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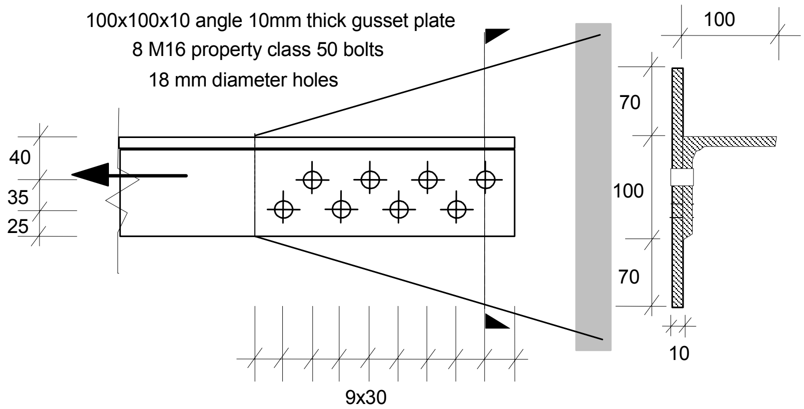
DESIGN EXAMPLE 6 – BOLTED JOINT

A 100×100×10 angle loaded in tension is to be connected to a gusset plate of 10 mm thickness. Stainless steel grade 1.4401 is used for the angle and the gusset plate. Eight austenitic 16 mm diameter bolts of property class 50 are used in a staggered line to connect one leg of the angle to the gusset plate. The proposed joint is shown in the following figure. It is required to determine the design resistance of the joint.



The connection is a Category A: Bearing Type connection. The design ultimate shear load should not exceed the design shear resistance nor the design bearing resistance. — EN 1993-1-8, clause 3.4.1

Material properties

The angle and plate is of material grade 1.4401:

The 0,2% proof stress = 220 N/mm^2 and the tensile strength is = 530 N/mm^2 — Table 3.1

Take f_y as the 0,2% proof stress = 220 N/mm^2 and f_u = 530 N/mm^2 — Section 3.2.4

The bolt material is of property class 50.

Take f_{yb} as the 0,2% proof stress = 210 N/mm^2 and f_{ub} = 500 N/mm^2 — Table 3.3

Partial safety factors

Partial safety factor on gross section resistance: $\gamma_{M0} = \gamma_{M1} = 1{,}1$ — Table 2.1

Partial safety factor on net section resistance: $\gamma_{M2} = 1{,}25$

Partial safety factor on bolt resistance in shear and in bearing: $\gamma_{M2} = 1{,}25$

Position and size of holes — Section 6.2.3

For M16 bolts a hole diameter d_0 = 18mm is required.

End distances e_1 = 30 mm and edge distances e_2 = 25 mm

e_1 and e_2 < 4t + 40 = 80 mm and > $1{,}2d_0 = 1{,}2 \times 18 = 21{,}6$ mm

For the staggered bolt rows :

- spacing p_1 = 60 mm > $2{,}2d_0$ = 39,6 mm

- distance between two bolts in staggered row

$\sqrt{30^2+35^2}$ = 46,1 mm $> 2{,}4d_0 = 43{,}2$ mm

- therefore, spacing for staggered rows p_2 = 35 mm $>$ $1{,}2d_0$ = 21,6 mm

Note: For compression loading, e_2 and p_1 should be checked that they satisfy local buckling requirements for an outstand element and an internal element respectively. Checks on both the angle and gusset plate are required.

Design resistance of the angle gross cross-section in tension — Section 6.2.3

Gross cross-sectional area of the angle A_g = 1915 mm²

Design plastic resistance

$$N_{pl,Rd} = \frac{A_g f_y}{\gamma_{M0}} = \frac{1915\times 220}{1{,}1\times 10^3} = 383\ \text{kN}$$ Eq. 6.4

Design resistance of the angle net cross-section in tension — Section 4.6.4

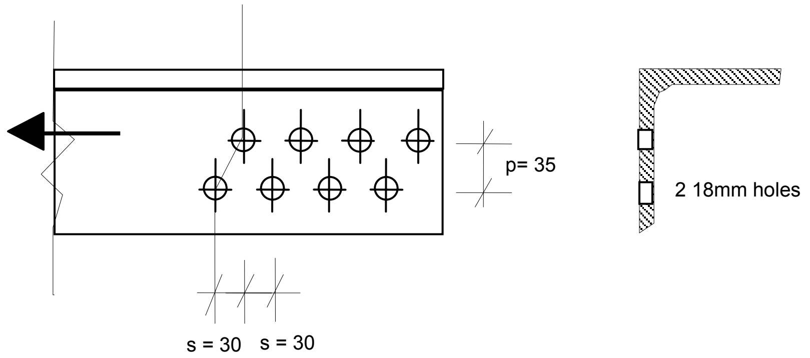
For staggered holes the net cross-sectional area should be taken as the lesser of:

- gross area minus the deduction for non-staggered holes
- $A_g - t\left(nd_0 - \Sigma\frac{s^2}{4p}\right)$

Deductions for non-staggered holes

$A_g - td_0 = 1915 - 10\times 18 = 1735$ mm²

Net cross- sectional area through two staggered holes, $n = 2$, s = 30 mm and p = 35 mm: Section 4.6.4



$$A_{net} = A_g - t\left(nd_0 - \Sigma\frac{s^2}{4p}\right) = 1915 - 10\left((2\times 18) - \frac{30^2}{4\times 35}\right)$$

= 1915 – 10(36-6.4) = 1619 mm²

Therefore A_{net} = 1619 mm²

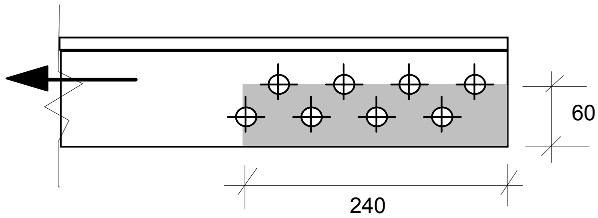
Conservatively the reduction factor for an angle connected by one leg with a single row of bolts may be used. By interpolation for more than 3 bolts in one row: β_3 = 0,57. Table 6.1

Design ultimate resistance of the net cross-section of the angle: *(Section 6.2.3, Eq. 6.8)*

$$N_{\mathrm{u,Rd}} = \frac{\beta_3 A_{\mathrm{net}} f_{\mathrm{u}}}{\gamma_{\mathrm{M2}}} = \frac{0{,}57\times1619\times530}{1{,}25\times10^3} = 391{,}3\ \mathrm{kN}$$

Design resistance of the angle in block tearing

The expressions for block tearing are taken from EN 1993-1-8 rather than EN 1993-1-1 since EN 1993-1-8 explicitly covers angles.



Design resistance in block tearing considering rows as staggered: *(EN 1993-1-8, clause 3.10.2(3) Eq. 3.10)*

$$V_{\mathrm{eff,2,Rd}} = \frac{0{,}5 f_{\mathrm{u}} A_{\mathrm{nt}}}{\gamma_{\mathrm{M2}}} + \frac{f_{\mathrm{y}} A_{\mathrm{nv}}}{\sqrt{3}\gamma_{\mathrm{M0}}}$$

$$= \frac{0{,}5\times530\times(60-18)\times10}{1{,}25\times10^3} + \frac{220\times(240-4\times18)\times10}{\sqrt{3}\times1{,}1\times10^3} = 89+194 = 283\ \mathrm{kN}$$

Design resistance in block tearing considering rows as if non staggered: *(EN 1993-1-8, clause 3.10.2(2) Eq. 3.9)*

$$V_{\mathrm{eff,2,Rd}} = \frac{0{,}5 f_{\mathrm{u}} A_{\mathrm{nt}}}{\gamma_{\mathrm{M2}}} + \frac{f_{\mathrm{y}} A_{\mathrm{nv}}}{\sqrt{3}\gamma_{\mathrm{M0}}}$$

$$= \frac{0{,}5\times530\times(60-18-9)\times10}{1{,}25\times10^3} + \frac{220\times(240-3\times18-9)\times10}{\sqrt{3}\times1{,}1\times10^3}$$

$$= 70 + 204 = 274\ \mathrm{kN}$$

Design resistance of the gross cross-section of the gusset plate *(Section 4.7.2)*

Gross cross-sectional area towards the end of the angle:

$A_{\mathrm{g}} = 10 \times (100 + 70 + 70) = 2400\ \mathrm{mm}^2$

Design plastic resistance *(Eq. 4.22)*

$$N_{\mathrm{pl,Rd}} = \frac{A_{\mathrm{g}} f_{\mathrm{y}}}{\gamma_{\mathrm{M0}}} = \frac{2400\times220}{1{,}1\times10^3} = 480\ \mathrm{kN}$$

Design resistance of the net cross-section of the gusset plate *(Section 4.7.2)*

Net cross-sectional area towards the end of the angle (where the applied load is greatest) through one hole non symmetrically placed on an element of width :

$b = 100 + 70 + 70 = 240\ \mathrm{mm}$:

$A_{\mathrm{net}} = A_{\mathrm{g}} - d_0 t = 2400 - 18\times10 = 2220\ \mathrm{mm}^2$

Net cross-sectional area towards the end of the angle through two staggered holes with $s = 30$ mm and $p = 35$ mm :

$$A_{\text{net}} = A_g - 2d_0 t + \frac{s^2 t}{4p} = 2400 - 2\times18\times10 + \frac{30^2\times10}{4\times35}$$

$$= 2400 - 360 + 64 = 2104 \text{ mm}^2$$

Therefore $A_{\text{net}} = 2104$ mm²

Design ultimate resistance of the net cross-section of the gusset plate near the end of the angle:

$$N_{\text{u,Rd}} = \frac{k_r A_{\text{net}} f_u}{\gamma_{M2}}$$ Eq. 4.23

Reduction factor k_r :

$k_r = [1 + 3r(d_0/u - 0{,}3)]$ but < 1.0

$u = 2e_2 \le p_2$ therefore, $u = 35$ mm Eq. 4.24

$$k_r = \left[1 + 2\times\frac{2}{8}\times\left(\frac{18}{35} - 0{,}3\right)\right] = 1{,}16 > 1{,}0$$

Take $k_r = 1{,}0$

$$N_{\text{u,Rd}} = \frac{1{,}0\times2104\times530}{1{,}25\times10^3} = 892{,}1 \text{ kN}$$

It is advisable to check the resistance of net cross-sections at intermediate cross-sections along the gusset plate.

<u>Cross-section at the 1st bolt hole near the gusset plate edge</u>

(Where $b = 100 + 30/240\times140 = 117{,}5$ mm)

$$A_{\text{net}} = A_g - d_0 t = 117{,}5\times10 - 18\times10 = 995 = 995 \text{ mm}^2$$ Section 4.6.4

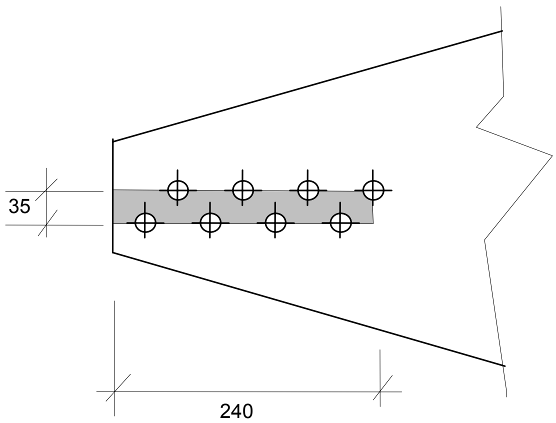
This cross-section must be capable of transmitting the load from one bolt

Design ultimate resistance at the section:

$$N_{\text{u,Rd}} = \frac{k_r A_{\text{net}} f_u}{\gamma_{M2}} = \frac{1{,}0\times995\times530}{1{,}25\times10^3} = 421{,}88 \text{ kN}$$ Eq. 4.23

It is obvious that there is no need to check any other cross-sections of the gusset plate as the load applied cannot exceed the design resistance of the angle itself which has been shown to be smaller than the above value.

Design resistance of the gusset plate in block tearing



Design resistance to block tearing considering rows as staggered: — EN 1993-1-8, clause 3.10.2(2) Eq. 3.9

$$V_{\text{eff,1,Rd}} = \frac{f_u A_{nt}}{\gamma_{M2}} + \frac{f_y A_{nv}}{\sqrt{3}\gamma_{M0}}$$

$$= \frac{530\times(35-9)\times10}{1{,}25\times10^3} + \frac{220\times(240-4\times18+240-3\times18-9)\times10}{\sqrt{3}\times1{,}1\times10^3}$$

$$= 110{,}2 + 398{,}4 = 508{,}6 \text{ kN}$$

Design resistance to block tearing considering rows as if non staggered: — EN 1993-1-8, clause 3.10.2(2) Eq. 3.9

$$V_{\text{eff,1,Rd}} = \frac{f_u A_{nt}}{\gamma_{M2}} + \frac{f_y A_{nv}}{\sqrt{3}\gamma_{M0}}$$

$$= \frac{530\times(35-2\times9)\times10}{1{,}25\times10^3} + \frac{220\times(2\times240-6\times18-2\times9)\times10}{\sqrt{3}\times1{,}1\times10^3}$$

$$= 72{,}1 + 408{,}8 = 480{,}9 \text{ kN}$$

Design resistance of the bolts in shear

The bolts are in single shear. Consider the shear to be in the plane of the threads. Therefore, $\alpha = 0{,}5$ — Section 6.2.4

Sectional area of M16 bolt: A_s = 157 mm²

Design resistance of class 50 M16 bolt of sectional area A_s = 157 mm² :

$$F_{v,Rd} = \frac{\alpha f_{ub} A_s}{\gamma_{M2}} = \frac{0{,}5\times500\times157}{1{,}25\times10^3} = 31{,}4 \text{ kN}$$ — Eq. 6.9

Design resistance of the bolt group in shear: $n_b F_{v,Rd}$ = 8 × 31,4 = 251,2 kN

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CALCULATION SHEET

Design resistance of the bolts/ply in bearing — Section 6.2.3

$$F_{\mathrm{b,Rd}} = \frac{k_1 \alpha_b f_{\mathrm{u,red}} d t}{\gamma_{\mathrm{M2}}}$$ Eq. 6.2

Design resistance in bearing on the 10 mm thick ply of the end M16 bolt where end distances e_1 = 30 mm, edge distances e_2 = 25 mm (> $1,2d_0$ = 21,6 mm) and bolt spacings p_1 = 60 mm and p_2 = 35 mm

The deformations at the serviceability load level: reduced design bearing stress $f_{\mathrm{u,red}}$ is used here in order to avoid excessive bolt hole

$$f_{\mathrm{u,red}} = 0,5 f_{\mathrm{y}} + 0,6 f_{\mathrm{u}} \text{ but } \leq f_{\mathrm{u}}$$ Eq. 6.1

$$0,5 \times 220 + 0,6 \times 530 = 428 \text{ N/mm}^2 < f_{\mathrm{u}}$$

$$\alpha_{\mathrm{d}} = \frac{e_1}{3d_0} = \frac{30}{3 \times 18} = 0.556$$

The reduction factor for the end bolt nearest the ends where e_1 = 30 mm, p_1 = 60 mm:

$$\alpha_{\mathrm{b}} = \min\left(\alpha_d; \quad f_{ub} / f_{u,red}; \quad 1,0\right)$$

$$= \min(0,556; \quad 500/428 = 1,17; \quad 1,0) = 0,556$$

$$k_1 = \min\left(2,8\left(\frac{e_2}{d_0}\right) - 1,7; \quad 2,5\right)$$

$$= \min\left(2,8\left(\frac{25}{18}\right) - 1,7 = 2,2; \quad 2,5\right) = 2,2$$

The bolt itself is not critical in bearing, since $f_{\mathrm{ub}}/f_{\mathrm{ur}}$ = 500/428 = 1,17 > 1,0

Design bearing resistance for the end bolt :

$$F_{\mathrm{b,Rd}} = \frac{k_1 \alpha_b f_{\mathrm{u,red}} d t}{\gamma_{\mathrm{M2}}} = \frac{2,2 \times 0,556 \times 428 \times 16 \times 10}{1,25 \times 10^3} = 67,0 \text{ kN}$$ Eq. 6.2

Design resistance of the joint in bearing: $n_{\mathrm{b}} F_{\mathrm{b,Rd}}$ = 8 × 67,0 = 536 kN

Note :The critical mode of failure for all of the bolts in the joint is shear.

Design resistance of the joint at the Ultimate Limit State

The smallest design resistance found was that for block tearing of the connected angle leg :

Design resistance to block tearing of the connected angle leg: $N_{\mathrm{Rd}} = V_{\mathrm{eff,2,Rd}}$ = 274 kN — Sheet 3