Senior Project: Heavy Timber Buckling-Restrained Brace Frame

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Advisor: Kevin Dong

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Introduction

Timber construction has historically been limited to low-rise buildings throughout the United States, with distributed load bearing shear walls acting as the lateral force resisting system. Being lightweight, it is an efficient material to decrease the seismic demand seen by a structure. Recently, advancements in mass timber construction are pushing timber into the mid and high-rise markets traditionally dominated by steel and concrete. With new applications for timber construction coming to light, a modified Buckling-Restrained Brace (BRB) has been conceived.

A Heavy Timber Buckling-Restrained Brace utilizes bolted timber sections as confinement in lieu of a rectangular/circular metal section filled with concrete. A BRB system resists the steel core buckling under a compressive load and works to equate the compressive yield strength (via rendering the unbraced length in compression zero) to its tensile yield strength, while also offering improved ductility over other systems. Some possible applications include:

- Irregular structures such as custom homes with architectural limitations for shear walls of sufficient length.
- Low-rise buildings such as offices or warehouses that contain open floor plans limiting the placement of shear walls or other systems to large lengths along the perimeter of the building
- Mid and high-rise structures mass timber structures where typical steel moment frames and other bracing systems are not necessary for the weight of the building

This system has the potential to be extremely economical compared to traditional steel systems in cost, weight, and constructability.

Background

A newly constructed two story office building in San Luis Obispo utilizes a standard Buckling Restrained Braced Frame System with eight bays of braces in each direction. Considering the minimum section requirements for a Steel BRB, this was seen as a good opportunity to explore the use of Heavy Timber BRBs in a practical setting. The scope of work included in this project includes analysis of three systems: Wooden Shear Walls, a Special Concentrically Braced Frame (SCBF), and a joint analysis of Steel BRBs and Heavy Timber BRBs. This exercise focuses on a realistic application of this system; a graduate student group is focusing on member analysis and lab testing of the BRBs themselves. Some data from their computations is used in this report.
**Design of the gravity system for this structure was relatively straightforward. The biggest question during the load takeoff process was the decision to include a topping slab, which resulted in a 21% increase of building weight and a significant effect on the lateral analysis portion of the study.**
KEY PLAN - SHEAR WALL

SHEARWALL BAYS ARE DASHED
Shear walls should not be considered when selecting the Lateral Force Resisting System for this structure if the open floor plan is to be maintained (i.e. no internal lateral members). As an office building, the base shear demands would require shear wall along nearly the entire exterior wall length, severely limiting window area and other architectural features.
FRAME BAYS ARE MARKED
A Special Concentrically Braced Frame is an effective, tried and tested system to resist lateral forces. Some drawbacks are Steel Cost, Welding and Connection detailing, increased action on the foundation, and buckling. SCBFs exhibit consistent, ductile behavior when in tension, however compression buckling is the achilles heal. Compression buckling results in a dramatic decrease in brace capacity and stiffness and leads to the formation of plastic hinges along the member. This imbalance between tension capacity and compression capacity can lead to an undesirable response from the system including inelastic drift and possible member fracture. While effective, the conclusions of this study show that it is not the ideal system to apply to the structure analyzed due to the high strength demand resulting in an overdesigned frame compared to the weight of the structure.
Considering both styles of BRBs, steel and heavy timber, the possible applications include almost every type and weight of structure. The balanced behavior between compression yielding and tension yielding is simply more efficient compared to other styles of braced frames. Because the steel core is restrained from buckling, it develops a uniform axial strain across the entire section without plastic hinge formation that results from buckling. Since there is no reduction in the available material strength due to instability, the effective length in compression can be considered zero. For this particular application, a Heavy Timber BRB is preferable to the traditional Steel BRB. Reduced strength level demands result in lighter frame members increasing constructability and lowering cost and weight. As Heavy Timber BRBs go through the codification process in the next several years, vendors will begin to offer them as both an efficient and economical lateral system solution.
### UPLIFT COMPARISON

- **SCBF**
  - W21x48
  - HSS 2 1/2 x 2 1/2 x 5/16 (2)

- **HT BRB**
  - W21x62
  - HSS 2 1/2 x 3 1/4 x 1/8 PL (2)

### WEIGHT COMPARISON

<table>
<thead>
<tr>
<th></th>
<th>SCBF</th>
<th>HT BRB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ROOF BEAM</strong></td>
<td>W21x48</td>
<td>W10x22</td>
</tr>
<tr>
<td></td>
<td>960 lb</td>
<td>440 lb</td>
</tr>
<tr>
<td><strong>2ND FLOOR BEAM</strong></td>
<td>W27x84</td>
<td>W16x36</td>
</tr>
<tr>
<td></td>
<td>1680 lb</td>
<td>720 lb</td>
</tr>
<tr>
<td><strong>COLUMNS</strong></td>
<td>W24x76 (4)</td>
<td>W21x62 (4)</td>
</tr>
<tr>
<td></td>
<td>3648 lb</td>
<td>2976 lb</td>
</tr>
<tr>
<td><strong>ROOF BRACE</strong></td>
<td>HSS 2 1/2 x 2 1/2 x 5/16 (2)</td>
<td>(2) 4x8</td>
</tr>
<tr>
<td></td>
<td>264 lb</td>
<td>203 lb</td>
</tr>
<tr>
<td></td>
<td>2&quot; x 3/8&quot; PL</td>
<td>56 lb</td>
</tr>
<tr>
<td><strong>2ND FLOOR BRACE</strong></td>
<td>HSS 3 1/2 x 3 1/4 x 1/4 (2)</td>
<td>(2) 4x8</td>
</tr>
<tr>
<td></td>
<td>328 lb</td>
<td>203 lb</td>
</tr>
<tr>
<td></td>
<td>3 1/2&quot; x 3/8&quot; PL</td>
<td>94 lb</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td>6880 lb</td>
<td>4692 lb</td>
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## LOAD TAKE OFF

<table>
<thead>
<tr>
<th>Item</th>
<th>(PSF)</th>
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<tbody>
<tr>
<td>ROOF</td>
<td></td>
</tr>
<tr>
<td>FRAMING</td>
<td>2.0</td>
</tr>
<tr>
<td>ROOFING &amp; 4&quot; RIGID INSULATION</td>
<td>5.0</td>
</tr>
<tr>
<td>CEILING &amp; LIGHTING PARTITIONS</td>
<td>2.0</td>
</tr>
<tr>
<td>MEP</td>
<td>5.0</td>
</tr>
<tr>
<td>COLUMNS</td>
<td>2.0</td>
</tr>
<tr>
<td>MISC.</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>DEAD</td>
<td></td>
</tr>
<tr>
<td>ROOF LIVE</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td>20.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>39.0</td>
</tr>
<tr>
<td>2ND FLOOR</td>
<td></td>
</tr>
<tr>
<td>FRAMING</td>
<td></td>
</tr>
<tr>
<td>1 1/4&quot; TOPPING SLAB</td>
<td>5.0</td>
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<tr>
<td>CARPET</td>
<td>15.0</td>
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<td>PARTITIONS</td>
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<tr>
<td>COLUMNS</td>
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<tr>
<td>FLOOR LIVE</td>
<td>37.0</td>
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<td>50.0</td>
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<tr>
<td>TOTAL</td>
<td>87.0</td>
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<tr>
<td>WALLS</td>
<td>PSF</td>
</tr>
<tr>
<td>5/8&quot; SHEET ROCK</td>
<td>3</td>
</tr>
<tr>
<td>6&quot; METAL STUD</td>
<td>2</td>
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<tr>
<td>GYPBOARD</td>
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<tr>
<td>WATERPROOFING</td>
<td>1</td>
</tr>
<tr>
<td>7/8&quot; PLASTER</td>
<td>8.0</td>
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<tr>
<td>TOTAL</td>
<td>16.0</td>
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<tr>
<td>LEVEL</td>
<td>LOAD (PSF)</td>
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<tr>
<td>-------------</td>
<td>------------</td>
</tr>
<tr>
<td>ROOF</td>
<td>19</td>
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<tr>
<td>2ND FLOOR</td>
<td>37</td>
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<thead>
<tr>
<th>LEVEL</th>
<th>HEIGHT (FT)</th>
<th>WEIGHT (PCF)</th>
<th>LENGTH (FT)</th>
<th>TOTAL (LBS)</th>
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<tbody>
<tr>
<td>ROOF</td>
<td>16</td>
<td>16</td>
<td>534</td>
<td>136704</td>
</tr>
<tr>
<td>2ND FLOOR</td>
<td>16</td>
<td>16</td>
<td>534</td>
<td>136704</td>
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</table>

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>DIAPHRAGM (LBS)</th>
<th>WALL (LBS)</th>
<th>TOTAL (KIPS)</th>
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<tbody>
<tr>
<td>ROOF</td>
<td>349913.5</td>
<td>136704</td>
<td>487</td>
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<tr>
<td>3RD FLOOR</td>
<td>681410.5</td>
<td>136704</td>
<td>818</td>
</tr>
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</table>

**BUILDING WEIGHT (KIPS)**

1305
SEISMIC PROCEDURE - SHEAR WALL

<table>
<thead>
<tr>
<th>$S_{ds}$</th>
<th>0.811</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
</tr>
<tr>
<td>R</td>
<td>6.5</td>
</tr>
</tbody>
</table>

$C_s = S_{ds}/(R/I)$

$C_s = 0.125$

$V = C_s W$

<table>
<thead>
<tr>
<th>W</th>
<th>1305</th>
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<tbody>
<tr>
<td>$V_s$</td>
<td>163</td>
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</tbody>
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$T = C_t h_n^x$

<table>
<thead>
<tr>
<th>$C_t$</th>
<th>0.02</th>
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<tbody>
<tr>
<td>x</td>
<td>0.75</td>
</tr>
<tr>
<td>$h_n$</td>
<td>24</td>
</tr>
<tr>
<td>$T$</td>
<td>0.22</td>
</tr>
</tbody>
</table>

$C_{s, max} = S_{ds}/(T*(R/I))$

<table>
<thead>
<tr>
<th>$C_{s, max}$</th>
<th>0.58</th>
<th>&gt;0.32</th>
<th>OK</th>
</tr>
</thead>
</table>

$C_{s, min} = 0.044*S_{ds}*I$

<table>
<thead>
<tr>
<th>$C_{s, min}$</th>
<th>0.036</th>
<th>&lt;0.32</th>
<th>OK</th>
</tr>
</thead>
</table>

VERTICAL DISTRIBUTION

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>W (KIPS)</th>
<th>h (FT)</th>
<th>$W_h$</th>
<th>$C_{vx} = (W_h)/\Sigma(W_h)$</th>
<th>$V = C_{vx}*V_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROOF</td>
<td>487</td>
<td>24</td>
<td>11679</td>
<td>0.54</td>
<td>88</td>
</tr>
<tr>
<td>2ND</td>
<td>818</td>
<td>12</td>
<td>9817</td>
<td>0.46</td>
<td>74</td>
</tr>
<tr>
<td>Σ</td>
<td>1305</td>
<td>21496</td>
<td>1.0</td>
<td>163</td>
<td></td>
</tr>
</tbody>
</table>
JOISTS 24' SPAN

33.4 PSF @ 2' O.C. = 67 plf

SELECT AN 18" RED-L OPEN - WEB TRUSS @ 2' O.C. (143 PLF)

GIRDER 20' SPAN

JOIST SW: (4 PLF x 12 x 24')/20 = 58 PLF

\[ W_D = 19 \text{ PSF} \times 24' \text{ TRIB} = 456 + 58 = 514 \text{ PLF} \]

\[ W_L = 19 \text{ PSF} \times 24' \text{ TRIB} = 346 \text{ PLF} \]

\[ V_D = \frac{(514 \text{ PLF} \times 20')}{2} = 5.1^k \quad M_d = \frac{(514 \text{ plf} \times 20')^2}{8} = 25.7^k \]

\[ V_L = \frac{(346 \text{ PLF} \times 20')}{2} = 3.5^k \quad M_L = \frac{(514 \text{ plf} \times 20')^2}{8} = 17.3^k \]

\[ V_U = 1.2(5.1^k) + 1.6(3.5^k) = 11.7^k \quad M_U = 1.2(25.7^k) + 1.6(17.3^k) = 58.5^k \]

\[ \text{TRY A W12x16} \quad \phi M_N = 75.4^k \]

\[ M_{\text{SELF}} = 0.016(1.2(20)^2)/8 = 0.96^k \quad M_U = 59.5^k < 75.4^k \checkmark \]

SHEAR CHECK

\[ V_U = 12^k < 79.2^k \checkmark \]

DEFLECTION CHECK

\[ \Delta_D = \frac{(5)(514)(20')(12^3)}{(384)(29000)(103)} = 0.077'' \quad \Delta_L = (346/514)(0.077) = 0.052'' \]

\[ \Delta_{\text{LIMIT}} = \frac{(20' \times 12'')}{240} = 1'' > 0.052'' \checkmark \]

SELECT A W12x16 A992
GRAVITY MEMBERS - 2ND FLOOR

JOISTS 24’ SPAN

66.6 PSF @ 2’ O.C. = 133.2 plf

SELECT AN 18” RED-L OPEN - WEB TRUSS @ 2’ O.C. (143 PLF)

GIRDER 20’ SPAN

JOIST SW:  (4 PLF x 12 x 24’)/20 = 58 PLF

W_D = 37 PSF x 24’ TRIB = 888 + 58 = 946 PLF

W_L = 29.6 PSF x 24’ TRIB = 711 PLF

V_D = (514 PLF x 20’)/2 = 9.5k

M_d = (514 plf x 20’)^2/8 = 47.3k

V_L = (346 PLF x 20’)/2 = 7.1k

M_L = (514 plf x 20’)^2/8 = 35.5k

V_U = 1.2(9.5k) + 1.6(7.1k) = 22.8k

M_U = 1.2(47.3k) + 1.6(35.5k) = 113.6k

M_SELF = .026(1.2(20)^2)/8 = 1.56k

M_U = 115.2k < 140k ✓

SHEAR CHECK

V_U = 22.8k < 84.2k ✓

DEFLECTION CHECK

Δ_o = (5)(946)(20’)(12^3)/(384)(29000)(204) = .072"

Δ_L = (711/946)(.077) = .054"

Δ_LIMIT = (20’ x 12”)/240 = 1” > .054” ✓

SELECT A W12x16 A992
GRAVITY MEMBERS - COLUMN

TYPICAL COLUMN - 12' TALL

ROOF: \( 1.2(19^k) + 1.6(14.4^k) = 46^k \)

2nd: \( 1.2(37^k) + 1.6(29.6^k) = 92^k \)

\[ P_U = 138^k \]

KL = 1.2(12') = 15'

SELECT A ROUND HSS5.500x.500 \( \phi P_n = 150^k \)
SEISMIC PROCEDURE - SCBF

\[ C_s = \frac{S_{ds}}{R/I} \]

\[ C_s = 0.135 \]

\[ V = C_v W \]

\[ W = 1305 \]

\[ V_s = 176 \]

\[ T = C_t h_n^x \]

\[ C_t = 0.02 \]

\[ x = 0.75 \]

\[ h_n = 24 \]

\[ T = 0.22 \]

\[ C_{s,\text{max}} = \frac{S_{ds}}{T(R/I)} \]

\[ C_{s,\text{max}} = 0.62 > 0.32 \text{ OK} \]

\[ C_{s,\text{min}} = 0.044 S_{ds} I \]

\[ C_{s,\text{min}} = 0.036 < 0.32 \text{ OK} \]

APPENDIX B

VERTICAL DISTRIBUTION

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>W (KIPS)</th>
<th>h (FT)</th>
<th>( W_h )</th>
<th>( C_{vx} = \frac{W_s h}{\Sigma W_h} )</th>
<th>( V = C_{vx} V_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROOF</td>
<td>487</td>
<td>24</td>
<td>11679</td>
<td>0.54</td>
<td>96</td>
</tr>
<tr>
<td>2ND</td>
<td>818</td>
<td>12</td>
<td>9817</td>
<td>0.46</td>
<td>81</td>
</tr>
<tr>
<td>Σ</td>
<td>1305</td>
<td>21496</td>
<td>1.0</td>
<td>176</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B

8 BAYS

ROOF: $96^k/4 = 24^k$

$2^{nd}$: $81^k/4 = 20.3^k$

$R = 6$

SCBF FRAME FORCES

FORCE IN A = 9.36$k$

FORCE IN B = 25.2$k$
SCBF ROOF MEMBER DESIGN

$A_{s} F_{ye} = 0.3 P_{D}$

$P_{u} = (1.2 + 0.2 S_{DS})(9.36^{K}) = 12.8^{K}$

$\phi P_{n} = 14.6^{K}$

TRY HSS $2^{1}\times 2^{1}\times 2^{8}/16$

$\frac{kL}{R} = \frac{1.0(12'x12'')}{0.88} = 191 < 200 \checkmark$ SATISFIES COMPACT SECTION REQUIREMENTS

$T = A_{s} F_{ye} = A_{s} R_{y} F_{y}$

$T = 2.35 \sin^2 (1.6) (46kpsi) = 173^{K}$

$C = 0.3 P_{n}$

$C = 0.3 \frac{14.6^{K}}{0.9} = 4.9^{K}$

$F_{ROOF} = (173^{K} + 4.9^{K}) \cos(39.8^{\circ}) = 137^{K}$

ROOF BEAM

$W_{DR} = 19 \text{ PSF}(24') = .456 \text{ klf} \\
W_{LR} = 14.4 \text{ PSF}(24') = .346 \text{ klf}$

$\Omega = 2 \quad S_{DS} = .811$

$w = (1.2 + 0.2 S_{DS})D + .5L$

$w = (1.2 + 0.2(.811))(.456\text{klf}) + .5(.346\text{klf})$

$w = .794 \text{ klf}$

$P_{BAL} = (173^{K} - 4.9^{K}) \sin(39.8^{\circ}) = 107.6^{K}$

$M = \frac{P_{BAL} \times L}{4} + \frac{wL^{2}}{8}$

$M = \frac{107.6^{K} \times 10'}{4} + \frac{.794\text{klf} (10^2)}{8}$

$M = 279^{K}$

TRY A W21x48

$\frac{P_{U}}{2(\phi P_{n})} + \frac{M_{UX}}{2(\phi M_{NXY})} < 1.0$

$\frac{137^{K}}{2} (0.00621) + \frac{9}{8} (279^{K} \cdot 0.00118) = .985 < 1.0 \checkmark$

SELECT A W21x48 A992
SCBF 2ND FLOOR MEMBER DESIGN

\[ P_U = (1.2+0.2\times0.811)(25.2^k) = 34.4^k \]
\[ \phi P_n = 40.6^k \]

TRY HSS 3\frac{1}{4}x3\frac{1}{4}x\frac{1}{4}

\[ \frac{kL}{R} = \frac{1.0(12' \times 12'')}{1.32} = 127.3 < 200 \checkmark \]

Satisfies compact section requirements

\[ T = A_s F_{yw} = A_s R_y F_y \]
\[ T = 2.91 \text{in}^2 \times (1.6) \times (46 \text{ksi}) = 214.2^k \]

\[ C = 0.3 P_n \]

\[ C = 0.3 \times \frac{40.6^k}{0.9} = 13.5^k \]

\[ F_{\text{roof}} = (4.9^k + 173^k + 214.2^k + 13.5^k) \cos(39.8^\circ) = 312^k \]

2nd FLOOR BEAM

\[ w = (1.2 + 0.2S_{DS})D + .5L \]
\[ w = (1.2 + 0.2 \times 0.811) \times \text{.456 klf} + .5 \times \text{.346 klf} \]
\[ w = 1.56 \text{ klf} \]

\[ P_{\text{bal}} = (214.2^k - 13.5^k) + (173^k - 4.9^k) \sin(39.8^\circ) = 236^k \]

\[ M = \frac{P_{\text{bal}} \times L}{4} + \frac{wL^2}{8} \]
\[ = \frac{236^k \times 10^{'}}{4} + \frac{1.56 \text{ klf} \times (10^{'})^2}{8} \]
\[ = \frac{610^k}{8} \]

TRY A W27x84

\[ \frac{P_U}{2(\phi P_n)} + \frac{M_{\text{ULX}}}{2(\phi M_{\text{ULX}})} < 1.0 \]
\[ \frac{312^k}{2} \times \frac{(0.00626) + \frac{9}{8} (610^k \times .00447)}{.947} = .947 < 1.0 \checkmark \]

Select A W27x84 A992
**SCBF COLUMN DESIGN**

**TYPICAL COLUMN**

\[ P_D = .456 \text{klf} \times 20' + .888 \text{klf} \times 20' = 27^k \]

\[ P_L = .346 \text{klf} \times 20' + .710 \text{klf} \times 20' = 21^k \]

\[ V_E = 24^k + 20.3^k = 44.3^k \]

\[ M_E = V_E \times L = 44.3^k \times 12' = 396^k \]

\[ P_U = (1.2+0.2(0.811))(27^k) + 21^k = 58^k \]

**TRY A W24x76**

\[
\frac{kl}{R} = \frac{1.0(12'x12'\text{})}{1.92} = 81.4
\]

\[
4.71 \sqrt{\frac{29000}{50000}} = 3.6
\]

\[ F_{CR} = 0.877 F_e \]

\[ F_e = \frac{T_{T^E} E}{kL} \frac{T_{T^E} (29000)}{1.0(12'x12'\text{})} = 44.8 \text{ksi} \]

\[ P_n = F_{cr} A_g \]

\[ = 44.8 \text{ksi} \ (20.1\text{in}^2) \]

\[ = 901^k \]

\[ \frac{P_U}{2(\phi P_n)} + \frac{M_{UX}}{2(\phi M_{NX})} < 1.0 \]

\[ \frac{58^k}{2} (0.00153) + \frac{9}{8} (532^k) (0.00141) = 0.89 < 1.0 \checkmark \]

**SELECT A W24x76 A992**
SCBF DRIFT ANALYSIS

RESULTS VIA ETABS

ROOF: 0.199"

2ND: 0.116"
SEISMIC PROCEDURE - HT BRB

\[ C_s = \frac{S_{ds}}{R/I} \]

\[ C_s = 0.101 \]

\[ V = C_v W \]

\[ W = 1305 \]

\[ V_s = 132 \]

\[ T = C_t h_n^x \]

\[ C_t = 0.02 \]

\[ x = 0.75 \]

\[ h_n = 24 \]

\[ T = 0.22 \]

\[ C_{s,\text{max}} = \frac{S_{ds}}{(T(R/I))} \]

\[ C_{s,\text{max}} = 0.47 > 0.32 \text{ OK} \]

\[ C_{s,\text{min}} = 0.044 \times S_{ds} \times I \]

\[ C_{s,\text{min}} = 0.036 < 0.32 \text{ OK} \]

VERTICAL DISTRIBUTION

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>W (KIPS)</th>
<th>h (FT)</th>
<th>W, h</th>
<th>C_{vx} = (W, h) / \Sigma(W, h)</th>
<th>V = C_{vx} \times V_s</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROOF</td>
<td>487</td>
<td>24</td>
<td>11679</td>
<td>0.54</td>
<td>72</td>
</tr>
<tr>
<td>2ND</td>
<td>818</td>
<td>12</td>
<td>9817</td>
<td>0.46</td>
<td>60</td>
</tr>
<tr>
<td>( \Sigma )</td>
<td>1305</td>
<td></td>
<td>21496</td>
<td>1.0</td>
<td>132</td>
</tr>
</tbody>
</table>

APPENDIX C
**APPENDIX C**

8 BAYS

ROOF: $72^k / 4 = 21^k$

$2^{nd}: 60^k / 4 = 39^k$

$R = 8$

---

**HT BRB FRAME FORCES**

<table>
<thead>
<tr>
<th>Force (kips)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>72</td>
<td>Reference</td>
</tr>
<tr>
<td>60</td>
<td>Reference</td>
</tr>
<tr>
<td>18</td>
<td>Reference</td>
</tr>
<tr>
<td>15</td>
<td>Reference</td>
</tr>
</tbody>
</table>

**FORCE IN A = 21^k**

**FORCE IN B = 17.5^k + 21^k = 39^k**

---

**A**

$P_{BRACE} \leq \phi F_Y A_B$

$21^k = 0.9(36)(A_{PL})$

$A_{PL} = 0.65 \text{ in}^2$

**B**

$P_{BRACE} \leq \phi F_Y A_B$

$39^k = 0.9(36)(A_{PL})$

$A_{PL} = 1.20 \text{ in}^2$

**USE 2" x 3/8" PL w/ (2) BOLTED 4x8 CONFINEMENT**

**USE 3/4" x 3/8" PL w/ (2) BOLTED 4x8 CONFINEMENT**

---

**HT BRB STRENGTH DESIGN**

<table>
<thead>
<tr>
<th>Force (ksi)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>Reference</td>
</tr>
<tr>
<td>39</td>
<td>Reference</td>
</tr>
<tr>
<td>38</td>
<td>Reference</td>
</tr>
<tr>
<td>66</td>
<td>Reference</td>
</tr>
</tbody>
</table>

**$P_t = R_Y F_Y A_G$**

$P_t = 38^k$

$P_t = 66^k$
HT BRB FRAME DESIGN

ROOF BEAM

\[ W_{DR} = 19 \text{ PSF}(24') = .456 \text{ klf} \]
\[ W_{LR} = 14.4 \text{ PSF}(24') = .346 \text{ klf} \]
\[ \Omega = 2 \quad S_{DS} = .811 \]

\[ E_{\text{Roof}} = 38^k \cos(31^\circ) = 33^k \]
\[ \Omega = 2 \quad S_{DS} = .811 \]

\[ w = (1.2+0.2S_{DS})D + .5L \quad P_{\text{Bal}} = 20^k \]
\[ w = (1.2+0.2(.811)).456\text{klf} + .5(.346\text{klf}) \]
\[ w = .794 \text{ klf} \]

\[ M = \frac{P_{\text{Bal}} \times L}{4} + \frac{wL^2}{8} \]
\[ = \frac{20^k \times 10'}{4} + \frac{.794\text{klf} (10^2)}{8} \]
\[ = 60^k \]

\[ \frac{33^k}{2} \left( \frac{0.00621}{2(\phi P_n)} + \frac{9}{8} (60^k)(.0117) \right) = .892 < 1.0 \]

SELECT A W10x22 A992
2ND FLOOR BEAM

\[
W_{DR} = 37 \text{ PSF}(24') = .888 \text{ klf}
\]
\[
W_{LR} = 29.6 \text{ PSF}(24') = .710 \text{ klf}
\]
\[
\Omega = 2 \quad S_{DS} = .811
\]

\[
E_{\text{ROOF}} = (38^k + 66^k) \cos(31^\circ) = 89^k
\]
\[
w = (1.2+0.2S_{DS})D + .5L
\]
\[
P_{\text{BAL}} = (38^k + 66^k) \sin(31^\circ) = 53.6^k
\]
\[
w = (1.2+0.2(.811))(.456\text{klf}) +.5(.710\text{klf})
\]
\[
w = 1.56 \text{ klf}
\]

\[
M = \frac{P_{\text{BAL}} \times L}{4} + \frac{wL^2}{8}
\]
\[
= \frac{53.6^k \times 10'}{4} + \frac{1.56\text{klf} (10^2)}{8}
\]
\[
= 154^k
\]

\[
\frac{P_U}{2(\phi P_n)} + \frac{M_{UX}}{2(\phi M_{NX})} < 1.0
\]
\[
\frac{89^k}{2} (0.00334) + \frac{9}{8} (60^k) (.00451) = .929 < 1.0 \checkmark
\]

SELECT A W16x36 A992
TYPICAL COLUMN

\[ P_D = .456 \text{klf} \times 20' + .888 \text{klf} \times 20' = 27^K \]

\[ P_L = .346 \text{klf} \times 20' + .710 \text{klf} \times 20' = 21^K \]

\[ P = 21^K \]

\[ V_E = 18^K + 15^K = 33^K \]

\[ M_E = V_E \times L = 33^K \times 12' = 396^K \]

\[ P_U = (1.2 + 0.2(0.811))(27^K) + 21^K = 58^K \]

**TRY A W21x62**

\[ \frac{KL}{R} = \frac{1.0(12' \times 12'\text{")}}{1.77} = 81.4 \]

\[ 4.71 \sqrt{\frac{29000}{50000}} = 3.6 \]

\[ F_{CR} = 0.877 F_e \]

\[ F_e = \frac{\Pi^2 E}{kL} \frac{\Pi^2 (29000)}{1.0(12' \times 12'\text{")}} = 51 \text{ ksi} \]

\[ P_n = F_{cr} A_g \]

\[ = 51 \text{ ksi} (18.3 \text{in}^2) \]

\[ = 933.3^K \]

\[ \frac{P_U}{2(\phi P_n)} + \frac{M_{UX}}{2(\phi M_{NX})} < 1.0 \]

\[ \frac{58^K}{2} (0.00198) + \frac{9}{8} (396^K) (0.00202) = .957 < 1.0 \checkmark \]

**SELECT A W21x62 A992**
HT BRB CONNECTION DESIGN

Gusset plate to Steel Frame

\[ K = (0.707)(0.0625)(70)(0.75) \]

\[ K = 1.392 \text{ kips/in} \]

\[ D = 4(1.392) = 5.7 \text{ kips/in} \]

\[ 55K \leq 5.7K/\text{in} (4) (l_w) \]

\[ l_w = 2.41'' \]

Gusset to BRB bolted connection

\[ R_N = F_{AV} A_B \]

\[ \phi R_N = 0.75 (54ksi) (0.785\text{in}^2) = 31.8K \]

\[ \# \text{ of bolts} = \frac{66K}{31.8K} = 2.1 \text{ Use (2) 1'' diam. bolts} \]

Gusset plate to timber frame

Check 55K load (worst case)

Service load = 55K (0.7)

\[ = 39'' \]

Try 1'' diam. lag screws

\[ Z = 1800\# (1.6) = 2880\# \]

\[ 39K /2880\# = 13.5 \]

Use (14) 1'' diam lag screws
HT BRB DRIFT ANALYSIS

RESULTS VIA ETABS

ROOF: 0.170"

2ND: 0.105"
STEEL FRAME TO HT BRB

3/4" = 1'-0"
HSS 5x.500, TYP.

3/8" GUSSET PLATE w/ BOTTOM FLANGE

1' - 0"

SIMPSON LCC SERIES COLUMN CAP

1/16" FILLET WELD

2" x 3/8" BRB w/ (2) BOLTED 4x8 CONFINEMENT

3/8" GUSSET PLATE w/ BOTTOM FLANGE

(10) 1" LAG SCREWS

STEEL COLUMN/TIMBER BEAM TO HT BRB

3/4" = 1'-0"

Scale 3/4" = 1'-0"
8x8 POST, TYP.

1 1/2"

14" PARALLAM/GLULAM, TYP.

2"

3"

2" x 3/8" BRB w/ (2) BOLTED 4x8 CONFINEMENT

(10) 1" LAG SCREWS

2" x 3/8" BRB w/ (2) BOLTED 4x8 CONFINEMENT

(10) 1" LAG SCREWS

14" PARALLAM/GLULAM, TYP.

STEEL STRAP

1 TIMBER FRAME TO HT BRB

3/4" = 1'-0"

SCALE

BAUM, INC.
KEVIN DONG
SENIOR PROJECT - HT BRB

CONNECTION DETAIL 3

GIDEON BAUM
SPRING 2018

Scale 3/4" = 1'-0"