



The analysis of the resistance of tee joint fillet welds according to Eurocode 3

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ABSTRACT:

The aim of the work is to find the relationship between the effective lengths of fillet welds determined by the directional method and the simplified method in a tee joint loaded in any way. This causes a complex state of stresses in the weld. The work shows for which loads it is important to use particular calculation methods in order to obtain a more economical solution. Thanks to this and careful execution of welds, measurable material savings can be achieved.

KEYWORDS:

fillet weld; directional method; simplified method

1. Introduction

To be able to check the resistance of fillet welds according to Eurocode 3 [1], the stress state must be determined by the directional or simplified method. The procedures for checking the resistance of such welds are given in [2, 3]. The calculation of reduced stresses using the directional method is quite tedious, therefore the standard [1] allows for the simplified method as an alternative. The latter comes down to the comparison between the resultant of all the forces per unit length transmitted by the weld $F_{w,Ed}$ at every point along the length of the weld joint and the design resistance $F_{w,Rd}$, determined from the formula:

$$F_{w,Rd} = f_{vw,d} a \quad (1)$$

in which the design shear strength of the weld $f_{vw,d}$ is given by:

$$f_{vw,d} = \frac{f_u/\sqrt{3}}{\beta_w \gamma_{M2}} \quad (2)$$

where: a – the effective throat thickness of a fillet weld; f_u – the nominal ultimate tensile strength of the weaker part joined; β_w – correlation factor depending on the steel grade (the values are given in Table 1); γ_{M2} – partial factor used for checking the resistance of cross-sections in tension to fracture (according to the standard [4] $\gamma_{M2} = 1.25$).

Table 1

Correlation factor β_w

Group of steel grades	S 235	S 275	S 355	S 420	S 460
Correlation factor β_w	0.80	0.85	0.90	1.00	1.00

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However, the simplified method usually results in excessive thickness or length of joints.

In turn, the determination of reduced stresses in the directional method resembles the Huber-Mises-Hencky stress hypothesis. This is a more general method and the design resistance of the fillet weld is sufficient if the following are both satisfied:

$$\sqrt{\sigma_{\perp}^2 + 3(\tau_{\perp}^2 + \tau_{\parallel}^2)} \leq \frac{f_u}{\beta_w \gamma_{M2}} \quad (3)$$

and

$$\sigma_{\perp} \leq \frac{0,9 f_u}{\gamma_{M2}} \quad (4)$$

The components of normal and shear stresses are assumed (Fig. 1):

- σ_{\perp} - the normal stress perpendicular to the throat,
- σ_{\parallel} - the normal stress parallel to the axis of the weld (is not considered when verifying the design resistance of the weld),
- τ_{\perp} - the shear stress (in the plane of the throat) perpendicular to the axis of the weld,
- τ_{\parallel} - the shear stress (in the plane of the throat) parallel to the axis of the weld.

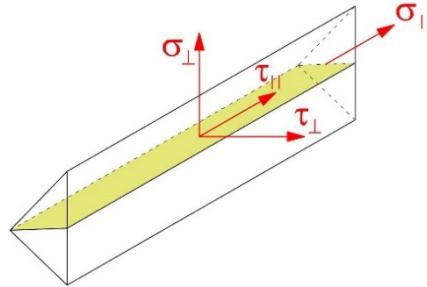


Fig. 1. Stresses on the throat section of a fillet weld [1]

2. Strength of the welds

The analysis was carried out by comparing the effective lengths of the welds calculated using the directional method l_D and simplified method l_S assuming that in the most stressed point of the weld the stresses reach 100% of the resistance for each of the methods.

Figure 2 shows a diagram of a tee joint with its load.

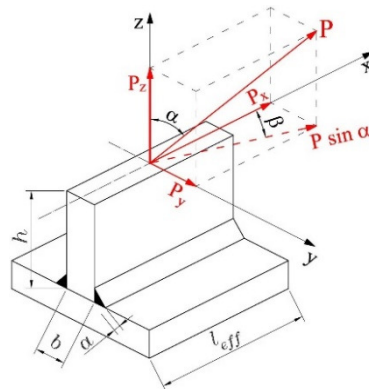


Fig. 2. Diagram of a tee joint

Geometric parameters of welds:

$$A_w = 2 a l_{eff} \quad I_x = \frac{l_{eff}(b+2a)}{12} - \frac{l_{eff} b^3}{12} \quad W_x = \frac{I_x}{a + \frac{b}{2}} \quad W_y = \frac{2a l_{eff}^2}{6}$$

The force loading the joint is applied symmetrically and can be directed in any direction. Its inclination to the vertical z axis defines the angle α , while its deviation from the x axis in the plane defined by the x and y axes determines the angle β . The components of the force P are:

$$P_x = P \sin \alpha \cos \beta \quad P_y = P \sin \alpha \sin \beta \quad P_z = P \cos \alpha$$

In order to determine the minimum weld length using the simplified method, it must be ensured that the stresses do not exceed the design shear strength of the weld $f_{vw,d}$ given by formula (2) at the most stressed point of the weld, that is:

$$\tau_w = \sqrt{(\sigma_t^z + \sigma_b^x + \sigma_b^y)^2 + (\tau_s^y)^2 + (\tau_s^x)^2} \leq \frac{f_u/\sqrt{3}}{\beta_w \gamma_{M2}} \quad (5)$$

This formula includes:

- stress from force P_z : $\sigma_t^z = \frac{P_z}{A_w} \leq \frac{f_u}{\beta_w \gamma_{M2}}$
- stresses from force P_x : $\sigma_b^x = \frac{P_x h}{W_y} \leq \frac{f_u}{\beta_w \gamma_{M2}} \quad \tau_s^x = \frac{P_x}{A_w} \leq \frac{f_u/\sqrt{3}}{\beta_w \gamma_{M2}}$
- stresses from force P_y : $\sigma_b^y = \frac{P_y h}{W_x} \leq \frac{f_u}{\beta_w \gamma_{M2}} \quad \tau_s^y = \frac{P_y}{A_w} \leq \frac{f_u/\sqrt{3}}{\beta_w \gamma_{M2}}$

The subscripts next to the stress symbols denote respectively the states caused by: tension (t), bending (g) and shear (s). The superscripts next to the stress symbols (x, y, z) denote respectively the states caused by the force components (P_x, P_y, P_z) acting on the given directions.

However, in order to calculate the length of the weld using the directional method, in general, 9 stress components should be determined.

The reduced stresses at the most stressed point of the weld must satisfy the condition (2), that is:

$$\sigma_r = \sqrt{(\sigma_{1t}^z + \sigma_{1g}^x + \sigma_{1g}^y + \sigma_{1b}^z)^2 + 3((\tau_{1s}^z + \tau_{1s}^x + \tau_{1s}^y + \tau_{1b}^z)^2 + (\tau_{1t}^x)^2)} \leq \frac{f_u}{\beta_w \gamma_{M2}} \quad (6)$$

and normal components of stresses perpendicular to the throat of the weld, condition (3), namely:

$$\sigma_{\perp} = \sigma_{1t}^z + \sigma_{1g}^x + \sigma_{1g}^y + \sigma_{1b}^z \leq \frac{0,9 f_u}{\gamma_{M2}} \quad (7)$$

where:

- perpendicular stresses due to the force P_z : $\sigma_{1t}^z = \frac{\sigma_t^z}{\sqrt{2}} \quad \tau_{1t}^z = \frac{\tau_t^z}{\sqrt{2}}$
- perpendicular stresses due to the force P_x : $\sigma_{1g}^x = \frac{\sigma_b^x}{\sqrt{2}} \quad \tau_{1g}^x = \frac{\tau_s^x}{\sqrt{2}}$
- and parallel stress due to the force P_x : $\tau_{1t}^x = \tau_s^x$

- perpendicular stresses due to the force P_y :

$$\sigma_{\perp b}^y = \frac{\sigma_b^y}{\sqrt{2}} \quad \tau_{\perp b}^y = \frac{\sigma_b^y}{\sqrt{2}}$$

$$\sigma_{\perp s}^y = \frac{\tau_s^y}{\sqrt{2}} \quad \tau_{\perp s}^y = \frac{\tau_s^y}{\sqrt{2}}$$

For the assumed tee joint, when the condition (6) is met, also the condition (7) is fulfilled for each load case.

3. Analytical example

In order to calculate the effective length of the welds using the directional method l_D and simplified method l_S , it was assumed that at the most stressed point of the weld, the stresses reach 100% of the design resistance, the weld is symmetrical, and the throat section is an isosceles triangle. As a result, by comparing the l_D and l_S lengths, the maximum differences between these methods were determined. The ineffectiveness of unequal-arm fillet welds was demonstrated in the article [5].

Data used for calculations:

- steel S 235: $f_u = 360$ MPa
- joint geometry (according to Fig. 2): $a = 3$ mm $h = 25$ mm $t = 12$ mm
- load: $P = 40$ kN

The calculation results are presented in Table 2.

Table 2
The results of the analysis

α [°]	β [°]	l_D [mm]	l_S [mm]	λ [%]	ϵ [-]
0	-	26.2	32.1	22.5	1
5	0	35.8	42.1	17.6	0.996
7.5		39.3	45.8	16.5	0.992
10		42.3	49.0	15.8	0.988
15		47.5	54.5	14.7	0.980
30		58.5	66.2	13.2	0.950
45		65.2	73.0	12.0	0.919
60		68.6	76.1	10.9	0.890
75		69.1	76.1	10.1	0.865
90		67.0	73.2	9.3	0.845
5		30	38.3	44.2	15.4
7.5	43.0		49.0	14.0	0.995
10	47.2		53.3	12.9	0.993
15	54.7		60.9	11.3	0.988
30	72.3		78.4	8.4	0.975
45	84.4		89.9	6.5	0.964
60	91.4		96.3	5.4	0.954
75	93.6		97.7	4.4	0.945
90	91.2		94.4	3.5	0.938
5	45		38.6	44.3	14.8
7.5		43.6	49.3	13.1	0.997
10		48.2	53.8	11.6	0.996
15		56.5	62.1	9.9	0.993
30		76.7	81.7	6.5	0.985
45		91.0	95.3	4.7	0.979
60		99.8	103.1	3.3	0.974
75		102.9	105.1	2.1	0.970
90		100.3	101.7	1.4	0.966
5		60	38.1	43.6	14.4
7.5	43.2		48.6	12.5	0.998
10	47.9		53.2	11.1	0.998
15	56.7		61.7	8.8	0.996
30	78.5		82.6	5.2	0.993
45	94.5		97.4	3.1	0.990
60	104.6		106.2	1.5	0.988
75	108.2		108.8	0.6	0.986
90	105.6		105.1	-0.5	0.985
5	90		34.8	39.9	14.7
7.5		38.9	43.7	12.3	1
10		43.0	47.4	10.2	1
15		51.0	54.7	7.3	1
30		72.2	74.1	2.6	1
45		88.5	88.7	0.2	1
60		98.8	97.3	-1.5	1
75		102.4	99.4	-2.9	1
90		99.0	95.0	-4.0	1

The obtained lengths of the welds meet the standard conditions, except for the case of loading only with the vertical force ($\beta = 0^\circ$). For the accepted data, the length determined by the directional method is smaller than the minimum required by the standard [1], that is $l_D < 30$ mm; however, it does not affect the correctness of the analysis. The results of the analysis are presented in the charts. The numerical indexes of the values λ and ε correspond to the data for different angles β of the inclination of the force P to the vertical axis. Figure 3 shows the percentage differences in the length of welds calculated using the simplified method l_S and the directional method l_D in relation to the length l_D :

$$\lambda = \frac{l_S - l_D}{l_D}$$

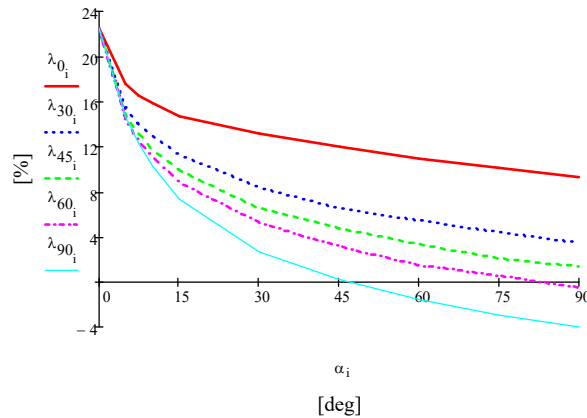


Fig. 3. Percentage differences in the length of the welds λ

For the directional method at the most stressed point of the weld, the ratio of the normal stress perpendicular to the throat section σ_{\perp} to the resultant shear stresses was additionally analyzed:

$$\varepsilon = \frac{\sigma_{\perp}}{\sqrt{(\tau_{\perp}^z + \tau_{\perp}^x + \tau_{\perp}^y + \tau_{\perp}^b)^2 + (\tau_{II}^x)^2}}$$

These relationships are shown in Figure 4.

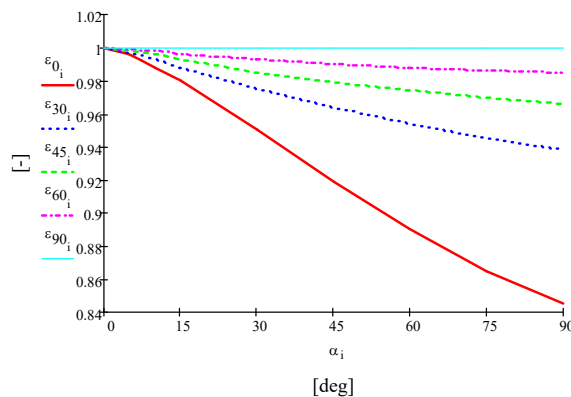


Fig. 4. The ratio between σ_{\perp} and the resultant of shear stresses

4. Conclusions

The above calculations show that for a tee joint, in most cases, the load by the directional method gives smaller effective lengths of welds than the simplified method. The largest disproportions in favor of the directional method occur in the case of loading only with vertical force ($\alpha = 0^\circ$) and reach 22,5%, and the coefficient $\varepsilon = 1$. Such a case occurs, for example, in the case of gusset plates of trusses connecting only the posts to the chord.

On the other hand, when the force acting in the plate plane ($\beta = 0^\circ$) is applied at a certain angle $0^\circ < \alpha < 90^\circ$, then the effective length of the welds determined by the directional method is also smaller, and the minimum savings reach over 9% for $\alpha = 90^\circ$ (state corresponding to the load only by the force P_x). With the increasing angle α the stress share σ_\perp decreases the fastest among the other load cases ($\varepsilon \rightarrow 0.845$).

With an increase in the value of the angle β profits from the use of the directional method get smaller. If the P_y force is dominant then the simplified method may even result in shorter weld lengths. The share of stresses σ_\perp then decreases slower, and in the extreme case, for $\beta = 90^\circ$ the value of $\varepsilon = 1$. However, in engineering practice, tee joints loaded in such a way are extremely rare. In this case, the load-bearing capacity of the sheet, which is strongly bent, may not be sufficient and the connection should be reinforced with transverse ribs.

For other, less stressed weld points, the proportions of stress σ_\perp to the resultant shear stress differs significantly from those calculated for the most stressed point. For example, for points lying on the opposite end of the weld at $\alpha = 10^\circ$ and $\beta = 60^\circ$, the coefficient $\varepsilon = 1,297$ – point on the same side of the plate, and $\varepsilon = 0,637$ – point on the other side of the plate.

The conclusions from the analysis carried out for other steel grades and different weld thicknesses are similar.

Even greater material savings can be achieved by making precise welds. Compared to a fillet weld with a perfectly flat face, a convex weld with an excess of weld metal with a radius of $r = \sqrt{2}a$ has as much as 57% more volume.

References

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Analiza nośności spoin pachwinowych połączenia teowego według Eurokodu 3

STRESZCZENIE:

Celem pracy jest znalezienie zależności pomiędzy długościami efektywnymi spoin pachwinowych wyznaczonymi metodą kierunkową i uproszczoną w złączu teowym obciążonym w dowolny sposób. Wywołuje to powstanie złożonego stanu naprężeń w spoinie. Pokazano, dla jakich obciążeń istotne jest stosowanie poszczególnych metod obliczeniowych, aby uzyskać bardziej ekonomiczne rozwiązanie. W połączeniu z jakością wykonania spoin można uzyskać wymierną oszczędność materiału.

SŁOWA KLUCZOWE:

spoina pachwinowa; metoda kierunkowa; metoda uproszczona