Senior Project: Heavy Timber Buckling-Restrained Brace Frame

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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.

Reference Appendix A for calculations.
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.
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.

REFERENCE APPENDIX B FOR CALCULATIONS
LATERAL SUMMARY - HT BRB

\[ V_{\text{BASE}} = 132^k \]

DISTRIBUTION WITH 4 BAYS:

- **ROOF**: 21^k
- **2ND FLOOR**: 39^k
- **ROOF BRACE**: 21^k
- **2ND BRACE**: 39^k

**STRENGTH LEVEL DEMANDS**

<table>
<thead>
<tr>
<th></th>
<th>( M_U )</th>
<th>( P_U )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ROOF</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEAM:</td>
<td>60^k</td>
<td>33^k</td>
</tr>
<tr>
<td>BRACE:</td>
<td></td>
<td>38^k</td>
</tr>
<tr>
<td><strong>2ND</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEAM:</td>
<td>154^k</td>
<td>89^k</td>
</tr>
<tr>
<td>BRACE:</td>
<td></td>
<td>66^k</td>
</tr>
</tbody>
</table>

**DRIFT RESULTS (ETABS)**

- **ROOF**: 0.170"
- **2ND**: 0.105"

**STEEL BRB STRENGTH LEVEL DEMAND**: 101^k

**REFERENCE APPENDIX C FOR CALCULATIONS**

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 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
  - 24k
  - 20.3k
  - 23k
- **HT BRB**
  - W10x22
  - 18k
  - 15k
  - 17k

### WEIGHT COMPARISON

<table>
<thead>
<tr>
<th></th>
<th>SCBF</th>
<th>HT BRB</th>
</tr>
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<tbody>
<tr>
<td><strong>ROOF BEAM</strong></td>
<td>W21x48 960 lb</td>
<td>W10x22 440 lb</td>
</tr>
<tr>
<td><strong>2ND FLOOR BEAM</strong></td>
<td>W27x84 1680 lb</td>
<td>w16x36 720 lb</td>
</tr>
<tr>
<td><strong>COLUMNS</strong></td>
<td>W24x76 (4) 3648 lb</td>
<td>W21x62 (4) 2976 lb</td>
</tr>
<tr>
<td><strong>ROOF BRACE</strong></td>
<td>HSS 2(\frac{1}{2})x2(\frac{1}{2})(\frac{5}{16}) (2) 264 lb</td>
<td>(2) 4x8 203 lb</td>
</tr>
<tr>
<td></td>
<td>2&quot; x (\frac{3}{8})&quot; PL 56 lb</td>
<td></td>
</tr>
<tr>
<td><strong>2ND FLOOR BRACE</strong></td>
<td>HSS 3(\frac{1}{2})x3(\frac{1}{2})(\frac{1}{4}) (2) 328 lb</td>
<td>(2) 4x8 203 lb</td>
</tr>
<tr>
<td></td>
<td>3(\frac{1}{2})&quot; x (\frac{3}{8})&quot; PL 94 lb</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>6880 lb</td>
<td>4692 lb</td>
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<tr>
<td>LOAD TAKE OFF</td>
<td>APPENDIX A</td>
<td></td>
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<tr>
<td>-----------------------</td>
<td>------------------------------------</td>
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</tr>
<tr>
<td></td>
<td>ROOF</td>
<td>(PSF)</td>
</tr>
<tr>
<td></td>
<td>FRAMING</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>ROOFING &amp; 4&quot; RIGID INSULATION</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>CEILING &amp; LIGHTING</td>
<td>2.0</td>
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<tr>
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<td>5.0</td>
</tr>
<tr>
<td></td>
<td>MEP</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>COLUMNS</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>MISC.</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>DEAD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ROOF LIVE</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>39.0</td>
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<td>2ND FLOOR</td>
<td>(PSF)</td>
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<td>FRAMING</td>
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<tr>
<td></td>
<td>1 1/4&quot; TOPPING SLAB</td>
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<td></td>
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<td>50.0</td>
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<td>TOTAL</td>
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<td></td>
<td>WALLS</td>
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<tr>
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<td>5/8&quot; SHEET ROCK</td>
<td>3</td>
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<tr>
<td></td>
<td>6&quot; METAL STUD</td>
<td>2</td>
</tr>
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<td></td>
<td>GYPBOARD</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>WATERPROOFING</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>7/8&quot; PLASTER</td>
<td>8.0</td>
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<tr>
<td></td>
<td>TOTAL</td>
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</table>
# Building Weight

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<thead>
<tr>
<th>LEVEL</th>
<th>LOAD (PSF)</th>
<th>AREA (SF)</th>
<th>TOTAL (LBS)</th>
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<tbody>
<tr>
<td>ROOF</td>
<td>19</td>
<td>18416.5</td>
<td>349913.5</td>
</tr>
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<td>2ND FLOOR</td>
<td>37</td>
<td>18416.5</td>
<td>681410.5</td>
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</table>

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

| BUILDING WEIGHT (KIPS) | 1305 |
SEISMIC PROCEDURE - SHEAR WALL

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

\[ C_s = 0.125 \]

\[ V = C_s W \]

\[ W = 1305 \]

\[ V_s = 163 \]

\[ T = C_t h_n^x \]

\[ C_t = 0.02 \]

\[ x = 0.75 \]

\[ h_n = 24 \]

\[ T = 0.22 \]

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

\[ C_{s,\text{max}} = 0.58 > 0.32 \text{ OK} \]

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

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

VERTICAL DISTRIBUTION

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>W (KIPS)</th>
<th>h (FT)</th>
<th>W_1h</th>
<th>(C_{vx} = (W_1h)/\Sigma(W_1h))</th>
<th>V = (C_{vx} \cdot 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>(\Sigma)</td>
<td>1305</td>
<td>21496</td>
<td>1.0</td>
<td></td>
<td>163</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: \((4 \text{ PLF} \times 12 \times 24')/20 = 58 \text{ PLF}\)

\(W_d = 19 \text{ PSF} \times 24' \text{ TRIB} = 456 + 58 = 514 \text{ PLF}\)

\(W_l = 19 \text{ PSF} \times 24' \text{ TRIB} = 346 \text{ PLF}\)

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

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

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

\[\Delta L = \frac{(20' \times 12'')}{240} = 1'' > .052'' \checkmark\]

SELECT A W12x16 A992
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 = 9.5 k

M_d = (514 plf x 20')^2/8 = 47.3 k

V_L = (346 PLF x 20')/2 = 7.1 k

M_l = (514 plf x 20')^2/8 = 35.5 k

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

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

TRY A W12x26 φM_N = 140 k

M_SELF = .026(1.2(20)^3)/8 = 1.56 k

M_U = 115.2 k < 140 k

SHEAR CHECK

V_U = 22.8 k < 84.2 k

DEFLECTION CHECK

Δ_o = (5)(946)(20')(12^3) = .072"

Δ = (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**

<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} \cdot 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>
SCBF FRAME FORCES

8 BAYS

ROOF: $96^k \div 4 = 24^k$
$2^{nd}$: $81^k \div 4 = 20.3^k$

$R = 6$

FORCE IN A = $9.36^k$
FORCE IN B = $25.2^k$
**SCBF ROOF MEMBER DESIGN**

\[ P_U = (1.2 + 0.2(0.811))(9.36^k) = 12.8^k \]

\[ \phi P_n = 14.6^k \]

**TRY HSS 2 1/2 x 2 1/2 x 5/16**

\[ \frac{kL}{R} = \frac{1.0(12' \times 12'\text{''})}{0.88} = 191 < 200 \]

Satisfies compact section requirements

\[ T = A_s F_{ye} = A_s R_y F_y \]

\[ T = 2.35 \text{in}^2 (1.6) (46 \text{ksi}) = 173^k \]

\[ C = 0.3 P_n \]

\[ C = 0.3 \frac{14.6^k}{0.9} = 4.9^k \]

\[ F_{ROOF} = (173^k + 4.9^k) \cos(39.8^\circ) = 137^k \]

**ROOF BEAM**

\[ W_{DR} = 19 \text{ PSF}(24') = .456 \text{ klf} \]

\[ W_{LR} = 14.4 \text{ PSF}(24') = .346 \text{ klf} \]

\[ \Omega = 2 \quad S_{DS} = .811 \]

\[ w = (1.2 + 0.2 S_{DS}) D + .5L \]

\[ w = (1.2 + 0.2(0.811))(.456 \text{ klf}) + .5(.346 \text{ klf}) \]

\[ w = .794 \text{ klf} \]

\[ P_{BAL} = (173^k \cdot 4.9^k) \sin(39.8^\circ) = 107.6^k \]

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

\[ = 107.6^k \times 10' + \frac{.794 \text{ klf} (10^2)}{8} \]

\[ = 279^k \]

\[ \text{TRY A W21x48} \]

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

\[ \frac{137^k}{2} (0.00621) + \frac{9}{8} (279^k) (0.00118) = .985 < 1.0 \]

Select A W21x48 A992
SCBF 2ND FLOOR MEMBER DESIGN

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

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

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

2nd FLOOR BEAM

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

\[ w = (1.2 + 0.2S_{DS}) D + .5L \]
\[ w = (1.2 + 0.2(.811))(.456 \text{ klf}) + .5(.346 \text{ klf}) \]
\[ w = 1.56 \text{ klf} \]

\[ P_{BAL} = (1.2 + 0.2S_{DS}) (25.2^k) = 34.4^k \]
\[ \phi P_n = 40.6^k \]

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

SATISFIES COMPACT SECTION REQUIREMENTS

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

TRY A W27x84

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

SELECT A W27x84 A992
**TYPICAL COLUMN**

\[
P_D = 0.456 \text{kip} \times 20' + 0.888 \text{kip} \times 20' = 27^K
\]

\[
P_L = 0.346 \text{kip} \times 20' + 0.710 \text{kip} \times 20' = 21^K
\]

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

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

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

\[
\text{TRY A W24x76}
\]

\[
\frac{\text{kl}}{R} = \frac{1.0(12' \times 12'\text{")}}{1.92} = \frac{81.4}{3.6}
\]

\[
F_{CR} = 0.877 F_e
\]

\[
F_e = \frac{T_t E}{1.0(12' \times 12'\text{")}} = 44.8 \text{ksi}
\]

\[
P_n = F_{cr} A_g
\]

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

\[
= 901^K
\]

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

\[
\frac{58^K}{2} \left(0.00153\right) + \frac{9}{8} \left(532^K\right) \left(0.00141\right) = .89 < 1.0 \checkmark
\]

**SELECT A W24x76 A992**
SCBF DRIFT ANALYSIS

RESULTS VIA ETABS

ROOF: 0.199"

2ND: 0.116"
\[ C_s = \frac{S_{ds}}{R/I} \]

\[ V = C_s W \]

\[ W = 1305 \]

\[ V_s = 132 \]

\[ T = C_t h_n^x \]

\[ C_t = 0.02 \]

\[ x = 0.75 \]

\[ h_n = 24 \]

\[ T = 0.22 \]

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

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

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

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

\[ V = C_{vx} V_s \]

**VERTICAL DISTRIBUTION**

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>W (KIPS)</th>
<th>h (FT)</th>
<th>( W_s h )</th>
<th>( C_{vx} = \frac{(W_s h)}{\Sigma(W_s 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>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>Σ</td>
<td>1305</td>
<td>21496</td>
<td>1.0</td>
<td>132</td>
<td></td>
</tr>
</tbody>
</table>
**HT BRB FRAME FORCES**

- 72k
- 60k

**APPENDIX C**

- 8 BAYS
- ROOF: $\frac{72k}{4} = 21k$
- $\frac{60k}{4} = 39k$
- $R = 8$

- 18k
- 15k

- 12' FORCE IN A = 21k
- 12' FORCE IN B = $17.5k + 21k = 39k$

- 20'

**HT BRB STRENGTH DESIGN**

**A**

- $P_{BRACE} \leq \phi F_Y A_B$
- $21k = 0.9(36)(A_{PL})$
- $A_{PL} = 0.65 \text{ in}^2$

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

**B**

- $P_{BRACE} \leq \phi F_Y A_B$
- $39k = 0.9(36)(A_{PL})$
- $A_{PL} = 1.20 \text{ in}^2$

- USE $3\frac{1}{2}" x 3/8"$ PL w/ (2) BOLTED 4x8 CONFINEMENT

**P_t = R_Y F_Y A_G**

- $P_t = 38k$
- $P_t = 66k$

- $= 1.4 \times 36 \text{ksi} \times (0.75\text{in}^2)$
- $= 1.4 \times 36 \text{ksi} \times (1.31\text{in}^2)$
ROOF BEAM

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

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

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

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

$P_{BAL} = 38^k \sin(31^\circ) = 20^k$

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

$w = .794 \text{ klf}$

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

$= \frac{20^k \times 10'}{4} + \frac{.794 \text{klf} (10^2)}{8}$

$= 60^k \quad \text{TRY A W10x22}$

$\frac{P_U}{2(\phi P_n)} + \frac{M_{UX}}{2(\phi M_{nx})} < 1.0$

$\frac{33^k}{2} \left(0.00621\right) + \frac{9}{8} \left(60^k \times .0117\right) = .892 < 1.0 \checkmark$

SELECT A W10x22 A992
2ND FLOOR BEAM

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

\[ E_{Roof} = (38^k + 66^k) \cos(31^\circ) = 89^k \]

\[ w = (1.2 + 0.2S_{DS})D + 0.5L \]
\[ P_{Bal} = (38^k + 66^k) \sin(31^\circ) = 53.6^k \]

\[ w = (1.2 + 0.2(0.811))(0.456\text{klf}) + 0.5(0.710\text{klf}) \]
\[ w = 1.56 \text{ klf} \]

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

\[ \frac{P_U}{2(\phi P_n)} + \frac{M_{UX}}{2(\phi M_{NX})} < 1.0 \]
\[ \frac{89^k}{2} (0.00334) + \frac{9}{8} (0.00451) = .929 < 1.0 \]

SELECT A W16x36 A992
TYPICAL COLUMN

\[
\begin{align*}
P_D &= .456\text{k}l\text{f} \times 20' + .888\text{k}l\text{f} \times 20' = 27^K \\
P_L &= .346\text{k}l\text{f} \times 20' + .710\text{k}l\text{f} \times 20' = 21^K \\
V_E &= 18^K + 15^K = 33^K \\
M_E &= V_E \times L = 33^K \times 12' = 396^K \\
P_U &= (1.2 + 0.2(0.811))(27^K) + 21^K = 58^K
\end{align*}
\]

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

TRY A W21x62

\[
\begin{align*}
kL & \quad 12' \\
R & \quad 1.0(12' \times 12'') \\
\frac{kL}{R} & \quad 1.77 \\
\frac{29000}{50000} & \quad 3.6
\end{align*}
\]

\[
F_{CR} = 0.877 F_e \\
F_e = \frac{\pi^2 E}{kL} \frac{1.0(12' \times 12'')}{R} = 51 \text{ ksi}
\]

\[
P_n = F_{cr} A_g = 51 \text{ ksi} (18.3\text{ in}^2) = 933.3^K
\]

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

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

SELECT A W21x62 A992
HT BRB CONNECTION DESIGN

GUSSET PLATE TO STEEL FRAME

TRY 1/16" FILLET WELDS

$$= (0.707)(0.0625)(70)(0.75) = 1.392 \text{ k/in}$$

$$D = 4(1.392) = 5.7 \text{ k/in}$$

$$55^k \leq 5.7 \text{ k/in}$$

$$l_w = 2.41"$$

GUSSET TO BRB BOLTED CONNECTION

$$R_N = F_{AV} A_B$$

$$\phi R_N = 0.75 (54 \text{ ksi}) (0.785 \text{ in}^2) = 31.8^k$$

$$# \text{ OF BOLTS} = \frac{66^k}{31.8^k} = 2.1$$ USE (2) 1" DIAM. BOLTS

GUSSET PLATE TO TIMBER FRAME

CHECK 55^k LOAD (WORST CASE)

SERVICE LOAD = 55^k (0.7) = 39^k

TRY 1" DIAM. LAG SCREWS

$$Z = 1800\# (1.6) = 2880\#$$

$$39^k /2880\# = 13.5$$

USE (14) 1" DIAM LAG SCREWS
HT BRB DRIFT ANALYSIS

RESULTS VIA ETABS

- ROOF: 0.170"
- 2ND: 0.105"
STEEL FRAME TO HT BRB

1/16" FILLET WELD

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

3/8" GUSSET PLATE

W21x62

1'-0"

W18x76

1'-0"

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
1
3/4" = 1'-0"

BAUM, INC.
KEVIN DONG
SENIOR PROJECT - HT BRB
GIDEON BAUM
SPRING 2018
31
Scale 3/4" = 1'-0"
1. TIMBER FRAME TO HT BRB

3/4" = 1'-0"

- 8x8 POST, TYP.
- (10) 1" LAG SCREWS
- 14" PARALLAM/GLULAM, TYP.
- STEEL STRAP
- 2" x 3/8" BRB w/ (2) BOLTED 4x8 CONFINEMENT
- 1' - 4"

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BAUM, INC.
SENIOR PROJECT - HT BRB

GIDEON BAUM
SPRING 2018

32
Scale 3/4" = 1'-0"