King Post Truss Joinery Analysis
Case Study

Timber Frame Engineering Council Symposium
Burlington, VT
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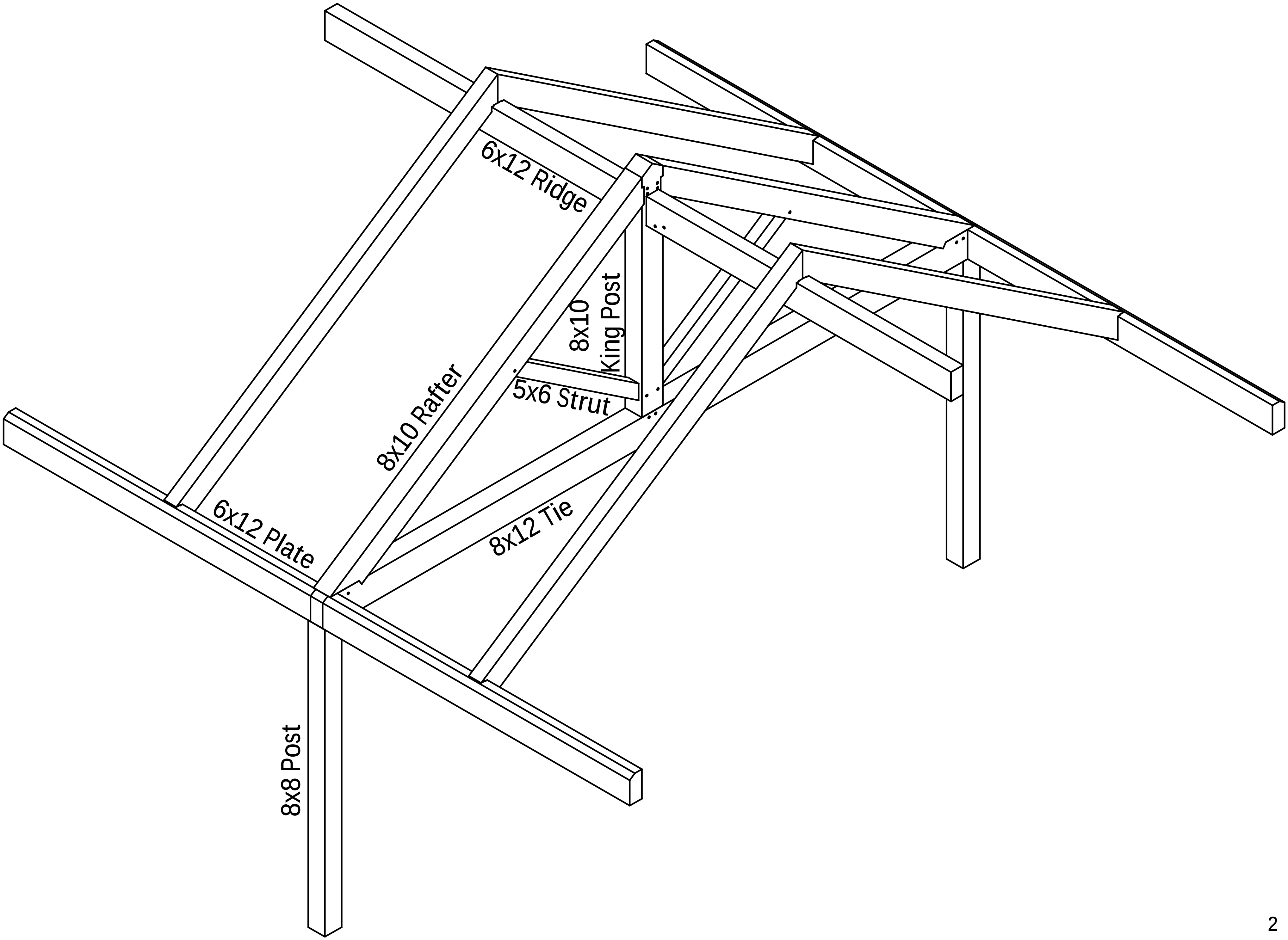
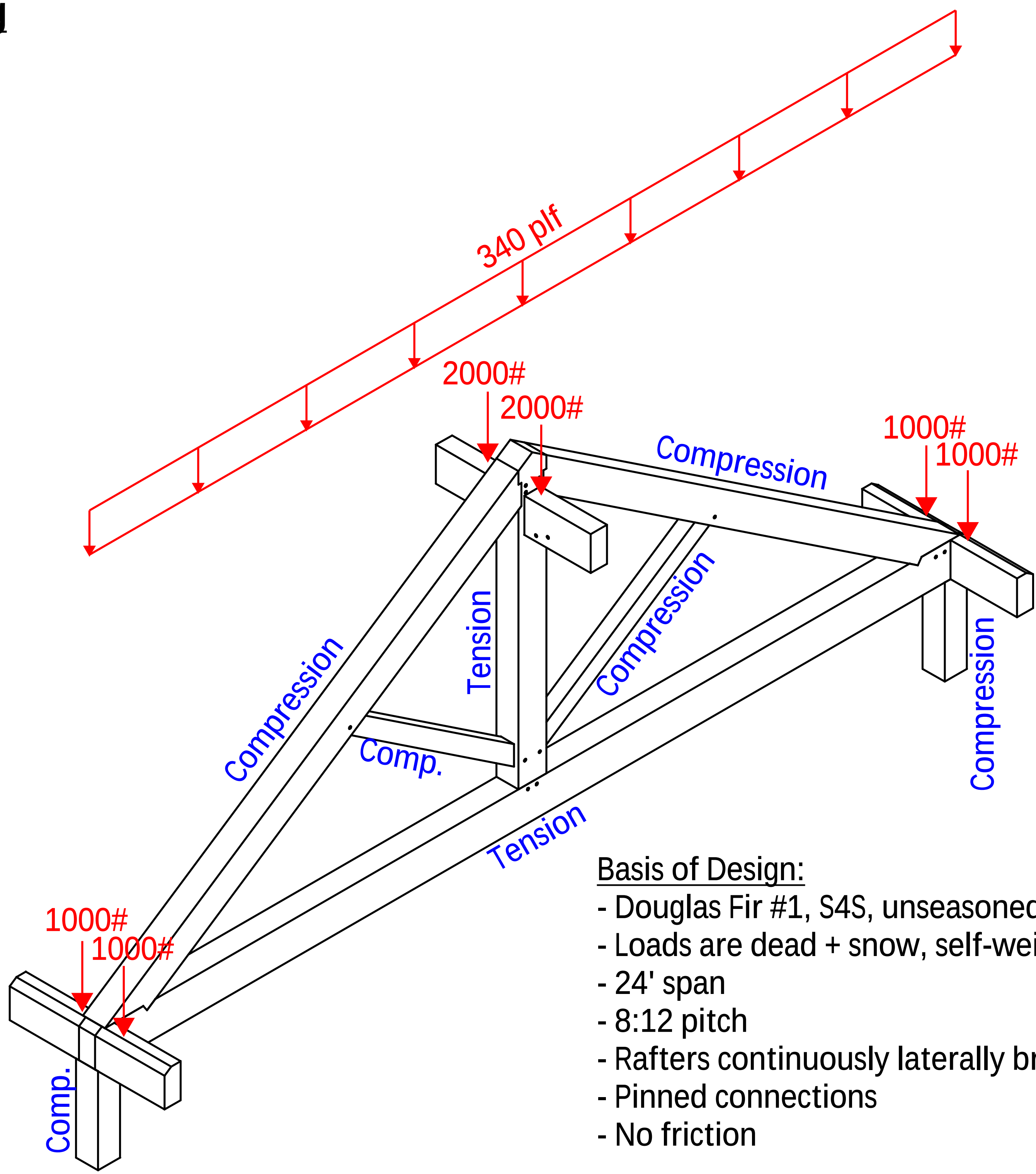
John Treybal, PE

ENGINEERING VENTURES PC

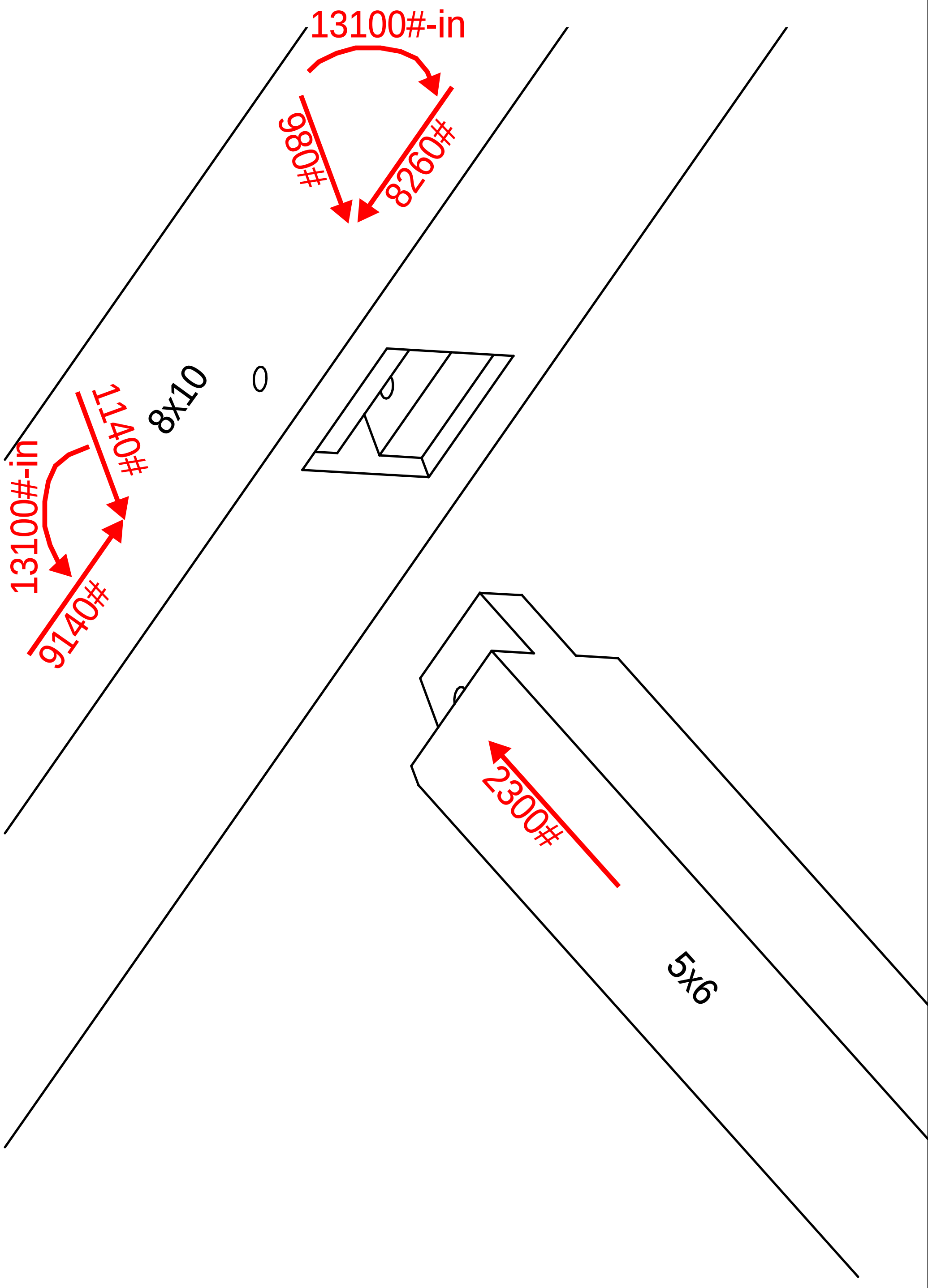

6x12 Ridge
8x10 King Post
5x6 Strut
8x10 Rafter
6x12 Plate
8x12 Tie
8x8 Post

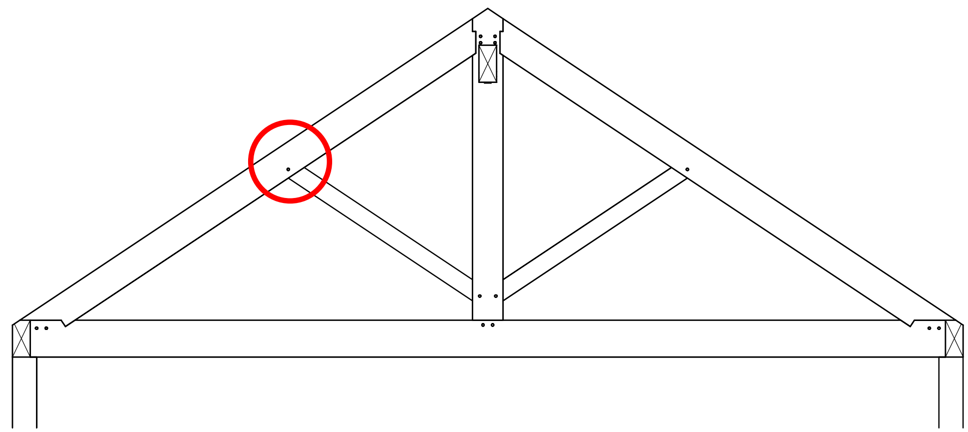
Truss Loading



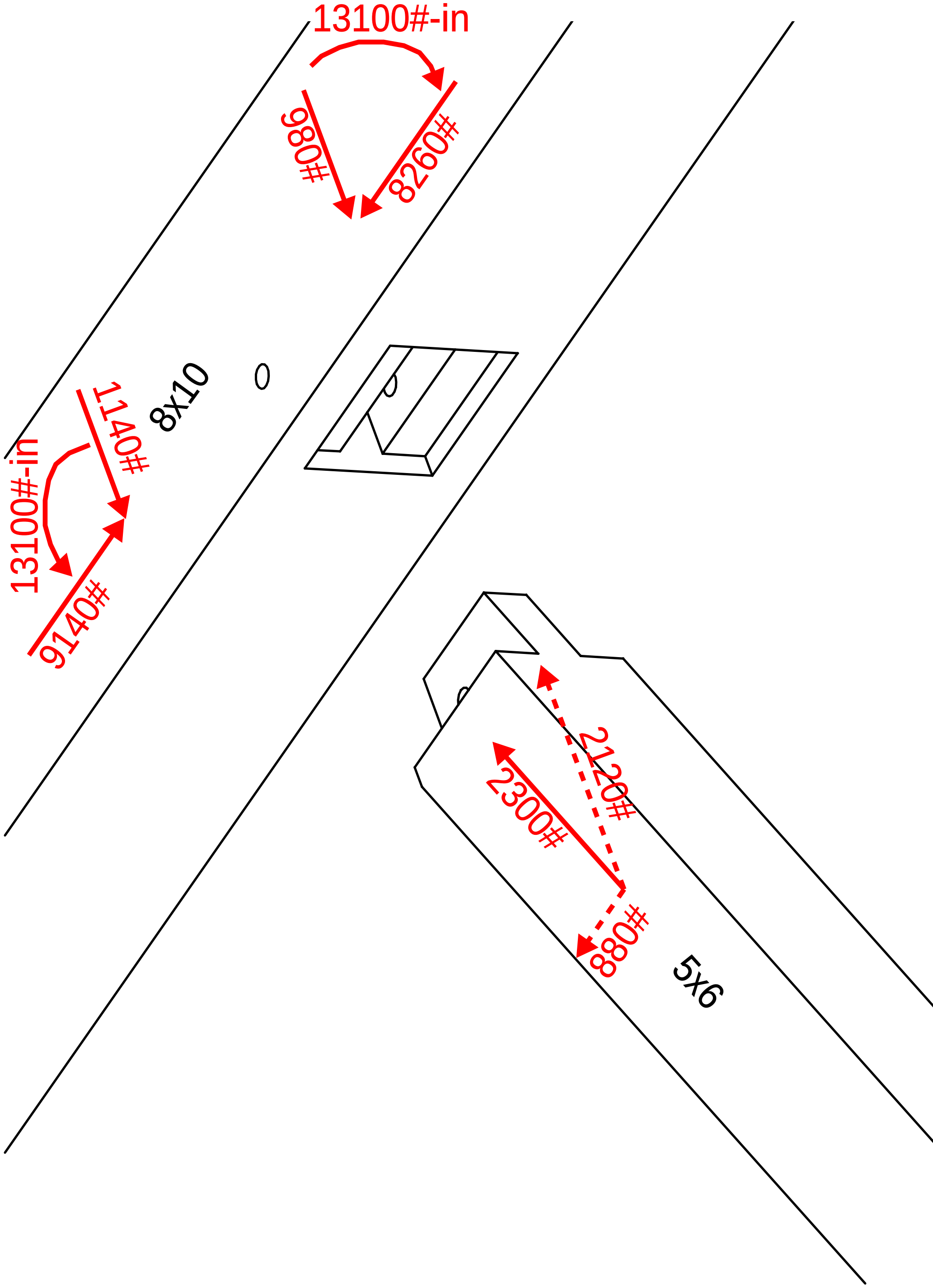
Basis of Design:
- Douglas Fir #1, S4S, unseasoned
- Loads are dead + snow, self-weight included
- 24' span
- 8:12 pitch
- Rafters continuously laterally braced
- Pinned connections
- No friction

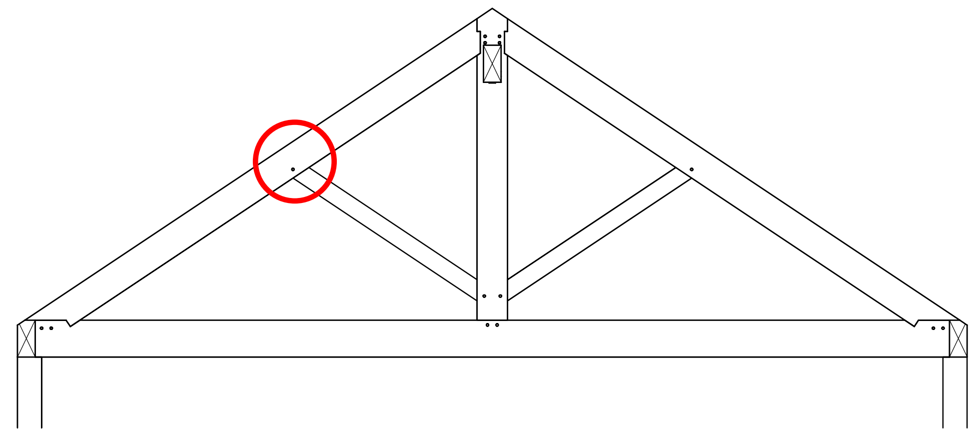
Strut / Rafter Joint





Strut / Rafter Joint



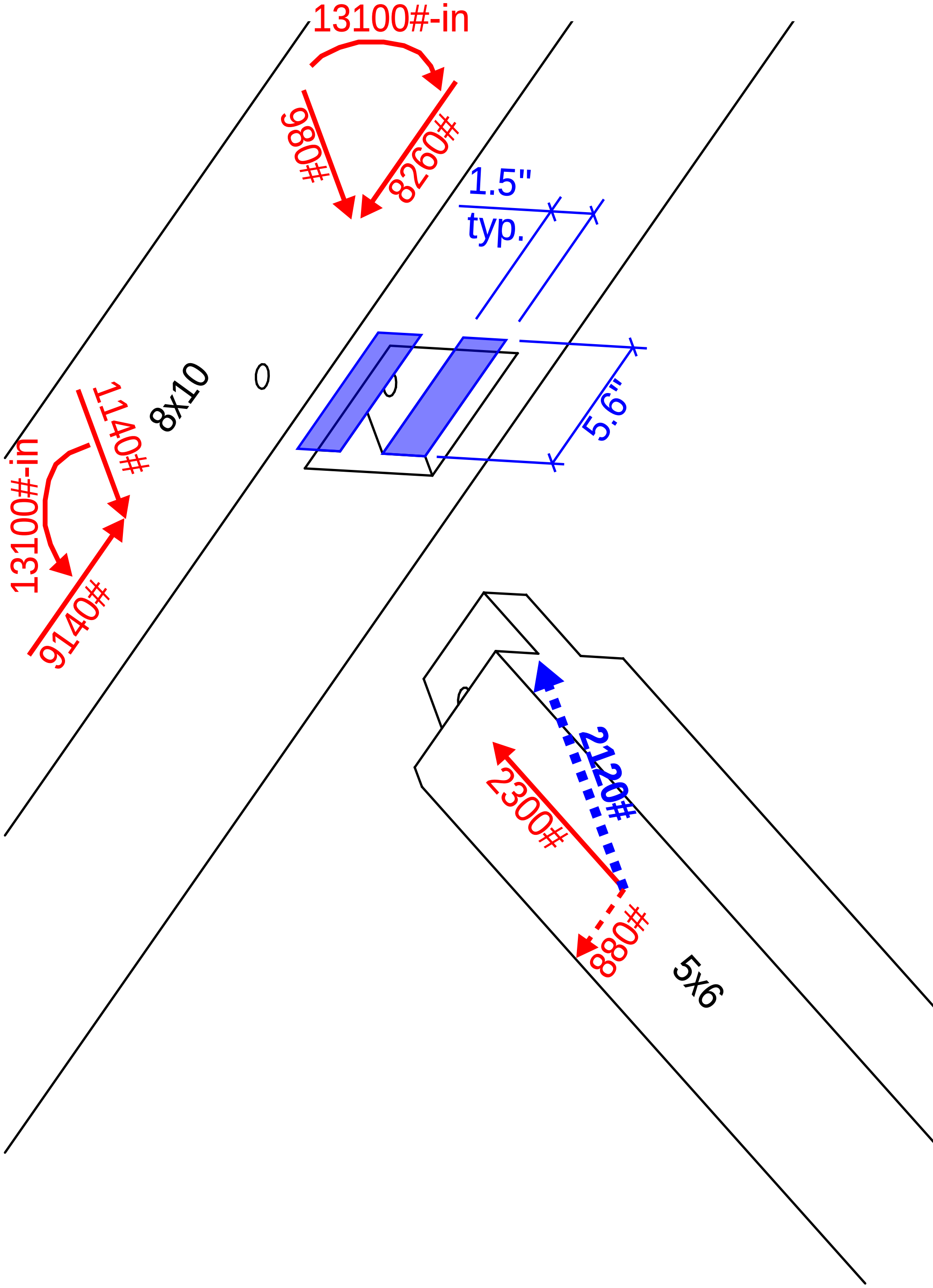


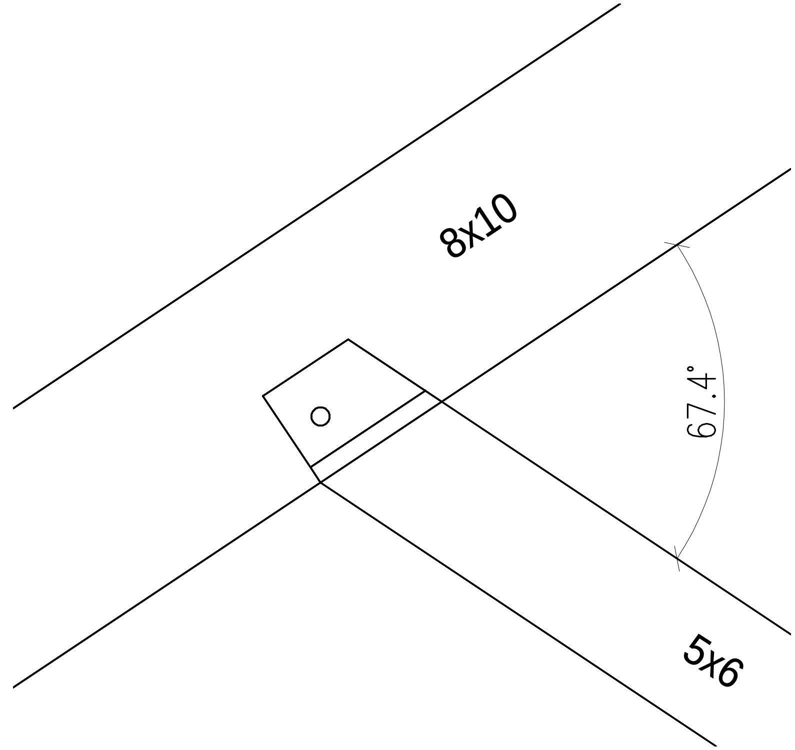
Failure Modes:

- Rafter Bearing on Strut

- Bending and Compression in Rafter at Reduced Section

Strut / Rafter Joint -
Rafter Bearing on Strut (Check 1)





$$f_c = \frac{C}{A} = \mathbf{126\ psi}$$

$$C = 2{,}120\#$$

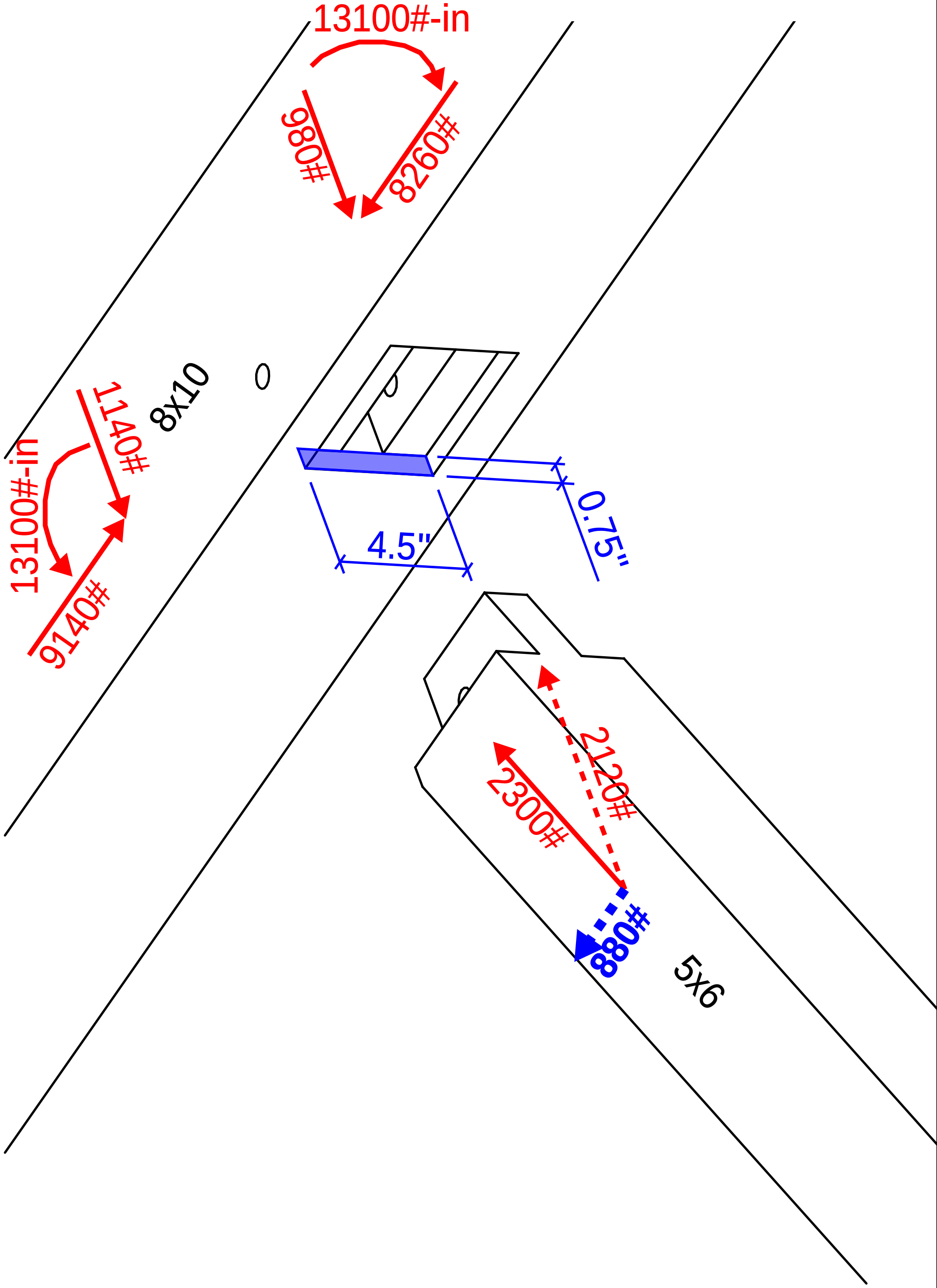
$$A = (1.5\,'' * 5.6\,'') * 2 = 16.8\ in^2$$

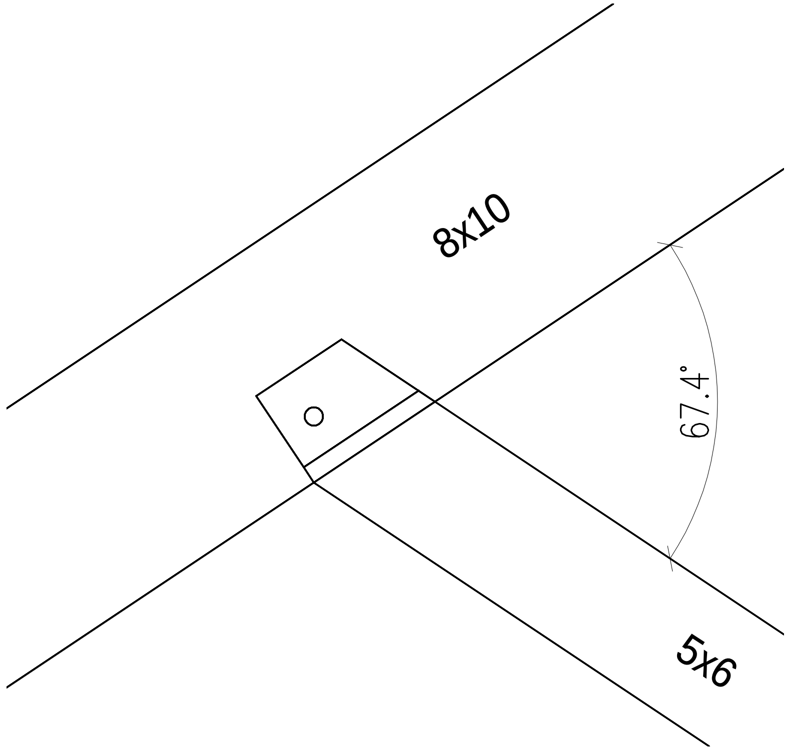
$$F_c'$$

$$= min. \begin{cases} F'_{22.6^\circ\ strut} = 1{,}020\ psi\ (Hankinson) \\ F'_{c\perp\ rafter} = 625\ psi \end{cases}$$

$$= \boxed{\mathbf{625\ psi > 126\ psi\ \therefore OK}}$$

Strut / Rafter Joint -
Rafter Bearing on Strut (Check 2)





$$f_c = \frac{C}{A} = \mathbf{260\ psi}$$

$$C = 880\#$$

$$A = 0.75" * 4.5" = 3.38\ in^2$$

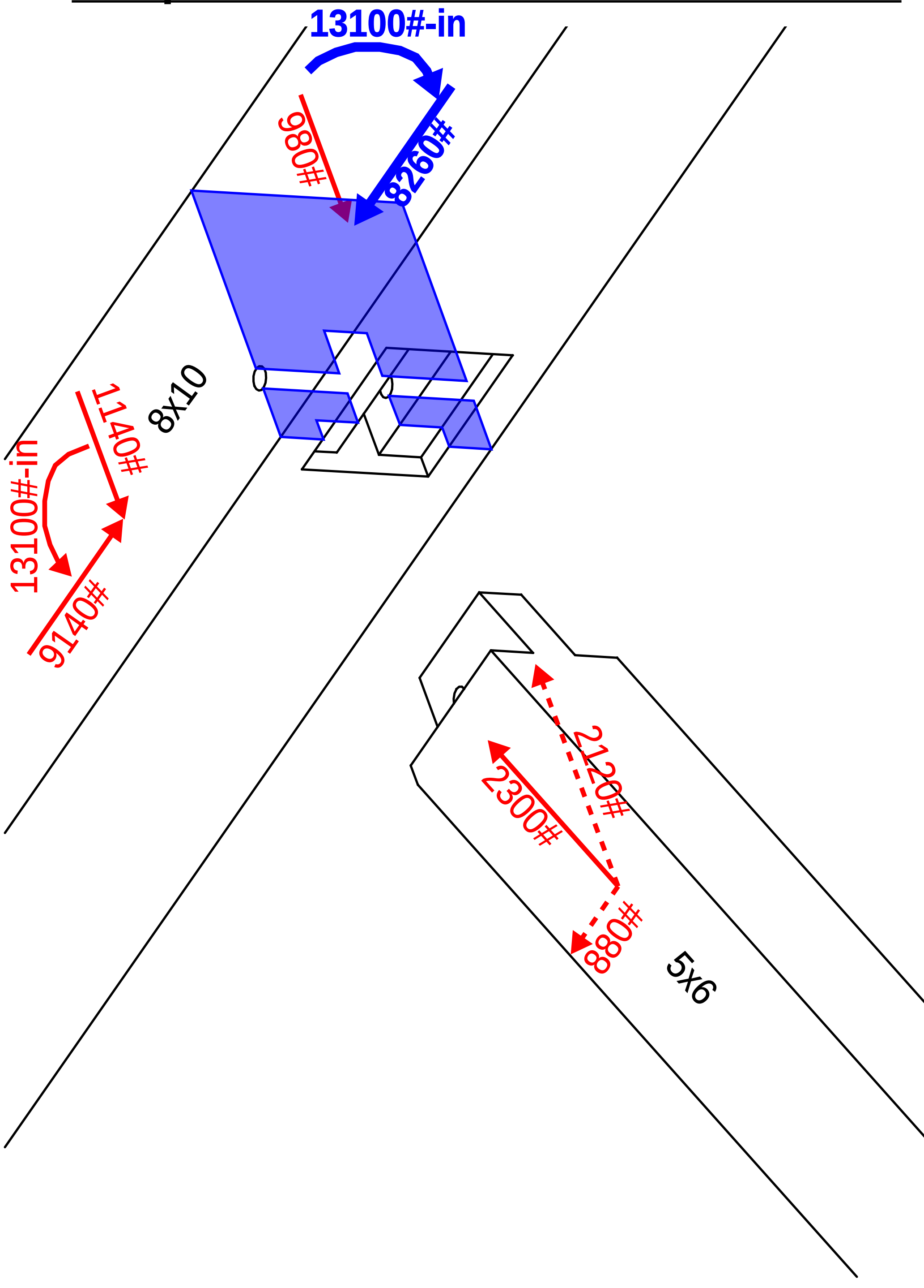
Conservatively ignoring tenon bearing – some might argue for using half of it or more

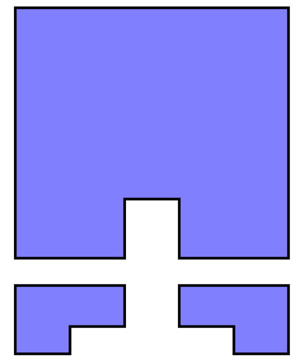
$$F_c'$$

$$= min. \begin{cases} F'_{67.4°\ strut} = 670\ psi\ (Hankinson) \\ F'_{c\ rafter} = 1{,}000\ psi * 1.15 = 1{,}150\ psi \end{cases}$$

$$= \boxed{\mathbf{670\ psi > 260\ psi\ \therefore OK}}$$

Strut / Rafter Joint - Bending and Compression in Rafter at Reduced Section





Rafter Net Section Properties:

$A = 58.1\ in^2$

$S = 71.5\ in^3$

Compression Only:

$$f_c = \frac{C}{A} = \frac{8{,}260\#}{58.1 in^2} = \mathbf{142\ psi}$$

$$F_c' = 1{,}000\ psi * 1.15$$

$$= \boxed{\mathbf{1,150\ psi} > 142\ psi \therefore \boldsymbol{OK}}$$

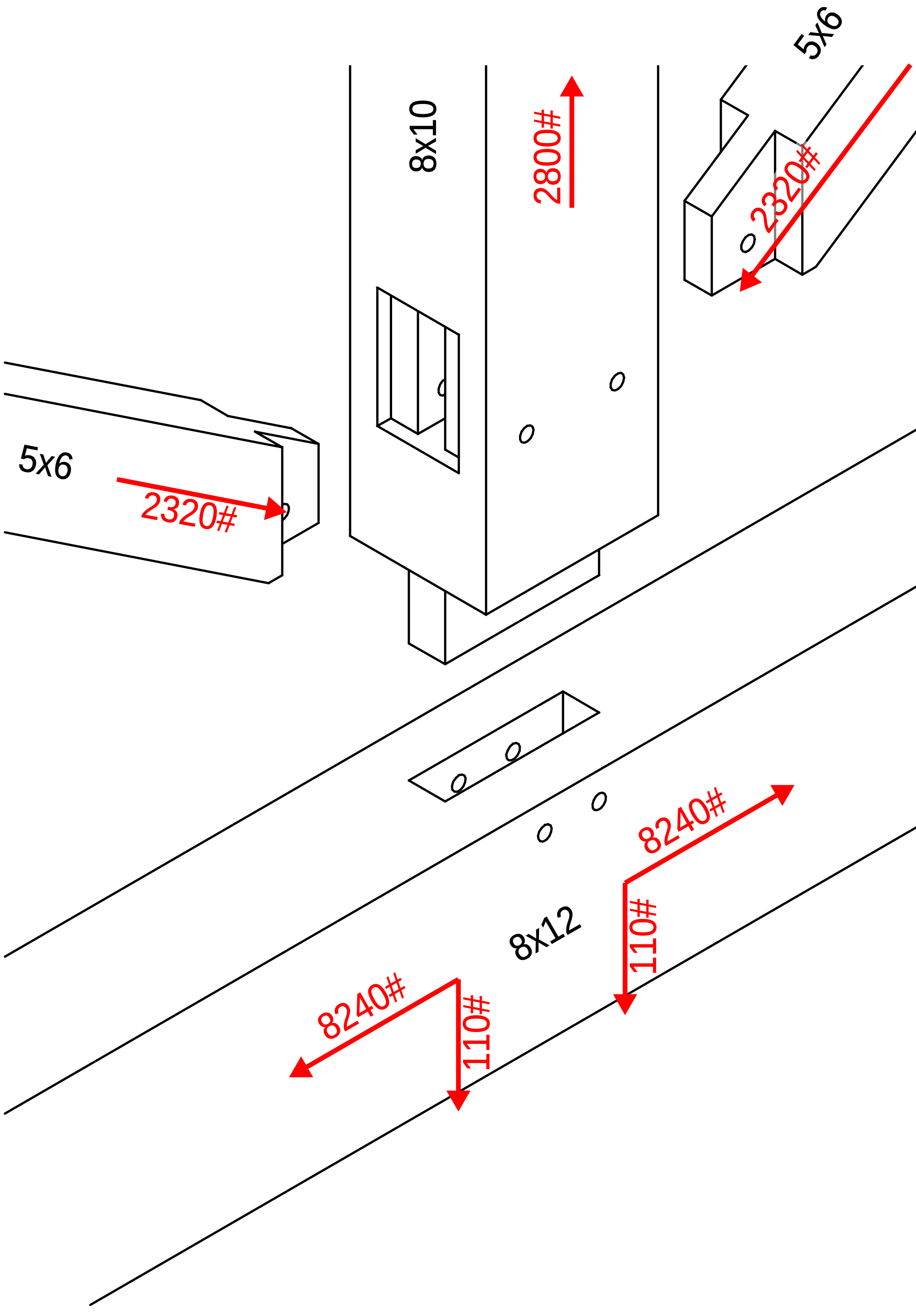
Bending and Axial Compression Interaction:

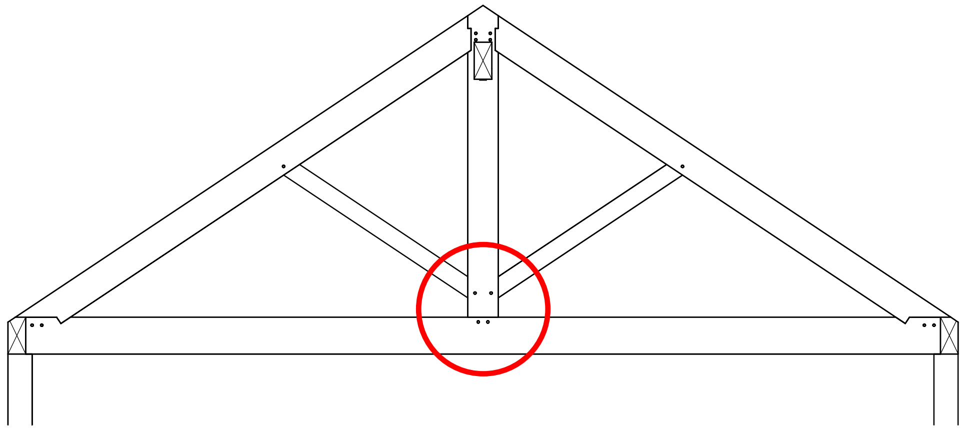
$$\left(\frac{f_c}{F_c{}'}\right)^2 + \left(\frac{f_b}{F_b{}'}\right) = \boxed{\mathbf{0.15} < 1.0 \quad \therefore \boldsymbol{OK}}$$

$$f_b = \frac{M}{S} = \frac{13{,}100\# - in}{71.5 in^3} = 183\ psi$$

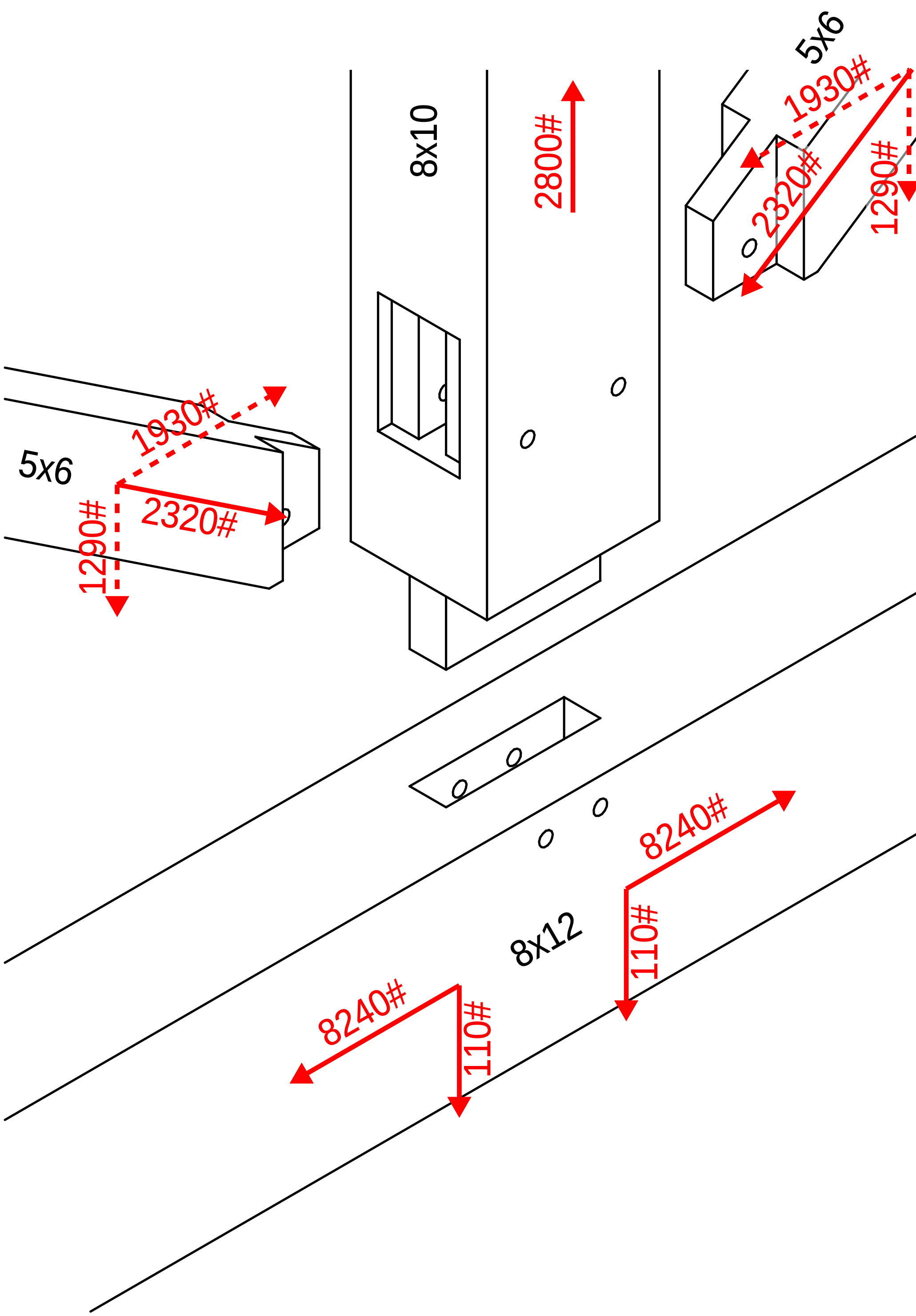
$$F_b' = 1{,}200\ psi * 1.15 = 1{,}380\ psi$$

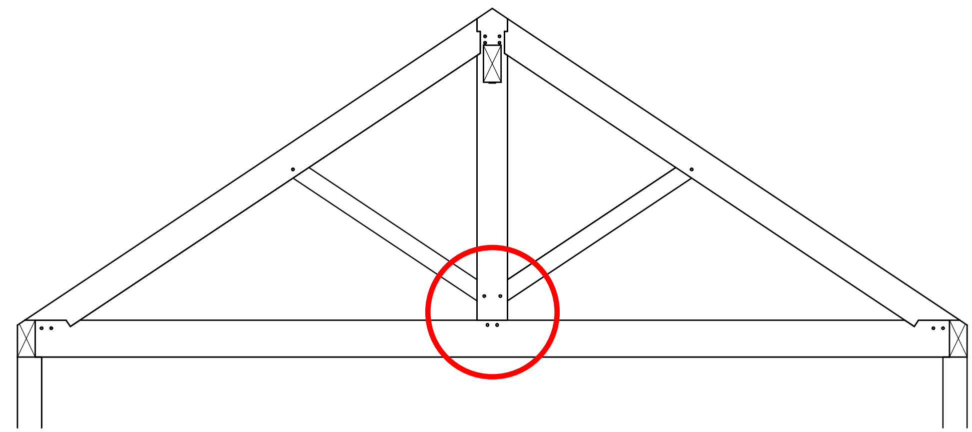
Strut / King Post Joint





Strut / King Post Joint





Failure Modes:

- Strut Bearing on King Post

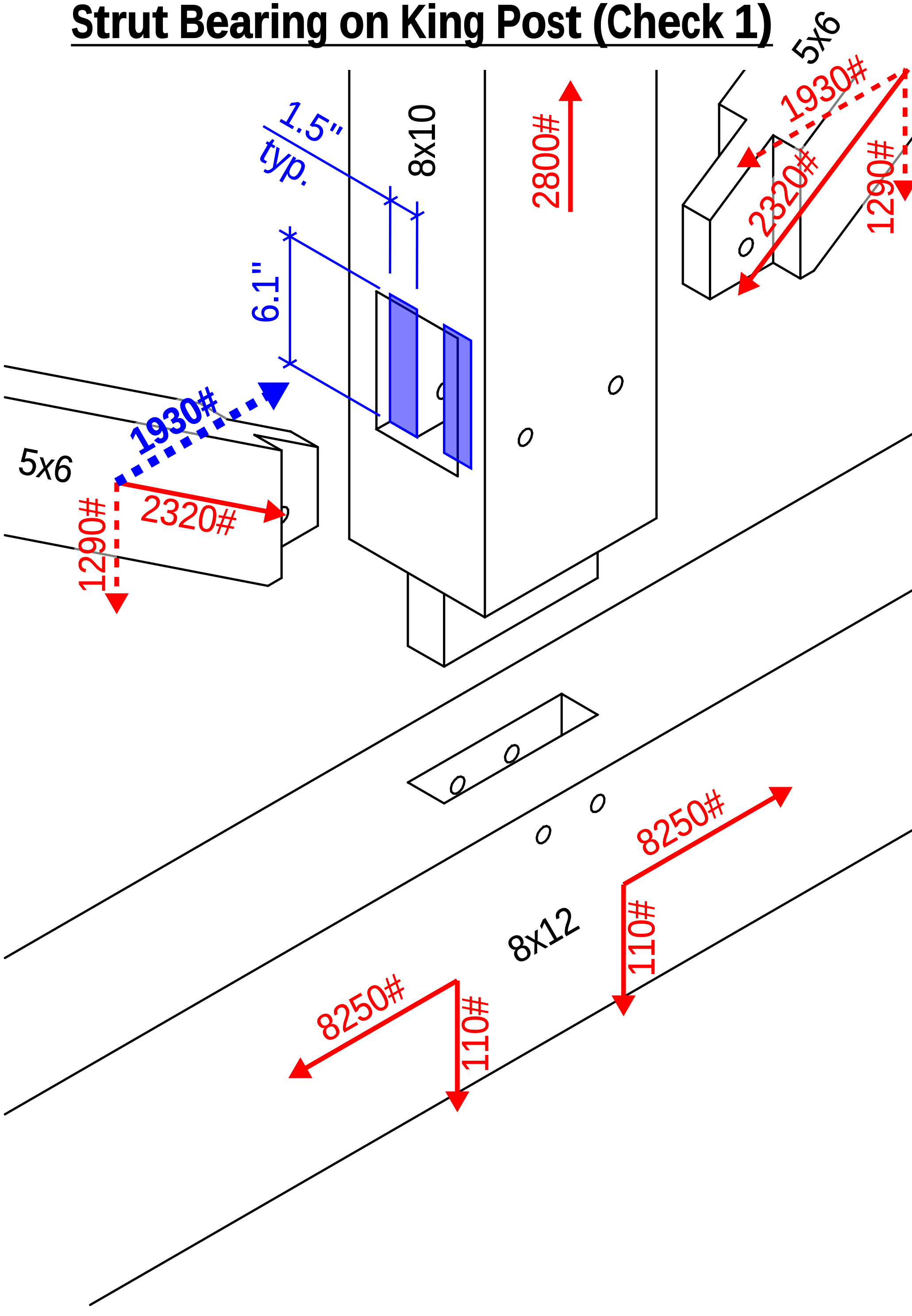
- Shear Through King Post Relish

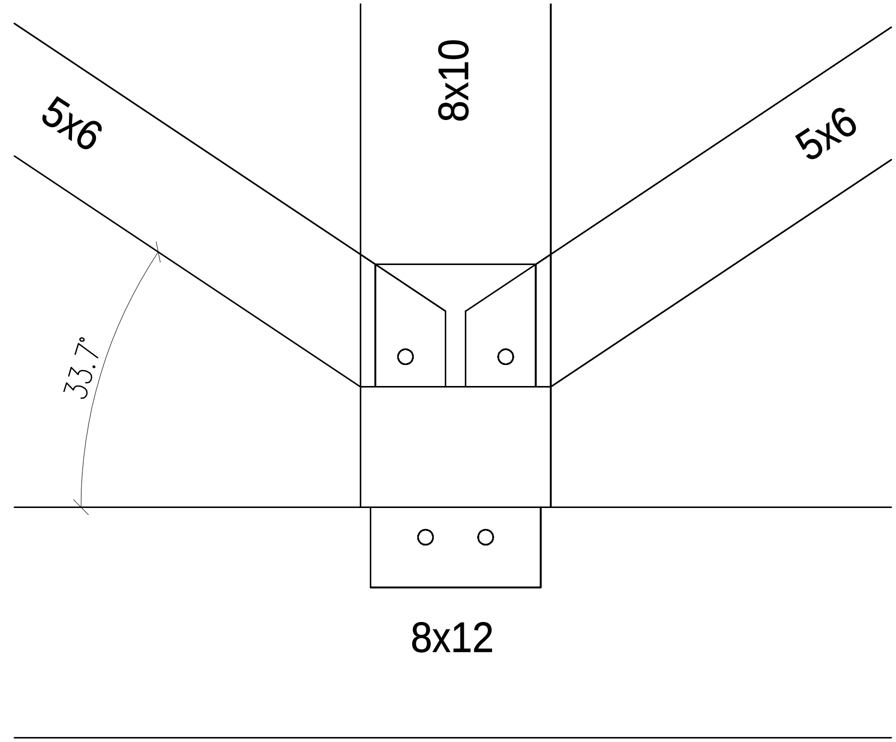
- King Post Tension at Reduced Section (not checked - top of king post joint will control due to lower cross-sectional area)

- Tie Tension at Reduced Section (not checked - heel joint will control)

- King Post/Tie Peg Shear (not checked- OK by inspection)

Strut / King Post Joint -
Strut Bearing on King Post (Check 1)





$$f_c = \frac{C}{A} = \mathbf{105\ psi}$$

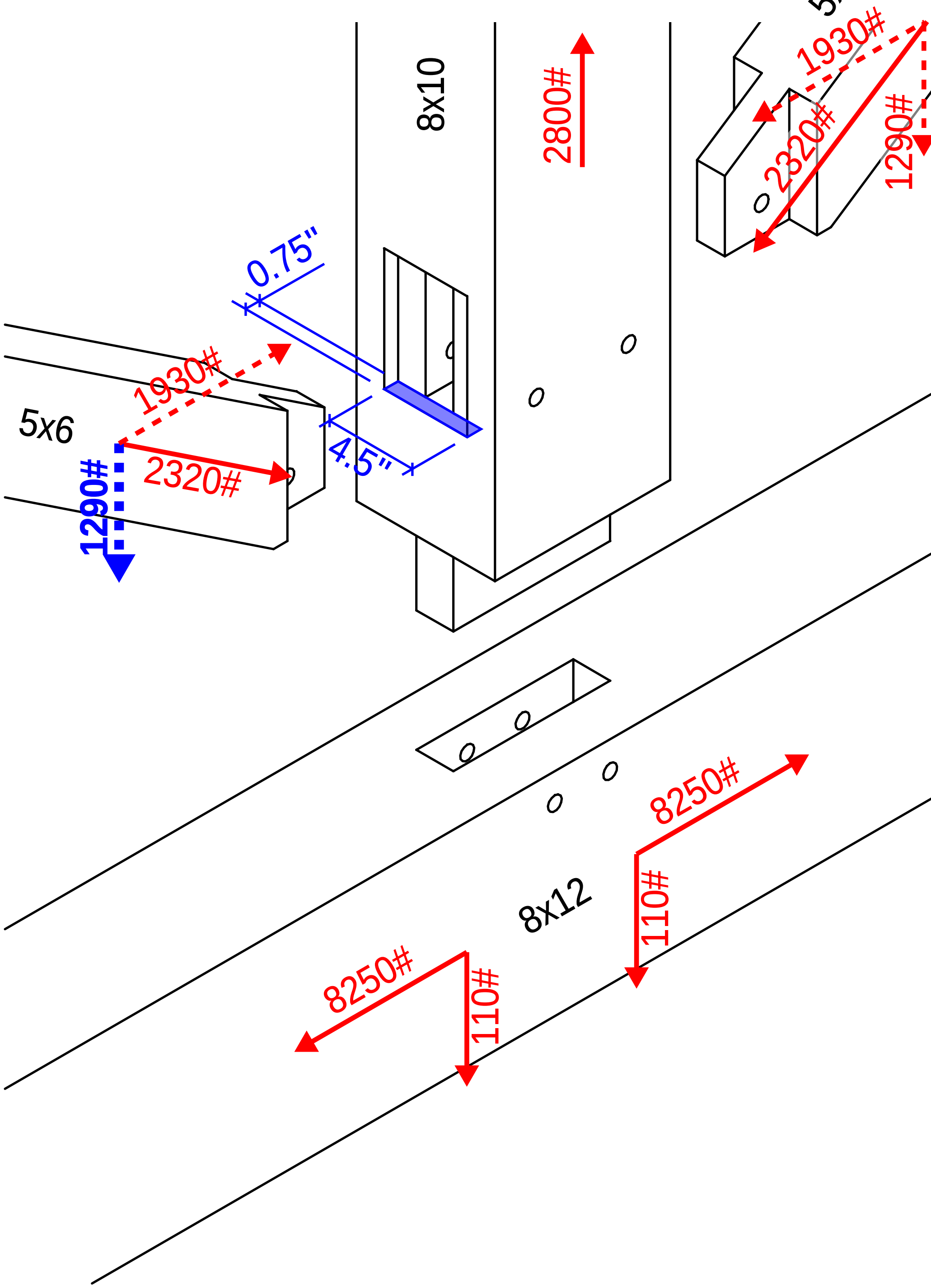
$$C = 1{,}930\#$$

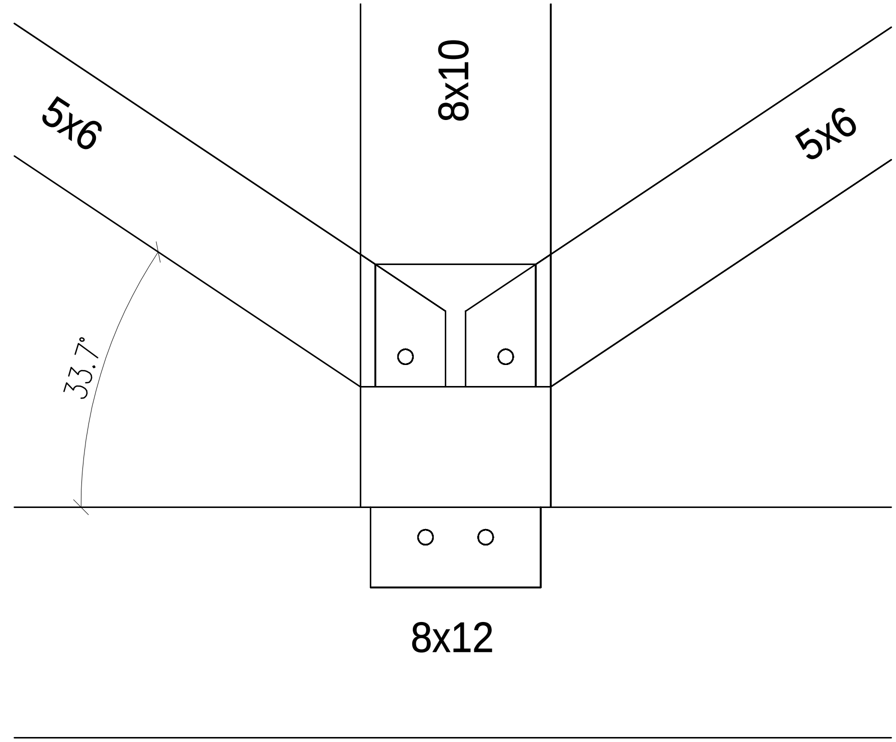
$$A = (1.5'' * 6.1'') * 2 = 18.3\ in^2$$

$$F'_c = min. \begin{cases} F'_{33.7^\circ\ strut} = 914\ psi\ (Hankinson) \\ F'_{c\perp\ king\ post} = 625\ psi \end{cases}$$

$$= \boxed{\mathbf{625\ psi > 105\ psi\ \therefore\ OK}}$$

Strut / King Post Joint -
Strut Bearing on King Post (Check 2)





$$f_c = \frac{C}{A} = \mathbf{382\ psi}$$

$$C = 1{,}290\#$$

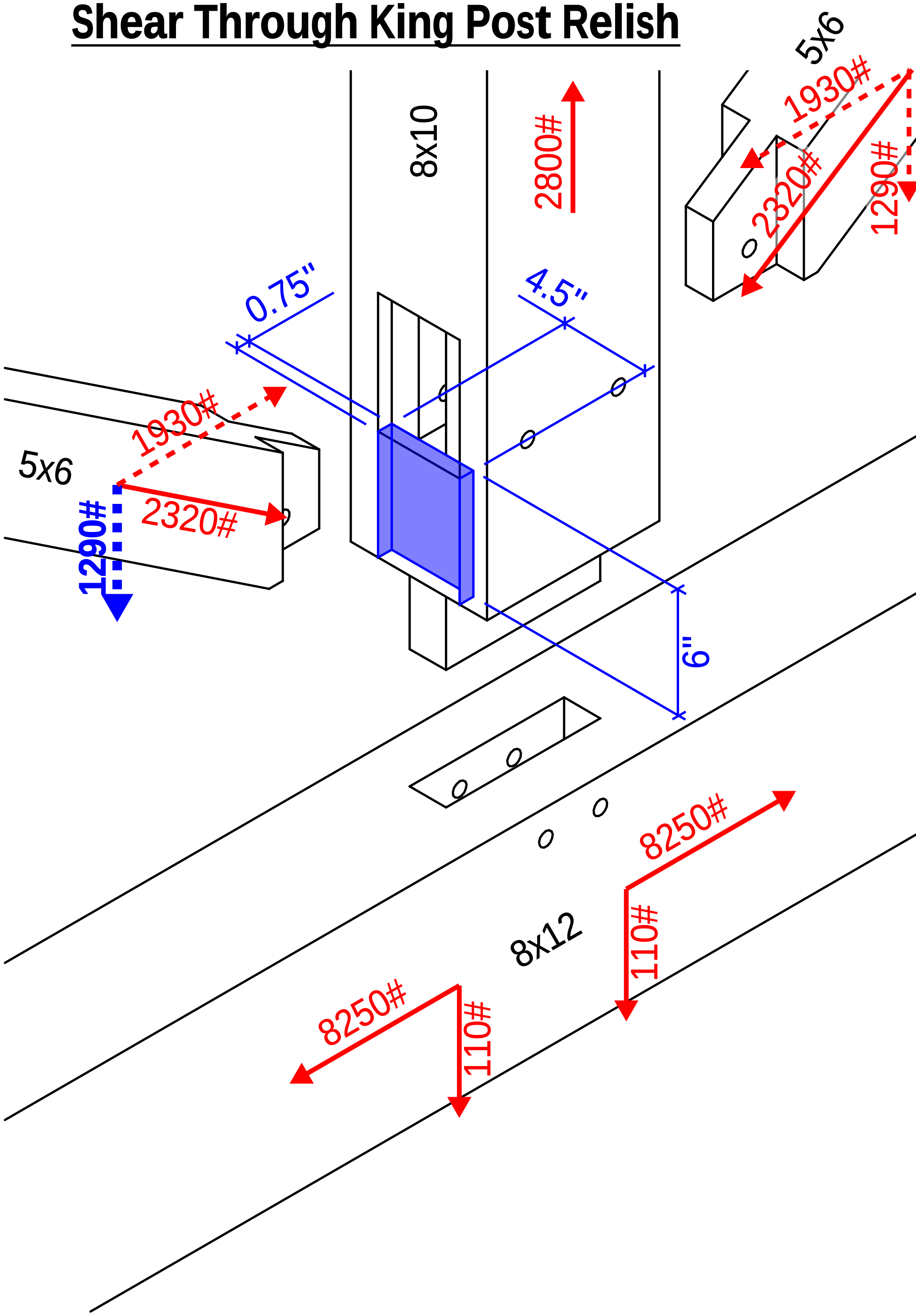
$$A = 0.75'' * 4.5'' = 3.38\ in^2$$

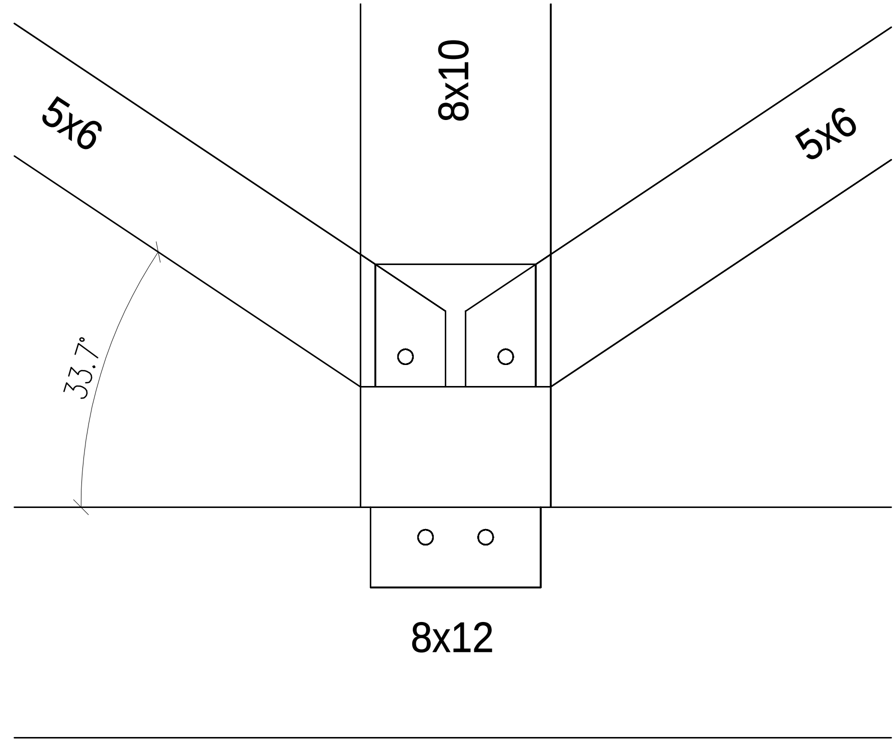
$$F'_c$$

$$= min.\begin{cases} F'_{56.3°\ strut} = 727\ psi\ (Hankinson) \\ F'_{c\ king\ post} = 1{,}000\ psi * 1.15 = 1150\ psi \end{cases}$$

$$= \boxed{\mathbf{727\ psi > 382\ psi\ \therefore OK}}$$

Strut / King Post Joint - Shear Through King Post Relish





$f_v = 2V/A = \mathbf{72\ psi}$

$V = 1{,}290\#$

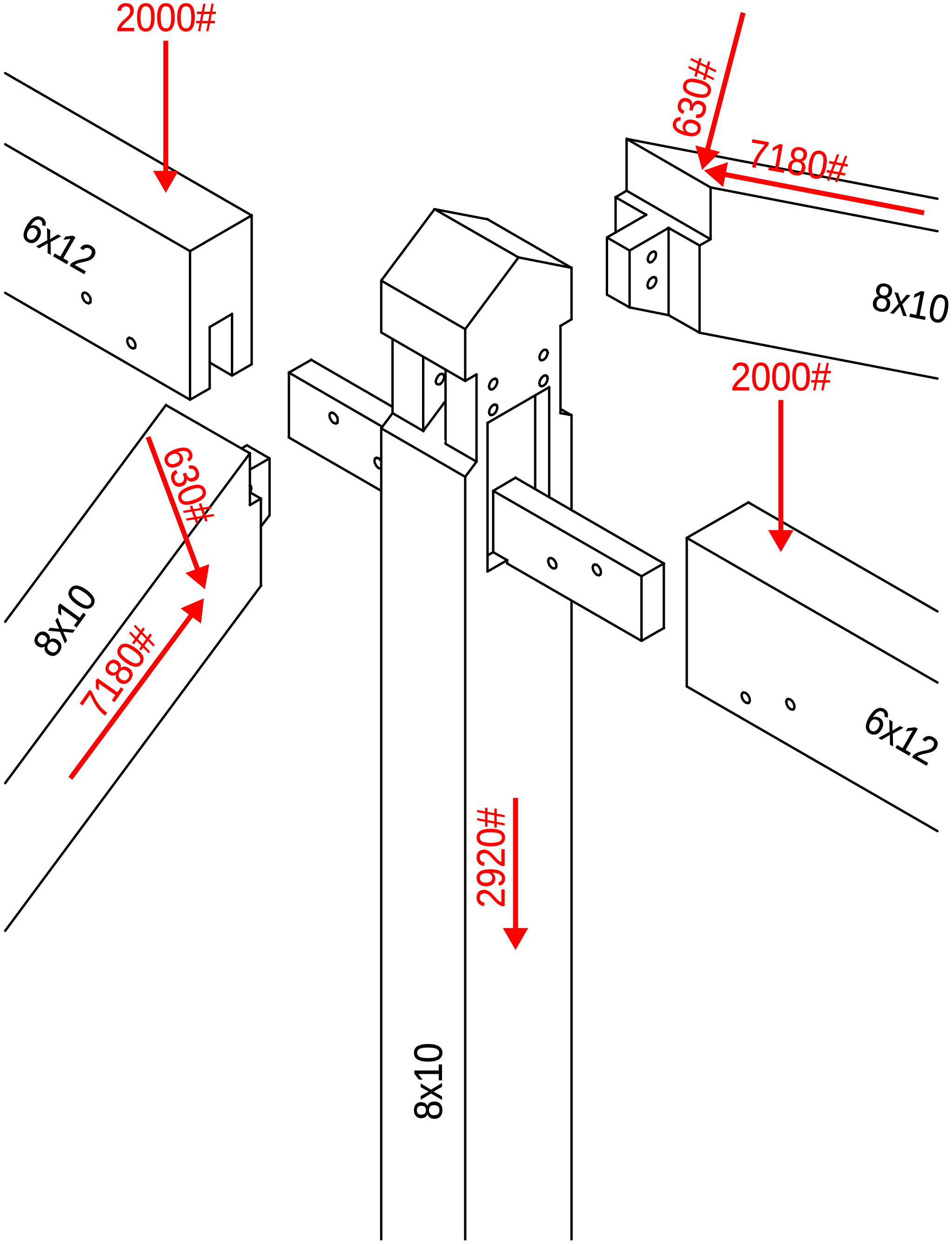
$A = (0.75" * 2 + 4.5") * 6" = 36\ in^2$

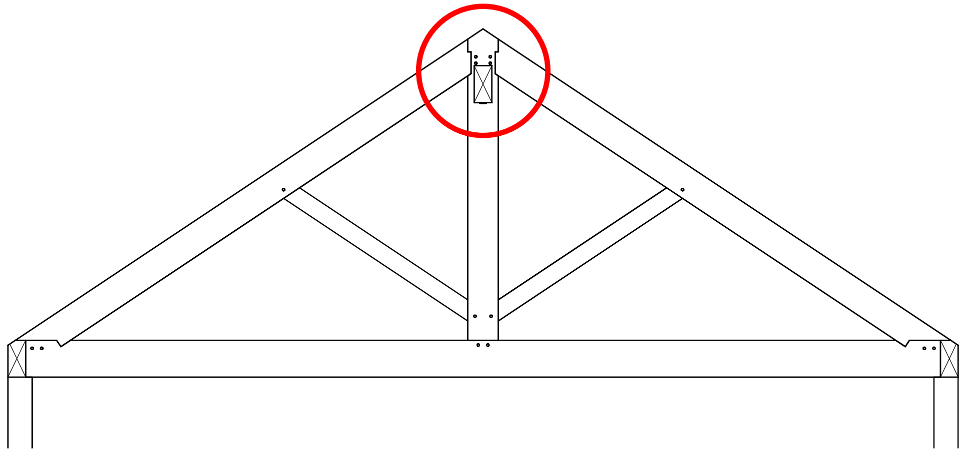
$F_v' = 170\ psi * 1.15$

$= \boxed{\mathbf{196\ psi > 72\ psi \quad OK}}$

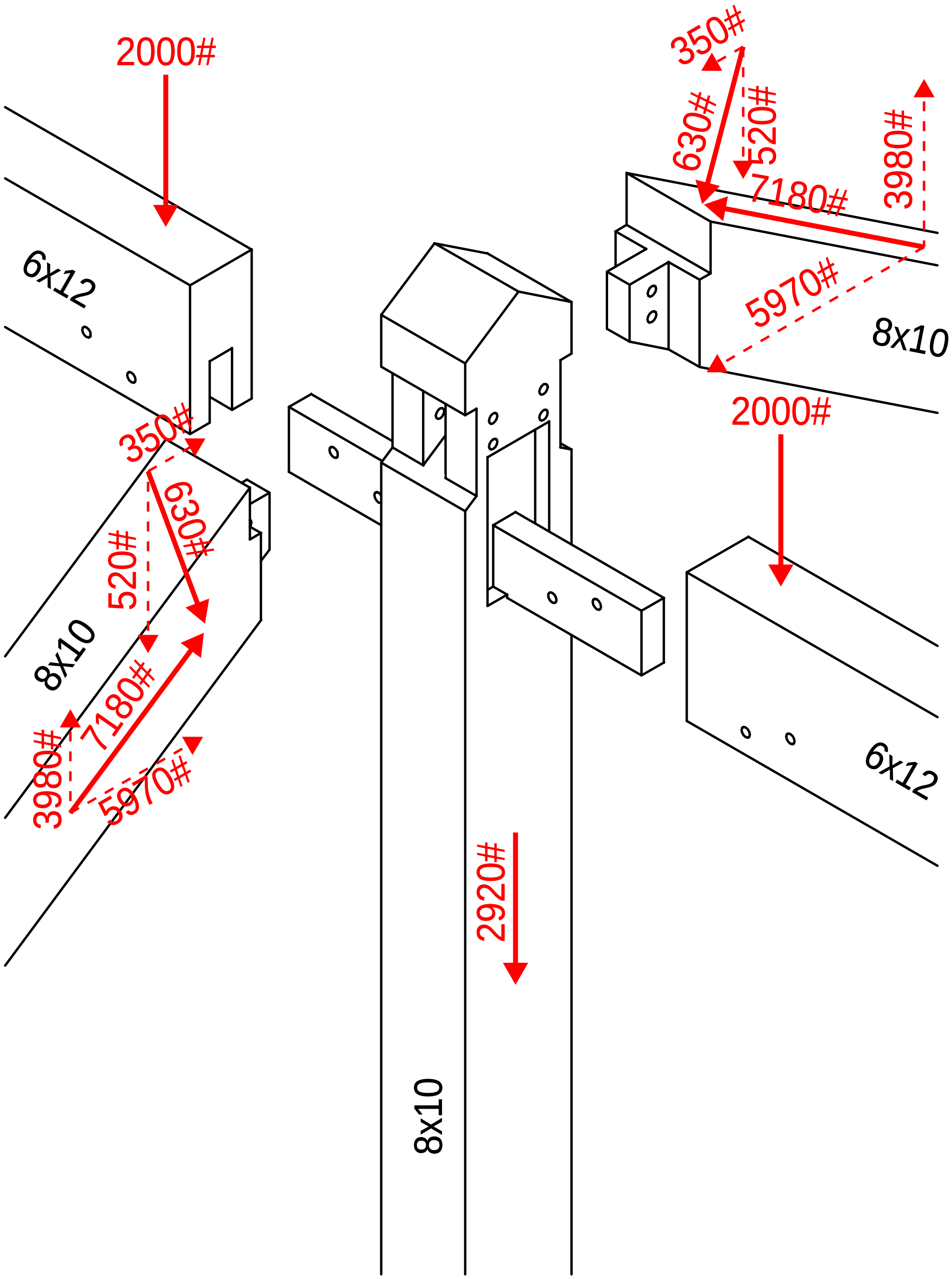
Updated on 10 March 2022 to conform with TFEC 1-2019, Section 3.6.

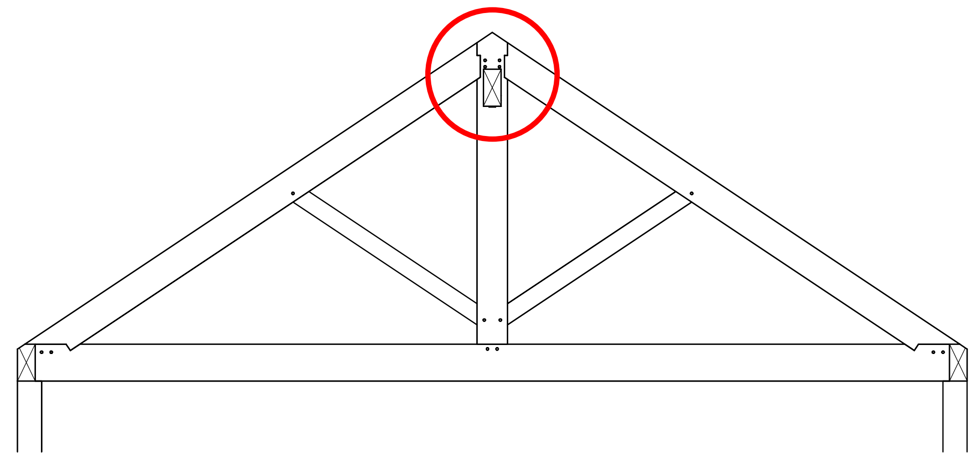
Rafter / King Post Joint





Rafter / King Post Joint

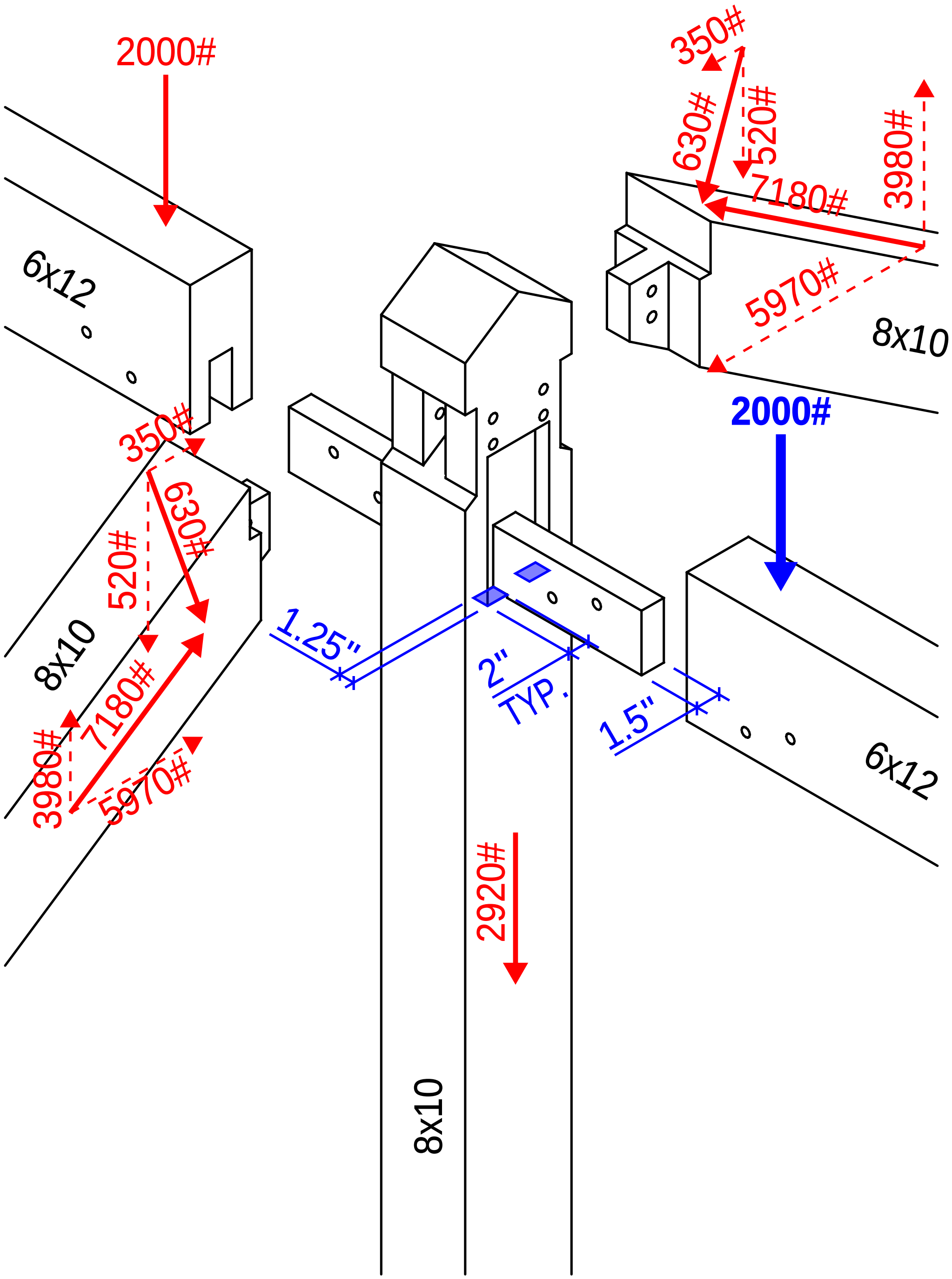




Failure Modes:

- Ridge Beam Bearing on King Post
- King Post Bearing on Rafters
- Shear Through King Post Relish
- King Post Tension at Reduced Section
- Rafter Compression over Effective Area at Connection

Rafter / King Post Joint - Ridge Beam Bearing on King Post



$$f_c = \frac{C}{A} = \mathbf{500\ psi}$$

$$C = 2{,}000\#$$

$$A = (1.25" - 0.25"\ shrinkage) * (5.5" - 1.5")$$

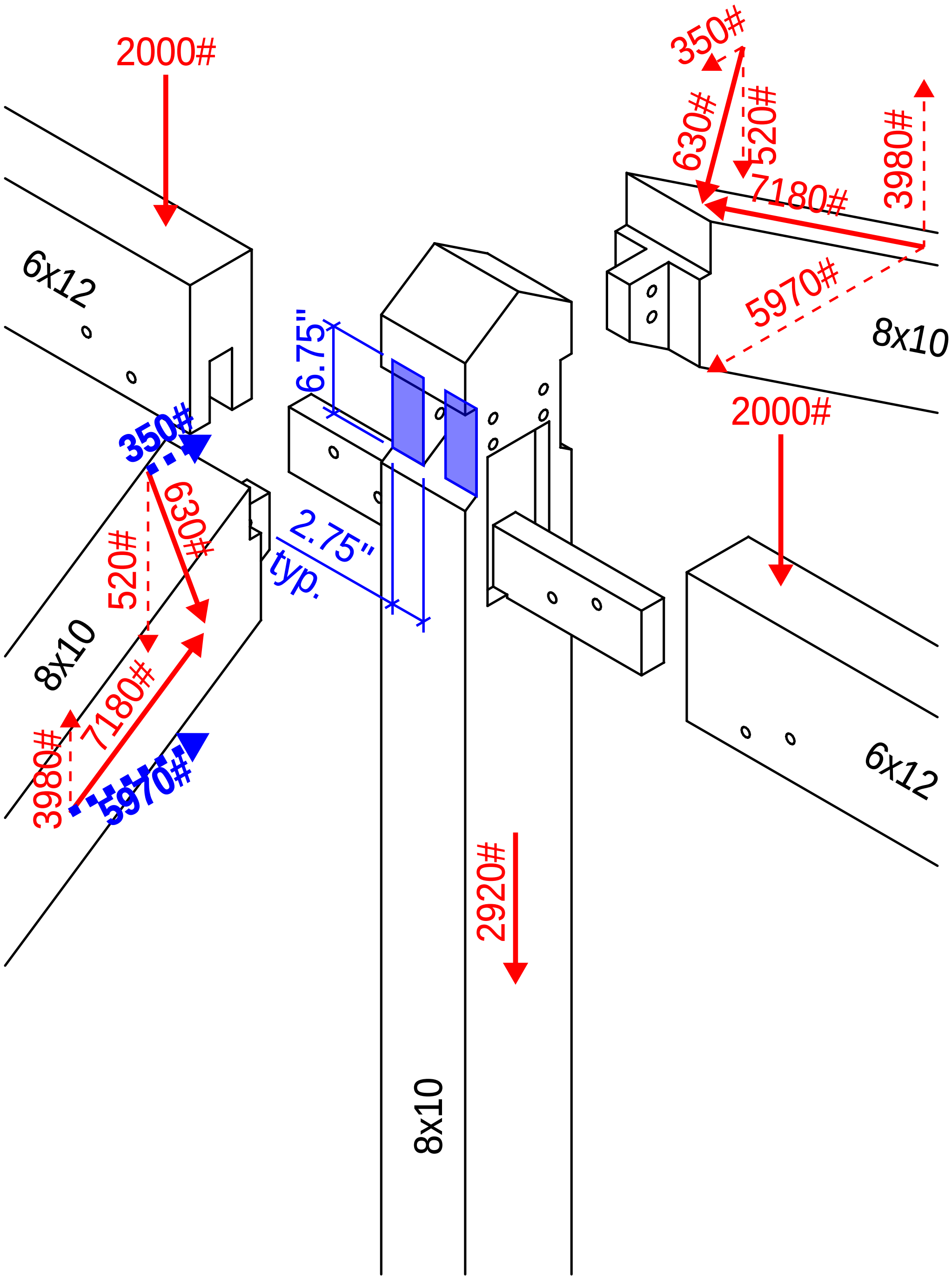
$$= 4.00\ in^2$$

$$F'_c$$

$$= min.\begin{cases} F'_{c\perp\, ridge} = 625\ psi \\ F'_{c\ king\ post} = 1{,}000\ psi * 1.15 = 1{,}150\ psi \end{cases}$$

$$= \boxed{\mathbf{625\ psi > 500\ psi\ \therefore OK}}$$

Rafter / King Post Joint - King Post Bearing on Rafters (Check 1)



$$f_c = \frac{C}{A} = \mathbf{170\ psi}$$

$$C = 5{,}970\# + 350\# = 6{,}320\#$$

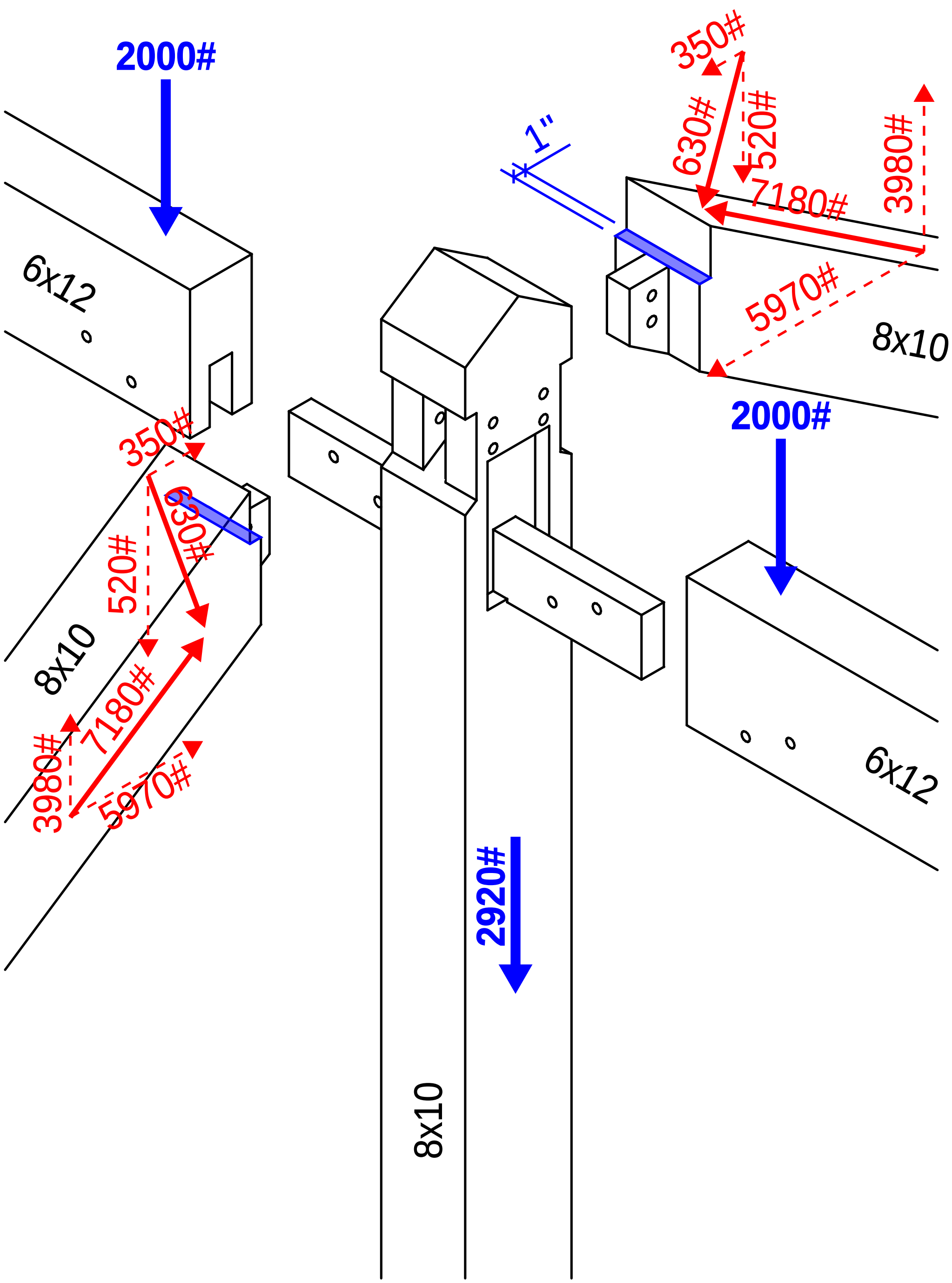
$$A = (6.75" * 2.75") * 2 = 37.1\ in^2$$

$$F_c'$$

$$= min. \begin{cases} F'_{c\perp\ king\ post} = 625\ psi \\ F'_{33.7°\ rafter} = 914\ psi\ (Hankinson) \end{cases}$$

$$= \boxed{\mathbf{625\ psi > 170\ psi\ \therefore OK}}$$

Rafter / King Post Joint - King Post Bearing on Rafters (Check 2)



$$f_c = \frac{C}{A} = \mathbf{461\ psi}$$

$$C = 2{,}920\# + 2{,}000\# + 2{,}000\# = 6{,}920\#$$

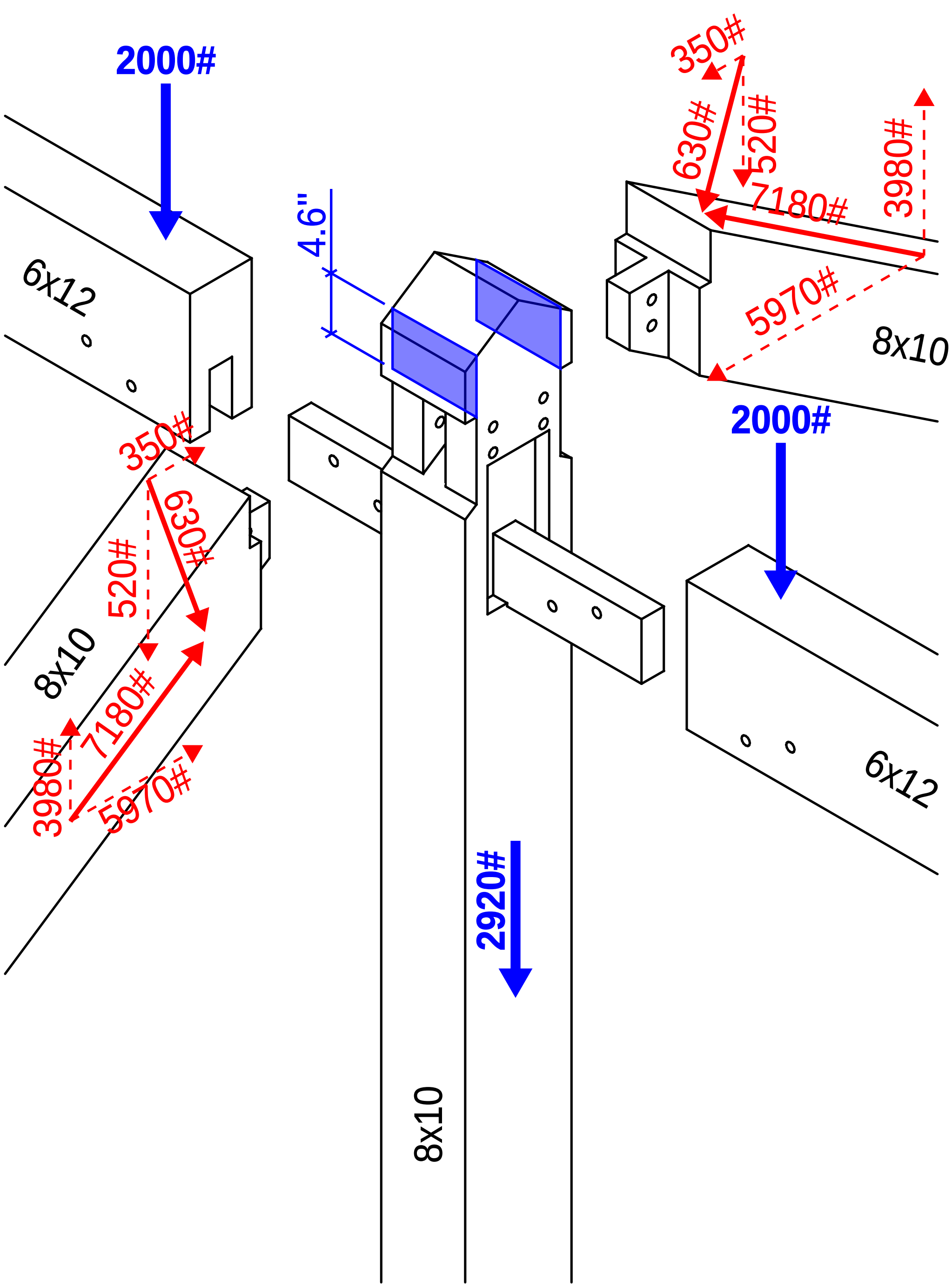
$$A = (1" * 7.5")2 = 15\ in^2$$

$$F'_c$$

$$= min. \begin{cases} F'_{c\ king\ post} = 1{,}000\ psi * 1.15 = 1{,}150\ psi \\ F'_{56.3°\ rafter} = 727\ psi\ (Hankinson) \end{cases}$$

$$= \boxed{\mathbf{727\ psi > 461\ psi\ \therefore OK}}$$

Rafter / King Post Joint - Shear Through King Post Relish



Conservatively neglecting rafter tenons

$f_v = 2V/A = \mathbf{200\ psi}$

$V = 2{,}920\# + 2{,}000\# + 2{,}000\# = 6{,}920\#$

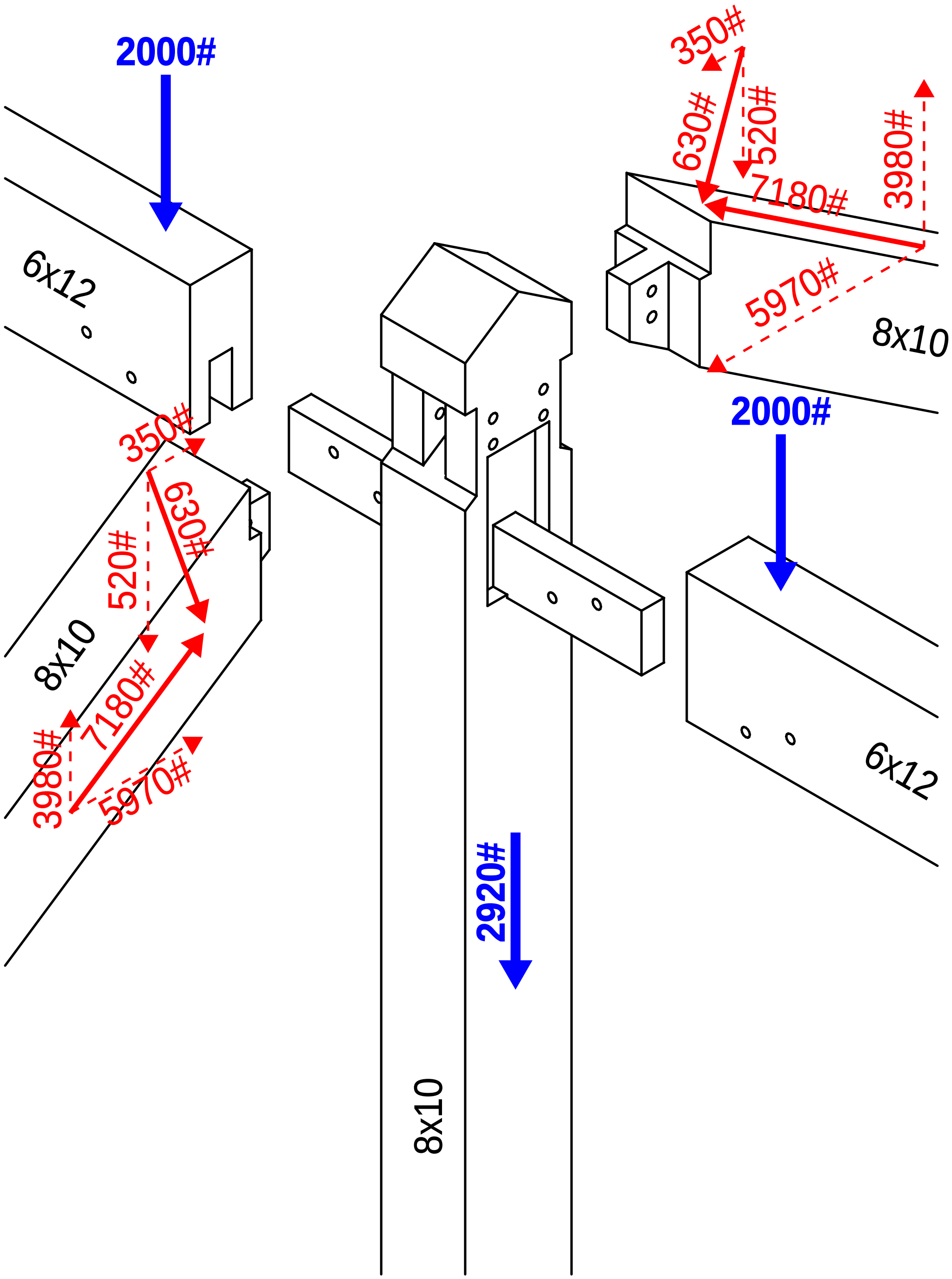
$A = (4.6" * 7.5") * 2 = 69.0\ in^2$

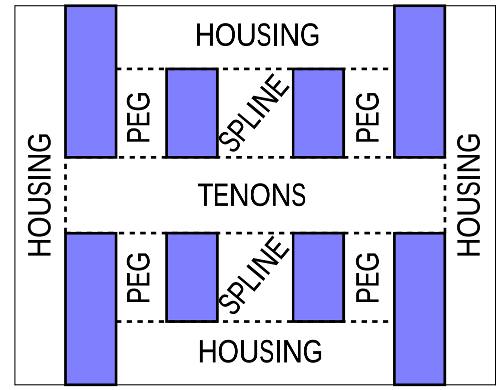
$F_v' = 170\ psi * 1.15$

$= \boxed{\mathbf{196\ psi} \approx \mathbf{200\ psi} \quad \mathbf{OK}}$

Updated on 10 March 2022 to conform with TFEC 1-2019, Section 3.6.

Rafter / King Post Joint - King Post Tension at Reduced Section





$$A = 19.0\ in^2$$

King Post Cross Section

$$f_t = \frac{T}{A} = \mathbf{364\ psi}$$

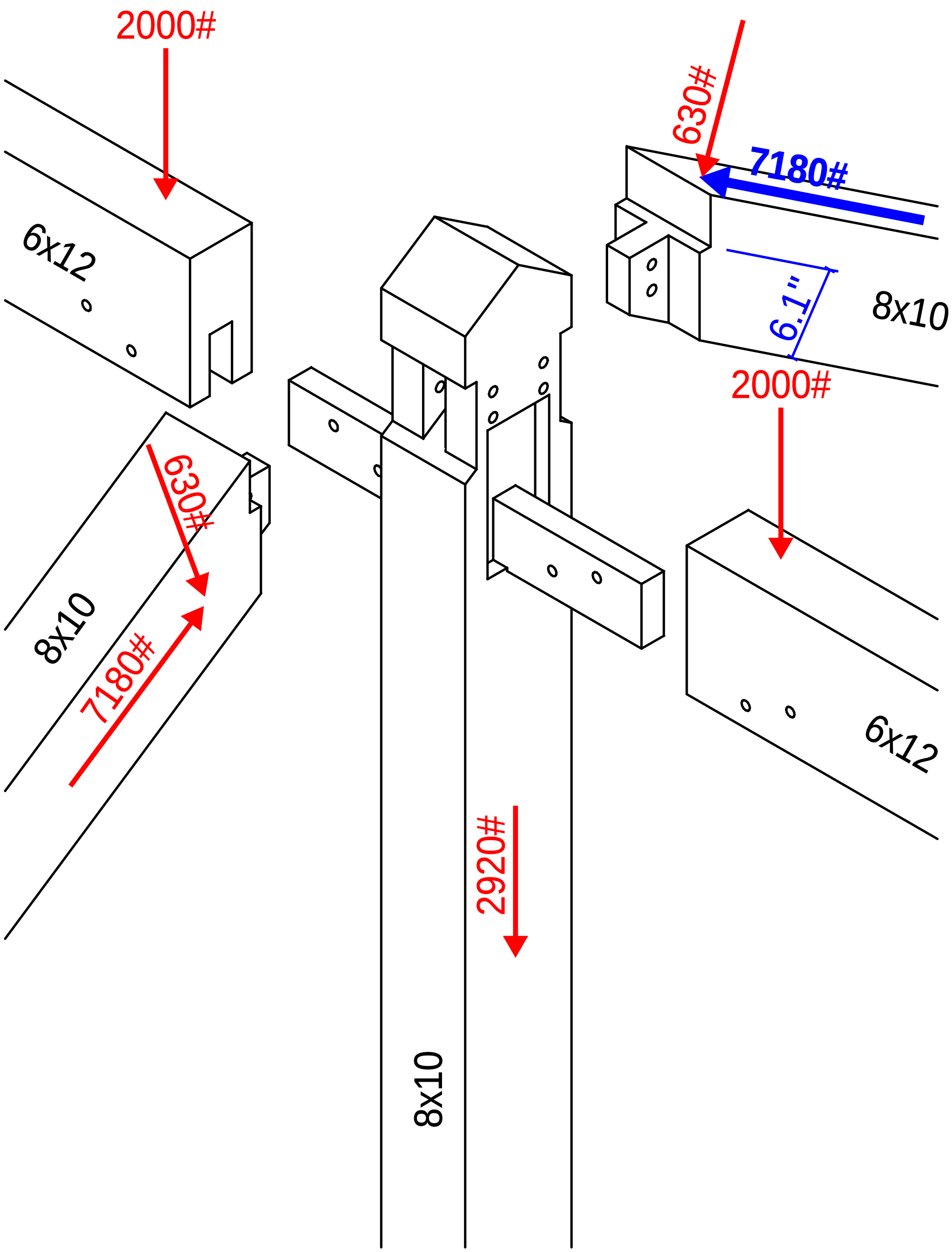
$$T = 2{,}920\# + 2{,}000\# + 2{,}000\# = 6{,}920\#$$

$$A = 19.0\ in^2$$

$$F_t' = 825\ psi * 1.15$$

$$= \boxed{\mathbf{949\ psi > 364\ psi\ \therefore\ OK}}$$

Rafter / King Post Joint - Rafter Compression Over Effective Area at Connection



$$f_c = \frac{C}{A} = \mathbf{157\ psi}$$

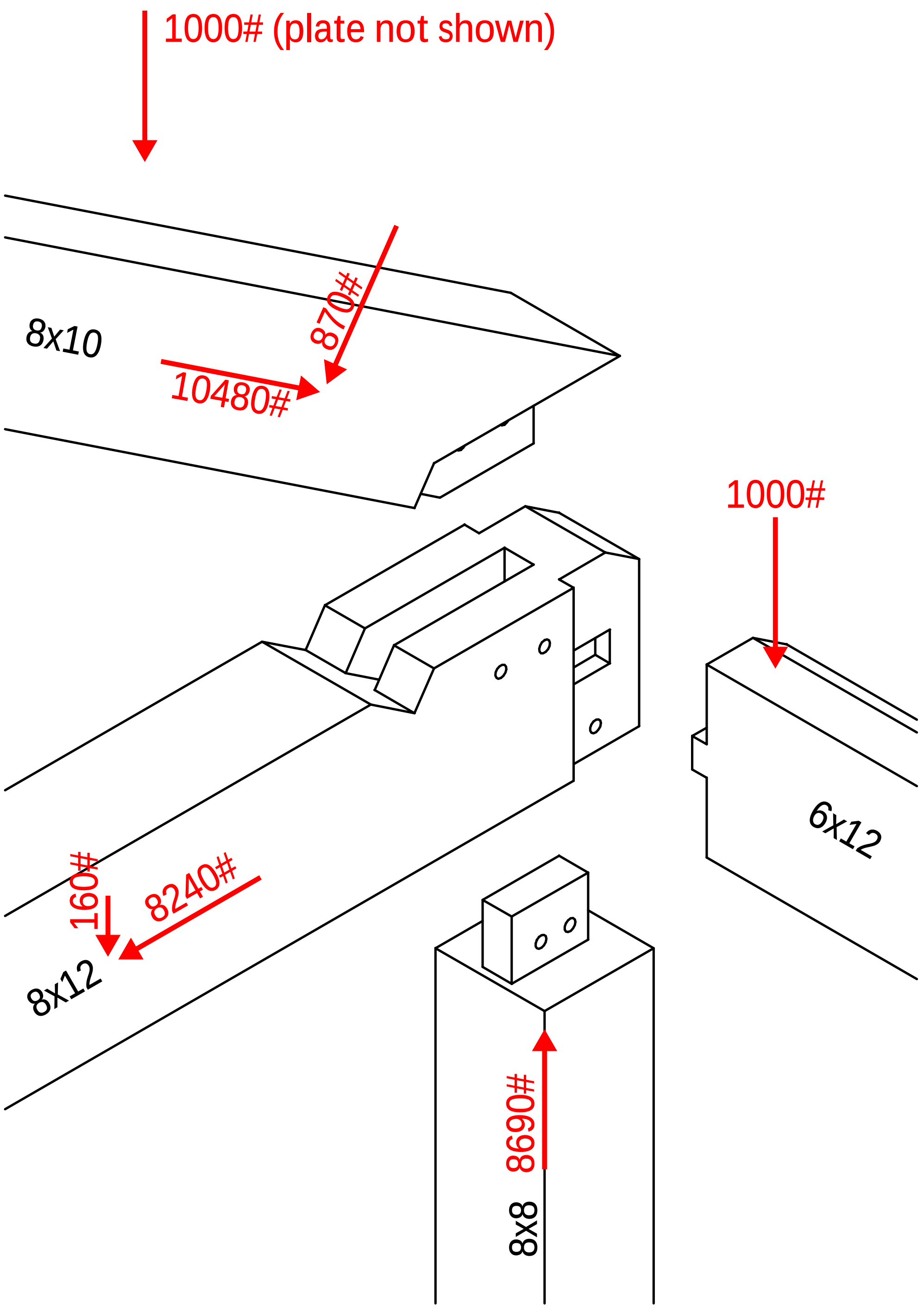
$$C = 7{,}180\#$$

$$A = 6.1" * 7.5" = 45.8\ in^2$$

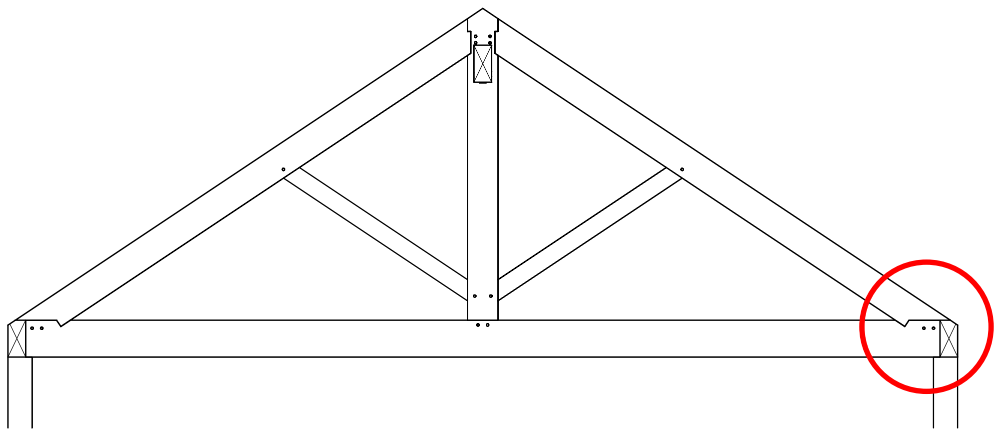
$$F_c' = 1{,}000\ psi * 1.15$$

$$= \boxed{\mathbf{1,150\ psi > 157\ psi\ \therefore\ OK}}$$

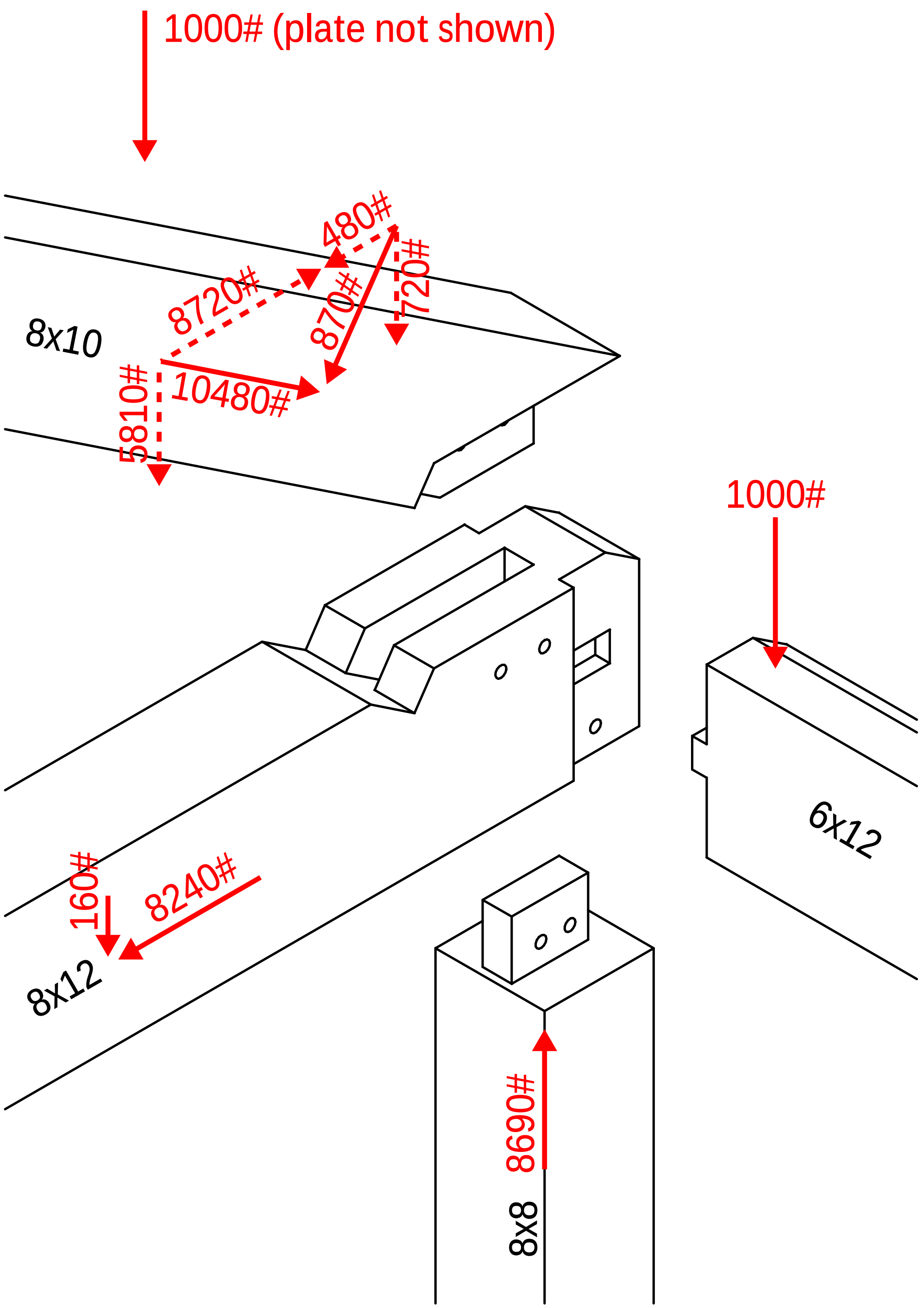
Heel Joint

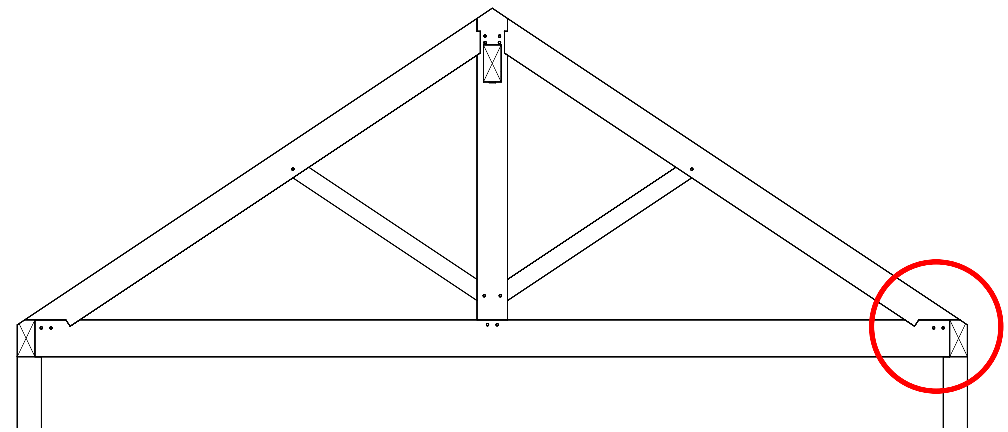


1000# (plate not shown)
8x10
870#
10480#
1000#
6x12
160#
8240#
8x12
8690#
8x8



Heel Joint





Failure Modes:

- Plate Bearing on Post

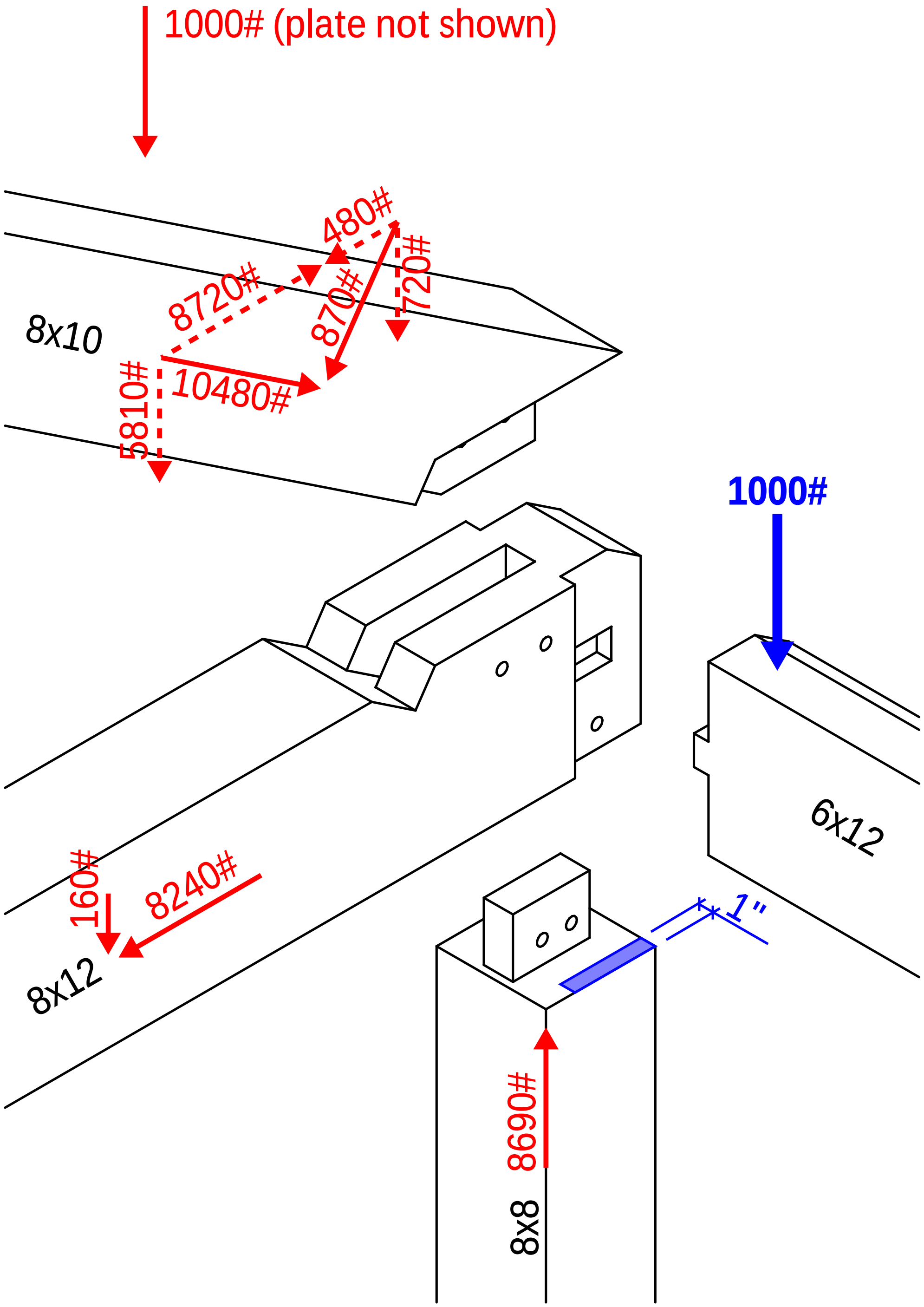
- Rafter Bearing on Tie

- Shear Through Tie Relish

- Tie Tension at Reduced Section

- Tie Bearing on Post

Heel Joint - Plate Bearing on Post



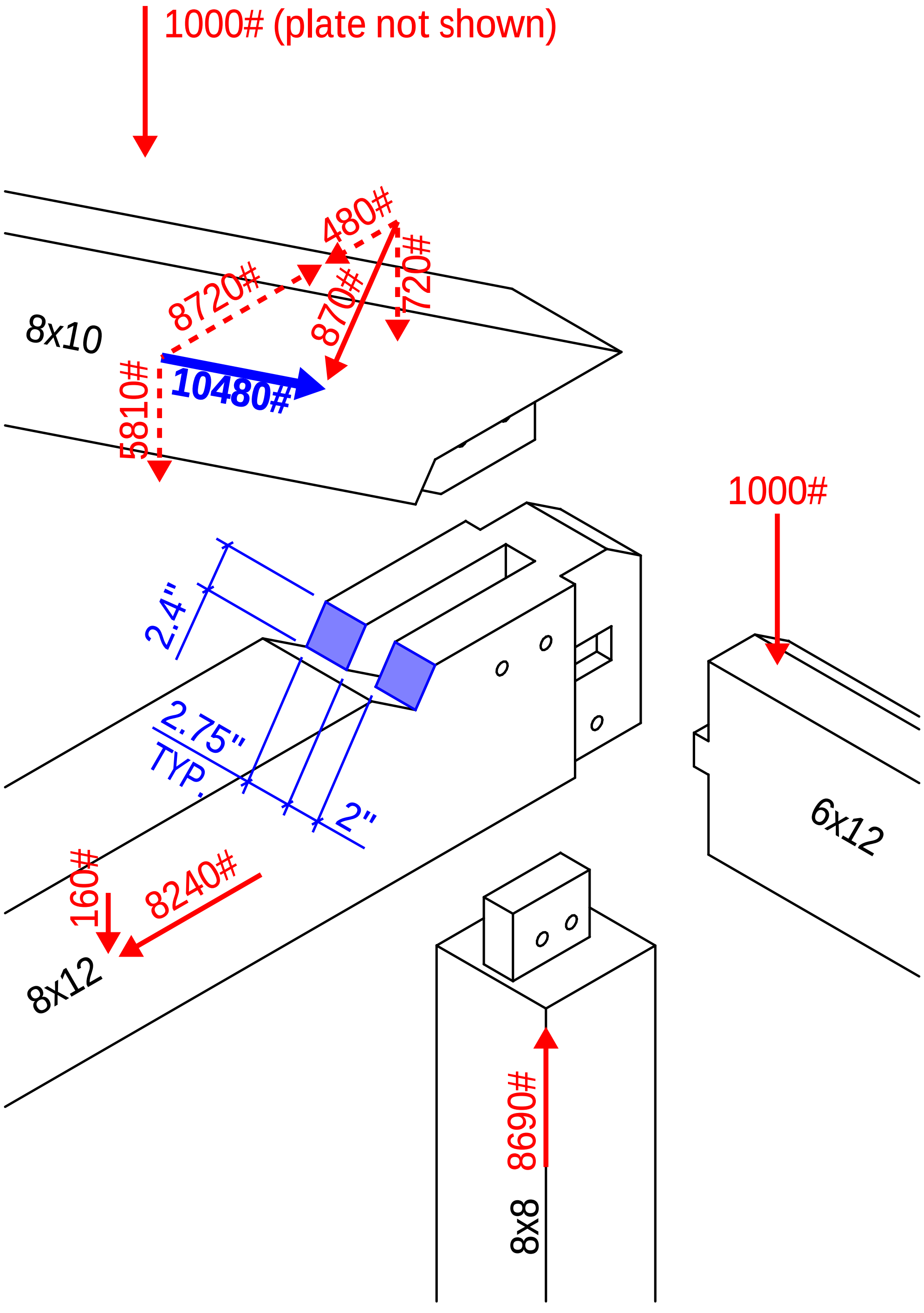
$$f_c = \frac{C}{A} = \mathbf{242\ psi}$$

$$C = 1{,}000\#$$

$$A = (1" - 0.25"\ shrinkage) * (5.5")$$
$$= 4.13\ in^2$$

$$F'_c$$
$$= min. \begin{cases} F'_{c\perp\ plate} = 625\ psi \\ F'_{c\ post} = 1{,}000\ psi * 1.15 = 1{,}150\ psi \end{cases}$$
$$= \boxed{\mathbf{625\ psi > 242\ psi\ \therefore OK}}$$

Heel Joint - Rafter Bearing on Tie



$$f_c = \frac{C}{A} = \mathbf{793\ psi}$$

$$C = 10{,}480\#$$

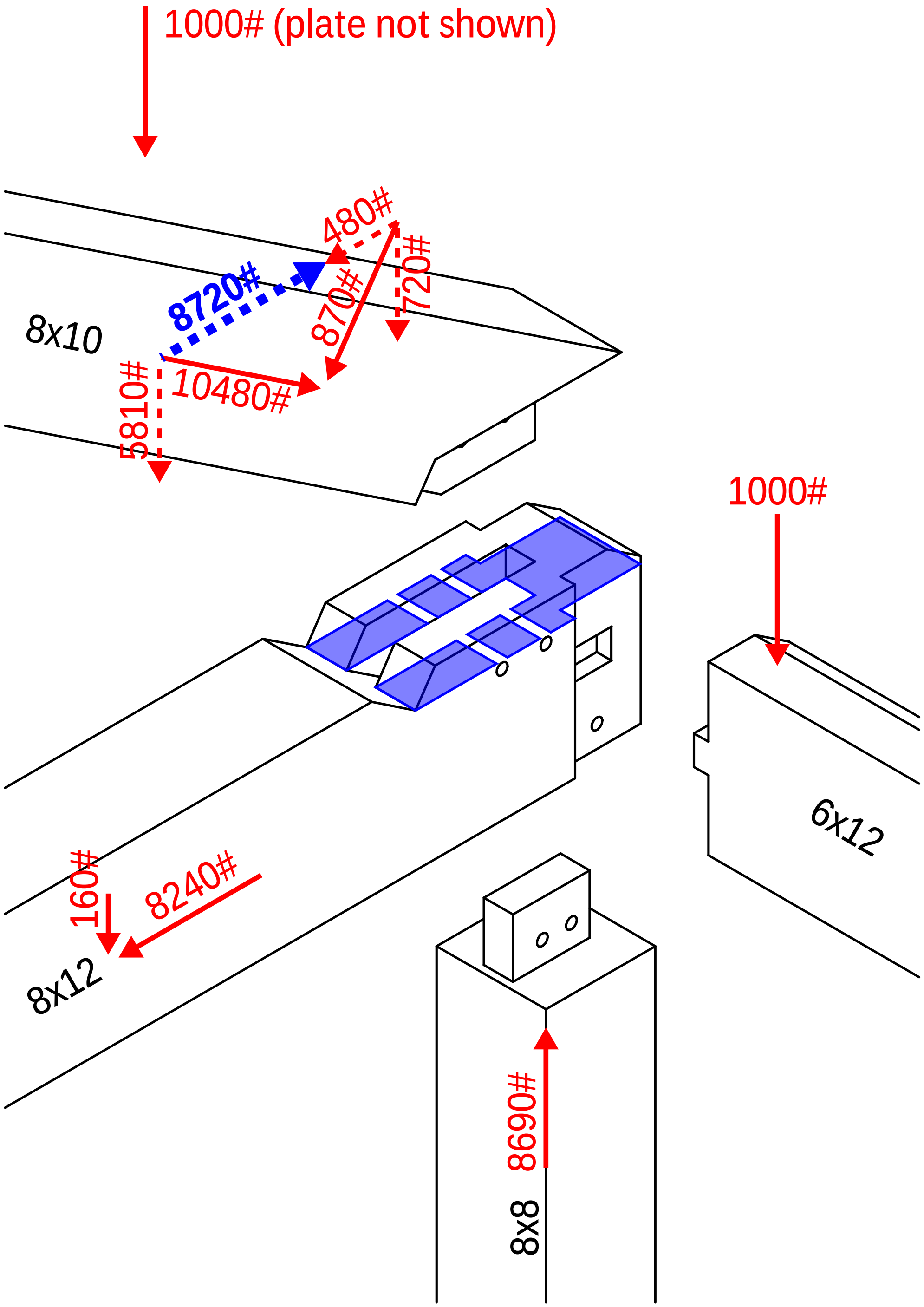
$$A = (2.4" * 2.75") * 2 = 13.2\ in^2$$

$$F_c'$$

$$= min. \begin{cases} F'_{33.7°\ tie} = 875\ psi\ (hankinson) \\ F'_{c\ rafter} = 1{,}000\ psi * 1.15 = 1{,}150\ psi \end{cases}$$

$$= \boxed{\mathbf{875\ psi > 793\ psi\ \therefore OK}}$$

Heel Joint - Shear Through Tie Relish



$f_v = 2V/A = \mathbf{218\ psi}$

$V = 8{,}720\#$

$A = 79.8\ in^2$

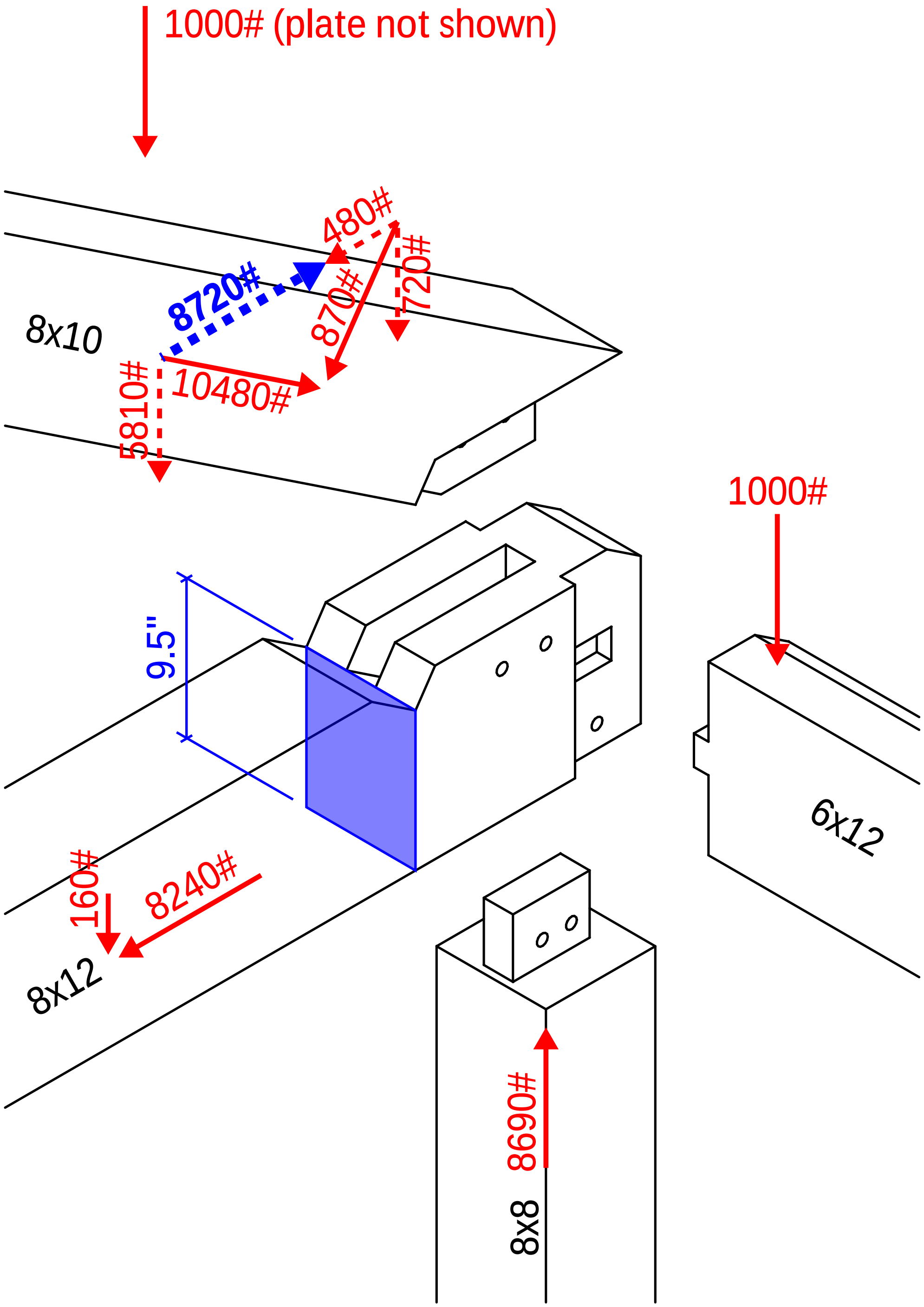
$F_v' = 170\ psi * 1.15$

$= \boxed{\mathbf{196\ psi < 218\ psi \quad NG}}$

The shear plane is 11% overstressed. Increase the area of the shear plane by using a stub tenon for alignment and eliminating the pegs. Secure the heel joint with self-tapping screws.

Updated on 10 March 2022 to conform with TFEC 1-2019, Section 3.6.

Heel Joint - Tie Tension at Reduced Section



$$f_t = \frac{T}{A} = \mathbf{122\ psi}$$

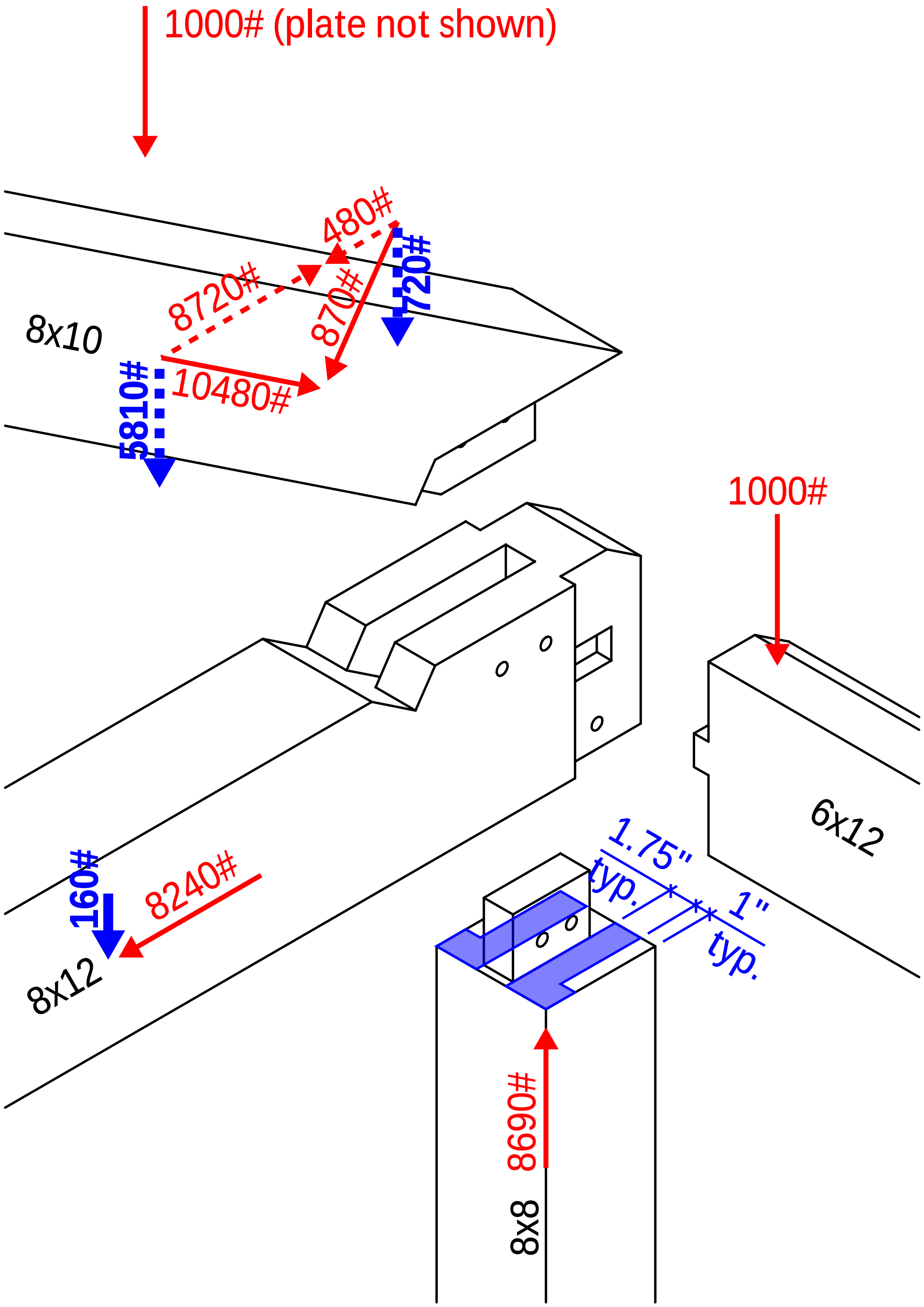
$$T = 8{,}720\#$$

$$A = 9.5" * 7.5" = 71.3\ in^2$$

$$F_t' = 675\ psi * 1.15$$

$$= \boxed{\mathbf{776\ psi > 122\ psi\ \therefore\ OK}}$$

Heel Joint - Tie Bearing on Post



$$f_c = \frac{C}{A} = \mathbf{221\ psi}$$

$$C = 5{,}810\# + 720\# + 160\# = 6{,}690\#$$

$$A = 30.3\ in^2$$

$$F'_c = min.\begin{cases} F'_{c\perp\ tie} = 625\ psi \\ F'_{c\ post} = 1{,}000\ psi * 1.15 = 1{,}150\ psi \end{cases}$$

$$= \boxed{\mathbf{625\ psi > 221\ psi\ \therefore OK}}$$

Thank You

Questions?
Comments?