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Post-Frame Building Design Resources and Design Methods

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Penn State University

Technical Advisor
National Frame Building Association (NFBA)

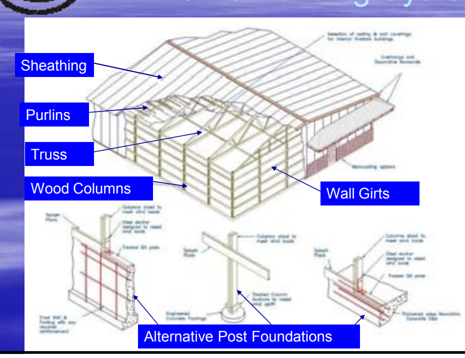
Learning Objectives

- Identify the primary structural components of post frame (PF) building systems
- Identify the available resources for design of PF building systems
- Identify the two primary structural design methodologies for PF systems
- Learn the conceptual structural design approach for PF buildings with emphasis on those elements unique to PF systems

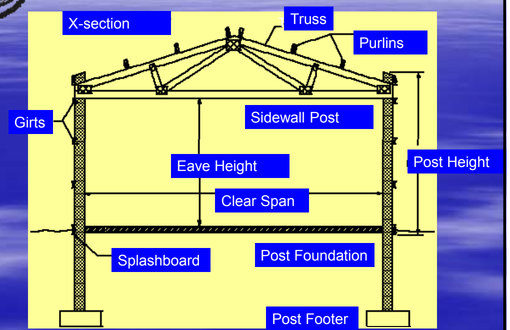
Scope of the Presentation

- Presents the basic design procedures for PF
- Presents some typical structural details for selected PF building components
- Does not present calculations and structural detailing for a specific project; these are the topics for a one to two day NFBA Workshop on PF Design

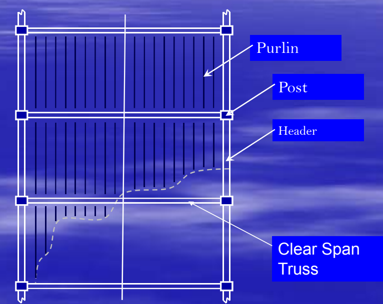
Pictorial of a Typical Post Frame Building System



Cross Section of a Typical Post Frame Building System



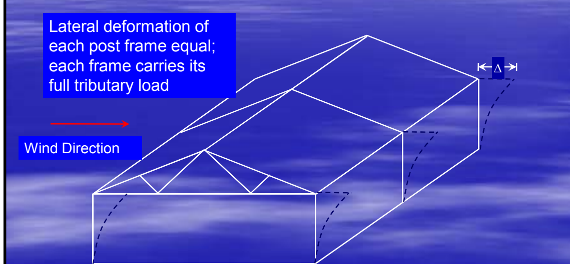
Typical Post Frame Plan View



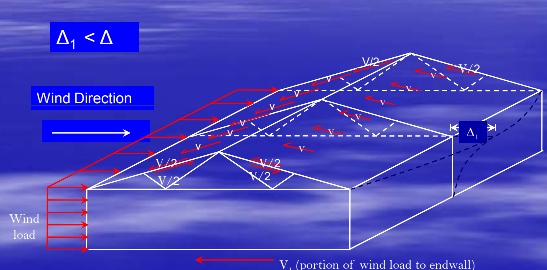
Primary Design Approaches for PF Buildings

- 2-Dimensional Frame Design Method- Only covered very briefly.
- Diaphragm Design Method (3-Dimenional Approach)-Session Focus

PF Response to Lateral Loads w/o Diaphragm Action

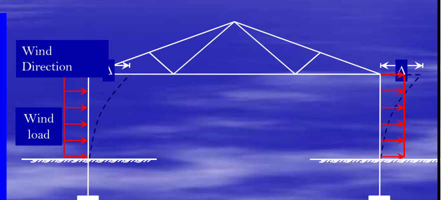


PF Response to Lateral Loads with Diaphragm Action



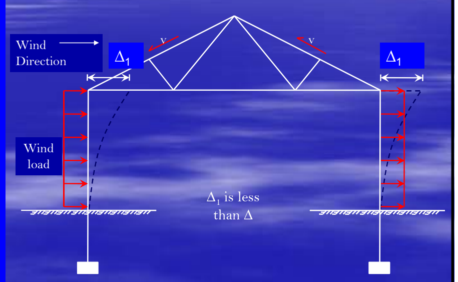
PF Response to Lateral Loads w/o Diaphragm Action

- Without diaphragm action each PF carries the full lateral wind load applied to tributary area of the frame
- The post frame sways an amount, Δ at the eave



PF Response to Lateral Loads with Diaphragm Action

- Portion of design lateral loading on sidewall and roof is transferred to the roof diaphragm
- The diaphragm exerts a resisting distributed shear force, v, to the post frame
- The post frame sway at the eave is $\Delta_1 < \Delta$ (sway of the post frame w/o diaphragm action



Post-Frame Building Design Methods

- Advantages of Diaphragm Design in Post-Frame

  - Smaller sidewall wall posts

  - Shallower post or pier embedment depths

Post-Frame Building Design Methods: Which to Use, When???

- 2-D Frame Method required for:

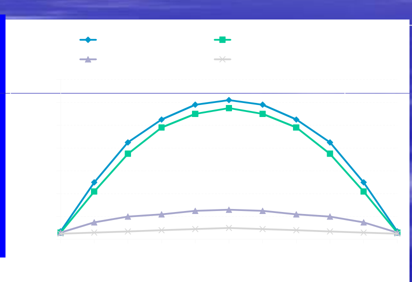
  - PF with open sidewalls or end walls
  - PF without adequate structural detailing or connection details to develop proper load paths for transfer of in-plane shear forces in the roof diaphragm and the shearwalls

Post-Frame Building Design Methods: Which to Use, When???

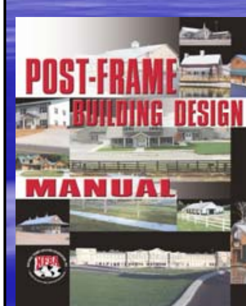
- Diaphragm Design is used for nearly all modern PF building systems with enclosed end walls and sidewalls
  - More economical design
  - Greater structural integrity
  - More durable PF structures

Comparison of 2-D vs. Diaphragm Design PF Performance

Fully sheathed roof and end walls reduced measured horizontal movement of eave by a factor of 12 over bare frame under typical design wind loads



Key PF Technical Resources from NFBA



- Structural design procedures for PF building systems
- Developed by the Technical and Research Committee of NFBA
- Cost: $150 (Non-member)
  $50 (Design Professional Member of NFBA)
- NFBA Design Professional Membership Cost: $95

Key Engineering Practices for PF

- ASAE (ASABE) EP 484, Diaphragm Design of metal-clad, post-frame rectangular buildings
- ASAE (ASABE) EP 486, Shallow post foundation design
- ASAE (ASABE) EP 559, Design requirements and bending properties for mechanically laminated columns
- EP 484, 486, and 559 referenced in Section 2306.1, IBC 2006

PF Structural Design Resources

ASAE EPs available at:

www.asabe.org

or

ASABE
2950 Niles Road
St. Joseph, MI 49085

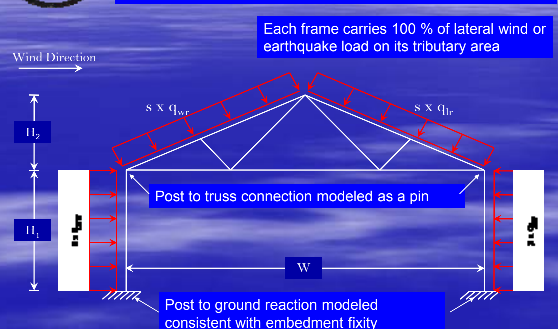
Key PF Technical Resources from NFBA

- Guide Specification for Post-Frame Building Systems developed by NFBAs T&R Committee
  - Follows Masterspec format
  - Available at www.postframeadvantage.com and www.nfba.org in Word format
  - Online version that auto-generates a spec customized to users needs will be available in 2009 at www.nfba.org

PF Structural Design Resources

- AWC/AF&PA – (2005). National Design Specification (NDS) for Wood Construction and Supplements
- ASCE 7 - (2005) Minimum Design Loads for Buildings and Other Structures
- AWPA U1-04: USE CATEGORY SYSTEM: User Specification for Treated Wood

2-D Frame Design Method

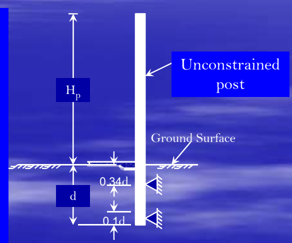


2-D Frame Design Method

- Except for the modeling of the post-soil interaction, design similar to any other 2-D wood frame
- Typical post-soil fixity models
  - constrained
  - unconstrained
  - spring loaded
  - fixed

PF Fixity Models for Post to Soil Interaction

•Shown is an approximate soil-post fixity model for a first estimate of the location of the vertical roller support for the unconstrained post case
•Procedures for more precise estimates of the location are discussed later



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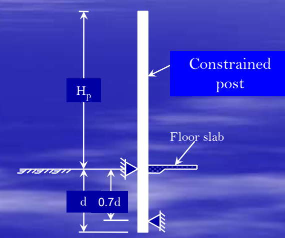
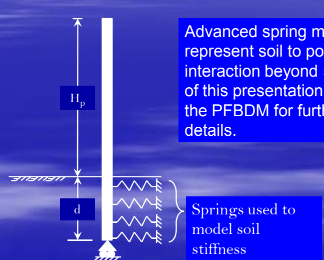


PF Fixity Models for Post to Soil Interaction

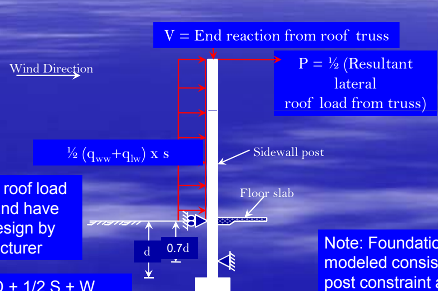


Advanced spring models to represent soil to post interaction beyond scope of this presentation; See the PFBDM for further details.

2-D Frame Design Method

- Conduct structural analysis using any standard computer analysis/design program which incorporates NDS wood design requirements and calculates Interaction Values for combined bending and compression/tension of wood members
- Consider the several load combinations prescribed in ASCE 7
- Dead + ½ Snow + Wind usually controls post design
- Dead + Snow usually controls roof framing design

Simplified 2-D Post-Frame Design Method



Specify roof load levels and have truss design by manufacturer

Post: D + 1/2 S + W

Roof Framing: D+ S

Note: Foundation modeled consistent with post constraint at ground line

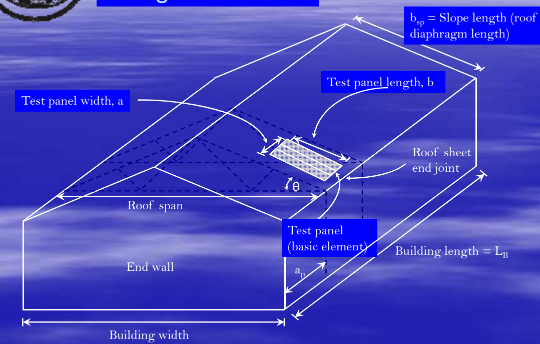
2-D Frame Design Method

- Once post moments and shears at ground line determined, post-embedment depth determined using ASAE EP 486.1
- Post embedment requirements covered more fully after presentation of Diaphragm Design methodology
- Posts, purlins, girts, etc. design then follows NDS specs for combined loading; i.e.; I ≤ 1.0

Diaphragm Design Method

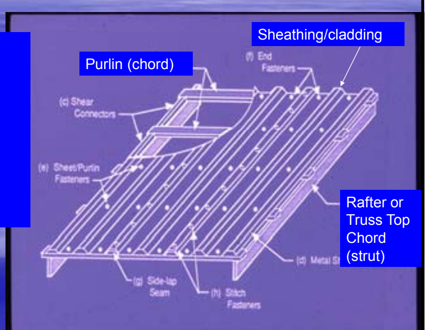
- Incorporates the contribution of the in-plane strength and stiffness of the sheathing (metal cladding or structural wood panels) in the roof and endwalls
- A 3-D approach
- Results in significant decreases in wall framing materials (At least one nominal size difference in post cross section dimensions)

Diaphragm Design Method



Post Frame Building Design-Diaphragm Design

Typical Post Frame Diaphragm Panel Construction and Details

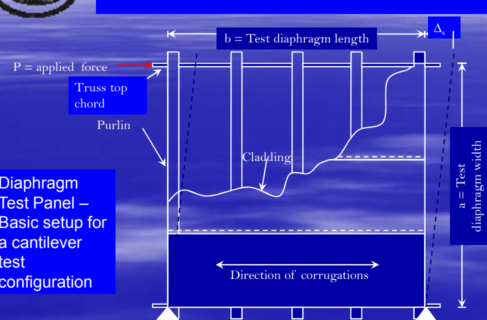


Diaphragm Design Method

- In-plane shear strength and stiffness of the roof and endwall diaphragms usually obtained by testing small diaphragm test panels
- An NFBA, T & R research effort is currently underway to develop simplified calculation methodologies to predict the in-plane shear strength and stiffness of metal-clad structural diaphragms

Diaphragm Design Method

Diaphragm Test Panel – Basic setup for a cantilever test configuration

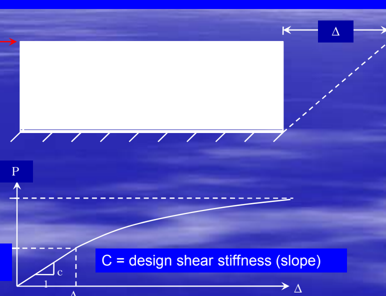


Diaphragm Design Method

Diaphragm test schematic and simplified test results

Ult. Strength = P_{ult}

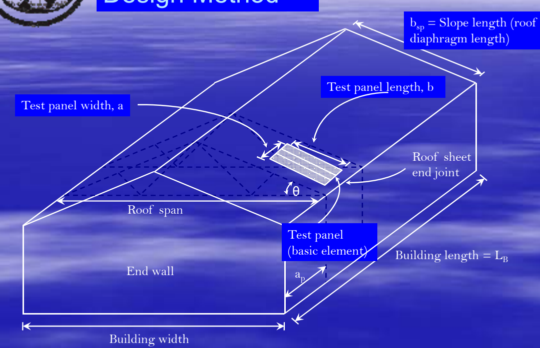
Design shear strength = 0.4 P_{ult}



Diaphragm Design Method

- Test Panel width, a, is often, but not necessarily, the same as the PF bay spacing
- Test diaphragm length, b, (dimension in direction perpendicular to the applied load) is usually much smaller than the roof diaphragm panel
- Thus the actual roof or ceiling panel shear strength and stiffness must be deduced from the small test panel results

Diaphragm Design Method



Diaphragm Design Method

- The in-plane shear strength and stiffness of a roof or ceiling diaphragm with width a_p and slope length b_{sp} derived from basic mechanics is:

$$c_p = c\,(a/b)\,(b_{sp}/a_p)$$

NOTE: Add colored subscripts to your handouts

where
c = test panel stiffness
a = test panel width
b = test panel length
b_{sp} = building roof panel slope length
a_p = building roof panel width (bay spacing)

Diaphragm Design Method

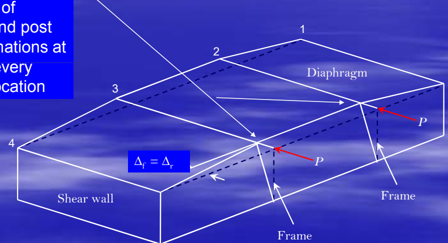
- For a roof diaphragm sloped at angle, Θ, the in-plane stiffness in the horizontal direction , c_h is defined as:

$$c_h = c_p\,(\cos^2 \Theta)$$

The horizontal stiffness component is required later in the development for compatibility of horizontal displacements of the post frame and the roof diaphragm at the building eave line.

Diaphragm Design Method

PF diaphragm design procedures based on compatibility of diaphragm and post frame deformations at the eave at every post frame location



Diaphragm Design Method

- For compatibility of deformations at the eave,

$$\Delta_{ri} = \Delta_{fi}$$

where $\Delta_{ri} = f(c_{h,i}, c_{h,i+1})\,P_i$

$\Delta_{fi} = k_i P_i$

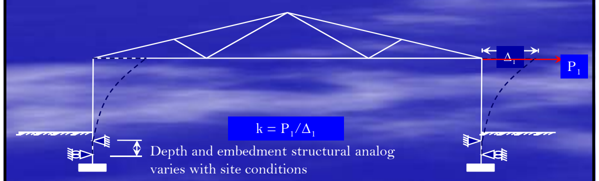
and k_i = bare frame stiffness @ frame i

$f(c_{h,i}, c_{h,i+1})$ = function of diaphragm shear stiffness of diaphragm panels adjacent to frame i

P_i = eave load at frame i

Diagram Design Method

Determination of frame stiffness, k, and diaphragm stiffness, c_h, are the first steps in the PF diaphragm method



Diaphragm Design Method

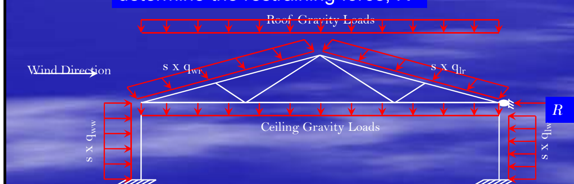
- ASAE EP and NFBAs PFBDM procedures for PF cases for which:
  - post frames are equally spaced
  - all interior post frames have equal stiffness, k
  - both endwalls have the same stiffness, k_e
  - all roof and ceiling diaphragms have equal stiffness

Diaphragm Design Method

- ASAE EP approach yields results for the most highly loaded frame (centermost post) and maximum shear load in diaphragm (at endwall)
- Methods for post frames buildings which don't meet the scope and limitations of the EP are also included in PFBDM

Diaphragm Design Method

Apply a vertical roller to the bare post frame at the eave and determine the restraining force, R



Diaphragm Design Method-Post Design

- Calculate the ratio, c_h/k
- Determine the proportion, mD, of the eave roller reaction force that is transferred to the frame by the roof diaphragm
  - mD = f(c_h/k, k_e/k, N) = sway restraining force factor
  - k_e = stiffness of the bare endwall post frame
  - mD values tabulated in ASAE EP 484 and in the PFBDM for range of c_h/k nd k_e/k ratios and N, the number of post frames in the building

Diaphragm Design Method-Post Design

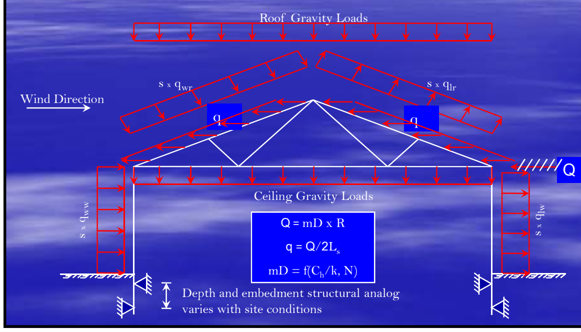
- Selected mD values from Table 5.2 of the PFBDM
- mD = sideway restraining force modifier

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

Diagram Design Method- Post Design

- Apply the sidesway restraining force, Q, to the centermost post frame
  - Q = mD (R)
- Then distribute Q along the entire slope length of the roof diaphragm as a distributed load, q_r
  - q_r = Q/(slope length of roof diaphragm)

Diaphragm Design Method- Post Design



Diaphragm Design Method- Post Design

- Conduct the structural design analysis of the post frame with the design loads and the distributed sidesway restraining force, q
- The controlling design load is usually the Dead + ½ Snow + Wind or Earthquake combination
- However, it is often prudent to conduct the design analysis for each design load combination with lateral load components
- Note that R and Q are not the same for each load combination

Diaphragm Design Method- Diaphragm Strength Check

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

    V_{all} = v (Length of roof diaphragm)

    v = unit shear strength of diaphragm from panel tests ($0.4P_{ult}/b$)
- Design Criteria for Diaphragm Shear Capacity

  $V_{max} \leq V_{all}$

Diaphragm Design Method- Diaphragm Strength Check

- 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 = $f(c_h/k, k_e/k, N)$

Diaphragm Design Method- Diaphragm Strength Check

- Selected mS values from Table 5.1 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

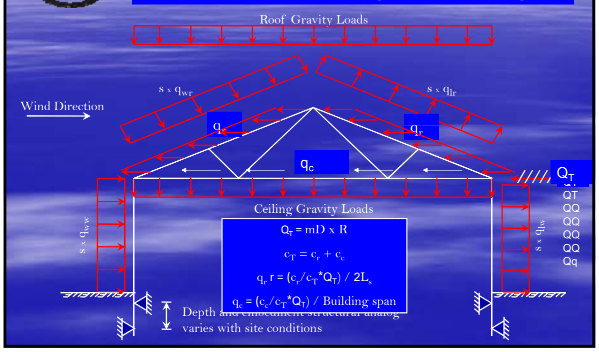
Diaphragm Design Method- Diaphragm Strength Check

- Note that 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
  - $V_p = V_h / \cos \Theta$

Diaphragm Design Method- Diaphragm Strength Check

- Diaphragm Strength must exceed V_{max}
- Connections between the end of roof diaphragm and the top of the endwall must be able to transfer V_{max} to the shearwall
- The shear wall in-plane shear strength must be greater than $V_p = V_{max}$

Diaphragm Design Method- Roof and Ceiling Diaphragm



Diaphragm Design Method- Roof and Ceiling Diaphragm

- Diaphragm maximum shear force, V_T

  $V_T = mS\ (R)$

- Distribution of V_T to roof and ceiling diaphragms

  $V_r = c_r/c_T\ (V_T)$

  $V_c = c_c/c_T\ (V_T)$

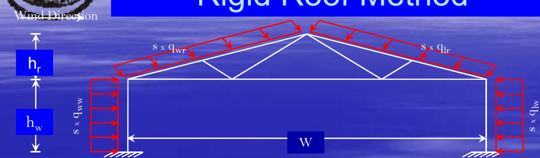
Diaphragm Design Method- Rigid Roof Method

- Use only if c_h or c_T >>>>>> k (Infinitely stiff roof diaphragms and shearwalls
- Maximum diaphragm shear force estimation

  $V_h = L[h_r(q_{wr} - q_{lr}) + h_w f(q_{ww} - q_{lw})]/2$

Where
- q_{ij} = respective roof and wall loads
- h_r = roof height
- h_w = wall height
- L = total length of building
- f = 3/8 for posts with substantial fixity against rotation at ground line
- f = ½ for all other cases

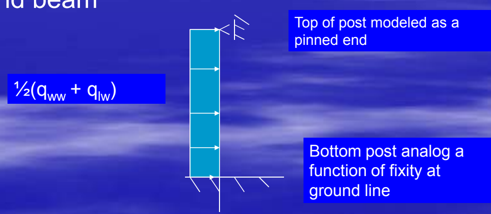
Diaphragm Design Method – Rigid Roof Method



- f = 3/8 for posts with substantial fixity against rotation at groundline
- f = ½ for all other cases

Diagram Design Method – Rigid Roof Method

- For very stiff diaphragms (c_h >>>>k), the sidewall post can be modeled as a propped end beam

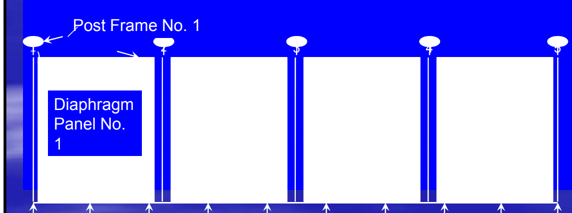


Diaphragm Design Method – DAFI

- DAFI is a computer based PF diaphragm analysis program that calculates eave displacements, frame element loads, and diaphragm element shear forces for each post frame in the building
- DAFI inputs are post frame eave loads, P_i, stiffness, k_i, for each post frame and diaphragm stiffness, c_{hi}, for each diaphragm element in the post frame building

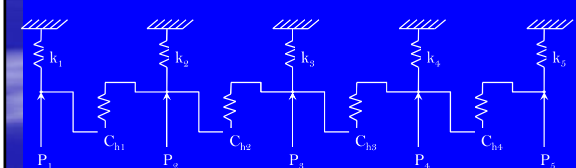
Diaphragm Design Method – DAFI

- Panel and PF Layout for Structural Analog of a 4 Bay Building for DAFI



Diaphragm Design Method – DAFI

- Spring analogy for DAFI Solution for a 4 bay PF building system; roof diaphragm represented by individual frame and diaphragm panel stiffnesses and eave loads



Diaphragm Design Method – DAFI

- DAFI useful for post frames building systems for which:
  - the stiffness, k_i, of each post frame element is ***not*** the same
  - the stiffness, c_{hi}, of each diaphragm panel element is ***not*** the same
  - the stiffness of the two endwalls is ***not*** the same

Diaphragm Design Method – DAFI

- DAFI is available to designers at no cost at:

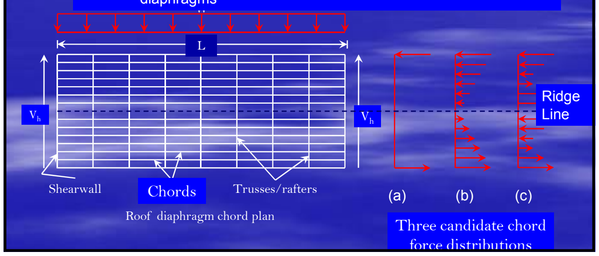
www.nfba.org

Diagram Design Method – Diaphragm Chord Forces

(a) – outside chords carry entire chord force

(b) - all chords loaded; two roof slopes act as one diaphragm

(c) - all chords loaded; two roof slopes act as two independent diaphragms



Diaphragm Design Method – Diaphragm Chord Forces

- Diaphragm bending moment, M_d

  $M_d = V_h L/4 = wL^2/8$

- Maximum chord force, P_e

  $P_e = M_d \alpha / b$

  α = f(chord force distribution)

Diaphragm Design Method – Diaphragm Chord Forces

- Chord force distribution factor, α

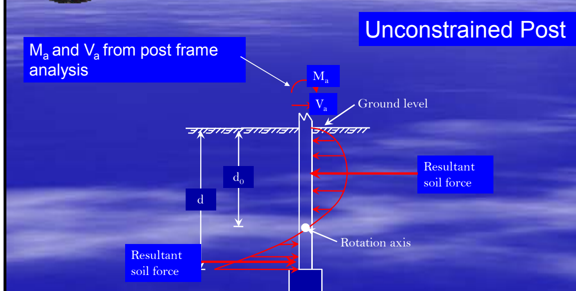
  α = 1 (conservative, assumes outer chord carries all the force)

  α defined for other cases on page 5-16 of the PFBDM (includes the chord force distributions in a previous slide

Post Embedment Design

- Two primary post embedment types:
  - -unconstrained
  - -constrained

Post Embedment Design- Unconstrained Case



Post Embedment Design

- Post embedment details must resist:
  - Shear force and moments from lateral loadings
  - Uplift post loads
  - Downward acting gravity loads (Nothing unique to post-frame)

Post Embedment Design

- Design methods documented in:

  - ASAE EP 486.2, “Shallow-post Foundation Design”

- Design methods outlined and illustrated in the “Post Frame Building Design Manual” (PFBDM, NFBA)

Post Embedment Design- Unconstrained Case

- $d^2 = (6V_a + 8\ M_a/d)/(S'b)$

d = embedment depth
V_a, M_a = shear and bending moment applied to foundation at ground surface (from PF structural analysis)
S´ = adjusted allowable lateral soil pressure
b = eff. post width (1.4B if narrow width of rectangular post pushing on soil)
B = narrow width of the post

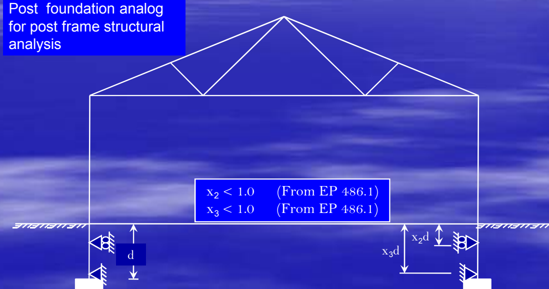
Post Embedment Design- Unconstrained Case

- Embedment depth solution requires an iterative solution

  - M_a and V_a depend upon post embedment analog in frame design/analysis
  - d depends up magnitude of M_a and V_a
  - d = 4 to 4.5 ft. is a good 1st assumption

Post Embedment Design- Unconstrained Case

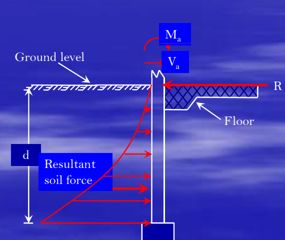
Post foundation analog for post frame structural analysis



Post Embedment Design- Constrained Case

M_a and V_a from post frame analysis

Constrained Post

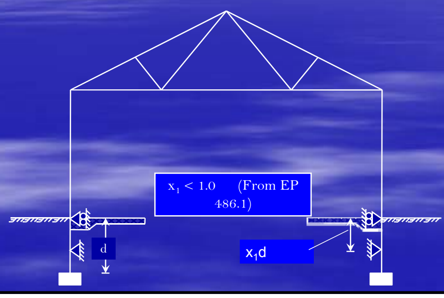


Post Embedment- Constrained Case

$d = [4\ M_a/ S'\ b]^{1/3}$

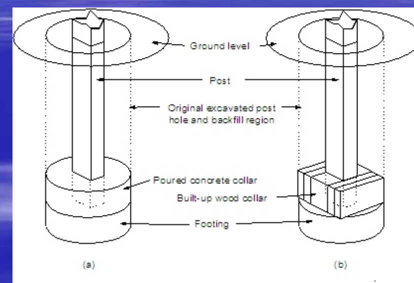
(Terms same as defined for the unconstrained case)

Post Embedment- Constrained Case



Post Foundations – Special Considerations

Concrete collars around posts embedded in ground



Post Embedment – Special Considerations

- Posts embedded in full depth concrete collars- ***Not a recommended practice due to frost heave potential!!***
- Posts partially embedded in concrete collars, either *just below ground line* ***(Not recommended)*** or just above post footer pad (***Okay to do this.***)
- Design equations included in ASAE EP 486.2 for these cases for both constrained and unconstrained posts

Post Embedment – Design for Post Uplift Forces

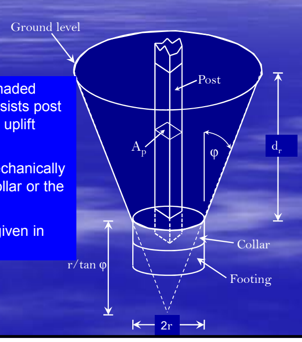
- Uplift resistance provided by:
  - mass of the footer and any collar mechanically attached to bottom of the post
  - mass of cone of soil above any footer and collar mechanically attached to the bottom of the post

Post Embedment – Design for Post Uplift Forces

•Mass of soil in shaded truncated cone resists post withdrawal due to uplift forces

•Post must be mechanically attached to the collar or the footing

•Eqn for volume given in PFBDM



Post Embedment – Design for Post Uplift Forces

- Uplift forces from structural analysis of the post frame
- Uplift Resistance, U

$U = g(M_F + wV_s)$

M_F = mass of foundation elements attached to post

w = soil density

V_s = vol. of displaced soil (See PFBDM, p.8-10)

g = gravitational constant (9.81 for SI units; 1.0 for English Units)

Special Considerations for Post Foundations

- Place footer below frost line
- Do not use partial concrete collars immediately below ground line (top collars)
- Do not backfill post holes with silts and clays
- Provide good drainage away from post holes
- Use only preservative treated wood for all wood elements in contact with the ground

Post Frame Design Consideratons

- Alternative PF foundations summarized in presentation, "Introduction to PF Building Systems"
- Alternative wood posts (solid sawn, glue-laminated, and nail-laminated) summarized in same presentation
- Available at www.Woodworks.org

Special Considerations for Post Frame Design

- Be sure post to footer connections have the required shear and moment capacity
- The post to truss connection is a critical connection for the post frame system. It is usually designed as a pinned connection
- Use hot dipped galvanized or stainless hardware for all below ground applications
- Use hot dipped galvanized or stainless hardware when in contact with preservative treated wood. (Contact preservative treatment suppliers for recommendations)

Post Frame Building Design

- Most other structural detailing design not much different from other wood structural systems
  - Purlin and girt design routine
  - Truss design usually by the truss mfgr.
  - Secondary wind bracing for trusses and side walls similar to other wood framing (See WCTA/TPI BSCI guides for installing and bracing wood trusses and specific recommendations for widely spaced trusses in PF)
  - Design of all wood elements and connectors governed by provisions of the National Design Specification (NDS) for Wood Construction

Post Frame Building Design

- Primary differences include:
  - Embedded posts, or one of the post foundation alternatives, serve as building foundation
  - Diaphragm design procedures for post frame are unique, but well formulated and documented
  - PF very often utilizes mechanically or glued laminated sidewall and endwall posts

More Information about Post Frame???

NFBA (National Frame Building Association)

www.PostFrameAdvantage.com
or
www.NFBA.org

OR

NFBA
4840 Bob Billings Parkway
Lawrence, KS 66049-3862


Post Frame Building Design
Questions????