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Post-Frame Building Design Methods and Resources

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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

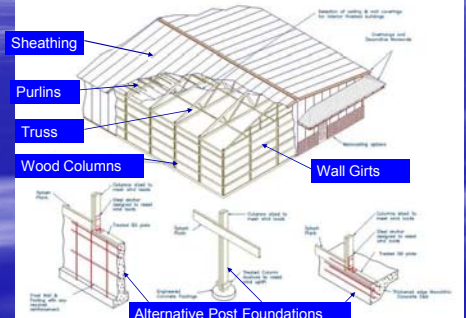


Scope of the Presentation

- Presents the basic design procedures for PF
- 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



The diagram illustrates the structural components of a post-frame building system. It shows a cross-section of the roof and walls. Labels include: Sheathing (on the roof), Purlins (horizontal members supporting the roof), Truss (the roof's structural framework), Wood Columns (vertical supports), Wall Girts (horizontal members supporting the walls), and Alternative Post Foundations (showing different ways to anchor the columns into the ground).

Primary Design Approaches for PF Buildings

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

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

Each 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)

$\Delta_1 < \Delta$

Post-Frame Building Design Methods

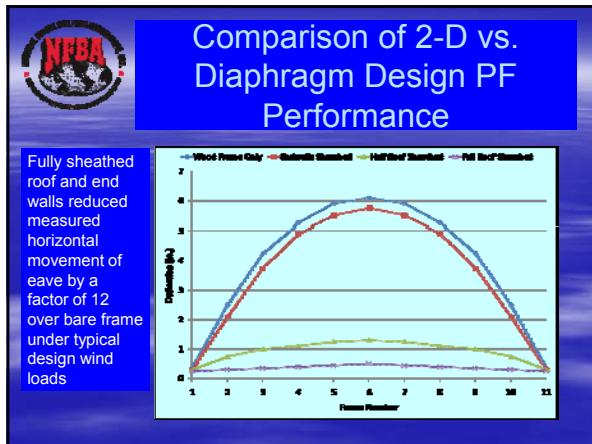
- Advantages of Diaphragm Design in Post-Frame
 - Smaller sidewall wall posts
 - Shallower post or pier embedment depths

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 and between 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



Key PF Technical Resources from NFBA

- This is the primary resource for post-frame design professionals

- ### 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

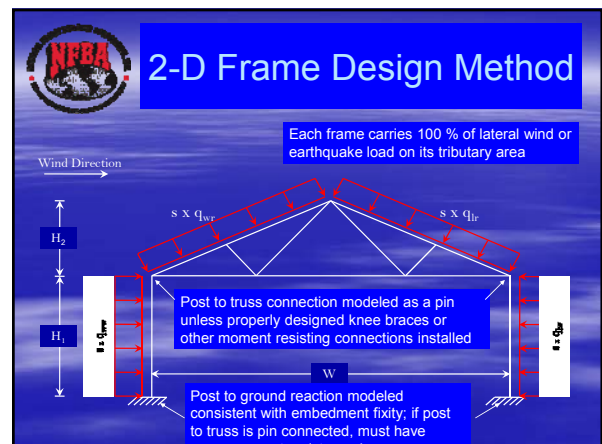
ASAE EPs available at:

www.asabe.org

or

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



NFBA 2-D Frame Design Method

- Except for the modeling of the post-soil interaction, design similar to any other 2-D wood frame
- The most common post-soil fixity models are the
 - constrained post
 - unconstrained post

NFBA 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 pin and roller locations are discussed later

NFBA 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 constrained post case

•Procedures for more precise estimates of the location are discussed later

NFBA 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.

Springs used to model soil stiffness

NFBA 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 + 1/2 Snow + Wind usually controls post design
- Dead + Snow usually controls roof framing design

NFBA 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: $D + S$

$V =$ End reaction from roof truss
 $P = 1/2$ (Resultant lateral roof load from truss)

$1/2 (q_{ww} + q_{hw}) \times s$

Note: Foundation modeled consistent with post constraint at ground line

NFBA 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
- Post, purlin, girt, etc. design then follows NDS specs for combined loading; i.e.; $I \leq 1.0$

NFBA 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)

NFBA Diaphragm Design Method

NFBA Post Frame Building Design-Diaphragm Design

Typical Post Frame Diaphragm Panel Construction and Details

NFBA Diaphragm Design Method

- In-plane shear strength and stiffness of the roof and endwall diaphragms usually obtained by testing small diaphragm test panels
- Recently sponsored research at NFBA developed calculation procedures to predict the in-plane shear strength and stiffness of metal-clad, wood-frame structural diaphragms
- NFBA now working to obtain IBC adoption of the calculation procedures for panel strength/stiffness

NFBA Diaphragm Design Method

Diaphragm Design Method

Diaphragm test schematic and simplified test results

Ult. Strength = P_{ult}

Design shear strength = $0.4 P_{ult}$

C = design shear stiffness (slope)

Diaphragm Design Method

- Test Panel width, a , is often, but not necessarily, the same as the PF bay spacing, a_p
- Test diaphragm length, b , is usually much smaller than the roof diaphragm panel length, b_{sp}

Thus the actual roof or ceiling panel shear strength and stiffness must be deduced from the small test panel results

Diaphragm Design Method

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

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

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

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

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

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

$\Delta_r = \Delta_f$

Diaphragm Design Method

- For compatibility of deformations at the eave,

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

where

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

$$\Delta_{fi} = P_i/k_i$$

NFBA Diaphragm Design Method

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

$k = P_1 / \Delta_1$

Depth and embedment structural analog varies with site conditions

NFBA Diaphragm Design Method

- ASAE EP and NFBA's 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

NFBA 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

NFBA Diaphragm Design Method

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

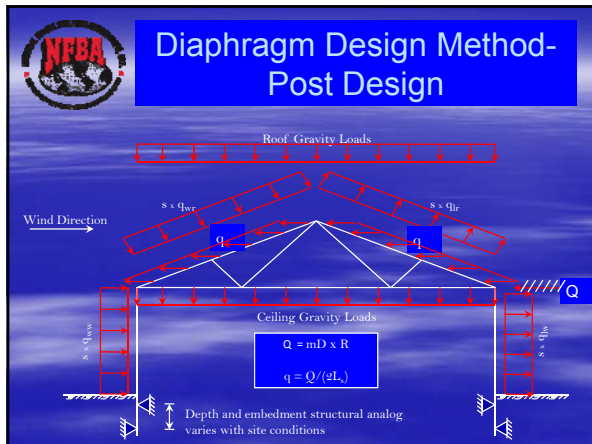
NFBA Diaphragm Design Method- Post Design

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

NFBA Diaphragm Design Method- Post Design

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

	k_e/k	C_n/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
Stiff Diaph	50	5	0.81	0.68	0.26
	50	1000	0.98	0.96	0.91



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- 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 + 1/2 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

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- 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
 - $mS = f(c_r/k, k_e/k, N)$

Diaphragm Design Method-Diaphragm Strength Check

- Selected mS values from Table 5.1 of the PFBDM

k_e/k	C_r/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
- $- V_p = V_{max} = V_h / \cos \Theta$

**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**

Roof Gravity Loads

Wind Direction

Ceiling Gravity Loads

$Q_c = mD \times R$
 $c_T = c_r + c_c$
 $q_r = (c_r/c_T \cdot Q_T) / (2L_e)$
 $q_c = (c_c/c_T \cdot Q_T) / \text{Building span}$

Depth varies with site conditions

**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 –
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

Post Frame No. 1

Diaphragm Panel No. 1

**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

$P_1, C_{11}, P_2, C_{12}, P_3, C_{13}, P_4, C_{14}, P_5$

k_1, k_2, k_3, k_4, k_5

Diaphragm Design Method – DAFI

- DAFI more flexible because it can be used for post frame building systems for which:
 - the stiffnesses, k_i , of each post frame element are **not** the same
 - the stiffnesses, c_{hi} , of each diaphragm panel element are **not** the same
 - the stiffnesses of the two endwalls are **not** the same

Diaphragm Design Method – DAFI

- DAFI is available to designers on-line at:

www.nfba.org

Diaphragm 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

Labels: Shear wall, Chords, Trusses/rafters, Ridge Line, Roof diaphragm chord plan, Three candidate chord force distributions

Diaphragm Design Method – Diaphragm Chord Forces

- Diaphragm bending moment, M_d

$$M_d = V_n L / 4 = w L^2 / 8$$
- Maximum chord force, P_e

$$P_e = M_d \alpha / b$$

$$\alpha = f(\text{chord force distribution})$$

Diaphragm Design Method – Diaphragm Chord Forces

- Chord force distribution factor, α
 - $\alpha = 1$ (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/Pier Embedment Design

- Two primary post embedment types:
 - Unconstrained
 - Constrained

Labels: M_a & V_a from post frame analysis, Ground level, Floor, Resultant soil force, Rotation axis, Unconstrained, Constrained

Procedures for calculating depth documented in PFBDM and ASAE EP 486

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/Pier 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/Pier Embedment-Constrained Case

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

(Terms same as defined for the unconstrained case)

Post Foundations – Special Considerations

Concrete collars around posts embedded in ground

The diagram illustrates two methods of post foundation construction. Part (a) shows a post embedded in a footing with a poured concrete collar around its base. Part (b) shows a post embedded in a footing with a built-up wood collar around its base. Labels include Ground level, Post, Original excavated post hole and backfill region, Poured concrete collar, Built-up wood collar, and Footing.

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 truncated cone of soil above any footer and collar mechanically attached to the post

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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
- Equation for volume given in PFBDM

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Special Considerations for Post Foundations

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

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Post Frame Design Considerations

- 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

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Special Considerations for Post Frame Design

- 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)

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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

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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????

Today's Agenda

8:30 am - 9:30 am:
Wood Framing in Commercial Buildings – How You Can Design with Wood
Scott Lockyear, P.E., Woodworks

9:40 am – 10:40 am:
Introduction to Post-Frame Construction, Buildings & Design
Dr. Harvey Manbeck, P.E., Professor Emeritus of Agricultural Eng, PSU.

10:50 am – 11:50 am:
Post-Frame Building Design Resources & Design Methods
Dr. Harvey Manbeck, P.E., Professor Emeritus of Agricultural Eng, PSU

11:50 am – 1:00 pm: Lunch Served