3 WELDING

The majority of welded connections are produced in the fabricator shop. During the design the ductility of the weld needs to be guaranteed. This is resolved by a set of design rules. For structural steel connections metal arc welding is used on all but a few special cases such as stud welding. When using this approach the weld metal should be compatible with the parent metal in terms of its mechanical properties. The material thickness should be at least *4 mm* (special rules need to be applied for welding thin walled elements). Welds can be classified as fillet welds, slot welds, butt welds, plug welds and flare groove welds. prEN 1993-1-8 provides requirements for the effective length of a fillet weld with a throat thickness *a*, see Figure 3.1.

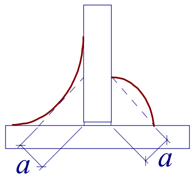


Figure 3.1 Definition of throat thickness a

In the design procedure the internal force on the fillet weld is resolved into components parallel and transverse to the critical plane of the weld throat, see Figure 3.2. A uniform stress distribution is assumed on the critical throat section of the weld, leading to the following normal stresses and shear stresses:

- $\sigma_\perp$ the normal stress perpendicular to the critical plane of the throat,
- $\sigma_{//}$ the normal stress parallel to the axis of the weld, it should be neglected when calculating the design resistance of a fillet weld,
- $\tau_\perp$ the shear stress (in the critical plane of the throat) perpendicular to the weld axis,
- $\tau_{//}$ the shear stress (in the critical plane of the throat) parallel to the weld axis.

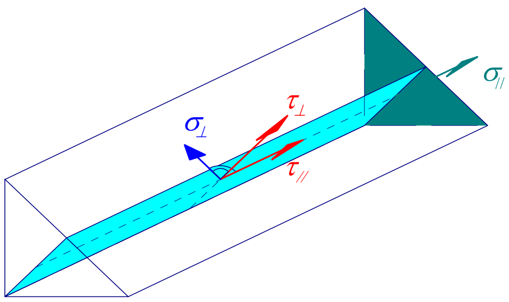


Figure 3.2 Stress in critical plane of fillet weld

The resistance of the fillet weld will be sufficient if the following two conditions are satisfied:

$$\sqrt{\sigma_\perp^{\,2} + 3\left(\tau_\perp + \tau_{//}\right)^2} \le \frac{f_u}{\beta_w\,\gamma_{Mw}} \tag{3.1}$$

and

$$\sigma_\perp \le \frac{f_u}{\gamma_{Mw}}. \tag{3.2}$$

The correlation factor β_w is summarised in Table 3.1.

prEN 1993-1-8 includes a simplified procedure for calculating the design shear resistance of the fillet weld per unit length independent of the direction of loading, see Figure 3.3,

$$f_{vw.d} = \frac{f_u}{\sqrt{3}\,\beta_w\,\gamma_{Mw}} \tag{3.3}$$

and the resistance of the weld per unit length is

$$F_{w,Rd} = a\, f_{vw,d}\,. \tag{3.4}$$

Table 3.1 Correlation factor for weld resistance

Standard and steel grade			Correlation factor β_w
EN 10025	**EN 10210**	**EN 10219**	
S 235 S 235 W	S 235 H	S 235 H	*0,8*
S 275 S 275 N/NL S 275 M/ML	S 275 H S 275 NH/NLH	S 275 H S 275 NH/NLH S 275 MH/MLH	*0,85*
S 355 S 355 N/NL S 355 M/ML S 355 W	S 355 H S 355 NH/NLH	S 355 H S 355 NH/NLH S 355 MH/MLH	*0,9*
S 420 N/NL S 420 M/ML		S 420 MH/MLH	*1,0*
S 460 N/NL S 460 M/ML S 460 Q/QL/QL1	S 460 NH/NLH	S 460 NH/NLH S 460 MH/MLH	*1,0*

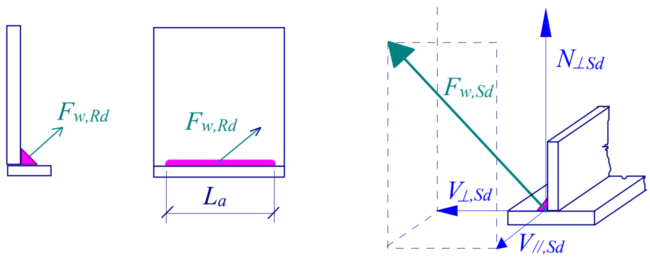
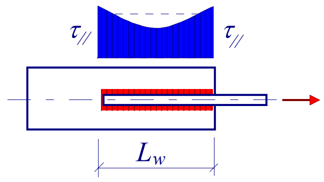


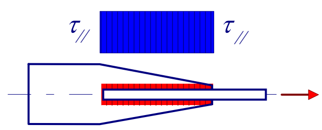
Figure 3.3 Design of fillet weld independent of the direction of loading

When very long welds are exposed to a force in the direction of the weld the stresses in the middle of the weld may be lower compare to the corners, see Figure 3.4a. This results from the deformations of the connected plate. If the plates are adequate the stresses in the welds are uniform, see Figure 3.4b. This overloading may result in failure of the ends of the welded connection (zip effect). Resistance of welds longer than *150 a* should be reduced by the factor β_{Lw}, see Figure 3.4c,

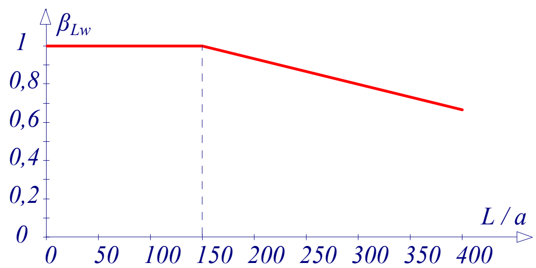
$$\beta_{Lw} = 1{,}2 - 0{,}2\left(\frac{L}{150\, a}\right) \tag{3.5}$$



a) non-uniform distribution of internal stresses



b) uniform distribution of internal stresses



c) reduction factor β_{Lw}

Figure 3.4 Long weld

As far as butt welds are concerned, full penetration welds have a design resistance that is equal to the design resistance of the weaker of the parts joined. The resistance of a partial penetration butt weld shall be determined in a similar way to that for deep penetration fillet welds. The depth of the penetration should be obtained by tests.

Joint details causing through-thickness stresses originating from welding carried out under conditions of restraint shall be avoided whenever possible, to reduce the possibility of lamellar tearing. Where such details are unavoidable appropriate measures must be taken. The distribution of forces in a welded connection may be calculated by using either an elastic or a plastic method.

Q&A 3.1 Connecting Two Angles to Gusset Plate

Should the eccentricity between the welds and the centre of the angle be taken into account?

In general the forces and moments due to all eccentricities should be taken into account when calculating the stresses in the weld. In the case of equal angles it is common European practice to neglect the eccentricity in the design of welds.

If the unequal angles are connected to a fin plate the eccentricity is taken into account by member design as well as by weld design. The following example shows how the forces in the weld can be calculated.

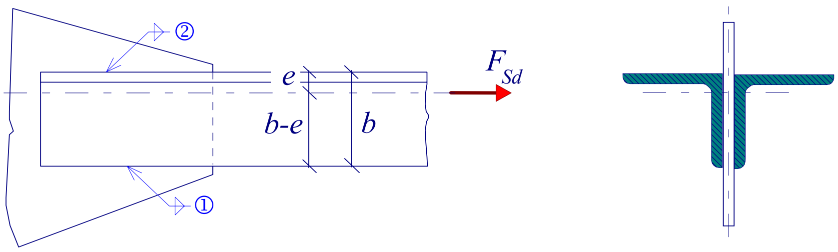


Figure 3.5 Angles connected to a gusset plate

The weld on the lower side, marked as weld ①, is loaded by the force F_1 equal to

$$F_1 = \frac{F_{Sd}}{2}\,\frac{e}{b}, \tag{3.6}$$

which causes shear stresses parallel to the axis of the weld $\tau_{//}$

$$\tau_{1,//} \le \frac{f_u}{\sqrt{3}\,\beta_w\,\gamma_{Mw}} \tag{3.7}$$

This is the only stress in this weld. The resistance of the weld can be checked using formula (3.3), which can be simplified to

$$\tau_{1,//} \le \frac{f_u}{\sqrt{3}\,\beta_w\,\gamma_{Mw}}. \tag{3.8}$$

The force F_2 on the upper weld, (weld ②), is equal to

$$F_2 = \frac{F_{Sd}}{2}\,\frac{(b-e)}{b} \tag{3.9}$$

and the shear stress $\tau_{//}$

$$\tau_{2,//} = \frac{F_2}{a_2\,L_2}. \tag{3.10}$$

Q&A 3.2 Effective Width of Welded Beam-to-Column Connection

When designing welded beam-to column connection, an effective width is used to calculate the resistance of the column flange in bending. Is it possible to design the welds connecting the beam flange to column flange using the width b_{eff}, if the effective width is smaller than width of the beam flange?

According to prEN1993-1-8 Clause 6.2.4.4 for unstiffened column flanges in bending, the tensile design resistance is calculated using the following formula:

$$F_{t.fc.Rd} = \left(t_{wc} + 2\,s + 7\,k\,t_{fc}\right) \frac{t_{fb}\,f_{yb}}{\gamma_{M0}} \tag{3.11}$$

where

$$k = min\left(\frac{f_{yc}\,t_{fc}}{f_{yb}\,t_{fb}};\,1\right) \tag{3.12}$$

and t_{wc} is thickness of column web, t_{fc} thickness of column flange, t_{fb} thickness of beam flange and s is equal to fillet radius r_c for hot rolled column sections, see Figure 3.6.

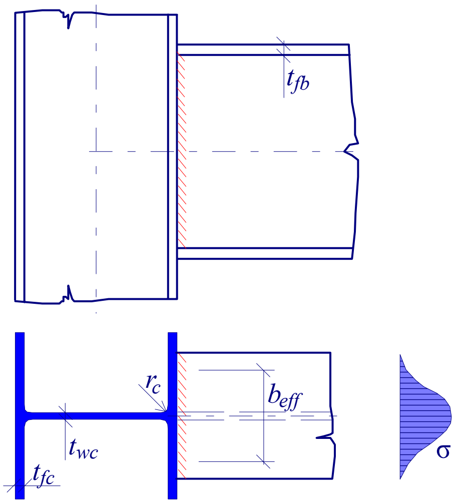


Figure 3.6 Effective width of beam flange of welded joint and stress in the connected flange

According to prEN 1993-1-8 Chapter 4.10 the effective width b_{eff} of a fillet weld connecting the beam flange is

$$b_{eff} = t_{wc} + 2\,s + 7\,t_{fc}\,, \tag{3.13}$$

but it is limited to

$$b_{eff} = t_{wc} + 2\,s + 7\left(\frac{t_{fc}^{\;2}}{t_{fb}}\right)\left(\frac{f_{yc}}{f_{yb}}\right). \tag{3.14}$$

Substituting equation 3.12 into 3.11 gives the same effective width for calculating the resistance of the beam flange in tension as that used for the fillet weld.

Q&A 3.3 Throat Thickness of a Fillet Weld used in a Hollow Section Joints

Do the rules for the throat thickness of a weld given in prEN 1993-1-8 guarantee, that there is enough deformation capacity in the welds such that the welds are not the weakest part of the whole joint?

The expressions given in prEN 1993-1-8 relate the throat thickness of the fillet weld a to the minimum thickness t of the welded hollow section members, see Table 3.2. If the previous relations are fulfilled, the fundamental criterion of welding between hollow sections is satisfied. Then, the design resistance of the weld per length of the perimeter of a diagonal member is not less than the design resistance of the cross section of this member per length of the perimeter. This criterion ensures that there is enough deformation capacity in the welds, which allows the redistribution of the bending moments.

Table 3.2 Minimum throat thickness for fillet welds of hollow section joints

Steel grades according to EN 10025	
S 235	$a / t \geq 0{,}84\ \alpha$
S 275	$a / t \geq 0{,}87\ \alpha$
S 355	$a / t \geq 1{,}01\ \alpha$
Steel grades according to EN 10113	
S 275	$a / t \geq 0{,}91\ \alpha$
S 355	$a / t \geq 1{,}05\ \alpha$

When $\gamma_{Mj} = 1{,}10$ and $\gamma_{Mw} = 1{,}25$, then $\alpha = 1{,}0$; otherwise $\alpha = 1{,}10\ \gamma_{Mw} /(1{,}25\ \gamma_{Mj})$

Q&A 3.4 Modelling the Resistance of a Fillet Weld

prEN 1993-1-8 gives two methods for the design of fillet welds, the exact method and the simplified one. What are the differences between these two methods?

There is no difference in the case of a connection loaded by a force parallel to the weld, see Figure 3.7.

$$f_{w.Rd} = \frac{f_u}{\sqrt{3}\,\beta_w \gamma_{Mw}}. \tag{3.15}$$

a) loaded by force parallel to weld *b) loaded by force perpendicular to weld*

Figure 3.7 Fillet weld

For a weld loaded perpendicular to its length the differences between the two models are significant. The stresses may be calculated as

$$\sigma_\perp = \tau_\perp = \frac{\sigma_w}{\sqrt{2}} \quad \text{and} \quad \tau_{//} = 0\,. \tag{3.16}$$

From the plane model we obtain

$$\sqrt{\left(\frac{\sigma_w}{\sqrt{2}}\right)^2 + 3\left(\frac{\sigma_w}{\sqrt{2}}\right)^2} \le \frac{f_u}{\beta_w \, \gamma_{Mw}} \quad \text{and} \quad \sigma_w \le \frac{f_u}{\beta_w \gamma_{Mw} \sqrt{2}} = f_{w.end.Rd} \,. \tag{3.17}$$

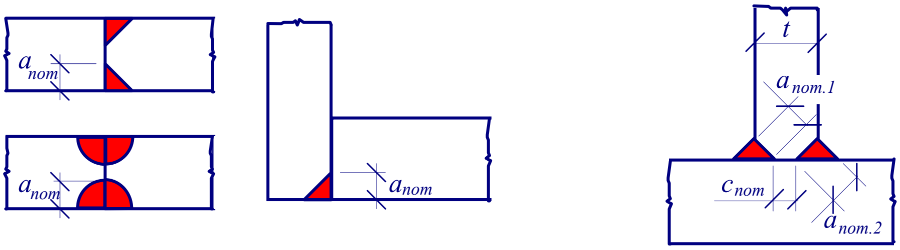
The difference will be

$$f_{w.end.Rd} \,/\, f_{w.Rd} = \sqrt{3} \,/\, \sqrt{2} = 1{,}22 \,. \tag{3.18}$$

Q&A 3.5 Design of Partially Penetrated Butt Weld

What procedure is recommended for the design of partially penetrated butt welds?

Partially penetrated butt welds may be designed as fillet weld with an effective width of $a = a_{nom} - 2\ mm$, see Figure 3.8a.



a) partially penetrated butt weld *b) T joint*

Figure 3.8 Effective width

For T joints full penetration is assumed in the case of

$$a_{nom.1} + a_{nom.2} \ge t$$

$$c_{nom} \le \frac{t}{5} \tag{3.19}$$

$$c_{nom} \le 3\ mm \,.$$

In the case of partial penetration in the T joint, see Figure 3.8b, the weld is designed as a fillet weld with an effective width

$$a_{nom.1} + a_{nom.2} < t$$

$$a_1 = a_{nom.1} - 2\ mm \tag{3.20}$$

$$a_2 = a_{nom.2} - 2\ mm \,.$$

Q&A 3.6 Weld Design for Full Resistance of Connecting Members

What are the recommendations for the design of a fillet welds in the case of a connection with full member resistance?

a) loading by normal force *b) loading by shear force*

Figure 3.9 Fillet weld effective thickness

In the above case, see Figure 3.9, the weld may be designed to resist the applied forces. The weld thickness may be calculated as

$$a > 0{,}7 \frac{\sigma\, t}{f_u / \gamma_{Mw}}\,, \tag{3.21}$$

where $\sigma = F_{Sd} / (t\, h)$, and F_{Sd} is the acting design force, f_u is plate design strength, t is the thinness of connecting plate, b is width of connecting plate. If an elastic global analysis is used the weld need to carry the full capacity of a plate the thickness, assuming S235 steel ($f_y = 235\ MPa$; $f_u = 360\ MPa$), is given by the following expressions

$$a > 0{,}7 \frac{(f_y / \gamma_{M0})\, t}{f_u / \gamma_{Mw}} = 0{,}7 \frac{(235 / 1{,}10)\, t}{360 / 1{,}25} = 0{,}52\, t \approx 0{,}5\, t\,. \tag{3.22}$$

When plastic global analysis it is for braced frames the weld thickness is given by

$$a > 1{,}4 \cdot 0{,}7 \frac{(f_y / \gamma_{M0})\, t}{f_u / \gamma_{Mw}} = 1{,}4 \cdot 0{,}7 \frac{(235 / 1{,}10)\, t}{360 / 1{,}25} = 0{,}73\, t \approx 0{,}7\, t\,, \tag{3.23}$$

and for unbraced frames

$$a > 1{,}7 \cdot 0{,}7 \frac{(f_y / \gamma_{M0})\, t}{f_u / \gamma_{Mw}} = 1{,}7 \cdot 0{,}7 \frac{(235 / 1{,}10)\, t}{360 / 1{,}25} = 0{,}88\, t \approx 0{,}9\, t\,. \tag{3.24}$$

Similarly for the design of a weld loaded parallel to its length, the weld thickness may be calculated as

$$a > 0{,}85 \frac{\tau\, t}{f_w / \gamma_{Mw}} \approx 0{,}85 \frac{f_y /(\sqrt{3}\, \gamma_{M0})\, t}{f_u / \gamma_{Mw}} = 0{,}85 \frac{235 /(1{,}1 * \sqrt{3}\,)\, t}{360 / 1{,}25} = 0{,}36\, t \cong 0{,}4\, t \tag{3.25}$$

where $\tau = V_{Sd} / (t\, h)$, V_{Sd} is the design shear force in weld.