KNEE BRACES IN POST-FRAME BUILDINGS WITH DIAPHRAGM-ACTION DESIGN

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Introduction

Not too long ago, installing knee braces between posts and trusses was a standard practice. Building designers applied lateral loads to structural framing without consideration of diaphragm action and the wood frame was designed to resist all lateral loads. In 1983, Hoagland and Bundy published an article on diaphragm design procedures for post frame buildings. Subsequently, in 1986, Gebremedhin and Woeste published an article on the effects of diaphragm action on a post-frame building with knee-braces with and without fastener slippage at knee-brace joints.

Fast forward to today, design with diaphragm action provided by light gauge corrugated metal panels, or structural wood panels, has become standard practice. In some cases, diaphragm action is the only mechanism providing lateral stability and resisting lateral loads. The diaphragm is the main component for resisting lateral forces. However, builders or end users sometimes install knee braces even when such braces are not specified in the design documents. This raises several questions. Do knee braces make a post-frame building stronger or more efficient? The objective of this study is to model the effects of knee braces, with and without fastener slippage, on a post-frame building including diaphragm action using modern design tools.

Modeling knee braces with fastener slippage

Knee brace forms a closed loop in the shape of a triangle. Fastener slippage occurs at every one of the three joints in the triangle, each independently contributing to the overall reduction of stiffness in the knee brace frame. Modeling all three-slip joints is time consuming and may not be necessary. The purpose of a knee brace is to modify the post-to-truss connection to behave as a moment-resisting joint. Moment is a rotational force, and rotation is associated with a circle. The relationship of the slip-joints can be better understood by comparing a knee-brace triangle to a circular ring where three short segments, representing the joints, are cut out and replaced by internal springs or members with significantly smaller axial stiffness (Figure 1). The ring analogy helps to recognize that there is only one load path to transfer rotational forces (moment) between the rafter (truss) and the post. This can be validated by observation: if the ring in Figure 1 is the only mechanism for transferring moments between the rafter and the column (assuming that individual joints do not have moment-resisting capabilities), and the continuity of the ring is severed at any of the three springs or at any other location along the circumference of the ring, the ability of the post-to-rafter connection to transfer moments is lost entirely (no alternative load path). Multiple springs arranged along a single load path behave independently of each other and have an equivalent spring constant calculated using Equation 1.

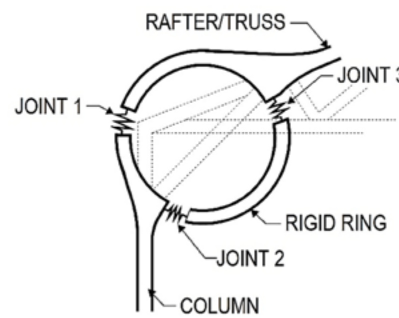

Figure 1:
Knee Brace with Slip – Ring Analog

$$k_{eq} = (1/k_1 + 1/k_2 + 1/k_3)^{-1} \qquad [1]$$

where, k_{eq}= equivalent stiffness of the knee brace, k_1, k_2 and k_3 are stiffness of Joints 1, 2 and 3.

The axial stiffness of a member, a ratio of force to axial deformation, which is equivalent to a spring constant, is defined by Equation 2 as

$P/\Delta = EA / L$ [2]

Where,

P/Δ = axial stiffness

E = elastic modulus

A = cross-sectional area of a member

L = length of a member

Even though a triangle is not an excellent representation of a circle (the ring), they both have a closed-loop geometry with a single load path, and the relationship of the joints and the overall concept is applicable. This can be validated by comparing two knee-brace models, one with three slip joints and the other with one equivalent slip joint. The frame on the left (Figure 2) is modeled with a slip at all three joints of the knee-brace triangle. The frame on the right has one slip joint at the bottom of the knee brace with axial stiffness that is equivalent to the axial stiffness of the three joints determined by merging Equations 1 and 2 into Equation 3. Because a segment of the main member (post, knee brace, rafter) is removed in the process, the new joint member is defined to represent both the slippage of the fasteners and the axial stiffness of the segment of the original member that the joint member is replacing (Equation 4). The equivalent axial stiffness of the joint member in the one-joint model is defined by Equation 5.

$(P/\Delta)_{j,eq} = [\ 1/(P/\Delta)_{j,1} + 1/(P/\Delta)_{j,2} + 1/(P/\Delta)_{j,3}\ ]^{-1}$ [3]

$(P/\Delta)_j = (EA/L)_j = [\ 1/(EA/L)_m + 1/(P/\Delta)_{slip}\ ]^{-1}$ [4]

$(P/\Delta)_{j,eq} = (EA/L)_{j,eq} = [\ 1/(EA/L)_{j,1} + 1/(EA/L)_{j,2} + 1/(EA/L)_{j,3}\ ]^{-1}$ [5]

where,

$(P/\Delta)_j$ = axial stiffness of the joint

$(EA/L)_j$ = axial stiffness of the joint expressed using terms E, A, and L

$(EA/L)_m$ = axial stiffness of the original frame member (segment) that is being replaced by the joint member

$(P/\Delta)_{slip}$ = slippage modulus of the fasteners (group) used in the connection at the joint

$(P/\Delta)_{j,eq}$ = axial stiffness of the equivalent joint for one-joint model

$(EA/L)_{j,eq}$ = axial stiffness of the equivalent joint for one-joint model expressed using terms E, A, and L

Each joint member in this analysis is 6 inches long and is rigidly attached to the member from which it extends and simply attached or supported to the connecting member. The weight of the framing is ignored. The material and geometry of the joint member is set to match the flexural stiffness, EI, of the main member from which it extends. The slip modulus is calculated using Wood Handbook FPL (2010) Equation 8-4 assuming five 0.148"x3" common wire nails at each joint. The depth and thickness of the joint member is calculated using Equations 7 and 8. Table 1 summarizes the geometry and structural properties of the frame.

$A_j = (P/\Delta)_j\ L_j / E$ [6]

$h_j = (12\ I/A_j)^{1/2}$ [7]

$b_j = A_j/h_j$ [8]

where,

A_j = cross section area of the joint member

h_j = depth of the joint member

b_j = thickness of the joint member

I = moment of inertia of the joint member (equal to moment of inertia of the main member)

L_j = length of the joint member

Since knee braces are only loaded axially, and assuming pin-pin connection at each end, and ignoring the weight of the members, the b_j and h_j of the joint member can be calculated using Equation 9. This simplification is not applied to the joint members at the top of the post and at the bottom of the rafter as these joint members require member-specific flexural stiffness to resist internal shear and bending forces.

$h_{j,\text{knee brace}} = b_{j,\text{knee brace}} = \sqrt{A_{j,\text{knee brace}}}$ [9]

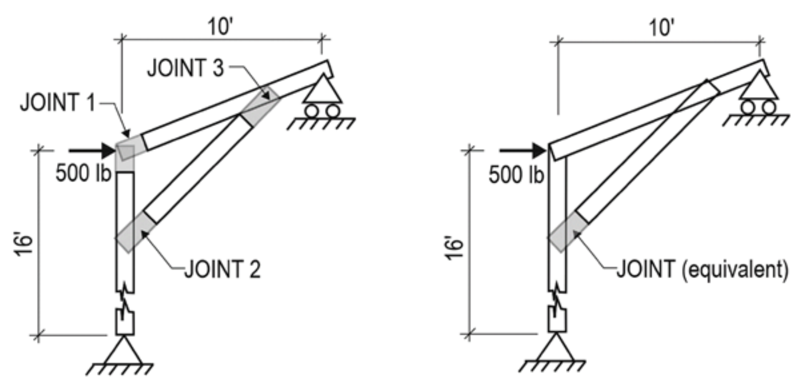

Figure 2:
Knee brace with slip at all joints (left) and with an equivalent slip at one joint (right)

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Table 1: Member properties

	b_m	h_m	$E_{m\&j}$	$I_{m\&j}$	$(P/\Delta)_{slip}$	$(P/\Delta)_m$	$(P/\Delta)_j$	A_j	L_j	b_j	h_j
	in	in	lb/in^2	in^4	lb/in	lb/in	lb/in	in^2	in	in	in
Post	5.5	5.5	1200000	76.26	77107	6050000	76137	0.381	6.0	0.008	49.03
Rafter	1.5	7.25	1600000	47.63		2900000	75110	0.282	6.0	0.006	45.05
Knee Brace @ Rafter	1.5	5.5	1600000	20.80	77107	2200000	74496	0.279	6.0	0.009	29.89
Knee Brace @ Post	1.5	5.5	1600000	20.80	77107	2200000	74496	0.279	6.0	0.009	29.89
Knee Brace (Eq)	1.5	5.5	1600000	20.80	25702	2200000	25406	0.095	6.0	0.002	51.18

where,

b = member thickness, h = member depth, E = elastic modulus, I = moment of inertia, A = cross section area, L = length of the joint member, P/Δ = axial stiffness, subscript "m" is for "main member" (post, knee brace, rafter), subscript "j" is for joint member

The results of this comparative analysis are summarized in Table 2. The difference in frame displacement between the two modeling methods is less than 1%, while the difference between the no slip model and one-slip model varies from 7.6 to 16.8%. Based on the results, it can be concluded that the performance of the one-joint model is equivalent to the performance of the three-joint model.

Table 2: Eave deflection and percent slippage for different assumptions

		Eave Deflection			Modeling Method	
Roof Pitch	Load on Frame	No Slip	Three Slip Joints	One Slip Joint	One Slip vs No Slip	One Slip vs Three Slip
	(lb)	(in)	(in)	(in)		
0:12	100	2.680	2.883	2.902	7.6%	0.7%
3:12	100	2.462	2.676	2.684	8.7%	0.3%
6:12	100	2.114	2.333	2.335	10.4%	0.1%
12:12	100	2.277	2.659	2.636	16.8%	0.8%

Knee Braces in Buildings with Diaphragm Action

To understand the effects of knee braces on a post-frame building with diaphragm action, three buildings are analyzed, and the results compared. The buildings are identified as #1, #2 and #3. All three buildings have the same size of 40'x80'x16', but have diaphragms with different effective shear modulus, G_{eff}. Building #1 represents a building with a relatively flexible diaphragm (G_{eff} = 1,260 lb/in). Building #2 represents an average diaphragm stiffness commonly used in post-frame buildings today (G_{eff} = 2,210 lb/in). Building #3 has a stiff diaphragm because of using stitch screws at the seams of overlapping panels (G_{eff} = 6,200 lb/in). Each of these three buildings is designed as follows: (1) without knee braces, (2) with knee braces but no slip at the joints, and (3) with knee braces with slip at the joints, which amounts to 9 separate designs.

Knee braces are known to be problematic in post-frame buildings with long-span trusses because they subject the posts to increased bending stresses due to the vertical deflection of the trusses under gravity loads (dead, snow, live). To consider this effect, Building #4 (60'x80'x16') and Building #5 (80'x160'x16') are added to this study. Both buildings are analyzed using a common diaphragm with effective shear modulus, G_{eff}, of 2,210 lb/in. With these two additional buildings, 15 separate designs are analyzed. The analyses compare how knee braces affect the following:

- Lateral displacement of the building at the eave line
- Load demand on end walls (maximum internal shear load in end walls)
- Load demand on diaphragm (maximum internal shear load in diaphragm)
- Load demand on the foundation (shear and moment post reactions at grade)
- Stress unities in posts (ratio of load demand to allowable capacity, combined axial and flexural loading)

Member sizes and properties are given in Table 3.

TABLE 3: MEMBER PROPERTIES

Member ID	40x80 Building	60x80 Building	80x160 Building
Post	5.5"x5.5" #2 SP	5.5"x5.5" #2 SP	7.5"x7.5" #2 SP
Truss Top Chord	2x12 SP MSR 2400f-2.0E	2x12 SP MSR 2400f-2.0E	(2) 2x12 SP MSR 2400f-2.0E
Truss Bottom Chord	2x12 SP MSR 2400f-2.0E	2x12 SP MSR 2400f-2.0E	(2) 2x12 SP MSR 2400f-2.0E
Truss Webs	2x4 #1 SP	2x4 #1 SP	(2) 2x4 #1 SP
Knee Brace	2x6 #2 SP	2x6 #2 SP	2x6 #2 SP
Knee Brace Connection	(6) 0.148"x3" Nails	(6) 0.148"x3" Nails	(6) 0.148"x3" Nails
Knee Brace Slip Member	0.369"x0.369"x6" E=1,400 ksi	0.369"x0.369"x6" E=1,400 ksi	0.369"x0.369"x6" E=1,400 ksi

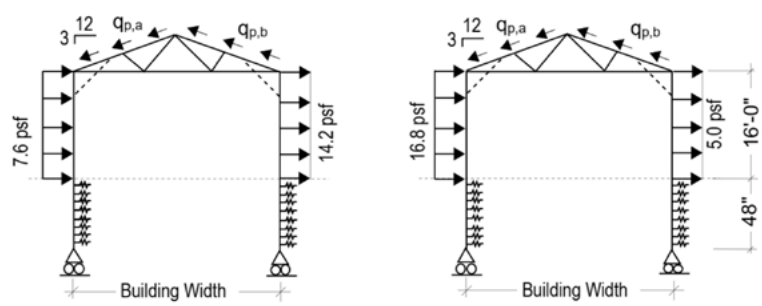
In all buildings, posts and trusses are spaced 8ft o.c. Slip modulus is calculated using Equation 8-4 in Wood Handbook FPL (2010). Fastener slippage is represented by one 0.3619" x 0.3619" x 6" long link member with elastic modulus, E, of 1,400,000 psi at the bottom of each knee brace. Standard procedure for lateral load analysis is described in ASABE EP484.3 (2017) and is summarized as follows:

(1) determine the lateral stiffness of the primary frame, (2) determine the lateral stiffness of the end walls and the roof diaphragm, (3) determine the lateral eave load at each frame, (4) distribute the lateral eave load to all participating components of the lateral force resisting system (frame, diaphragm, end walls) and calculate eave horizontal deflections using equations and tables given in EP484.3 or using the DAFI computer program (available free from NFBA website). Similar analysis can be performed using General Solution for Post-Frame Roof Diaphragm Deflections (Patrick M. McGuire, 1998). In this paper, the lateral loads are distributed using the method developed by McGuire and validated using DAFI.

Wind load on the building is calculated using the envelope procedure given in ASCE 7-16, Chapter 28, using 115 mph wind speed, wind Exposure C, internal pressure coefficient +/- 0.18 (enclosed building). Two wind load cases are considered in this study (Figure 3). The total diaphragm sides way restraining force, Q, which is determined by structural analysis per EP484.3, is applied to the top chord of truss using continuous uniform loads $q_{p,a}$ and $q_{p,b}$.

The minimum ASCE 7 load requirements of 16 psf and 8 psf pressures on wall and roof, respectively, are not considered. A 4 psf dead load and 20 psf snow (live) load is applied to the top chord of the truss and 1 psf dead load is applied to the bottom chord.

The foundation is a non-constrained shallow post foundation modeled with lateral springs consistent with the Universal Method of the ASABE EP486.3. The water table is assumed to be below the footer. The increase in Young's modulus per unit depth below grade, A_E, as defined in EP486.3, is 220 (lb/in^2)/in. This value includes 100% increase per EP486.3, Table 1, Footnote e (this is due to water table). There are 8 soil springs spaced 6 inches apart. The first (top) and the last (bottom) springs are located at 3 inches and 45 inches below grade, respectively. The stiffness constant increases linearly from 7920 lb/in at the first spring to 118,800 lb/in at the last spring.



CASE 1: GC_{PI} = +0.18 CASE 2: GC_{PI} = - 0.18

FIGURE 3. Wind load cases; load effect on the main wind force resisting system in Case 1 and Case 2 is greater when roof wind pressures are ignored (ASCE 7-16, Figure 28.3.1, Footnote 6), $q_{p,a}$ and $q_{p,b}$ are uniform in-plane diaphragm forces

A percentage of the lateral wind load is transferred into the frame and the roof diaphragm at the top of the post (eave load, R), and the remainder is transferred into the soil at the bottom of the post. Clause 6.3 of EP484.3 uses "post fixity factor" ratios to describe the ratio of the total wall load transferred up into the frame and the diaphragm. The prescribed post fixity factors are not used in this analysis and should not be used in post frame buildings with knee braces. Instead, the eave load, R, is determined by installing a horizontal restraint at the eave line of the structural model as described in EP484.3, Clause 6.2. The eave load is equal to the reaction at the horizontal restraint.

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The lateral stiffness of the primary frame is determined by applying a horizontal load, P, at the eave line and dividing this load by the resulting frame displacement, Δ as

$k = P/\Delta$ [10]

The roof and walls are sheathed with light gage corrugated metal panels with an effective shear modulus, G_{eff}, of varying magnitude. Enwalls have no openings. The horizontal stiffness of the diaphragm is calculated using EP484.2, Equation 3:

$C_h = G_{eff}\,(\cos\theta)(b_h,s)$ [11]

For example, C_h for the 40'x80'x16' building with G_{eff} of 1260 lb/in is calculated as follows:

C_h = 1,260 (cos 14.04)(40/8) = 6,112 lb/in. (Diaphragm Stiffness, Building 1)

Horizontal stiffness of the bare frame at each 40ft, 60ft and 80ft endwall is 465 lb/in, 697 lb/in and 2,857 lb/in, respectively. The bare frame stiffness in the 40-foot wide and 80-foot wide buildings was determined by structural models and was estimated for the 60-foot building using a 60/40 ratio multiplied by the stiffness of the 40-foot building. Endwall posts are continuous to the top chord of truss, and have the same size, spacing and foundation as the sidewall posts. The horizontal stiffness of the metal siding and secondary framing is calculated using the product of the effective shear modulus, G_{eff}, and the building width to eave height ratio. The total endwall stiffness is taken as the sum of the bare frame stiffness and stiffness of the metal siding assembly. For example, the endwall stiffness of Building 1 is calculated as follows:

In Plane Stiffness of Bare Frame = 465 lb/in (from a structural model)

Horizontal Stiffness of Siding Assembly = 1,260 lb/in (40/16) = 3150 lb/in

Endwall Stiffness, k_e = 465 + 3150 = 3615 lb/in (Endwall Stiffness, Building 1)

Stress unities are calculated using NDS 2018 Equation 3.9-3 for bending and axial compression (individual bending and axial checks were also performed). Posts below grade are assumed to be continuously braced by compacted soil. The wet-use factor of 0.7 is applied only to a post segment located below grade. Above grade, posts are braced by wall girts and metal siding to prevent buckling in the plane of the wall. The unbraced length for post buckling in the plane of the truss is calculated using the buckling length coefficients, K_e, from NDS Appendix G, Table G1: The coefficients are 0.8 for posts without knee braces and 0.65 for posts with knee braces. Analysis and design are done in Visual Analysis 21 by Integrated Engineering Software, Inc., (IES, 2023). The results of the analysis are summarized in Table 4 and compared in Table 5.

Analysis of Results

Frame: Knee braces significantly increased the lateral stiffness of the primary frames.

Eave Load: Rotational rigidity at the top of posts created by knee braces attracts a higher percentage of wall load up the post into the frame and the diaphragm. This can be seen by a significant increase in eave load (up to 45% increase). If eave load, R, was calculated using Clause 6.3 of EP484.3, the post fixity factors, determined by structural analysis, would be as tabulated below:

Post Fixity Factors

Building Description	Prescribed (EP484)	Determined by Structural Analysis		
		40' Wide	60' Wide	80' Wide
Buildings without knee braces	0.375	0.41	0.41	0.43
Buildings with knee braces, no slip	0.375	0.60	0.60	0.59
Buildings with knee braces, with slip	0.375	0.58	0.58	0.55

Deflections: Knee braces reduced horizontal eave deflection in Buildings 1 and 5 by up to 33% when joint slip is considered and by 38% when no slip is considered. This is an expected behavior. In Buildings 2, 3 and 4, however, knee braces have a negative effect on horizontal eave deflection, increasing the deflection by up to 23% with slip and 26% without slip. This behavior may appear counter intuitive and should be noted.

Diaphragm: Knee braces increased load demand on endwalls in Buildings 2, 3 and 4 by up to 27%, and increased load demand on the diaphragm by up to 25%. In Buildings 1 and 5, this trend is reversed.

Foundation: At windward post, knee braces reduced load demand on the foundation. At leeward posts, the results are mixed. Knee braces reduced load demand on the foundation in Buildings 2, 3 and 4, but increased the load demand in Buildings 1 and 5. Changes in load demand on the foundation are significant and range from 33% reduction to 39% increase.

Posts: In buildings with 40-foot-span trusses, knee braces have mostly a positive effect on stress unities. In buildings with 60-foot and 80-foot-truss spans, knee braces have a negative effect on stress unities. The stress unities in posts above grade in Buildings 3, 4, and 5 with knee braces are controlled by gravity loads (D+S); load combinations with wind load are not controlling the design. Posts with knee braces in Building 4 failed by up to 38% while posts in the same building but without knee braces passed by 0.94 stress unity.

Slippage: The effects of fastener slippage at knee brace connections are relatively insignificant. Buildings with knee braces with slippage performed within a few percent of the buildings with knee braces without slippage. The only difference observed was in Building 5 (80-foot truss span), a difference of 23% in knee brace axial compression forces. The slip modulus in all the buildings was based on (6) 0.148"x3" nails. This would not be enough for knee braces in Building 5. Increasing the quantity of nails to resist the required load will diminish the difference between the slip and no slip designs in Building 5.

Before considering knee bracing, it is recommended that the building designer first check if they are beneficial when diaphragm action is included in the design. Certain building sizes may not benefit from knee braces when diaphragm action is included in the design. For example, a full-scale (40'x80'x16' to the eave height) post-frame building test showed that horizontal eave deflection dropped from 6.1" when metal cladding was not put in place (frame only) to 0.44" when metal cladding was put in place (Gebremedhin, 1991).

Table 4: Results of structural analysis

Building ID Number	Building Size (ft)	Knee Brace (KB) condition	Effective Shear Modulus of Roofing/Siding G_{eff} (lb/in)	Number of Bays	Diaphragm Horizontal Shear Stiffness C_h (lb/in)	Endwall Stiffness k_e (lb/in)	Interior Frame Stiffness k (lb/in)	Eave Load R (lb)	Restraining Force at Max Deflection Q (lb)	Max. Horizontal Displacement at Eave Δ_{max} (in)	Deflection at Endwalls Δ_e (in)	Shear Load at Endwalls V_e (lb)	Max. Internal Horizontal Diaphragm Load $V_{max,d}$ (lb)
1	40x80	No KB	1260	10	6112	3615	58	693	576	2.03	0.83	2996	2650
		KB no slip					306	1002	453	1.79	0.77	2770	2269
		KB w/ slip					278	968	464	1.81	0.77	2784	2300
2	40x80	No KB	2210	10	10720	5990	58	693	621	1.26	0.53	3173	2827
		KB no slip					306	1002	602	1.31	0.56	3380	2879
		KB w/ slip					278	968	605	1.31	0.56	3361	2877
3	40x80	No KB	6200	10	30074	15965	58	693	665	0.49	0.21	3353	3006
		KB no slip					306	1002	815	0.61	0.27	4249	3748
		KB w/ slip					278	968	801	0.60	0.26	4160	3676
4	60x80	No KB	2210	10	16080	8980	58	693	643	0.87	0.36	3262	2916
		KB no slip					307	1003	700	0.99	0.42	3784	3283
		KB w/ slip					279	968	696	0.98	0.42	3735	3251
5	80x160	No KB	2210	20	21440	13907	182	712	443	1.48	0.37	5089	4733
		KB no slip					862	985	201	0.91	0.26	3650	3157
		KB w/ slip					680	913	238	0.99	0.28	3846	3389

Building ID Number	Building Size (ft)	Knee Brace (KB) condition	Effective Shear Modulus of Roofing/Siding G_{eff} (lb/in)	Max. Axial Compression Load in Knee Brace $P_{k,comp}$ (lb)	Max. Axial Tension Load in Knee Brace $P_{k,ten}$ (lb)	Max. Shear at Grade in Windward Post $V_{G,Wind}$ (lb)	Max. Moment at Grade in Windward Post $M_{G,Wind}$ (lb-ft)	Max. Shear at Grade in Leeward Post $V_{G,Leew}$ (lb)	Max. Moment Grade in Leeward Post $M_{G,Leew}$ (lb-ft)	Stress Unity for Windward Post Below Grade	Stress Unity for Windward Post Above Grade	Stress Unity for Leeward Post Below Grade	Stress Unity for Leeward Post Above Grade
1	40x80	No KB	1260	-	-	814	2705	698	2443	0.95	0.93	0.85	0.83
		KB no slip		1231	549	780	2488	741	2538	0.88	0.81	0.89	0.84
		KB w/ slip		1105	498	785	2510	737	2529	0.89	0.82	0.89	0.83
2	40x80	No KB	2210	N/A	N/A	792	2351	676	2085	0.84	0.81	0.74	0.72
		KB no slip		976	212	706	2019	666	2065	0.73	0.68	0.74	0.71
		KB w/ slip		869	186	715	2054	667	2066	0.74	0.67	0.74	0.70
3	40x80	No KB	6200	-	-	770	1995	653	1721	0.73	0.69	0.64	0.61
		KB no slip		1271	610	660	1346	559	1424	0.51	0.68	0.53	0.68
		KB w/ slip		1139	551	618	1412	568	1420	0.53	0.61	0.53	0.61
4	60x80	No KB	2210	-	-	781	2171	665	1918	0.79	0.94	0.69	0.88
		KB no slip		1602	272	643	1648	648	2114	0.63	**1.38**	0.78	**1.38**
		KB w/ slip		1432	248	657	1702	642	2044	0.63	**1.24**	0.76	**1.24**
5	80x160	No KB	2210	-	-	874	3660	764	3493	0.51	0.48	0.48	0.46
		KB no slip		3474	864	864	2997	1062	4088	0.48	0.98	0.6	0.98
		KB w/ slip		2660	750	879	3145	948	3732	0.45	0.74	0.55	0.74

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Table 5: Comparison of results

Building ID Number	Building Size (ft)	Knee Brace (KB) condition	Effective Shear Modulus of Roofing/Siding G_{eff} (lb/in)	Number of Bays	Diaphragm Horizontal Shear Stiffness C_h % Δ	Endwall Stiffness k_e % Δ	Interior Frame Stiffness k % Δ	Eave Load R % Δ	Restraining Force at Max Deflection Q % Δ	Max. Horizontal Displacement at Eave Δ_{max} % Δ	Deflection at Endwalls Δ_e % Δ	Shear Load at Endwalls V_e % Δ	Max. Internal Horizontal Diaphragm Load $V_{max,d}$ % Δ
1	40x80	No KB											
		KB no slip	1260	no change			431%	45%	-21%	-12%	-8%	-8%	-14%
		KB w/ slip					383%	40%	-20%	-11%	-7%	-7%	-13%
2	40x80	No KB											
		KB no slip	2210	no change			431%	45%	-3%	4%	7%	7%	2%
		KB w/ slip					383%	40%	-3%	3%	6%	6%	2%
3	40x80	No KB											
		KB no slip	6200	no change			431%	45%	22%	26%	27%	27%	25%
		KB w/ slip					383%	40%	20%	23%	24%	24%	22%
4	60x80	No KB											
		KB no slip	2210	no change			429%	45%	9%	14%	16%	16%	13%
		KB w/ slip					381%	40%	8%	13%	14%	14%	11%
5	80x160	No KB											
		KB no slip	2210	no change			374%	38%	-55%	-38%	-28%	-28%	-33%
		KB w/ slip					274%	28%	-46%	-33%	-24%	-24%	-28%

Building ID Number	Building Size (ft)	Knee Brace (KB) condition	Effective Shear Modulus of Roofing/Siding G_{eff} (lb/in)	Max. Axial Compression Load in Knee Brace $P_{k,comp}$ % Δ	Max. Axial Tension Load in Knee Brace $P_{k,ten}$ % Δ	Max. Shear at Grade in Windward Post $V_{G,Wind}$ % Δ	Max. Moment at Grade in Windward Post $M_{G,Wind}$ % Δ	Max. Shear at Grade in Leeward Post $V_{G,Leew}$ % Δ	Max. Moment Grade in Leeward Post $M_{G,Leew}$ % Δ	Stress Unity for Windward Post Below Grade % Δ	Stress Unity for Windward Post Above Grade % Δ	Stress Unity for Leeward Post Below Grade % Δ	Stress Unity for Leeward Post Above Grade % Δ
1	40x80	No KB											
		KB no slip	1260	n/a		-4%	-8%	6%	4%	-7%	-13%	5%	1%
		KB w/ slip				-4%	-7%	6%	4%	-6%	-12%	5%	0%
2	40x80	No KB											
		KB no slip	2210	n/a		-11%	-14%	-1%	-1%	-13%	-16%	0%	-1%
		KB w/ slip				-10%	-13%	-1%	-1%	-12%	-17%	0%	-3%
3	40x80	No KB											
		KB no slip	6200	n/a		-14%	-33%	-14%	-17%	-30%	-1%	-17%	11%
		KB w/ slip				-20%	-29%	-13%	-17%	-27%	-12%	-17%	0%
4	60x80	No KB											
		KB no slip	2210	n/a		-18%	-24%	-3%	10%	-20%	47%	13%	57%
		KB w/ slip				-16%	-22%	-3%	7%	-20%	32%	10%	41%
5	80x160	No KB											
		KB no slip	2210	n/a		-1%	-18%	39%	17%	-6%	104%	25%	113%
		KB w/ slip				1%	-14%	24%	7%	-12%	54%	15%	61%

Conclusions and Recommendations

The following key points can be withdrawn from the analysis:

1. In the 5 buildings analyzed in this study, use of knee braces produced inconsistent results. Knee braces may increase or decrease horizontal eave deflection, load demand on the diaphragm and end walls, load demand on the foundation, and stress unity in the posts.

2. Modeling knee bracing within a post-frame building is complex. The complexity extends to the roof-truss design because the truss design must include the knee brace reaction forces. The building designer is responsible for reviewing truss drawings and verify that knee brace loads are applied correctly, and that correct governing load combinations are applied while the truss designer must incorporate the load impact of the knee brace into the component design.

3. In all buildings with knee braces, posts were subjected to additional bending stresses under gravity loads. This behavior was more pronounced in buildings with long truss spans (Buildings #4 and #5).

4. Knee braces should not be added to a building if knee braces are not specified in the design documents. Knee braces should not be specified in the design documents unless their effects on the building are considered by structural analysis.

5. Knee braces may benefit buildings with certain geometrical configurations and loading conditions where diaphragm action alone is not enough. It is recommended that the building designer first check the need for knee bracing when diaphragm action is included in the design. In the buildings analyzed herein, however, knee braces did not produce a consistent advantage in any of the relevant metrics of design. The stiffer frames did not consistently translate to a stronger or more efficient design. The results were mixed and highly dependent on relative stiffness of the primary frame and diaphragm.

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This article was subjected to a peer review process conducted by the NFBA Editorial Committee, which consists of at least 10 members from engineering and academic organizations throughout the United States who are each knowledgeable about Post-Frame construction.