Disciplina: Tópicos e Especiais em Projeto I
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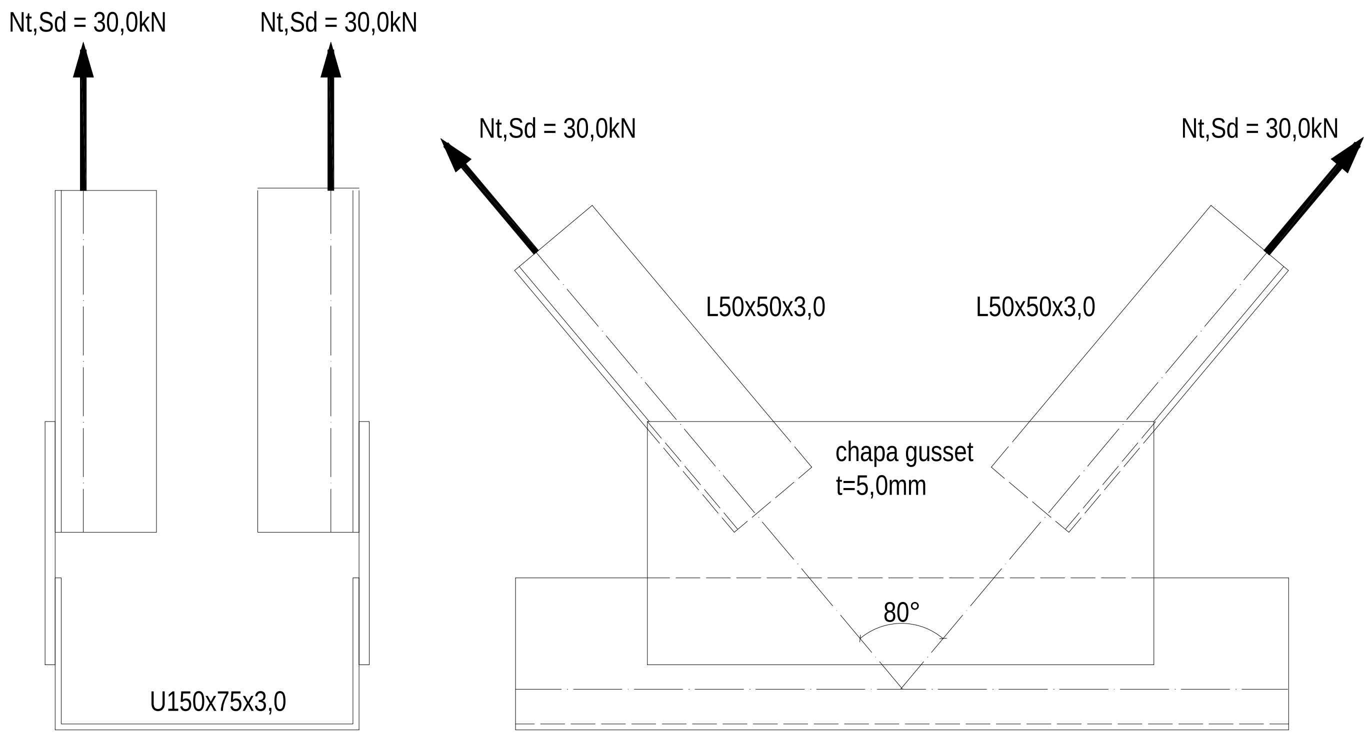
Sala 5016 – Bloco A

Lista de Exercícios – Ligações Chapa Dobrada
(Entrega: 15 dias)

1. Pede-se dimensionar a ligação soldada apresentada abaixo considerando-se que o banzo é formado por um perfil U150x75x3 e as diagonais por cantoneiras L50x50x3, ambos de um aço MR250. A chapa de gusset tem espessura de 3,0 mm também constituída de um aço MR250. A tensão de ruptura da solda é igual a 415 MPa.



2. Resolver o exemplo 8.4 em anexo pela norma européia de perfis de chapa dobrada.

TABLE 8.10a (ASD) Nominal Tension Stress, F'_{nt} (ksi), for Bolts Subject to the Combination of Shear and Tension[1.314]

Description of Bolts	Threads Not Excluded from Shear Planes	Threads Excluded from Shear Planes	Factor of Safety, Ω
A325 Bolts A354 Grade BD Bolts A449 Bolts A490 Bolts	$110-3.6f_v \le 90$ $122-3.6f_v \le 101$ $100-3.6f_v \le 81$ $136-3.6f_v \le 112.5$	$110-2.8f_v \le 90$ $122-2.8f_v \le 101$ $100-2.8f_v \le 81$ $136-2.8f_v \le 112.5$	2.0
A307 Bolts, Grade A When $\frac{1}{4}$ in. $\le d < \frac{1}{2}$ in. When d $\ge \frac{1}{2}$ in.	$52-4f_v \le 40.5$ $58.5-4f_v \le 45$		2.25

The shear stress, f_v, shall also satisfy Table 8.9.

TABLE 8.10b (ASD) Nominal Tension Stress, F'_{nt} (MPa), for Bolts Subject to the Combination of Shear and Tension[1.314]

Description of Bolts	Threads Not Excluded from Shear Planes	Threads Excluded from Shear Planes	Factor of Safety, Ω
A325 Bolts A354 Grade BD Bolts A449 Bolts A490 Bolts	$758-25f_v \le 607$ $841-25f_v \le 676$ $690-25f_v \le 552$ $938-25f_v \le 745$	$758-19f_v \le 607$ $841-19f_v \le 676$ $690-19f_v \le 552$ $938-19f_v \le 745$	2.0
A307 Bolts, Grade A When 6.4 mm $\le d <$ 12.7 mm When $d \ge$ 12.7 mm	$359-28f_v \le 276$ $403-28f_v \le 310$		2.25

TABLE 8.11a (LRFD) Nominal Tension Stress, F'_{nt} (ksi), for Bolts Subject to the Combination of Shear and Tension[1.314]

Description of Bolts	Threads Not Excluded from Shear Planes	Threads Excluded from Shear Planes	Resistance Factor, ϕ
A325 Bolts A354 Grade BD Bolts A449 Bolts A490 Bolts	$113-2.4f_v \le 90$ $127-2.4f_v \le 101$ $101-2.4f_v \le 81$ $141-2.4f_v \le 112.5$	$113-1.9f_v \le 90$ $127-1.9f_v \le 101$ $101-1.9f_v \le 81$ $141-1.9f_v \le 112.5$	0.75
A307 Bolts, Grade A When $\frac{1}{4}$ in. $\le d < \frac{1}{2}$ in. When $d \ge \frac{1}{2}$ in.	$47-2.4f_v \le 40.5$ $52-2.4f_v \le 45$		0.75

The shear stress, f_v, shall also satisfy Table 8.9.

TABLE 8.11b (LRFD) Nominal Tension Stress, $F'ei_{nt}$ (MPa), for Bolts Subject to the Combination of Shear and Tension[1.314]

Description of Bolts	Threads Not Excluded from Shear Planes	Threads Excluded from Shear Planes	Resistance Factor, ϕ
A325 Bolts A354 Grade BD Bolts A449 Bolts A490 Bolts	$779-17f_v \le 621$ $876-17f_v \le 696$ $696-17f_v \le 558$ $972-17f_v \le 776$	$779-13f_v \le 621$ $876-13f_v \le 696$ $696-13f_v \le 558$ $972-13f_v \le 776$	0.75
A307 Bolts, Grade A When 6.4 mm. $\le d < 12.7$ mm When $d \ge 12.7$ mm	$324-25f_v \le 279$ $359-25f_v \le 310$		0.75

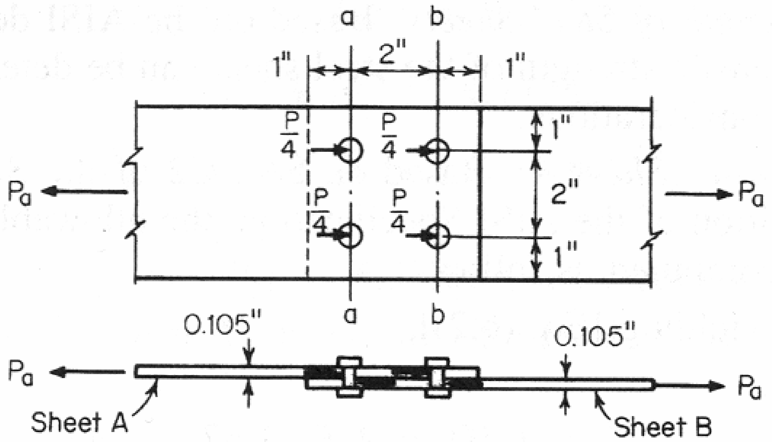


Figure 8.41 Example 8.4.

Example 8.4 Determine the allowable load for the bolted connection shown in Fig. 8.41. Use four $\frac{1}{2}$-in. diameter A307 bolts with washers under bolt head and nut. The steel sheets are A570 Grade 33 steel (F_y = 33 ksi and F_u = 52 ksi). Use ASD and LRFD methods. Assume that the dead-to-live load ratio is 1/5 and that the deformation around bolt holes is not a design consideration.

Solution

A. ASD Method

In the determination of the allowable load, consideration should be given to the following items:

- Shear, spacing, and edge distance in line of stress (Art. 8.4.2.5)
- Tensile strength of connected parts at connection (Art. 8.4.2.6)
- Bearing strength between bolts and connected parts (Art. 8.4.2.7)
- Shear strength in bolts (Art. 8.4.2.8)

1. *Shear, Spacing, and Edge Distance in Line of Stress.* The distance from the center of a standard hole to the nearest edge of an adjacent hole is

$$e_1 = 2 - \frac{d + \frac{1}{16}}{2} = 2 - \frac{\frac{1}{2} + \frac{1}{16}}{2} = 1.72 \text{ in.}$$

The distance from the center of a standard hole to the end of the plate

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in the line of stress is

$$e_2 = 1 \text{ in.}$$

Since $e_2 < e_1$, the allowable load should be determined by e_2.

Because $F_u/F_y = 52/33 = 1.58 > 1.08$, according to Eq. (8.45), the allowable shear strength of the connected sheet using four bolts can be computed as

$$\begin{aligned} P_1 &= 4P_n/\Omega = 4(te_2F_u)/2.0 \\ &= 4(0.105 \times 1 \times 52)/2.0 = 10.92 \text{ kips} \end{aligned}$$

In addition, some other AISI requirements should be checked on the basis of Sec. E3.1 of the AISI Specification or Art. 8.4.2.5 as follows:

a. Distance between centers of bolt holes

$$2 \text{ in.} > (3d = 1.5 \text{ in.}) \qquad \text{O.K.}$$

b. Distance from center of any standard hole to end of plate

$$1 \text{ in.} > (1\tfrac{1}{2}d = 0.75 \text{ in.}) \qquad \text{O.K.}$$

c. Clear distance between edges of two adjacent holes

$$2 - (\tfrac{1}{2} + \tfrac{1}{16}) = 1.44 \text{ in.} > (2d = 1.0 \text{ in.}) \qquad \text{O.K.}$$

d. Distance between edge of hole and end of plate

$$1 - \frac{\frac{1}{2} + \frac{1}{16}}{2} = 0.72 \text{ in.} > (d = 0.5 \text{ in.}) \qquad \text{O.K.}$$

2. *Tensile Strength of Steel Sheets.* Based on the AISI design criteria, the allowable tensile strength of the steel sheet can be determined under the following considerations:

   a. *Section a–a* (*Sheet A*). Based on Sec. C2 of the Supplement to the 1996 edition of the AISI Specification, the allowable tensile strength can be computed as follows:

      (i) For yielding [Eq. (6.2)],

$$T_a = T_n/\Omega_t = A_g F_y/1.67$$
$$= (4.0 \times 0.105)(33)/1.67 = 8.30 \text{ kips}$$

      (ii) For fracture away from the connection [Eq. (6.3)],

$$T_a = T_n/\Omega_t = A_n F_u/2.00$$
$$= (4.0 \times 0.105)(52)/2.00 = 10.92 \text{ kips}$$

Use $T_a = 8.30$ kips for the requirement of Sec. C2 of the Specification.

According to Sec. E.3.2(1) of the Supplement to the 1996 edition of the Specification for bolts with washers under bolt head and nut and for a single shear connection ($\Omega = 2.22$), the allowable tensile strength should be determined by Eq. (8.46) as follows:

$$P_a = P_n/\Omega = A_n F_t/\Omega$$

where

$$A_n = [4 - 2(1/2 + 1/16)](0.105) = 0.30 \text{ in.}^2$$
$$F_t = [1.0 - 0.9r + 3r(d/s)]F_u \leq F_u$$

in which

$$r = \frac{2P_2/4}{P_2} = \frac{1}{2}$$
$$d/s = 0.5/2.0 = 0.25$$

Therefore,

$$F_t = [1.0 - 0.9(0.5) + 3(0.5)(0.25)](52)$$
$$= 48.1 \text{ ksi} < 52 \text{ ksi O.K.}$$
$$P_a = (0.30)(48.1)/2.22 = 6.50 \text{ kips}$$

Since $P_a < T_a$, use $(P_2)_a = 6.50$ kips for section *a–a*.

b. *Section b–b* (*Sheet A*). From the above calculation,

$$T_a = 8.30 \text{ kips}$$
$$r = \frac{2P_2/4}{P_2 - 2P_2/4} = 1$$
$$F_t = [1.0 - 0.9(1) + 3(1)(0.25)](52) = 44.2 \text{ ksi} < 52 \text{ ksi O.K.}$$
$$P_a = (0.30)(44.2)/2.22 = 5.97 \text{ kips}$$

Since $P_a < T_a$, use $P_a = 5.97$ kips.
Because at Section *b–b*, only 50% of the load *P* acts in sheet *A*, therefore,

$$\frac{(P_2)_b}{2} = P_a$$
$$(P_2)_b = 2P_a = 2 \times 5.97 = 11.94 \text{ kips} > (P_2)_a$$

Use $P_2 = (P_2)_a = 6.50$ kips

3. *Bearing Strength between Bolts and Steel Sheets.* Because 0.036 in. $< t < \frac{3}{16}$ in. and the connection is a single shear condition, then according to Table 8.7, the allowable bearing strength per bolt is

$$P_{pa} = P_n/\Omega = 3F_u dt/2.22$$
$$= (3)(52)(\tfrac{1}{2})(0.105)/2.22 = 3.69 \text{ kips}$$

The allowable bearing strength for four bolts is

$$P_3 = 4 \times 3.69 = 14.76 \text{ kips}$$

4. *Shear Strength in Bolts.* From Table 8.9, the nominal shear stress for the $\frac{1}{2}$-in. diameter A307 bolts is 27 ksi and the gross area of the bolt is 0.196 in.^{2} Therefore, the allowable shear strength for four bolts is

$$P_4 = 4(A_b F_{nv})/\Omega$$
$$= 4(0.196)(27)/2.4 = 8.82 \text{ kips}$$

Comparing P_1, P_2, P_3, and P_4, the allowable load for the given bolted connection is 6.50 kips, which is governed by the tensile strength of sheet *A* at section *a–a*.

B. LRFD Method

For the LRFD method, the design considerations are the same as for the ASD method. The design strength can be calculated by applying some of the values used for the ASD method.

1. *Shear, Spacing, and Edge Distance in Line of Stress.* Use Eq. (8.45) for $F_u/F_y > 1.08$, the design shear strength of connected sheet using four bolts is

$$(\phi P_n)_1 = 4(0.70)(te_2F_u) = 4(0.70)(0.105)(1)(52)$$
$$= 15.288 \text{ kips}$$

2. *Tensile Strength of Steel Sheets*
   a. *Section a–a* (*Sheet A*). Based on Sec. C2 of the Supplement to the 1996 edition of the Specification, the design tensile strength of connected sheet is
      (i) For yielding [Eq. (6.2)],

$$\phi_t T_n = (\phi_t)(A_g F_y) = (0.90)(4 \times 0.105)(33) = 12.474 \text{ kips}$$

      (ii) For fracture away from the connection [Eq. (6.3)],

$$\phi_t T_n = \phi_t(A_n F_n) = (0.75)(4 \times 0.105)(52) = 16.38 \text{ kips}$$

Use $\phi_t T_n = 12.474$ kips for the requirement of Sec. C2 of the Specification.

On the basis of Sec. E3.2(1) of the Supplement to the 1996 edition of the Specification, the design tensile strength on the net section of sheet A at Section *a–a* can be computed from Eq. (8.46) as follows:

$$\phi P_n = \phi(A_n F_t)$$

From the ASD method, $A_n = 0.30$ in.^{2} and $F_t = 48.1$ ksi. Therefore,

$$\phi P_n = (0.55)(0.30)(48.1) = 7.937 \text{ kips}$$

Since

$$\phi P_n < \phi_t T_n, \text{ use } (\phi P_n)_a = 7.937 \text{ kips}$$

b. *Section b–b* (*Sheet A*). From the above calculation,

$$\phi_t T_n = 12.474 \text{ kips}$$

Based on Eq. (8.46), the design tensile strength on the net section of sheet A at Section *b–b* can be computed from the values of A_n and F_t calculated for the ASD method, i.e.,

$$\phi P_n = \phi(A_n F_t) = (0.55)(0.30)(44.2) = 7.293 \text{ kips} < 12.474 \text{ kips}$$

Use $\phi P_n = 7.293$ kips
Because at Section *b–b*, only 50% of the load acts in sheet *A*, therefore, the design tensile strength based on Section *b–b* is

$$(\phi P_n)_b = 2(\phi P_n) = 2(7.293) = 14.586 \text{ kips}$$

Comparing $(\phi P_n)_a$ and $(\phi P_n)_b$, the governing design tensile strength is

$$\phi(P_n)_2 = (\phi P_n)_a = 7.937 \text{ kips}$$

3. *Bearing Strength between Bolts and Steel Sheets.* According to Table 8.7, the design bearing strength between four bolts and the steel sheet is

$$(\phi P_n)_3 = 4(0.60)(3F_u dt) = 4(0.60)(3)(52)(\tfrac{1}{2})(0.105)$$
$$= 19.656 \text{ kips}$$

4. *Shear Strength in Bolts.* Based on Table 8.9, the design shear strength of four bolts is

$$\phi(P_n)_4 = 4(0.65)(A_b F_{nv}) = 4(0.65)(0.196)(27)$$
$$= 13.759 \text{ kips}$$

Comparing the values of $(\phi P_n)_1$, $(\phi P_n)_2$, $(\phi P_n)_3$, and $(\phi P_n)_4$, the controlling design strength is 7.937 kips, which is governed by the tensile strength of sheet *A* at section *a–a*.

The required strength can be computed from Eqs. (3.5*a*) and (3.5*b*) for the dead load-to-live load ratio of 1/5.

From Eq. (3.5*a*),

$$(P_u)_1 = 1.4P_D + P_L = 1.4P_D + 5P_D = 6.4P_D$$

From Eq. (3.5*b*),

$$(P_u)_2 = 1.2P_D + 1.6P_L = 1.2P_D + 1.6(5P_D) = 9.2P_D$$

$9.2P_D$ controls.

The dead load P_D can be computed as follows:

$$9.2P_D = 7.937 \text{ kips}$$

$$P_D = 0.863 \text{ kips}$$

$$P_L = 5P_D = 4.315 \text{ kips}$$

Total allowable load based on the LRFD method is

$$P_a = P_D + P_L = 5.178 \text{ kips}$$

It can be seen that the LRFD method is more conservative than the ASD method due to the use of a relatively low resistance factor.