An Introduction to Structural Design of Post-Frame Buildings

Course Description
This program begins with a brief description of post-frame building systems followed by an overview of key concepts for their structural design. Information is presented from a conceptual standpoint as opposed to an equation and computational standpoint. Two design methods are addressed: one for post-frame systems without diaphragm action, the other for post-frame systems with diaphragm action. The majority of the program is focused on the latter. The presentation shows how a simple, yet powerful and readily available program, DAFI, determines the proportion of design lateral loads carried to ground by the individual post-frames and that carried to ground by roof diaphragms & shear walls. The program then shows how isolated post foundations are designed to resist lateral and uplift forces. Technical resources available to design professionals are also discussed.

Learning Objectives
1. Identify the primary structural components of post-frame (PF) building systems
2. Identify two PF structural design methodologies
3. Understand how to conduct structural design of PF systems without diaphragm action and with diaphragm action using DAFI
4. Identify post-frame design resources available to architects and engineers
TYPICAL POST-FRAME BUILDING SYSTEM

- Sheathing
- Purlins
- Truss
- Wood columns
- Wall girts

POST OR PIER FOUNDATIONS

PF BUILDING DESIGN: FEATURES

- Diaphragm design procedures are unique, but well formulated and documented
- Sidewall framing often uses mechanically or glued laminated sidewall and endwall posts
- Embedded wood posts or concrete piers often serve as the building foundation

PRIMARY PF DESIGN METHODS

- 2-dimensional frame design method
  - Without diaphragm action
- 3-dimensional diaphragm design method
  - With diaphragm action
PF SYSTEMS WITHOUT DIAPHRAGM ACTION

Unsheathed walls

PF SYSTEM WITH DIAPHRAGM ACTION

Sheathed Version of This Building

LATERAL LOADS: WITHOUT DIAPHRAGM ACTION

Wind direction

LATERAL LOADS: WITH DIAPHRAGM ACTION

Wind direction

$V_i$ (portion of wind load to end wall)
**ADVANTAGES OF DIAPHRAGM DESIGN**

- Smaller sidewall posts
- Shallower post or pier embedment depths
- Benefits:
  - More economical design
  - Greater structural integrity
  - More durable post-frame structures

**FULL-SCALE PF BUILDING TESTS**

- 29 ga ribbed steel sheathing
- Full-scale test setup:
  - Hydraulic cylinder
  - Load cell
  - 40 ft W x 80 ft L x 16 ft H

**DIAPHRAGM VS NO DIAPHRAGM ACTION**

**WHEN TO USE 2-D FRAME DESIGN METHOD**

- Side or endwalls are open, or not sheathed
- PF Building with $L:W \geq 2.5:1$
- Connections and other structural detailing don’t develop a continuous load path for transfer of in-plane shear forces
  - Through the roof sheathing
  - Between the diaphragm and the top of the endwall
  - Through the endwall or shearwall
  - Between bottom of the endwall and the endwall foundation
EMBEDDED POST/PIER FOUNDATIONS

- Common post-soil fixity models for embedded post or pier foundations:
  - Constrained post or pier
  - Unconstrained post or pier

POST FOUNDATIONS: UNCONSTRAINED MODEL

- Embedded into the ground
- Not constrained from displacing horizontally at the ground line
- Pin located 0.1d above the bottom of the embedded post and a vertical roller located about \(\frac{1}{3}\) the embedment depth below the ground line

POST FOUNDATIONS: CONSTRAINED SOIL-POST MODEL

- Embedded into the ground
- Horizontal displacement prevented by properly designed connection between the post and floor slab at the ground line
- Soil interaction is modeled with a vertical roller 0.7d below ground line and with a pin at the ground line

POST/PIER EMBEDMENT DESIGN

- \(\frac{1}{2}\)-inch horizontal movement permitted
- Horizontal movement prevented by floor and connection

Unconstrained

Constrained
DESIGN METHODS: 2-D POST FRAME

2-D DESIGN ANALYSIS

ASCE-7-05 Governing Load Combinations

- Dead + 3/4 snow + 3/4 wind (or seismic)
  - or
  - 0.6 dead + wind (or seismic)
    - Usually controls post design
- Dead + snow
  - Usually controls roof-framing design

SIMPLIFIED 2-D PF DESIGN METHOD

- Specify dead & snow loads for truss manufacturer

DIAPHRAGM DESIGN METHOD

- Incorporates in-plane shear strength and stiffness of the roof and wall sheathing to transfer design lateral loads to the foundation
- Three-dimensional structural analysis method
- Significantly decreases wall-post size and post-foundation embedment depth
PF DIAPHRAGM DESIGN

- Key Definitions
  - In-plane shear stiffness of the roof diaphragm panel, \( c \)
  - Bare frame stiffness of the post-frame, \( k \)
  - Design eave lateral load, \( P \)

DIAPHRAGM TEST PANEL

- Test panel width, \( a \)
- Test panel length, \( b \)
- Roof sheet end joint

DIAPHRAGM TEST PANEL

- Sheathing/cladding
- Purlin (chord)
- Shear connectors
- Fixings
- Rafter or truss top chord (strut)

CANTILEVER TEST CONFIGURATION

- Applied force, \( P \)
- Test diaphragm length, \( b \)
- Building width, \( L_B \)
- Building length, \( L_B \)
- Cladding
- Rafter or truss top chord (strut)
DIAPHRAGM DESIGN METHOD – ROOF PANEL STIFFNESS

- Shear stiffness of a roof diaphragm panel
  - test panel stiffness, \( c \)
  - roof panel width, \( a_p \)
  - roof panel roof slope length \( b_{sp} \)
  - roof slope \( \Theta \)

\[
c_h = [c \,(a/b)] \,(b_{sp}/a_p)\cos^2\Theta
\]

DIAPHRAGM DESIGN METHOD-ROOF PANEL STRENGTH

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

\[
V = [\text{unit shear strength}](\text{roof diaphragm length})
V = [0.4(P_{ult}/b)](b_{sp})
\]
DIAPHRAGM DESIGN METHOD - BARE FRAME STIFFNESS, K

\[ k = \frac{P_i}{\Delta_i} \]

Depth and embedment structural analog varies with site conditions

DIAPHRAGM DESIGN METHOD

PF diaphragm design procedures based on:
1. Compatibility of post-frame and roof panel eave deformations and
2. Equilibrium of horizontal forces at each eave

\[ P = \text{Design Lateral Eave Load} \]

DIAPHRAGM DESIGN METHOD

• Equilibrium of forces at each PF eave

\[ P_i = P_{fi} + P_{ri} \]

- \( P_i \) = design eave load in \( i^{th} \) PF
- \( P_{fi} \) = portion of the design eave load carried by the \( i^{th} \) PF
- \( P_{ri} \) = portion of the design eave load carried by the roof diaphragm panel at the \( i^{th} \) PF

DIAPHRAGM DESIGN METHOD

• Compatibility of roof and PF deformations at each PF eave

\[ \Delta_i = \Delta_{fi} \]

- \( \Delta_i \) = roof panel eave deformation at the \( i^{th} \) PF (dependent upon \( c_i, k_i \), and \( P_i \))
- \( \Delta_{fi} = \frac{P_{fi}}{k_i} \)
DAFI COMPUTER PROGRAM

- Windows based program
- Calculates portion of lateral load carried by:
  - Each post frame
  - Roof diaphragm
- Available at no cost at www.postframeadvantage.com

DAFI COMPUTER PROGRAM

- DAFI program calculates
  - Eave displacement of each post frame
  - Portion of eave load carried by each post frame
  - Shear forces carried by each roof diaphragm panel in the building system

DAFI INPUTS

- Total number of bays in the building
- Design eave loads at each post frame, $P_i$
- Bare frame stiffness of each post frame, $k_i$
- In-plane shear stiffness of each roof diaphragm panel, $c_{hi}$

DIAPHRAGM DESIGN METHOD

![Diagram showing diaphragm design method]
DIAPHRAGM DESIGN – STRUCTURAL ANALOG

Panel/PF structural analog of a 3-bay building

PF 1
(k1)

PF 2
(k2)

PF 3
(k3)

PF 4
(k4)

Diaphragm Panel
1(ch1)

2(ch2)

3(ch3)

4(ch4)

P1 P2 P3 P4

DAFI: UNDEFORMED POSITION

DAFI: DEFORMED EQUILIBRIUM POSITION

DAFI COMPUTER PROGRAM

Datum

Datum

Datum

Datum

1

2

3

4

k1

k2

k3

k4

P1

P2

P3

P4

Pf1

Pf2

Pf3

Pf4

1

2

3

4

1

2

3

4

Pf1

Pf2

Pf3

Pf4

Diaphragm

Shear wall

Frame

Frame

Frame

Frame
DAFI COMPUTER PROGRAM

DAFI: HIGHLY FLEXIBLE

- Can be used for post-frame building systems where:
  - Stiffness, $k_i$, of the interior post frame elements are not the same
  - Stiffness, $c_{hir}$, of the diaphragm panel elements are not the same
  - Stiffness, $k_i$ of the two endwall post-frames are not the same
- Available at no cost to designers at www.PostFrameAdvantage.com

DAFI: MINI DEMONSTRATION

- 48-ft-wide by 96-ft-long post frame
- Post frames 8-ft o.c.
- Number of bays —12
- Post-frame stiffness ($k$) — 300 lbs/in.
- Endwall stiffness ($k_e$) — 10,000 lbs/in.
- Roof diaphragm stiffness ($C$) — 12,000 lbs/in.
- Horizontal eave load at interior post frame — 800 lbs

Access DAFI by:

- Going to www.postframeadvantage.com
- Clicking onto “DAFI” icon
- Running “DAFI” when prompted
POST/PIER EMBEDMENT DESIGN

- Post-embedment details must resist
  - Shear force and moments from lateral loadings
  - Uplift post loads
  - Downward acting gravity loads

POST AND PIER FOUNDATIONS: DESIGN CONSIDERATIONS

- Unconstrained post; no collar
  - $d^2 = (6V_a + 8M_a/d)/(S\cdot b)$
  - $d$ = the embedment depth
  - $V_a, M_a$ = the shear and bending moment applied to foundation at ground surface
  - $S\cdot$ = the adjusted allowable lateral soil pressure
  - $b = 1.4B$ = the effective post width of the post or pier
  - $B$ = the narrow width of the post
POST/PIER EMBEDMENT DESIGN: CONSTRAINED POST; NO COLLAR

Embedment depth design equation for lateral resistance for a constrained post without any partial depth attached collars or cleats

\[ d = \left[ \frac{4 \, M_a}{S^\prime \, b} \right]^{1/3} \]

POST/PIER EMBEDMENT DESIGN: POSTS WITH BOTTOM COLLARS

• Design equations in:
  
  ASAE EP 486, Shallow Post Foundation Design
  
  www.asabe.org

POST/PIER EMBEDMENT DESIGN: 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 wood cleat

POST/PIER FOUNDATION DESIGN: UPLIFT DESIGN

• Design Equations for Uplift Resistance of Embedded Posts with Collars

2. ASAE EP 486, Shallow Post Foundation Design (www.asabe.org)
POST EMBEDMENT DETAILS

- Place footings 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

PF DESIGN:
SPECIAL CONSIDERATIONS

- Designer or architect should use hot-dipped galvanized or stainless steel hardware
  - In all below-ground applications
  - When hardware is in contact with preservative-treated wood

POST-FRAME TECHNICAL RESOURCES

Provides structural design procedures for post-frame building systems

PF TECHNICAL RESOURCES

- ANSI/ASAE (ASABE) EP 484
  - Diaphragm design procedures
- ANSI/ASAE (ASABE) EP 486
  - Shallow post foundation design
- ANSI/ASAE (ASABE) EP 559
  - Requirements and bending properties for mechanically laminated columns
  - asabe.org or nfba.org
PF STRUCTURAL DESIGN RESOURCES

• AWC/AF&PA (2005, 2012)
• ASCE 7 (2005, 2010)
• AWPA’s U1-09

OTHER PF TECHNICAL RESOURCES

• DAFI
• Framing Tolerance Guidelines
• Metal Cladding Installation Tolerance Guidelines
• Post Frame Construction Guide
• Design Documents for Engineers & Architects: Wind and Seismic
• 1 hour and 3 hour PF Firewall Reports
• www.postframeadvantage.com or www.nfba.org

MORE PF DESIGN GUIDANCE?

• Visit PostFrameAdvantage.com
• Take PFMI Online University courses
  – Six 1-hour session course on engineering-based information
  – Three 1-hour session course on PF for architects
  – Free
  – CE credits available for design professionals

Design No. V304 January 20, 2012
Bearing Wall Rating – 3 Hr

5/8 Gyp Board (SCX)
4 layers, both sides

Nail-lam post
4-ply, 2x6

Vertical blocking
2x4 wall girts
KEY WEBSITES FOR POST-FRAME DESIGN

WWW.POSTFRAMEADVANTAGE.COM

WWW.NFBA.ORG

Questions??

This concludes The American Institute of Architects Continuing Education Systems Course.

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