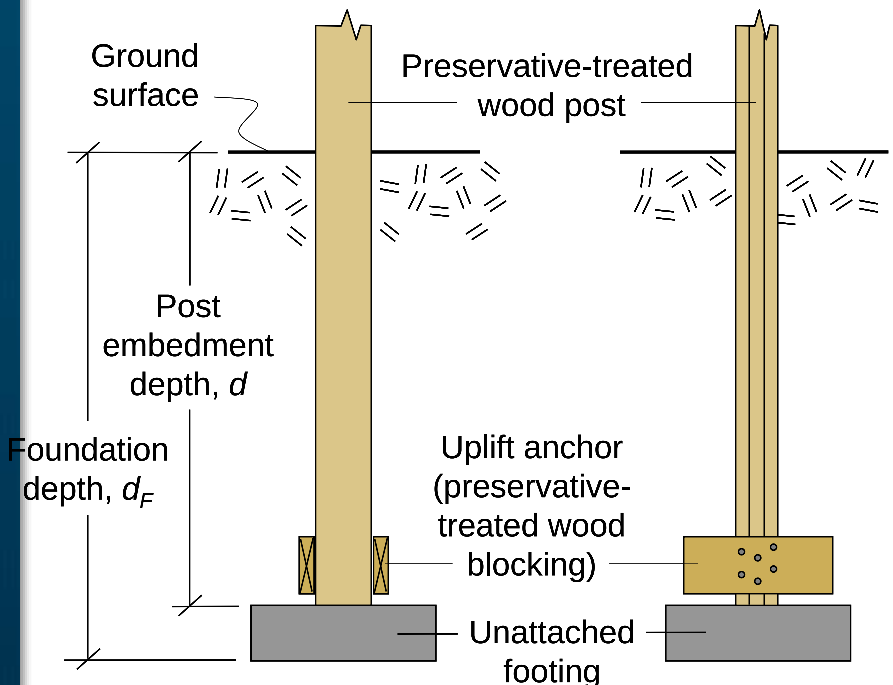
Participants will learn how to:

- Design shallow post/pier foundations to **resist bearing and uplift loads**
- Determine when the **Simplified** method may be used for shallow post/pier foundation design
- Determine **ground line shear and moment** in shallow post/pier foundation systems using the **simplified method**
- Determine design **embedment depths** for shallow post/pier foundation systems using the **simplified design method**

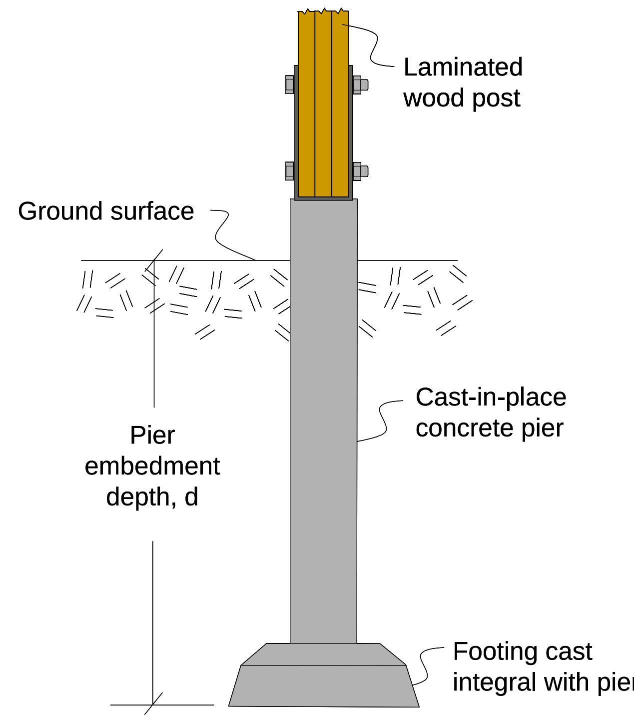
POST-FRAME PICTORIAL



TYPICAL POST AND PIER FOUNDATIONS

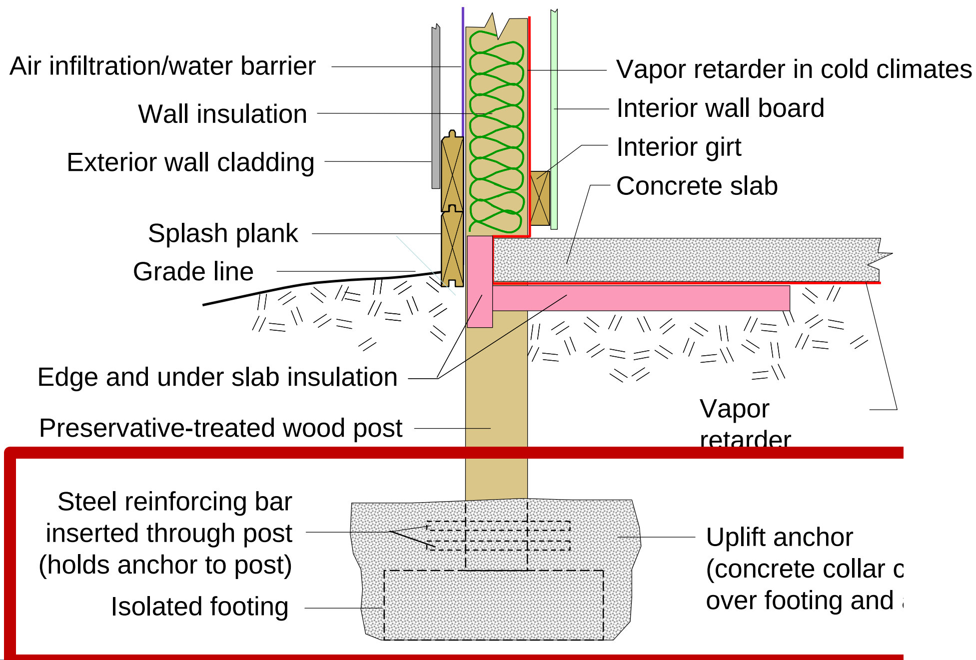


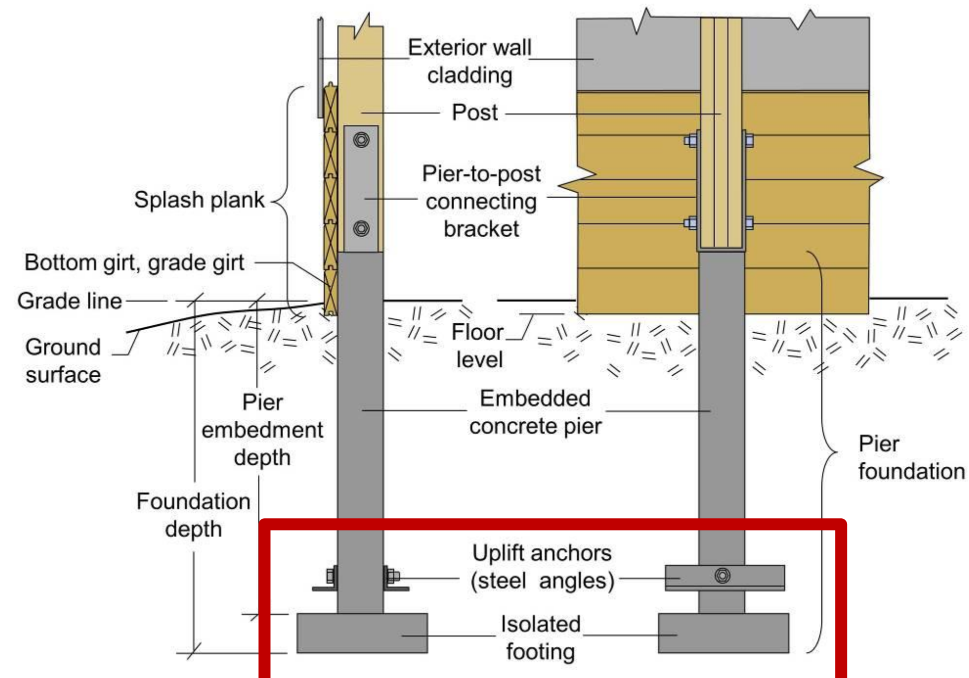
Preservative-treated wood post foundation w/ preservative-treated uplift anchor



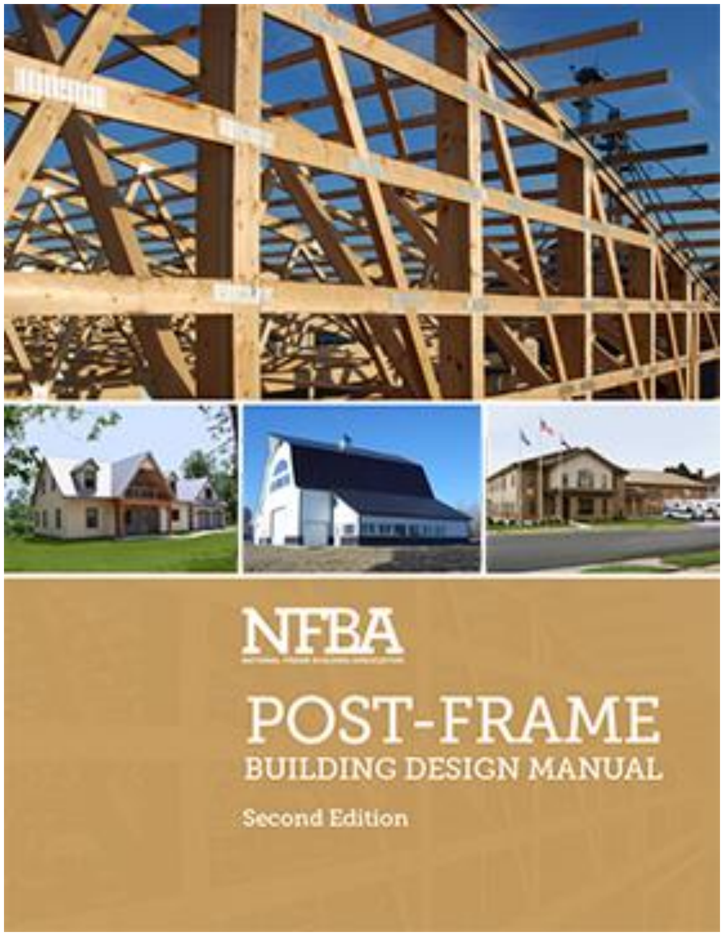
Cast-in-place concrete pier foundation. Attached footing functions as uplift resisting system.

TYPICAL POST-FRAME FOUNDATION DETAILS





POST-FRAME BUILDING DESIGN MANUAL (PFBDM-2015)



- Design Procedures & data, commentary & design examples for post-frame systems
- Chapter 5: Post & Pier Foundation Design

POST-FRAME ENGINEERING PRACTICE

- ANSI/ASAE (ASABE)
  EP 486.3 Shallow post
  & pier foundation design

asabe.org


ANSI/ASAE EP486.1 OCT00
Shallow Post Foundation Design

ASAE

American Society of Agricultural Engineers

STANDARD

PFBDM SHALLOW POST & PIER FOUNDATION DESIGN PROVISIONS

- **Structural Provisions in Chapter 5, PFBDM**

  - Bearing Resistance

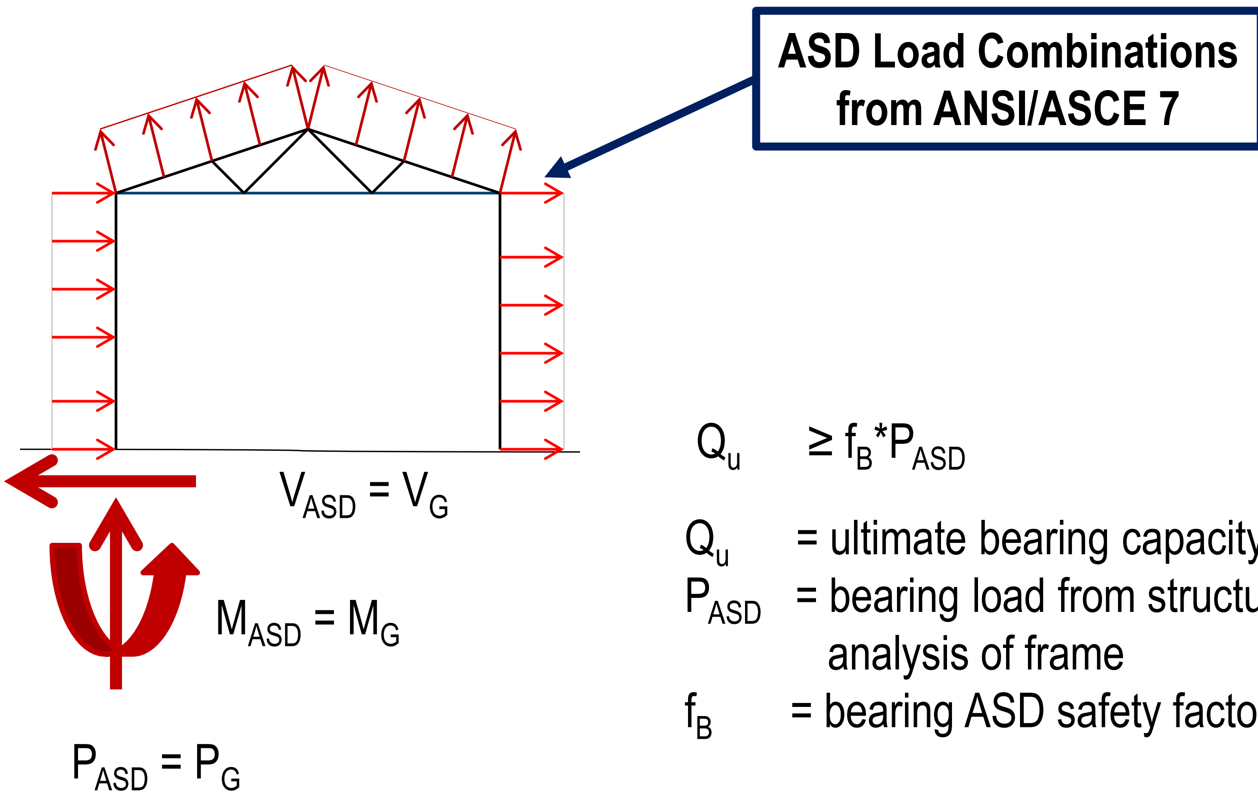
  - Uplift Resistance

  - Lateral Resistance

- **ASD and LRFD Provisions Throughout**

SHALLOW POST & PIER FOUNDATION ASD DESIGN FORMAT

ASD Design Format (Bearing Resistance Example)



$Q_u \geq f_B * P_{ASD}$

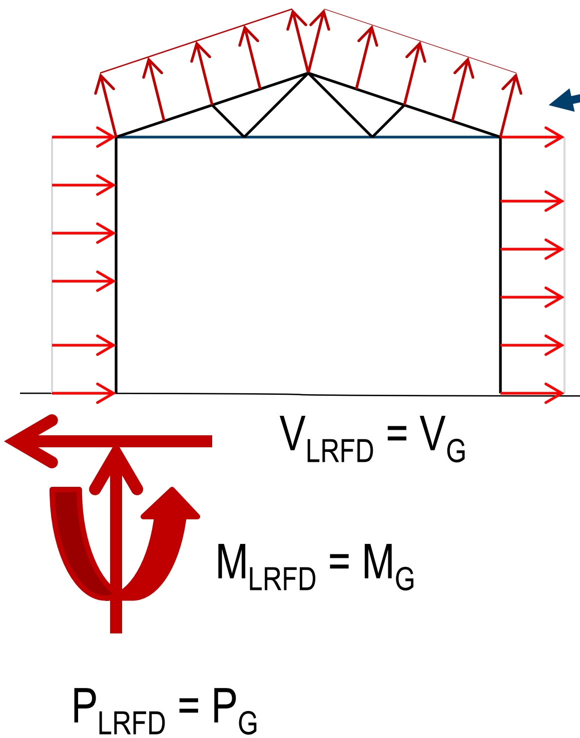
Q_u = ultimate bearing capacity

P_{ASD} = bearing load from structural analysis of frame

f_B = bearing ASD safety factor (Table 5-3)

SHALLOW POST & PIER LRFD FOUNDATION DESIGN FORMAT

LRFD Design Format (Bearing Resistance Example)



LRFD Load Combinations from ANSI/ASCE 7

$$Q_u * R_B \geq P_{LRFD}$$

- Q_u = ultimate bearing capacity
- P_{LRFD} = bearing load from structural analysis of frame with LRFD loads
- R_B = bearing load resistance factor(Table 5-3)

SOIL PROPERTIES FOR SHALLOW POST & PIER FOUNDATION DESIGN

- Engineering Properties of Soils (S. 5.4, PFBDM)

  - E_s : Young's Modulus

  - S_u : Undrained Shear Strength (cohesive soils)

  - ϕ : Soil Friction Angle (cohesionless soils)

  - γ : Moist Unit Weight

SOIL PROPERTIES FOR SHALLOW POST & PIER FOUNDATION DESIGN

- Engineering Properties Based on either:

  - Presumptive Engineering Properties by Unified Soil Class (T5.1 & 5.2, PFBDM)

  - Lab Testing

  - In-Situ Testing, or (S. 5.4.3 – 7, PFBDM)

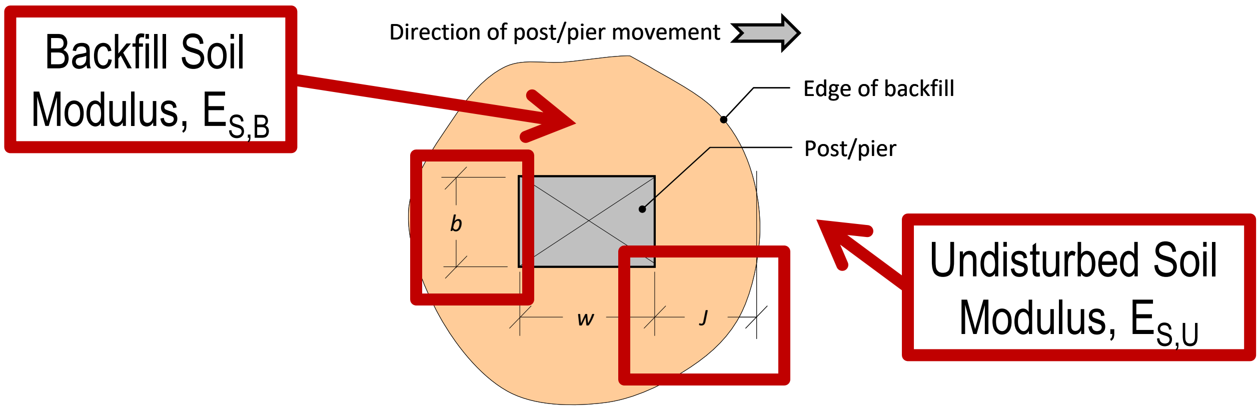
  - Combination of In-Situ & Lab Testing

SAFETY (F_B) AND LRFD LOAD RESISTANCE (R_B) FACTORS

- f_B and R_B Dependent Upon **Source of Soil Properties** (S. 5.7.2, Tables 5.3 to 5.6, PFBDM)
  - Presumptive Tabulated Values **[MOST CONSERVATIVE]**
  - Presumptive Values with Soil Type Verified On-Site
  - Field Testing On-Site
  - Direct Lab Testing **[LEAST CONSERVATIVE]**

EFFECTIVE YOUNG'S MODULUS FOR SHALLOW POST & PIER FOUNDATION DESIGN

Effective Young's Modulus of Soil, E_{SE} (S. 5.6.2, PFBDM)



$$E_{SE} = \frac{1}{I_S / E_{S,B} + (1-I_S)/ E_{S,U}} \quad \text{for } 0 < J < 3b \qquad (5\text{-}2a)$$

$E_{SE} = E_{S,U}$ for $J = 0$ (5-2c)

$E_{SE} = E_{S,B}$ for $J \geq 3b$ (5-2b)

I_S = strain influence factor,

= $[\ln(1 + J/b)]/1.386$ for $0 < J < 3b$ (5-3)

SOIL CLASSIFICATIONS FOR SHALLOW POST & PIER FOUNDATION DESIGN

Unified Soil Classification System
(S. 5.3.9, PFBDM)

Cohesive vs. Cohesionless (non-cohesive) soils
(S. 5.3.5, PFBDM)

UNIFIED SOIL CLASSIFICATION SYSTEM (USCS) FROM ASTM 2487

Table 5.1, PFBDM

Criteria for Assigning Group Symbols and Names Using Laboratory Tests (Based on material passing the 3-inch (75 mm) sieve)				Group Symbol	Typical Names
Course-Grained Soils More than 50% retained on the No. 200 sieve	Gravels 50% or more of course fraction retained on the No. 4 sieve	Clean Gravels (Less than 5% fines[A])	$C_U \geq 4$ and $1 \leq C_C \leq 3$ [B]	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
			$C_U < 4$ and/or $1 > C_C > 3$ [B]	GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
		Gravels with Fines (more than 12% fines[A])	Fines classify as ML or MH	GM[D]	Silty gravels, gravel-sand-silt mixtures
			Fines classify as CL or CH	GC[D]	Clayey gravels, gravel-sand-clay mixtures
	Sands 50% or more of course fraction passes the No. 4 sieve	Clean Sands (Less than 5% fines[C])	$C_U \geq 6$ and $1 \leq C_C \leq 3$ [B]	SW	We... gra... fin...
			$C_U < 6$ and/or $1 > C_C > 3$ [B]	SP	Po... gra... fines
		Sands with Fines (More than 12% fines[C])	Fines classify as ML or MH	SM[D]	Silty sands, sand-silt mixtures
			Fines classify as CL or CH	SC[D]	Clayey sands, sand-clay mixtures
Fine-Grained Soils 50% or more passes the No...	Silts and Clays Liquid Limit less than 50%	Inorganic	PI > 7 and plots on or above "A" line	ML	Inorganic silts, very fine sands, rock four, silty or clayey fine sands
			PI < 4 or plots below "A" line	CL	Inorganic clays of low to medium plasticity, gravelly/s...
		Organic	Oven dried liquid limit divided by regular liquid limit is less than 0.75	OL	Organic s... clays of lo...
			PI plots on or above...		Inorganic...

Cohesionless Soils

Cohesive Soils

PRESUMPTIVE SOIL PROPERTIES FOR SHALLOW POST/PIER FOUNDATION DESIGN

Table 5-2, (PFBDM)

Table 5-2. Presumptive Soil Properties for Post and Pier Foundation Design from ANSI/ASAE EP486.2

Soil Type	Unified Soil Classification	Consistency	Moist unit weight, γ	Drained soil friction angle[(a)], ϕ'	Undrained soil shear strength[(b)], S_U	Young's modulus for soil[(c)(d)], E_S	Increase in Young's modulus per unit depth below grade[(c)(d)(e)], A_E		Poisson's ratio[(f)], ν
			lbf/ft³	deg	lbf/in²	lbf/in²	lbf / in²-ft	lbf / in³	
Homogeneous inorganic clay, sandy or silty clay	CL	Soft	125	NA	3.5	3920	-	-	
		Medium to Stiff	130		7	6160	-	-	
		Very Stiff to Hard	135		14	8400	-	-	
Homogeneous inorganic clay of high plasticity	CH	Soft	110	NA	3.5	1680	-	-	0.5
		Medium to stiff	115		7	2800	-	-	
		Very Stiff to Hard	120		14	4480	-	-	
Inorganic silt, sandy or clayey silt, varved silt-clay-fine sand of low plasticity	ML	Soft	120	NA	3.5	3920	-	-	0.5
		Medium to stiff			7	6160	-	-	
		Very Stiff to Hard			14	8400	-	-	
Inorganic silt, sandy or clayey silt, varved silt-clay-fine sand of high plasticity	MH	Soft	105	NA	3.5	1680	-	-	0.5
		Medium to stiff			7	2800	-	-	
		Very Stiff to Hard			14	4480			
Silty or clayey fine to coarse sand	SM, SC, SP-SM, SP-SC, SW-SM SW-SC	Loose	105	30	NA	-	440	37	0.3
		Medium to Dense	110	35		-	660	55	
		Very Dense	115	40		-	880	73	
Clean sand with little gravel	SW, SP	Loose	115	30	NA	-	880	73	
		Medium to Dense	120	35		-	1320	11	
		Very Dense	125	40		-	1760	14	
Gravel, gravel-sand mixture, boulder-gravel mixtures	GW, GP	Loose	135	35	NA	-	2640	22	
		Medium to Dense		40		-	3520	29	
		Very Dense		45		-	4400	367	
Well-graded mixture of fine- and coarse-grained soil: glacial till, hardpan, boulder clay	GW-GC GC, SC	Loose	120	35	NA	-	1320	110	0.3
		Medium to Dense	125	40		-	1760	147	

Cohesive Soils

Cohesionless Soils

BEARING DESIGN FOR SHALLOW POST & PIER FOUNDATIONS

- **General Governing Bearing Design Equations for ASD or LRFD (S. 5.8, PFBDM)**

$$Q_u = (\mathbf{q_B} - \gamma d_f)A \geq f_B * P_{ASD}$$

$$Q_u * R_B = (\mathbf{q_B} - \gamma d_f)A * R_B \geq P_{LRFD}$$

* Q_u = foundation ultimate bearing load
* d_f = foundation depth
* A = foundation bearing area
* γ = unit weight of soil
* **q_B = ultimate soil bearing capacity**

BEARING DESIGN: ULTIMATE SOIL BEARING CAPACITY (SECTION 5.8,PFBDM)

q_B from one of the following:

- General Bearing Capacity Eqn (Section 5.8.3 & Table 5-7, PFBDM) – **Presumptive Value**
- Standard Penetration Test Results (SPT)- (Section 5.8.4, PFBDM)
- Cone Penetration Test Results (CPT)- (Section 5.8.5, PFBDM)
- Pressuremeter Test Results (PMT)- (Section 5.8.6, PFBDM)

POST FOUNDATION DESIGN: BEARING AREA - ASD

Design Criterion for **Cohesionless Soil & ASD (S. 5.8.1, PFBDM)**

$$Q_u = (q_B - \gamma d_F)/f_B \geq P_{ASD}/A$$

- q_B - Ultimate soil bearing capacity
- γ - soil density
- d_F - foundation depth
- f_B - bearing ASD factor of safety (EP486, T.2)
- P_{ASD} - ASD design bearing load
- A - footing bearing area

$$A = P_{ASD} f_B/(q_B - \gamma d_F)$$

POST FOUNDATION DESIGN: BEARING RESISTANCE

Assuming water table much deeper than footing depth and footing diameter, B, and using the **general bearing capacity equation** (C_{w1} and C_{w2} = 1.0)

$q_B = \gamma(0.5BN_\gamma s_\gamma + d_F N_q d_q s_q)$ (S. 5.8.3, PFBDM)

Term-values in q_B equation tabulated in Section 5.8.3 and Table 5.7, PFBDM for a range of soil properties

ϕ (T. 5-2)	γ (T. 5-2)
s_γ (S. 5.8.3)	
N_q (T. 5.7)	N_γ (T. 5.7)
d_q (T. 5.7)	s_q (T. 5.7)

Using presumptive soil properties from Table 5.7, PFBDM

$f_B = 1.4/(0.77 – 0.01\phi)$ (Table 5.3, PFBDM)

SHALLOW POST & PIER FOUNDATION DESIGN: LATERAL RESISTANCE

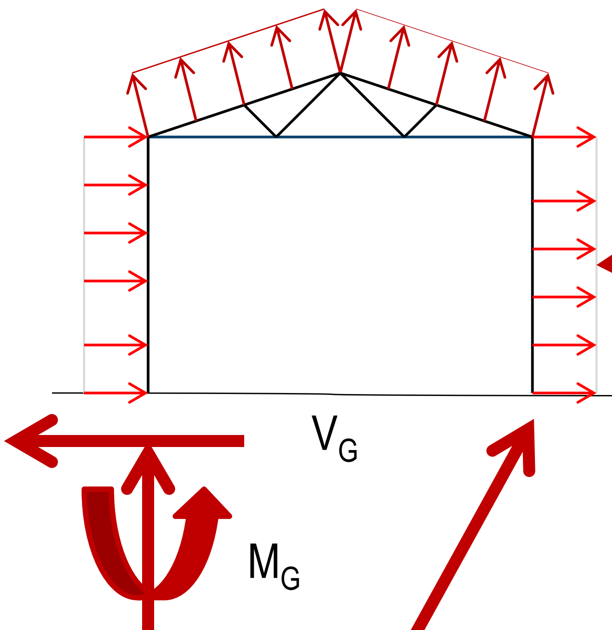
Two Issues

- Structural Analogs for Determining Post-Frame Groundline Shear & Moment (V_G & M_G)

- Methods for Determining Post/Pier **ULTIMATE** Lateral Load Capacity (V_u & M_u) & Embedment Depth

SHALLOW POST & PIER FOUNDATION DESIGN: LATERAL RESISTANCE

Design Ground-line Shear (V_G) and Moment, (M_G)



ASD or LRFD Load Combinations per ASCE/SEI 7

What end conditions to use for structural analysis of PF???

$$V_G = V_{ASD} \text{ or } V_{LRFD}$$

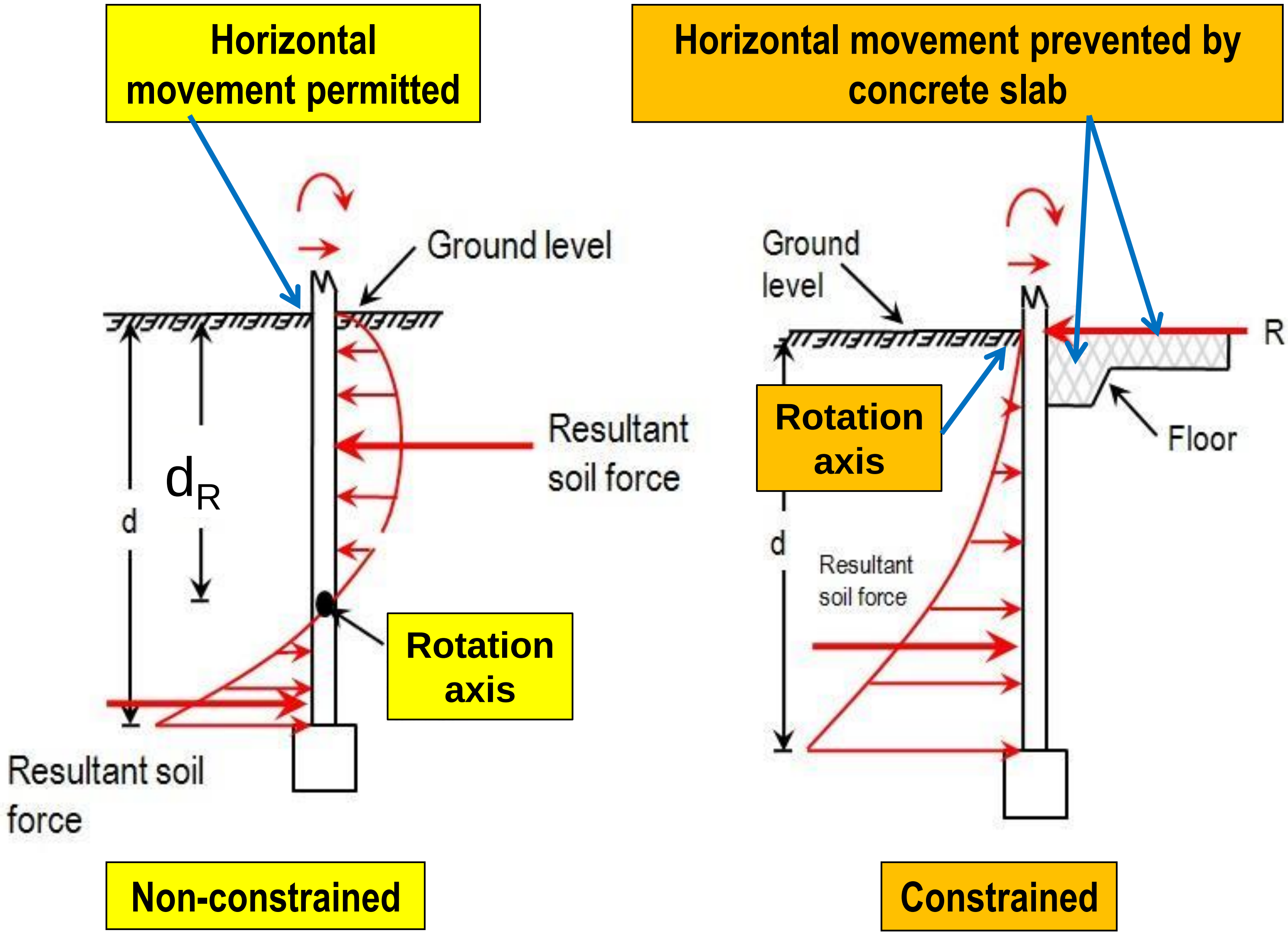
$$M_G = M_{ASD} \text{ or } M_{LRFD}$$

SHALLOW POST & PIER FOUNDATION DESIGN: POST-SOIL FIXITY MODELS

- Two post-soil fixity models for embedded post or pier foundations:
  - Constrained post or pier
  - Non-constrained post or pier

CONSTRAINED VS. NON-CONSTRAINED POSTS & PIERS

S. 5.2.4, PFBDM



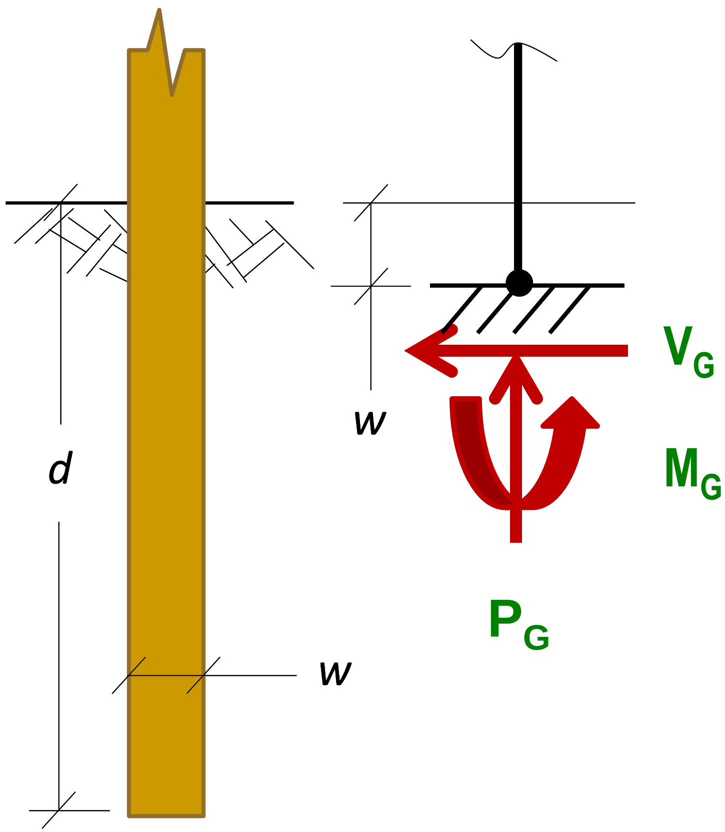
SHALLOW POST & PIER FOUNDATIONS: GROUNDLINE POST-SOIL INTERACTION

Structural Analogs for Groundline Post-Soil Interaction – Two Approaches

- **Simplified Method (S. 5.6 & 6.3.3.2, PFBDM)**
- Universal Method (S. 5.6, PFBDM)

NON-CONSTRAINED POST & PIERS: M_G & V_G BY SIMPLIFIED METHOD

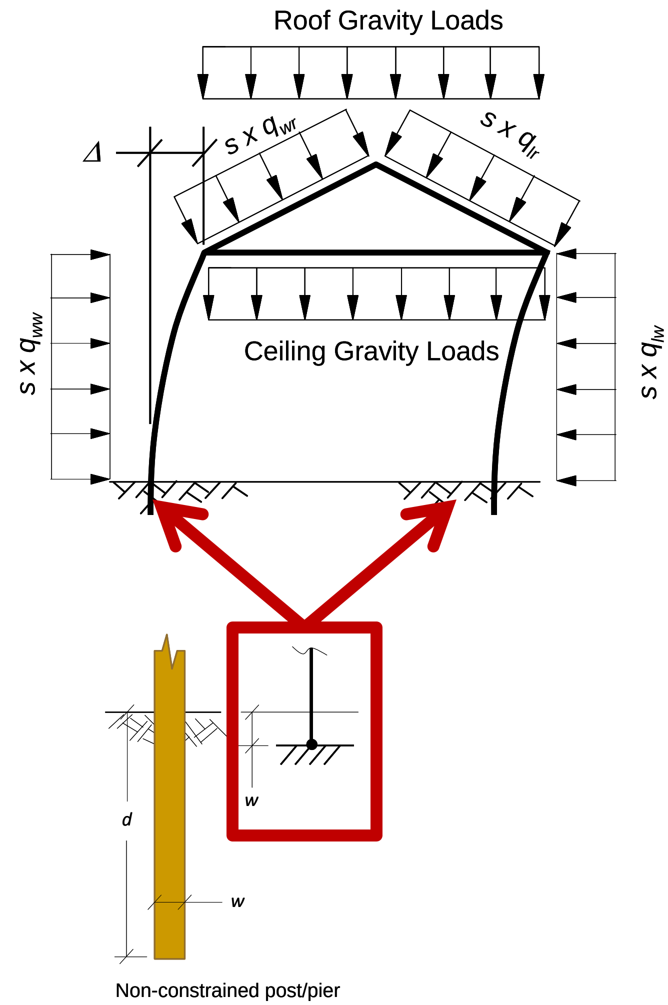
Simplified Method – V_G & M_G



Non-Constrained Post/Pier

- Fixed end at depth w below grade
- w = face width of post bearing against soil

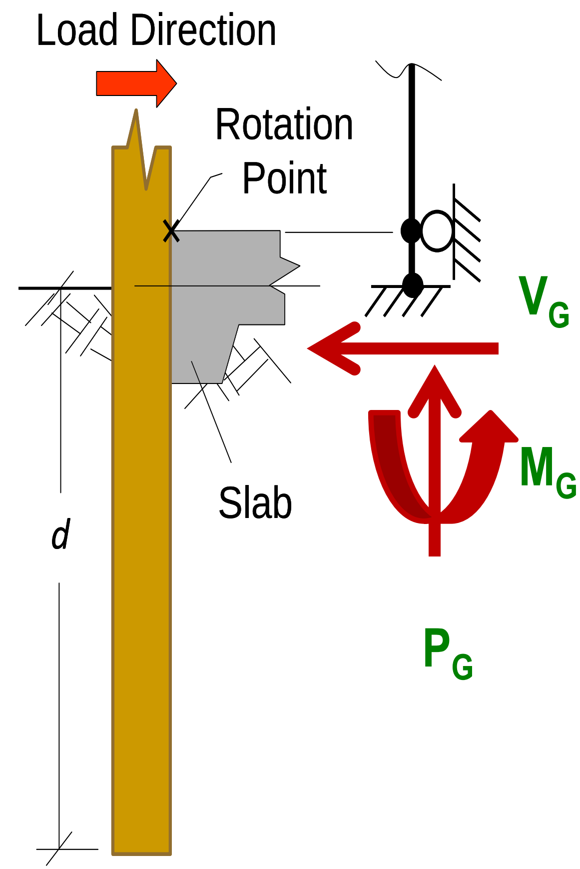
STRUCTURAL ANALOG FOR NON-CONSTRAINED PIER FOUNDATION V_G & M_G



CONSTRAINED POST & PIERS: M_G & V_G BY SIMPLIFIED METHOD

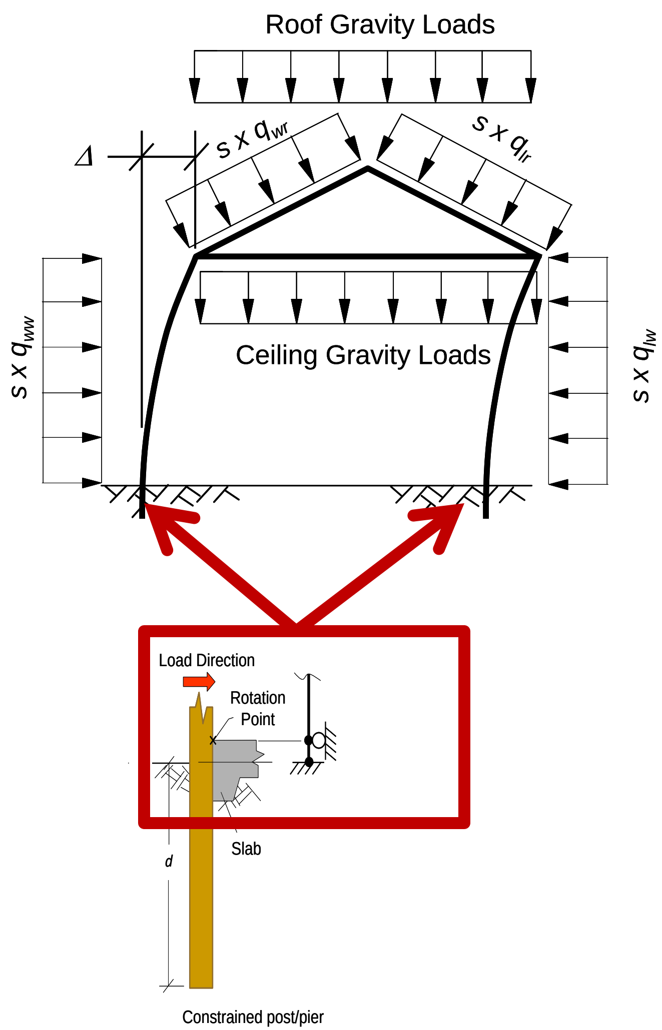
Simplified Model-V_G & M_G

- Vertical roller at top edge of slab
- Fixed end at ground line

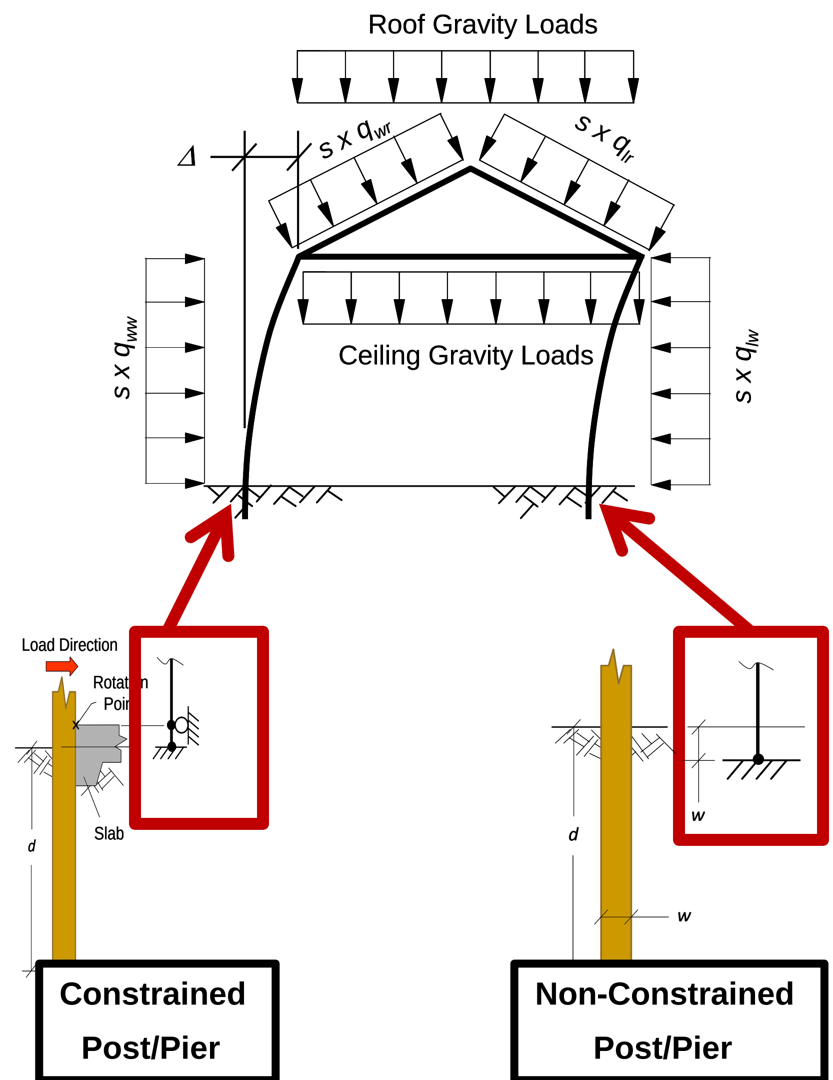


Constrained Post/Pier

STRUCTURAL ANALOG FOR CONSTRAINED PIER FOUNDATION V_G & M_G



STRUCTURAL ANALOGS FOR V_G & M_G CALCS: SIMPLIFIED METHOD



REQURED CONDITIONS FOR USING SIMPLIFIED METHOD

Simplified Method Requirements for V_G & M_G Calcs

(S. 5.6.6, PFBDM)

- Homogeneous soil throughout the entire embedment depth
- Constant or linearly increasing soil stiffness for all depths below grade
- Width of the below-grade portion of the foundation is constant
- Below grade portion of the foundation approximates infinite flexural rigidity (EI)

INFINITE STIFFNESS CRITERIA FOR SIMPLIFIED METHOD

(S. 5.6.6, PFBDM)

- $d \leq 2\{E\,I/(2A_E)\}^{0.20}$ (cohesionless soils)

- $d \leq 2\{E\,I/(2E_S)\}^{0.25}$ (cohesive soils)

where * *d* is depth of embedment;

* *EI* is flexural rigidity of the post/pier

* E_S is Young's modulus of the soil

* A_E is the linear increase in Young's modulus of soil with depth below grade

LATERAL LOAD RESISTANCE (V_U & M_U) AND EMBEDMENT DEPTH CALCS

Two Design Approaches

- **Simplified Method**
- Universal Method

SHALLOW POST & PIER FOUNDATION DESIGN

Simplified Method Requirements for V_u & M_u Calcs S. 5.9.3

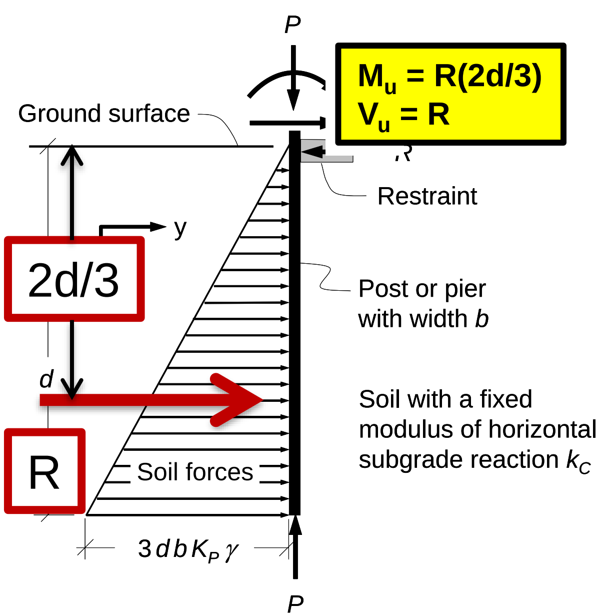
- Homogeneous soil throughout the entire embedment depth
- Constant or linearly increasing soil stiffness for all depths below grade
- Width of the below-grade portion of the foundation is constant

NOTE: Infinite rigidity of post/pier foundation not required for simplified method V_u & M_u calcs

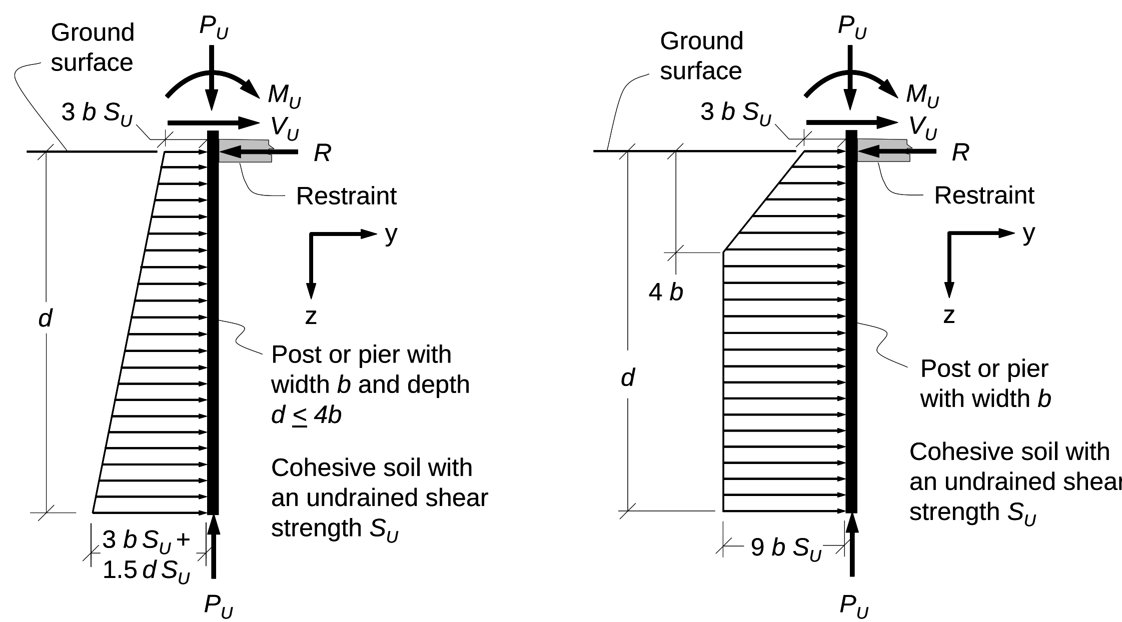
LATERAL LOAD RESISTANCE & EMBEDMENT DEPTH

(S. 5.9.3.4-5, PFBDM)

Simplified Method: Constrained at Ground Surface



Case 1
Cohesionless Soil



Case 2
Cohesive Soil

(a) d ≤ 4b

(b) d > 4b

LATERAL LOAD RESISTANCE & EMBEDMENT DEPTH

Constrained at Ground Surface – Design Criteria

CASE 1: (Cohesionless Soil)

ASD

LRFD

$$M_u = R(2d/3) = d^3 b K_p \gamma \geq M_G(f_L \text{ or } 1/R_L)$$

M_u = ultimate groundline moment capacity

d = embedment depth

b = foundation width bearing against soil

γ = soil density

K_p = passive pressure coefficient $(1 + \sin\varphi)/(1 - \sin\varphi)$

M_G = groundline moment (from structural analysis)

f_L = lateral resistance factor of safety (ASD)

R_L = load resistance factor (LRFD)

LATERAL LOAD RESISTANCE & EMBEDMENT DEPTH

Constrained at Ground Surface – Design Equation

CASE 2: (Cohesive Soil)

(a) $d \leq 4b$

$$M_u = d^3 b S_u[3/2 + d/(2b)] \geq M_G(f_L \text{ or } 1/R_L)$$

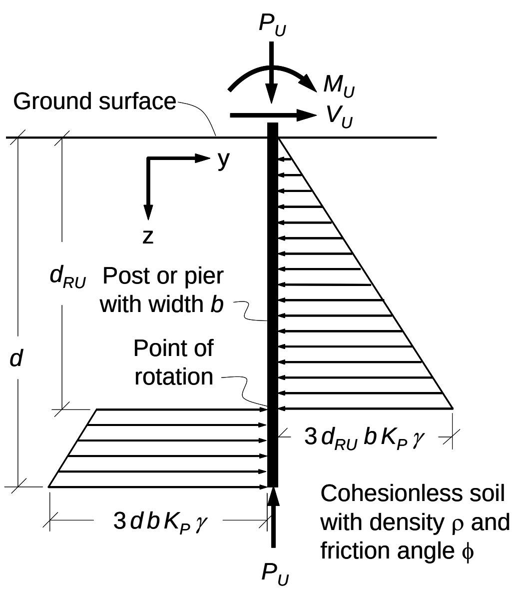
(b) $d > 4b$

$$M_u = bS_u(4.5d^2 - 16b^2) \geq M_G(f_L \text{ or } 1/R_L)$$

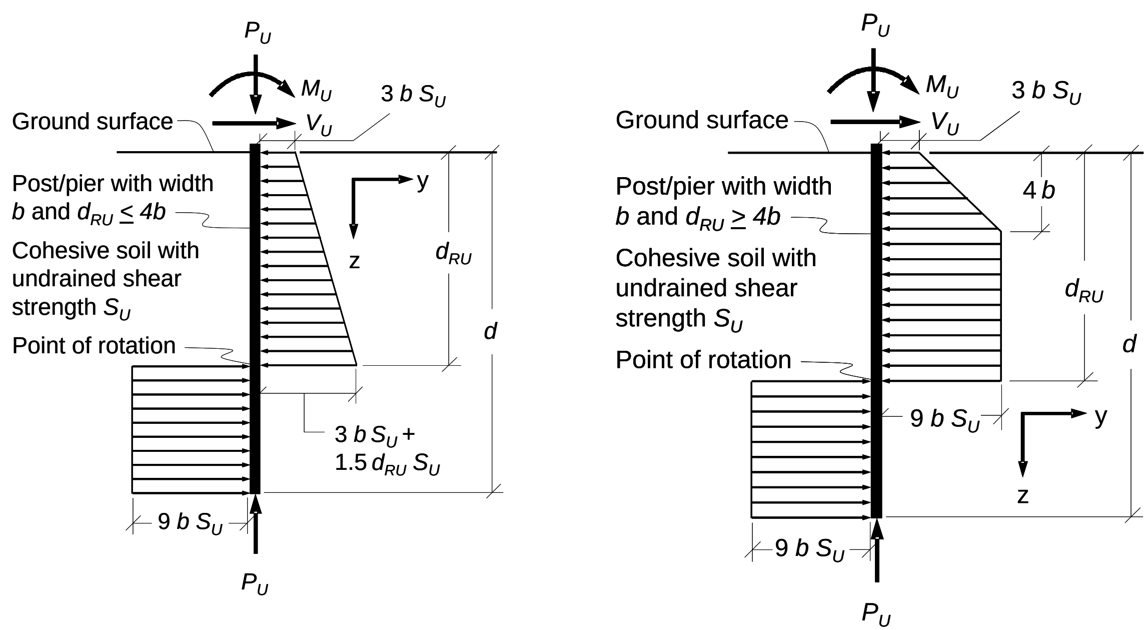
where S_u = Soil undrained shear strength (soil cohesion)

LATERAL LOAD RESISTANCE & EMBEDMENT DEPTH

Simplified Method: Non-Constrained at Ground Surface



Case 1
Cohesionless Soil



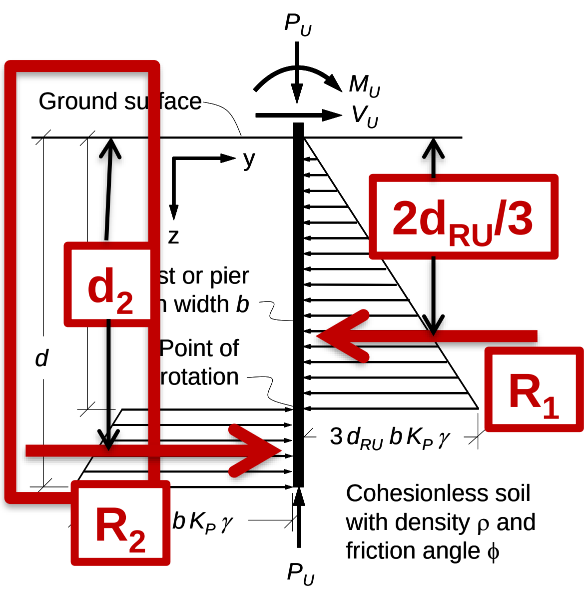
Case 2
Cohesive Soil

(a) d_{Ru} ≤ 4b and d > 4b

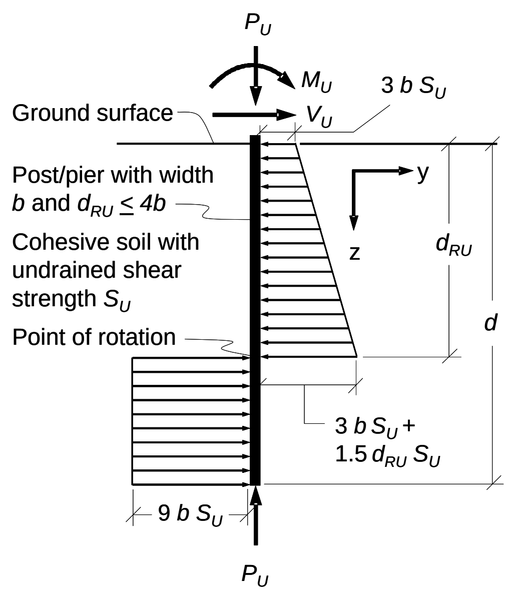
(b) d_{Ru} > 4b and d > 4b

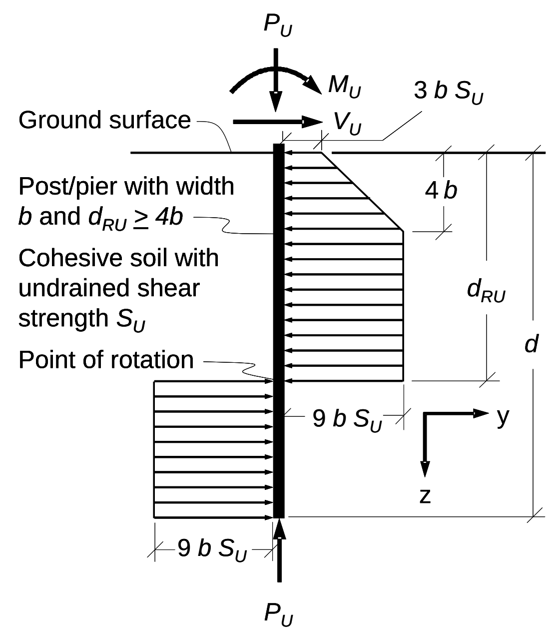
LATERAL LOAD RESISTANCE & EMBEDMENT DEPTH

Simplified Method: Non-Constrained at Ground Surface



Case 1
Cohesionless Soil





Case 2
Cohesive Soil

(a) $d_{Ru} \leq 4b$ and
$d > 4b$

(b) $d_{Ru} > 4b$ and
$d > 4b$

LATERAL LOAD RESISTANCE & EMBEDMENT DEPTH: NON-CONSTRAINED

Non-constrained at Ground Surface

Case 1: (Cohesionless Soil)

$M_u = R_1(2d_{RU}/3) + R_2(d_2) = S_{Lu}(d^3 - 2d_{Ru}{}^3)/3 \geq f_L M_G$

$S_{Lu} = 3bK_p\gamma$ (increase per unit depth in the ultimate lateral load applied to a foundation by a cohesionless soil)

$d_{Ru} = (V_u/S_{Lu} + d^2/2)^{0.5} \geq 0$

$V_u = V_{LRFD}/R_L$ for LRFD

$V_u = V_{ASD}(f_L)$ for ASD

LATERAL LOAD RESISTANCE & EMBEDMENT DEPTH: NON-CONSTRAINED

Non-constrained at Ground Surface

Case 2: (Cohesive Soil)

(a) $d_{Ru} < 4b$

$$M_u = bS_u[4.5\, d^2 - 6d_{Ru}^{\,2} - d_{Ru}^{\,3}/(2b)] \geq f_L M_G$$

where S_u = undrained shear strength (cohesive strength) of soil

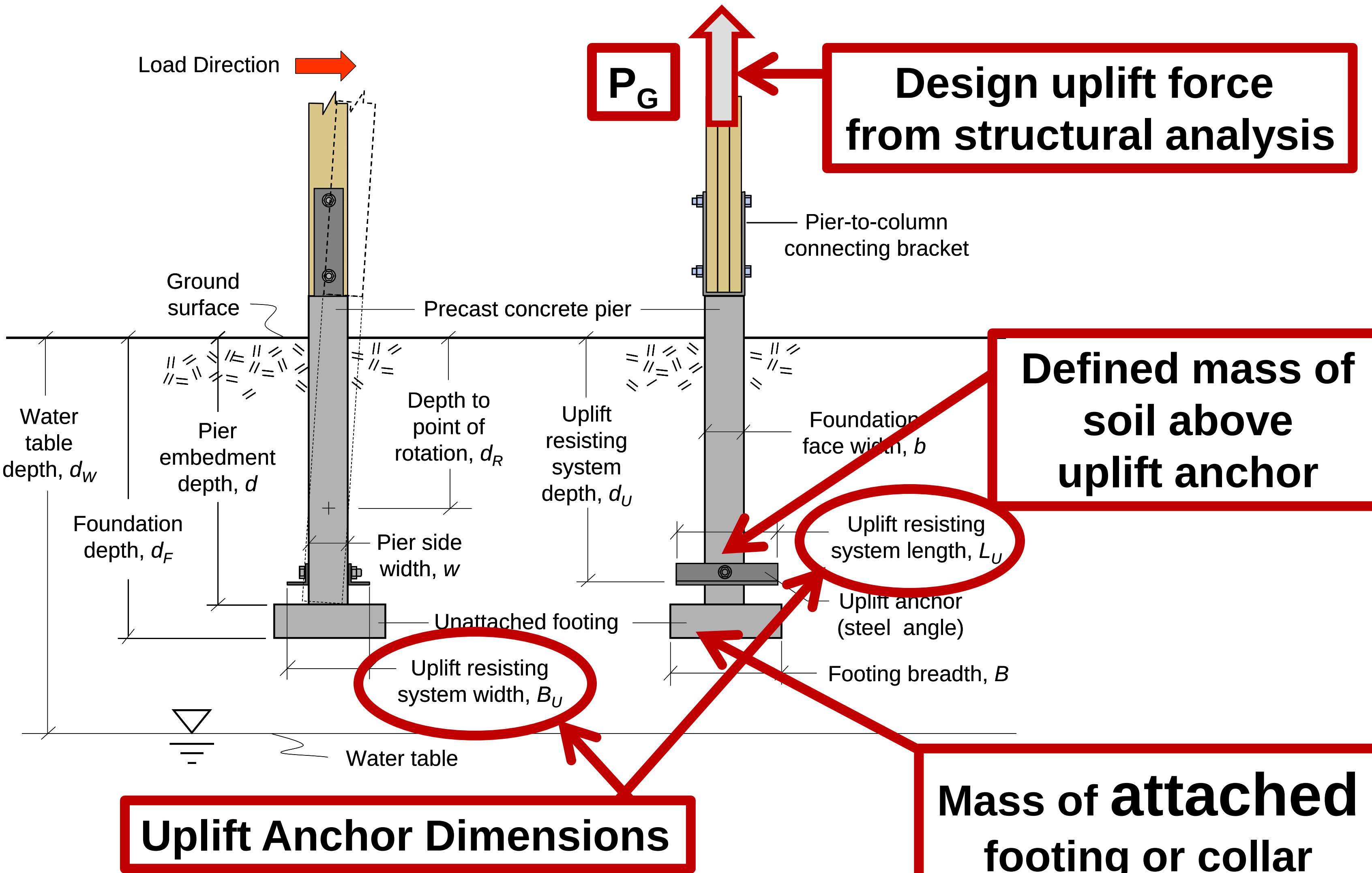
$$d_{Ru} = [64b^2 + 4V_u/(3S_u) + 12\, bd]^{0.5} - 8b \leq d$$

(b) $d_{Ru} \geq 4b$

$$M_u = 9bS_u(d^2/2 - d_{Ru}^{\,2} + 16b^2/9) \geq f_L M_G$$

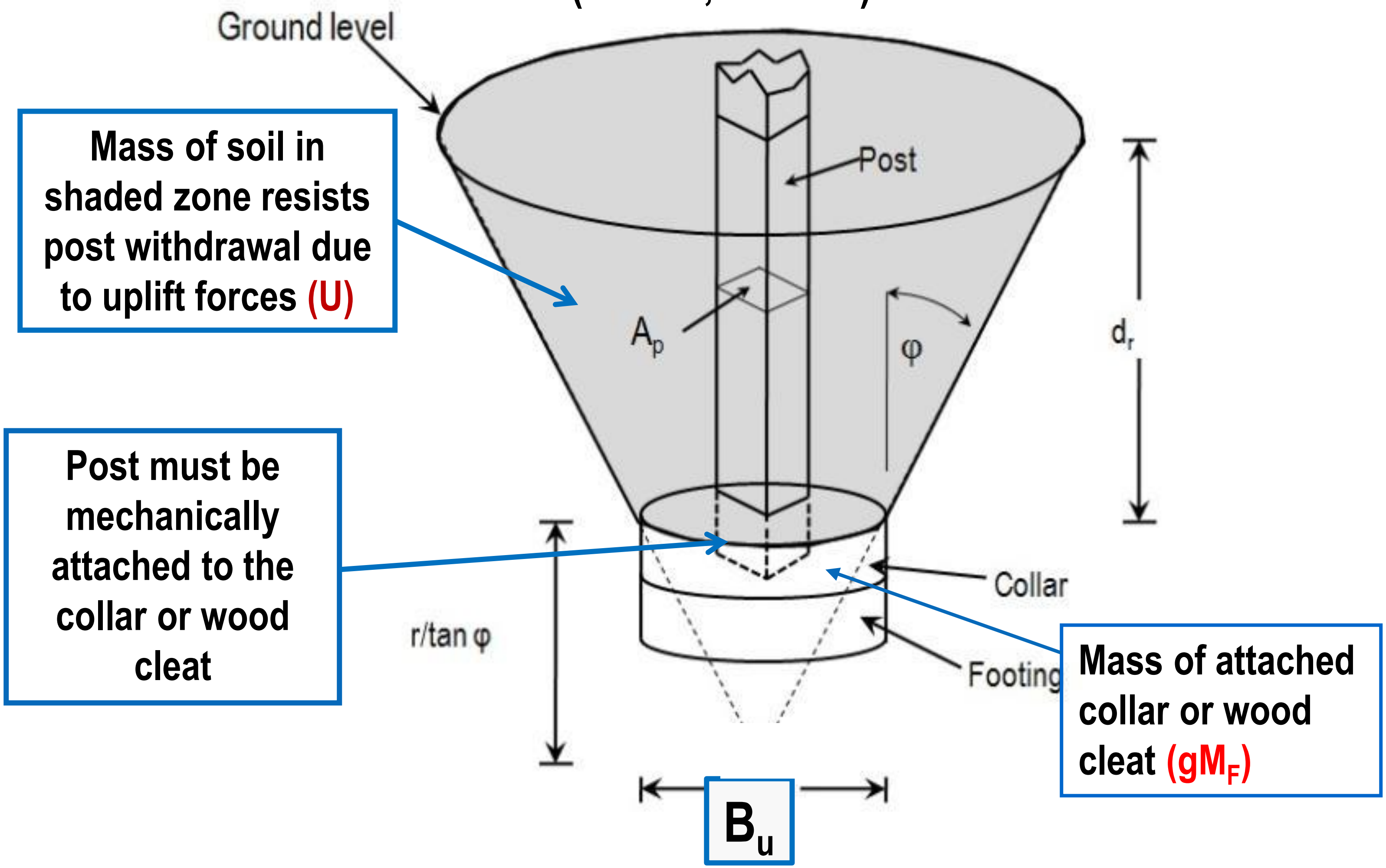
where $d_{Ru} = V_u/(18bS_u) + d/2 + 2b/3 \leq d$

POST/PIER FOUNDATION EMBEDMENT: UPLIFT RESISTANCE ELEMENTS



SHALLOW POST & PIER EMBEDMENT DESIGN: UPLIFT RESISTANCE

(S. 5.10, PFBDM)



SHALLOW POST & PIER FOUNDATION DESIGN – UPLIFT DESIGN CRITERIA

Governing Design Equations (S. 5.10.1, PFBDM)

$U \geq f_U(P_{ASD} - gM_F)$ ------ ASD

$U^*R_U \geq P_{LRFD} - gM_F$ ----------LRFD

- U = soil ultimate uplift resistance
- P_{ASD} & P_{LRFD} = design uplift force
- gM_F = weight of attached uplift anchors
- f_U = uplift factor of safety
- R_U = uplift load resistance factor

SHALLOW POST & PIER FOUNDATION DESIGN – UPLIFT RESISTANCE, U

U-value equations provided in ASAE/ANSI EP 486.2 and PFBDM for several cases

- Cohesive soils – circular uplift anchors
- Cohesive soils – rectangular uplift anchors
- Cohesionless soils – circular uplift anchors (shallow and deep foundations)
- Cohesionless soils – rectangular uplift anchors (shallow and deep foundations)

SHALLOW POST & PIER FOUNDATION DESIGN – UPLIFT RESISTANCE, U

U-value equations provided in ASAE/ANSI EP 486.2 and PFBDM for several cases

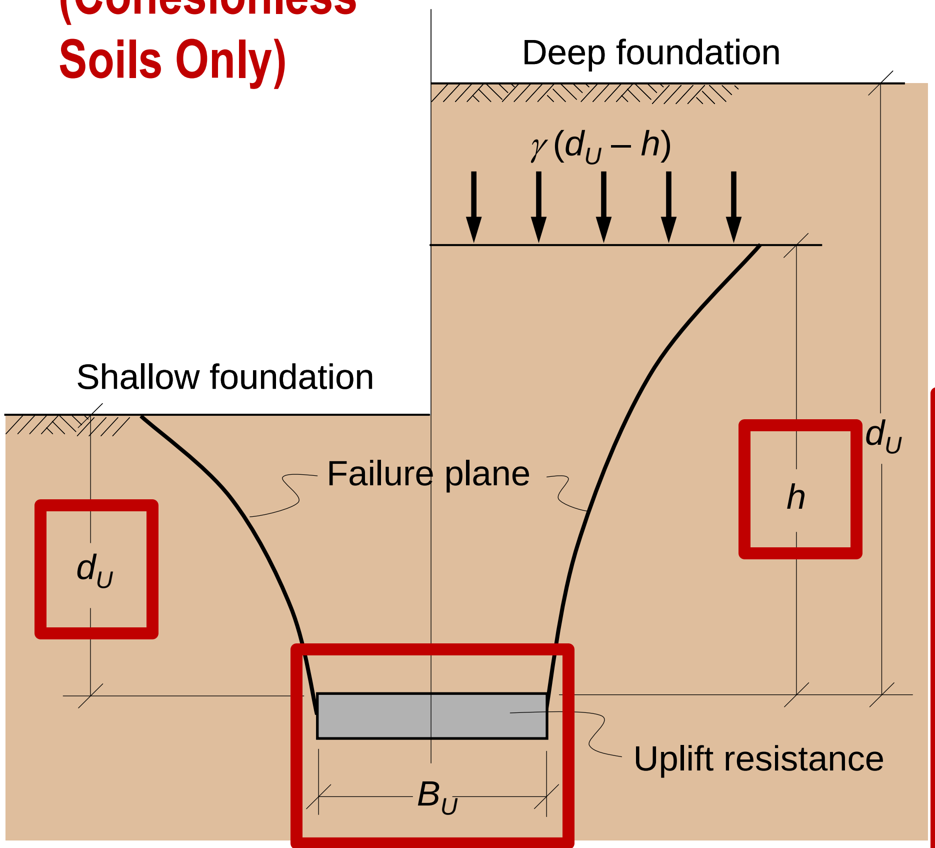
- Cohesive soils – circular uplift anchors
- Cohesive soils – rectangular uplift anchors
- Cohesionless soils – circular uplift anchors
- s)
- (shallow and deep foundations)

See ANSI/ASAE EP486.3 or PFBDM-2015 (Chapter 5, Section 5.10.3) for U- Design Equations

POST/PIER FOUNDATIONS: UPLIFT RESISTANCE, U

Shallow vs. Deep Foundations (S. 5.10.3, PFBDM)

(Cohesionless Soils Only)



Shallow: $d_u \leq h$

Deep: $d_u \geq h$

$h = 2.5B_u$ if $\phi \leq 20$

$h = B_u(5.78 - 0.350\,\phi + 0.00947\,\phi^2)$ if $\phi > 20$

ϕ = soil internal friction angle

UPLIFT RESISTANCE, U, OF SOIL ABOVE CIRCULAR CYLINDRICAL ANCHOR SYSTEM

Cohesive Soils (S. 5.10.4, PFBDM)

$$U = \gamma d_u(B_u^2\pi/4 - A_p) + F_c S_u B_u^2\pi/4$$

- d_u = embedment depth **to uplift anchor**
- γ = soil density
- B_u = anchor diameter
- A_p = post cross sectional area
- F_c = breakout factor for soil uplift ($1.2d_u/B_u$)
- S_u = undrained soil shear strength

DESIGN EXAMPLE 1: CONSTRAINED POST & COHESIONLESS SOIL

- Design **Constrained Post/Pier** Foundation in **Cohesionless Soil** for Gravity & Lateral Loads by Simplified Method – **Presumptive soil props w/ soil type verified by field testing (Uplift design covered in Example 5)**

  - Post foundation

  - **Medium to dense silty or clayey** fine to coarse sand– verified by construction testing **(SP/SC);** uniform throughout embedment depth

EXAMPLE 1: LATERAL & GRAVITY LOAD RESISTANCE

ASD Groundline Design Loads (Examples 1 thru 4)

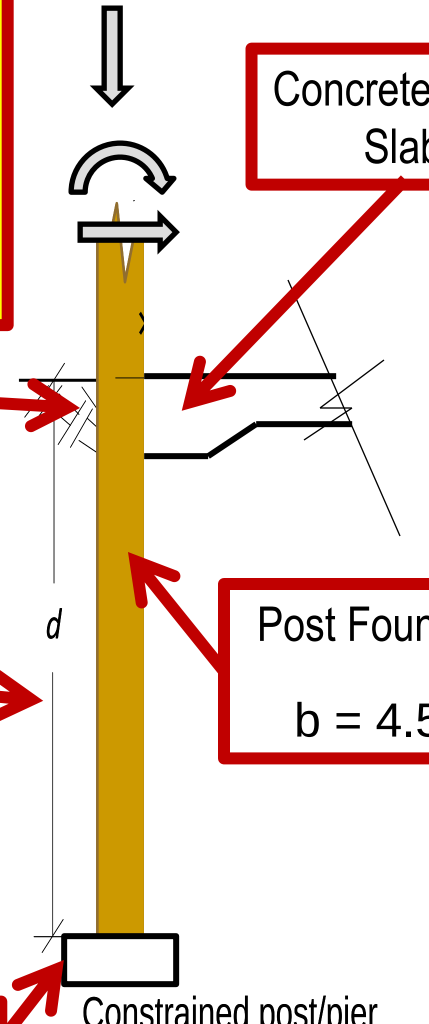
P_G = 4,800 lb

M_G = 4,600 lb.ft

V_G = 980 lb

Concrete Floor Slab

Constrained Post Foundation



Medium to dense silty or clayey fine to coarse sand – verified by construction testing (SP/SC); uniform throughout embedment depth

ϕ = 35; γ = 110 pcf (Table 5.2, PFBDM)

Post Foundation

b = 4.5 in.

Unattached Footing

EXAMPLE 1: POST FOUNDATION BEARING RESISTANCE DESIGN

Post-foundation footing design

Design Criterion for Cohesionless Soil (Sect. 5.8.3, PFBDM)

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

q_B - Ultimate soil bearing capacity

γ - soil density **(110 pcf)**

d_F - foundation depth **(Assume 4.5 ft)**

f_B - bearing ASD factor of safety

P_{ASD} - ASD design bearing load **(4,800 lb)**

A - footing bearing area

EXAMPLE 1: POST FOUNDATION BEARING RESISTANCE DESIGN

Assuming water table much deeper than footing depth and footing diameter, B, of 1.5 ft

$q_B = \gamma(0.5BN_\gamma s_\gamma + d_F N_q d_q s_q)$ (Sect. 5.8.3, PFBDM)

From PFBDM, Section 5.8.3 and Tables 5.2 and 5.7

$\phi = 35$ & $\gamma = 110$ (Table 5.2)
$s_\gamma = 0.60$ (Section 5.8.3)
$s_q = 1 + \tan\phi = 1.70$ (Section 5.8.3)

$N_q = 33.29$ & $N_\gamma = 48.02$ (Table 5.7)
$d_q = 1.32$ for $d_F/B = 4.5/1.5$ (Table 5.7)

Substituting, $q_B = 39{,}355$ psf

EXAMPLE 1: POST FOUNDATION BEARING RESISTANCE DESIGN

Rearranging the bearing area design criteria and using the bearing factor of safety

$f_B = 1.4/(0.77 – 0.01\phi) = 3.33$ (Table 5.3, PFBDM)

$A = P_{ASD}f_B/(q_B – \gamma d_F) = 3.33$**(4,800)**$/[39,355 - (110)(4.50)]$

= **0.41** ft^2

Footing diameter = sqrt[4A/π] = sqrt[4**(0.38)/**3.14]

= **0.72 ft (Recommend 16 to18 in min)**

EXAMPLE 1: POST FOUNDATION LATERAL RESISTANCE DESIGN

Design Criteria (Section 5.9.3.4, PFBDM)

$M_u = d^3 b K_p \gamma$ = Ultimate Moment for **Constrained Post/Pier in Cohesionless Soil**

And $M_G \leq M_u/f_L$

- d – embedment depth
- b – face width of embedded column **(0.38 ft)**
- K_p – $(1+\sin\phi)/(1 - \sin\phi)$
- γ – soil density **(110 pcf)**
- f_L – ASD factor of safety for lateral resistance
- M_G – ground surface moment **(4,600 lb-ft)**

EXAMPLE 1: POST FOUNDATION LATERAL RESISTANCE DESIGN

- Presumptive Soil Properties (Table 5.2, PFBDM)

  ϕ = 35 deg. γ = 110 pcf

- Lateral Foundation Design Factor of Safety (Table 5.5, PFBDM) (Soil Type verified at construction site)

  $f_L = 1.4/(0.80 - 0.01\phi) = 3.11$

- $K_p = (1+\sin 35)/(1 - \sin 35) = 3.65$

EXAMPLE 1: POST FOUNDATION LATERAL RESISTANCE DESIGN

- Substituting **z = d = 4.33 ft**. into the design criteria

  $M_u = [(4.33)^3](0.38)(3.65)(110) = 12,386$ lb-ft

  $M_u/f_L = 12,386/3.11 = 3,983$ lb-ft $\leq M_G = 4,600$ lb-ft

  Thus, a deeper embedment depth required

- Substituting **z = d = 4.5 ft** into the design criteria yields

  $M_u/f_L = 14,197/3.11 = 4,565$lb-ft $\approx M_G = 4,600$ lb-ft

  Thus depth of 4.5 ft is satisfactory

EXAMPLE 1: CLOSURE

- Experience dictates that this embedment depth could be reduced by

  - Attaching a lateral force resisting collar near the post/pier bottom (Example No. 5)

  - Using less conservative method for determining soil properties to reduce factor of safety

DESIGN EXAMPLE 2: PRESUMPTIVE SOIL PROPERTIES – LATERAL LOADS

- Design **Constrained** Post/Pier Foundation in **Cohesionless Soil** for Lateral Loads by Simplified Method – **Presumptive soil props from Table 5-2, PFBDM)**
  - All loads and foundation details same as in Example 1 except source of soil properties
  - Lateral resistance factor of safety, $\mathbf{f_L}$, is the only design change

$$f_L = 1.4/[0.60 - 0.01\phi] = 1.4/[0.60-0.01(35)] = 5.60$$

(T. 5.5, PFBDM)

EXAMPLE 2: POST FOUNDATION LATERAL RESISTANCE DESIGN

$M_u = d^3 b K_p \gamma$ = Ultimate Moment for Constrained Post/Pier in Cohesionless Soil (Section 5.9.3.4, PFBDM)

- Substituting **z = d = 5.5 ft.** into the design criteria
  $M_u = [(5.75)^3](0.38)(3.65)(110) = 25{,}383$ lb-ft

  $M_u/f_L = 25{,}383/\mathbf{5.60} = 4{,}532$ lb-ft $\leq M_G = 4{,}600$ lb-ft

- Substituting **z = d = 5.6 ft** into the design criteria yields
  $M_u/f_L = 26{,}797/5.60 = 4{,}785$ lb-ft $> M_G = 4{,}600$ lb-ft

Thus depth of 5.6 ft required (compared to 4.6 ft in Example 1)

DESIGN EXAMPLE 3: LATERAL LOAD RESISTANCE -CONSTRAINED POST & COHESIVE SOIL

- Design **Constrained Post/Pier** Foundation in **Cohesive Soil** for Lateral Loads by Simplified Method – **Presumptive soil props from Table 5-2, PFBDM with soil type verified by field tests)**
- - All loads and foundation details same as in Example 1 except soil type to a cohesive soil **(Medium stiff sandy or clayey silt - ML)** with soil props verified by construction testing

  - uniform soil throughout embedment depth

EXAMPLE 3: LATERAL LOAD RESISTANCE

ASD Groundline Design Loads (Examples 1 thru 4)

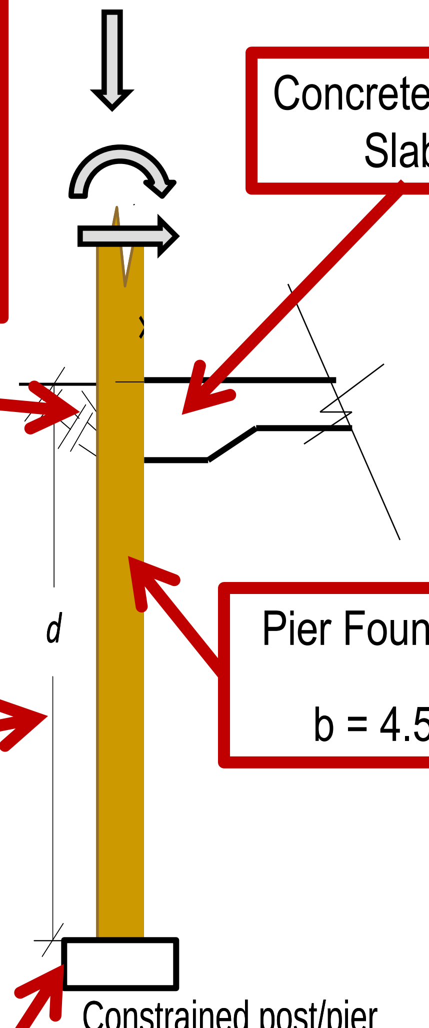
P_G = 4,800 lb

M_G = 4,600 lb.ft

V_G = 980 lb

Concrete Floor Slab

Constrained Post Foundation



Pier Foundation

b = 4.5 in.

Cohesive soil (Medium stiff sandy or clayey silt ML) with soil props verified by construction testing; uniform soil throughout embedment depth

S_u = 7 psi and γ = 120 pcf

(PFBDM, Table 5.2)

Unattached Footing

EXAMPLE 3: POST FOUNDATION LATERAL RESISTANCE DESIGN – COHESIVE SOIL

Design Criteria (Section 5.9.3.2, PFBDM)

$d > 4b$

$M_u = bS_u(4.5d^2 - 16b^2) \geq M_G(f_L)$

- M_u - ultimate moment capacity
- M_G – ASD design moment **(4,600 lb.ft)**
- d – embedment depth
- b – face width of embedded column **(0.38 ft)**
- **S_u** - undrained soil shear strength **(7 psi)**
- f_L – ASD factor of safety for lateral resistance

EXAMPLE 3: POST FOUNDATION LATERAL RESISTANCE DESIGN – COHESIVE SOIL

- Presumptive Soil Properties (PFBDM, Table 5.2)

  S_u = 7 psi or 1008 psf γ = 120 pcf

- Lateral Foundation Design Factor of Safety – Soil Type verified at construction site (Table 5.5, PFBDM)

  f_L = 2.2

EXAMPLE 3: POST FOUNDATION LATERAL RESISTANCE DESIGN – COHESIVE SOIL

- Substituting **z = d = 4.5 ft**. into the design criterion

$$\mathbf{M_u = bS_u(4.5d^2 - 16b^2) \geq M_G(f_L)}$$

$$M_u = (0.38)(1008)[\,(4.5)(4.5)^2 - 16(0.38)^2] = 34{,}020 \text{ lb.ft}$$

$$M_u/f_L = 34{,}020/2.2 = 15{,}463 \text{ lb-ft} \gg M_G = 4{,}600 \text{ lb-ft}$$

EXAMPLE 3: POST FOUNDATION LATERAL RESISTANCE DESIGN – COHESIVE SOIL

- Substituting **z = d = 3.5 f**t into the design criterion yields

  M_u = 20,390 lb.ft

  and M_u/f_L = 20,390/2.2 = 9,268 lb.ft >> M_G = 4,600 lb.ft

- Substituting **z = d = 2.6** ft into the design criterion yields

  M_u = 10,853 lb.ft and M_u/f_L = 4,933 lb.ft ≈ M_G = 4,600 lb-ft

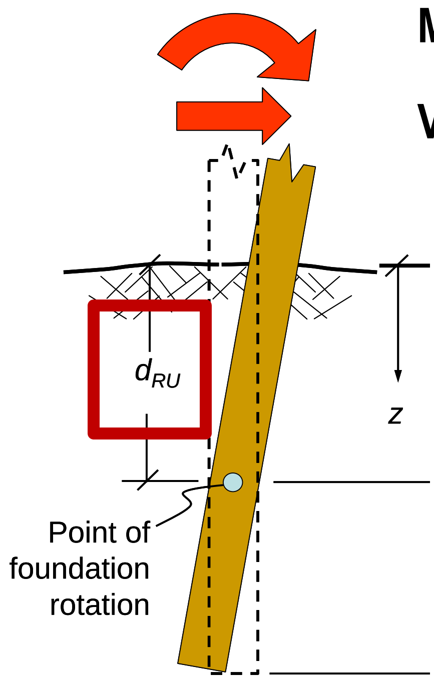
  Thus a 2.6 ft embedment depth ft is satisfactory (but don’t recommend using less than 3.5 ft to accommodate minimum frost depth requirements, etc)

DESIGN EXAMPLE 4: LATERAL LOAD RESISTANCE FOR NON-CONSTRAINED POST & COHESIVE SOIL

- Design **Non-Constrained** Post/Pier Foundation in **Cohesive** Soil for Lateral Loads by Simplified Method – **Presumptive soil props from Table 5-2, PFBDM with soil type verified by field tests)**

- All loads and foundation details same as in Example 3 except ground restraint changed to non-constrained

EXAMPLE 4: NON-CONSTRAINED POST



M_G = 4,600 lb.ft

V_G = 980 lb

Non-Constrained Post Foundation

Cohesive soil (Medium Stiff Sandy or Clayey Silt (ML) – verified by construction testing; uniform soil throughout embedment depth

S_u = 7 psi and γ = 120 pcf
(PFBDM, Table 5.2)

EXAMPLE 4: POST FOUNDATION LATERAL RESISTANCE DESIGN

Design Criteria (Section 5.9.3.2, PFBDM)

$d_{Ru} \geq 4b$

- **$M_u = 9bS_u(d^2/2 - d_{Ru}^2 + 16b^2/9) \geq M_G f_L$**
- **And $d_{Ru} = V_u/(18bS_u) + d/2 + 2b/3 \leq d$**

M_u - ultimate moment capacity

d_{Ru} - depth to rotation axis at ultimate load

d – embedment depth

b – face width of embedded post/pier **(0.38 ft)**

S_u **-** undrained soil shear strength **(7 psi)**

V_u - ultimate shear load (V_G*f_L)

f_L – ASD factor of safety for lateral resistance

EXAMPLE 4: POST FOUNDATION LATERAL RESISTANCE DESIGN

- Lateral Foundation Design Factor of Safety –
  Soil Type verified at construction site (Table 5.5, PFBDM)

  $f_L = 2.2$

- $V_u = 980*2.2 = 2,156$ lb

- Assuming **d = 4 ft** and substituting parameters into equation,

  $$\mathbf{d_{Ru} = V_u/(18bS_u) + d/2 + 2b/3 \leq d}$$

- $d_{Ru} = 2156/[(18)(0.38)(1008)] + 4/2 + 2(0.38)/3 = 2.56$ ft

EXAMPLE 4: POST FOUNDATION LATERAL RESISTANCE DESIGN

- Substituting **z = d = 4 ft** and d_{Ru} = 2.56 ft. into the design criteria

$$\mathbf{M_u = 9bS_u(d^2/2 - d_{Ru}^2 + 16b^2/9) \geq 0}$$

$$M_u = (9)(0.38)(2016)[(4)^2/2 - (2.56)^2 + 16(0.38)^2/9] = 4{,}985 \text{ lb.ft}$$

$$M_u/f_L = 4985/2.2 = 2492 \text{ lb-ft} < M_G = 4{,}600 \text{ lb-ft}$$

EXAMPLE 4: POST FOUNDATION LATERAL RESISTANCE DESIGN

- Substituting **z = d = 4.5 ft** into the two design criteria yields

d_{Ru} = 2.80 ft and M_u = **6,625 lb.ft**

M_u/f_L = 6,625/2.2 = 3,011 lb-ft < M_G = 4,600 lb-ft

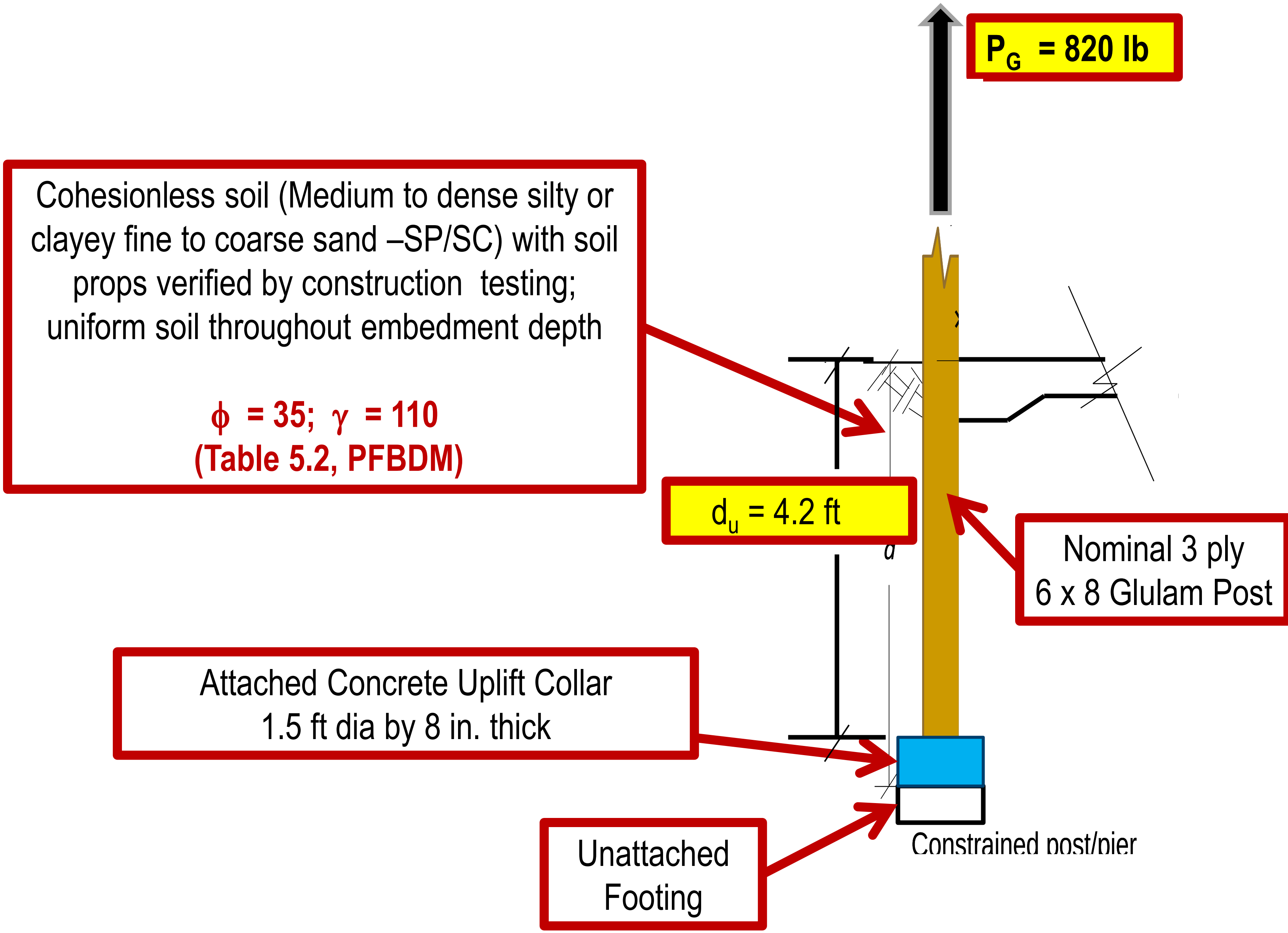
- Substituting **z = d = 4.75** ft into the two design criteria yields

d_{Ru} = 2.92 ft and M_u = **10,380 lb.ft**

and M_u/f_L = 10,380/2.2 = 4,718 lb.ft ≈ M_G = 4,600 lb.ft

(4.75 ft embedment depth is satisfactory)

EXAMPLE 5: UPLIFT LOAD RESISTANCE



EXAMPLE 5: POST FOUNDATION DESIGN: UPLIFT RESISTANCE

ASD Design Criterion

$gM_f + U/f_u \geq P_{ASD}$ (Section 5.10.1, PFBDM)

gM_f = weight of attached footing and/or anchor

U = uplift resistance from soil mass above anchor

f_u = ASD factor of safety for uplift resistance

P_{ASD} = ASD design uplift load **(820 lb)**

EXAMPLE 5: POST FOUNDATION DESIGN - UPLIFT RESISTANCE

- **Shallow Foundation Criterion** for uplift anchor in cohesionless Soil (S. 5.10.3, PFBDM)

$$d_u \le B_u(5.78 - 0.350\phi + 0.00947\,\phi^2) = h$$

d_u - depth to top of uplift anchor = **4.2 ft**
h - limiting depth for shallow case
B_u - diameter of attached concrete collar = **1.5 ft.**
ϕ - angle of internal friction = **35**

- $h = (1.5)[5.78 - 0.35(35) + 0.00947(35^2)] =$ **7.6 ft**

- Since **d_u = 4.2 ft < h**, the foundation is **shallow** for uplift

EXAMPLE 5: POST FOUNDATION DESIGN - UPLIFT RESISTANCE

- U- resisting force due to mass of soil above cylindrical collar (EP486.2, Section 12.5.1.1 or **Section 5.10.3, PFBDM**)

$$U = \gamma d_u [\pi d_u s_F B_U K_U \tan\phi/2 + B_u^2 \pi/4 - A_p]$$

d_u = embedment depth **to uplift anchor = 4.2 ft**

γ = soil density = **110 pcf**

B_u = anchor diameter = **1.5 ft.**

A_p = post X-sectional area = **4.5(7.25)/144 = 0.23 ft²**

s_F = $1 + 1.105(10^{-5})\ \phi^{2.815} h/B_u$ = **1.69**

K_u = **0.95** (S. 5.10.3, PFBDM)

$\tan\phi/2$ = Tan(17.5) =**0.31**

EXAMPLE 5: POST FOUNDATION DESIGN - UPLIFT RESISTANCE

- U- resisting force due to mass of soil above anchor

  $U = \gamma d_u [\pi d_u s_F B_U K_U \tan\phi/2 + B_u^2 \pi/4 - A_p]$

  $U = 110(4.2)\{\pi(4.2)(1.69)(1.5)(0.95)(\tan(17.5)) + (1.5)^2 (\pi/4) - (4.5)(7.25)/144\}$

  U = **5,258 lb**

- $f_u = 1.4/(1.16 - 0.015\phi)$ = **2.2**

- $gM_F = \gamma_c [\pi B_u^2/4 - A_p] (t_c) = 150[3.14)(1.5)^2/4 - 0.23](0.67)$ = **154 lb**

- Substituting into the governing design equation

  $gM_F + U/f_u = 154 + 5{,}258/2.2$ = **2,554 lb > P_{ASD} = 820 lb**

- The collar size & location is satisfactory

CLOSURE

- Embedment Depth for Constrained Case < Non-constrained Case – Always true for same loads and soils

- Embedment Depth for Cohesive Case < Non-cohesive Case – Not always true

DESIGN AID FOR SHALLOW POST & PIER FOUNDATIONS

- Shallow Post and Pier Design Workbook (Excel Workbook)
- Post and Pier Design Aid User's Guide (Word File)

www.nfba.org/Resources/Technical

SHALLOW FOUNDATION DESIGN AID WORKBOOK OVERVIEW (SECTIONS)

- Introduction
- Definitions and Nomenclature
- Soil Profile
- **Bearing Strength Assessment**
- Lateral Strength Assessment-U (Universal Method)
- **Lateral Strength Assessment-S (Simplified Method)**
- **Uplift Strength Assessment**

MORE POST-FRAME STRUCTURAL DESIGN DETAILS?

NFBA's On-Line University Course, "Engineering Design of Post Frame Builidng Systems" (1 ceu per session)

www.nfba.org

Session 1: Introduction to Post Frame Building Systems
Session 2: 2015 Post Frame Building Design Manual (2nd Ed.)
Session 3: Non-Diaphragm Post-Frame Building Design Guide – 2019
Session 4: Non-Diaphragm Post-Frame Structural Design Examples: Engineering Details
Session 5: Architectural Alternatives for Post-Frame Building Systems
Session 6:Modern Post-Frame Structural Design Practice: An Introduction
Session 7: Diaphragm Design of Post Frame Using Sway & Shear Modifiers – Engineering Details
Session 8: Diaphragm Design of Post Frame Using DAFI – Engineering Details
Session 9: Simplified Method for Shallow Post and Pier Foundation Design
Session 10: Universal Method for Shallow Post and Pier Foundation Design
Session 11: Design Aid for Shallow Post and Pier Foundations

MORE ABOUT POST FRAME?

- National Frame Building Association (NFBA)
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