Ligações - Exemplos EC3

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1. Exemplo 1

Example 7.1: Bolted lap joint. Determine the design resistance of the lap bolted connection in tension shown in Figure 7.31.

Given: Steel grade S350GD+Z
Connected part: f_{yb}=350 N/mm^2, f_u=420 N/mm^2
Bolt grade 8.8 with a bolt diameter d=12 mm; d_o=13 mm, f_{ub}=800 N/mm^2
A_s=84.3 mm^2.

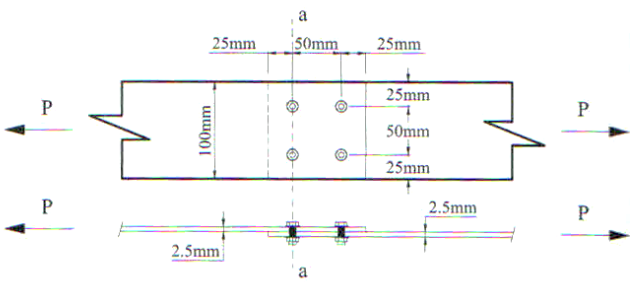

Figure 7.31 – Lap bolted connection in tension

1. Exemplo 1

Bolt position:

Bolt pitch distance between centre of the holes:

$$p_1 = p_2 = 50 \text{ mm} > 3d = 36 \text{ mm};$$

Distance from the centre of the hole to the end of part:

$$e_1 = 25 \text{ mm} > 1.5d = 18 \text{ mm}.$$

Tension resistance of connected parts:

$$N_{t,Rd} = f_y \cdot A_g / \gamma_{M0}\,;\ \ \gamma_{M0} = 1.0$$

$$= 350\ N/\text{mm}^2 \times 100\ \text{mm} \times 2.5\ \text{mm}/1.0/1000 = 87.5\ \text{kN}$$

Evaluate the net section resistance of the connection at line a-a.

$$F_{n,Rd} = (1 + 3 \cdot r \cdot (d_o / u - 0.3)) \cdot A_{net} \cdot f_u / \gamma_{M2}\,;\ \ \gamma_{M2} = 1.25$$

$$= (1 + 3 \times 0.5 \times (13\text{mm}/50\text{mm} - 0.3)) \times 185\text{mm}^2 \times 420\ \text{N/mm}^2/1.25/1000$$
$$= 58.4\,\text{kN}$$

1. Exemplo 1

$$A_{net} \cdot f_u / \gamma_{M2} = 185\,\text{mm}^2 \times 420\ N/\text{mm}^2/1.25/1000 = 62.6\,\text{kN}$$

$$F_{n,Rd} = 58.4\,\text{kN} < 62.6\,\text{kN}$$

The tension resistance of the connected part is governed by the net section resistance of connection.

Bearing resistance:

$$F_{b,Rd} = 2.5 \cdot \alpha_b \cdot k_t \cdot f_u \cdot d \cdot t / \gamma_{M2}$$

$$= 2.5 \times 0.694 \times 1 \times 420\ N/\text{mm}^2 \times 12\text{mm} \times 2.5\,\text{mm}/1.25/1000 = 17.5\,\text{kN/bolt}$$

where

$k_t = 1.0$ for $t > 1.25$mm

$\alpha_b = \min(1, e_1/(3d)) = \min(1, 25/(3\cdot 12) = \min(1, 0.694) = 0.694$

Total bearing resistance = 4 bolts×17.5 kN/bolt = 70 kN.

1. Exemplo 1

Shear resistance of bolts:

$$F_{u,Rd} = 0.6 \cdot f_{ub} \cdot A_s / \gamma_{M2}$$
$$= 0.6 \times 800\,\text{N/mm}^2 \times 84.3\,\text{mm}^2 / 1.25 / 1000 = 32.4\,\text{kN/ bolt}$$

Total bolt shear resistance = 4 bolts×32.4 kN/bolt = 129.6 kN > 70 kN

Conclusions: The net section resistance of the connection governs the connection resistance, $F_{n,Rd} = 58.4\,\text{kN}$.

2. Exemplo 2

Example 7.2: Purlin-to-rafter cleat bolted connection

Determine the design resistance of a purlin-to-rafter cleat bolted connection, shown in Figure 7.32, under longitudinal and transversal wind.

a) Longitudinal action of wind

A metal building roof system consists of cold-formed steel Z-sections. When a longitudinal wind load is applied to the end wall of a building, a common structural system to resist the wind load is to assume that the wind load is transferred longitudinally in the framing system to a braced bay. If the purlins are single span members, cleats are required over the rafter to provide the force transfer. Figure 7.32 shows a typical simple span purlin connection at a rafter.

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2. Exemplo 2

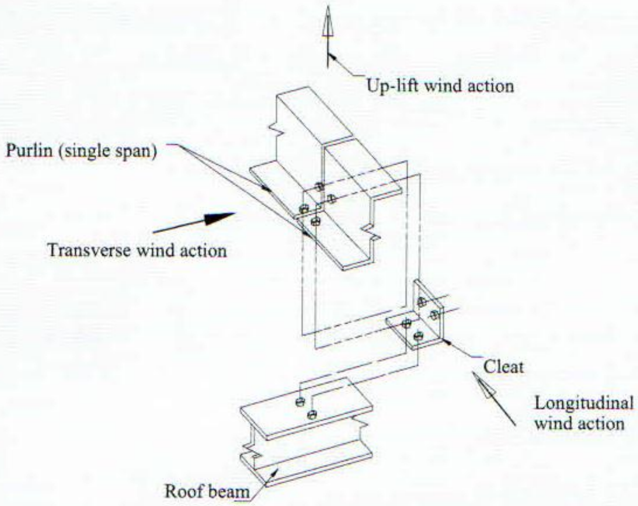

Figure 7.32 – Cleat bolted connection of a single span purlin

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2. Exemplo 2

In this case the purlin-to-rafter connection is working in shear under a longitudinal wind force.

Given:

Connected part: Steel grade S320GD+Z

f_{yb}=320 N/mm^2, f_u=390 N/mm^2

Purlin thickness=1.5 mm

Cleat thickness=2.0 mm

Bolt grade 8.8 with a bolt diameter d=12 mm; A_s=84.3 mm^2, f_{ub}=800 N/mm^2.

Bolt position:

Minimum distance from centre of hole to end of part e_l=1.5d=18 mm.

Bearing resistance:

$$F_{b,Rd} = 2.5 \cdot \alpha_b \cdot k_t \cdot f_u \cdot d \cdot t / \gamma_{M2}$$

$$= 2.5 \times 0.5 \times 1 \times 390\,\text{N/mm}^2 \times 12\text{mm} \times 1.5\,\text{mm} / 1.25 / 1000 = 7.02\,\text{kN/ bolt}$$

2. Exemplo 2

where

$k_t = 1.0$ for $t > 1.25$mm

$\alpha_b = \min(1, e_1/(3d)) = \min(1, 18/(3 \cdot 12) = \min(1, 0.5) = 0.5$

Total bearing resistance = 2 bolts × 7.02 kN/bolt = 14.04 kN

Shear resistance of bolts:

$$F_{u,Rd} = 0.6 \cdot f_{ub} \cdot A_s / \gamma_{M2}$$
$$= 0.6 \times 800\,\text{N/mm}^2 \times 84.3\,\text{mm}^2 / 1.25 = 32.4\,\text{kN/bolt}$$

Total bolt shear resistance = 2 bolts × 32.4 kN per bolt= 64.8 kN

Conclusion: The bearing resistance governs the connection shear resistance.

Note: The up-lift wind action is also loading the connection in shear. The calculations for this case are practically the same as those for longitudinal wing action.

2. Exemplo 2

b) Transverse action of wind

When a transverse wind load is applied to the roof panel of a building, a common structural system to resist the wind load is to assume that the wind load is transferred to the purlin, and the purlin transfers the wind to the framing rafter. If the purlins are simple span members, the bolt that connects the purlin to the rafter working in tension must have adequate resistance to transfer the force from the purlin to the rafter.

Tension resistance of bolts:

$$F_{u,Rd} = 0.9 \cdot f_{ub} \cdot A_s / \gamma_{M2}$$
$$= 0.9 \times 800\,\text{N/mm}^2 \times 84.3\,\text{mm}^2 / 1.25 = 48.6\,\text{kN/bolt}$$

The connection contains only one bolt per purlin, therefore, the connection tension resistance = 48.6 kN

2. Exemplo 2

EN1993-1-3 also stipulates that the tension capacity is to be limited by the pull-through resistance. That is, the strength of the bolted connection to resist the purlin bottom flange from pulling over the head of the bolt. The pull-through resistance, $F_{p,Rd}$, cannot be computed and must be determined by tests. Thus, before it can be concluded that the tension resistance is 48.6 kN, a test for pull-through resistance is required.

3. Exemplo 3

Example 7.4: Sheeting-to-purlin connection

Determine the design resistance of the screwed connection of the sheeting on the purlin as shown in Figure 7.34.

Given:
Sheet material, $t = 0.6$ mm, S250GD+Z: $f_y = 250$ N/mm^2, $f_u = 330$ N/mm^2;
Base material, $t = 2.5$ mm, S350GD+Z: $f_y = 350$ N/mm^2, $f_u = 420$ N/mm^2.
Screw $d = 4.8$ mm, washer $d_w = 16$ mm and $F_{v,Rk} = 5.2$ kN, $F_{t,Rd} = 5.0$ kN.

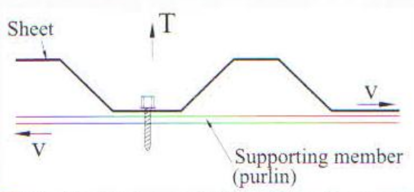

Figure 7.34 – Screwed connection of sheeting on the purlin

3. Exemplo 3

Screw position (see Figure 7.27):

Distance between centres of fastener: p_1=36mm > 3d
Distance from centre of fastener to the end of part: e_1=36 mm > 3d

Tension Resistance: Tension resistance must be evaluated for pull-through, pull-out, and screw tension resistance.

a) Pull-through resistance (screws subjected to wind load)

$$F_{p,Rd} = 0.5 \cdot d_w \cdot t \cdot f_u / \gamma_{M2}$$
$$= 0.5 \times 16\,\text{mm} \times 0.6\,\text{mm} \times 330\,\text{N/mm}^2 / 1.25 = 1.27\,\text{kN}$$

3. Exemplo 3

b) Pull-out

$$F_{o,Rd} = 0.65 \cdot d \cdot t_{sup} \cdot f_{u,sup} / \gamma_{M2}$$
$$= 0.65 \times 4.8\,\text{mm} \times 2.5\,\text{mm} \times 420\,\text{N/mm}^2 / 1.25 = 2.62\,\text{kN}$$

c) Tension resistance of screw

Consider that one sheet is fixed on the supporting member with the screw

$$F_{t,Rd} \geq F_{p,Rd}$$

3. Exemplo 3

The manufacturers tested tension resistance of screw $F_{t,Rd} = 5.0\text{ kN} > F_{p,Rd} = 1.27\text{ kN}$, therefore the screw is adequate. Tension resistance is governed by the pull-through of the fastener in the connection.

Bearing resistance:

t=0.6 mm, t_1=2.5 mm

t_1/t=4.17, therefore linear interpolation must be used to determine α.

Because $t_1 \geq 2.5 \cdot t$ and $t < 1.0$ mm: $\alpha = 3.2 \cdot \sqrt{t/d}$ but $\alpha \leq 2.1$

t_1=2.5 mm > 2.5 ×0.6 mm = 1.5 mm, t = 0.6mm < 1.0 mm

$$\Rightarrow \alpha = 3.2 \cdot \sqrt{t/d} = 3.2\sqrt{0.6/4.8} = 1.13 \leq 2.1, \text{ use } \alpha = 1.13$$

$$F_{b,Rd} = \alpha \cdot f_u \cdot d \cdot t / \gamma_{M2}$$

$$= 1.13 \times 330\,\text{N/mm}^2 \times 4.8\,\text{mm} \times 0.6\,\text{mm} / 1.25 = 0.86\,\text{kN/screw}$$

3. Exemplo 3

Shear resistance of screw:

$$F_{v,Rd} = F_{v,Rk} / \gamma_{M2} = 5.2\text{kN} / 1.25 = 4.16\text{kN}$$

$$F_{v,Rd} > 1.2 \cdot F_{b,Rd} = 1.2 \times 0.86\text{kN} = 1.03\,\text{kN/screw}$$

The manufacturers tested shear resistance of screw is $F_{v,Rd} = 4.16\text{ kN} > 1.03\text{ kN}$, therefore the screw is adequate.

Conclusion: The shear resistance of the connection is governed by the bearing resistance = 1.03 kN. The tension resistance of the connection is governed by the pull-through resistance = 1.27 kN.

4. Exemplo 4

Example 7.7: Spot weld lap joint

Determine the resistance of the spot weld lap joint shown in Figure 7.42.

Given: Base material, Steel grade S355 MC, f_y=355 N/mm^2, f_u=430 N/mm^2, of thickness t = 1.0 mm and t_1 = 3.0 mm;
Fusion welds: d_s=0.5·t + 5mm = 5.5 mm.

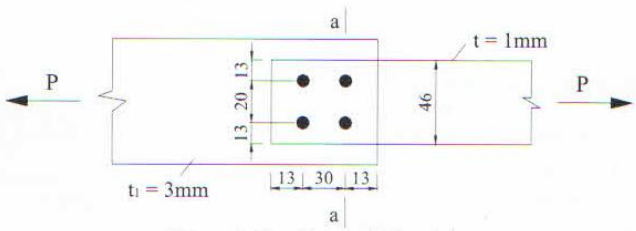

Figure 7.42 – Spot weld lap joint

4. Exemplo 4

Weld position:

$$2 \cdot d_s = 11\,\text{mm} < e_1 = 13\,\text{mm} < 6 \cdot d_s = 33\,\text{mm}$$
$$e_2 = 13\,\text{mm} < 4 \cdot d_s = 22\,\text{mm}$$
$$3 \cdot d_s = 16.5\,\text{mm} < p_1 = 30\text{mm} < 8 \cdot d_s = 44\,\text{mm}$$
$$3 \cdot d_s = 16.5\,\text{mm} < p_2 = 20\text{mm} < 6 \cdot d_s = 33\,\text{mm}$$

Tearing and bearing resistance:

$$t = 1.0\,\text{mm};\ t_1 = 3.0\,\text{mm and } t_1 > 2.5t$$
$$F_{tb,Rd} = 2.7 \cdot \sqrt{t} \cdot d_s \cdot f_u / \gamma_{M2}$$
$$= 2.7 \cdot \sqrt{1.0} \cdot 5.5 \cdot 430 / 1.25 / 1000 = 5.11\text{kN/ weld}$$

4. Exemplo 4

but

$$F_{tb,Rd} \leq 0.7 \cdot d_s^{\,2} \cdot f_u / \gamma_{M2} = 0.7 \cdot 5.5^2 \cdot 430 / 1.25 / 1000 = 7.28 \, \text{kN/ weld}$$

and

$$F_{tb,Rd} \leq 3.1 \cdot t \cdot d_s \cdot f_u / \gamma_{M2} = 3.1 \cdot 1 \cdot 5.5 \cdot 430 / 1.25 / 1000 = 5.87 \, \text{kN/ weld}$$

$$\Rightarrow F_{tb,Rd} = 5.11 \, \text{kN/ weld}$$

End resistance:

$$F_{e,Rd} = 1.4 \cdot t \cdot e_1 \cdot f_u / \gamma_{M2} = 1.4 \cdot 1.0 \cdot 13 \cdot 430 / 1.25 / 1000 = 6.26 \, \text{kN/weld}$$

Net section resistance:

$$F_{n,Rd} = A_{net} \cdot f_u / \gamma_{M2}$$

Corresponding to section *a-a* in Figure 7.42:

$$A_{net} = 1 \cdot (46 - 2 \cdot 5.5) = 35 \, \text{mm}^2$$

$$F_{n,Rd} = 35 \cdot 430 / 1.25 / 1000 = 12.04 \, \text{kN}$$

4. Exemplo 4

Weld shear resistance:

$$F_{v,Rd} = \frac{\pi}{4} \cdot d_s^2 \cdot f_u / \gamma_{M2} = \frac{\pi}{4} \cdot 5.5^2 \cdot 430 / 1.25 / 1000 = 8.17 \, \text{kN/ weld}$$

Checking ductility conditions:

$$F_{v,Rd} = 8.17 \, \text{kN} > 1.25 \cdot F_{tb,Rd} = 6.39 \, \text{kN}$$

$$F_{v,Rd} = 8.17 \, \text{kN} > 1.25 \cdot F_{e,Rd} = 7.83 \, \text{kN}$$

$$nF_{v,Rd} = 16.34 \, \text{kN} > 1.25 \cdot F_{n,Rd} = 15.05 \, \text{kN} \, (n_w = 2)$$

The total resistance of the connection is governed by the tearing and bearing resistance and is:

$$4 \, \text{welds} \cdot 5.11 \, \text{kN/weld} = 20.44 \, \text{kN} \quad (n_w = 4)$$

5. Exemplo 5

Example 7.9: Fillet lap joint

Determine the design resistance of the lap side welded strap-to-gusset connection shown in Figure 7.44, in which $t_1 = 3$ mm, $t = 1$ mm and $f_u = 420$ N/mm^2. In order to ensure that the joint resistance is governed by the tearing of the sheet, the throat size is taken as equal to the strap thickness, t=1 mm.

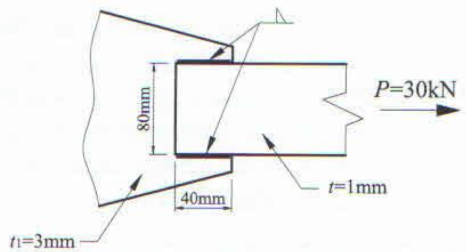

Figure 7.44 – Lap side welded strap-to-gusset

5. Exemplo 5

Design resistance of weld:

$$L_{w,s} = 40\,\text{mm} < b = 80\,\text{mm}$$

$$L_{w,Rd} = t \cdot L_{w,s} \cdot (0.9 - 0.45 \cdot L_{w,s} / b) \cdot f_u / \gamma_{M2}$$

$$= 1.0 \cdot 40 \cdot (0.9 - 0.45 \cdot 40/80) \cdot 420/1.25/1000 = 9.07\,\text{kN/weld}$$

The total welded connection resistance, for two sided fillet weld is:

$$2 \cdot 9.07\,\text{kN/weld} = 18.14\,\text{kN} < P = 30\,\text{kN}$$

In order to improve the resistance of the connection an end fillet is added, with a supplementary capacity of:

$$F_{w,Rd} = t \cdot L_{w,e} \cdot (1 - 0.3 \cdot L_{w,e} / b) \cdot f_u / \gamma_{M2}$$

$$= 1.0 \cdot 80 \cdot (1 - 0.3 \cdot 80/80) \cdot 420/1.25 = 18.82\,\text{kN}$$

The total resistance of connection in this case is:

18.14 kN + 18.82 kN

Thus, the force P = 30kN ≤ 37 kN.