STRUCTURAL DESIGN OF POST-FRAME BUILDINGS: A CONCEPTUAL PRESENTATION

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WoodWorks

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Learning Objectives

At the end of this program, participants will be able to:

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
4. Understand how to conduct structural design of PF systems with diaphragm action
5. Identify post-frame design resources available to architects and engineers

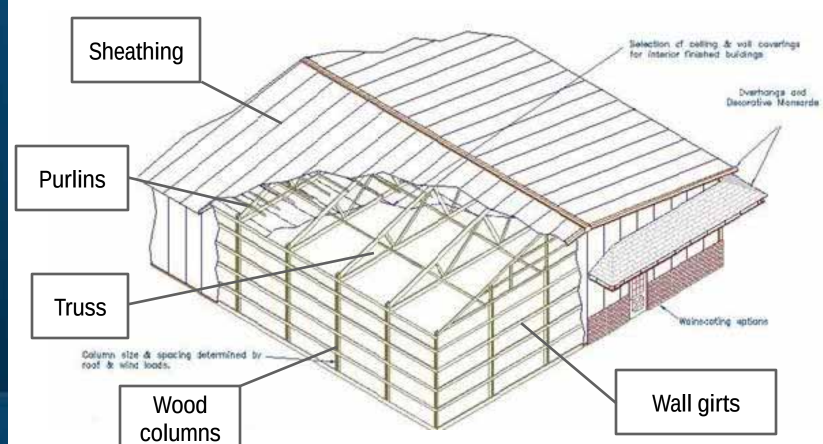
WoodWorks POST-FRAME ADVANTAGE

LEARNING OBJECTIVES

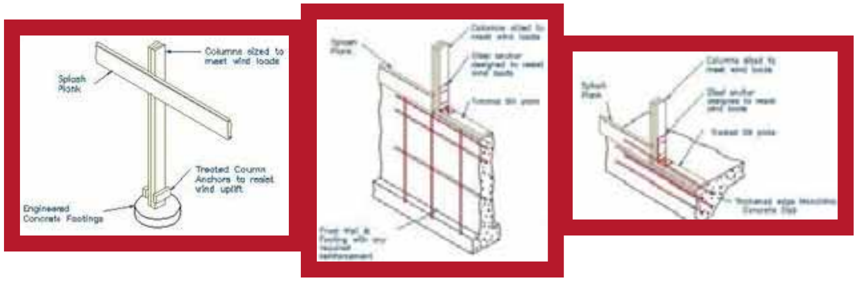
- Identify the primary structural components of post-frame (PF) building systems
- Identify two PF structural design methodologies
- Understand how to conduct structural design of PF systems without diaphragm action
- Understand how to conduct structural design of PF systems with diaphragm action
- Identify post-frame design resources available to architects and engineers

STRUCTURAL DESIGN OF POST-FRAME BUILDINGS: A CONCEPTUAL PRESENTATION

TYPICAL POST-FRAME BUILDING SYSTEM



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

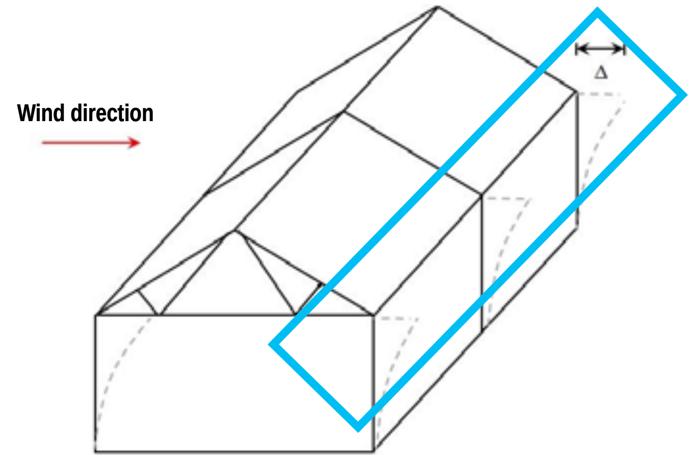
PRIMARY PF DESIGN METHODS

- 2-dimensional frame design method
  - Without diaphragm action
- 3-dimensional diaphragm design method
  - With diaphragm action

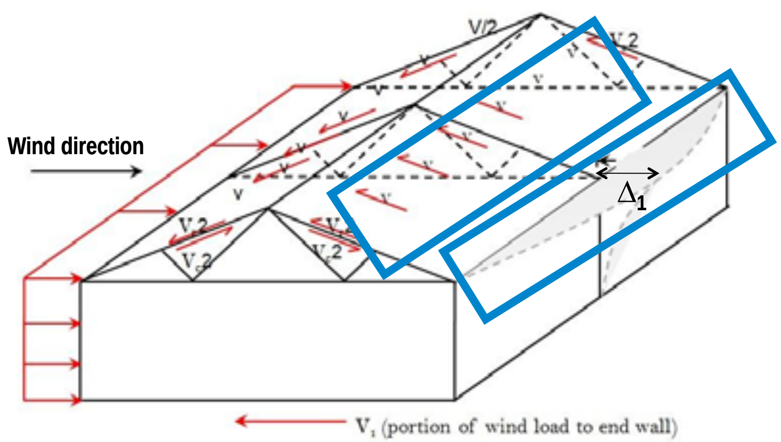
PF SYSTEMS WITHOUT DIAPHRAGM ACTION

PF SYSTEM WITH DIAPHRAGM ACTION

LATERAL LOADS: WITHOUT DIAPHRAGM ACTION



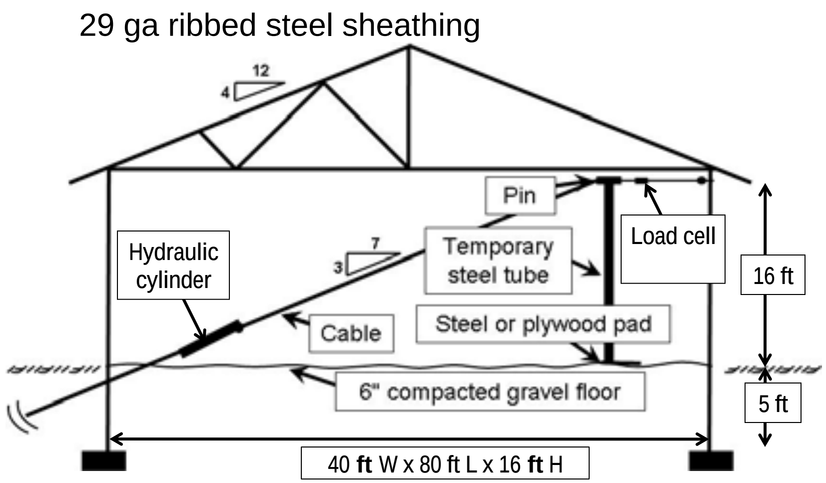
LATERAL LOADS: WITH DIAPHRAGM ACTION



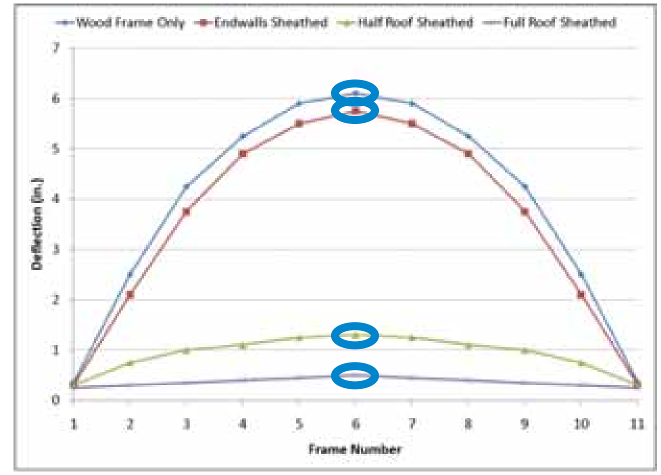
ADVANTAGES OF DIAPHRAGM DESIGN

- 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



DIAPHRAGM VS NO DIAPHRAGM ACTION



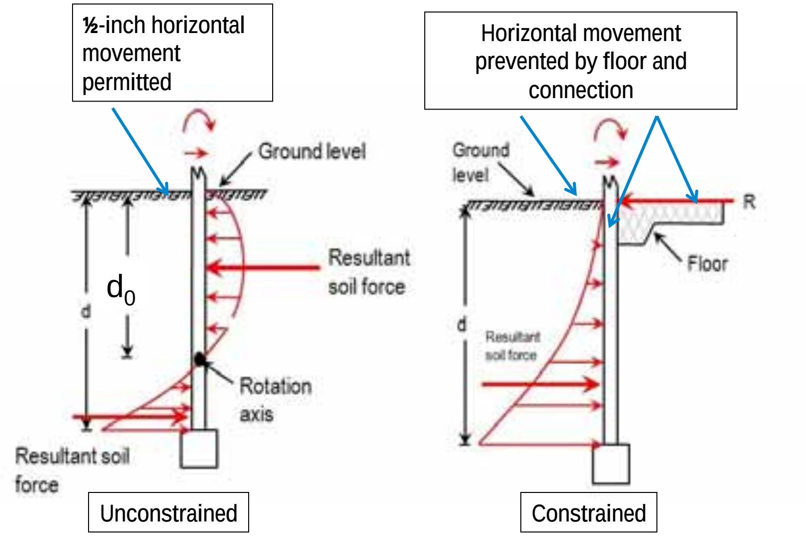
WHEN TO USE 2-D FRAME DESIGN METHOD

- Side or endwalls are open, or not sheathed
- PF Building with L:W ≥ ≈ 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

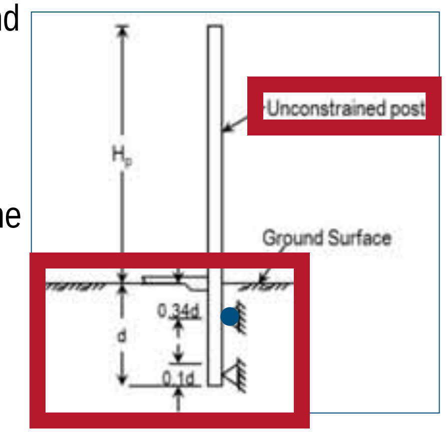
- Common post-soil fixity models for embedded post or pier foundations:
  - Constrained post or pier
  - Unconstrained post or pier

POST/PIER EMBEDMENT DESIGN



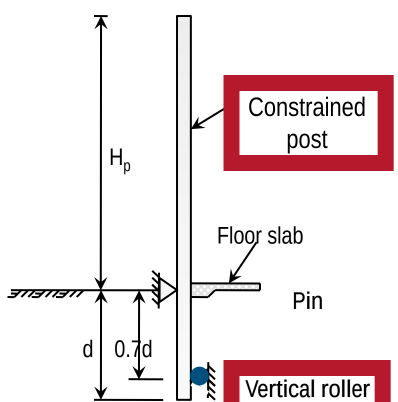
POST FOUNDATIONS: UNCONSTRAINED MODEL

- 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 $^1/_3$ the embedment depth below the ground line

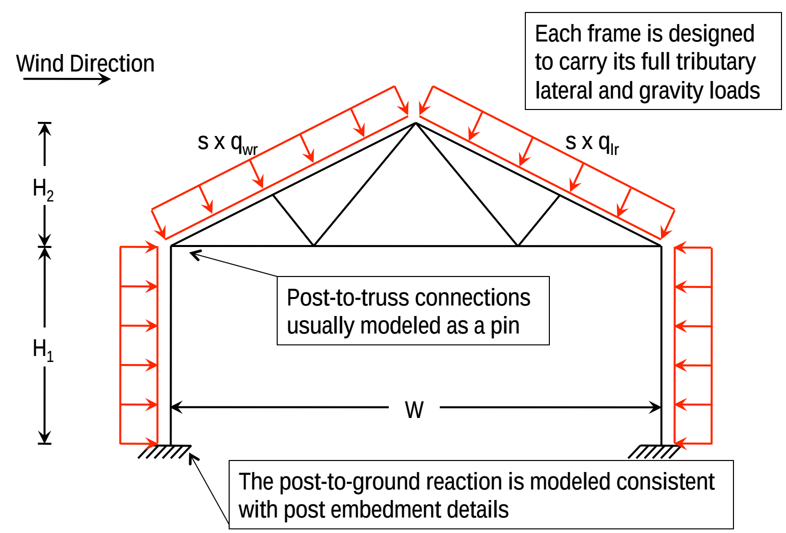


POST FOUNDATIONS: CONSTRAINED SOIL-POST MODEL

- 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



DESIGN METHODS: 2-D POST FRAME



2-D DESIGN ANALYSIS

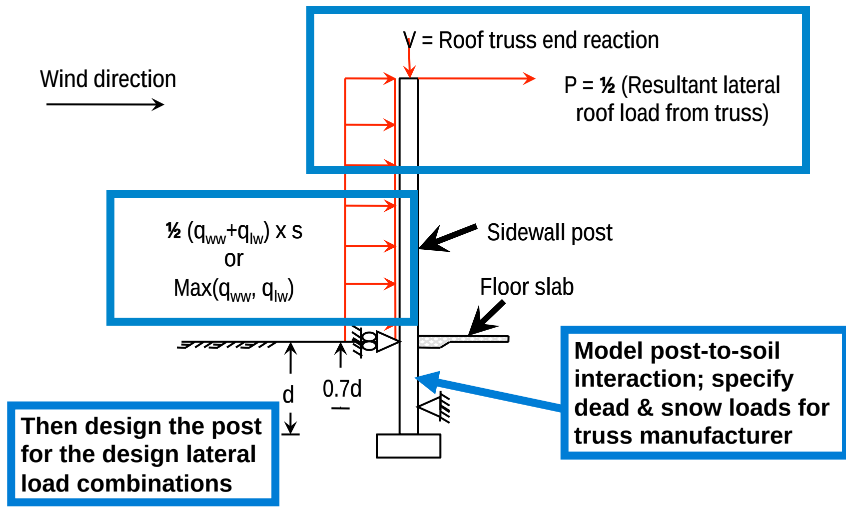
ASCE-7 Governing Load Combinations

- Dead + ¾ snow + ¾ wind (or seismic)

  or

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

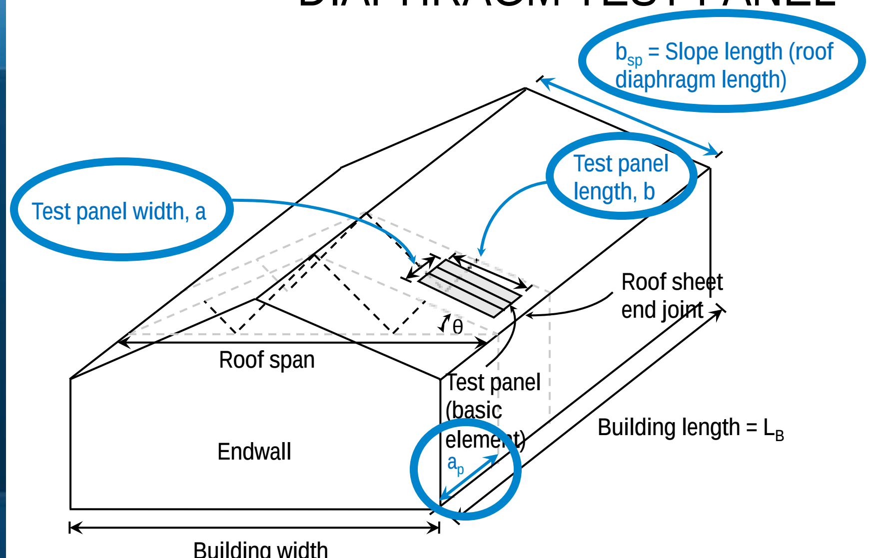
SIMPLIFIED 2-D PF DESIGN METHOD



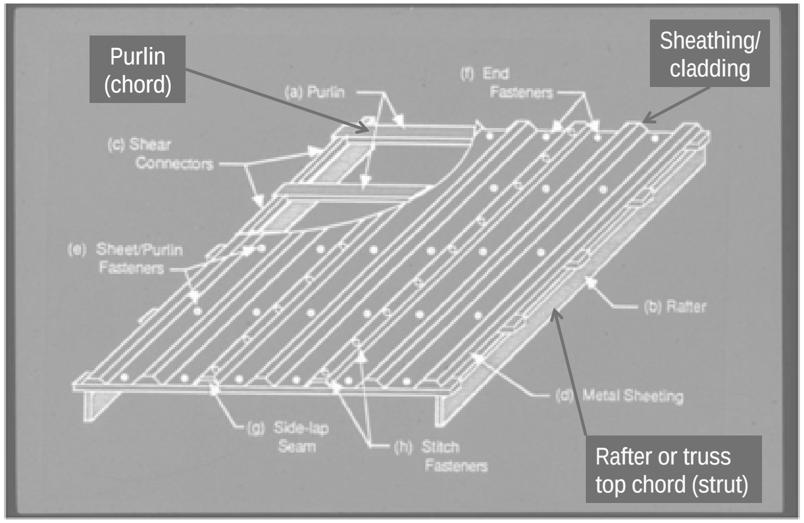
DIAPHRAGM DESIGN METHOD

- 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

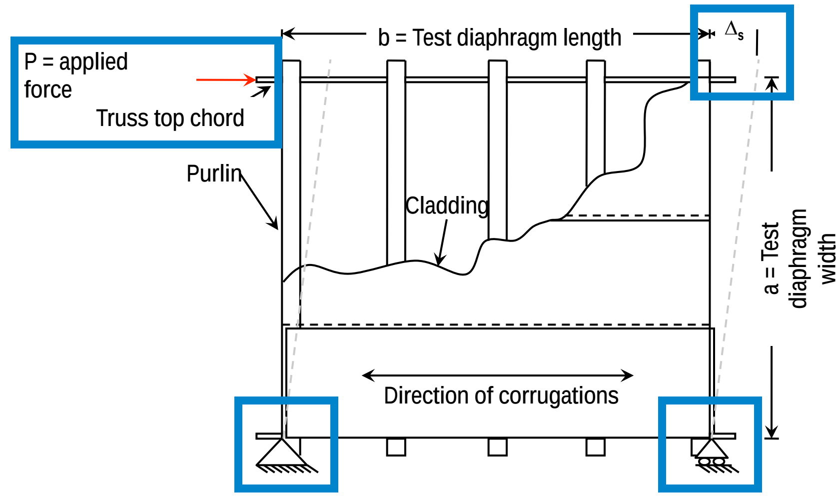
DIAPHRAGM TEST PANEL



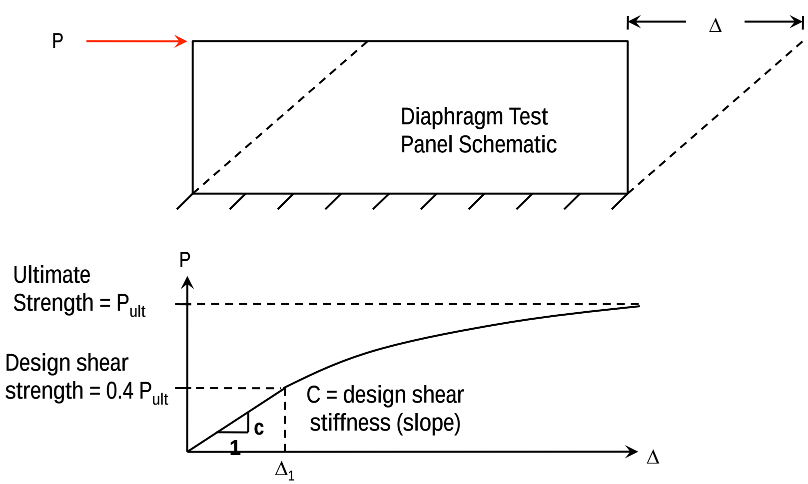
DIAPHRAGM TEST PANEL



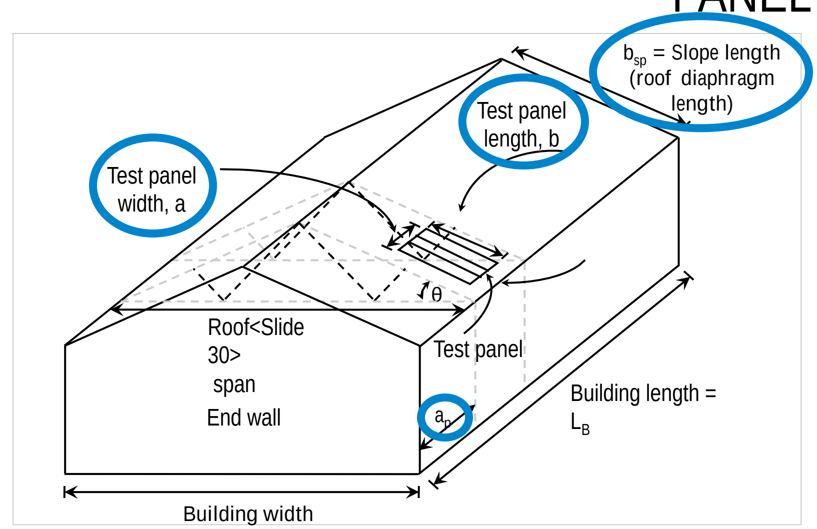
CANTILEVER TEST CONFIGURATION



DIAPHRAGM TEST RESULTS, IN-PLANE STRENGTH & STIFFNESS



DIAPHRAGM DESIGN-TEST VS. ROOF PANEL



DIAGRAPHRAGM 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 Θ

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

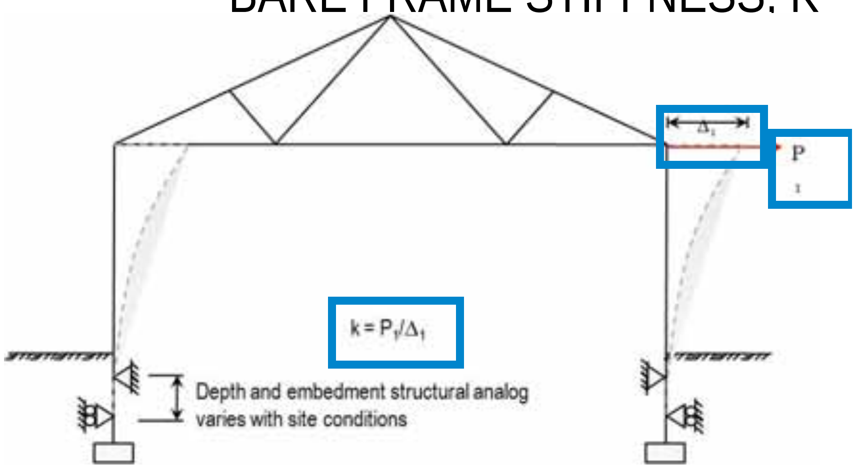
DIAPHRAGM DESIGN METHOD-ROOF PANEL STRENGTH

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

V = [unit shear](roof diaphragm length)

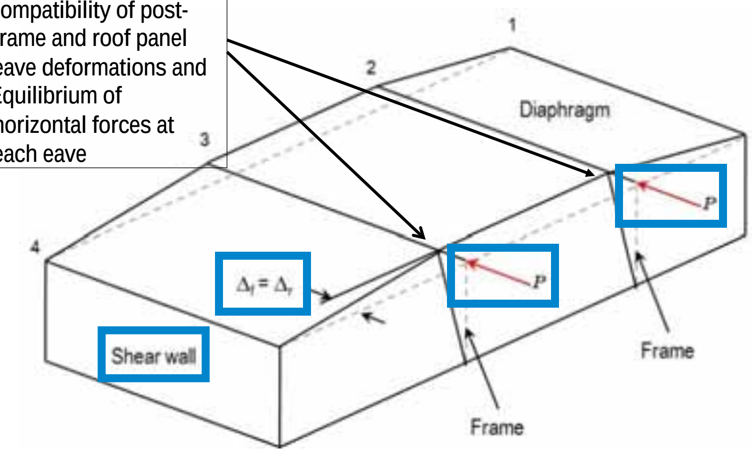
$$V = [0.4(P_{ult}/b)](b_{sp})$$

DIAPHRAGM DESIGN METHOD-BARE FRAME STIFFNESS, K



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



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

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

  - Δ_{ri} = roof panel eave deformation at the i^{th} PF (dependent upon c_i, k_i, and P_i)
  - $\Delta_{fi} = P_{fi}/k_i$

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

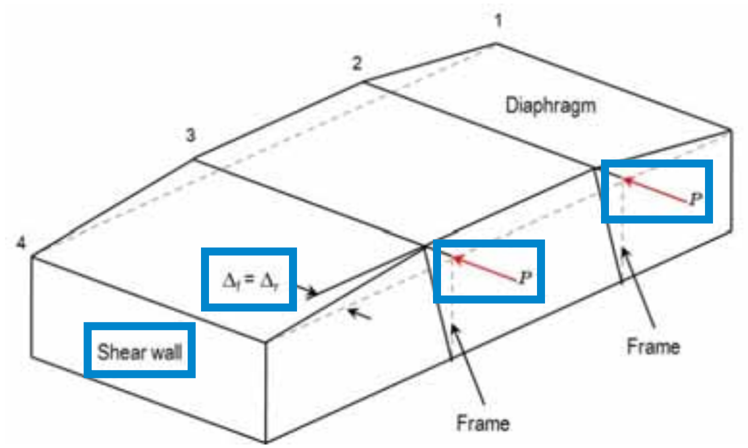
DAFI COMPUTER PROGRAM

- 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

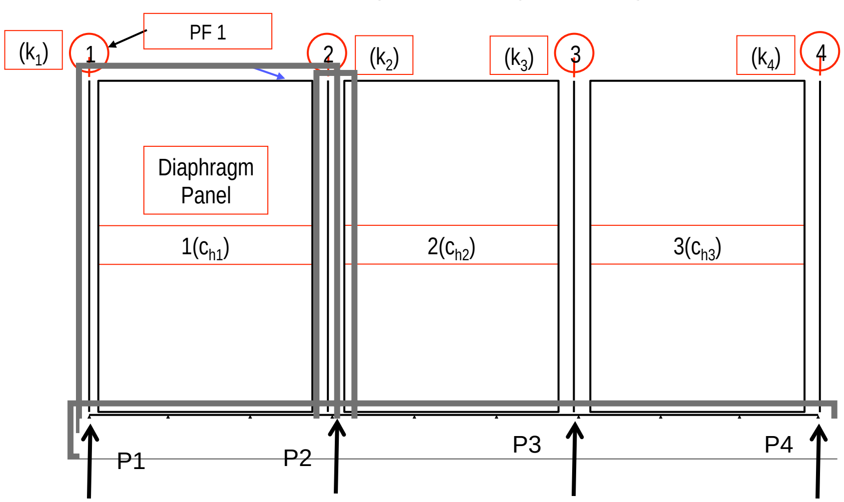
- Total number of bays in the building
- Design eave loads at each post frame, P_i
- Bare frame stiffness of each post frame, k_i
- In-plane shear stiffness of each roof diaphragm panel, c_{hi}

DIAPHRAGM DESIGN METHOD

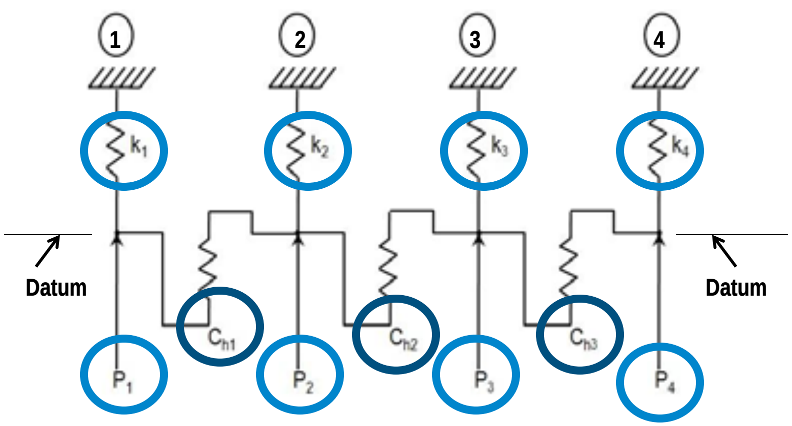


DIAPHRAGM DESIGN – STRUCTURAL ANALOG

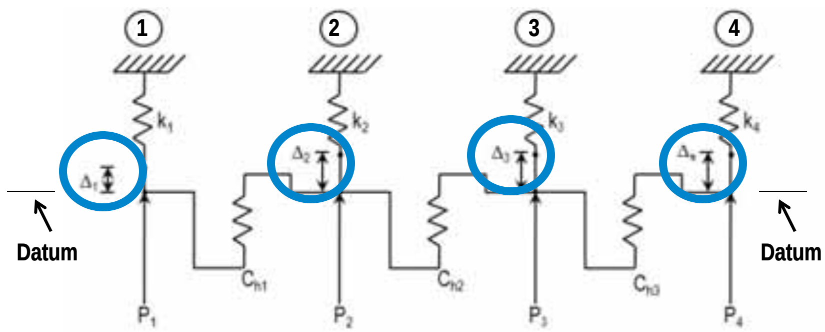
Panel/PF structural analog of a 3-bay building



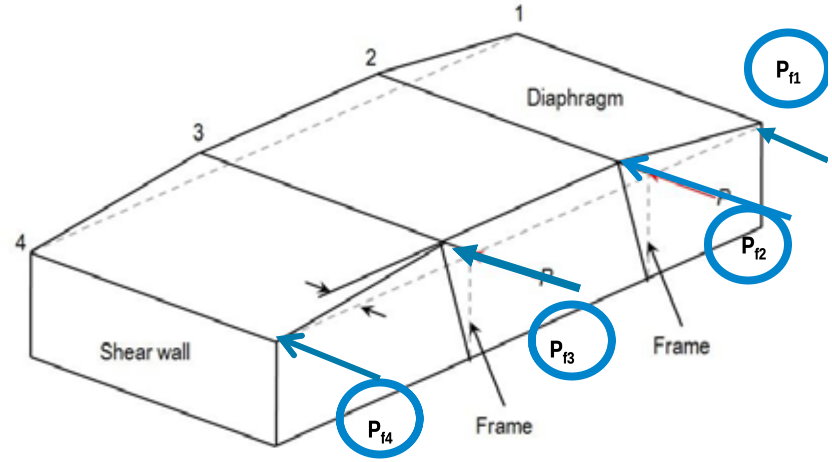
DAFI: UNDEFORMED POSITION



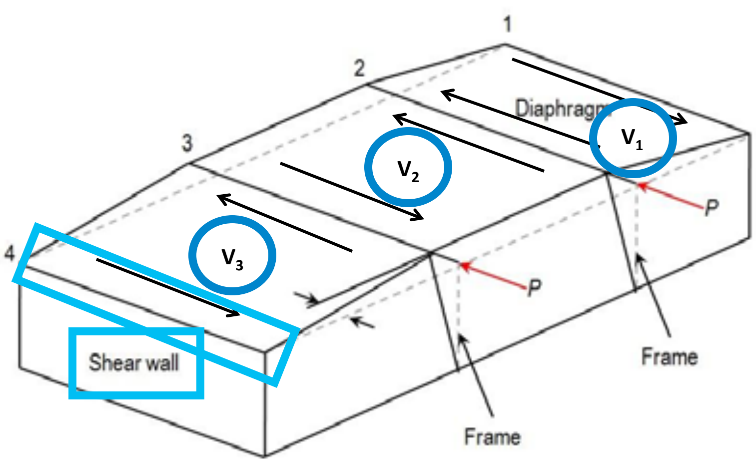
DAFI: DEFORMED EQUILIBRIUM POSITION



DAFI COMPUTER PROGRAM



DAFI COMPUTER PROGRAM



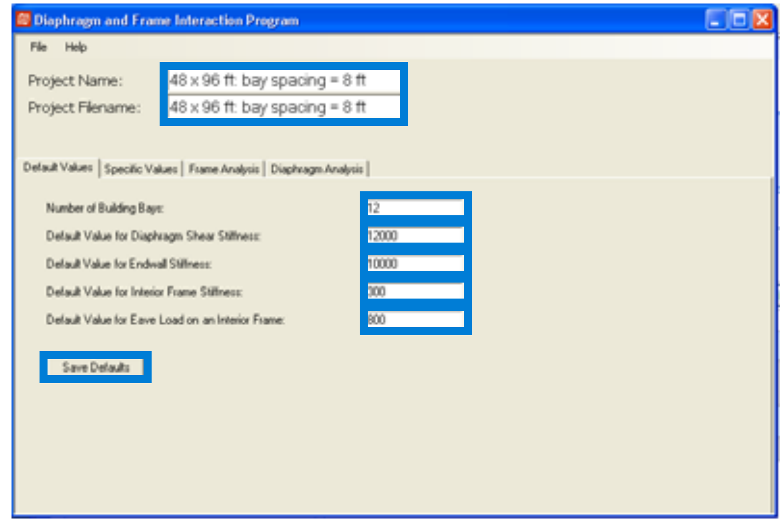
DAFI: HIGHLY FLEXIBLE

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

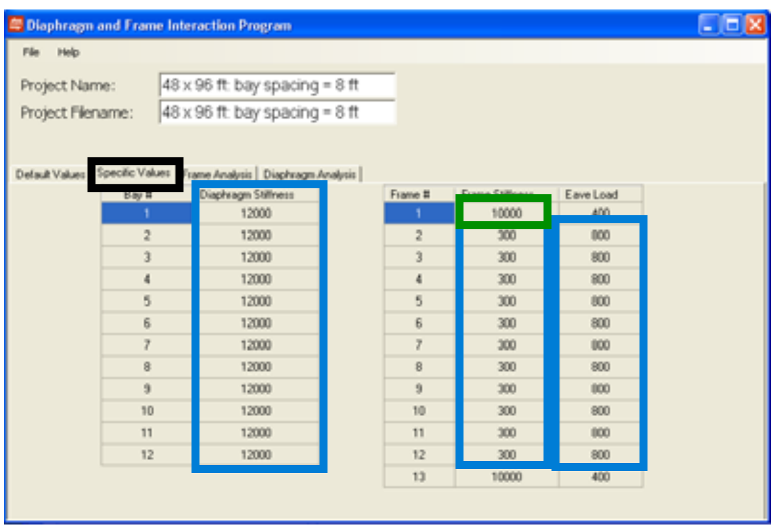
DAFI: MINI DEMONSTRATION

- 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

DAFI: MINI DEMONSTRATION



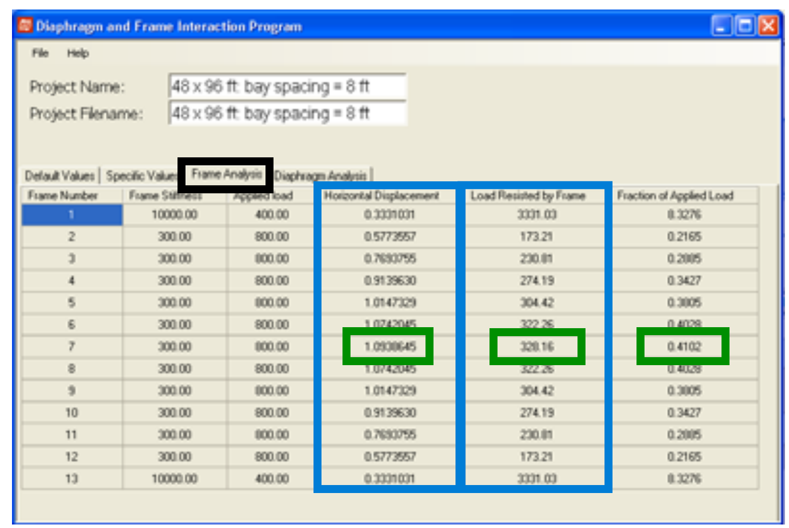
DAFI: MINI DEMONSTRATION



Bay #	Diaphragm Stiffness
1	12000
2	12000
3	12000
4	12000
5	12000
6	12000
7	12000
8	12000
9	12000
10	12000
11	12000
12	12000

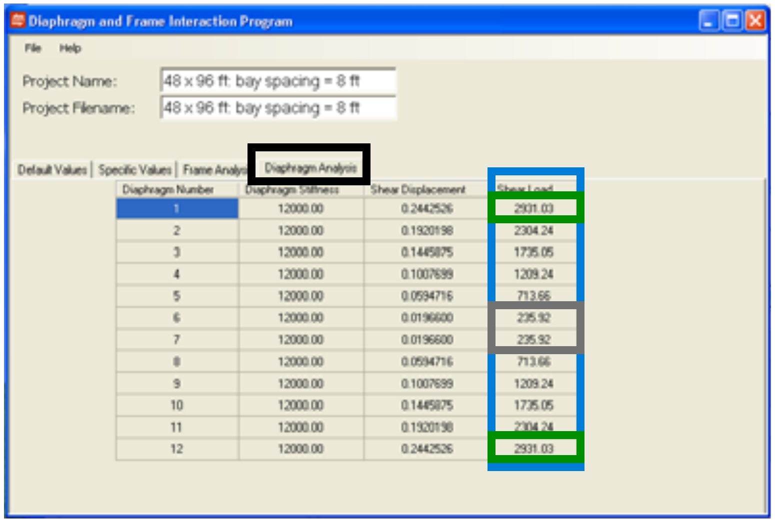
Frame #	Frame Stiffness	Eave Load
1	10000	400
2	300	800
3	300	800
4	300	800
5	300	800
6	300	800
7	300	800
8	300	800
9	300	800
10	300	800
11	300	800
12	300	800
13	10000	400

DAFI: MINI DEMONSTRATION



Frame Number	Frame Stiffness	Applied load	Horizontal Displacement	Load Resisted by Frame	Fraction of Applied Load
1	10000.00	400.00	0.3331031	3331.03	8.3276
2	300.00	800.00	0.5773557	173.21	0.2165
3	300.00	800.00	0.7693755	230.81	0.2885
4	300.00	800.00	0.9139630	274.19	0.3427
5	300.00	800.00	1.0147329	304.42	0.3805
6	300.00	800.00	1.0742045	322.26	0.4028
7	300.00	800.00	1.0938645	328.16	0.4102
8	300.00	800.00	1.0742045	322.26	0.4028
9	300.00	800.00	1.0147329	304.42	0.3805
10	300.00	800.00	0.9139630	274.19	0.3427
11	300.00	800.00	0.7693755	230.81	0.2885
12	300.00	800.00	0.5773557	173.21	0.2165
13	10000.00	400.00	0.3331031	3331.03	8.3276

DAFI: MINI DEMONSTRATION


Diaphragm and Frame Interaction Program

File Help

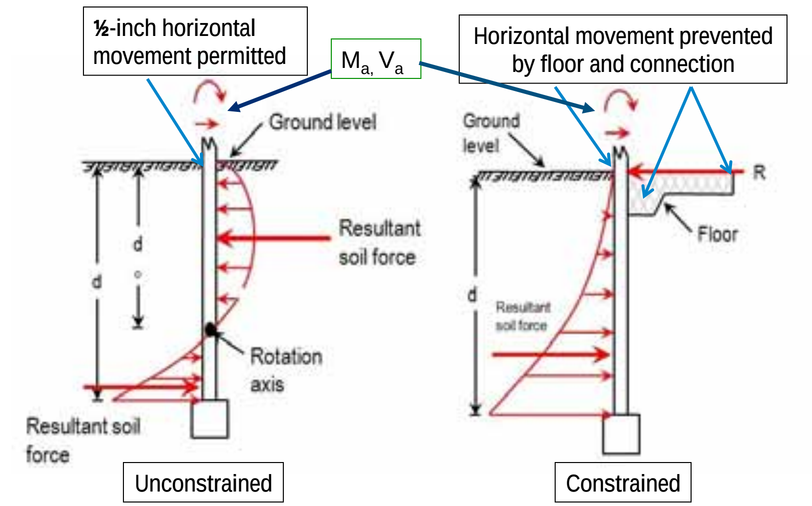
Project Name: 48 x 96 ft: bay spacing = 8 ft

Project Filename: 48 x 96 ft: bay spacing = 8 ft

Default Values | Specific Values | Frame Analysis | Diaphragm Analysis

Diaphragm Number	Diaphragm Stiffness	Shear Displacement	Shear Load
1	12000.00	0.2442526	2931.03
2	12000.00	0.1920198	2304.24
3	12000.00	0.1445875	1735.05
4	12000.00	0.1007699	1209.24
5	12000.00	0.0594716	713.66
6	12000.00	0.0196600	235.92
7	12000.00	0.0196600	235.92
8	12000.00	0.0594716	713.66
9	12000.00	0.1007699	1209.24
10	12000.00	0.1445875	1735.05
11	12000.00	0.1920198	2304.24
12	12000.00	0.2442526	2931.03

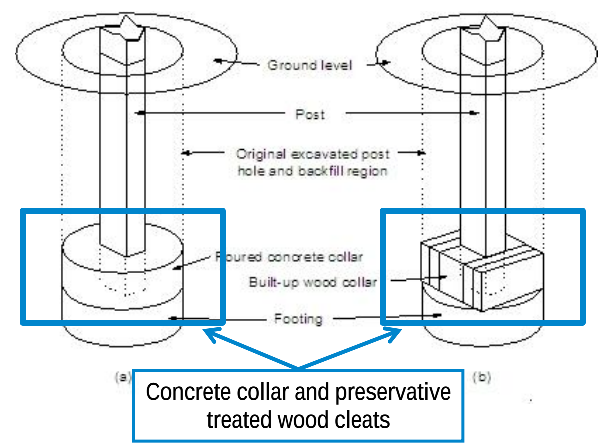
POST/PIER EMBEDMENT DESIGN



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



POST/PIER EMBEDMENT DESIGN: UNCONSTRAINED POST; NO COLLAR

- d^2 = $(6V_a + 8\,M_a/d)/(S'b)$
- d = the embedment depth
- V_a, M_a = the shear and bending moment applied to foundation at ground surface
- S´ = 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

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

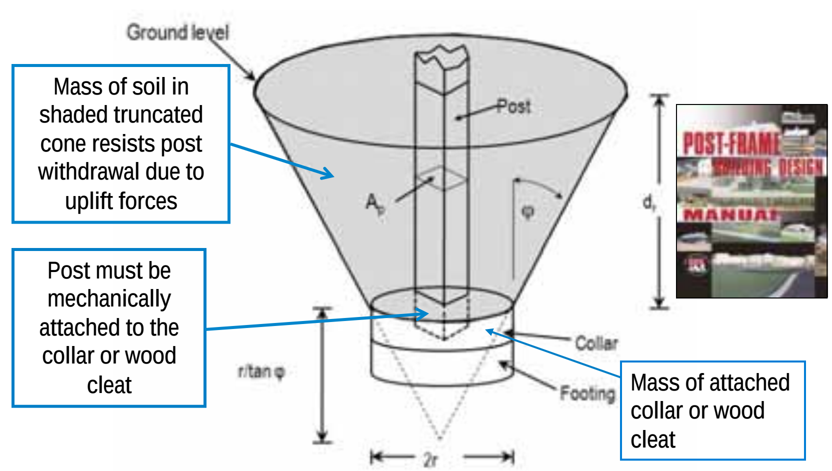
POST/PIER EMBEDMENT DESIGN: POSTS WITH BOTTOM COLLARS

- Design equations in:

ASAE EP 486, Shallow Post Foundation Design

www.asabe.org

POST/PIER EMBEDMENT DESIGN: UPLIFT FORCES



POST/PIER FOUNDATION DESIGN: UPLIFT DESIGN

- Design Equations for Uplift Resistance of Embedded Posts with Collars

1. Post Frame Building Design Manual (www.nfba.org or www.postframeadvantage.com)
2. ASAE EP 486, Shallow Post Foundation Design (www.asabe.org)

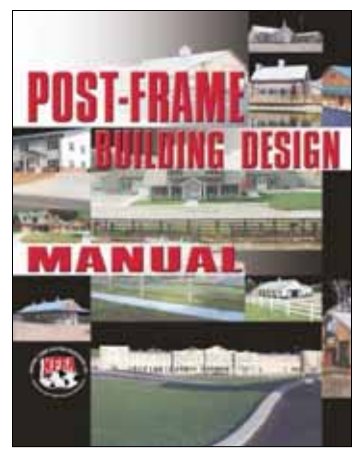
POST EMBEDMENT DETAILS

- 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



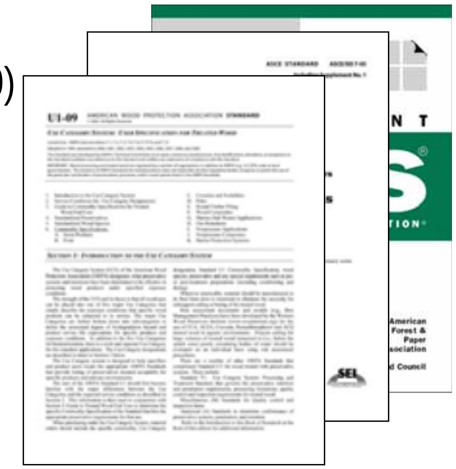
Provides structural design procedures for post-frame building systems

PF TECHNICAL RESOURCES

- ANSI/ASAE
  - Diaphragm
- ANSI/ASAE
  - Shallow po
- ANSI/ASAE
  - Requireme properties f laminated c
  - asabe.org c

PF STRUCTURAL DESIGN RESOURCES

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

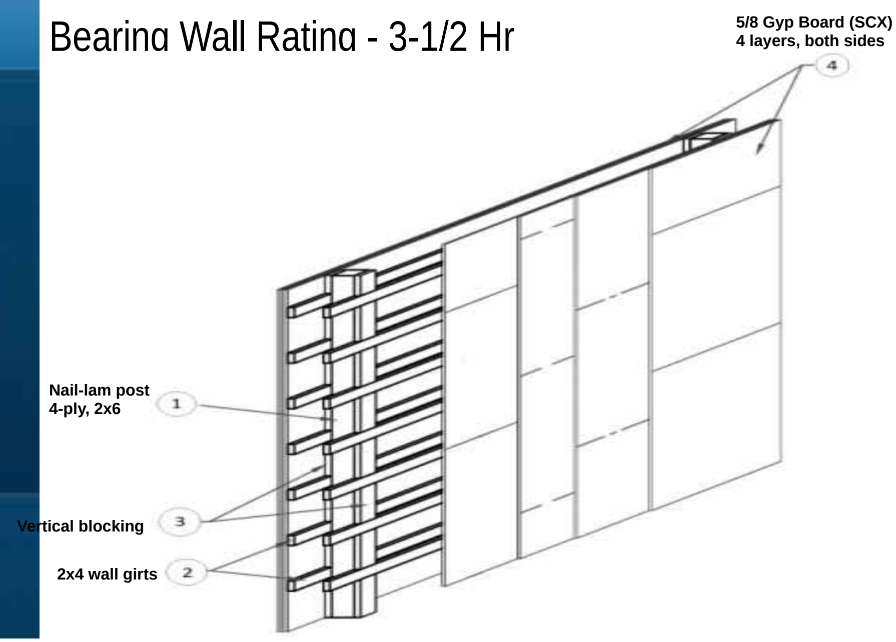


OTHER PF TECHNICAL RESOURCES

- DAFI
- Framing Tolerance Guidelines
- Metal Cladding Installation Tolerance Guidelines
- Post Frame Construction Guide
- Design Documents for Engineers & Architects: Wind and Seismic
- Guide specification for PF Building Systems
- 1 hour and 3 hour PF Firewall Reports

Design No. V304 January 20, 2012

Bearing Wall Rating - 3-1/2 Hr



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

Questions?

This concludes The American Institute of Architects Continuing Education Systems Course

Harvey B. Manbeck
Manbeck Engineering, LLC
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POST-FRAME ADVANTAGE

KEY WEBSITES FOR POST-FRAME DESIGN

WWW.POSTFRAMEADVANTAGE.COM

WWW.NFBA.ORG