STRUCTURAL STEEL DESIGN

Tension Members
-5-

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Pin-Connected Members

Tension members connected with a single pin as diagonal bracing are subject to the failure modes covered in Section D5 of the AISC specification .There are three main failure modes that need to be checked for pin-connected members :tensile rupture on the net area , shear rupture on the effective area and bearing on the projected area of the pin as shown below :

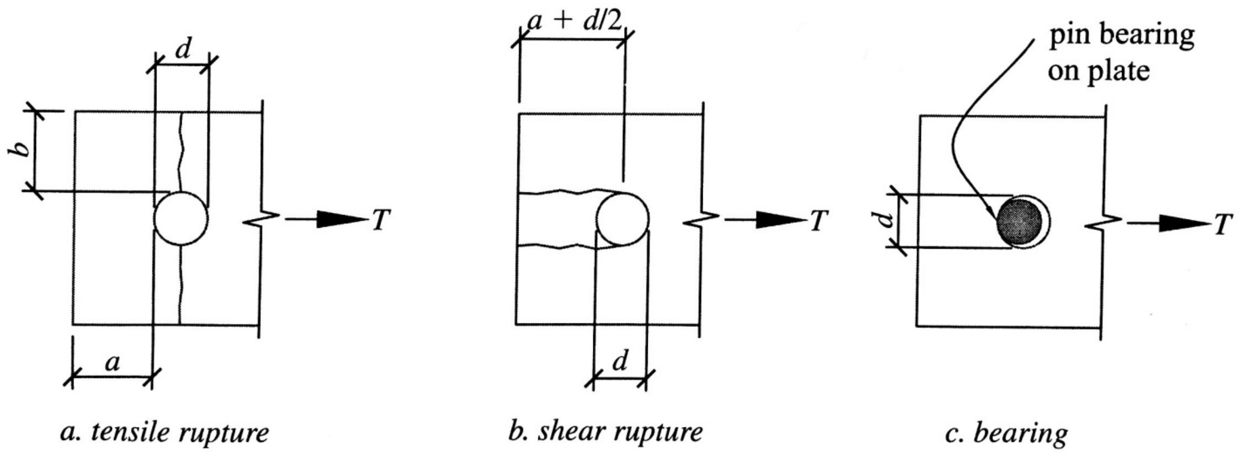


Figure 4-22 Failure modes for pin-connected members.

From chapter 2 of ASCE / SEI 7 , the required tensile strength is :

1. Tensile Rupture

$$P_u = \varnothing F_u \ (2t.b_{eff})$$

2. Shear Rupture

$$P_u = \varnothing\, 0.6\, F_u\, A_{sf}$$

3. Bearing

$$R_u = \varnothing\, 1.8\, F_y\, A_{pb}$$

4. Tensile Yielding

$$P_u = 0.90\, F_y\, A_g$$

$\phi = 0.75,$

$$A_{sf} = 2t\left(a + \frac{d}{2}\right) \text{ in.}^2,$$

a = Shortest distance from the edge of the hole to the plate edge parallel to the direction of the force,

$b_{\text{eff}} = 2t + 0.63 \text{ in.} < b,$

b = Distance from the edge of the hole to the plate edge perpendicular to the direction of the force,

d = Pin diameter (noted as p in the *AISCM* Table 15-4),

t = Plate thickness,

A_{pb} = Projected bearing area ($A_{pb} = dt$),

F_y = Minimum yield stress, and

F_u = Minimum tensile stress.

For pin-connected members, there are also dimensional requirements for the gusset plate that must be satisfied, and these are indicated below and are shown in Figure 4-23. Note that the edges of the gusset plate can be cut 45°, provided that the distance from the edge of the hole to the cut is not less than the primary edge distance.

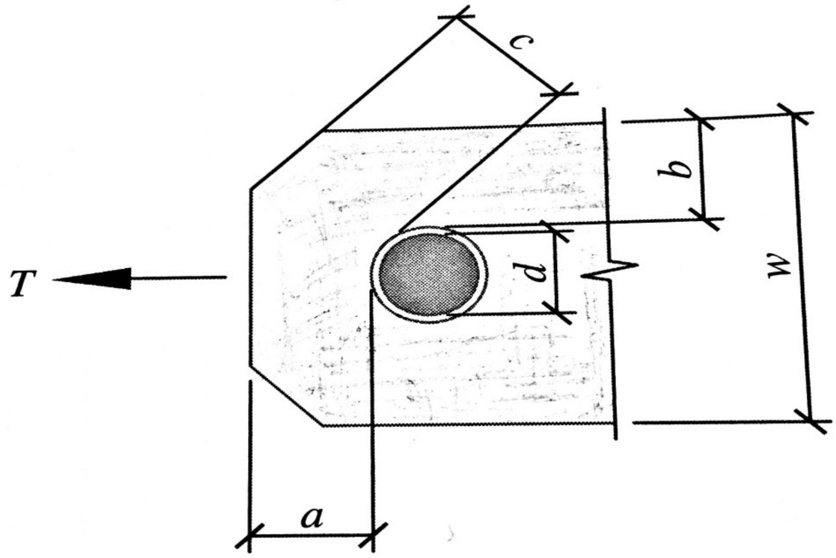


Figure 4-23 Dimensional requirements for pin-connected members.

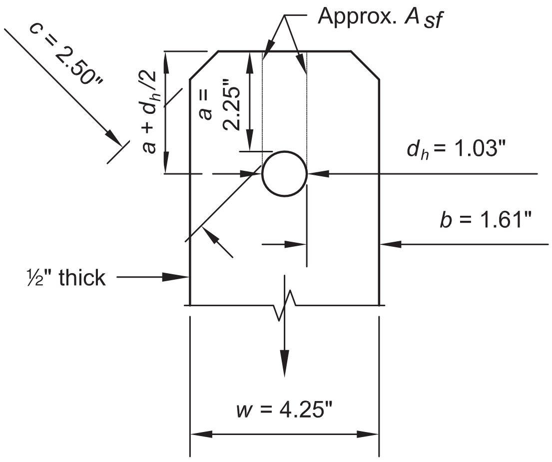
Dimensional requirement using AISC specification section D5.2 :

- beff. = 2t + 0.63 < b
- a $\geq$ 1.33 beff.
- w $\geq$ 2 beff. + d
- c $\geq$ a

EXAMPLE D.7 PIN-CONNECTED TENSION MEMBER

Given:

An ASTM A36 pin-connected tension member with the dimensions shown as follows carries a dead load of 4 kips and a live load of 12 kips in tension. The diameter of the pin is 1 inch, in a ⅓₂-in. oversized hole. Assume that the pin itself is adequate. Verify the member tensile strength.



Solution:

From AISC *Manual* Table 2-5, the material properties are as follows:

Plate
ASTM A36
F_y = 36 ksi
F_u = 58 ksi

The geometric properties are as follows:

w = 4.25 in.
t = 0.500 in.
d = 1.00 in.
a = 2.25 in.
c = 2.50 in.
d_h = 1.03 in.

Check dimensional requirements using AISC *Specification* Section D5.2.

1. $b_e = 2t + 0.63$ in.
$= 2(0.500 \text{ in.}) + 0.63$ in.
$= 1.63 \text{ in.} \leq 1.61$ in.
$b_e = 1.61$ in. **controls**

2. $a \geq 1.33b_e$
$2.25 \text{ in.} \geq 1.33(1.61 \text{ in.})$
$= 2.14$ in. **o.k.**

3. $w \geq 2b_e + d$
   4.25 in. $\geq$ 2(1.61 in.) + 1.00 in.
   = 4.22 in. **o.k.**

4. $c \geq a$
   2.50 in. $\geq$ 2.25 in. **o.k.**

From Chapter 2 of ASCE/SEI 7, the required tensile strength is:

LRFD	ASD
P_u = 1.2(4 kips) + 1.6(12 kips) = 24.0 kips	P_a = 4 kips + 12 kips = 16.0 kips

Tensile Rupture

Calculate the available tensile rupture strength on the effective net area.

$$P_n = F_u(2tb_e) \quad \text{(\textit{Spec}. Eq. D5-1)}$$
$$= 58 \text{ ksi } (2)(0.500 \text{ in.})(1.61 \text{ in.})$$
$$= 93.4 \text{ kips}$$

From AISC *Specification* Section D5.1, the available tensile rupture strength is:

LRFD	ASD
$\phi_t = 0.75$ $\phi_t P_n = 0.75(93.4 \text{ kips})$ $= 70.1 \text{ kips}$	$\Omega_t = 2.00$ $\dfrac{P_n}{\Omega_t} = \dfrac{93.4 \text{ kips}}{2.00}$ $= 46.7 \text{ kips}$

Shear Rupture

$$A_{sf} = 2t(a + d/2)$$
$$= 2(0.500 \text{ in.})[2.25 \text{ in.} + (1.00 \text{ in.}/2)]$$
$$= 2.75 \text{ in.}^2$$

$$P_n = 0.6F_uA_{sf} \quad \text{(\textit{Spec}. Eq. D5-2)}$$
$$= 0.6(58 \text{ ksi})(2.75 \text{ in.}^2)$$
$$= 95.7 \text{ kips}$$

From AISC *Specification* Section D5.1, the available shear rupture strength is:

LRFD	ASD
$\phi_{sf} = 0.75$ $\phi_{sf} P_n = 0.75(95.7 \text{ kips})$ $= 71.8 \text{ kips}$	$\Omega_{sf} = 2.00$ $\dfrac{P_n}{\Omega_{sf}} = \dfrac{95.7 \text{ kips}}{2.00}$ $= 47.9 \text{ kips}$

Bearing

$$A_{pb} = 0.500 \text{ in.}(1.00 \text{ in.})$$
$$= 0.500 \text{ in.}^2$$

$R_n = 1.8F_yA_{pb}$ (*Spec*. Eq. J7-1)
$= 1.8(36 \text{ ksi})(0.500 \text{ in.}^2)$
$= 32.4 \text{ kips}$

From AISC *Specification* Section J7, the available bearing strength is:

LRFD	ASD
$\phi = 0.75$ $\phi P_n = 0.75(32.4 \text{ kips})$ $= 24.3 \text{ kips}$	$\Omega = 2.00$ $\dfrac{P_n}{\Omega} = \dfrac{32.4 \text{ kips}}{2.00}$ $= 16.2 \text{ kips}$

Tensile Yielding

$A_g = wt$
$= 4.25 \text{ in.} (0.500 \text{ in.})$
$= 2.13 \text{ in.}^2$

$P_n = F_yA_g$ (*Spec*. Eq. D2-1)
$= 36 \text{ ksi} (2.13 \text{ in.}^2)$
$= 76.7 \text{ kips}$

From AISC *Specification* Section D2, the available tensile yielding strength is:

LRFD	ASD
$\phi_t = 0.90$ $\phi_t P_n = 0.90(76.7 \text{ kips})$ $= 69.0 \text{ kips}$	$\Omega_t = 1.67$ $\dfrac{P_n}{\Omega_t} = \dfrac{76.7 \text{ kips}}{1.67}$ $= 45.9 \text{ kips}$

The available tensile strength is governed by the bearing strength limit state.

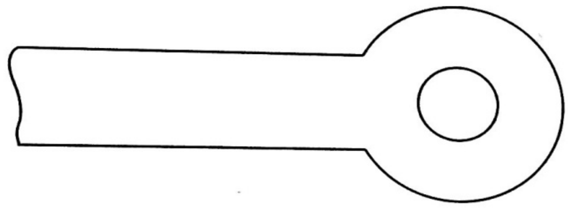
LRFD	ASD
$\phi P_n = 24.3 \text{ kips}$ 24.3 kips > 24.0 kips **o.k.**	$\dfrac{P_n}{\Omega} = 16.2 \text{ kips}$ 16.2 kips > 16.0 kips **o.k.**

See Example J.6 for an illustration of the limit state calculations for a pin in a drilled hole.

Eye Bar Tension Member

An eyebar is a special type of pin-connected member whose ends where the pin holes are located are enlarged ,as shown below .Eyebars at one time were very commonly used for the tension members for long span of bridges trusses .

FIGURE 4.6
End of an eyebar.



Requirements using AISC Specification section D6.1 and D6-2 .

- $t \geq 1/2$ in
- $w < 8\,t$
- $d \geq 7/8\,w$
- $d_h \leq d + 1/32$
- $R \geq d_{head}$
- $2/3\,w \leq b \leq 3/4\,w$

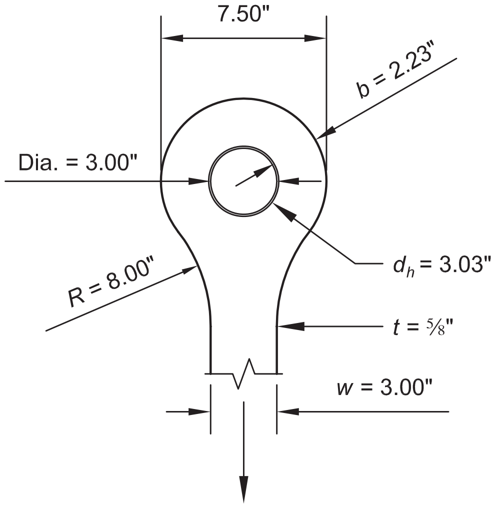
AISC Specification section D2

$Pu = Ø\,Fy\,Ag$ where $Ag = w.t$

EXAMPLE D.8 EYEBAR TENSION MEMBER

Given:

A ⅝-in.-thick, ASTM A36 eyebar member as shown, carries a dead load of 25 kips and a live load of 15 kips in tension. The pin diameter, *d*, is 3 in. Verify the member tensile strength.



Solution:

From AISC *Manual* Table 2-5, the material properties are as follows:

Plate
ASTM A36
F_y = 36 ksi
F_u = 58 ksi

The geometric properties are as follows:

w = 3.00 in.
b = 2.23 in.
t = ⅝ in.
d_{head} = 7.50 in.
d = 3.00 in.
d_h = 3.03 in.
R = 8.00 in.

Check dimensional requirements using AISC *Specification* Section D6.1 and D6.2.

1. $t \geq$ ½ in.
   ⅝ in. $\geq$ ½ in. **o.k.**

2. $w \leq 8t$
   3.00 in. $\leq$ 8(⅝ in.)
   = 5.00 in. **o.k.**

3. $d \geq ⅞\,w$
   3.00 in. $\geq ⅞$(3.00 in.)
   = 2.63 in. **o.k.**

4. $d_h \leq d + \frac{1}{32}$ in.
   3.03 in. $\leq$ 3.00 in. + ($\frac{1}{32}$ in.)
   = 3.03 in. **o.k.**

5. $R \geq d_{head}$
   8.00 in. $\geq$ 7.50 in. **o.k.**

6. $⅔\,w < b \leq ¾\,w$
   ⅔(3.00 in.) < 2.23 in. $\leq$ ¾(3.00 in.)
   2.00 in. < 2.23 in. $\leq$ 2.25 in. **o.k.**

From Chapter 2 of ASCE/SEI 7, the required tensile strength is:

LRFD	ASD
P_u = 1.2(25.0 kips) + 1.6(15.0 kips) = 54.0 kips	P_a = 25.0 kips + 15.0 kips = 40.0 kips

Tensile Yielding

Calculate the available tensile yielding strength at the eyebar body (at w).

$$A_g = wt$$
$$= 3.00 \text{ in.}(⅝ \text{ in.})$$
$$= 1.88 \text{ in.}^2$$

$$P_n = F_y A_g \qquad (\textit{Spec}. \text{ Eq. D2-1})$$
$$= 36 \text{ ksi}(1.88 \text{ in.}^2)$$
$$= 67.7 \text{ kips}$$

From AISC *Specification* Section D2, the available tensile yielding strength is:

LRFD	ASD
ϕ_t = 0.90 $\phi_t P_n$ = 0.90(67.7 kips) = 60.9 kips 60.9 kips > 54.0 kips **o.k.**	Ω_t = 1.67 $\dfrac{P_n}{\Omega_t} = \dfrac{67.7 \text{ kips}}{1.67}$ = 40.5 kips 40.5 kips > 40.0 kips **o.k.**

The eyebar tension member available strength is governed by the tensile yielding limit state.

Note: The eyebar detailing limitations ensure that the tensile yielding limit state at the eyebar body will control the strength of the eyebar itself. The pin should also be checked for shear yielding, and, if the material strength is less than that of the eyebar, bearing.

See Example J.6 for an illustration of the limit state calculations for a pin in a drilled hole.