WELCOME TO THE DIAPHRAGM DESIGN OF POST FRAME USING SWAY & SHEAR MODIFIERS –ENGINEERING DETAILS WEBINAR



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POST-FRAME ADVANTAGE

LEARNING OBJECTIVES

Upon completion of this session, participants will be able to:

- Determine required sidewall post sizes in PF systems using Sway and Shear Modifiers (mD and mS) (Principles + Example)
- Identify how diaphragm design reduces the structural loads carried by sidewall posts in PF systems
- Identify and access the PF design resources available to architects and engineers

TYPICAL PF BUILDING SYSTEM

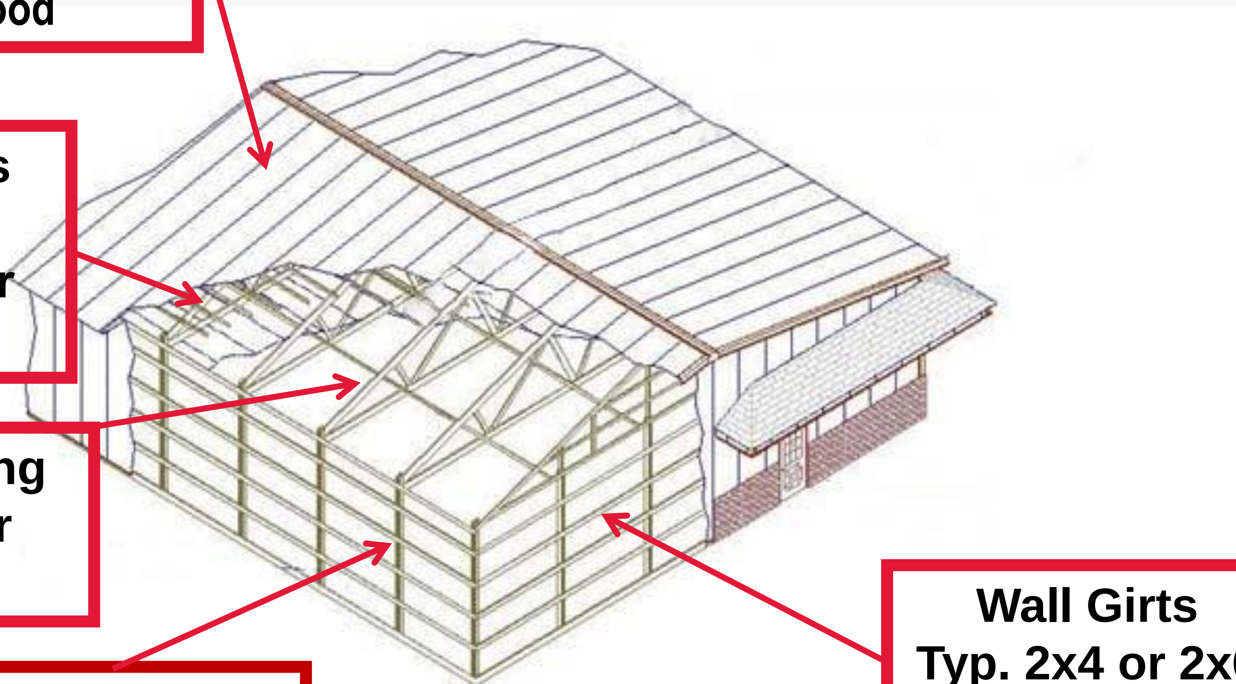
Sheathing:

- 26 to 29 ga Painted Ribbed Steel OR
- OSB or Plywood

Roof Purlins
Typ. 2x4s
“on edge” or
“flat”

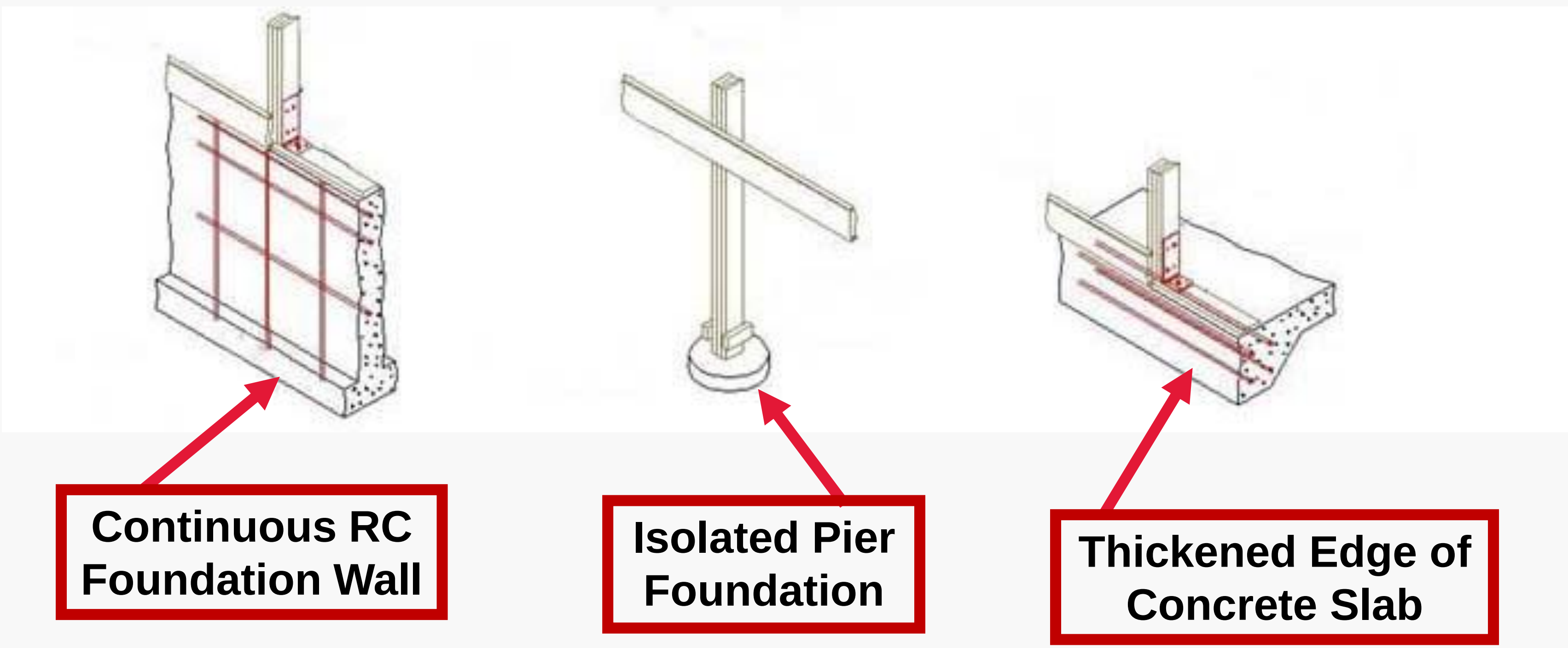
Roof Framing
Trusses or
Rafters

Laminated or Solid-
Sawn
Wood Columns

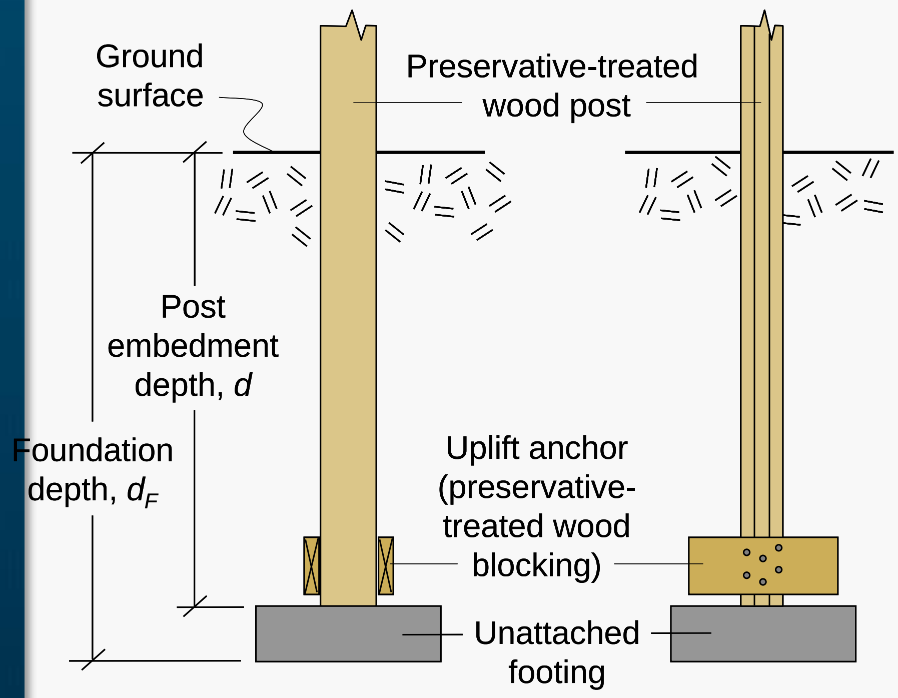


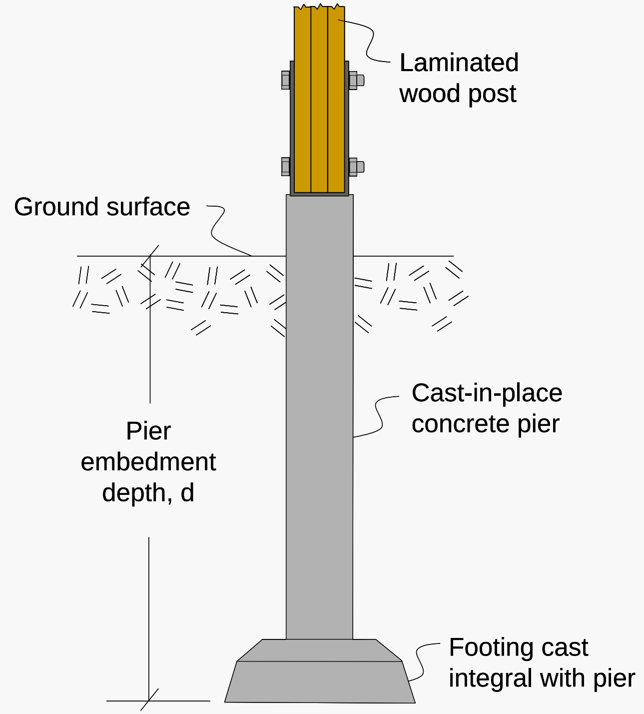
Wall Girts
Typ. 2x4 or 2x6
“flat”

PF BUILDING SYSTEM FOUNDATION OPTIONS



TYPICAL POST AND PIER FOUNDATIONS

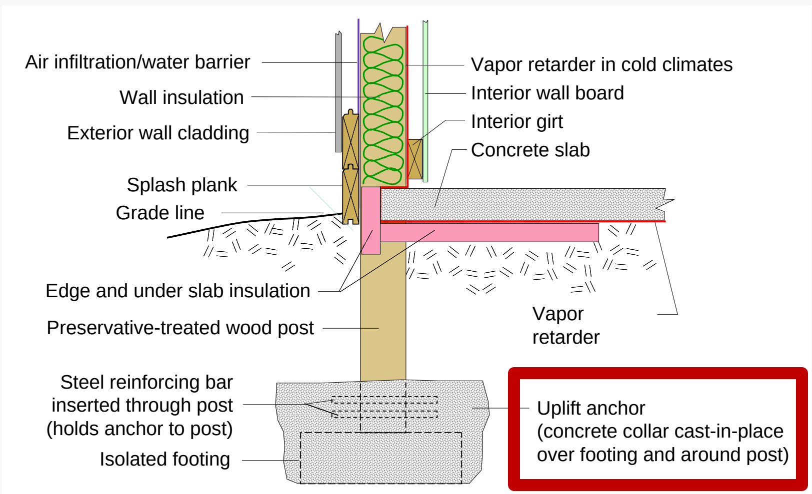


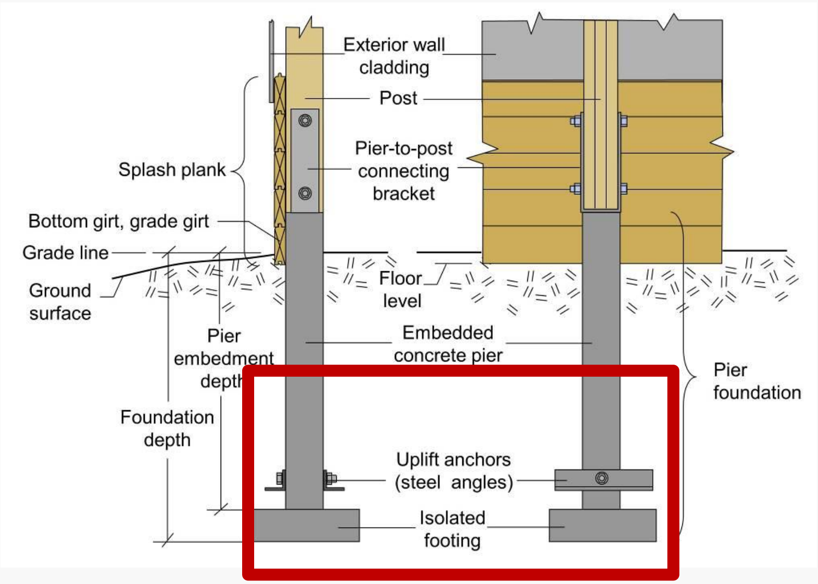


Preservative-treated wood post foundation w/ preservative-treated uplift anchor

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

TYPICAL POST& PIER FOUNDATION DETAILS

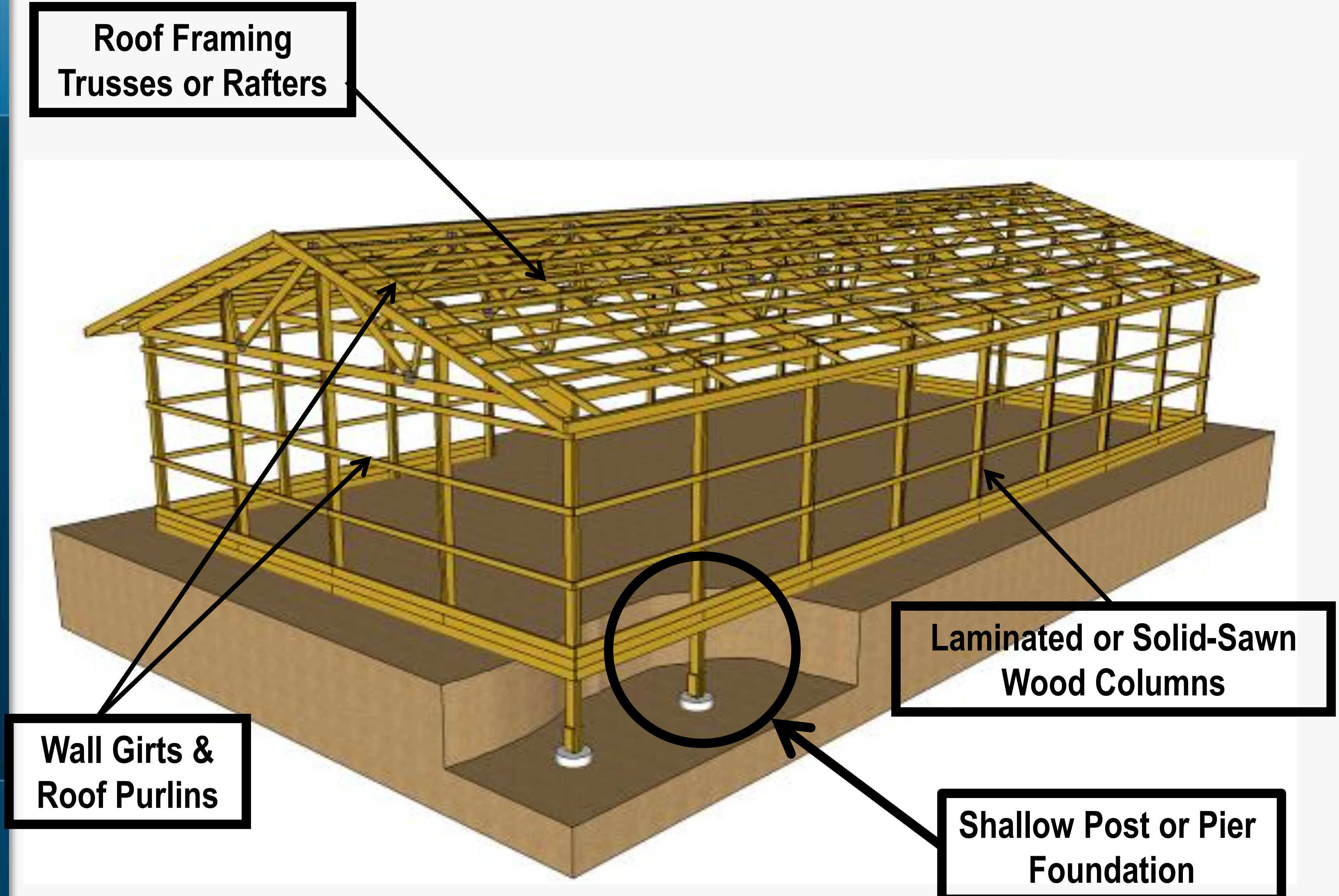




Preservative treated post w/ cylindrical cast-in-place concrete uplift anchor

Precast concrete pier w/ steel angle uplift anchor

POST-FRAME PICTORIAL

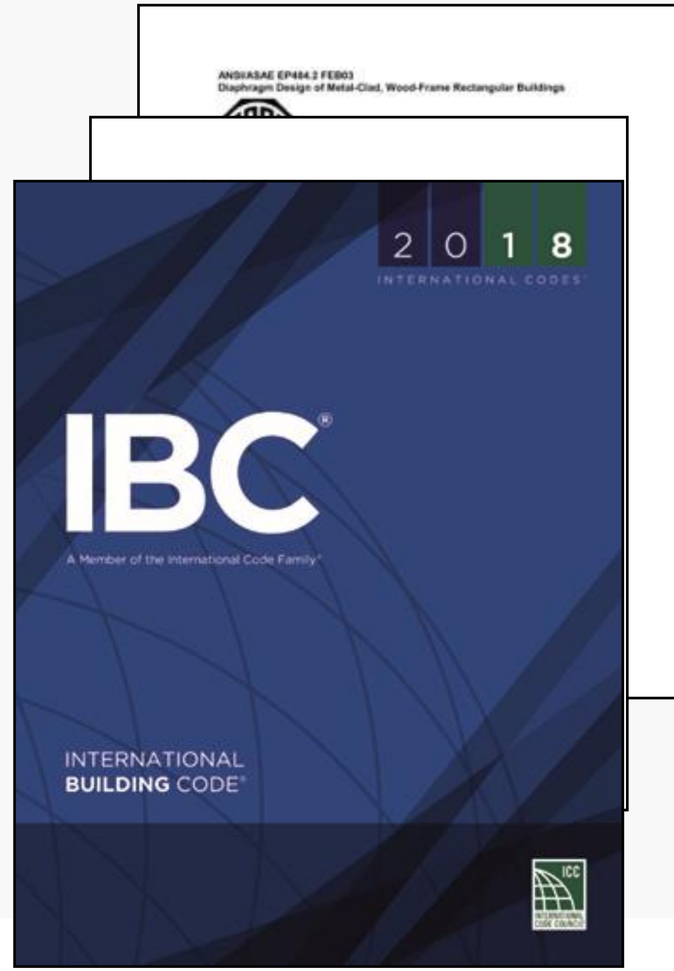


SESSION SCOPE

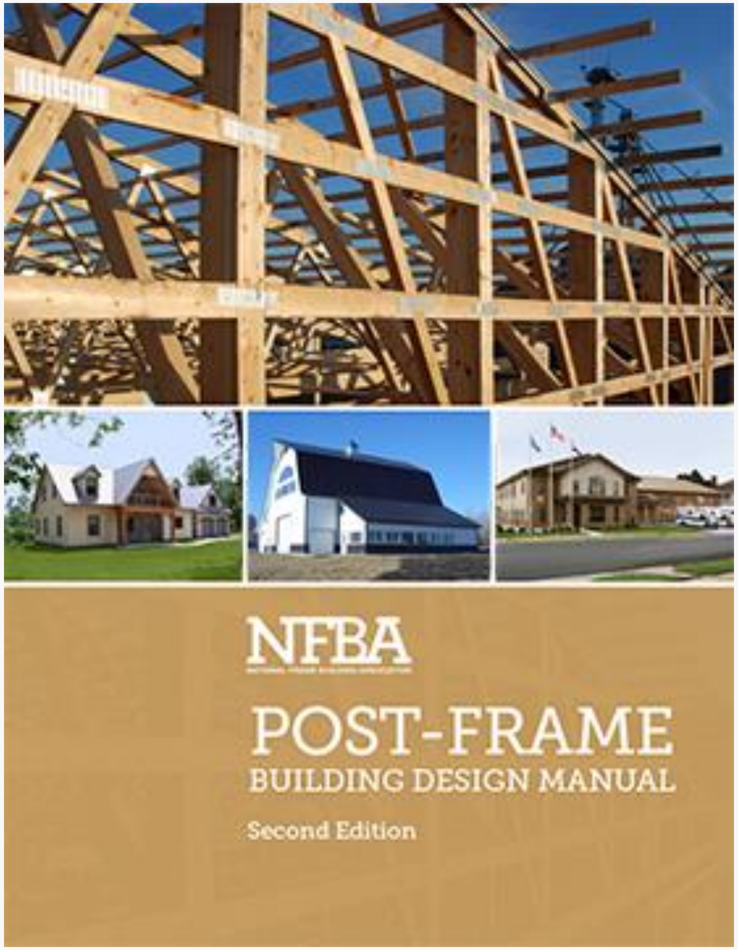
- Design of:
  - Sidewall Post
  - Metal-Clad (26 to 29 ga), Wood Framed (MCWF) Roof Diaphragm
- **Shallow Post/Pier Design – Separate Webinars**
- **Purlin & Girt Design – Not Covered**

POST-FRAME TECHNICAL RESOURCES

- **ANSI/ASAE (ASABE) EP 484**
  - **Diaphragm design procedures**
- ANSI/ASAE (ASABE) EP 486.3
  - Shallow post & pier foundation design
- ANSI/ASAE (ASABE) EP 559
  - Requirements and bending properties for mechanically laminated columns
  - www.asabe.org

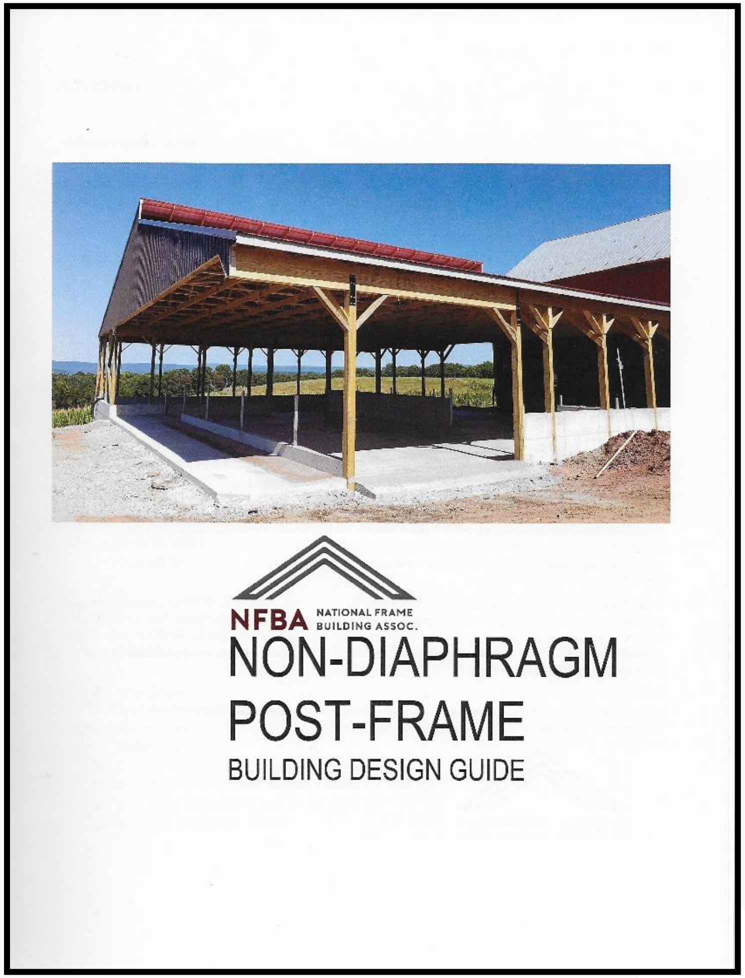


PF TECHNICAL RESOURCES



- PF Building Design Manual (PFBDM – Second Edition)
- Structural design procedures for **all** PF building systems
  – www.NFBA.org
  – Member Cost
    $95 – Digital Copy
    $130 - Print Copy
  - Non-Member Cost
    $175 – Digital Copy
    $205 – Print Copy

PF TECHNICAL RESOURCES



Structural Design Guidelines and Examples for PF Systems w/o Diaphragm Action (e.g., open sided buildings and with knee braces, wye braces, K-braces or X-braces)

www.nfba.org

Member Cost
$85/$120 (Digital/Print)

Non-Member Cost
$160/$195 (Digital/Print)

POST-FRAME
TECHNICAL RESOURCES

DAFI

An interactive On-line Computer Program to Conduct Diaphragm Design of PF Structural Systems

www.nfba.org

(No Cost)

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

(No Cost)

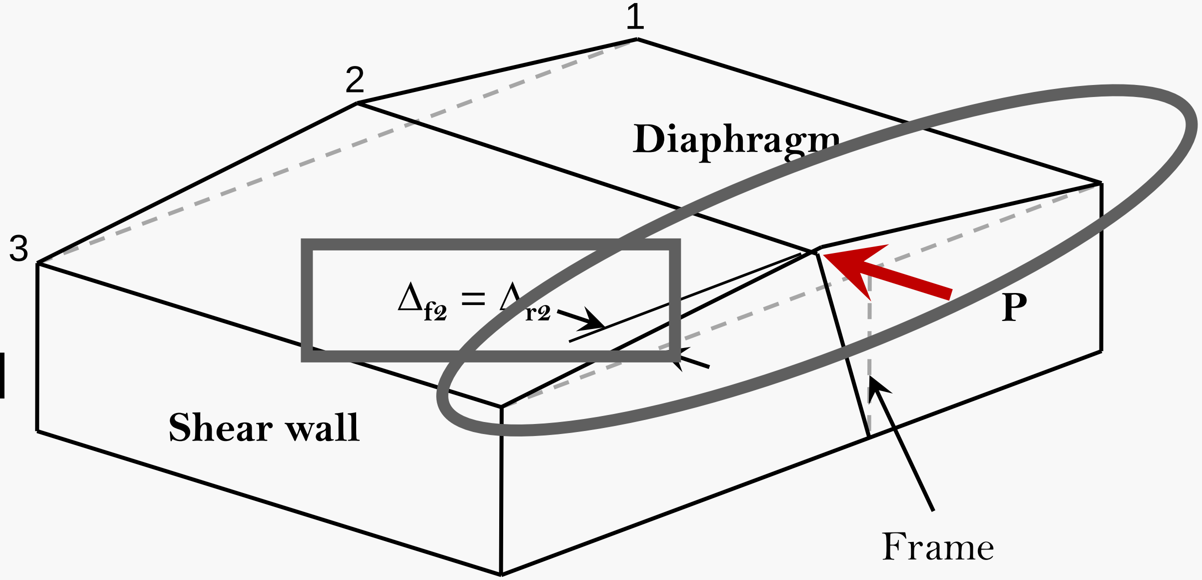
(Discussed in Detail in Companion 1 Hour Webinar)

THEORETICAL BASIS FOR PF DIAPHRAGM DESIGN

- Basic Principles
  - **Compatibility** of the horizontal deformation of the bare post frame and the roof diaphragm at the post frame eave
  - **Equilibrium** of forces at the eave of each post frame in the building system

COMPATIBILITY OF EAVE DEFORMATIONS: TWO-BAY PF

For simplicity the posts are assumed to be fixed at the groundline and the shearwalls are assumed to be rigid (These constraints can be released.)

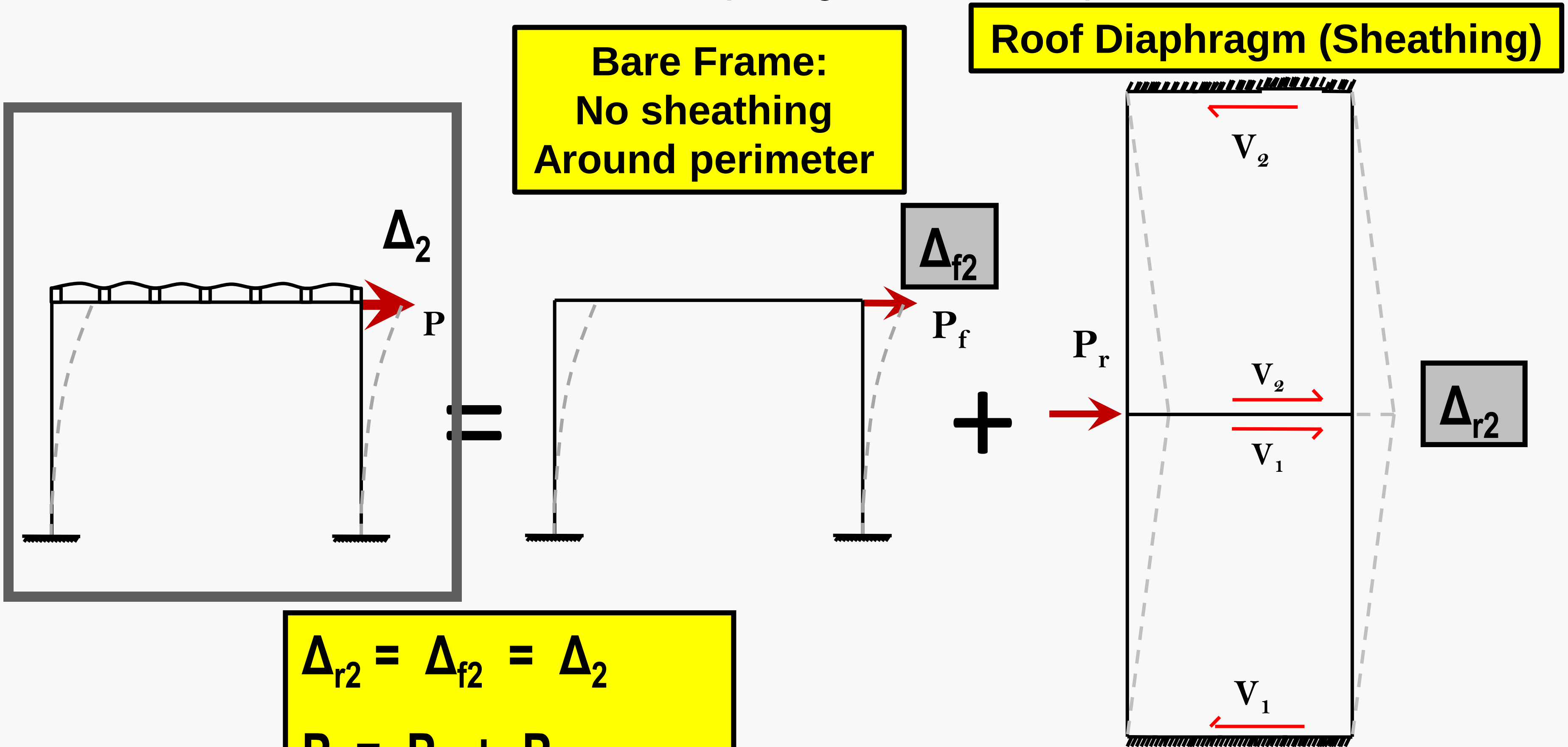


Compatibility Requirement

$$\Delta_{f2} = \Delta_{r2}$$

COMPATIBILITY OF EAVE DEFORMATIONS: TWO-BAY PF

- Using principle of superposition, the eave forces and deformations of the center PF and roof diaphragm can be separated as shown below



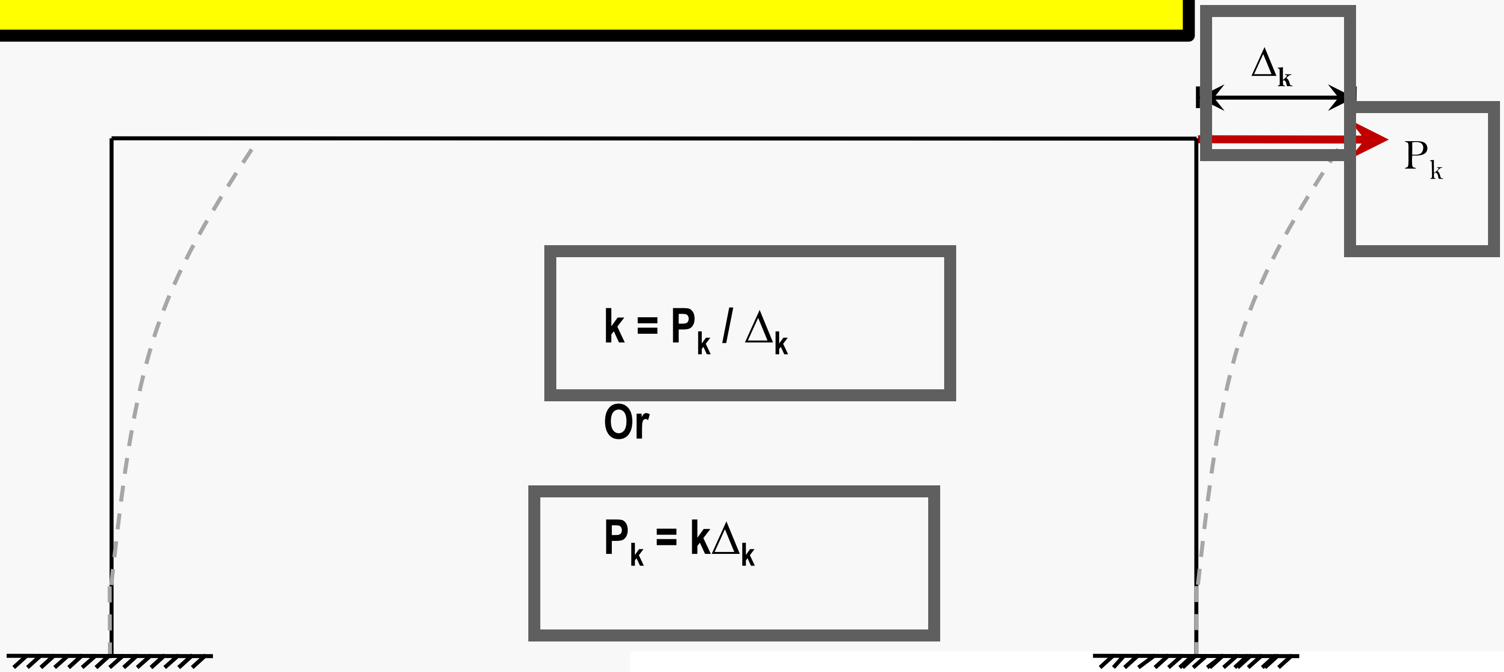
$$\Delta_{r2} = \Delta_{f2} = \Delta_2$$

$$P = P_f + P_r$$

BARE FRAME STIFFNESS

No sheathing attached around post-frame perimeter; sheathing may be placed in plane of post-frame

The eave force in the bare post frame can be expressed in terms of its bare frame stiffness, k

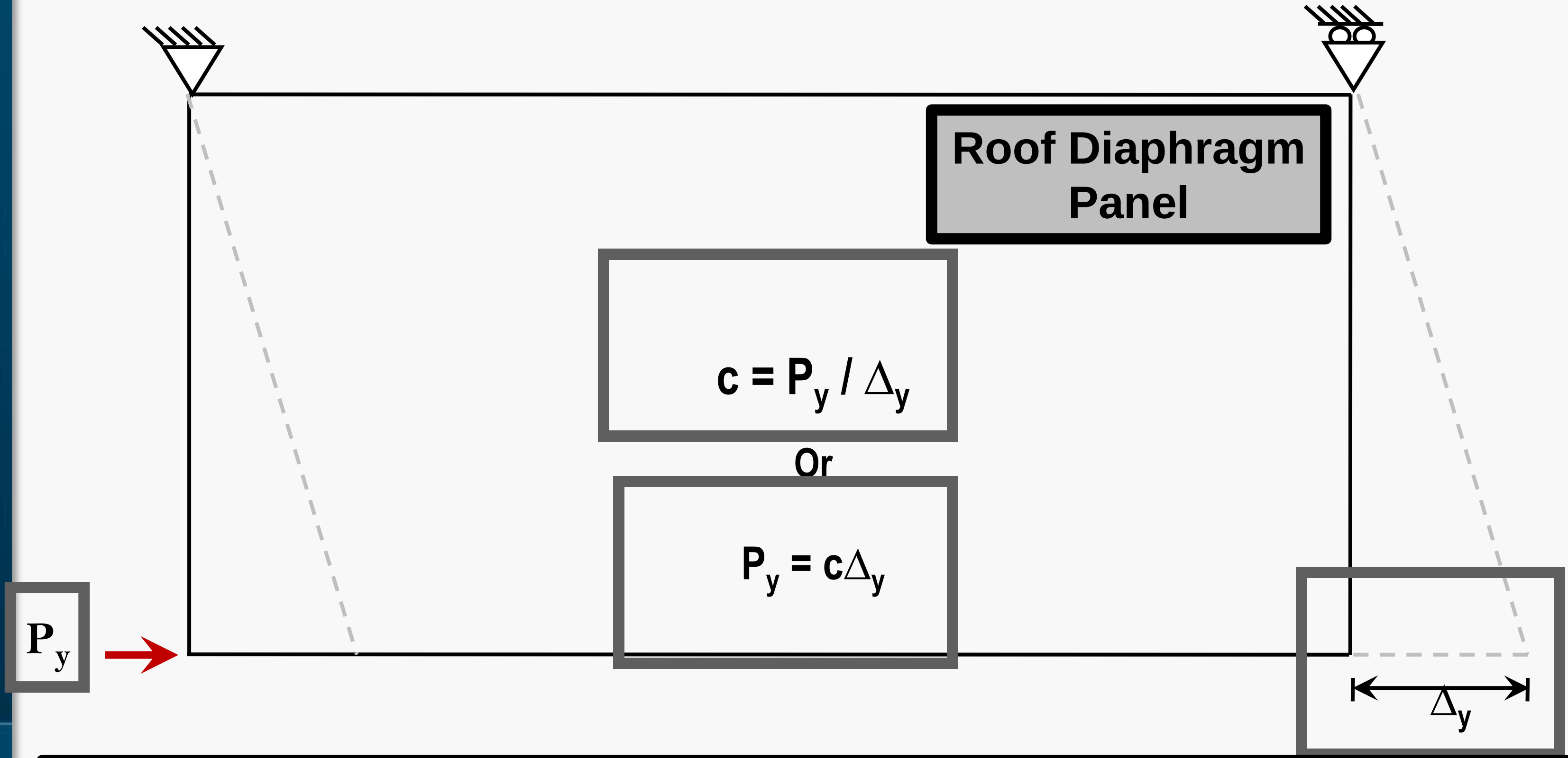


$$k = P_k / \Delta_k$$

Or

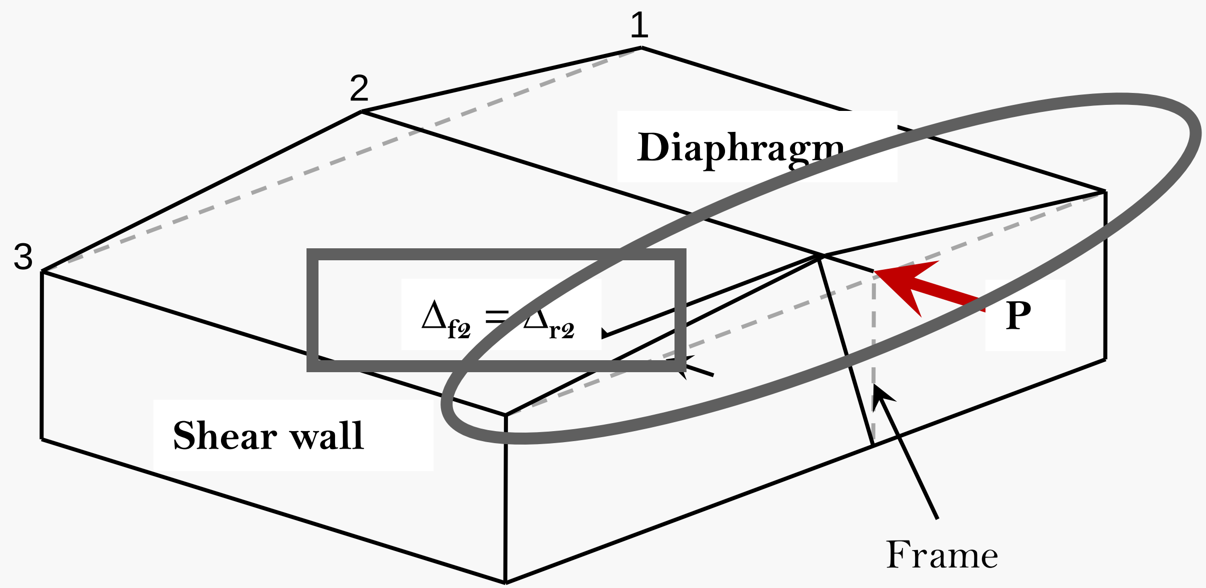
$$P_k = k\Delta_k$$

ROOF DIAPHRAGM IN-PLANE SHEAR STIFFNESS, C



Shear force in the roof diaphragm can be expressed in terms of its in-plane shear stiffness, c

COMPATIBILITY & EQUILIBRIUM OF EAVE DEFORMATIONS: TWO-BAY PF



Compatibility Requirement

$$\Delta_{f2} = \Delta_{r2}$$

Equilibrium Requirement

$$P_2 = P_{f2} + P_{r2}$$

COMPATIBILITY OF EAVE DEFORMATIONS: TWO-BAY PF

- Rewriting the equilibrium equation at **post frame 2 eave** in terms of the roof and bare frame stiffness yields:

  $P = P_f + P_r = k\Delta_{f2} + 2c\Delta_{r2} = (k + 2c)\Delta_2$

- The portion, m_f, of P carried by the frame is

  $\mathbf{m_f} = P_f/P = k\Delta_2/[(k+2c)\Delta_2] = \mathbf{k/(k+2c)}$

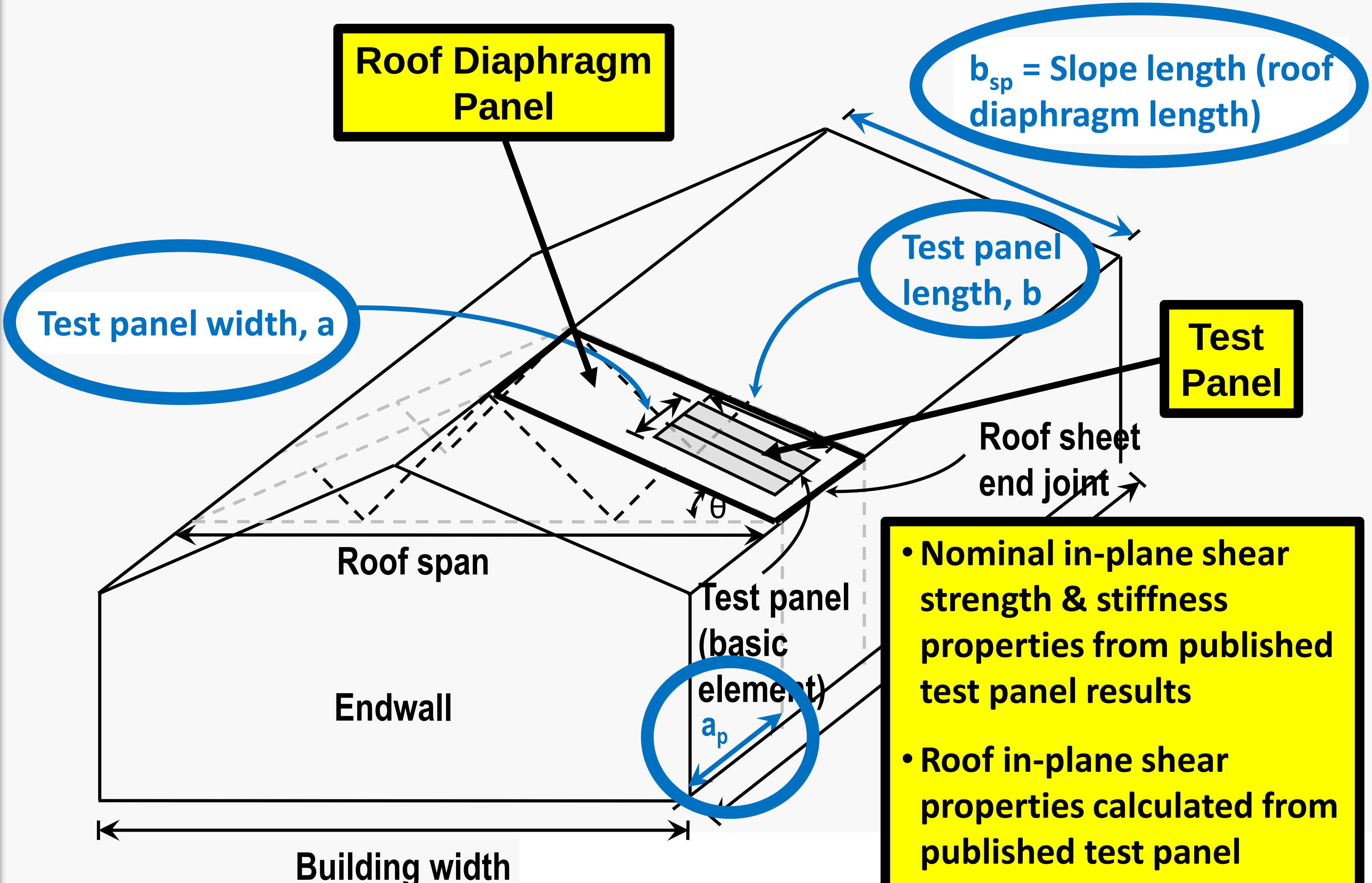
- The portion, m_d, of P carried by the roof diaphragm is

  $\mathbf{m_d} = 1 - m_f = \mathbf{mD}$, the **sway restraining factor**

- The maximum portion of the total eave loads carried by the roof diaphragm is:

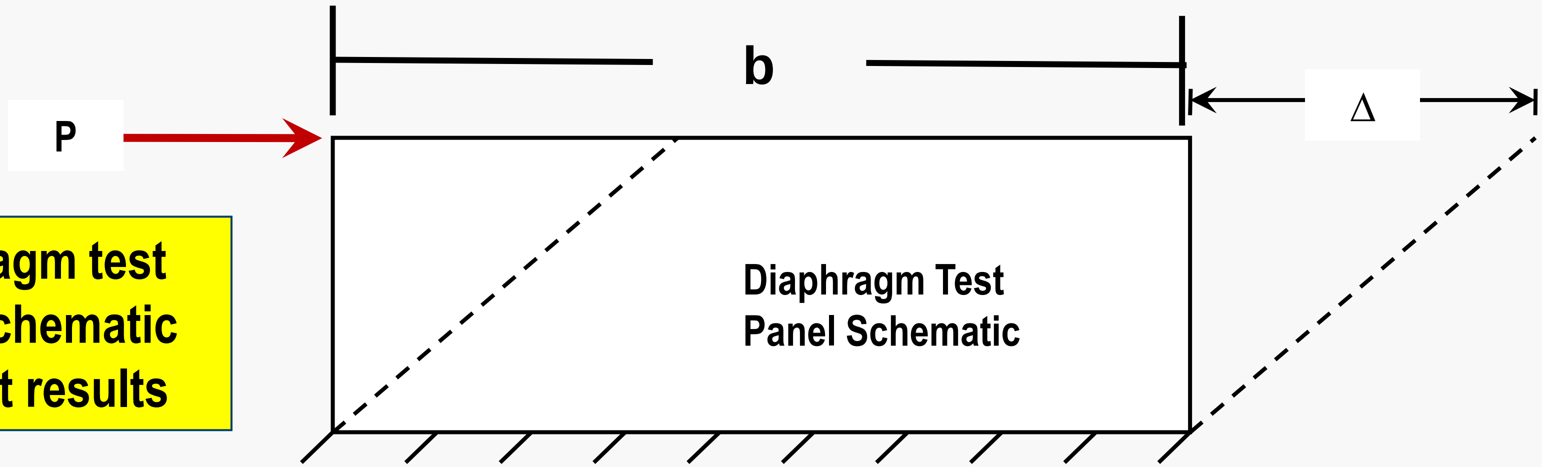
  $\mathbf{mS} = (½)\sum(1 - m_f)$, the **shear force modifier**

TEST PANEL & ROOF DIAPHRAGM PANEL DEFINITIONS

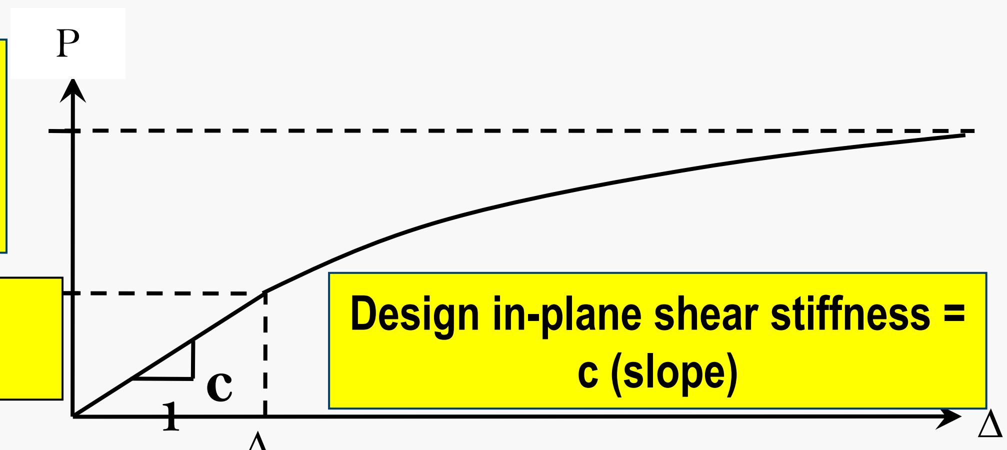


- Nominal in-plane shear strength & stiffness properties from published test panel results
- Roof in-plane shear properties calculated from published test panel results

DIAPHRAGM TEST PANEL SHEAR PROPERTIES



Diaphragm test panel schematic and test results



Ult. in-plane shear strength = P_{ult}

Design in-plane shear strength = 0.4 P_{ult}

Design in-plane shear stiffness = c (slope)

Design in-plane unit shear strength = 0.4 P_{ult}/b

ROOF DIAPHRAGM PANEL SHEAR STRENGTH (V) AND IN-PLANE STIFFNESS (C_P)

- The horizontal component of in-plane shear stiffness of a **roof or ceiling diaphragm** with width a_p, length b_{sp}, and slope θ is:

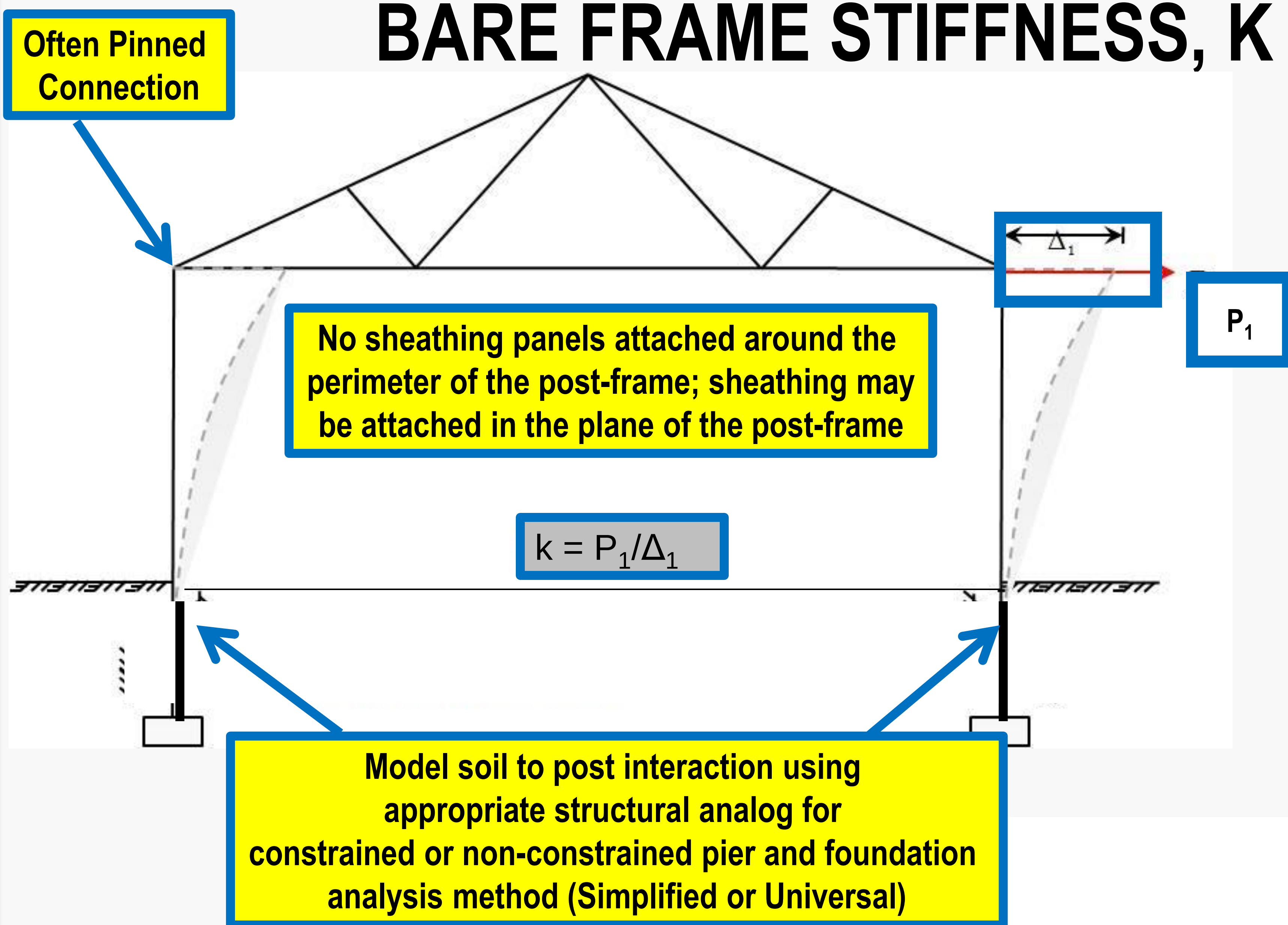
$$c_p = \boxed{\mathbf{c\ (a/b)}}(b_{sp}/a_p)(\cos^2\theta)$$

- In-plane strength is a linear function of diaphragm length, b_{sp}

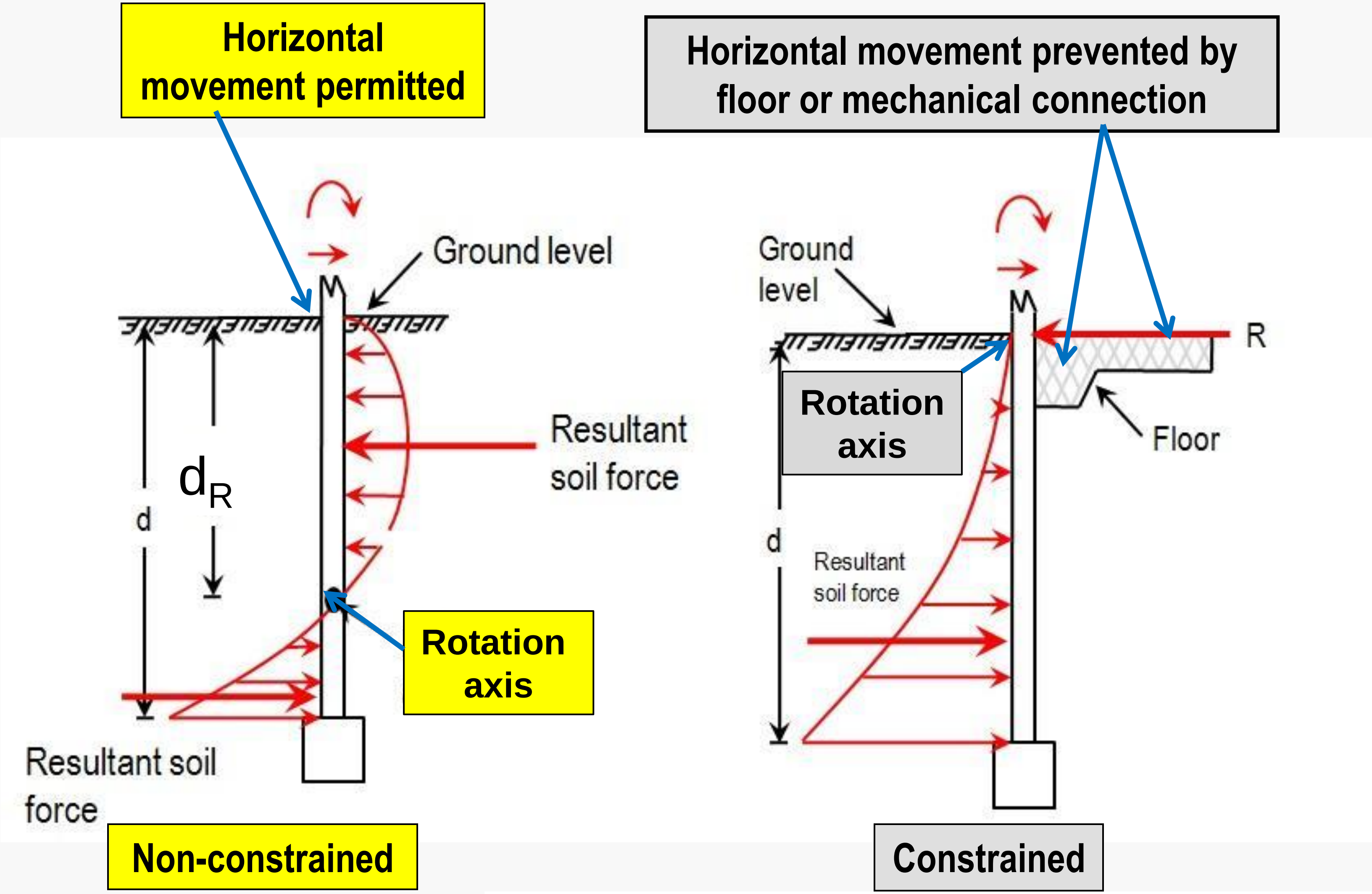
$$V = (\text{unit shear})(\text{roof diaphragm length})$$

$$V = \mathbf{0.4(P_{ult}/b)}(b_{sp})$$

DIAPHRAGM DESIGN METHOD-BARE FRAME STIFFNESS, K



POST/PIER FOUNDATION TYPES



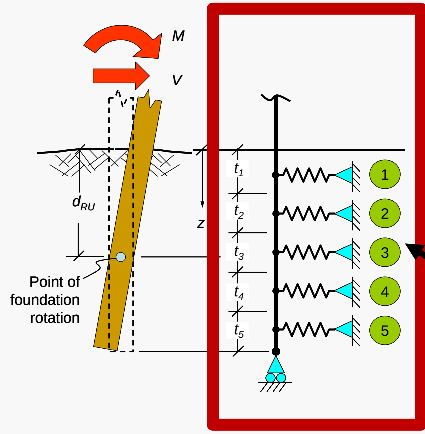
ANALYSIS METHODS FOR POST & PIER FOUNDATIONS

Simplified Method (Can use only if specified conditions met)

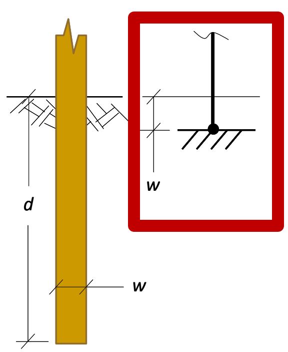
Universal Method (Can always use)

STRUCTURAL ANALOGS FOR NON-CONSTRAINED PIER FOUNDATION

Universal Foundation Design Method



Simplified Foundation Design Method



Non-constrained post/pier

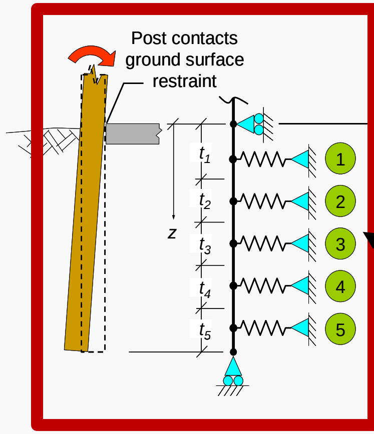
-Elastic-perfectly plastic springs

-Spring properties are function of soil strength & stiffness

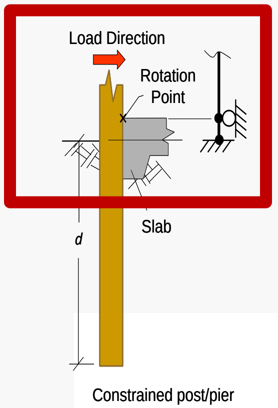
-Covered in companion session, “Universal Method for Shallow Post/Pier Foundations”

STRUCTURAL ANALOGS FOR CONSTRAINED PIER FOUNDATION

Universal Foundation Design Method



Simplified Foundation Design Method



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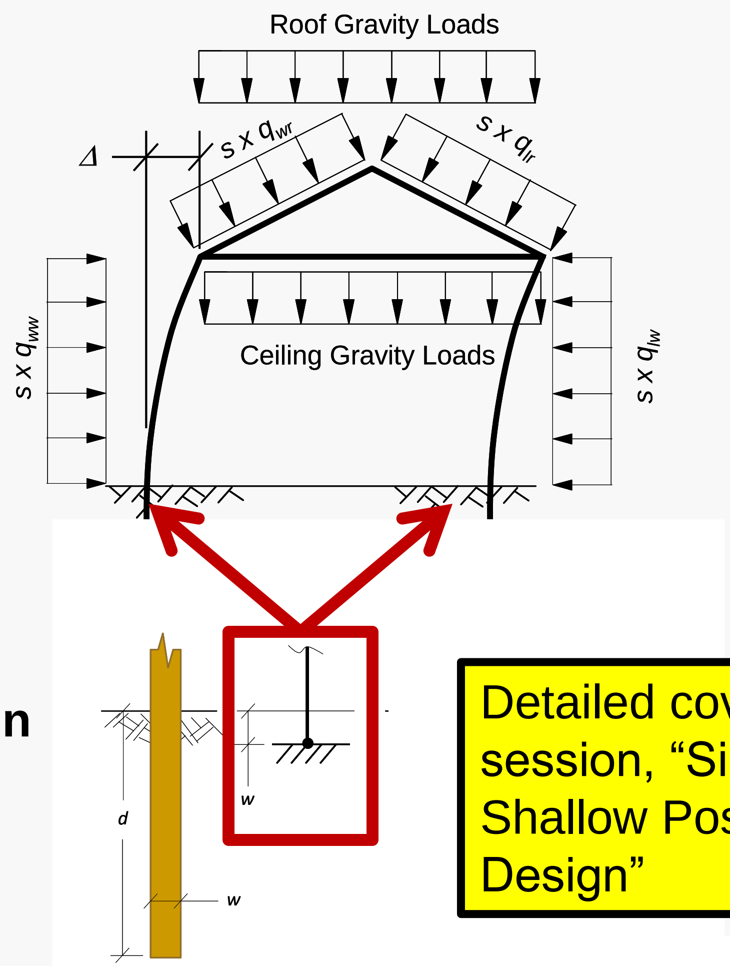
STRUCTURAL ANALOG FOR NON-CONSTRAINED PIER FOUNDATION

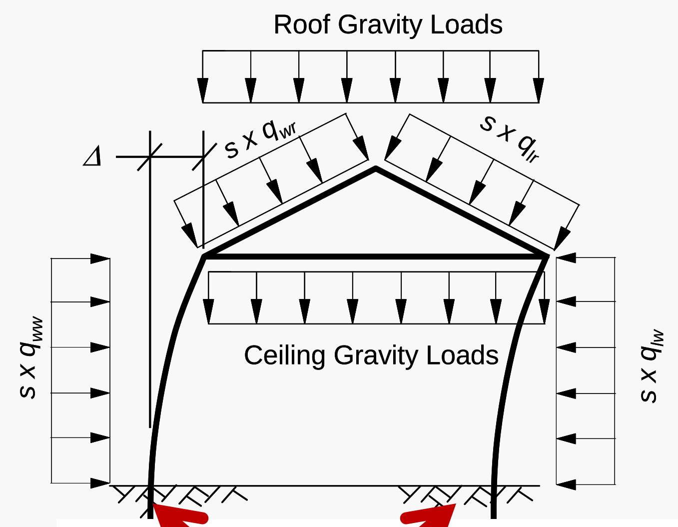


Non-constrained post/pier

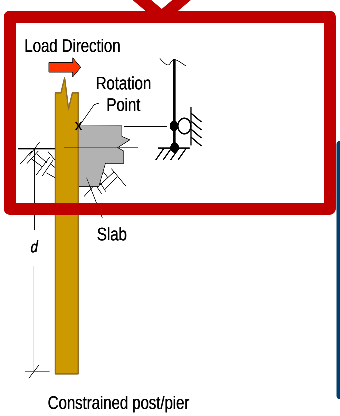
Simplified Foundation Design Method

Detailed coverage in companion session, “Simplified Method for Shallow Post & Pier Foundation Design”

STRUCTURAL ANALOG FOR CONSTRAINED PIER FOUNDATION

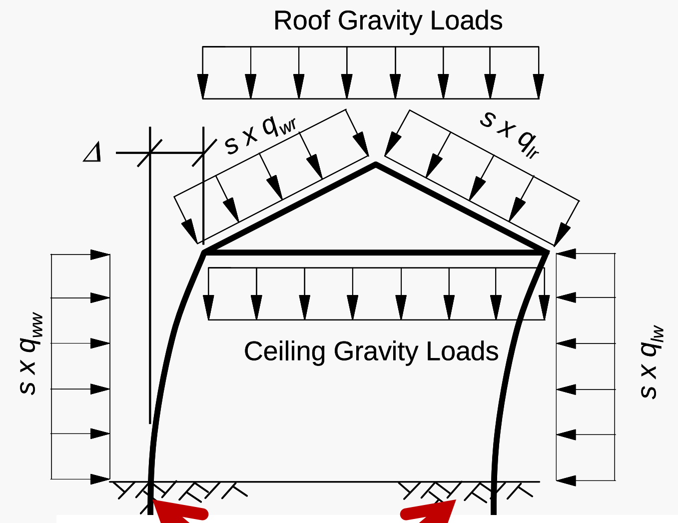


Simplified Foundation Design Method

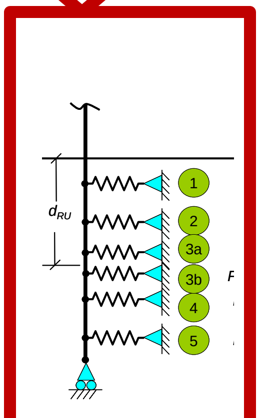


Detailed coverage in companion session, “Simplified Method for Shallow Post & Pier Foundation Design”

STRUCTURAL ANALOG FOR NON-CONSTRAINED PIER FOUNDATION

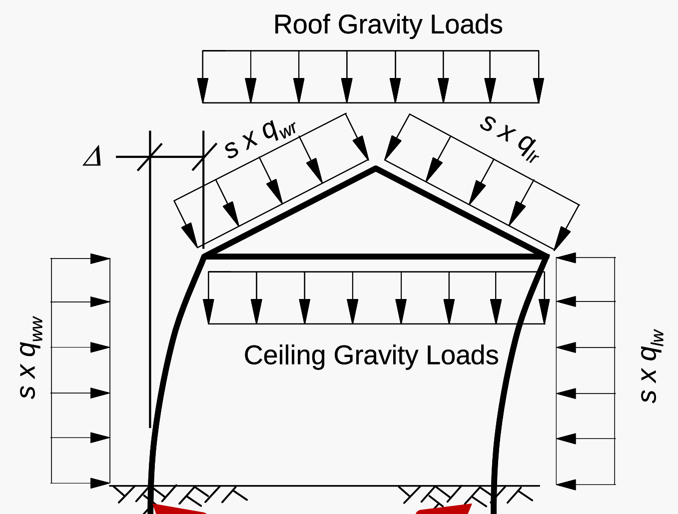


Universal Foundation Design Method

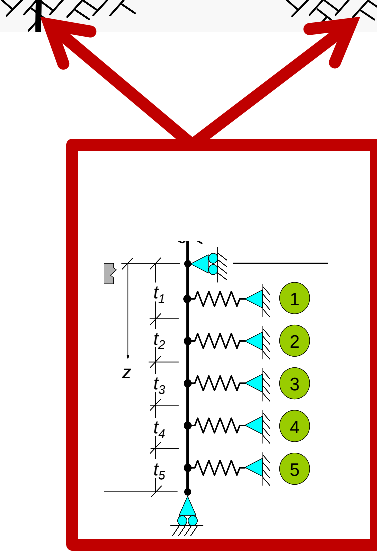


Detailed coverage in companion session, "Universal Method for Shallow Post & Pier Foundation Design"

STRUCTURAL ANALOG FOR CONSTRAINED PIER FOUNDATION



Universal Foundation Design Method



Detailed coverage in companion session, “Universal Method for Shallow Post & Pier Foundation Design”

REQUIRED CONDITIONS FOR USING THE SIMPLIFIED MODEL FOR MODELING POST/PIER GROUNDLINE CONSTRAINT

- Soil is homogeneous throughout the entire embedment depth.
- Soil stiffness is either constant for all depths below grade or linearly increases with depth below grade.
- Width 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.**
- Post/pier foundation approximates infinite stiffness (EI_{pier})

Infinite stiffness criteria

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

  OR
- $d \leq 2\{EI/(2E_S)\}^{0.25}$ (cohesive soils)

where * d is depth of embedment;

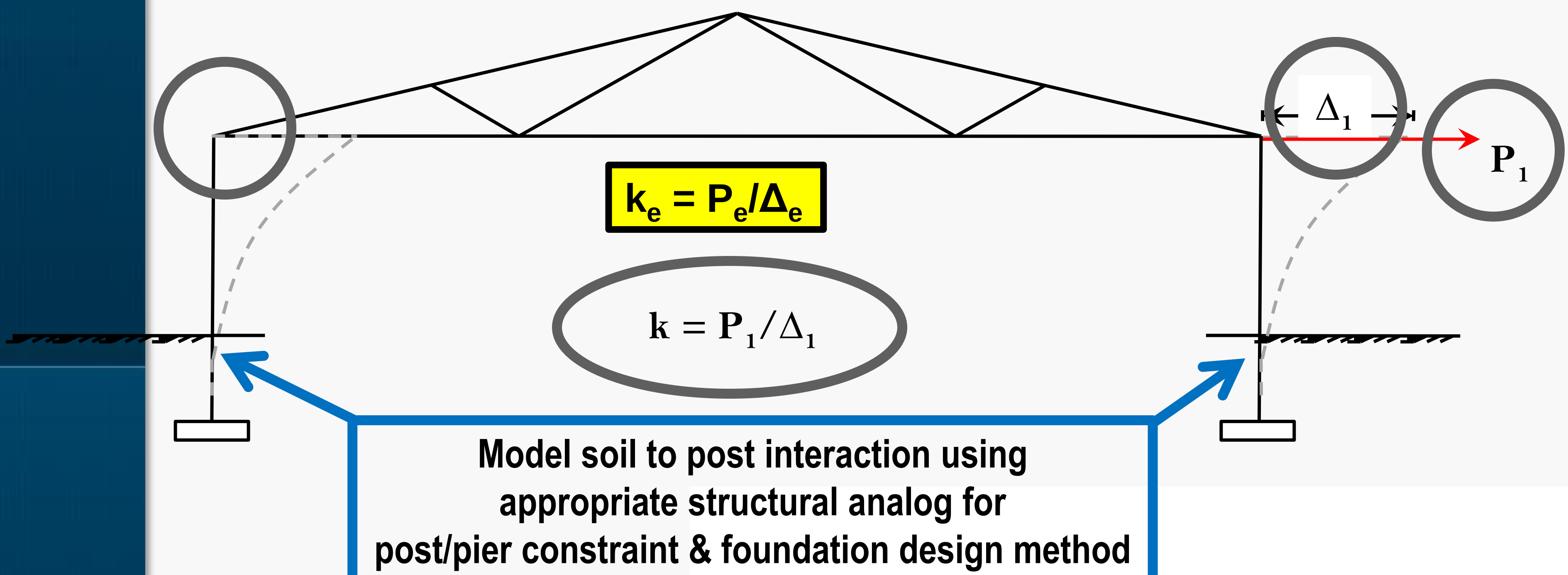
* EI is flexural rigidity of the post/pier
* E_S is Young's modulus of the soil
* A_E is the linear increase in Young's modulus of soil with depth below grade

SWAY AND SHEAR MODIFIER METHOD

- A fundamental PF diaphragm design approach
- Uses tabulated sway and shear modifiers, mD & mS
- Yields sway modifier, **mD, for only the most highly loaded frame (centermost post)**
- Yields the **maximum shear load, mS(R), in the roof diaphragm** (most often in roof diaphragm panel closest to the end wall)

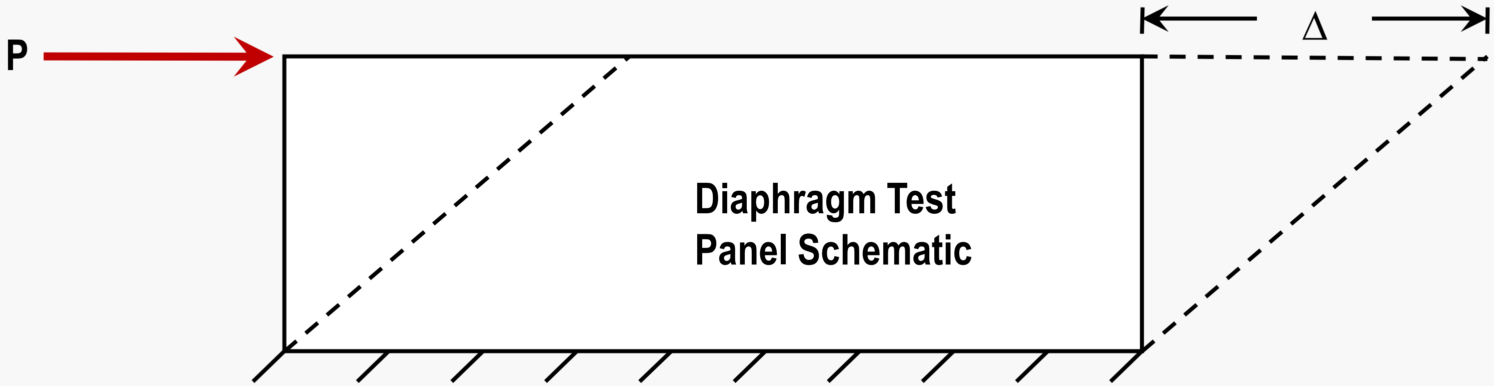
SWAY AND SHEAR MODIFIER METHOD – STEP 1

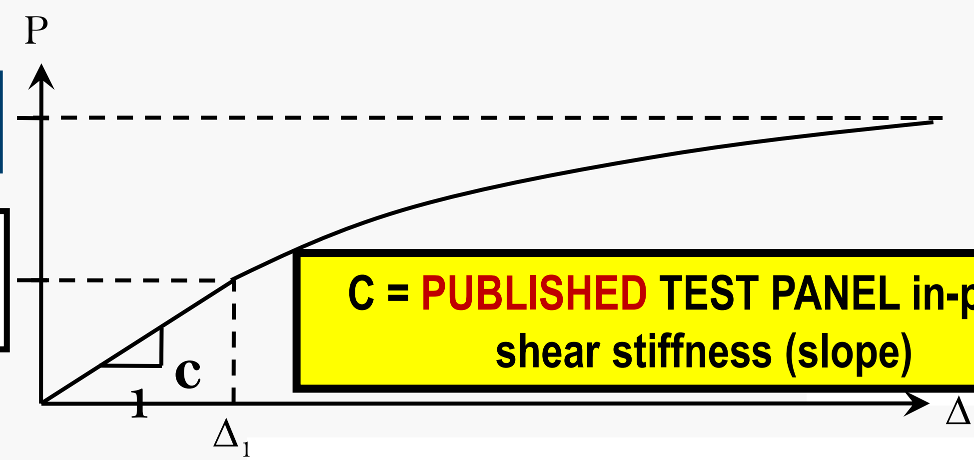
Step 1A: Determine the **bare frame stiffness, k,** of the interior post frames and k_e of the sheathed endwall post frames



SWAY AND SHEAR MODIFIER METHOD – STEP 1

Step 1.B: Determine the horizontal component of the roof diaphragm shear stiffness, c_h,





Ult. Strength = P_{ult}

Design shear strength = 0.4 P_{ult}

C = PUBLISHED TEST PANEL in-plane shear stiffness (slope)

Design unit shear strength = 0.4 P_{ult}/b

SWAY AND SHEAR MODIFIER METHOD – STEP 1

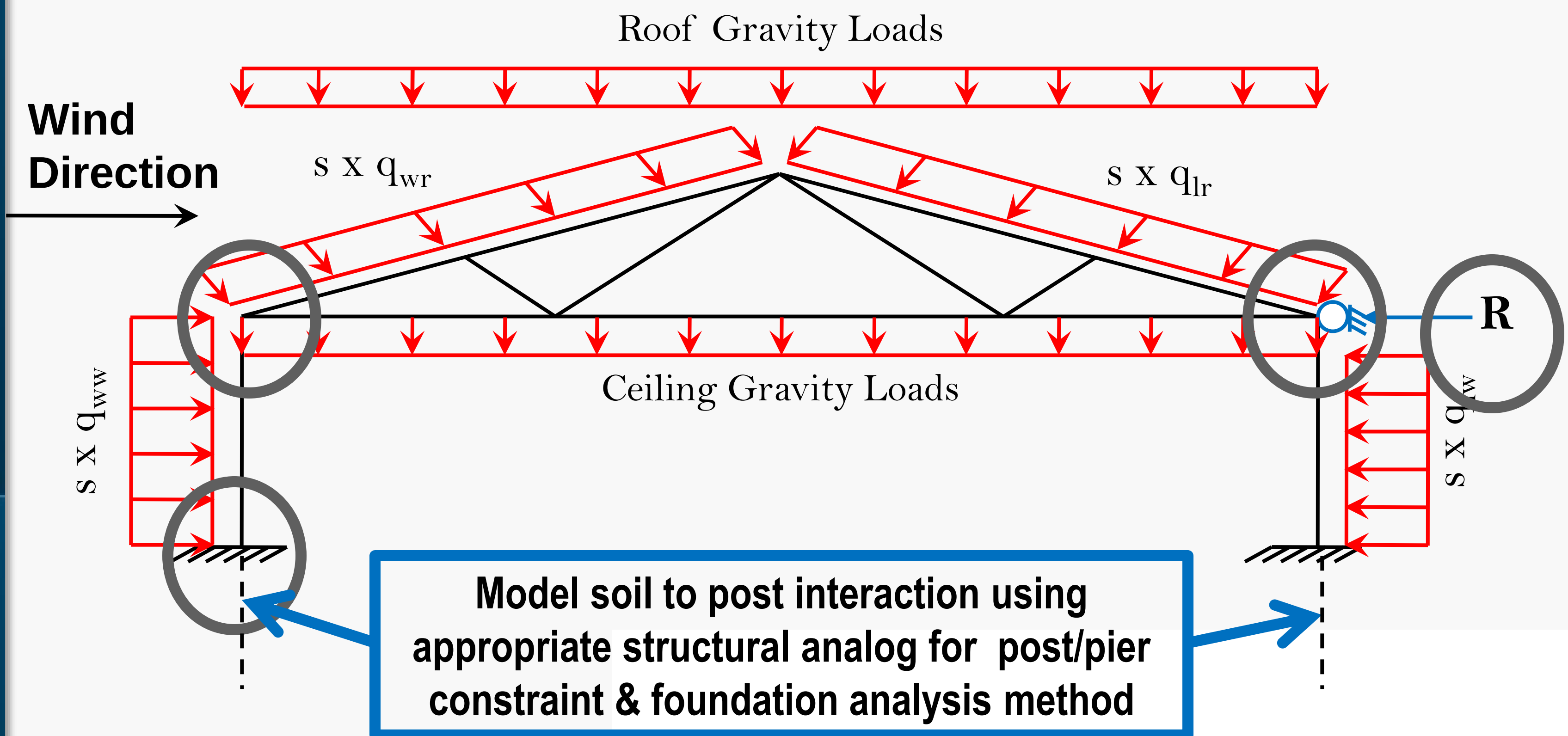
Step 1B: Determine the horizontal component of the roof diaphragm shear stiffness, c_h,

The horizontal component of in-plane shear stiffness of a roof or ceiling diaphragm with width a_p, length b_{sp}, and slope θ is calculated from published test panel results and the roof panel aspect ratio:

$$c_h = \mathbf{c\ (a/b)}\ (b_{sp}/a_p)(\cos^2\theta)$$

SWAY AND SHEAR MODIFIER METHOD – STEP 2

Step 2: Apply a vertical roller to the bare post frame at the eave and determine the restraining force, R (s=spacing of frames)



SWAY AND SHEAR MODIFIER METHOD – STEP 3

Step 3: Determine the Sway Modifier, mD

Determine the proportion, mD, of the eave roller reaction force, R, that is transferred to the frame by the roof diaphragm

- mD = f(c_h/k, k_e/k, N) = sway restraining force factor
  - c_h/k = ratio of horizontal component of roof panel shear stiffness to interior bare frame stiffness
  - k_e/k = ratio of end wall to interior bare frame stiffness
  - N = number of post frames in the building

- mD values tabulated in ASAE EP 484 and in the PFBDM (Chapter 6, Table 6.7) for range of c_h /k, k_e/k and N values

SWAY & SHEAR MODIFIER METHOD – SWAY RESTRAINING MODIFIERS

- Selected mD values from **Table 6.7 of the PFBDM**
- mD = sidesway restraining force modifier

Soft Diaph

Stiff Diaph

k_e/k	C_h/k	N = 3	N = 5	N = 10
5	5	0.75	0.52	0.18
5	1000	0.82	0.69	0.50
50	5	0.81	0.68	0.26
50	1000	0.98	0.96	0.91

SWAY & SHEAR MODIFIER METHOD – SWAY RESTRAINING MODIFIERS

- Selected mD values from **Table 6.7 of the PFBDM**
- mD = sidesway restraining force modifier

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k_e/k	C_h/k	N = 3	N = 5	N = 10
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5	1000	0.82	0.69	0.50
50	5	0.81	0.68	0.26
50	1000	0.98	0.96	0.91

Stiff Diaph

SWAY & SHEAR MODIFIER METHOD – SWAY RESTRAINING MODIFIERS

- Selected mD values from **Table 6.7 of the PFBDM**
- mD = sidesway restraining force modifier

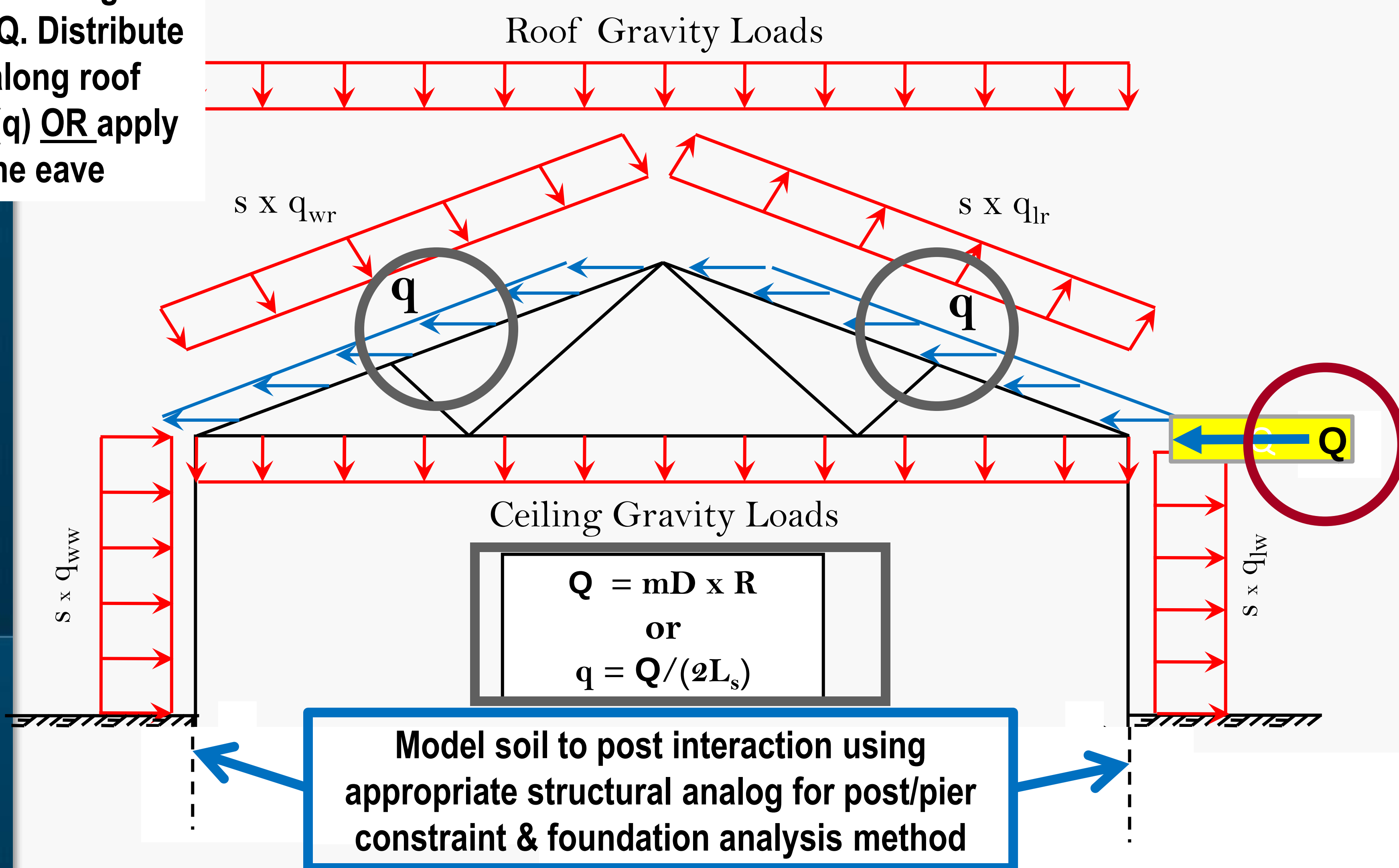
Soft Diaph

Stiff Diaph

k_e/k	C_h/k	N = 3	N = 5	N = 10
5	5	0.75	0.52	0.18
5	1000	0.82	0.69	0.50
50	5	0.81	0.68	0.26
50	1000	0.98	0.96	0.91

SWAY AND SHEAR MODIFIER METHOD – LATERAL LOAD DISTRIBUTION

Step 4: Determine the restraining force, Q. Distribute force along roof slope (q) OR apply Q at one eave



SWAY AND SHEAR MODIFIER METHOD – POST DESIGN OVERVIEW

- Conduct the structural design analysis of the post frame with the design loads and the distributed sidesway restraining force, Q or q, applied
- The controlling ASD design load combination is usually the Dead + 0.75(Snow) + 0.75(Wind or Earthquake) or the 0.6 Dead + Wind case
- However, it is prudent to conduct the design analysis for each ASCE-7 defined design load combination with lateral load components
- **Note that R and Q are not the same for each load combination**

SWAY AND SHEAR MODIFIER METHOD - DIAPHRAGM SHEAR STRENGTH CHECK

Step 5: Determine Maximum Roof Diaphragm Shear

- Maximum Shear in Roof Diaphragm Occurs in Outermost Diaphragm panel (at the endwall)
- $V_{max} = V_h = mS\ (R)$------HORIZONTAL component
- mS = shear force modifier
- mS = $f(c_h/k, k_e/k, N)$

SWAY AND SHEAR MODIFIER METHOD- DIAPHRAGM STRENGTH CHECK

- Selected mS values from **Table 6.6 of the PFBDM**

k_e/k	C_h/k	N = 3	N = 5	N = 10
5	5	0.88	1.33	1.65
5	1000	0.91	1.54	2.49
50	5	0.95	1.79	2.14
50	1000	0.99	1.94	4.14

SWAY AND SHEAR MODIFIER METHOD- DIAPHRAGM STRENGTH CHECK

- Selected mS values from **Table 6.6 of the PFBDM**

k_e/k	C_h/k	N = 3	N = 5	N = 10
5	5	0.88	1.33	1.65
5	1000	0.91	1.54	2.49
50	5	0.95	1.79	2.14
50	1000	0.99	1.94	4.14

SWAY AND SHEAR MODIFIER METHOD-DIAPHRAGM STRENGTH CHECK

- Selected mS values from **Table 6.6 of the PFBDM**

k_e/k	C_h/k	N = 3	N = 5	N = 10
5	5	0.88	1.33	1.65
5	1000	0.91	1.54	2.49
50	5	0.95	1.79	2.14
50	1000	0.99	1.94	4.14

SWAY AND SHEAR MODIFIER METHOD - DIAPHRAGM STRENGTH CHECK

- V_h is the horizontal component of the shear force in the roof panel and in the roof diaphragm to shearwall connections
- For diaphragms sloped at an angle, θ, the in-plane shear force, V_p is

$$V_p = V_h / \cos\theta = (mS^*R) / \cos\theta$$

SWAY AND SHEAR MODIFIER METHOD - DIAPHRAGM STRENGTH CHECK

- Diaphragm Strength Check

  - Roof diaphragm strength, V_{all} varies linearly with panel length

$$\boxed{V_{all} = \mathbf{v_a}(\text{Length of roof diaphragm})}$$

$\mathbf{v_a}$ = unit shear strength of diaphragm from panel tests ($0.4P_{ult}/b$)

- Design Criteria for Diaphragm Shear Capacity

$$V_p \leq V_{all}$$

SWAY AND SHEAR MODIFIER METHOD– DIAPHRAGM STRENGTH CHECK

- Roof diaphragm panel in-plane shear strength must exceed the maximum shear force

$$V_p \leq V_{all}$$

$$V_P = V_h/\cos\theta \leq V_{all} = (\mathbf{v_a})\text{*Length of Roof}$$

- Connections between the end of roof diaphragm and the top of the endwall must be able to transfer V_p to the shearwall

DESIGN EXAMPLE: PF DESIGN BY SWAY AND SHEAR MODIFIER METHOD

- Problem Statement
  - Determine the required sidewall post size for a 40 ft. wide by 120 ft long PF building with 10 ft eave height and post frames spaced 8 ft. o.c. (Same example is used in the Diaphragm Design of PF Using DAFI webinar)
  - The walls and roof are sheathed and connected sufficiently to develop diaphragm action.
  - Gable shaped metal-plate connected roof truss with 3/12 pitch and horizontal lower chord

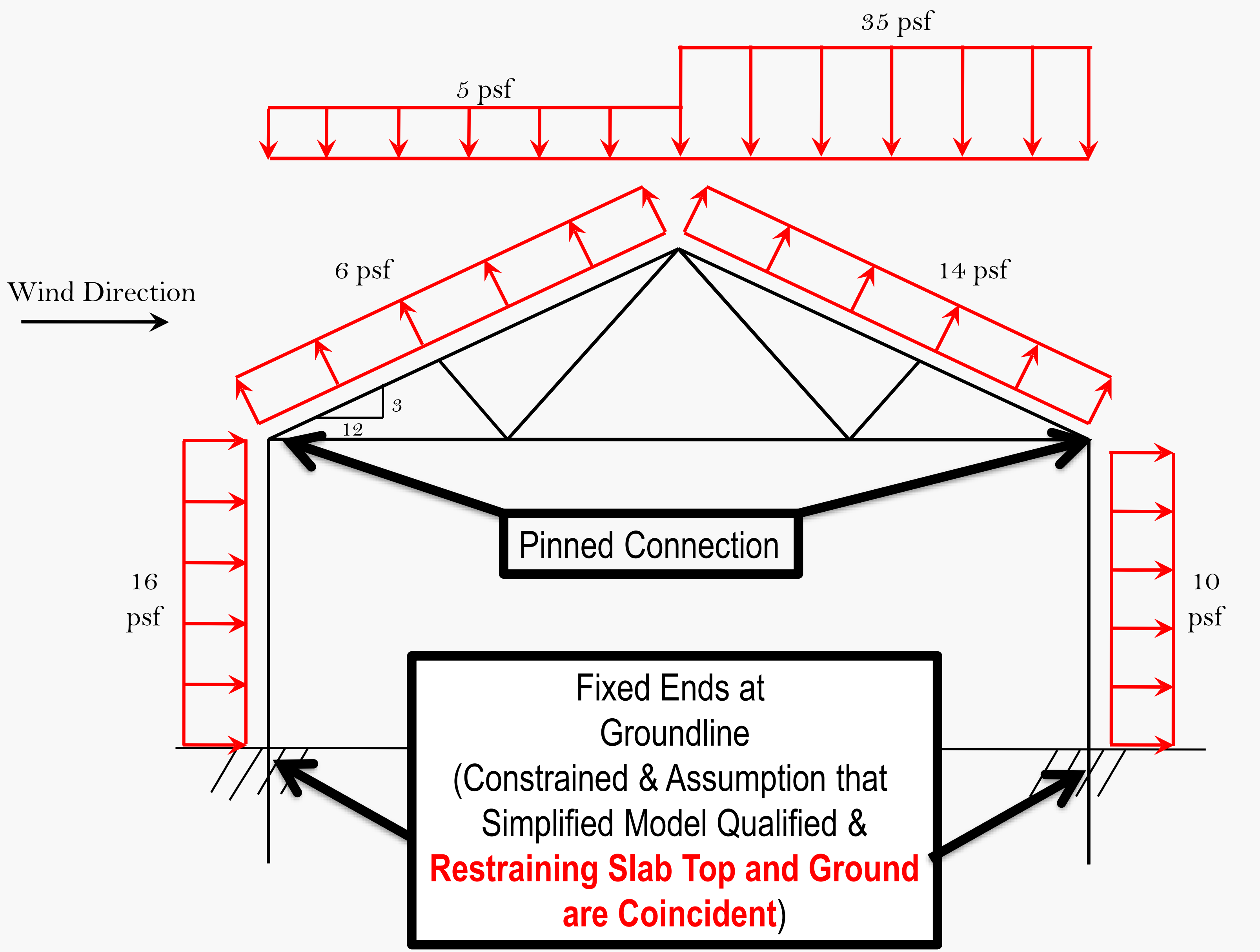
DESIGN EXAMPLE STATEMENT (CONTINUED)

- The sidewall columns are unspliced, glued-laminated wood posts
- The posts are embedded directly into the ground and are constrained at the ground line in all directions**; the ground line and top of restraining slab are at the same elevation.**
- The posts are set on a circular concrete pad footing
- The top of the post nearly constrained from swaying in the plane of the PF by the diaphragm restraining force; the top of the post is restrained from swaying in the direction of the sidewalls by the wall girts and longitudinal wind bracing.

DESIGN EXAMPLE ASSUMPTIONS

- Post foundation qualifies for simplified shallow post foundation analysis
- Metal-plate-connected wood truss design supplied by truss manufacturer

DESIGN EXAMPLE-ASD DESIGN LOADS



DESIGN EXAMPLE - ROOF DIAPHRAGM PANEL SPECIFICATIONS

- Roof is sheathed with 29 ga ribbed steel diaphragm panels with published geometric, shear strength, and shear stiffness properties (Test Assembly No. 5 in Table 7.1, PFBDM):
  - b = 12 ft (test panel length)
  - a = 6 ft (test panel width)
  - v_a = 133 lb_f/ft (test panel allowable unit shear strength)
  - c = 2980 lb_f/in (test panel in-plane shear stiffness)

DIAPHRAGM PROPERTIES-PFBDM

Table 7-1. cont., MCWF Roof Diaphragm Test Assembly Data

Test Assembly Number	5	6	7	8
Test Configuration	Cantilever	Cantilever	Cantilever	Cantilever
Cladding				
Manufacturer/Trade Name	Midwest Manufacturing	Grandrib 3	Grandrib 3	Walters STR-28
Base Metal Thickness Gauge	29	29	29	28
Major Rib Spacing, inches	12	12	12	12
Major Rib Height, inches	1.0	0.75	0.75	0.94
Major Rib Base Width, inches	2.5	1.75	1.75	
Major Rib Top Width, inches	0.5	0.5	0.5	
Yield Strength, ksi	80	80	80	80
Overall Design				
Width, feet	6	9	9	9
Length, *b* , feet	12	12	12	16
Purlin Spacing, feet	2	2	2	2
Rafter Spacing, feet	6	9	9	9
Purlin Location	Top running	Top running	Top running	Top running
Purlin Orientation	On edge	On edge	On edge	On edge
Number of Internal Seams	2	2	2	2
Wood Properties				
Purlin Size	2- by 4-inch	2- by 4-inch	2- by 4-inch	2- by 4-inch
Purlin Species and Grade	No.2 SYP	No.2 DFL	No.2 SPF	No.2 SYP
Rafter Species and Grade	No. 1 SYP	No. 2 DFL	No. 2 SPF	1950f1.7E SYP
Stitch Fastener				
Type	EZ Seal Nail	None	None	Screw
Length, inches	2.5			1.5
Diameter	8d			#10
On Center Spacing, inches	24			24
Sheet-to-Purlin Fasteners				
Type	Screw	Screw	Screw	Screw
Length, inches	0.75	1.0	1.0	1.5
Diameter	#12	#10	#10	#10
Location in Field	In Flat	In Flat	In Flat	In Flat
Location on End	In Flat	In Flat	In Flat	In Flat
Avg. On-Center Spacing in Field, in.	6	12	12	12 and 18
Avg. On-Center Spacing on End, in.	6	6	6	12
Purlin-to-Rafter Fastener	60d Threaded Hardened Nail	1-60d Spike + 2-10d Toenails	1-60d Spike + 2-10d Toenails	60d Threaded Hardened Nail
Engineering Properties				
Ultimate Strength, P_u, lbf.	3995	3300	2775	4884
Allowable Shear Strength, v_a, lbf/ft	133	110	93	122
Effective In-Plane Stiffness, *c* ,lbf/in	2980	2920	2950	3890
Effective Shear Modulus, G, lbf/in	1490	2190	2210	2190
Reference	Wee & Anderson, 1990	Lukens & Bundy, 1987	Lukens & Bundy, 1987	Bohnhoff and others, 1991

DESIGN EXAMPLE – BARE FRAME STIFFNESS

- Two bare frame stiffnesses:

  - sheathed end wall frame stiffness, k_e

  - interior frame stiffness, k

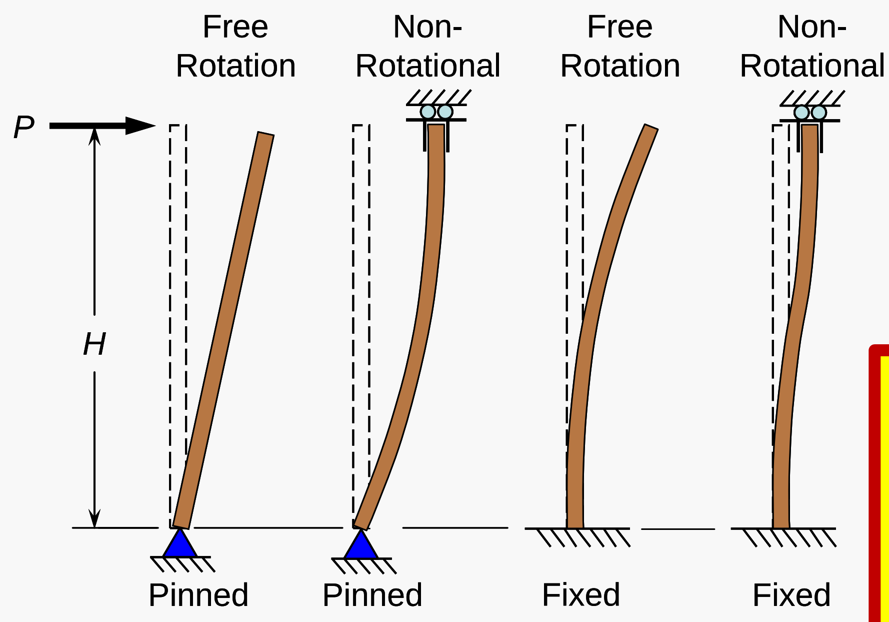
  - we will assume the endwall frame is very stiff with a stiffness 10,000 times that of the bare interior PF

DESIGN EXAMPLE – BARE FRAME STIFFNESS

- Solution parameters
  - Interior PF bare frame stiffness estimated by summing 2 sidewall post stiffnesses in lieu of a complete plane frame structural analysis
  - Can easily justify doing this since top of post is pin connected to the roof truss and there are no knee braces attached to the sidewall columns & roof trusses

DIAPHRAGM DESIGN

Bare Frame Stiffness by Summation of Individual Post Stiffness Values ($k = \sum k_{P,i}$)-Table 6.1, PFBDM



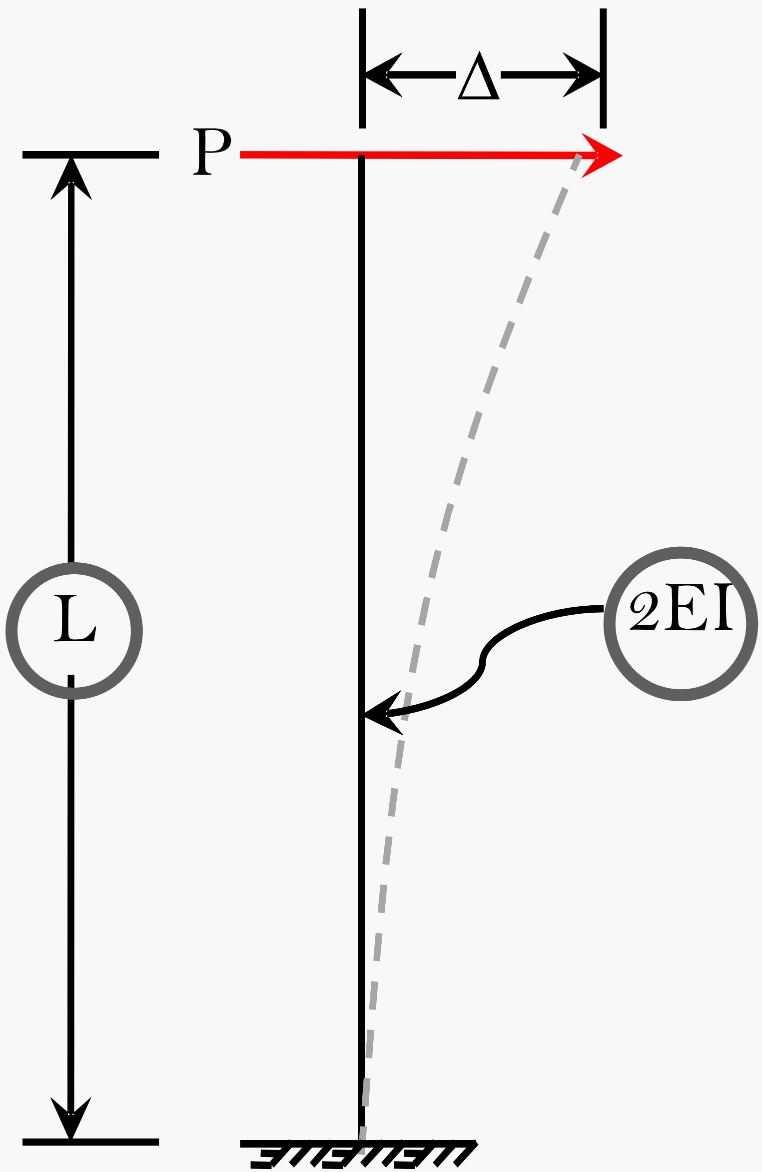
Fixity Case	Post-to-Base Connection	Post Top Restrained from Rotating? (a)	Post Stiffness, (b)
1	Pinned	No	0
2	Pinned	Yes	$3EI/H^3$
3	Fixed	No	$3EI/H^3$
4	Fixed	Yes	$12EI/H^3$

Post to ground fixity is a "Fixed End" in this example because the top of constraining slab and groundline are coincident

Top of post is "Free Rotation" In this example because the truss pin-connected to post AND there is no diaphragm action for determining Bare Frame Stiffness

Use Case 3 for this example

BARE FRAME STIFFNESS – INTERIOR PF



Approximated as bending stiffness of 2 cantilevered beams

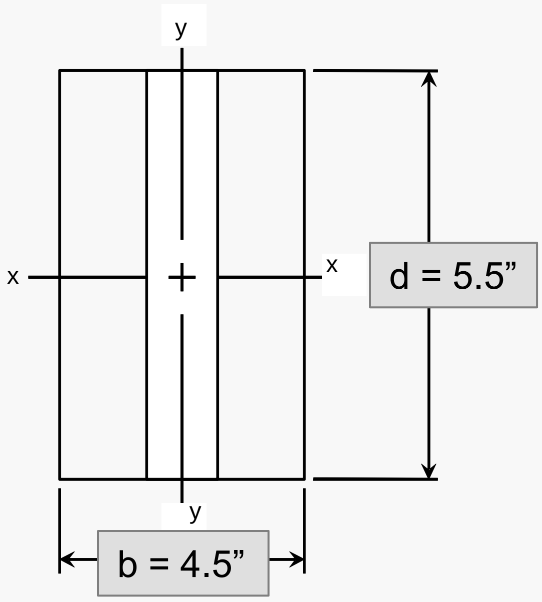
$K = 2(\mathbf{3EI/L^3}) = 6EI/L^3$

Where:

- P = applied load at the free end, lb_f
- L = column length, in
- EI = bending stiffness of one sidewall column, $lb_f\text{-}in^2$

DESIGN EXAMPLE - NAIL-LAMINATED COLUMN SECTION PROPERTIES

Assuming, as a first estimate, a nominal 6-x-6 unspliced glued-laminated (1750f1.5E) sidewall column with X-sectional dimensions shown in sketch



$E = 1.5\text{x}10^6$ psi

$S_{xx} = bd^2/6 = (4.5)(5.5)^2/6 = 22.68 \text{ in}^3$

$A = (4.5)(5.5) = 24.75 \text{ in}^2$

$I = bd^3/12 = 62.4 \text{ in}^4$

$K = 6(1.5E6)(62.4)/(120)^3 = 325 \text{ lb}_f/\text{in}$

DESIGN EXAMPLE - ROOF IN-PLANE SHEAR STIFFNESS CALCULATION

The **horizontal** component of **roof diaphragm** stiffness, c_h

c_h = $\mathbf{c(a/b)}(b_{sp}/a_p)\cos^2\theta$

c = effective test panel stiffness = 2980 $\mathbf{lb_f}$/in

a = test panel width = 6 ft

b = test panel length = 12 ft

a_p = PF spacing = 8 ft

b_{sp} = roof slope length = **2**(20/cos14) = 41.2 ft

c_h = **2980(6/12)**(41.2/8)$\cos^2$14 = 7,226 lb_f/in

DESIGN EXAMPLE - BARE FRAME AND ROOF PANEL STIFFNESS SUMMARY

$k_2 = k_3 = \ldots = k_{15} = k = 325\ lb_f/in$

$k_1 = k_{16} = 10{,}000\ (325) = k_e = 3.25E6\ lb_f/in$

$c_{h1} = c_{h2} = \ldots = c_{h15} = 7{,}226\ lb_f/in$

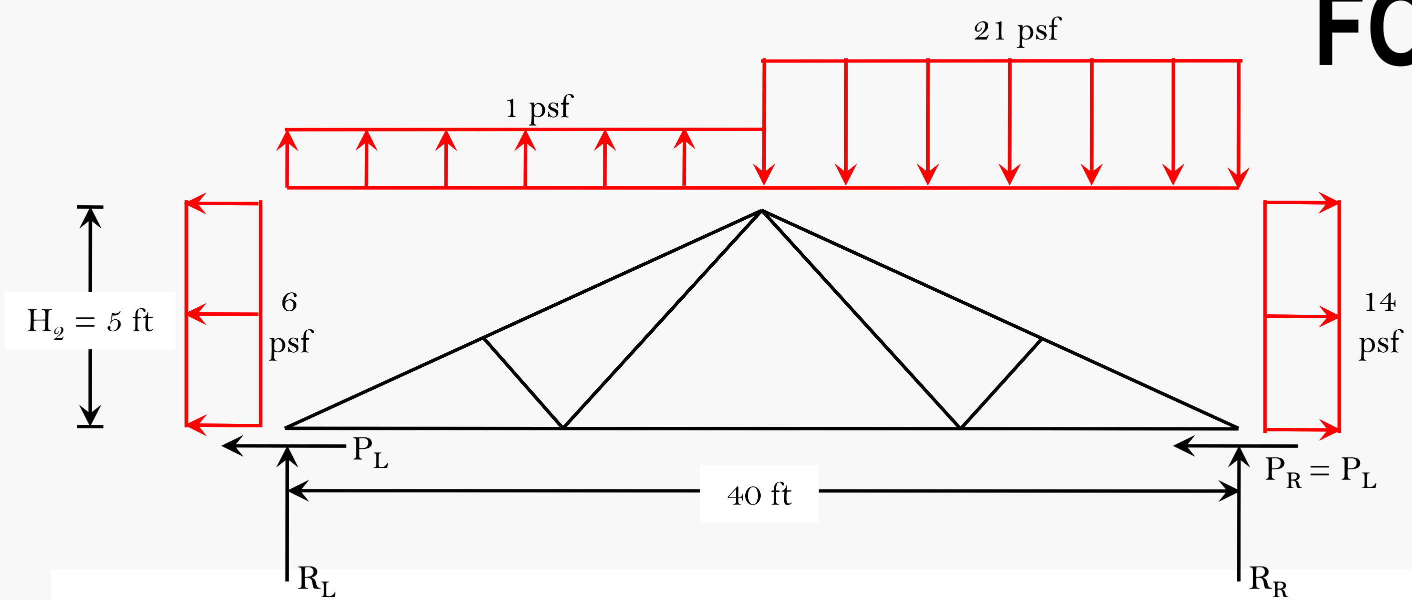
DESIGN EXAMPLE - SWAY & SHEAR MODIFIERS (mD & mS)

Entering Tables 6.6 and 6.7 in the PFBDM for N = 16 frames, k_e/k = 10,000, and c_h/k = 7,226/325 = 22.3,

mD = 0.39

mS = 4.23

DESIGN EXAMPLE - TRUSS REACTIVE FORCES



- Summing moments about the truss' left heel joint

R_R = 2,500 lb_f (upward)

- Summing forces in the vertical direction yields

R_L = 700 lb_f (upward)

- Summing forces in the horizontal direction assuming $P_R = P_L$

$P = P_R = P_L = 160\ lb_f$

DESIGN EXAMPLE – EAVE RESTRAINING FORCE, R

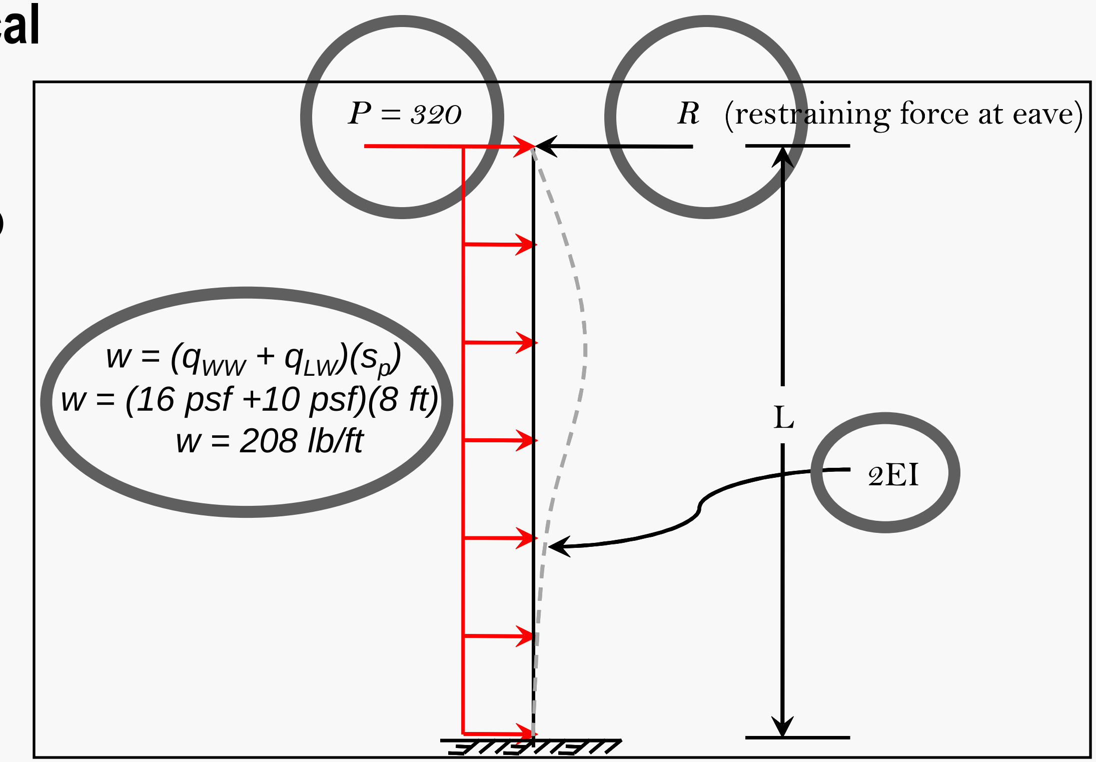
Maximum restraining force, R, due to vertical roller at eave

R is the force required to cause the sidewall column to act as a propped end beam with zero sway at the top.

$R = P + 3wL/8$

$R = 320 + 3(208)(10)/8$

$R = 1100\ lb_f$

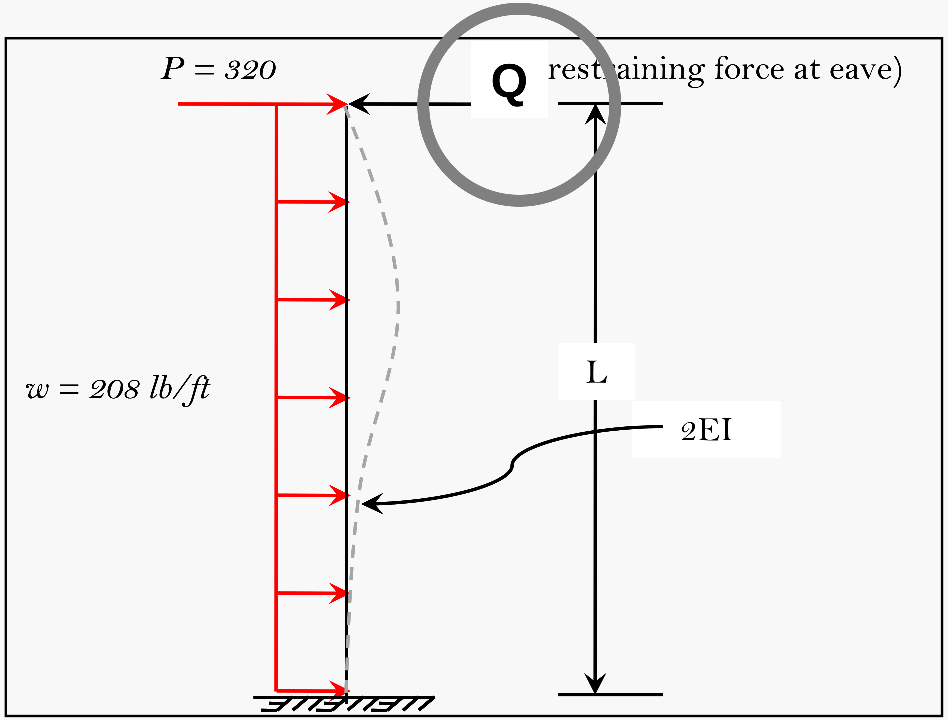


Fixed end because constrained AND the top of restraining slab and ground elevation are identical, AND Simplified foundation analysis method qualified

DESIGN EXAMPLE- DIAPHRAGM RESTRAINING FORCE, Q

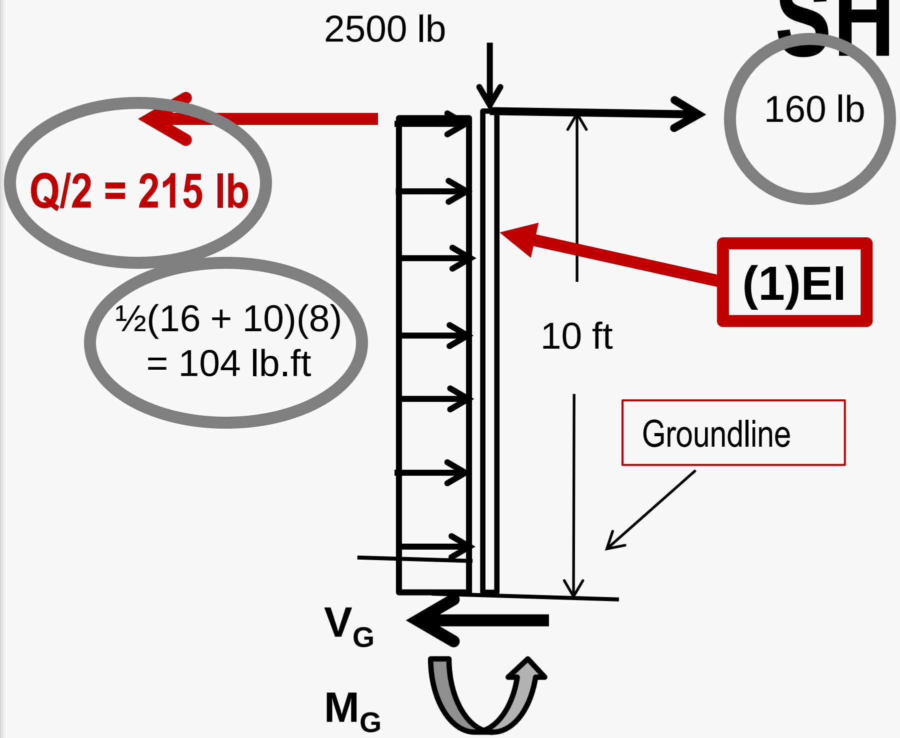
- Q is the restraining force at the eave due to the roof diaphragm action

- Q = mD(R)
  = 0.39(1100)
  = 430 lb_f



Fixed end because constrained, slab and ground elevation are identical, and simplified foundation analysis method qualified

DESIGN EXAMPLE – SIDEWALL POST SHEAR AND MOMENT



Free body diagram of the right hand post for the prescribed loading.

Since the slab top elevation is the same as the groundline elevation, the post-to-soil foundation analog is a fixed end at the groundline

From static equilibrium,

$\mathbf{V_G = 985\ lb}$ and $\mathbf{M_G = 4650\ lb\ ft}$

DESIGN EXAMPLE - ROOF DIAPHRAGM PANEL SHEAR FORCE

Maximum roof diaphragm shear force, V_{max}

- The horizontal component of the roof diaphragm maximum shear force, V_h

$$V_h = mS(R) = 4.23(1100) = 4{,}653\ lb_f$$

- The in-plane component of the maximum shear force, V_p

$$V_p = V_{max} = V_h/\cos\theta = 4{,}653/0.97 = 4{,}797\ lb_f$$

DESIGN EXAMPLE - ROOF DIAPHRAGM PANEL SHEAR FORCE (CONT.)

Check unit shear strength of the selected roof diaphragm construction.

- The maximum unit shear in the roof diaphragm, v_{max}

$$v_{max} = V_{max}/(2L_s) = 4{,}797/(2 \times 20/0.97) = 116\ lb_f/ft$$

- The allowable shear strength of the selected roof diaphragm panel, v_a

$$v_a = 133\ lb_f/ft \geq v_{max} = 116\ lb_f/ft$$

- Therefore, the selected panel is adequate.

SIDEWALL POST DESIGN CRITERION

Design criterion for the sidewall column (NDS-2015)

Interaction equation for combined axial compression and bending:

$$\left(\frac{f_c}{F'_c}\right)^2 + \left(\frac{f_b}{F'_b(1 - f_c/F_{cEx})}\right) \leq 1.0$$

DESIGN EXAMPLE – SIDEWALL POST SECTION PROPERTIES

Structural and Section Properties for a trial 6x6 1750f-1.5E un-spliced, 3 ply, glued-laminated wood section

F_b = 1750(1.15) = 2015 psi (repetitive member use)

F_c = 1500 psi

S = 22.7 in^3

A = 24.75 in^2

I = $(1/12)(4.5)(5.5)^3$ = 62.39 in^4

E = 1.5E6 psi

DESIGN EXAMPLE – BASIC BENDING & AXIAL COMPRESSION STRENGTHS

- Input parameters for the interaction equation

$F_b^* = 2015(1.6)(0.8) = 2580$ psi (Load duration; wet use)

$f_b = M/S = 4650(12)/22.7 = 2458$ psi

$f_c = 2500/24.75 = 101$ psi

ADJUSTED AXIAL COMPRESSIVE STRENGTH, F_c'

F_c' -calculation

$(L_e/d)_{max}$ = 0.8(120)/5.5 = 17.4 (fixed-pinned, no displacement)

F_c^* = 1500(1.6)(0.73) = 1750 psi (Load duration; wet)

$(E')_{min}$ = 0.63E6 psi (Lower 5th percentile MOE)

F_{cE} = $0.822'E'_{min}/(L_e/d)_{max}^2$ = $0.822(0.63E6/(17.4)^2$ = 1711 psi
(Theoretical Euler Buckling Strength based on max L/d)

F_{cE}/F_c^* = 1711/1750 = 0.98

C_p = $(F_{cE}/F_c^*)/1.8 - [(F_{cE}/F_c^*)^2 - F_{cE}/F_c^* /0.9]^{1/2}$

C_p = $1.98/1.8 - [(1.98/1.8)^2 - 0.98/0.9]^{1/2}$ = 0.65
(Column stability factor)

F_c' = 0.65(1750) = 1135 psi

DESIGN EXAMPLE-ADJUSTED BENDING STRENGTH, F_b' & CSI

- F_b' -calculation

  The wall girts and wall sheathing provide lateral support every 24 inches o.c. Clearly, with L_u = 24 inches and a nearly square section, R_B = bending slenderness ratio = $(L_e d/b^2)^{1/2}$ <<<< 10 and $C_L \approx 1.0$. Thus,

  $$F_b' = C_L F_b^* = F_b^* = 2{,}436 \text{ psi}$$

- Substituting parameters into the interaction equation yields

  $$\begin{aligned} CSI &= (101/1135)^2 + 2458/[2580(1 - 101/1711)] \\ &= 0.008 + 1.01 = 1.018 \approx 1.00 \end{aligned}$$

- The 3 ply, 1750f-1.5E 6x6 unspliced glued-laminated wood post is satisfactory for the wall column

EXAMPLE SUMMARY

Design Parameter	No Diaphragm Action Session 6	Diaphragm Action DAFI-Session 6	Diaphragm Design Sh./Sway Mod.
Max. Post Shear(lb)	1200	980	985
Max. Post Moment (lb-ft)	6800	4600	4650
Post Size (in x in) Post Type Post Grade	4.5 x 7.25 3-ply Glulam 1800f-1.6E	4.5 x 5.5 3-ply Glulam 1750f-1.5E	4.5 x 5.5 3-ply Glulam 1750f-1.5E
Max Shear in Roof Diaphragm (lb/ft)	0	107	116
Post Foundation Depth[1] (in)	37	30	30

Note 1: Cohesive (ML) soil; simplified method for determining embedment depth (Sessions 4 & 5 for details)

LIMITATIONS OF THE SWAY/SHEAR MODIFIER METHOD

Only applicable when:

- post frames are equally spaced
- all interior post frames have equal bare frame stiffness, k
- both end walls have the same bare frame stiffness, k_e
- all roof diaphragm panels have equal in-plane shear stiffness

The Diaphragm and Frame Interaction (DAFI) Method for post frames buildings releases these limitations (Diaphragm Design of PF Using DAFI webinar)

Shallow Post-Foundation Design

Details for determining embedment depth, anchorage and footing requirements for the loads in this Example are provided in other webinars in this series.

MORE POST-FRAME STRUCTURAL DESIGN DETAILS?

NFBA's On-Line University Course, "Diaphragm Design of PF Using Sway Shear Modifiers " (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.) 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)
- www.NFBA.org
- NFBA

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