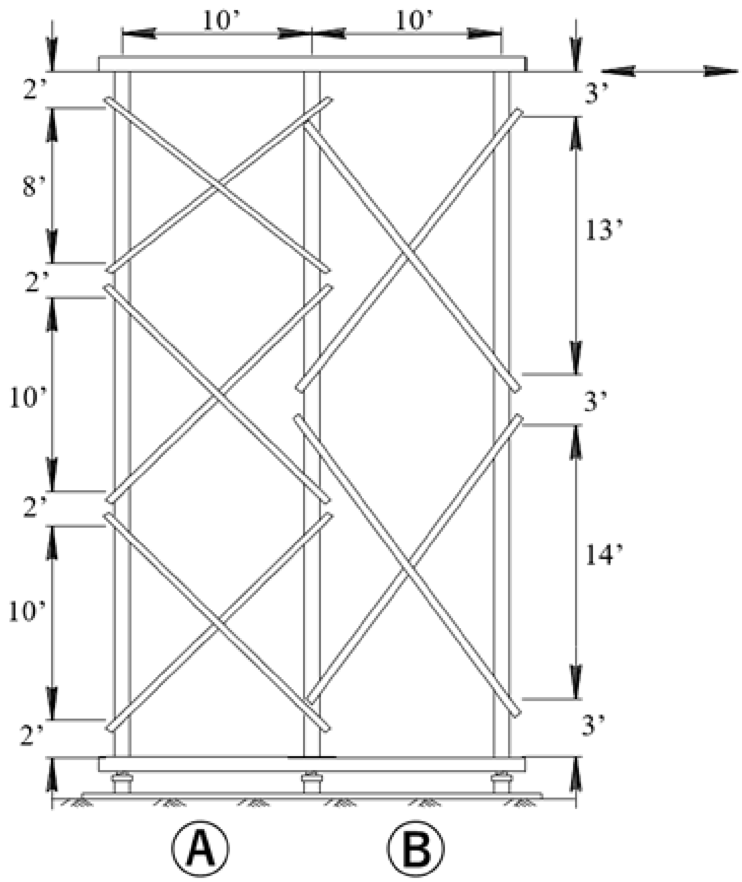
Appendix D Example 17 – Diagonal Bracing of Multi-Tiered Framed Bents – Multiple Posts

Refer to *Falsework Manual,* Section 6-3, *Diagonal Bracing* and Section 5-3, *Timber Fasteners*. This example demonstrates how to determine if the bracing system of a multi-tiered framed bent is adequate. The falsework bent has multiple posts, and the tiers are different heights. The brace to post connections and mid brace connections are bolted.

Given Information



2% Dead load = 3500 lb
Wind load = 3200 lb

Posts:
12 x 12 Rough Douglas Fir-Larch #2
(G=0.50)

Diagonal Braces:
2x8 S4S Douglas Fir-Larch #2 (G=0.50)

Connectors:
Brace to Post: 1x3/4″ Ø bolt
Intersection of brace: 1x3/4″ Ø bolt
(All bolts in single shear)

Figure D-17-1. Multi-Tiered Framed Bent with Multiple Posts

Determine if the Bracing System is Adequate

ANALYZE THE TOP TIER IN BRACING Ⓐ

1. Determine the connection capacity between brace and post

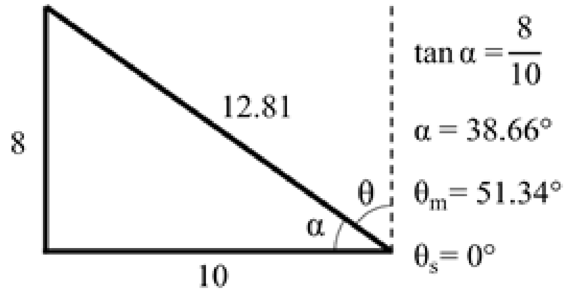


Figure D-17-2. Bracing Ⓐ Top Tier Member Lengths and Orientation

Main Member Properties

l_m = 12 in	*thickness (12x12)*
$t_m = l_m$ = 12 in	
θ_m= 51.34°	*angle between direction of loading & direction of grain*
G = 0.50	*Specific Gravity NDS Table 12.3.3*

Side Member Properties

l_s = 1.5 in	*thickness (2x8)*
$t_s = l_s$ = 1.5 in	
θ_s= 0°	*angle between direction of loading & direction of grain*

Connector Properties

D = 0.75 in	*connector diameter*
F_{yb} = 45000 psi	*Yield Strength (See Footnote #2 of Bolt Tables)*
$F_{e.pll}$ = 11200G psi = 5600 psi	*Dowel Bearing Strength Parallel to Grain*
$F_{e.perp} = \frac{6100G^{1.45}}{\sqrt{D}}$ = 2578 psi	*Dowel Bearing Strength Perpendicular to Grain*

Compare values to NDS Table 12.3.3:

$F_{e.pll\ (NDS\ Table\ 12.3.3)} = 5600$ psi

$F_{e.perp\ (NDS\ Table\ 12.3.3)} = 2600$ psi

Use calculated value for $F_{perp} = 2578$ psi

Find Dowel Bearing Strength at an Angle to Grain (NDS Section 12.3.4):

$$F_{em} = \frac{F_{e.pll} F_{perp}}{F_{e.pll}(\sin(\theta_m))^2 + F_{perp}(\cos(\theta_m))^2} = 3266 \text{ psi}$$

$$F_{es} = \frac{F_{e.pll} F_{perp}}{F_{e.pll}(\sin(\theta_s))^2 + F_{perp}(\cos(\theta_s))^2} = 5600 \text{ psi}$$

Find Reduction Term, R_d (NDS Table 12.3.1B):

$\theta = \max(\theta_m, \theta_s) = 51.34°$ *Maximum angle between direction of load and direction of grain for any member in connection (See Table 12.3.1B)*

$$K_\theta = 1 + 0.25 \frac{\theta}{90 \text{ deg}} = 1.1426$$

$R_{d\_I} = 4\ K_\theta = 4.57$ *Reduction Term for Yield Mode I_m and I_s*

$R_{d\_II} = 3.6\ K_\theta = 4.11$ *Reduction Term for Yield Mode II*

$R_{d\_III.IV} = 3.2\ K_\theta = 3.66$ *Reduction Term for Yield Mode III_m, III_s, and IV*

Find Yield Limit Equations for Single Shear (NDS Table 12.3.1A):

$$R_e = \frac{F_{em}}{F_{es}} = 0.5832$$

$$R_t = \frac{l_m}{l_s} = 8$$

$$k_1 = \frac{\sqrt{R_e + 2R_e^2\left(1 + R_t + R_t^2\right) + R_t^2 R_e^3} - R_e(1 + R_t)}{(1 + R_e)} = 1.6956$$

$$k_2 = -1 + \sqrt{2(1 + R_e) + \frac{2F_{yb}(1 + 2R_e)D^2}{3F_{em} l_m^2}} = 0.8011$$

$$k_3 = -1 + \sqrt{\frac{2(1+R_e)}{R_e} + \frac{2F_{yb}(2+R_e)D^2}{3F_{em}l_s^2}} = 2.3707$$

$$Z_{Im} = \frac{Dl_mF_{em}}{R_{d\_I}} = 6431 \text{ lb}$$ *NDS Eqn 12.3-1*

$$Z_{Is} = \frac{Dl_sF_{es}}{R_{d\_I}} = 1378 \text{ lb}$$ *NDS Eqn 12.3-2*

$$Z_{II} = \frac{k_1Dl_sF_{es}}{R_{d\_II}} = 2597 \text{ lb}$$ *NDS Eqn 12.3-3*

$$Z_{IIIm} = \frac{k_2Dl_mF_{em}}{(1+2R_e)R_{d\_III.IV}} = 2973 \text{ lb}$$ *NDS Eqn 12.3-4*

$$Z_{IIIs} = \frac{k_3Dl_sF_{em}}{(2+R_e)R_{d\_III.IV}} = 922 \text{ lb}$$ *NDS Eqn 12.3-5*

$$Z_{IV} = \frac{D^2}{R_{d\_III.IV}}\sqrt{\frac{2F_{em}F_{yb}}{3(1+R_e)}} = 1210 \text{ lb}$$ *NDS Eqn 12.3-6*

The controlling value is the minimum single shear capacity from the above equations.

$Z_{control}$ = min (Z_{Im}, Z_{Is}, Z_{II}, Z_{IIIm}, Z_{IIIs}, Z_{IV}) = 922 lb *(Yield Mode IIIs controls)*

Adjustment factors from NDS Table 11.3.1:

C_D = 1.25	*Duration Factor for 2% lateral loading*
C_M = 1.0	*Wet Service Factor NDS 11.3.3 (Assume < 19% moisture content)*
C_t = 1.0	*Temperature Factor NDS 11.3.4 (Temp up to 100ºF)*
C_g = 1.0	*Group Action Factor NDS 11.3.6 (Single Fastener)*
C_Δ = 1.0	*Geometry Factor NDS 12.5.1 (Assume End Dist. & spacing meet Tables 12.5.1A and 12.5.1B)*
C_{eg} = 1.0	*End Grain Factor NDS 12.5.2 (Does not apply)*
C_{di} = 1.0	*Diaphragm Factor NDS 12.5.3 (Does not apply)*
C_{tn} = 1.0	*Toe Nail Factor NDS 12.5.4 (Does not apply)*

Adjusted lateral design value Z' = $Z(C_D)(C_M)(C_t)(C_g)(C_\Delta)$ = 1153 lb

2. Determine the capacity of the diagonal brace in tension

Reference design value in tension F_t = 575 psi (NDS supplement table 4A)

Adjustment factors from NDS table 4.3.1:

C_D = 1.25 *Duration Factor for 2% lateral loading*

C_M = 1.0 *Wet Service Factor NDS table 4A (Assume < 19% moisture content)*

C_t = 1.0 *Temperature Factor NDS table 2.3.3 (Temp up to 100ºF)*

C_F = 1.2 *Size Factor NDS Table 4A*

C_i = 1.0 *Incising Factor NDS 4.3.8*

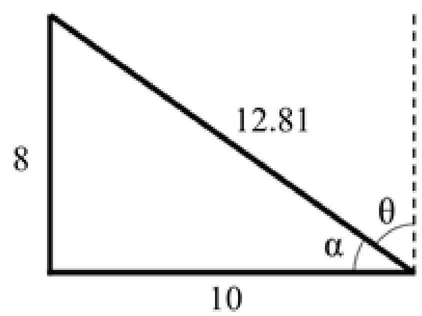
Adjusted design value $F_t' = F_t (C_D)(C_M)(C_t)(C_F)(C_i)$ = 862.5 psi

Tension capacity = 862.5 psi(1.5”)(7.25”) = 9380 lb

3. Determine the strength value of the tension members

9380 lb > 1153 lb ∴ Connection strength controls

4. Calculate the horizontal component of the strength value for the tension members



$T = 1153 \cos\alpha = 900$ lb

Figure D-17-3. Geometric Components of Tension Strength Value for Bracing Ⓐ Top Tier

5. Determine the capacity of diagonal brace in compression

Check cross brace capacity in compression:

Reference design value in compression F_c = 1350 psi (NDS supplement table 4A)

Adjustment factors from NDS table 4.3.1:

C_D = 1.25 *Duration Factor for 2% lateral loading*

C_M = 1.0 *Wet Service Factor NDS table 4A (Assume < 19% moisture content)*

C_t = 1.0 *Temperature Factor NDS table 2.3.3 (Temp up to 100ºF)*

C_F = 1.05 *Size Factor NDS Table 4A*

C_i = 1.0 *Incising Factor NDS 4.3.8*

$$C_p = \frac{1 + (F_{cE}/F_c^*)}{2c} - \sqrt{\left[\frac{1 + (F_{cE}/F_c^*)}{2c}\right]^2 - \frac{F_{cE}/F_c^*}{c}} = 0.1003$$

Column Stability Factor NDS Eqn. 3.7-1

where:

l_e	= (12.81'/2) = 6.405' = 76.86"	*unsupported length*
d	= 1.5"	*member width, weak direction*
E_{min}	= 580,000 psi	*NDS supplement table 4A*
F_{cE}	$= \dfrac{0.822E_{min}'}{(l_e/d)^2} = 182$	*NDS 3.7.1*
F_c^*	$= F_c\,(C_D)(C_M)(C_t)(C_F)(C_i)$ = 1772 psi	*Adjusted design compression value except C_p*
c	= 0.8 for sawn lumber	*NDS 3.7.1*

Adjusted design compression value $F_c' = F_c\,(C_D)(C_M)(C_t)(C_F)(C_i)(C_p)$ = 177.7 psi

Compression brace capacity = 177.7 psi (1.5")(7.25") = 1932 lb

6. Determine the strength value of the compression members

Connection capacity = 1153 lb

(See step 1. Capacity in tension and compression are the same)

1932 lb > 1153 lb ∴ connection controls compression

Limit to 1/2 theoretical strength for compression values: See section 6-3.02, *Wood Cross Bracing.*

Reduced compression brace capacity = $\dfrac{1153 \text{ lb}}{2}$ = 576 lb

7. Calculate the horizontal component of the strength value for the compression member

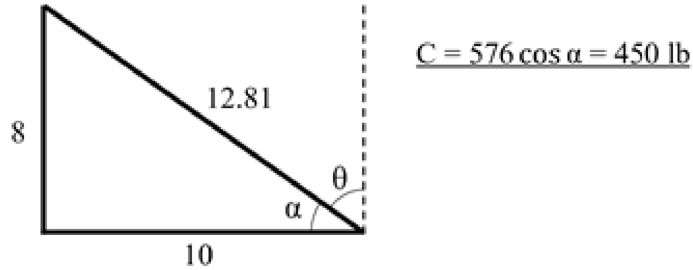


Figure D-17-4. Geometric Components of Compression Strength Value for Bracing Ⓐ Top Tier

8. **Calculate the total resisting capacity of the top tier of bracing**

   Total resisting capacity = Σ(C+T) = 450 + 900 = 1350 lb

ANALYZE THE MIDDLE TIER IN BRACING Ⓐ

1. **Determine the connection capacity between brace and post:**

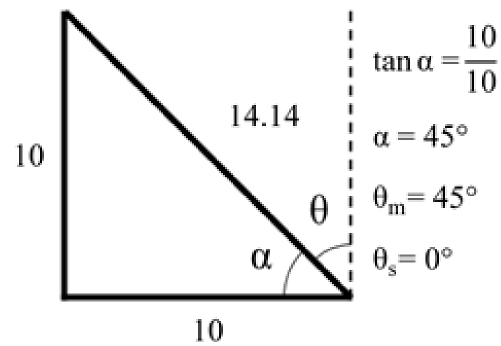


Figure D-17-5. Bracing Ⓐ Middle Tier Member Lengths and Orientation

Main Member Properties		Side Member Properties	
l_m = 12 in	*thickness (12x12)*	l_s = 1.5 in	*thickness (2x8)*
$t_m = l_m$ = 12 in		$t_s = l_s$ = 1.5 in	
θ_m= 45°	*angle between direction of loading & direction of grain*	θ_s= 0°	*angle between direction of loading & direction of grain*
G = 0.50	*Specific Gravity*		
	NDS Table 12.3.3		

Connector Properties

By inspection, same properties as previous tier. $F_{e.pll} = 5600$ psi $F_{e.perp} = 2578$ psi

Find Dowel Bearing Strength at an Angle to Grain (NDS Section 12.3.4):

$$F_{em} = \frac{F_{e.pll}F_{perp}}{F_{e.pll}(\sin(\theta_m))^2 + F_{perp}(\cos(\theta_m))^2} = 3531 \text{ psi}$$

$$F_{es} = \frac{F_{e.pll}F_{perp}}{F_{e.pll}(\sin(\theta_s))^2 + F_{perp}(\cos(\theta_s))^2} = 5600 \text{ psi}$$

Find Reduction Term, R_d (NDS Table 12.3.1B):

$\theta = \max(\theta_m, \theta_s) = 45°$ *Maximum angle between direction of load and direction of grain for any member in connection (See Table 12.3.1B)*

$$K_\theta = 1 + 0.25\frac{\theta}{90 \text{ deg}} = 1.125$$

$R_{d\_I} = 4\ K_\theta = 4.5$ *Reduction Term for Yield Mode I_m and I_s*

$R_{d\_II} = 3.6\ K_\theta = 4.05$ *Reduction Term for Yield Mode II*

$R_{d\_III.IV} = 3.2\ K_\theta = 3.6$ *Reduction Term for Yield Mode III_m, III_s, and IV*

Find Yield Limit Equations for Single Shear (NDS Table 12.3.1A):

$$R_e = \frac{F_{em}}{F_{es}} = 0.6305$$

$$R_t = \frac{l_m}{l_s} = 8$$

$$k_1 = \frac{\sqrt{R_e + 2R_e^2\left(1 + R_t + R_t^2\right) + R_t^2R_e^3} - R_e(1 + R_t)}{(1 + R_e)} = 1.8209$$

$$k_2 = -1 + \sqrt{2(1 + R_e) + \frac{2F_{yb}(1 + 2R_e)D^2}{3F_{em}l_m^2}} = 0.8265$$

$$k_3 = -1 + \sqrt{\frac{2(1 + R_e)}{R_e} + \frac{2F_{yb}(2 + R_e)D^2}{3F_{em}l_s^2}} = 2.2802$$

$$Z_{Im} = \frac{Dl_mF_{em}}{R_{d\_I}} = 7062 \text{ lb}$$ *NDS Eqn 12.3-1*

$$Z_{Is} = \frac{Dl_sF_{es}}{R_{d\_I}} = 1400 \text{ lb}$$ *NDS Eqn 12.3-2*

$$Z_{II} = \frac{k_1Dl_sF_{es}}{R_{d\_II}} = 2833 \text{ lb}$$ *NDS Eqn 12.3-3*

$$Z_{IIIm} = \frac{k_2Dl_mF_{em}}{(1 + 2R_e)R_{d\_III.IV}} = 3227 \text{ lb}$$ *NDS Eqn 12.3-4*

$$Z_{IIIs} = \frac{k_3Dl_sF_{em}}{(2 + R_e)R_{d\_III.IV}} = 956 \text{ lb}$$ *NDS Eqn 12.3-5*

$$Z_{IV} = \frac{D^2}{R_{d\_III.IV}}\sqrt{\frac{2F_{em}F_{yb}}{3(1 + R_e)}} = 1259 \text{ lb}$$ *NDS Eqn 12.3-6*

The controlling value is the minimum single shear capacity from the above equations.

$Z_{control} = \min(Z_{Im}, Z_{Is}, Z_{II}, Z_{IIIm}, Z_{IIIs}, Z_{IV}) = 956$ lb *(Yield Mode IIIs controls)*

Adjustment factors from NDS Table 11.3.1:

$C_D = 1.25$ *Duration Factor for 2% lateral loading*

$C_M = 1.0$ *Wet Service Factor NDS 11.3.3 (Assume < 19% moisture content)*

$C_t = 1.0$ *Temperature Factor NDS 11.3.4 (Temp up to 100ºF)*

$C_g = 1.0$ *Group Action Factor NDS 11.3.6 (Single Fastener)*

$C_\Delta = 1.0$ *Geometry Factor NDS 12.5.1 (Assume End Dist. & spacing meet Tables 12.5.1A and 12.5.1B)*

$C_{eg} = 1.0$ *End Grain Factor NDS 12.5.2 (Does not apply)*

$C_{di} = 1.0$ *Diaphragm Factor NDS 12.5.3 (Does not apply)*

$C_{tn} = 1.0$ *Toe Nail Factor NDS 12.5.4 (Does not apply)*

Adjusted lateral design value $Z' = Z(C_D)(C_M)(C_t)(C_g)(C_\Delta) = 1196$ lb

2. Determine the capacity of the diagonal brace in tension

By inspection, same as previous tier. See top tier, step #2.

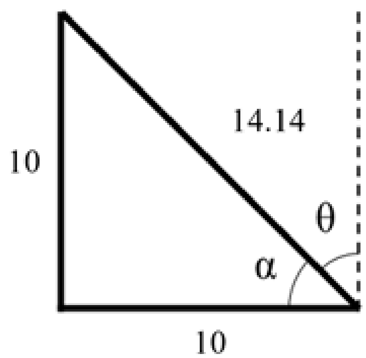
Adjusted design value $F_t' = F_t (C_D)(C_M)(Ct)(C_F)(C_i) = 862.5$ psi

Tension capacity = 862.5 psi(1.5")(7.25") = 9380 lb

3. Determine the strength value of the tension members

9380 lb > 1196 lb ∴ Connection strength controls

4. Calculate the horizontal component of the strength value for the tension members



T = 1196 cos α = 845 lb

Figure D-17-6. Geometric Components of Tension Strength Value for Bracing Ⓐ Middle Tier

5. Determine the capacity of diagonal brace in compression

Check cross brace capacity in compression:

Reference design value in compression $F_c = 1350$ psi (NDS supplement table 4A)

Adjustment factors from NDS table 4.3.1:

C_D = 1.25 *Duration Factor for 2% lateral loading*
C_M = 1.0 *Wet Service Factor NDS table 4A (Assume < 19% moisture content)*
C_t = 1.0 *Temperature Factor NDS table 2.3.3 (Temp up to 100ºF)*
C_F = 1.05 *Size Factor NDS Table 4A*
C_i = 1.0 *Incising Factor NDS 4.3.8*

$$C_p = \frac{1+(F_{cE}/F_c^*)}{2c} - \sqrt{\left[\frac{1+(F_{cE}/F_c^*)}{2c}\right]^2 - \frac{F_{cE}/F_c^*}{c}} = 0.0826$$

Column Stability Factor NDS Eqn. 3.7-1 where:

l_e	= (14.14'/2) = 7.071' = 84.85"	*unsupported length*
d	= 1.5"	*member width, weak direction*
E_{min}	= 580,000 psi	*NDS supplement table 4A*
F_{cE}	$= \frac{0.822E_{min}'}{(l_e/d)^2} = 149$	*NDS 3.7.1*
F_c^*	= F_c (C_D)(C_M)(C_t)(C_F)(C_i) = 1772 psi	*Adjusted design compression value except C_p*
c	= 0.8 for sawn lumber	*NDS 3.7.1*

Adjusted design compression value F_c' = F_c (C_D)(C_M)(C_t)(C_F)(C_i)(C_p) = 146.4 psi

Compression brace capacity = 146.4 psi (1.5")(7.25") = 1592 lb

6. **Determine the strength value of the compression members**

Connection capacity = 1196 lb

(See step 1. Capacity in tension and compression are the same)

1196 lb < 1592 lb ∴ connection controls compression

Limit to ½ theoretical strength for compression values: See section 6-3.02, *Wood Cross Bracing.*

Reduced compression brace capacity = $\frac{1196 \text{ lb}}{2}$ = 598 lb

7. **Calculate the horizontal component of the strength value for the compression member**

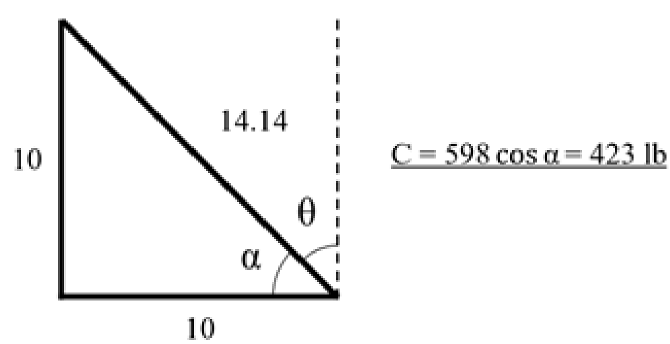


Figure D-17-7. Geometric Components of Compression Strength Value for Bracing Ⓐ Middle Tier

8. **Calculate the total resisting capacity of the top tier of bracing**

   Total resisting capacity = $\Sigma(C+T)$ = 423 + 845 = 1268 lb

ANALYZE THE BOTTOM TIER IN BRACING A

By inspection, middle tier and bottom tier are the same.

Total resisting capacity = 1268 lb

ANALYZE THE TOP TIER IN BRACING B

1. **Determine the connection capacity between brace and post**

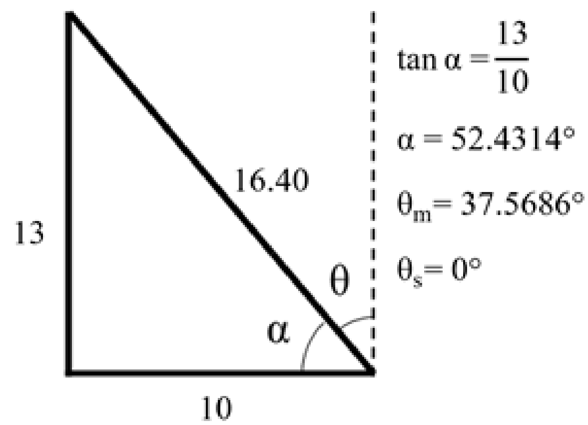


Figure D-17-8. Bracing B Top Tier Member Lengths and Orientation

Main Member Properties

l_m = 12 in	*thickness (12x12)*
$t_m = l_m$ = 12 in	
θ_m = 37.56°	*angle between direction of loading & direction of grain*
G = 0.50	*Specific Gravity NDS Table 12.3.3*

Side Member Properties

l_s = 1.5 in	*thickness (2x8)*
$t_s = l_s$ = 1.5 in	
θ_s = 0°	*angle between direction of loading & direction of grain*

Connector Properties

By inspection, same properties as previous tiers. $F_{e.pll}$ = 5600 psi $F_{e.perp}$ = 2578 psi

Find Dowel Bearing Strength at an Angle to Grain (NDS Section 12.3.4)

$$F_{em} = \frac{F_{e.pll}F_{perp}}{F_{e.pll}(\sin(\theta_m))^2 + F_{perp}(\cos(\theta_m))^2} = 3900 \text{ psi}$$

$$F_{es} = \frac{F_{e.pll}F_{perp}}{F_{e.pll}(\sin(\theta_s))^2 + F_{perp}(\cos(\theta_s))^2} = 5600 \text{ psi}$$

Find Reduction Term, R_d (NDS Table 12.3.1B):

$\theta = \max(\theta_m, \theta_s) = 37.5686°$ *Maximum angle between direction of load and direction of grain for any member in connection (See Table 12.3.1B)*

$$K_\theta = 1 + 0.25\frac{\theta}{90 \text{ deg}} = 1.1044$$

$R_{d\_I} = 4\ K_\theta = 4.42$ *Reduction Term for Yield Mode I_m and I_s*

$R_{d\_II} = 3.6\ K_\theta = 3.98$ *Reduction Term for Yield Mode II*

$R_{d\_III.IV} = 3.2\ K_\theta = 3.53$ *Reduction Term for Yield Mode III_m, III_s, and IV*

Find Yield Limit Equations for Single Shear (NDS Table 12.3.1A):

$$R_e = \frac{F_{em}}{F_{es}} = 0.6965$$

$$R_t = \frac{l_m}{l_s} = 8$$

$$k_1 = \frac{\sqrt{R_e + 2R_e^2\left(1 + R_t + R_t^2\right) + R_t^2R_e^3} - R_e(1 + R_t)}{(1 + R_e)} = 1.9940$$

$$k_2 = -1 + \sqrt{2(1 + R_e) + \frac{2F_{yb}(1 + 2R_e)D^2}{3F_{em}l_m^2}} = 0.8614$$

$$k_3 = -1 + \sqrt{\frac{2(1 + R_e)}{R_e} + \frac{2F_{yb}(2 + R_e)D^2}{3F_{em}l_s^2}} = 2.1712$$

$$Z_{Im} = \frac{Dl_mF_{em}}{R_{d\_I}} = 7947 \text{ lb}$$ *NDS Eqn 12.3-1*

$Z_{Is} = \dfrac{DI_sF_{es}}{R_{d\_I}} = 1426$ lb *NDS Eqn 12.3-2*

$Z_{II} = \dfrac{k_1DI_sF_{es}}{R_{d\_II}} = 3160$ lb *NDS Eqn 12.3-3*

$Z_{IIIm} = \dfrac{k_2DI_mF_{em}}{(1 + 2R_e)R_{d\_III.IV}} = 3576$ lb *NDS Eqn 12.3-4*

$Z_{IIIs} = \dfrac{k_3DI_sF_{em}}{(2 + R_e)R_{d\_III.IV}} = 1000$ lb *NDS Eqn 12.3-5*

$Z_{IV} = \dfrac{D^2}{R_{d\_III.IV}}\sqrt{\dfrac{2F_{em}F_{yb}}{3(1 + R_e)}} = 1322$ lb *NDS Eqn 12.3-6*

The controlling value is the minimum single shear capacity from the above equations.

$Z_{control} = \min(Z_{Im}, Z_{Is}, Z_{II}, Z_{IIIm}, Z_{IIIs}, Z_{IV}) = 1000$ lb *(Yield Mode IIIs controls)*

Adjustment factors from NDS Table 11.3.1:

$C_D = 1.25$	*Duration Factor for 2% lateral loading*
$C_M = 1.0$	*Wet Service Factor NDS 11.3.3 (Assume < 19% moisture content)*
$C_t = 1.0$	*Temperature Factor NDS 11.3.4 (Temp up to 100ºF)*
$C_g = 1.0$	*Group Action Factor NDS 11.3.6 (Single Fastener)*
$C_\Delta = 1.0$	*Geometry Factor NDS 12.5.1 (Assume End Dist. & spacing meet Tables 12.5.1A and 12.5.1B)*
$C_{eg} = 1.0$	*End Grain Factor NDS 12.5.2 (Does not apply)*
$C_{di} = 1.0$	*Diaphragm Factor NDS 12.5.3 (Does not apply)*
$C_{tn} = 1.0$	*Toe Nail Factor NDS 12.5.4 (Does not apply)*

Adjusted lateral design value $Z' = Z(C_D)(C_M)(C_t)(C_g)(C_\Delta) = 1250$ lb

2. Determine the capacity of the diagonal brace in tension

By inspection, same as previous tiers. See top tier, step #2.

Adjusted design value Ft' = Ft (CD)(CM)(Ct)(CF)(Ci) = 862.5 psi

Tension capacity = 862.5 psi(1.5")(7.25") = 9380 lb

3. Determine the strength value of the tension members

9380 lb > 1250 lb ∴ Connection strength controls

4. Calculate the horizontal component of the strength value for the tension members

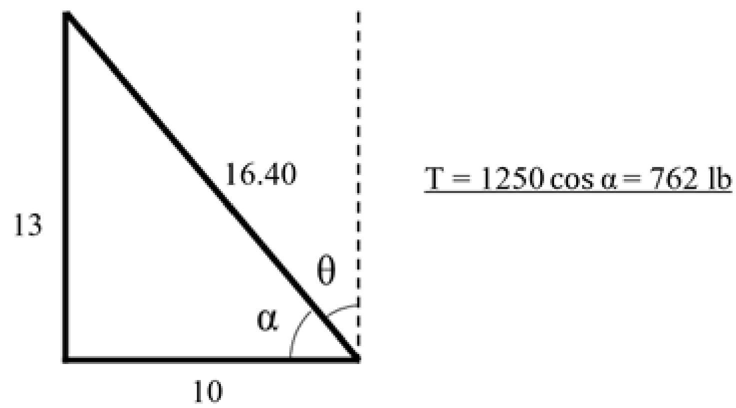


Figure D-17-9. Geometric Components of Tension Strength Value for Bracing Ⓑ Top Tier

5. Determine the capacity of diagonal brace in compression

Check cross brace capacity in compression:

Reference design value in compression F_c = 1350 psi (NDS supplement table 4A)

Adjustment factors from NDS table 4.3.1:

C_D	= 1.25	*Duration Factor for 2% lateral loading*
C_M	= 1.0	*Wet Service Factor NDS table 4A (Assume < 19% moisture content)*
C_t	= 1.0	*Temperature Factor NDS table 2.3.3 (Temp up to 100ºF)*
C_F	= 1.05	*Size Factor NDS Table 4A*
C_i	= 1.0	*Incising Factor NDS 4.3.8*

$$C_p = \frac{1 + (F_{cE}/F_c^*)}{2c} - \sqrt{\left[\frac{1 + (F_{cE}/F_c^*)}{2c}\right]^2 - \frac{F_{cE}/F_c^*}{c}} = 0.0617$$

Column Stability Factor NDS Eqn. 3.7-1

where:

l_e = (16.40'/2) = 8.20’ = 98.40” *unsupported length*

d	= 1.5”	*member width, weak direction*
E_{min}	= 580,000 psi	*NDS supplement table 4A*
F_{cE}	$= \frac{0.822E_{min}'}{(l_e/d)^2} = 111$	*NDS 3.7.1*
F_c^*	$= F_c (C_D)(C_M)(C_t)(C_F)(C_i) = 1772$ psi	*Adjusted design compression value except C_p*
c	= 0.8 for sawn lumber	*NDS 3.7.1*

Adjusted design compression value $F_c' = F_c (C_D)(C_M)(C_t)(C_F)(C_i)(C_p) = 109.3$ psi

Compression brace capacity = 109.3 psi (1.5”)(7.25”) = 1189 lb

6. Determine the strength value of the compression members

Connection capacity = 1250 lb

(See step 1. Capacity in tension and compression are the same)

1250 lb > 1189 lb ∴ member controls compression

Limit to 1/2 theoretical strength for compression values: See section 6-3.02, *Wood Cross Bracing.*

Reduced compression brace capacity = $\frac{1189 \text{ lb}}{2}$ = 595 lb

7. Calculate the horizontal component of the strength value for the compression member

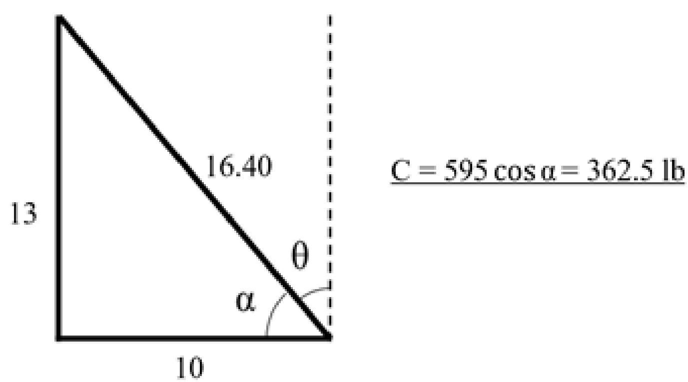


Figure D-17-10. Geometric Components of Compression Strength Value for Bracing Ⓑ Top Tier

8. Calculate the total resisting capacity of the top tier of bracing

Total resisting capacity = Σ(C+T) = 362.5 + 762 = 1224.5 lb

ANALYZE THE BOTTOM TIER IN BRACING □

1. Determine the connection capacity between brace and post

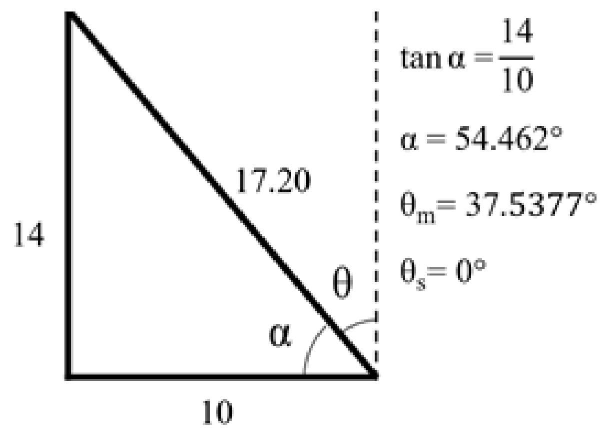


Figure D-17-11. Bracing Ⓑ Bottom Tier Member Lengths and Orientation

Main Member Properties

l_m = 12 in — *thickness (12 x 12)*

$t_m = l_m$ = 12 in

θ_m= 35.54° — *angle between direction of loading & direction of grain*

G = 0.50 — *Specific Gravity NDS Table 12.3.3*

Side Member Properties

l_s = 1.5 in — *thickness (2 x 8)*

$t_s = l_s$ = 1.5 in

θ_s= 0° — *angle between direction of loading & direction of grain*

Connector Properties

By inspection, same properties as previous tiers. $F_{e.pll}$ = 5600 psi $F_{e.perp}$ = 2578 psi

Find Dowel Bearing Strength at an Angle to Grain (NDS Section 12.3.4):

$$F_{em} = \frac{F_{e.pll} F_{perp}}{F_{e.pll}(\sin(\theta_m))^2 + F_{perp}(\cos(\theta_m))^2} = 4012 \text{ psi}$$

$$F_{es} = \frac{F_{e.pll} F_{perp}}{F_{e.pll}(\sin(\theta_s))^2 + F_{perp}(\cos(\theta_s))^2} = 5600 \text{ psi}$$

Find Reduction Term, R_d (NDS Table 12.3.1B):

$\theta = \max(\theta_m, \theta_s) = 35.5377°$ *Maximum angle between direction of load and direction of grain for any member in connection (See Table 12.3.1B)*

$K_\theta = 1+0.25\frac{\theta}{90\ deg} = 1.0987$

$R_{d\_I} = 4\ K_\theta = 4.39$ *Reduction Term for Yield Mode I_m and I_s*

$R_{d\_II} = 3.6\ K_\theta = 3.96$ *Reduction Term for Yield Mode II*

$R_{d\_III.IV} = 3.2\ K_\theta = 3.52$ *Reduction Term for Yield Mode III_m, III_s, and IV*

Find Yield Limit Equations for Single Shear (NDS Table 12.3.1A):

$$R_e = \frac{F_{em}}{F_{es}} = 0.7163$$

$$R_t = \frac{l_m}{l_s} = 8$$

$$k_1 = \frac{\sqrt{R_e + 2R_e^2\left(1 + R_t + R_t^2\right) + R_t^2 R_e^3} - R_e(1 + R_t)}{(1 + R_e)} = 2.0456$$

$$k_2 = -1 + \sqrt{2(1 + R_e) + \frac{2F_{yb}(1 + 2R_e)D^2}{3F_{em}l_m^2}} = 0.8718$$

$$k_3 = -1 + \sqrt{\frac{2(1 + R_e)}{R_e} + \frac{2F_{yb}(2 + R_e)D^2}{3F_{em}l_s^2}} = 2.1417$$

$$Z_{Im} = \frac{Dl_mF_{em}}{R_{d\_I}} = 8215\ lb$$ *NDS Eqn 12.3-1*

$$Z_{Is} = \frac{Dl_sF_{es}}{R_{d\_I}} = 1433\ lb$$ *NDS Eqn 12.3-2*

$$Z_{II} = \frac{k_1Dl_sF_{es}}{R_{d\_II}} = 3258\ lb$$ *NDS Eqn 12.3-3*

$$Z_{IIIm} = \frac{k_2Dl_mF_{em}}{(1 + 2R_e)R_{d\_III.IV}} = 3680\ lb$$ *NDS Eqn 12.3-4*

$$Z_{IIIs} = \frac{k_3 D l_s F_{em}}{(2 + R_e) R_{d\_III.IV}} = 1012 \text{ lb}$$ *NDS Eqn 12.3-5*

$$Z_{IV} = \frac{D^2}{R_{d\_III.IV}} \sqrt{\frac{2F_{em}F_{yb}}{3(1 + R_e)}} = 1340 \text{ lb}$$ *NDS Eqn 12.3-6*

The controlling value is the minimum single shear capacity from the above equations.

$Z_{control}$ = min (Z_{Im}, Z_{Is}, Z_{II}, Z_{IIIm}, Z_{IIIs}, Z_{IV}) = 1012 lb *(Yield Mode IIIs controls)*

Adjustment factors from NDS Table 11.3.1:

C_D = 1.25	*Duration Factor for 2% lateral loading*
C_M = 1.0	*Wet Service Factor NDS 11.3.3 (Assume < 19% moisture content)*
C_t = 1.0	*Temperature Factor NDS 11.3.4 (Temp up to 100ºF)*
C_g = 1.0	*Group Action Factor NDS 11.3.6 (Single Fastener)*
C_Δ = 1.0	*Geometry Factor NDS 12.5.1 (Assume End Dist. & spacing meet Tables 12.5.1A and 12.5.1B)*
C_{eg} = 1.0	*End Grain Factor NDS 12.5.2 (Does not apply)*
C_{di} = 1.0	*Diaphragm Factor NDS 12.5.3 (Does not apply)*
C_{tn} = 1.0	*Toe Nail Factor NDS 12.5.4 (Does not apply)*

Adjusted lateral design value Z’ = $Z(C_D)(C_M)(C_t)(C_g)(C_\Delta)$ = 1265 lb

2. Determine the capacity of the diagonal brace in tension

By inspection, same as previous tiers. See top tier, step #2.

Adjusted design value $F_t' = F_t\ (C_D)(C_M)(C_t)(C_F)(C_i)$ = 862.5 psi

Tension capacity = 862.5 psi(1.5”)(7.25”) = 9380 lb

3. Determine the strength value of the tension members

9380 lb > 1265 lb ∴ Connection strength controls

4. Calculate the horizontal component of the strength value for the tension members

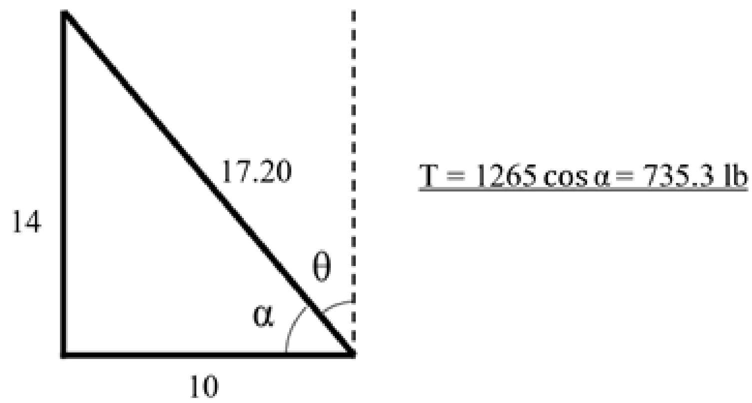


Figure D-17-12. Geometric Components of Tension Strength Value for Bracing Ⓑ Bottom Tier

5. Determine the capacity of diagonal brace in compression

Check cross brace capacity in compression:

Reference design value in compression F_c = 1350 psi (NDS supplement table 4A)

Adjustment factors from NDS table 4.3.1:

C_D	= 1.25	*Duration Factor for 2% lateral loading*
C_M	= 1.0	*Wet Service Factor NDS table 4A (Assume < 19% moisture content)*
C_t	= 1.0	*Temperature Factor NDS table 2.3.3 (Temp up to 100ºF)*
C_F	= 1.05	*Size Factor NDS Table 4A*
C_i	= 1.0	*Incising Factor NDS 4.3.8*

$$C_p = \frac{1 + (F_{cE}/F_c^*)}{2c} - \sqrt{\left[\frac{1 + (F_{cE}/F_c^*)}{2c}\right]^2 - \frac{F_{cE}/F_c^*}{c}}$$

Column Stability Factor NDS Eqn. 3.7-1

= 0.0561

where:

l_e	= (17.20'/2) = 8.60’ = 103.20”	*unsupported length*
d	= 1.5”	*member width, weak direction*
E_{min}	= 580,000 psi	*NDS supplement table 4A*

F_{cE}	$= \dfrac{0.822E_{min}{'}}{(l_e/d)^2} = 101$	*NDS 3.7.1*
F_c^*	$= F_c\,(C_D)(C_M)(C_t)(C_F)(C_i) = 1772$ psi	*Adjusted design compression value except C_p*
c	= 0.8 for sawn lumber	*NDS 3.7.1*

Adjusted design compression value $F_c' = F_c\,(C_D)(C_M)(C_t)(C_F)(C_i)(C_p) = 99.5$ psi

Compression brace capacity = 99.5 psi (1.5”)(7.25”) = 1081.8 lb

6. Determine the strength value of the compression members

Connection capacity = 1265 lb

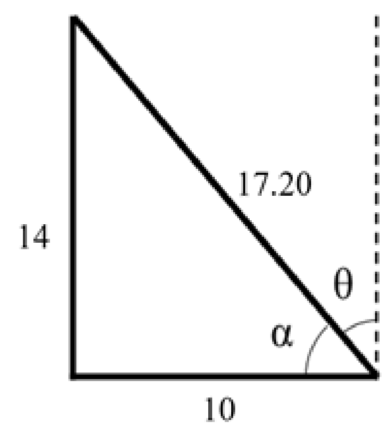
(See step 1. Capacity in tension and compression are the same)

1265 lb > 1081.8 lb ∴ member controls compression

Limit to 1/2 theoretical strength for compression values: See section 6-3.02, *Wood Cross Bracing.*

Reduced compression brace capacity = $\dfrac{1081.8\text{ lb}}{2} = 540.9$ lb

7. Calculate the horizontal component of the strength value for the compression member



$C = 540.9\cos\alpha = 314.4$ lb

Figure D-17-13. Geometric Components of Compression Strength Value for Bracing Ⓑ Bottom Tier

8. Calculate the total resisting capacity of the top tier of bracing

Total resisting capacity = Σ(C+T) = 314.4 + 735.3 = 1050 lb

SUMMARY

Summarize Results for All Tiers for 2% Dead Load

Tier	Horizontal Tension	Horizontal Compression	Total Capacity
A_{TOP}	900 lb	450 lb	1350 lb
A_{MID} = A_{BOTTOM}	845 lb	423 lb	1268 lb
B_{TOP}	762 lb	363 lb	1125 lb
B_{BOTTOM}	735 lb	315 lb	1050 lb

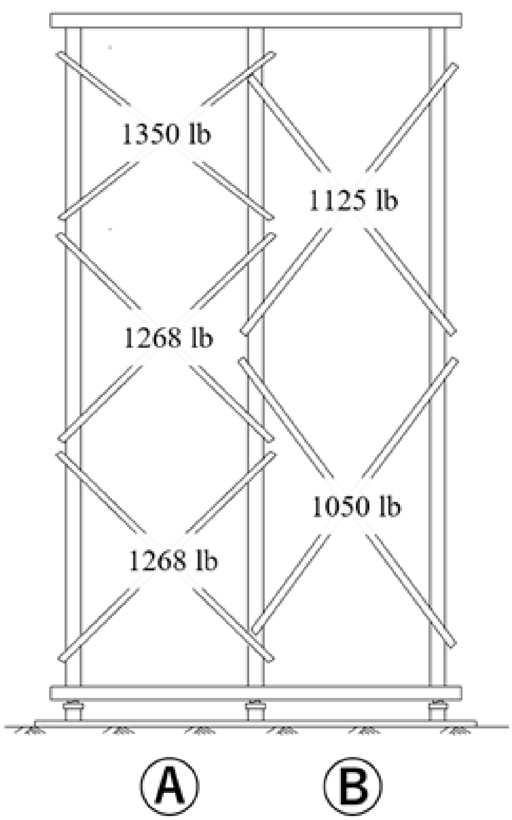


Figure D-17-14. Bracing Total Resisting Capacity for 2% Dead Load

The total resisting capacity of the bracing = the sum of the weaker pair of braces in A and the weaker pair of braces in B.

Total resisting capacity = 1268 lb + 1050 lb = 2318 lb

2318 lb (smallest total capacity) < 3500 lb (2% Dead Load)

Bracing system is inadequate for 2% Dead Load

Summarize Results for All Tiers for Wind Load

Repeat above process for wind load to calculate the Resisting Capacity, using C_D = 1.6 rather than 1.25. All other factors are the same.

The Resisting Capacity for wind load can also be derived by multiplying the resisting capacity for 2% Dead Load (above table) by the factor $\frac{1.6}{1.25}\left[\frac{C_D \text{ Wind Load}}{C_D \text{ 2\% Dead Load}}\right]$

Tier	Horizontal Tension	Horizontal Compression	Total Capacity
A_{TOP}	1152 lb	576 lb	1728 lb
$A_{MID} = A_{BOTTOM}$	1082 lb	541 lb	1623 lb
B_{TOP}	975 lb	465 lb	1440 lb
B_{BOTTOM}	941 lb	403 lb	1344 lb

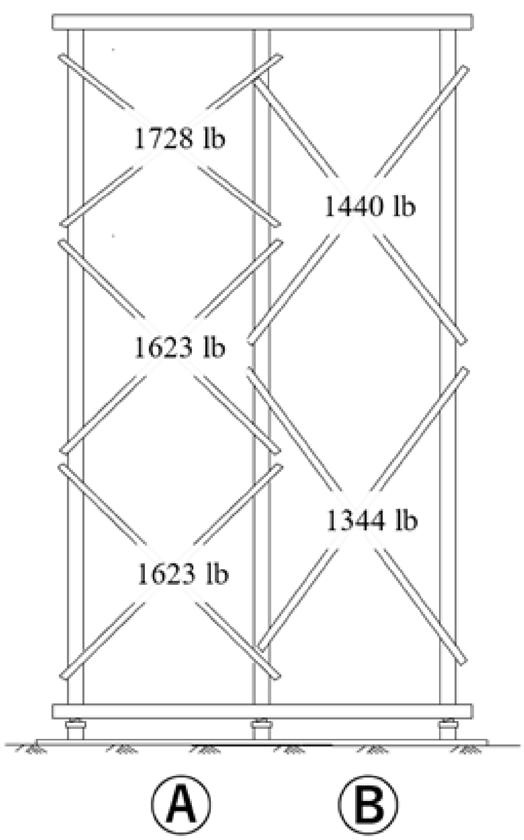


Figure D-17-15. Bracing Total Resisting Capacity for Wind Load

The total resisting capacity of the bracing = the sum of the weaker pair of braces in A and the weaker pair of braces in B.

Total resisting capacity = 1623 lb + 1344 lb = 2967 lb

2967 lb (smallest total capacity) < 3200 lb (Wind Load)

Bracing system is inadequate for Wind Load

Conclusion:
Bracing system would be adequate if bracing capacity is greater for both 2% Dead Load and Wind Load conditions.

∴ Bracing System is inadequate