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THE β-FORMULA FOR THE DESIGN OF FILLET WELDS

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THE β-FORMULA FOR THE DESIGN OF FILLET WELDS*

ABSTRACT

In the past few years changes have been proposed to the IIW design rules for the calculation of arc welded connections. Also some objections have been raised. This article gives a summary of these proposals and objections and also the results of recent discussions in Committee XV of the IIW. Finally some design results with the β-formula and a simplified formula, proposed in Eurocode 3, are compared.

1. INTRODUCTION

In 1976, design rules for statically loaded arc-welded connections in steel were published in Welding in the World [1].
These design rules have been worked out by sub-commission XV-A "Calculation of welded constructions subject to static loading" and were approved by the plenary commission in 1975.
The research program which was carried out, included about 700 tests performed in 11 countries.

The design rules are intended to design and calculate statically loaded welded connections in carbon and low alloy steels, having a minimum tensile strength less than 600 N/mm^2, a ratio of yield to ultimate strength ≤ 0.8, and a minimum elongation $\epsilon_{10} \geq 12\%$.

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*Edited by A.M. Gresnigt, Delft University of Technology (until 01-02-'88 TNO-IBBC), The Netherlands, on behalf of commission XV of the IIW.

For the calculation of fillet welds, the β-formula is recommended:

$$\sigma_c = \beta \sqrt{\sigma_\perp^2 + 3\,(\tau_\perp^2 + \tau_{/\!/}^2)} \leq \bar{\sigma}_t$$

and:

$$\sigma_\perp \leq \bar{\sigma}_t$$

with:

σ_c = comparison stress

$\sigma_\perp$ = normal stress perpendicular to the throat section

$\tau_\perp$ = shear stress acting in the throat section transverse to the axis of the weld

$\tau_{/\!/}$ = shear stress acting in the throat section parallel to the axis of the weld

$\bar{\sigma}_t$ = permissible tensile stress in the base material

β = 0.70 for FeE 240 (Euronorm 25: Fe 360)

= 0.85 for FeE 360 (Euronorm 25: Fe 510)

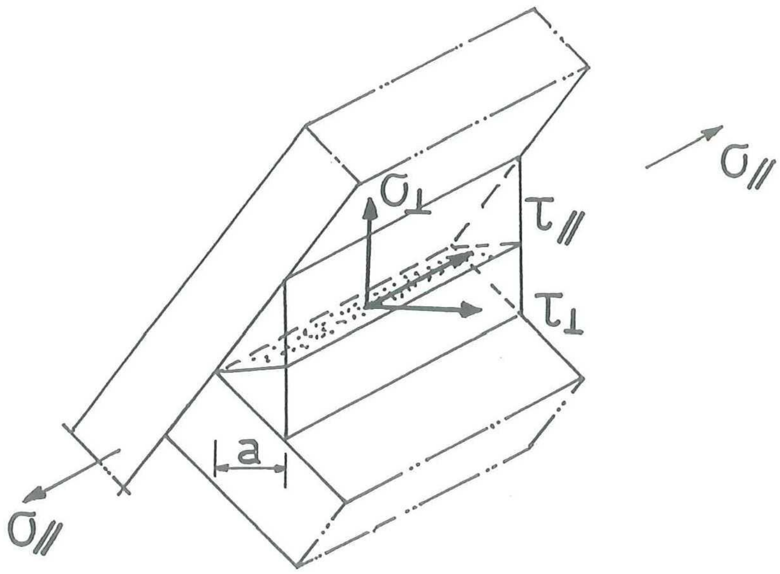

Figure 1: Stress components on a fillet weld.

For other steel grades, β may be determined by means of linear interpolation, proportional to the guaranteed yield strength (f_y).

In the past few years changes have been proposed and objections have been raised in ISO 167, Eurocode 3 [2], ECCS and in publications [3]. These have been discussed in commission XV of the IIW. A summary is given below.

2. PROPOSALS, OBJECTIONS AND DISCUSSION

a. The strength of the weld metal is not taken into account

The β-factor accounts for the difference in the strength of the weld metal and the strength of the base metal.
This difference in strength depends on the steel grade, the steel quality, the welding process and the welding consumables. During the research mentioned before, it has been shown that by using the β-formula, safe results are obtained. See the references given in [1].
By not taking into account the strength of the weld metal explicitly and by considering only the throat section, a relative simple design formula could be obtained. Of course, these simplifications contribute to the scatter when compared with test results (the β-formula is not intended for explaining test results).

b. The actual strength of the welds is much greater than predicted with the β-formula

The β-formula is established such that if $\sigma_c = \bar{\sigma}_t$ (in ultimate limit state design $\bar{\sigma}_t = f_y$), the rupture strength of the welded joint equals at least the rupture strength of the connected member. It has been shown that if $\sigma_c = f_y$, the rupture strength of the welded joint is at least 1.4 times the real yield strength of the member. Through this, weakening effects, such as weld discontinuities, can be tolerated to a certain extent [4].

c. The formula is based on a yield criterion (Von Mises), whereas the deciding phenomenon is rupture

For rupture a factor less than 3 (i.e. 2) for the shear stresses in the β-formula seems more appropriate. See for instance the formula for bolts in Eurocode 3:

$$\sigma_c = \sqrt{\sigma^2 + 2\,\tau^2}$$

During the discussions after the International test series, the best factor appeared to be about 2.2 (see the references mentioned in [1]). Commission XV-A has chosen the β-formula with the factor 3, because designers were familiar with this factor, and the differences with the "best" factor were not significant.

During the Annual Assembly 1987 in Sofia, it was decided that questions about this factor are not important enough to start a discussion about changing the β-formula.

d. The IIW does not give design rules for higher strength steels than FeE 360

To this it is pointed out that in sub-commission XV-A, work is in progress to establish design rules for welded joints in higher strength steels.

e. The presentation can be improved

In Eurocode 3 a different presentation is proposed (ultimate limit state):

$$\sigma_c = \sqrt{\sigma_\perp^2 + 3\,(\tau_\perp^2 + \tau_{/\!/}^2)} \leq \frac{f_u}{\beta\,\gamma_{mw}}$$

and:

$$\sigma_\perp \leq \frac{f_u}{\beta\,\gamma_{mw}}$$

with:

f_u = guaranteed tensile strength of the base metal
γ_{mw} = 1.5

The advantages of the proposed presentation are:
. The actions and the resistance are separated (by the $\leq$ sign).

. The yield strength of the weld is not very relevant for the behaviour of a welded joint. The limit state is rupture. Therefore it is better to take f_u instead of f_y.

. For FeE 240 - FeE 360 the result of the calculation will not change, since for these steel grades $f_u/f_y \approx 1.5$.

During the Annual Assembly 1987 in Sofia, commission XV agreed to the proposed Eurocode 3 presentation.

f. The β-formula is too complicated

The examples given in [1], demonstrate that the application of the β-formula is not complicated. For typical cases of loading of fillet welds, simple formulae can be derived, thus eliminating the necessity to solve the β-formula. For instance for front welds:

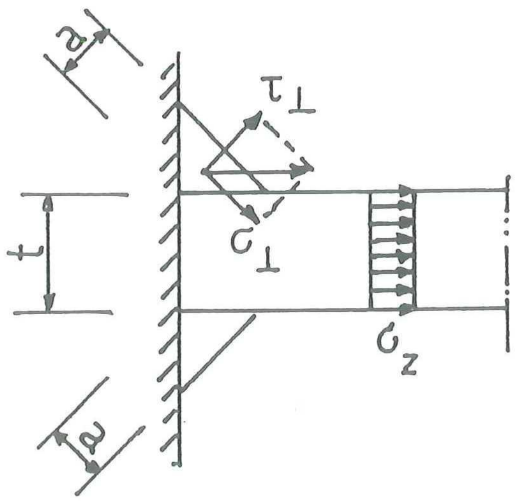

Figure 2: Stress components on a front weld.

$$a \geq \frac{\beta}{\sqrt{2}} \frac{\sigma_z}{f_y} t = 0.71 \beta t \frac{\sigma_z}{f_u} \gamma_{mw}$$

$$\text{FeE 240} \rightarrow a \geq 0.50 \frac{\sigma_z}{f_y} t$$

$$\text{FeE 360} \rightarrow a \geq 0.60 \frac{\sigma_z}{f_y} t$$

In [1] it is stated that simplifying the design rules is allowed, provided that any approximation lies on the safe side of the ellipsoid described by the β-formula. In Eurocode 3 such a simplified formula is given, complementary to the β-formula:

$$\sigma_c = \frac{F}{\Sigma\, a\, \ell} \leq \frac{0.6\, f_u}{\beta\, \gamma_{mw}}$$

with:

F = applied load on the connection
a = throat thickness of each weld
ℓ = length of each weld

For the mentioned front welds it follows, with $F = t\, \ell\, \sigma_z$ and $\Sigma\, a\, \ell = 2\, a\, \ell$:

$$a \geq \frac{\beta\, t}{1.2} \frac{\sigma_z}{f_u} \gamma_{mw} = 0.83\, \beta\, t \frac{\sigma_z}{f_u} \gamma_{mw}$$

For a side fillet weld with only $\tau_{//} = F/a\, \ell$, it follows:

. Method 1 (β-formula):

$$a \geq \frac{\beta\, F\, \sqrt{3}}{\ell\, f_u} \gamma_{mw} = 1.73 \frac{\beta\, F}{\ell\, f_u} \gamma_{mw}$$

. Method 2:

$$a \geq \frac{\beta\, F}{0.6\, \ell\, f_u} \gamma_{mw} = 1.67 \frac{\beta\, F}{\ell\, f_u} \gamma_{mw}$$

The table below gives a summary:

Weld / Formula	Front welds	Side welds
Method 1 (β-formula)	$a \geq 0.71\ \beta\ t\ \frac{\sigma_z}{f_u}\ \gamma_{mw}$	$a \geq 1.73\ \frac{\beta\ F}{\ell\ f_u}\ \gamma_{mw}$
Method 2	$a \geq 0.83\ \beta\ t\ \frac{\sigma_z}{f_u}\ \gamma_{mw}$	$a \geq 1.67\ \frac{\beta\ F}{\ell\ f_u}\ \gamma_{mw}$

It appears that for front welds, the method 2 formula gives greater a-values, while for side welds the results are nearly the same.

Method 2 has the advantage of simplicity, but a disadvantage of about 12% when calculating front welds as compared with method 1.

3. REFERENCES

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