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Change History:

08	External hyperlink updated	Siemer	06/07/2021
07	Change of company logo	Siemer	03/21/2019
06	Company standard revised	Siemer/Freihofer	04/05/2018
05	Approval module revised	Otholt, S.	11/18/2014
04	Chapter structures corrected	Wilken, L	05/27/2013
03	Change of company logo	Baumann	08/09/2012
02	Company standard revised	Wilken, L	06/23/2011
01	Author	Wilken, L	06/16/2009
Index	**Description**	**Name**	**Date**

Released:

The authoritative and approved version of this company standard is only available on the Broetje-Automation intranet. Hard copies and locally stored copies must be verified, as they are not subject to change management.
The website of Broetje Automation “www.broetje-automation.de” serves as an alternative source of company standards for external parties.

1 General principles for design

1.1 Materials

Standard materials for welded components can be found in the company standard BN20.010.

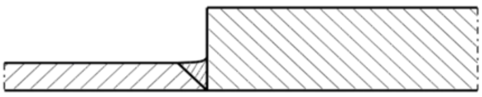
CDB Material selection list

When selecting the material, the selection list of the CATIA standard tool shall be used. If materials other than those specified there are to be used, the welding engineer shall be consulted.
When special steel materials are required, such as X5CrNi18-10 (1.4301), the welding engineer must also be consulted.

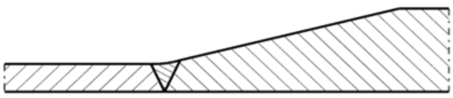
Caution when using ALUMINUM! Even with proper welding practices, Al alloys tend to soften significantly in the heat affected zone. Increased pore formation in the weld metal is also possible. The higher the aluminum material is alloyed, the greater the risk of cracking (hot cracking tendency). Aluminum die-cast is not weldable.

1.2 The steady flow of force must be observed!

Every change in direction of the force flow leads to the formation of stress peaks (notch effect), which are the higher, the more the force flow is disturbed. When the load is at rest, stress peaks caused by notches can be reduced by plasticizing the material. However, this is not possible under dynamic load. The notch can cause the starting point of a fatigue fracture. Butt welds are preferable. At a T-joint, the fillet weld must be completed as a double seam. Extreme cross-section jumps must be avoided.



unfavorable flow of force



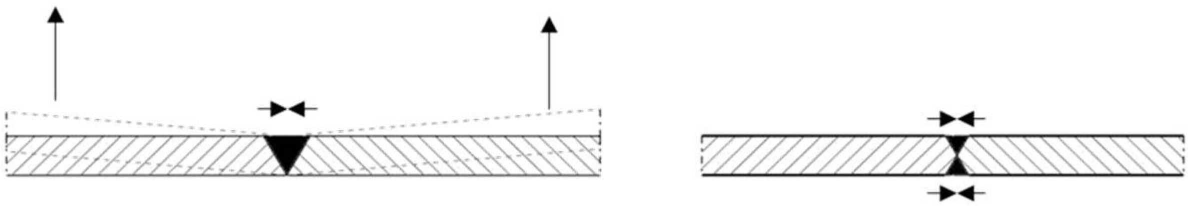
better flow of force (1:4 or less)

1.3 Possibilities to minimize distortion in the welded component

Every weld warps. The larger the weld, the more attention must be paid to distortion. Welds make a "jump up" as soon as single-sided multi-layer welding is required (from 6 mm). Therefore, from 6 mm thick seams, the designer should use methods to minimize distortion in the component, if necessary. There are a number of simple ways to minimize the distortion:

A. Arrange welds symmetrically

One-sided distortion or torsion is avoided and thus necessary straightening work is minimized. This type of welding is suitable for highly stressed weld seams

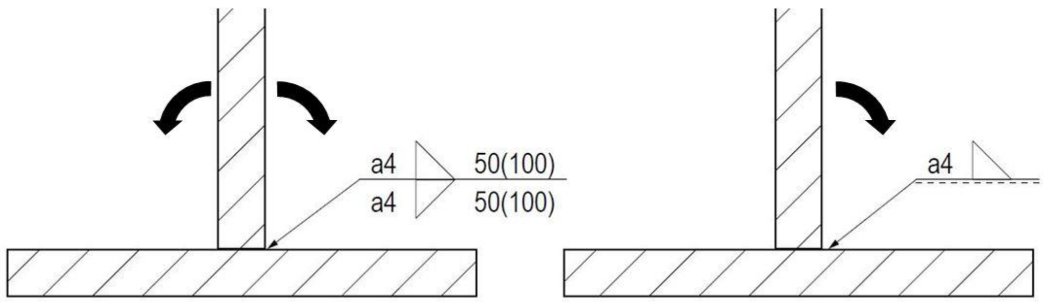


B. Avoid seam accumulations and intersection of seams!

Seam accumulations are prohibited. However, if they are unavoidable because there is no other structural solution, they affect the distortion in a similar way as multi-layer welds affect the warp.

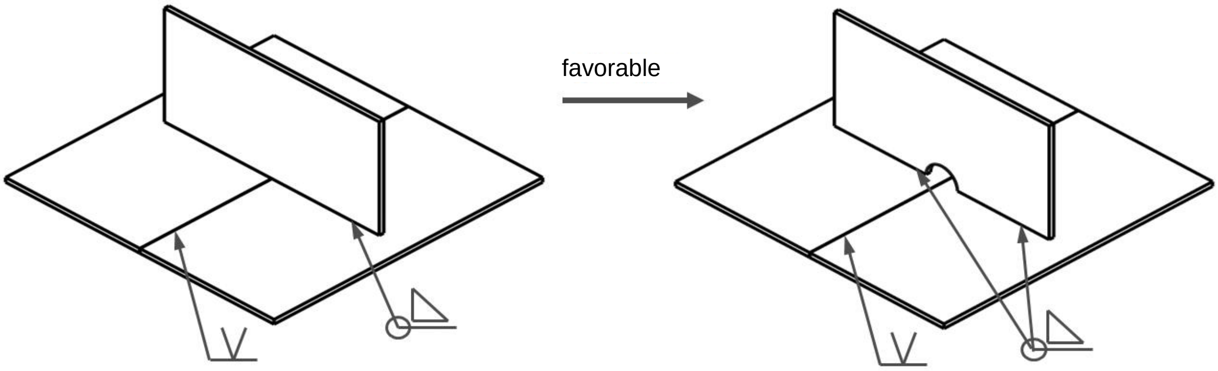
C. Use of interrupted welds

Interrupted weld seams reduce the heat input and thus minimize the distortion, they are suitable for long and/or low stressed welds.



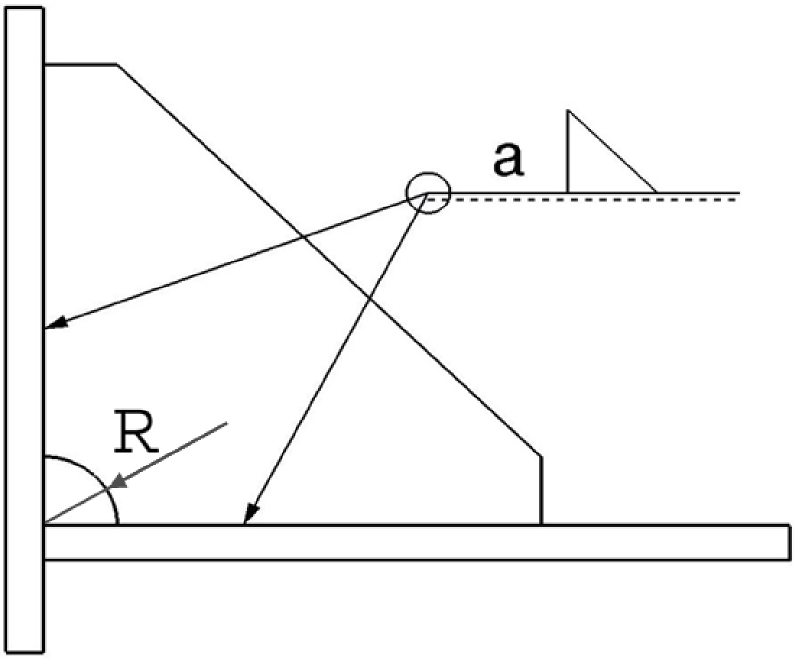
1.4 Design of seam intersections

Avoid seam accumulations and intersection of seams!



1.5 Beam stiffeners

The economic utilization of the material requires the use of thin web plates for bending beams. The associated risk of buckling is eliminated by the arrangement of the stiffeners.
A sufficiently large cut-out must be left in stiffening and corner plates. A circular cut-out is preferable to a straight corner section, since the circular cutout is easier to weld around and is not as prone to tension.

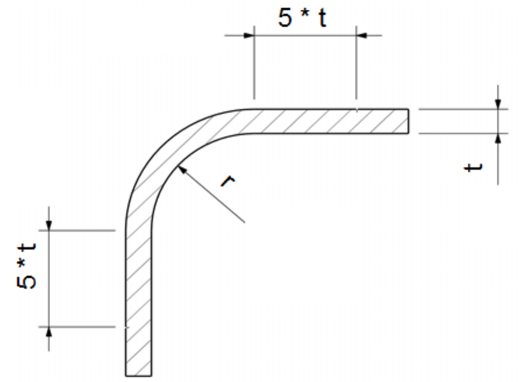


$R \geq 35mm$

1.6 Welding in cold formed areas

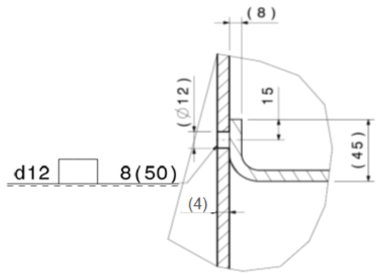
When welding in cold formed areas, including the adjacent areas having a width of 5*t, the minimum (r/t) limits must be observed according to the table below. The values of lines 1 to 5 may be linearly interpolated.
Compliance with the values of the degrees of deformation according to the table below is not mandatory if cold-formed parts are normally annealed **before** welding.

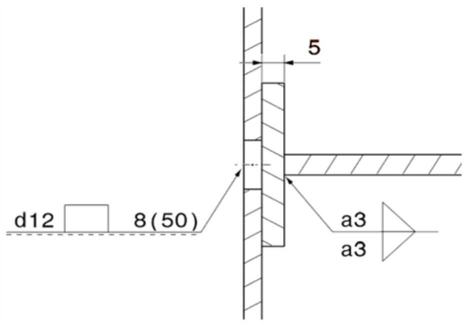
	1 max t mm	2 min (r/t)
1	50	10
2	24	3
3	12	2
4	8	1,5
5	4	1
6	< 4	1

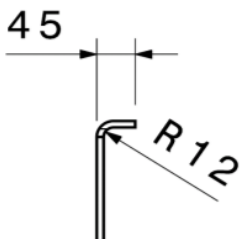


- Alternatives to welding in cold formed area

Section K-K
Scale 1:2







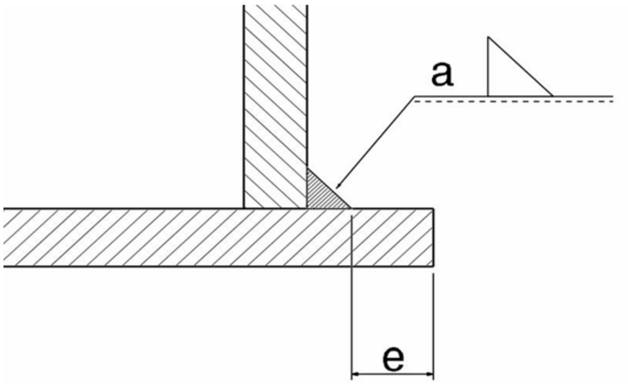
Usual stiffening plate design at Broetje-Automation. Here, welding is done in the cold-formed area. The table for welding in the cold-formed area applies

$$\left(\frac{R}{t}\right)\min \geq 1{,}5$$

permitted

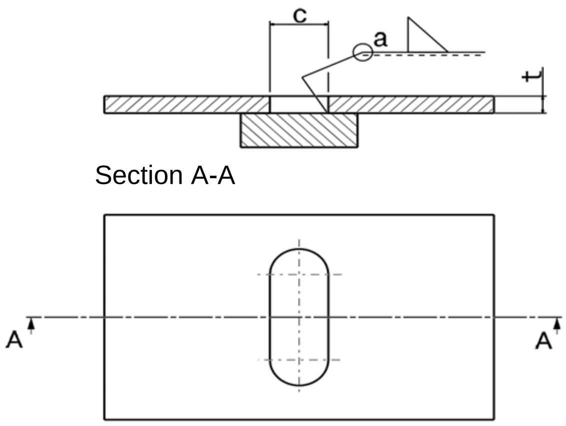
$$\left(\frac{12mm}{8mm}\right) = 1{,}5$$

1.7 Edge distance



The edge distance should be $e \geq 2 \times a$

1.8 Slotted hole welding, slotted hole width

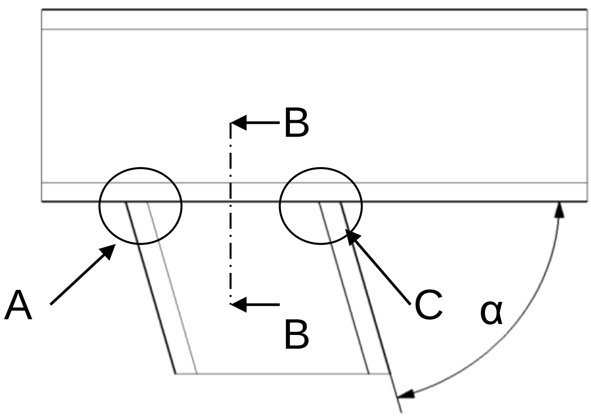


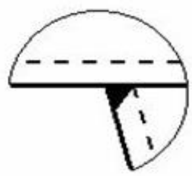
When using fillet welds in oblong holes, a slot width of $c \geq 3 \times t$ shall be provided

1.9 Connecting angle of welded components

A fillet weld is always preferable to other seams because it is easier to make than other types of seams and causes less quality problems.

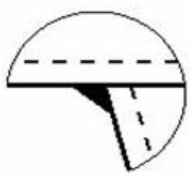
When joining profiles with each other, a distinction must be made between the areas A, B and C.





Detail A

Figure 1



Detail A

Figure 2

In area A:

At an angle of 90 - 120°, a fillet weld must be used. From 121° fillet weld must not be used anymore; here, for example a V-seam or HY-seam must be used.

In area B:

At an angle of 90°, a fillet weld must always be used if this is feasible from a design point of view.

In area C:

At an angle of 60 - 90°, a fillet weld must be used. Below 59°, fillet weld must not be used anymore; here, for example a V-seam must be used.

1.10 Information on the structural design

If structurally or statically nothing else is required, compliance with the following instructions is mandatory:
The general tolerances for welded constructions according to DIN EN ISO 13920 must be used:

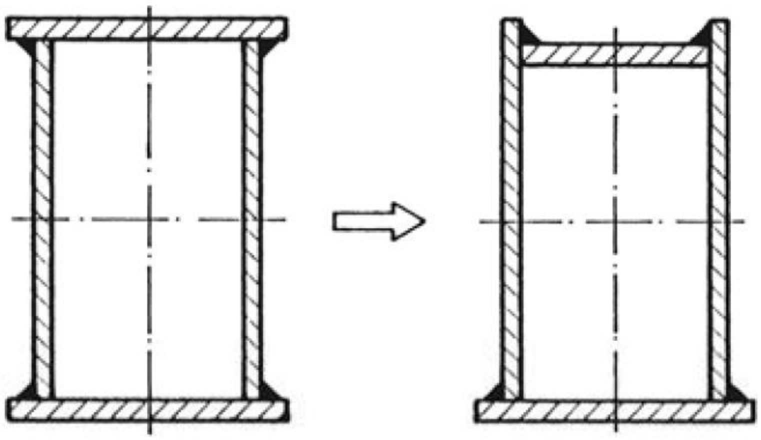
- For length and angular dimensions — Tolerance class B
- For straightness, flatness and parallelism tolerances — Tolerance class F

If the cross-sections are closed, vent holes must be provided
(Ø 8 mm for steel, Ø 6 mm for aluminum)

Fillet welds and butt welds with a backing strip are preferable to other seams.

All seams should be welded while held in a clamping device, if possible. The most important seams should be laid parallel to the main axes of the workpiece.

unfavorable favorable



Welds should be as thin as possible (seams that are too thick lead to distortion and large shrinkage forces)

Welding bent sections should be avoided

The workplace of the welder must be well planned, easy access to the welds is most important

Avoid acute angles, narrow gaps and small opening angles.

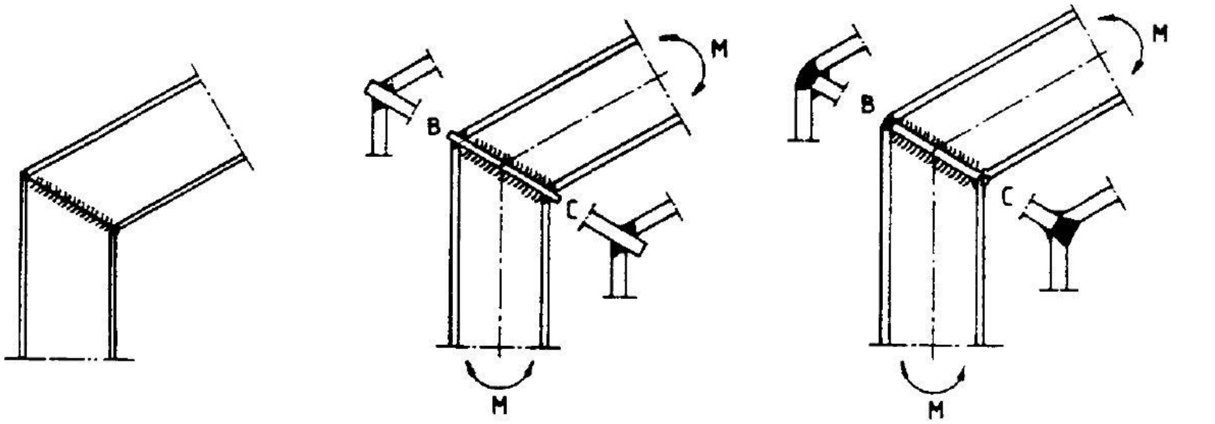
1.11 Frame and frame support structures

Design using open cross-sections (no torsion and predominantly static stress).

Advantages:
- Connections can be easily designed and manufactured.
- Empty compartments can be used for installations.
- Standard rolled sections can be used several times. (For example DIN 1025-1 to 4)

Disadvantages:
- little area or moment of resistance in one direction.
- expensive conservation.

Design examples of frame corners not fully stresses to their capacity



Miter cut with butt weld (left)
Miter cut with cross butt joint and end plate (center)
Miter joint with 3 sheet metal seam (right), not recommended

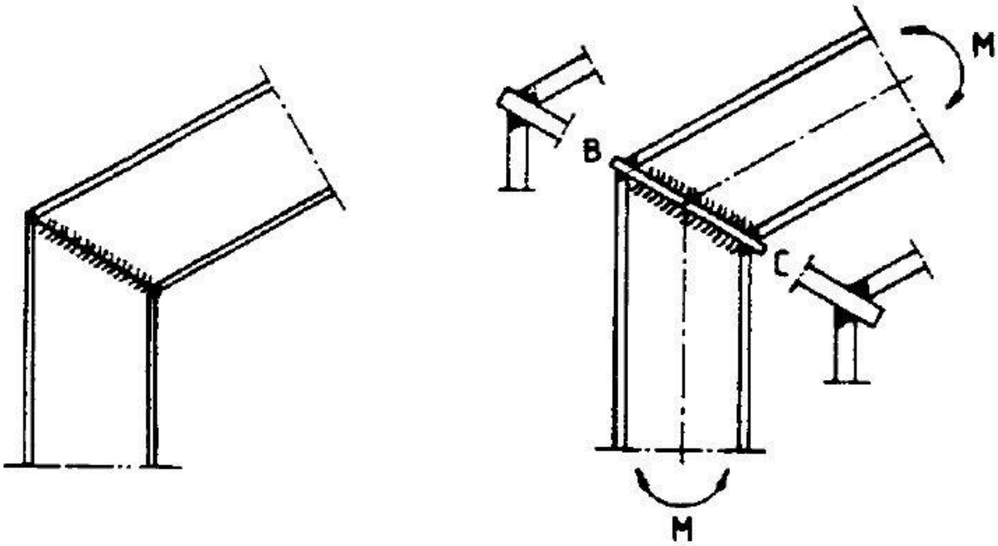
If the frame corners are excessively stressed, other types of frame corners must be used!

Designs using closed structural sections (torsion stressed frame).
For welded constructions made of closed structural sections, in principle, hot-finished structural hollow sections (DIN EN 10210) must be used.

Advantages:
- almost the same moment of inertia and resistance in both directions.
- simple conservation.

Disadvantages:
- design and manufacture of the joints are expensive.
- material costs are high (by a factor of 2 higher than with rolled sections)

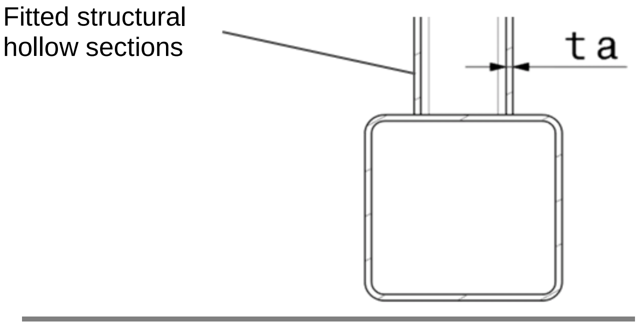
Design examples of frame corners not fully stresses to their capacity



Miter cut with butt weld (left) Miter cut with cross butt joint and end plate (right)

If the frame corners are excessively stressed, other types of frame corners must be used!

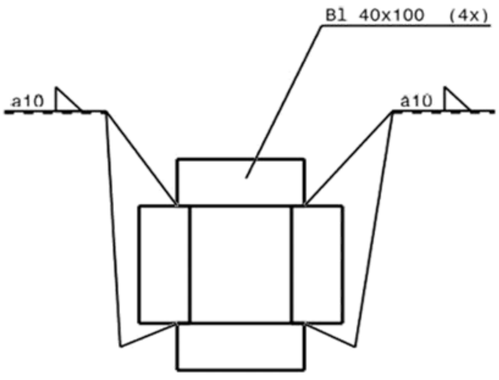
When using fitted structural hollow sections, the weld thickness must be the same as that of the attached section: however, at least a2



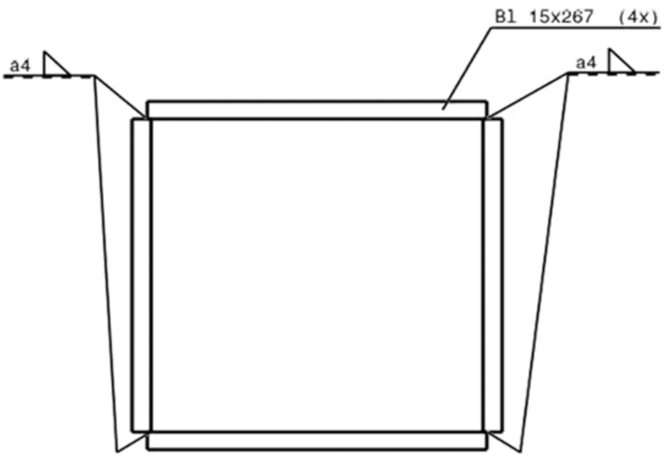
1.12 Box-type design

If special requirements for the stiffness of a support are required, box-type or cellular design is recommended in which the cross sections of the individual sheets can be reduced or enlarged.

Advantages:
- smaller weld thicknesses, this means saving of welding metal
- the workpiece is subjected to less heat during welding, this means less distortion
- Cost reduction by eliminating thickness surcharges when using sheet thickness up to t = 25 mm
- The risk of brittle fracture due to multi-axial stress conditions in large sheet metal sections is counteracted
- Weight savings



Unfavorable cross-section design under tensile load

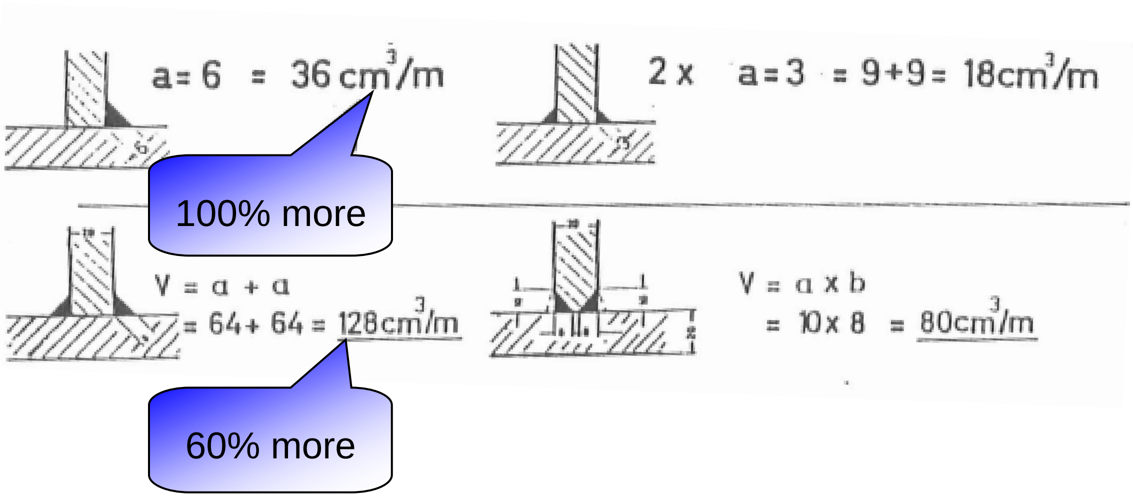


More favorable cross-section design under tensile load

1.13 Cost-effective design

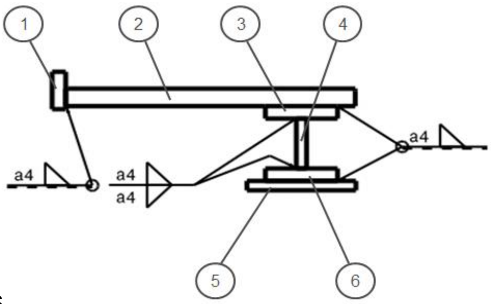
Depending on the design, the production of welded components with identical function can vary greatly.

Costs due to the seam design:

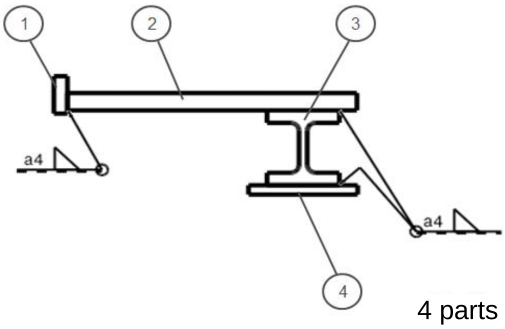


Costs due to the selection of structural sections:

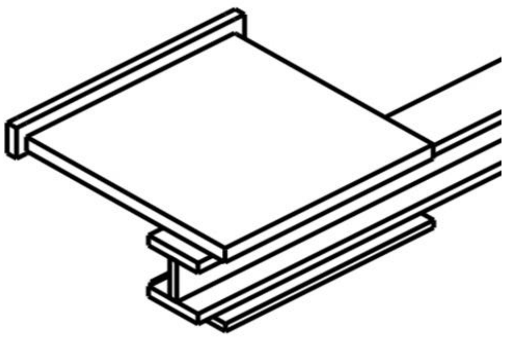
Basically, structural sections are preferable to use in order to minimize the number of welds

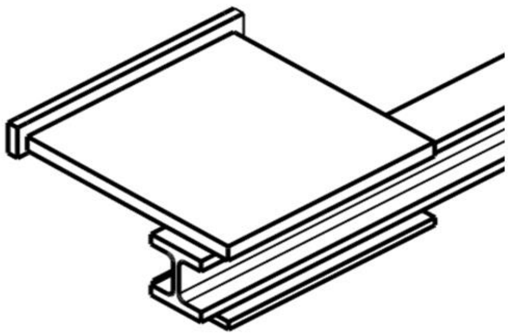


6 parts



4 parts





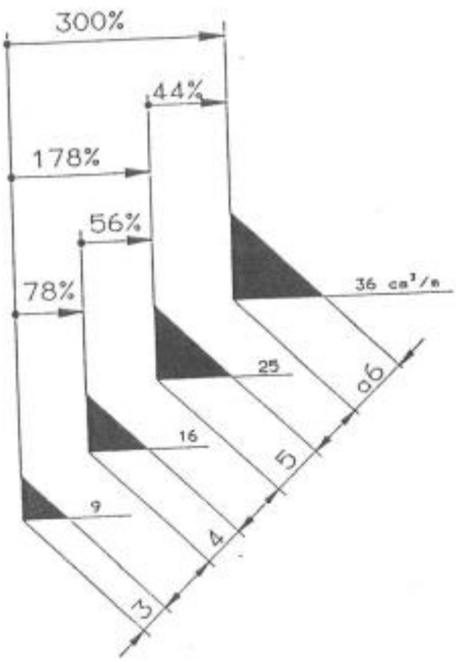
Interrupted weld seams

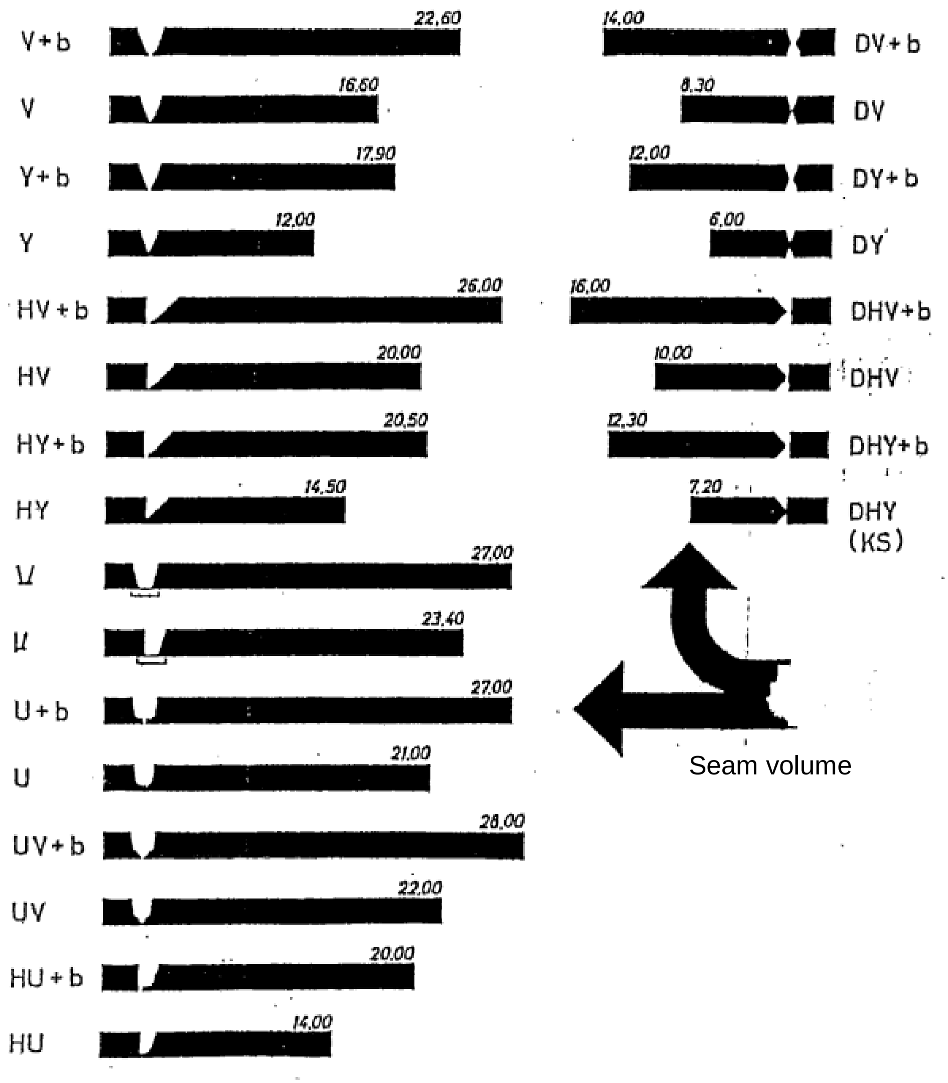
If the seam is not fully utilized mechanically, an interrupted seam can save up to 75% of the weld metal.

Selection of the weld seam

In principle, I-type seams and fillet welds are to be preferred, since these seams hardly produce seam preparation for the welder.

Selection of the required seam thickness and seam shape





Selection of common structural steel sections

Not every structural steel section is a standard item. When choosing non-typical structural steel sections, the purchasing department must be included in the selection.

2 Design/calculation

2.1 Supporting structures pursuant to DIN 1090

2.1.1 Definition of a supporting structure

A construction becomes a supporting structure only when environmental forces are transmitted directly or indirectly onto the foundation of the hall. However, if there is a separate foundation within a hall which has no connection to the hall foundation, this construction is treated as a machine component.

Only in the case of supporting structures may and **must** the certification be based on DIN EN 1090.

Examples:
a) Outdoors:
- Bridges
- Railings
- Weirs
- River boundary fences
- Outdoor masts
- Outdoor stairs

b) Indoors
- Construction built onto building foundation
- Construction suspended from a hall ceiling
- Construction leans on a hall wall

2.1.2 Classification according to EXC

There are different classifications for DIN_EN 1090, which must be selected by the designer according to the following criteria.

SC1: predominantly static load;
SC1: not predominantly static load.

<u>Selection of manufacturing category</u>:
PC1: non-welded parts; welded parts manufactured from steel grade products with yield strength below 355 MPa.
PC2: welded parts manufactured from steel grade products with a yield strength greater than or equal to 355 MPa.

Selection of consequence class:
CC1: low consequence for loss of human life and small or negligible economic consequences. Subordinate structures. Examples: Maintenance steps, fences.
CC2: Medium consequence for loss of human life; considerable economic, consequences. Common structures. Examples: Stairs, platforms.
CC3: High consequence for loss of human life. Very great economic consequences. Exceptional structures. Examples: Stadiums, office buildings.
The selection of proper execution classes lies within the responsibility of the design engineer in charge. The rationale behind selecting execution classes EXC3 or EXC4 must be fully documented by the responsible design engineer.

Execution class selection

	CC1		CC2		CC3	
	SC1	SC2	SC1	SC2	SC1	SC2
PC1	EXC1	EXC2	EXC2	EXC3	EXC3	EXC3
PC2	EXC2	EXC2	EXC2	EXC3	EXC3	EXC4

The constructions manufactured at Broetje Automation, usually comply with EXC 1 and EXC 2 are manufactured.

2.2 Machine components acc. to 3834

2.2.1 Structural component categories

Category 1: Weld seams with exclusively joining function or sealing function, for example covers

Category 2: standard welds, seams that have - at a minimum - a static force transmission function in the component

Category 3: heavily stressed weld seams. Seams which, in case of failure, will cause injury to people.
Possible constructive measure: Safety factor 2

A component to be manufactured shall be classified in the highest category of the total welds that must be welded.

2.2.2 Operational requirements for component production

Category 1: DIN EN ISO 3834-4 / 1090-2/-3 EXC1
/ no approval, but certified welders
Category 2: DIN EN ISO 3834-3 / 1090-2/-3 EXC2
Category 3: DIN EN ISO 3834-2 / 1090-2/-3 EXC3 u. EXC4

The classification of the entire component into a category pursuant to DIN EN ISO 3834 corresponds to the weld with the highest category.
The component is subsequently to be classified by the designer according to its technical requirement.

Classification as follows:
DIN EN ISO 3834-4: Basic quality requirements
DIN EN ISO 3834-3: Standard quality requirements
DIN EN ISO 3834-2: Comprehensive quality requirements

2.2.3 Structural component test

Category 1: 100% VT (Visual Testing) with evaluation group D pursuant to DIN EN ISO 5817
Category 2: 100% VT with quality level C pursuant to DIN EN ISO 5817
Category 3: 100% VT with quality level C pursuant to DIN EN ISO 5817 with additional non-destructive testing (NDT):

Fillet weld (FW):
Magnetic Particle Testing (MT) is used when seams are accessible (generally external sutures).

- Butt welds (BW):
If accessible, use RT inspection. If RT is not possible, use MT and UT inspection

If NDT tests are to be carried out in addition to VT tests for Category 3 seams, this must be indicated in the symbol of the corresponding weld seam on the engineering drawing.

2.3 Throat thickness

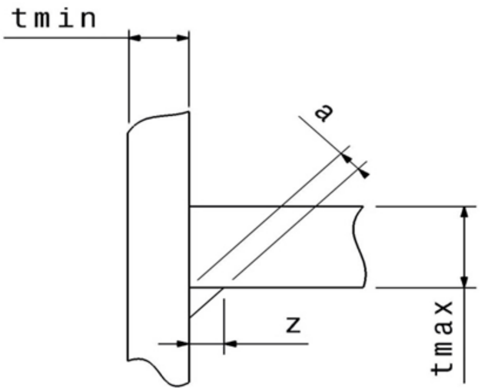
The throat thickness of fillet welds should generally be taken from the structural analysis and specified in the technical documentation (engineering drawings).
Compliance with certain limits is mandatory:

Minimum throat thickness – **a min**

$$a_{min} = \sqrt{t_{max}} - 0{,}5 \quad [mm] \qquad \text{For } t \leq 30 \text{ mm}$$

Maximum throat thickness – **a max**

$$a_{max} = 0{,}7 * t_{min}$$



It should be noted here, when welding fillet seams, these seams should not be based on the limit dimension of a max, but their thickness should comply with the absolutely necessary and calculated throat thickness.

Unless otherwise required structurally or statically, all sheet metal, hollow structural U, I, L section, and combinations thereof, require complete, circumferential and full penetration welds. Long, low stressed welds can be executed as interrupted double fillet welds.

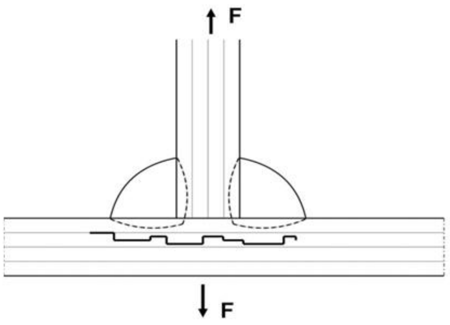
If special seam thicknesses are not required, in most cases, it is easier to work with the seam thicknesses from the following table.

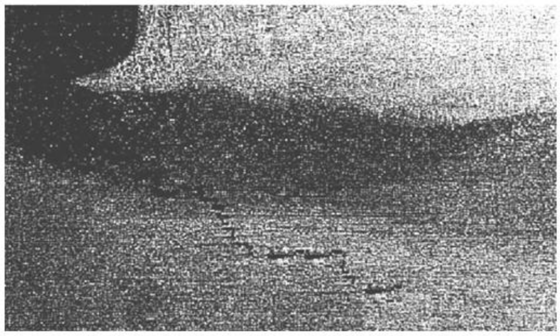
Weld thickness without dimensioning	
Fillet welds	
Sheet metal thickness t [mm]	Fillet weld thickness a [mm]
bis 6	3
> 6 - 12	4
> 12 - 15	5
> 15 - 20	6 (multi layer)
> 20 - 30	7
> 30 - 40	8
> 40	10
Butt welds	
Generally, butt welds should be made as full-depth welds	

Butt welds must **always** be calculated and executed as a full-depth connection.

2.4 Stress in the thickness direction (lamellar tearing)

When stress occurs in the thickness direction of rolled products, the ductility relative to the longitudinal or transverse direction is often reduced. This is due to the layered arrangements of non-metallic inclusions occurring during rolling parallel to the surface. When stressed, these inclusions do not participate in the deformation as much as the metallic matrix. This results in the risk of fractures parallel to the surface of rolled products.

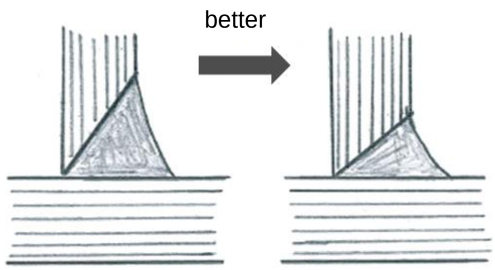




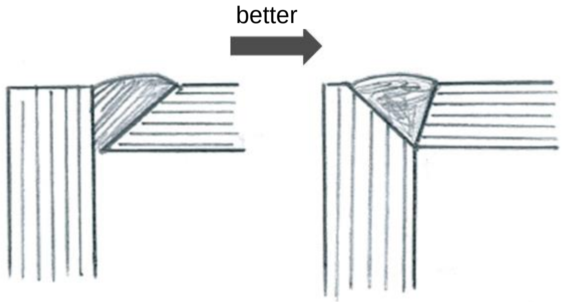
Various measures can be taken to avoid lamellar tearing:

1. Design methods (favored solution)

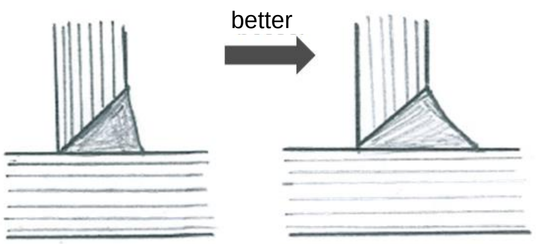
Avoiding unnecessary seam volumes:



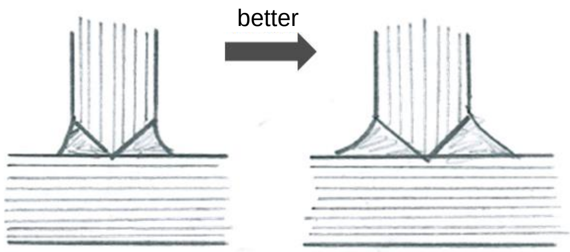
Connection across the thickness of the sheet



Increasing the weld base



Increasing the weld base



2. Material-related measures (expensive and uncertain)

The material-related measures aim to improve the ductility under stress in the thickness direction. In particular, steels with little contraction at fracture in the thickness direction, lamellar tearing presents a risk.

DIN EN 1993-1-10 (Eurocode 3) Tab.3 specifies criteria for the calculation and selection of the required material.
Starting with a sheet metal thickness > 30 mm, the required Z_{Ed} must be calculated, using Table 3.2. The risk of lamellar tearing can be neglected if the following conditions are met:

$Z_{Ed} \leq Z_{Rd}$

This follows that

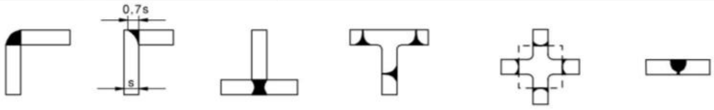
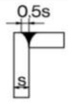
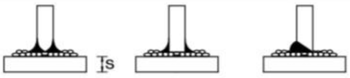
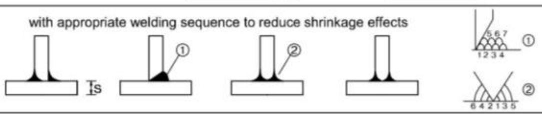
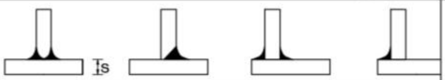
Z_{Ed} = the required Z-value, which results from the magnitude of the strain of the base material due to obstructed weld shrinkage.

Z_{Rd} = the available Z value of the material pursuant to EN 10164, that is to say Z15, Z25 or Z35.

The required Z value Z_{Ed} can be determined using the following formula and Table 3.2 from DIN EN 1993-1-10:

$Z_{Ed} = Z_a + Z_b + Z_c + Z_d + Z_e$

Table 3.2: Criteria affecting the target value of Z_{Ed}

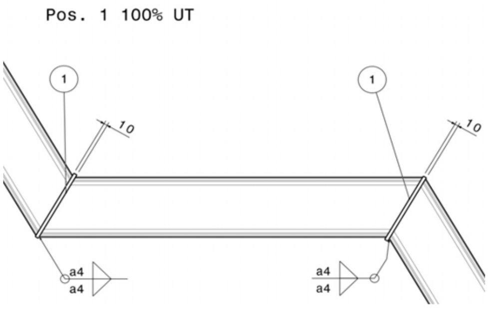
a)	Weld depth relevant for straining from metal shrinkage	AC Effective weld depth a_{eff} (see Figure 3.2) AC	AC Throat thickness a of fillet welds AC	Z_i
		$a_{eff} \leq 7mm$	a = 5 mm	$Z_a = 0$
		$7 < a_{eff} \leq 10mm$	a = 7 mm	$Z_a = 3$
		$10 < a_{eff} \leq 20mm$	a = 14 mm	$Z_a = 6$
		$20 < a_{eff} \leq 30mm$	a = 21 mm	$Z_a = 9$
		$30 < a_{eff} \leq 40mm$	a = 28 mm	$Z_a = 12$
		$40 < a_{eff} \leq 50mm$	a = 35 mm	$Z_a = 15$
		$50 < a_{eff}$	a > 35 mm	$Z_a = 15$
b)	Shape and position of welds in T- and cruciform- and corner-connections			$Z_b = -25$
		corner joints		$Z_b = -10$
		single run fillet welds $Z_a = 0$ or fillet welds with $Z_a > 1$ with buttering with low strength weld material		$Z_b = -5$
		multi run fillet welds		$Z_b = 0$
		partial and full penetration welds		$Z_b = 3$
		partial and full penetration welds		$Z_b = 5$
		corner joints		$Z_b = 8$
c)	Effect of material thickness *s* on restraint to shrinkage	$s \leq 10mm$		$Z_c = 2^*$
		$10 < s \leq 20mm$		$Z_c = 4^*$
		$20 < s \leq 30mm$		$Z_c = 6^*$
		$30 < s \leq 40mm$		$Z_c = 8^*$
		$40 < s \leq 50mm$		$Z_c = 10^*$
		$50 < s \leq 60mm$		$Z_c = 12^*$
		$60 < s \leq 70mm$		$Z_c = 15^*$
		$70 < s$		$Z_c = 15^*$
d)	Remote restraint of shrinkage after welding by other portions of the structure	Low restraint:	Free shrinkage possible (e.g. T-joints)	$Z_d = 0$
		Medium restraint:	Free shrinkage restricted (e.g. diaphragms in box girders)	$Z_d = 3$
		High restraint:	Free shrinkage not possible (e.g. stringers in orthotropic deck plates)	$Z_d = 5$
e)	Influence of preheating	Without preheating		$Z_e = 0$
		Preheating ≥ 100°C		$Z_e = -8$

* May be reduced by 50% for material stressed, in the through-thickness direction, by compression due to predominantly static loads.

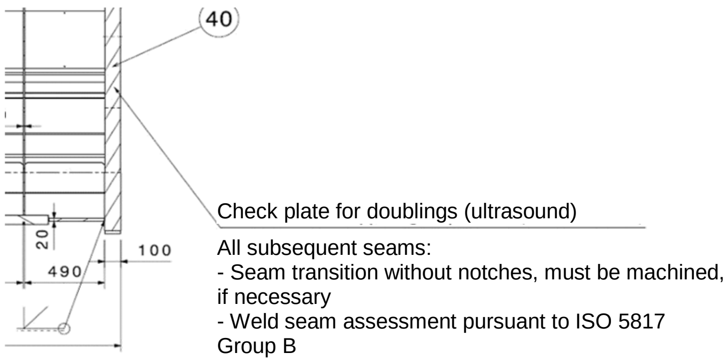
- Stress in the thickness direction (doubling)

End plates which are subjected to tension in the thickness direction must be ultrasonically tested starting with a nominal thickness of 10 mm.

Example 1: U180 stair stringers with end plates



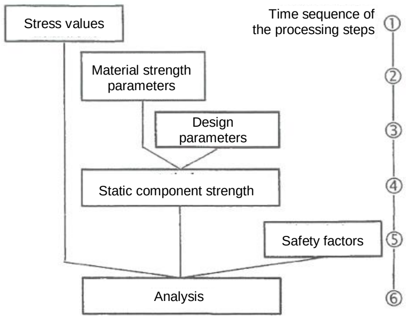
Example 2:



2.5 Calculation of weld dimension

Structures made of steel shall be designed pursuant to DIN EN 1993 “Eurocode 3: Design of steel structures”. If this is not applicable and no other standards, regulations or guidelines are required. Welds can be verified using the latest edition of the guideline “Analytical strength assessment of components in mechanical engineering” published by the Forschungskuratorium Maschinenbau – FKM (German Research Committee Mechanical Engineering). The following takes a look at this guideline.
Among other things, this guideline describes the verification of a defined weld seam. In order to dimension the weld seam, the weld seam geometry is defined in the first step, the strength of which is mathematically verified in the second step. This might require having to jump back to the first step.
The FKM guideline distinguishes between stress analysis and fatigue analysis. In this verification, the stresses occurring in the material and the permissible stresses are calculated and compared. The calculations are material-dependent. The guideline distinguishes between different materials and between welds, heat affected zone around the weld (for aluminum) and base material. The following text (within *2.5 General principles for design*) provides only an abridged description of the static strength proof for welds in rolled steel products.

The stress analysis is divided into six working steps. The graphic on the right-hand side is taken from the FKM guideline. It shows the dependencies of the work steps and the time sequence of the calculation. Each of these steps will be discussed in a separate section below.



2.5.1 Stress values

There are two options to determine stress: The calculation with nominal stresses and with local stresses. Nominal stresses are usually determined according to the elementary formulas of engineering mechanics. Local stresses are usually calculated numerically, using the Finite Element Method (FEM). In the following test, the verification is considered by using nominal stresses for rod-shaped components.
The verification with rated stresses is intended for (ideal) rod-shaped components with stress types that are relevant to their cutting size. If the welds of a rod-shaped component are not longitudinal or orthogonal to the rod axis, the verification using local stresses is also recommended.
In order to determine the loads in the weld, the flow of the force in the component's cross-section is determined. In order to do that, a cross-section of the component must be obtained. The coordinate system of the cross-section is aligned so that the x-axis is orthogonal to the cross section. In general, there are six cutting forces and moments in the cross-section. From these internal forces, the nominal stresses present in the weld seam interface can be derived. The components of the welds at which the stresses are maximized are the most relevant parts. The weld geometries are to be considered as simplified geometries. For this, the dimension "a" is used as the seam width.

Cutting forces and moments		Corresponding stress in the weld
F_{zd}	Force in *x*-direction	F_{zd}/A
M_{by}	Bending moment around the *y*-axis	$M_{by}/I_y * z$
M_{bz}	Bending moment around the *z*-axis	$M_{bz}/I_z * y$
Q_{sy}	Transverse force in the *y*-direction	$Q_{SY} * S_Y(y)/(I_y * t_y)$ *1
Q_{sz}	Transverse force in the *z*-direction	$Q_{sz} * S_z(z)/(I_z * t_z)$ *1
M_t	Moment around the *x*-axis	$M_t/I_P * r$

A	Cross-section of the weld seam
I_y, I_z	Area of inertia of the total cross-section *y* or *z*-axis
y, z	Position of the weld on the y or *z*-axis (relative to the centroid of the area)
$S_y(y)$, $S_z(z)$	Static moments depending on the location. The location is the location of the weld seam (*y* or *z*). If the weld seams completely divides part of the cross-section, then *b* shall be the distance from the centroid of the split area to the total area centroid, and *A* shall be the size of the split area and thus, the following applies: $S = b * A$
t_z, t_y	The sum of the widths of the welds in the cross-section over which the shear force is transmitted (either dimension "a" or length)
I_P	Polar moment of inertia
r	Distance of the weld from the total center of gravity
*1	If using direct rod connections (the weld line lies exactly in the cross-section) the shear stress (not according to FKM) seems to be calculated in a simplified way. In this calculation, *A* is the total cross-section area of the welds whose position is suitable for transferring the lateral force *Q*. The following approximation formula seems to be common: $S = Q/A$

The weld stresses are named after a coordinate system whose x-axis lies in in line with the weld seam. This system is generally rotated with respect to the coordinate system of the overall cross-section. The FKM guideline lists the following stresses:

- $S_{\perp zd}$ Normal stress orthogonal to the seam line (mostly due to tension/pressure on contact surface between the weld and the base material). The stress is constant along the seam length.
- $S_{\perp,by}$ Normal stress orthogonal to seam line due to bending. $S_{\perp,by}$ depends on the x-coordinate of the seam and acts in a linear direction.
- $S_{\perp,by}$ Normal stress orthogonal to seam line due to bending. $S_{\perp,by}$ depends on the x-coordinate of the seam and acts in a linear direction.
- $T_{\perp}$ Shear stresses acting orthogonal direction of the seam. When using fillet welds, they can be applied as $S_{\perp zd}$. When using butt welds $T_{\perp}$, are not mentioned in the FKM guideline. Therefore, the verification of T⊥ is preferred over others; otherwise, $T_{\perp}$ must be considered under $T_{\parallel}$.
- $T_{\parallel}$ Shear stresses parallel to the weld.
- $S_{\parallel}$ Normal stresses along the weld. $S_{\parallel}$ will not be included in the analysis. $S_{\parallel}$ occur, for example, in bending beam with a longitudinal weld.

In order to carry with the calculation $S_{\perp,zd}$, $S_{\perp,by}$, $S_{\perp,bz}$ and $T_{\parallel}$ are rquired. In $S_{\perp,zd}$ and $T_{\parallel}$ several stresses of different utilisation could be included. The FKM guideline does not specify how these can be calculated. When using rolled steel, the most conservative way of calculating the stresses is to use the amounts of all stresses and to add them (within $S_{\perp,zd}$ and $T_{\parallel}$). This works because the amounts of allowable stress and compression for rolled steel are identical.

2.5.2 Characteristic values for material properties

Characteristic values for material properties depend on the material used and the dimensions of the semi-finished product in use. The most important parameters are the tensile strength (R_m) and the yield strength (R_e). These do not only depend on the material but also, for example, on the product's thickness and the operating temperature.
Tensile strength and yield strength are to be based on the values of the base material, that is to say, the values of the parts that must be welded. The basis for this is DIN 18800. Example:

Material grade	**t** [mm]	$\mathbf{R_e}$ [MPa]	$\mathbf{R_m}$ [MPa]
S355	to 40	360	470
	40 to 100	335	

When compared to the tensile strength, the shear strength is reduced in steel. When using rolled steel, the shear strength factor f_t applies:
$f_t = 0{,}577$
In case of extreme temperature effects, R_e and R_m are multiplied by the temperature factors. When using temperatures between -40 and 60 °C, the value of these factors is always 1.

2.5.3 Design parameters

Design parameters are determined for a concrete load case in a concrete design.
Each type of stress referred to in chapter *2.5.1 Stress values* is a separate load case, for which specific design factors are determined.
For steel components two factors are relevant: First, the plastic support numbers $n_{pl,by}$ and $n_{pl,bz}$ for the full usage of bearing reserves; secondly the weld seam factor α_w, which describes the reduction of the strength of the weld in relation to the adjacent material.

The following tables derive from the FKM guideline. Their use is explained below.

Table 1.3.3 Plastic mold numbers for welded components (based on DIN 18800)

Cross-sectional shape	Bend $K_{p,b}$
I, y-axis (transverse axis)	1.14
I, z-axis (vertical axis), plate	1.25
Box, y-axis✧7	✧8
Annulus	1.27 ✧9

✧7 z-axis limit switch analogous

✧8 $K_{p,b} = 1.5 \cdot \frac{1-(b/B)\cdot(h/H)^2}{1-(b/B)\cdot(h/H)^3}$, but maximum 1.25 (1.3.9)

b, B inner and outer width, h, H inner and outer height

✧9 thin walls, 1.27 = 4 / π

Table 1.3.4 Welding seam factor α_w for steel

Weld seam	Weld seam quality✧1	Type of voltage	S235 GS200 GS240 G17Mn5+QT	S275 P275	S355 P355 G20Mn5+N G20Mn5+Q	S420 S460 S460	S690
fully penetrated or back-welded	all	pressure	1.0	1.0	1.0	1.0	0.9
	verified	tension or shear	0.95	0.85	0.8	0.7	0.55
	not verified						
weld not penetrated or fillet weld	all	pressure/ tension or shear					

✧1 The seam quality is considered verified if after inspecting 10% of the seams, the result of the radiographic or ultrasonic test is flawless.

2.5.3.1 Plastic support number

In order to permit plasticization and for the use of the plastic support number, several requirements must be met:

- Only for stress types $S_{\perp,by}$, $S_{\perp,bz}$
- Either full penetration weld or cross-section-covering (for example, double fillet weld)

The plastic support number depends on the material and geometry. The number is calculated by using the cross-sectional dimensions of the sheet metal panels. The left table of the previous figure indicates the plastic support number for typical cross sections. The calculation method for determining the plastic support number for other cross sections is not copied from the FKM guideline.

2.5.3.2 Weld seam factor

The weld seam factor α_w can be read in the previous figure from the table on the right-hand side.

2.5.4 Component strength

The values of the static component strength must be calculated individually for each stress type as follows.

Type of voltage	Component strength
$S_{\perp,zd}$	$S_{SK\perp zd} = R_p * \alpha_w$
$S_{\perp,by}$	$S_{SK\perp by} = R_p * \alpha_w * n_{pl,by}$
$S_{\perp,bz}$	$S_{SK\perp by} = R_p * \alpha_w * n_{pl,bz}$
$T_{\parallel}$	$S_{\parallel} = R_p * \alpha_w$

2.5.5 Safety factors

The safety factors mentioned here should lead to a survival probability of 97.5%. The total safety factor j is a product of two partial safety factors: the load factor j_S and the material factor j_F.

$j = j_S * j_F$

The operating loads should always be calculated in a conservative manner (i.e. high). In this case, the following applies:

$j_s = 1{,}0$

Subsequently, $j_s = 1{,}0$ is accepted and j_S is no longer listed separately.
Several basic safety factors are incorporated into the material factor j_F.

2.5.5.1 Basic safety factors

When using rolled steel at normal temperatures, the following factors are relevant:

- Jm_m Fracture analysis (tensile strength)
- Jp_p Material flow analysis (yield point)

The following safety factors apply to ductile materials (elongation at break A> 6%), including rolled steel.

			Effect of damage		
			High	Medium	Low *1
Probability of occurrence of stress or combination stress *2	High	j_m	2.0	1.85	1.75
		j_p	1.5	1.4	1.3
	Low *3	j_m	1.8	1.7	1.6
		j_p	1.35	1.25	1.2

*1 Consequences of damage is minor and importance of the component is low in terms of “non-catastrophic” effects in the event of failure; e.g. due to load transfer possibilities in a statically indeterminate system. **Reduction by a factor of 1.15** (rounded to 0.05).

*2 Generally, this refers to the amount of the load, not the frequency.

*3 Also certainly rare, accurately estimable loads, for example, the condition of the test and assembly. **Reduction by a factor of 1.10** (rounded to 0.05)

2.5.5.2 Total safety factor

The total safety factor j_{ges} must derive from the individual safety factors. Due to the components contained (yield ratio), it cannot immediately interpreted as a safety factor in the sense of safety in order to prevent failure.

$$j_{ges} = \max(\frac{R_p}{R_m} * j_m; j_P)$$

2.5.6 Analysis

The verifications must first be performed individually for all types of stress (stress/compression, bending around two axes and shear). In addition, superimposing the individual types of stress must be carried out by calculating the degree of utilisation for the composite types of stress. All degrees of utilisation must be less than or equal to 1.0.

2.5.6.1Degree of utilisation of the individual types of stress

The individual degrees of utilisation are listed below:

$$a_{SK\perp zd} = \left| \frac{S_{\perp,zd}}{S_{SK\perp zd}/j_{ges}} \right| \leq 1$$
$$a_{SK\perp by} = \left| \frac{S_{\perp,by}}{S_{SK\perp by}/j_{ges}} \right| \leq 1$$
$$a_{SK\perp bz} = \left| \frac{S_{\perp,bz}}{S_{SK\perp bz}/j_{ges}} \right| \leq 1$$
$$a_{SK||} = \left| \frac{T_{||}}{T_{SK||}/j_{ges}} \right| \leq 1$$

2.5.6.2 Superimposing the individual types of stress

During the analysis of the welds, an empirical strength hypothesis based on DIN 18800 is used:
In order to superimpose the individual stresses, the utilisation rate $a_{SK,SN}$ is calculated according to an empirical strength hypothesis and based on DIN 18800:

$$s = a_{SK\perp zd} + a_{SK\perp by} + a_{SK\perp bz}$$
$$t = a_{SK||}$$
$$a_{SK,SN} = \sqrt{s^2 + t^2} \leq 1$$

According to the FKM guideline, when calculating *s*, that is to say, superimposing the individual types of stress, the degrees of utilisation may be applied if the prefix of the stress types is used.

2.5.6.3 Normative degree of utilisation

Proof is provided if all required degrees of utilisation are 1 or less.

3 Engineering Drawings

3.1 Creating welding drawings

The structure of welded assemblies in the CAD system is always based on the CAD handout:

Development of welding assemblies.pdf

Can be found in the TCE portal.
Exceptions and deviations from this must be discussed with the welding engineer and the Project Manager.

3.2 Generating the welding stamp

In order to complete the welding stamp, the following CAD handout:

Development of welding assemblies.pdf

must be observed.

Stahl Steel		
Schweißverfahren Welding process	DIN EN ISO 4063	135/141
Schweißzusatzwerkstoff Filler material	DIN EN ISO 14341	3Si1 / 4Si1
Schutzgas Shield gas	DIN EN ISO 14175	M21/ I1
Allgemeintoleranzen General tolerances	DIN EN ISO 13920	-BF
Schweißtechnische Qualitätsanforderungen Welding quality requirements	DIN EN ISO 3834	-3
	DIN EN 1090-2	
Schweißnahtprüfung VT /Weld seam testing	DIN EN ISO 5817	C
spannungsarm geglüht stress relieved	ISO/TR 14745	Yes
alle nicht kategorisierten Schweißnähte not categorised welding seams	Nahtkategorie Class	2
Schweißnahtvorbereitung Welding preparation		DIN EN ISO 9692-1
Symbolische Darstellung Symbolic representation		DIN EN ISO 2553-A
Weitere wichtige Informationen sind im Downloadbereich der Broetje-Automation Homepage abrufbar Further important information is available in the download area of the Broetje-Automation homepage		

The welding stamp contains the most important information for the welder and is available as a table. Detailed information and explanations can be found in the company standard BN30.070. The company standard can be found on the Broetje Supplier Portal under the following link: http://www.broetje-automation.de/en/downloads/

3.3 Legacy drawings prior to 22.10.2018

Legacy drawings without revisions are still included in the current version of the Welding Annex (BN10.051).
The system automatically attaches welding supplements to the welding part drawing.
Only the welding supplements attached to the respective engineering drawing must be observed.

ATTENTION: As soon as legacy drawings have to be indexed, the new welding stamp **must** be inserted as well. This stamp can be found in CATIA in the BA catalog.
When approving an index, the welding supplement will **not** be attached in the future.

3.4 Stress-relief annealing

Components meeting the following criteria must be annealed after welding pursuant to ISO/TR 14745:

- Sheet metal thicknesses exceeding 25 mm with full connection and high existing stress in the component,
- Components that are subject to high dynamic loads,
- Components that require a high machining accuracy
- Customer demand.

3.5 Information on test scopes

All welds must be 100% visually inspected by the welder. The quality (D - B) is decided by checking off selection box in the seam category.

If there are special quality requirements for individual seams, these can be indicated separately in the tail of the welding symbol.
The reason for individual, separate welds can be very diverse, e.g. Seams with higher loads within a lightly stressed component

In this case, the following remark must be added to the welds:

PT100 A dye penetration test must be performed on the entire seam.
PT50 A dye penetration test must be performed on 50% of the seam.

- <u>Application examples:</u>
  Highly stressed seams
  If the seam is obstructed during shrinkage

MT100 A magnetic particle inspection must be performed on the entire seam.
MT50 A magnetic particle inspection must be performed on 50% of the seam.

- Application examples:
  Highly stressed seams
  If the seam is obstructed during shrinkage

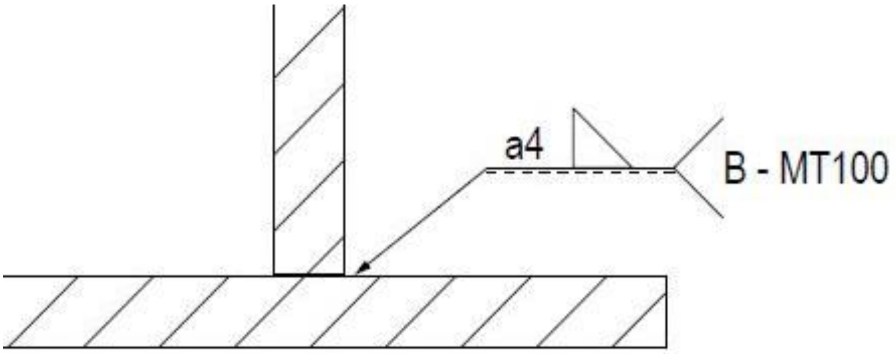
UT100 An ultrasonic test must be performed on the entire seam.
UT50 An ultrasonic test must be performed on 50% of the seam.

- Application example:
  Highly stressed seams
  End plates subject to tension

RT100 An X-ray inspection must be performed on the entire seam.
RT50 An X-ray inspection must be performed on 50% of the seam.

RT is not a common practice at Broetje Automation!

Example of a seam that must be tested separately



In this case, the entire seam must be VT tested, welded in accordance with grade B and in addition, the seam must be magnetically tested at 100%.

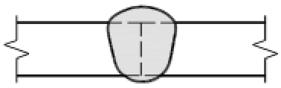
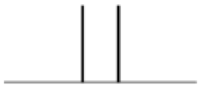
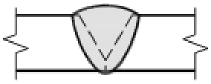
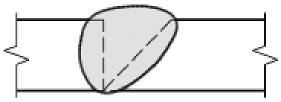
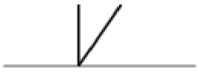
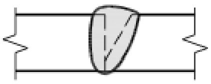
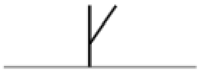
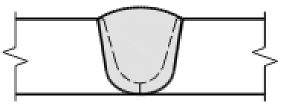
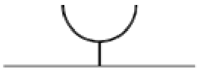
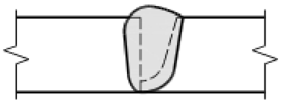
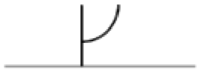
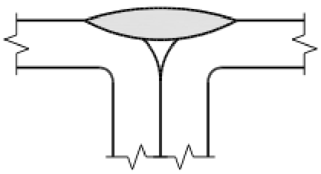
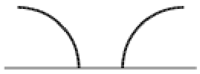
NOTICE:
Some customers do request not to paint load-bearing welds on lifting platforms, because the latter are subject to periodic inspections during operation in the future. This must be indicated in the engineering drawing and must be coordinated with the Project Manager and the welding engineer.

3.6 Weld seams

There are different types of welds and correspondingly, there are different welding symbols that must be used.
The basic symbols can be supplemented by additional sings, dimensions and other information.

Below are the basic and additional symbols valid pursuant to DIN EN ISO 2553:

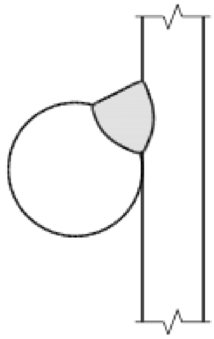
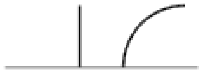
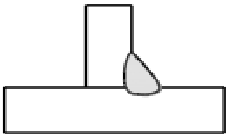
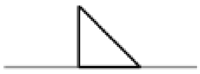
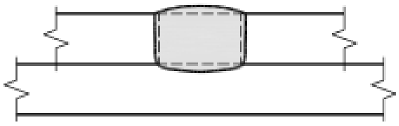
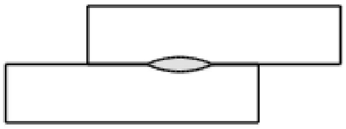
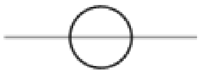
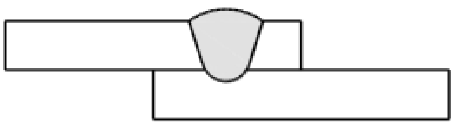
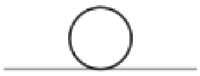
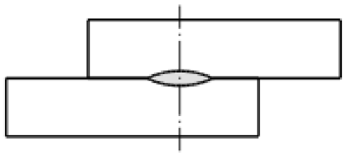
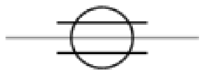
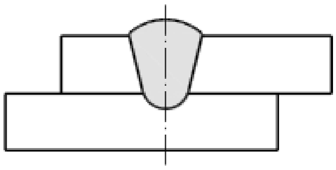
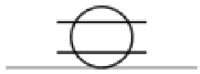
Table 1 — Elementary symbols

No.	Designation (weld type)	Illustration of weld type (dashed lines show joint preparation prior to welding)	Symbol [a]
1	Square butt [b]		
2	Single-V butt [b]		
3	Single-V butt with broad root face [b]		
4	Single-bevel butt [b]		
5	Single-bevel butt with broad root face [b]		
6	Single-U butt [b]		
7	Single-J butt [b]		
8	Flare V		

[a] The grey line is not part of the symbol. It indicates the position of the reference line.

[b] Butt welds are full penetration unless otherwise indicated by dimensions on the welding symbol or by reference to other information, for example the WPS.

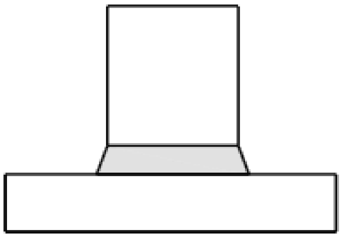
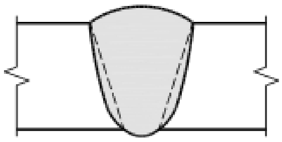
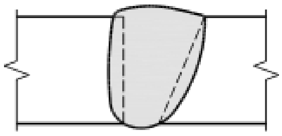
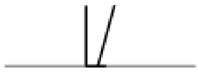
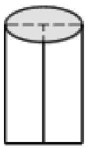
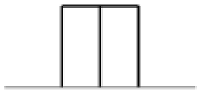
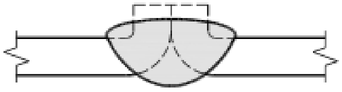
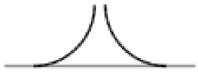
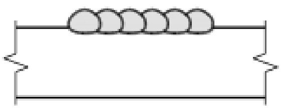
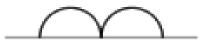
[c] Symbol can also be used for joints with more than 2 members.

No.	Designation (weld type)	Illustration of weld type (dashed lines show joint preparation prior to welding)	Symbol [a]
9	Flare bevel		
10	Fillet		
11	Plug (in slots or circular holes)		
12	Resistance spot (including projection welding in system A) [c]		
13	Fusion spot (and projection welding in system B)		
14	Resistance seam [c]		
15	Fusion seam		

[a] The grey line is not part of the symbol. It indicates the position of the reference line.

[b] Butt welds are full penetration unless otherwise indicated by dimensions on the welding symbol or by reference to other information, for example the WPS.

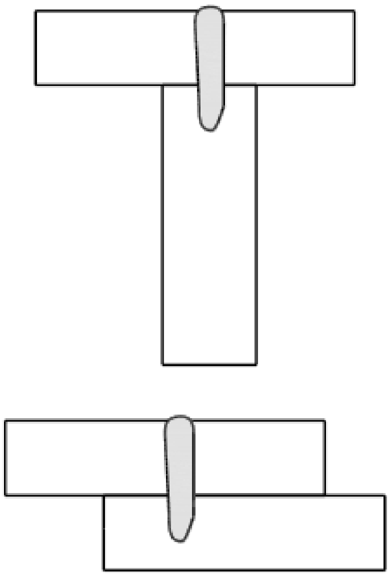
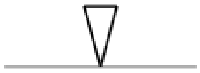
[c] Symbol can also be used for joints with more than 2 members.

No.	Designation (weld type)	Illustration of weld type (dashed lines show joint preparation prior to welding)	Symbol [a]
16	Stud		
17	Steep-flanked single-V butt [b]		
18	Steep-flanked single-bevel butt [b]		
19	Edge [c]		
20	Flanged butt/corner weld (see also Table 4)		
21	Overlay		

[a] The grey line is not part of the symbol. It indicates the position of the reference line.

[b] Butt welds are full penetration unless otherwise indicated by dimensions on the welding symbol or by reference to other information, for example the WPS.

[c] Symbol can also be used for joints with more than 2 members.

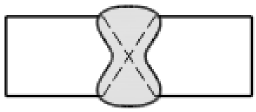
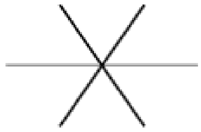
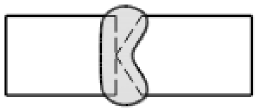
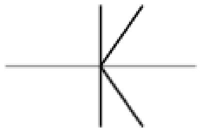
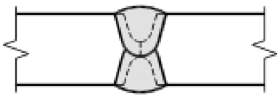
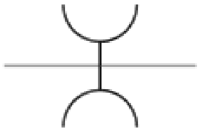
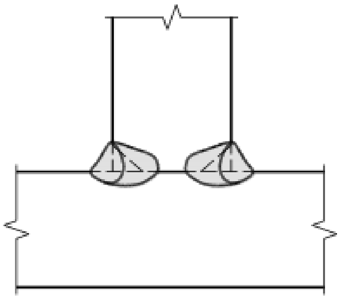
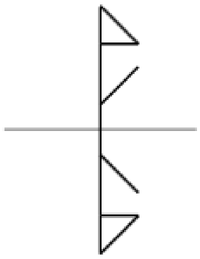
No.	Designation (weld type)	Illustration of weld type (dashed lines show joint preparation prior to welding)	Symbol [a]
22	Stake [c]		

[a] The grey line is not part of the symbol. It indicates the position of the reference line.

[b] Butt welds are full penetration unless otherwise indicated by dimensions on the welding symbol or by reference to other information, for example the WPS.

[c] Symbol can also be used for joints with more than 2 members.

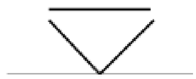
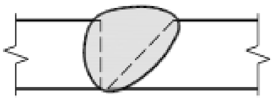
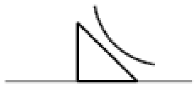
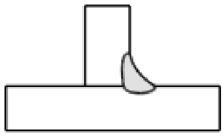
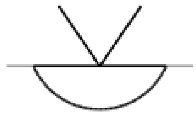
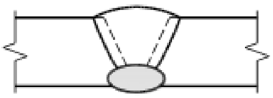
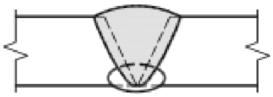
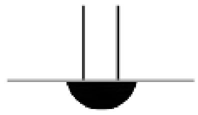
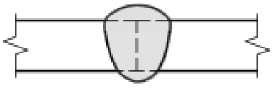
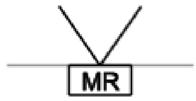
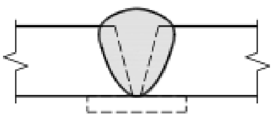
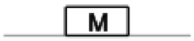
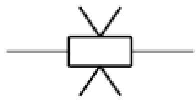
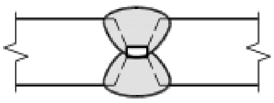
Table 2 — Combined elementary symbols to represent symmetrical double-sided welds

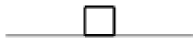
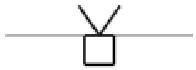
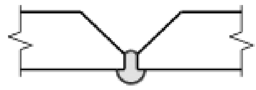
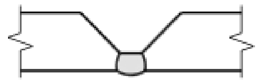
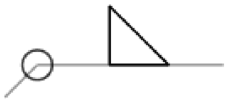
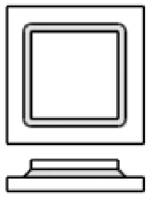
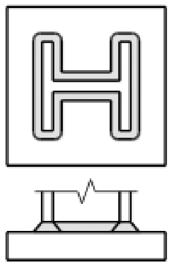
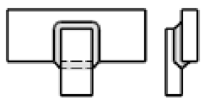
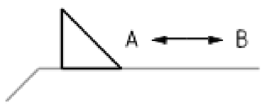
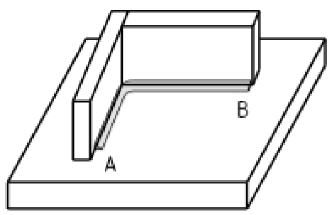
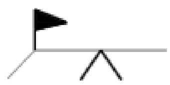
No.	Weld type	Illustration of weld [a]	Symbol [b]
1	Double-V butt		
2	Double bevel butt		
3	Double-U butt		
4	Double bevel butt (with broad root face) and fillet welds		

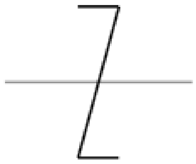
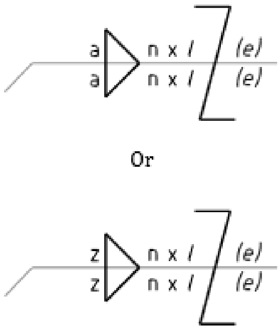
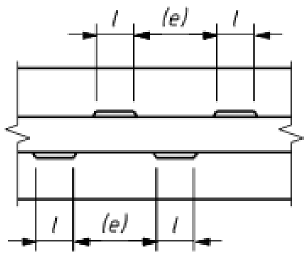
[a] Welds may be partial or full penetration which is to be indicated by dimensions on the welding symbol (see Table 5) or by reference to other information, for example the WPS.

[b] The grey line is not part of the symbol. It indicates the position of the reference line.

Table 3 — Supplementary symbols

No.	Designation	Symbol [a]	Application example [a]	Illustration of weld
1	Flat-finished flush [b]			
2	Convex [b]			
3	Concave [b]			
4	Toes blended smoothly [c]			No example
5	a) Back run [d] (made after the single-V butt weld)			
	b) Backing weld [d] (made before the single-V butt weld)			
6	Specified root reinforcement (butt welds) [e]			
7a	Backing (unspecified)			
7b	Permanent backing [f]			
7c	Removable/ temporary backing [f]			
8	Spacer [h]			
For explanation of footnotes, see end of Table				

No.	Designation	Symbol [a]	Application example [a]	Illustration of weld
9	Consumable insert [h]			 a) Joint showing insert in place  b) Welded joint showing root bead (insert incorporated into root). Single V but weld not shown
10	Weld all-around			 Example A  Example B  Example C
11	Weld between two points			
12	Field weld			No example
For explanation of footnotes, see end of Table				

No.	Designation	Symbol [a]	Application example [a]	Illustration of weld
13	Staggered intermittent welds [h]			

[a] The grey line is not part of the symbol and is included to show the position of symbol on reference line and/or the arrow line only.

[b] Welds that require approximately flush or convex faces without post weld finishing are specified by use of the flush or convex contour symbol.

Welds to be finished flush or convex by post weld finishing or that require a flat but not flush surface require additional information, e.g. addition of a note in the tail of the welding symbol

Other symbols in accordance with ISO 1302 may be used to specify surface finish.

[c] The toes shall be blended smoothly by welding or finishing. Processing details may be specified in the work instructions or WPS.

[d] The weld run sequence may be indicated on the drawing e.g. by use of multiple reference lines, a note in the tail or by reference to a weld procedure specification.

[e] In system B, also used to designate flanged butt/corner welds (see 4.5.6)

[f] M = material to be part of the final welded joint, MR = material to be removed after welding. Further information on the material can be included in the tail or elsewhere.

[g] The material and the dimensions of the consumable insert or spacer can be specified in the tail of the welding symbol or on the drawing.

[h] Explanations of *a*, *z*, *n*, *l* and *(e)* are given in Clause 5.

The symbol for all-around welds must not be used if:

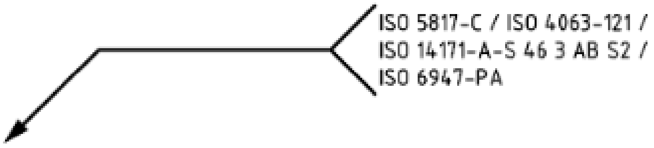
a) the seam does not start and end at the same point, that is to say, the seam is not continuous;

b) the seam type is changed, for example, from fillet weld to butt weld

c) the dimensions are changed, for example, the throat thickness of a fillet weld. In this scenario, each seam must be identified by applying a separate welding symbol.

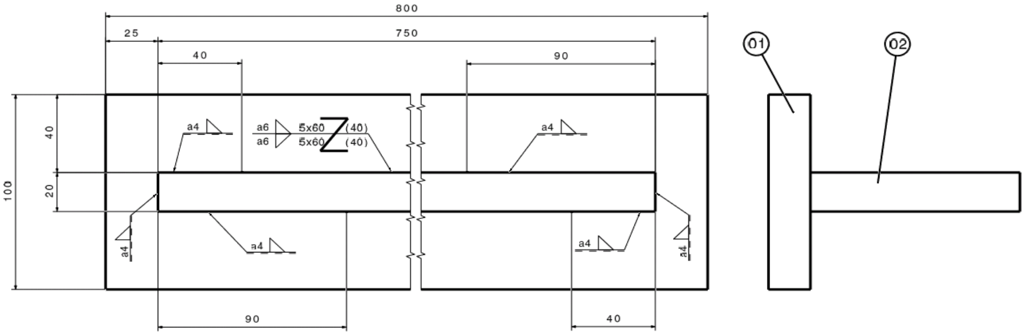
Seams that extend beyond the circumference of a round profile/hole or slot do not require the all-around seam icon in order to define a continuous seam

The tail is an optional element that can be added at the end of the reference line in order to add additional information to the welding symbol. For example, the tail can incorporate an assessment group, a welding process, the welding position or additional test applications of a weld.



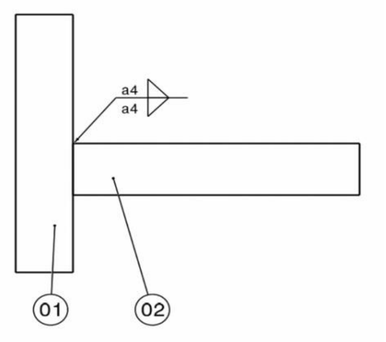
Examples:

- An offset, interrupted seam with different seam thicknesses

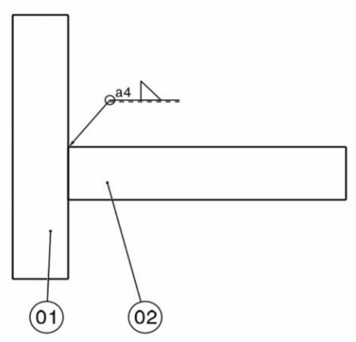


The welded seam must be split (see explanatory diagram) and the symbol must be completed accordingly. The ends must be welded around.

- Fillet weld



Example Double fillet



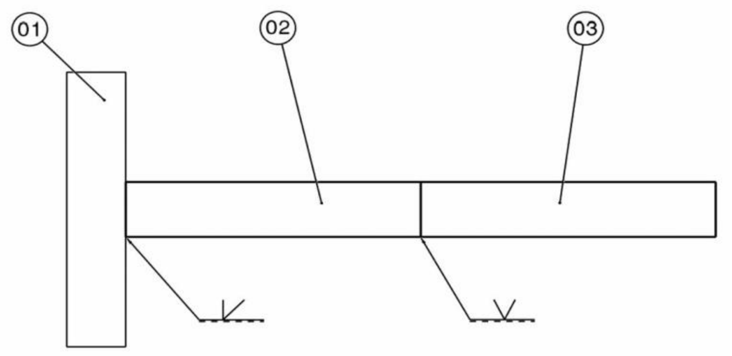
Example All-around fillet weld

Dimension “a” between 2 and 15 mm are possible. **Preferred choice between 3 and 8 mm**. The selection depends on the sheet metal thickness and the static consideration. All-around fillet welds are preferred.

Caution: Fillet welds with a dimension “a” of more than 5 mm are produced by a multi-layered structure (greater effort).

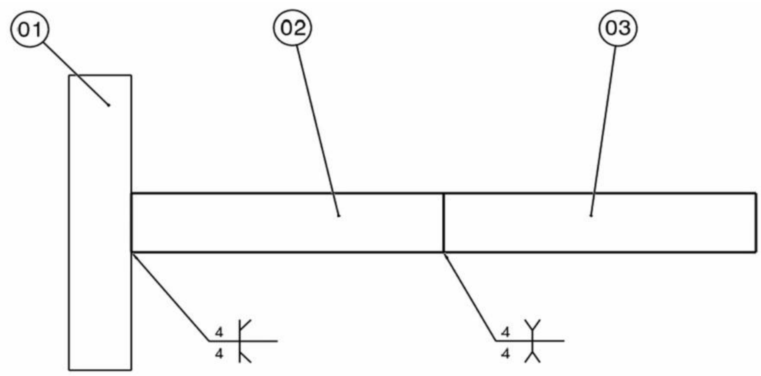
Example of a multi-layer fillet weld a = 10 mm, number of layers approx. 4 to 5

- V-weld



Example of a half V-weld Example V-weld

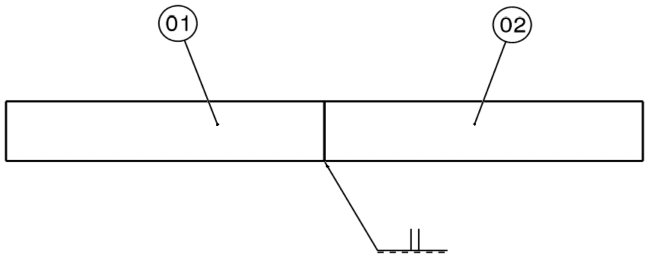
- Y-weld



Example of a half Y-weld Example Y-weld

The weld thickness “s” [mm] is written as a numerical value preceding the weld symbol.

- I-weld



Example of a half I-weld

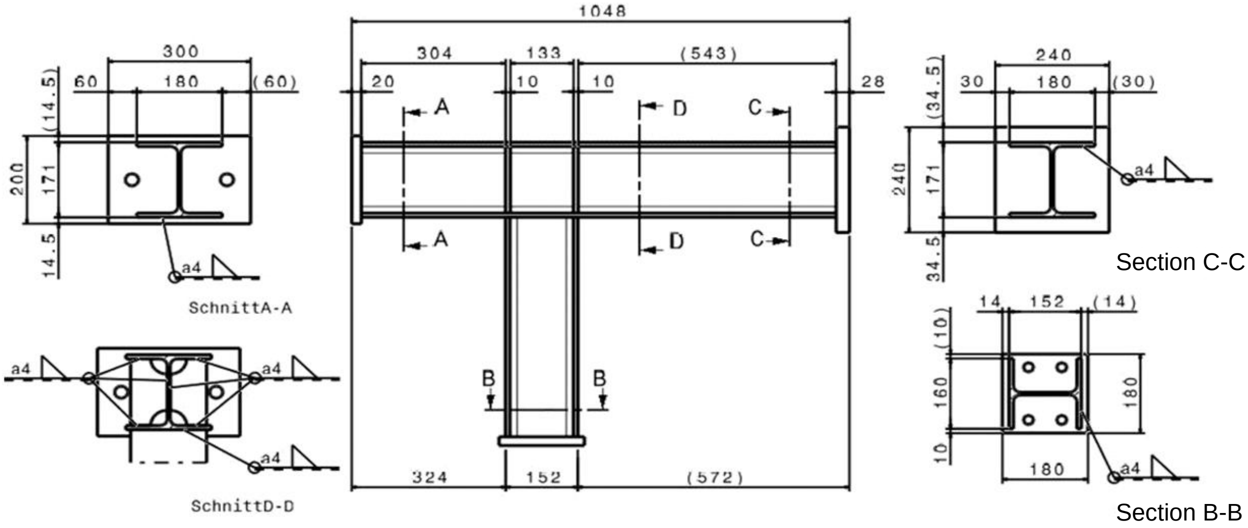
Usually used for sheet metal thicknesses up to 3 mm

The weld thickness “s” [mm] is written as a numerical value preceding the weld symbol.

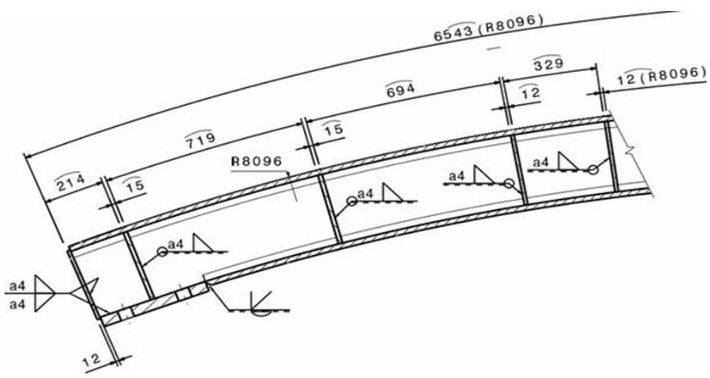
3.7 Dimensioning

Dimensions should be rounded to the nearest millimeter, if possible. In order to utilize symmetries or similar aspects use 1/10 mm.

Contrary to mechanical engineering practices, it is common to enter (closed) chain dimensions. Reference dimensioning in the steel construction is often less suitable for production.



When dimensioning bent parts, it is often preferred to use radians. The radius of curvature, to which the radian or the radian chain dimension refers, must be placed in brackets following the radian or the radian chain dimension.



View of a curved beam (rolled section) with add-on parts dimensioned properly for production purposes.

3.8 Weld preparation

When preparing a weld seam for a steel structure, compliance with DIN EN ISO 9692-1 is mandatory. When preparing a structure made of aluminum and/or aluminum alloys, DIN EN ISO 9692-3 shall apply. The standardized procedure for weld seam preparation is the responsibility of the welder and **need not** be indicated on the engineering drawing or in the 3D model.

4 Engineering drawing and design review

When designing load-bearing welded parts and other welded parts that may increase the risk of placing people in harm’s way or even cause fatal injuries, a drawing and design review must be conducted. In the case of welding quality control, a distinction is made between individual assemblies, parent assemblies and child assemblies.

4.1 Individual assemblies, parent assemblies

Assemblies containing welding parts must be approved by the welding engineer. To do this, the designer must forward the main assembly to the welding engineer in the CDB. He then inspects the welding of the individual parts, as well as the entire assembly. After finishing the inspection and any subsequent work, the welding engineer must fill in the checklist. This concludes the welding inspection.

4.2 Child assemblies

If identical assemblies are to be released, only the parent assembly is transferred to the welding engineer. The release of the child assemblies is the responsibility of the respective designer in charge. In the CDB drop down checklist, the designer must select the function “Not inspection-relevant” and refer to the parent module in the comments column.