# Design Example
# TD40

## Tension Member
## +
## End Connection

N.M. Holtz

Feb 13, 2020

Revisions:

- Feb 14, 2020 - Original posting.

Design tension member + end connections for $T_f$ = 800 kN.

| | | |
|---|---|---|
| Angles & plates - | 300W | $F_y$ = 300 MPa, $F_u$ = 440 MPa |
| HSS | 350W | $F_y$ = 350 MPa, $F_u$ = 450 MPa |
| Bolts | A325 | $F_u$ = 825 MPa |
| Welds | E49xx | $X_u$ = 490 MPa |

## 1. Main Member

Estimate $A_n = 0.9 A_g$

$A_{ne} = 0.85 A_n$

from net area fracture

$T_r = \phi_u A_{ne} F_u$

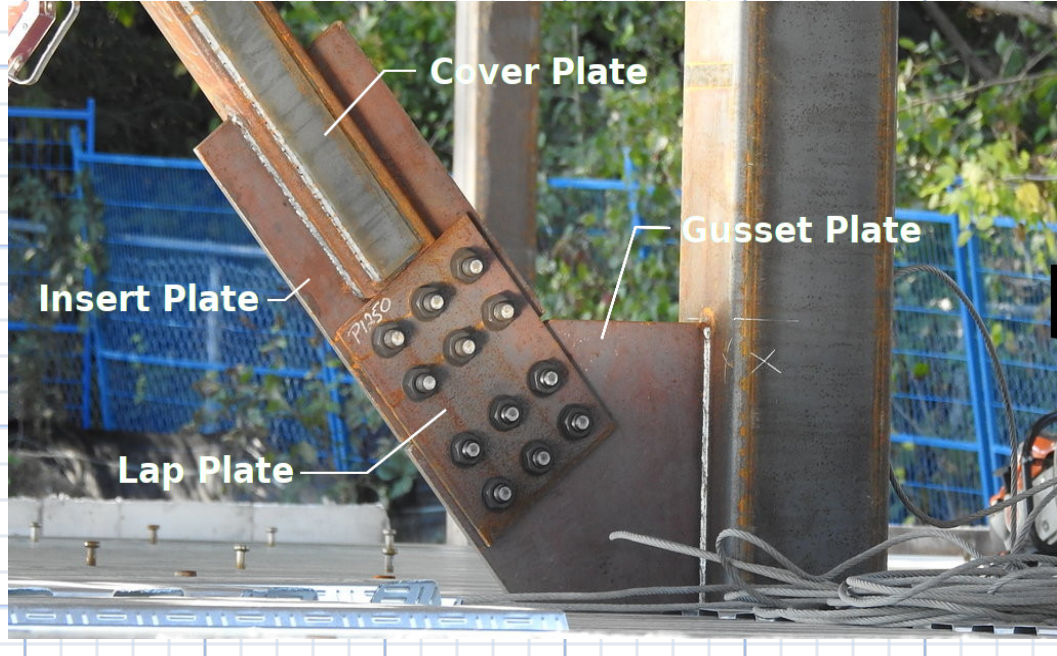
$= \phi_u \times 0.85 \times 0.9 \times A_g \times 0.45 \frac{kN}{mm^2} \geq 800\ kN$

$A_g \geq 2582\ mm^2$

Try HSS 127 x 127 x 6.4

$A = 2960\ mm^2$

In an arrangement similar to this:



## Bolting details

min spacing = 2.7 x 19.05 = 51.4mm. §22.3.1

min edge = 25mm (rolled edge) Table 6
32mm (cut edge)

min end distance = 32 mm (cut end) Table 6

max edge distance: 12t ≤ 150 §22.3.3

## 2. Bolting Requirements

$\frac{3}{4}$" A325 bolts in 22mm punched holes

bearing-type connection, threads intercepted

$A_b = \pi \times (\frac{3}{4} \times 25.4)^2/4 = 285\ mm^2$ Double Shear

1 bolt: $V_r = 0.6 \phi_b n_m A_b F_u \times 0.7$

$= 0.6 \times 0.8 \times 1 \times 2 \times 285\ mm^2 \times 0.825 \frac{kN}{mm^2} \times 0.7$

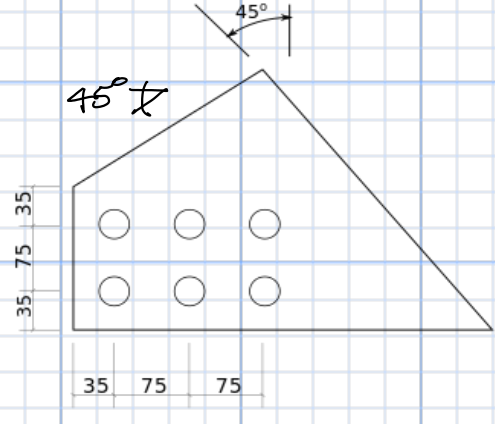
$= 158\ kN$ (or see Table 3-4)

# of bolts reqd $= \frac{800}{158} = 5.06$

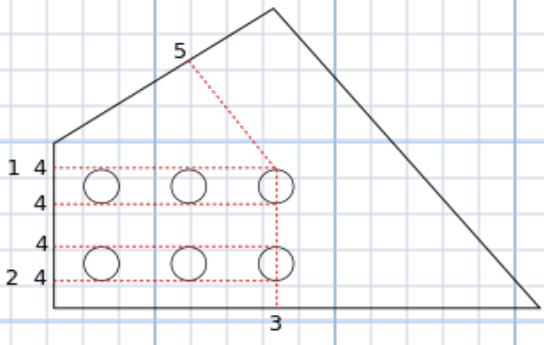
Try 6 bolts in a 2 x 3 pattern.

(to keep connection narrow)

## 3. Gusset Plate




Compute capacity of 1mm thick, then compute reqd thickness.




## 3.1 Block Shear - Path 1-2

$$A_n = \left(75 - \frac{24}{2} \times 2\right) \times 1 = 51 \text{ mm}^2$$

$$U_t = 1.0$$

$$A_{gv} = 2 \times (35 + 75 + 75) \times 1 = 370 \text{ mm}^2$$

$$v_{r_1} = 0.75\left[1 \times 51 \times .44 + .6 \times 370 \times \frac{.30 + .44}{2}\right]$$

$$= 78.44 \text{ kN/mm of thickness}$$

## 3.2 Block Shear - Path 1-3

$$A_n = (35 + 75 - \tfrac{24}{2} \times 3) \times 1 = 74 \text{ mm}^2$$

$$U_t = 0.6 \quad \text{(conservative)}$$

$$A_{gv} = 1 \times (35 + 75 + 75) \times 1 = 185 \text{ mm}^2$$

$$v_{r_2} = 0.75(0.6 \times 74 \times .44 + .6 \times 185 \times .37)$$

$$= 45.45 \text{ kN/mm} \longleftarrow \text{governs}$$

## 3.3 Tearout - Path 4-4-4-4

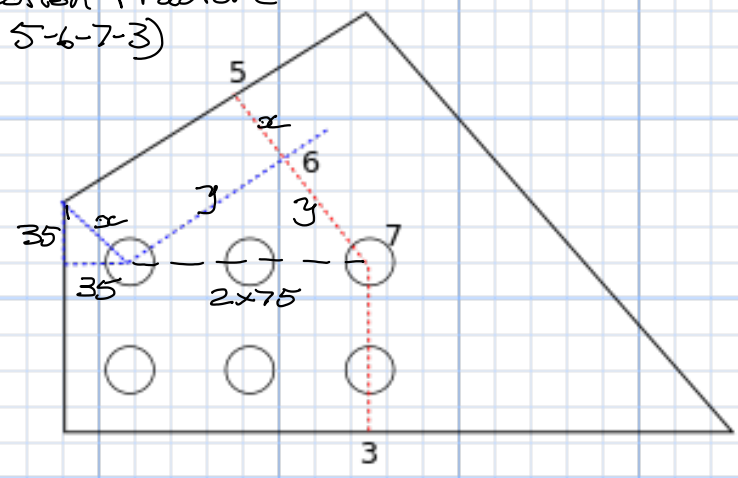
$$A_n = 0$$

$$A_{gv} = 4 \times 185 = 740 \text{ mm}^2$$

$$v_{r_3} = .75 \times .6 \times 740 \times .37$$

$$= 123 \text{ kN/mm}$$

3.4 Net Section Fracture (Path 5-6-7-3)

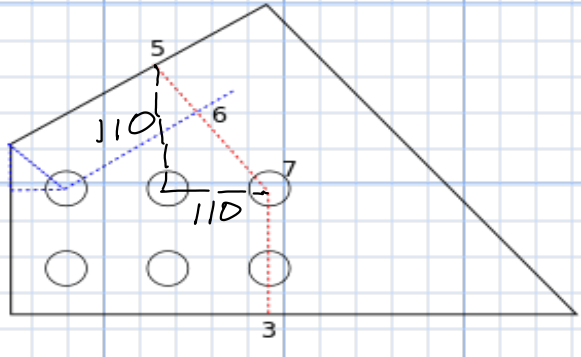



dist 5-6 = $x = \sqrt{35^2 + 35^2}$ = 49.5 mm.

dist 6-7 = $y = 150/\sqrt{2}$ = 106.1 mm

dist 5-7 = x+y = 155.6 mm

dist s = g = $\frac{155.6}{\sqrt{2}}$ = 110 mm




$A_{ne} = (35 + 75 + 155.6 - 2 \times 24 + \frac{110^2}{4 \times 110}) \times 1$

$= 245.1 \text{ mm}^2$

$tr_t = 0.75 \times 245.1 \times 0.44$

$= 80.87 \text{ kN}$ / mm of thickness

3.5 Bearing Resistance

$$B_r = 3\phi_{br} \times n \times d \times t \times F_u$$
$$= 3 \times 0.8 \times 6 \times 19.05 \times 1 \times 0.440$$
$$= 120.7 \text{ kN}$$

Block Shear path 1-3 governs

$$b_r = 45.45 \text{ kN/mm}$$

Req'd thickness

$$\frac{800}{45.45} = 17.6 \text{ mm.}$$

3.7 Try 20 mm Gusset Plate

## 4: Insert Plate

Plate - slotted into HSS - must be same thickness as gusset

Width required:

4.1 - Gross Area Yield:

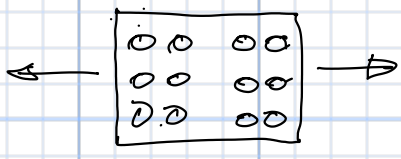
$$0.9 \times wt \times 0.30 \geq 800$$
$$w \geq 148 \text{ mm.}$$

4.2 - Net section Fracture

$$0.75(w - 2 \times 24) \times 20 \times 0.44 \geq 800$$
$$w \geq \frac{800}{.75 \times 20 \times .44} + 48$$
$$w \geq 169 \text{ mm.}$$

this leads to edge dist of $\frac{169-75}{2} = 50\,mm.$

Might be better to use 3x2 arrangement



reqd width, net section fracture

$$w \geq \frac{800}{.75 \times 20 \times .44} + 3 \times 24$$

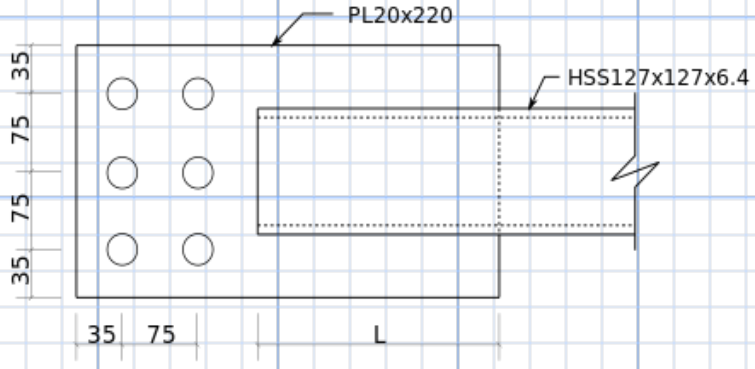
$$w \geq 193.2\,mm.$$

using min edge distance

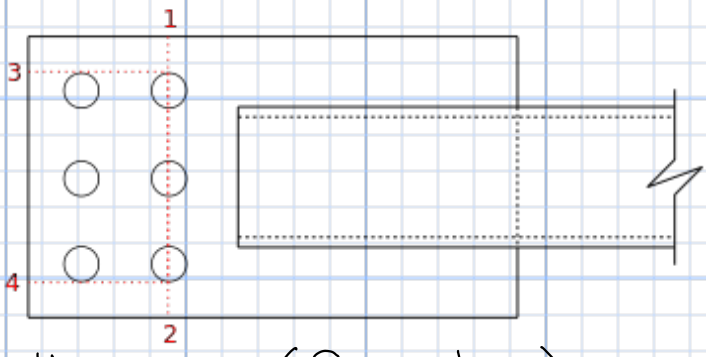
$$w = 32 + 75 + 75 + 32 = 214\,mm.$$

4.3 try 220 mm wide plate

35 mm edge distance
35 mm end distance



## 5. Insert Plate - Bolted End




Gross Area Yield Ok (from above)
Net Sect Fracture Ok (from above)

### 5.1 Block Shear - Path 3-2

$A_n = (75+75+35 - 2.5\times24)\times20 = 2500\ mm^2$

$U_t = 0.6$

$A_{gv} = (35+75)\times20 = 2200\ mm^2$

$T_r = 0.75\left[0.6\times2500\times.44 + 0.6\times2200\times\frac{.3+.44}{2}\right]$

$= 861\ kN > 800\ kN$ Ok

### 5.2 Block Shear - Path 3-4

$A_n = (75+75-2\times24)\times20 = 2040\ mm^2$

$U_t = 1.0$

$A_{gv} = 2\times(35+75)\times20 = 4400\ mm^2$

$T_r = 0.75[1\times2040\times.44 + .6\times4400\times.37]$

$= 1406 > 800\ kN$ Ok

### 5.3 Tearout

$A_n = 0$

$A_{gv} = 6(35+75)\times20 = 13200\ mm^2$

$T_r = 0.75\times0.6\times13200\times.37$

$= 2198\ kN > 800\ kN$ Ok

### 5.4 Bearing

Ok (from 3.5, above)

## 6. Insert Plate - Welded End

### 6.1 Size, and Length, $L_y$ of Weld

Min weld size, $t = 20$ mm

for $12 \leq t \leq 20$ $\quad D_{min} = 6$ $\quad$ (p 6-186)

Longer welds are preferable wrt shear lag in the HSS. Therefore use min size weld

$D = 6$ mm.

1 mm of 6mm fillet weld, $\theta = 0°$

$v_r = 0.67\, \phi_w\, A_w\, X_u$ $\quad$ §13.13.2.2

$= 0.67 \times 0.67 \times 0.707 \times 6 \times 1 \times 0.49$

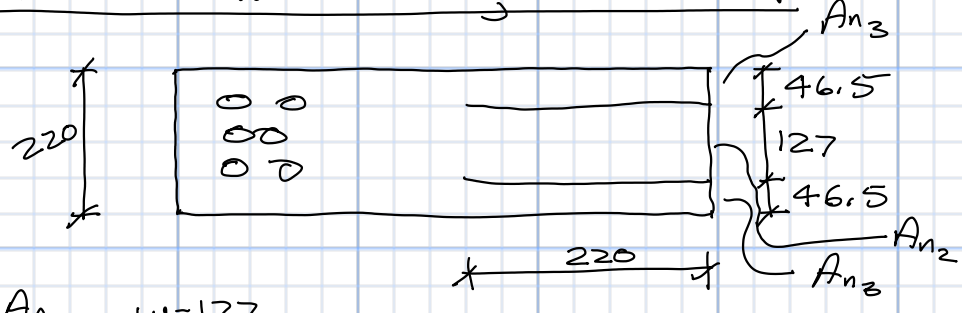
$v_r = 0.933$ kN $\quad$ (also see Table 3-24b)

$4L \times 0.933 \geq 800$

$L \geq 214.2$ mm.

Try 220 mm of weld in 4 locations

### 6.3 Net Section Fracture, Welded End




$A_{n_2}$ $\quad w = 127$

$L = 220$

$t = 20$

$2w \geq L \geq w$

$\therefore A_{n_2} = .5wt + .25Lt$ $\quad$ §12.3.3.3. b) ii)

$= .5 \times 127 \times 20 + .25 \times 220 \times 20$

$= 2370\ mm^2$

$A_{n_3}$: $w = 46.5$
$L = 220$
$t = 20$

$\bar{x} = \frac{w}{2} = 23.25$

$A_{n_3} = \left(1 - \frac{23.25}{220}\right) \times 46.5 \times 20$

$A_{n_3} = 831.7 \text{ mm}^2$

$A_{ne} = 2A_{n_3} + A_{n_2}$
$= 2 \times 831.7 + 2370$
$= 4033 \text{ mm}^2$

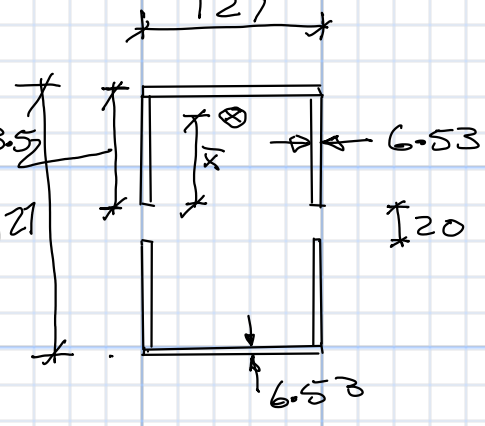
$T_r = 0.75 A_{ne} F_u$
$= 0.75 \times 4033 \times 0.44$
$= 1331 \text{ kN} > 800 \text{ kN}$ OK.

∴ Insert Plate OK

## 7. HSS Net Section Fracture

HSS 127 x 127 x 6.4

$t = 6.53 \text{ mm}$
$A_g = 2960 \text{ mm}^2$




$A_n = 2960 - 2 \times 20 \times 6.53$
$= 2706 \text{ mm}^2$

From § 12.3.3.4

Fig on page 7-88 CISC HB with

$d = 127$

$b = 53.5$

$t = w = 6.35$

$A = dw + 2(b-w)t = 1405$

$\bar{x} = b - x$

$= 53.5 - \frac{1}{2A}\left((d-2t)w^2 + 2tb^2\right)$

$= 38.93 \text{ mm}$

$\bar{x}/L = 38.93/220 = 0.177$

$\bar{x}/L > 0.1$

$\therefore A_{ne} = (1.1 - 0.177) A_n$

$= 0.923 \times 2706$

$= 2498 \text{ mm}^2 \quad > 0.8 A_n$

$T_r = 0.75 \times 2498 \times 0.45$

$T_r = 843 \text{ kN} > 800 \text{ kN}$ Ok

$\therefore$ HSS 127 x 127 x 6.4

## 8. Lap Plates

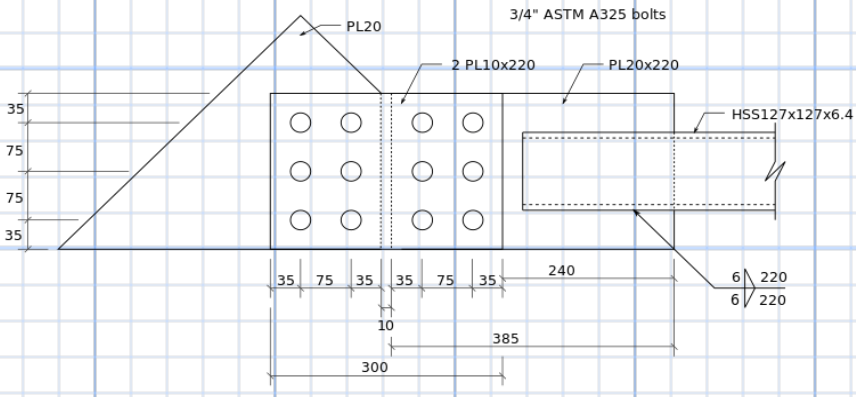
Use 2 PL 10 x 220

As thickness of 2 = thickness of insert plate, nothing need be checked. All Ok.

## 9. Gusset Plate

Bolt arrangement changed since checked in step 3. But all Ok as per step 6.

## 10. Summary




## 11. Comments & Observations

a. Probably would have been better to start with the design of the insert plate in step 3, rather than the gusset. Would have more quickly determined the bolt pattern.

b. In step 7, if net section fracture $T_r < T_f$ you would have these remedies:
   i) decrease t of insert plate
   ii) increase L of weld
      - neither of these would help much
   iii) increase size of HSS (perhaps next larger thickness)
   iv) add cover plate to HSS (see photo)