Autodesk Inventor Engineer s Handbook

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Joints / Fixed Joints

Weld Joint Calculator

Statically loaded weld joint mechanical calculator

1. Standard Calculation Procedure

Checks joint strength by direct comparison of calculated normal, shear, or resulting reduced stress with the allowable stress by using a standard calculation procedure. With a view to the type of the weld joint, design and loading (that is, with respect to acting stress), strength check can be defined with the following formulas.

$\sigma \leq \sigma_{Al}$, $\tau \leq \tau_{Al}$, $\sigma_R \leq \sigma_{Al}$

where the formulas for allowable loading of the weld joint are (with respect to the required safety):

$s_{Al} = S_Y / n_s$ or $t_{Al} = S_Y / n_s$.

The size of allowable stress, and after the required minimum joint safety, depends on the type of acting stress. For example, the type, design, and loading of the weld joint.

This method is for experienced users who can estimate correctly (according to type, design, and weld loading) the required minimum size of safety factor of the weld joint.

2. Method of Comparative Stresses

Allowable stress is compared with auxiliary comparative stress, which is determined from the calculated partial stresses by using conversion factors of the weld joint when the strength check is carried out with this method. Strength check can be described by the $s_S \leq s_{Al}$ formula, in which allowable loading of the weld joint is $s_{Al} = S_Y / n_s$.

While using empirical conversion factors, effects of different stress types to weld joint safety are included in the calculated comparative stress. You can work with only one value of the safety factor, regardless of the type, design, and loading of the selected weld joint. The recommended minimum value of the safety factor for the method of comparative stresses is within the n_S =< 1.25...2> interval.

This method is for less experienced users.

Weld Joint Calculation Parameters

1. Total versus throat (active) weld length

The size of throat area of the weld has a substantial effect on strength of the weld joint. Generally this value is a multiple of the weld length and height (thickness). For eventual reduction of the area at the beginning and at the end of the weld, in more precise calculations it is better to use only the weld part for the throat length that has the given area.

The weld throat length is determined by using L' = L - 2s formula for butt welds or L' = L - 2a for fillet welds,

where:

sless thickness of welded parts.

afillet weld height.

Recommended size of the throat (active) length of fillet weld is in the L' =< 3a...35a> range.

This switch has no effect for peripheral welds, where the throat weld length is always the full weld length.

2. Thickness of flange and web is ignored

Thickness of flange and web can be ignored in calculations of beams with T or I section, connected with fillet welds. For standard sections, the ratio of flange or web thickness and beam width is small and for this reason the calculation is sufficiently precise if thickness is ignored.

We recommend that you switch off this calculation option for precise calculations or for special sections (with a greater flange or web thickness).

3. Distribution of shear stress is considered

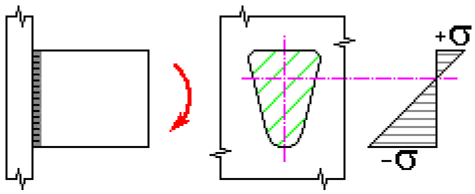
For beams joined by fillet weld and loaded with shear force and for more precise calculation, we recommend that you use the theory of shear stress distribution in the loaded section and to consider only welds that carry the shear force within the calculation. According to this theory, the shear force is carried only by welds parallel with stress direction. Shear stress is then calculated by using the formula $t = F_Y / A_s$, where:

$F_y$shear force.

$A_s$reduced throat of weld group.

4. Only positive stress value from bending moment is considered

For beams joined by filled welds and loaded with bend moment, normal stress is originated in the weld. The following is an image of the stress diagram.



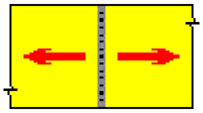
The maximum stress is originated in the outer points of the weld group, the most distant places from the neutral axis. For welds, symmetrical along the neutral axis the size of these stresses is identical. For nonsymmetrical welds, pressure stress might be greater. Normally the program tests a greater value from these peaks during strength check, regardless of the stress direction, which is pressure stress in this case.

When loading capacity of the weld joint is considered, tensile stress has substantially greater significance for such welded beam. This switch suppresses the pressure stress check and allows a check of the maximum tensile stress value only, even if the pressure stress is greater in the weld.

This switch is applicable only for static calculation because there is no difference between positive or negative value for fatigue calculation and the calculation is always controlled by maximum stresses in the weld.

Calculation of butt end weld

Butt end weld loaded with normal force



Normal stress

$$\sigma_1 = \frac{F_n}{A} \quad [\text{MPa, psi}]$$

where:

F_n normal force [N, lb]

A throat area of the weld [mm^2, in^2]

Reference stress

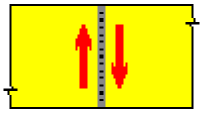
$$\sigma_S = \frac{\sigma_1}{\alpha_1} \quad [\text{MPa, psi}]$$

where:

σ_1 normal stress [MPa, psi]

α_1 factor of the weld joint [-]

Butt end weld loaded with shear force



Shear stress

$$\tau = \frac{F_t}{A} \qquad [MPa, psi]$$

where:

F_t shear force [N, lb]

A throat area of the weld [mm^2, in^2]

Reference stress

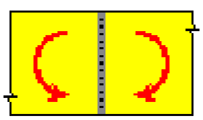
$$\sigma_S = \frac{\tau}{\alpha_2} \qquad [MPa, psi]$$

where:

τ shear stress [MPa, psi]

α_2 factor of the weld joint [-]

Butt end weld loaded with bending in the plane of welded parts



Normal stress

$$\sigma_2 = \frac{u \cdot M_1}{W} \qquad [MPa, psi]$$

where:

u constant

α_2 - for calculation in metric units u = 1000

α_2 - for calculation in English units u = 12

M_{1n} bending moment [Nm, lb ft]

W section modulus of throat area of the weld [mm^3, in^3]

Reference stress

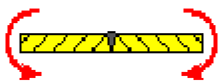
$$\sigma_5 = \frac{\sigma_2}{\alpha_1} \qquad [MPa, psi]$$

where:

σ_2 normal stress [MPa, psi]

α_1 factor of the weld joint [-]

Butt end weld loaded with bending in the plane perpendicular to the plane of welded parts



Normal stress

$$\sigma_3 = \frac{u \cdot M_2}{W} \qquad [MPa, psi]$$

where:

u constant

- for calculation in metric units u = 1000

- for calculation in English units u = 12

M_2 bending moment [Nm, lb ft]

W section modulus of throat area of the weld [mm^3, in^3]

Reference stress

$$\sigma_5 = \frac{\sigma_3}{\alpha_1} \qquad [MPa, psi]$$

where:

σ_3 normal stress [MPa, psi]

α_1 factor of the weld joint [-]

Butt end weld loaded with combined loading

Resultant reduced stress

$$\sigma_R = \sqrt{(\sigma_1 + \sigma_2 + \sigma_3)^2 + 3 \cdot (\tau)^2} \qquad [MPa, psi]$$

where:

σ 1 , σ 2 , σ 3normal stress [MPa, psi]

τ shear stress [MPa, psi]

Reference stress

$$\sigma_S = \sqrt{\left(\frac{\sigma_1 + \sigma_2 + \sigma_3}{\alpha_1}\right)^2 + 3 \cdot \left(\frac{\tau}{\alpha_2}\right)^2} \qquad [MPa, psi]$$

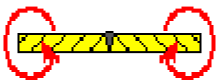
where:

σ 1 , σ 2 , σ 3normal stress [MPa, psi]

τ shear stress [MPa, psi]

α 1 , α 2 factor of the weld joint [-]

Butt end weld loaded with torque



Shear stress

$$\tau_{max} = \frac{u \cdot T}{W} \qquad [MPa, psi]$$

where:

u constant

- for calculation in metric units u = 1000
- for calculation in English units u = 12

T torque [Nm, lb ft]

Wsection modulus of throat area of the weld [mm^3, in^3]

Reference stress

$$\sigma_S = \frac{\tau_{max}}{\alpha_2} \qquad [MPa, psi]$$

where:

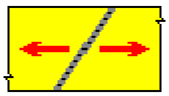
τ_{max} shear stress [MPa, psi]

α_2 factor of the weld joint [-]

Meaning of used variables:

A	throat area of the weld [mm^2, in^2]
F_n	normal force [N, lb]
F_t	shear force [N, lb]
M_1, M_2	bending moments [Nm, lb ft]
s	plate thickness [mm, in]
T	torque [Nm, lb ft]
W	section modulus of throat area of the weld [mm^3, in^3]
α_1, α_2	factor of the weld joint [-]

alculation of oblique butt weld



Normal stress

$$\sigma = \frac{F \cdot \cos \delta}{A} \qquad [MPa, psi]$$

where:

F acting force [N, lb]

δ weld direction angle [°]

A throat area of the weld [mm^2, in^2]

Shear stress

$$\tau = \frac{F \cdot \sin \delta}{A} \qquad [MPa, psi]$$

where:

F acting force [N, lb]

δ weld direction angle [°]

A throat area of the weld [mm^2, in^2]

Resultant reduced stress

$$\sigma_R = \sqrt{\sigma^2 + 3 \cdot \tau^2} \qquad [MPa, psi]$$

where:

σ normal stress [MPa, psi]

τ shear stress [MPa, psi]

Reference stress

$$\sigma_S = \sqrt{\left(\frac{\sigma}{\alpha_1}\right)^2 + 3 \cdot \left(\frac{\tau}{\alpha_2}\right)^2} \qquad \text{[MPa,psi]}$$

where:

σ normal stress [MPa, psi]

τ shear stress [MPa, psi]

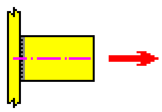
α_1, α_2 factor of the weld joint [-]

Meaning of used variables:

A throat area of the weld [mm^2, in^2]
F acting force [N, lb]
α_1, α_2 factor of the weld joint [-]
δ weld direction angle [°]

Calculation of plate joining with double-sided butt weld

Butt weld loaded with normal stress



Normal stress

$$\sigma_1 = \frac{F_z}{A} \qquad [MPa, psi]$$

where:

F_z normal force [N, lb].

A throat area of the weld [mm ^{2}, in ^{2}].

Comparative stress

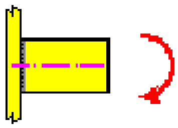
$$\sigma_S = \frac{\sigma_1}{\alpha_1} \qquad [MPa, psi]$$

where:

σ_1 normal stress [MPa, psi]

α_1 conversion factor of the weld joint [-]

Butt weld loaded with bending moment



Normal stress

$$\sigma_2 = \frac{u \cdot M}{W} \quad [MPa, psi]$$

where:

u constant

- for calculation in metric units u = 1000
- for calculation in English units u = 12

M bending moment [Nm, lb ft]

W section modulus of throat area of the weld [mm ^{3} , in ^{3}]

Comparative stress

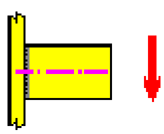
$$\sigma_5 = \frac{\sigma_2}{\alpha_1} \quad [MPa, psi]$$

where:

σ_2 normal stress [MPa, psi]

α_1 conversion factor of the weld joint [-]

Butt weld loaded with bending force



Normal stress

$$\sigma_3 = \frac{F_Y \cdot e}{W} \quad [MPa, psi]$$

where:

F_y bending force [N, lb]

e force arm [mm, in]

W section modulus of throat area of the weld [mm ^{3} , in ^{3}]

Shear stress

$$\tau = \frac{F_z}{A} \qquad [MPa, psi]$$

where:

F_z axial force [N, lb].

A throat area of the weld [mm^2, in^2].

Resultant reduced stress

$$\sigma_R = \sqrt{\sigma_3^2 + 3 \cdot \tau^2} \qquad [MPa, psi]$$

where:

σ_3 normal stress [MPa, psi]

τ shear stress [MPa, psi]

Comparative stress

$$\sigma_S = \sqrt{\left(\frac{\sigma_3}{\alpha_1}\right)^2 + 3 \cdot \left(\frac{\tau}{\alpha_2}\right)^2} \qquad [MPa, psi]$$

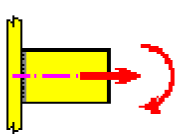
where:

σ_3 normal stress [MPa, psi]

τ shear stress [MPa, psi]

α_1, α_2 conversion factors of weld joint [-]

Butt weld loaded with combined loading



Total normal stress

$\sigma = \sigma_1 + \sigma_2$ [MPa, psi]

where:

σ_1, σ_2 normal stress [MPa, psi]

Comparative stress

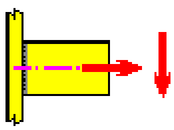
$$\sigma_S = \frac{\sigma_1 + \sigma_2}{\alpha_1} \qquad [\mathrm{MPa, psi}]$$

where:

σ_1, σ_2 normal stress [MPa, psi]

α_1 conversion factor of the weld joint [-]

Butt weld loaded with combined loading



Resultant reduced stress

$$\sigma_R = \sqrt{(\sigma_1 + \sigma_3)^2 + 3 \cdot (\tau)^2} \qquad [\mathrm{MPa, psi}]$$

where:

σ_1, σ_3 normal stress [MPa, psi]

τ shear stress [MPa, psi]

Comparative stress

$$\sigma_S = \sqrt{\left(\frac{\sigma_1 + \sigma_3}{\alpha_1}\right)^2 + 3 \cdot \left(\frac{\tau}{\alpha_2}\right)^2} \qquad [\mathrm{MPa, psi}]$$

where:

σ_1, σ_3 normal stress [MPa, psi]

τ shear stress [MPa, psi]

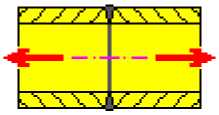
α_1, α_2 conversion factors of the weld joint [-]

Meaning of used variables:

A throat area of the weld group [mm^2, in^2].
F_Z axial force [N, lb]
F_Y bending shearing force [N, lb]
e force arm [mm, in]
W section modulus of throat area of the weld [mm^3, in^3]
M bending moment [Nm, lb ft]
α_1, α_2 conversion factors of the weld joint [-]

Calculation of loaded tube joined by peripheral butt weld

Peripheral butt weld loaded with normal stress



Normal stress

$$\sigma = \frac{F_z}{A} \qquad [MPa, psi]$$

where:

F_z axial force [N, lb]

A throat area of the weld [mm^2, in^2]

Comparative stress

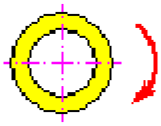
$$\sigma_S = \frac{\sigma}{\alpha_1} \qquad [MPa, psi]$$

where:

σ normal stress [MPa, psi]

α_1 shear stress [MPa, psi]

Peripheral butt weld loaded with torque



Shear stress

$$\tau = \frac{u \cdot T}{W} \qquad [MPa, psi]$$

where:

u constant

- for calculation in metric units u = 1000

- for calculation in English units u = 12

T torque [Nm, lb ft]

Wsection modulus of throat area of the weld [mm ^{3}, in ^{3}]

Comparative stress

$$\sigma_S = \frac{\tau}{\alpha_2} \qquad [MPa, psi]$$

where:

τ shear stress [MPa, psi]

$\alpha_2$conversion factor of the weld joint [-]

Peripheral butt weld loaded with combined loading

Resultant reduced stress

$$\sigma_R = \sqrt{\sigma^2 + 3 \cdot \tau^2} \qquad [MPa, psi]$$

where:

σnormal stress [MPa, psi]

τshear stress [MPa, psi]

Comparative stress

$$\sigma_S = \sqrt{\left(\frac{\sigma}{\alpha_1}\right)^2 + 3 \cdot \left(\frac{\tau}{\alpha_2}\right)^2} \qquad [MPa, psi]$$

where:

σ normal stress [MPa, psi]

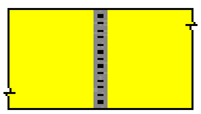
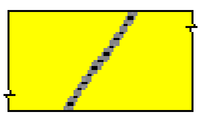
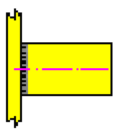
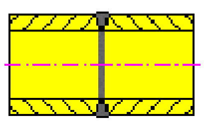
τ shear stress [MPa, psi]

α_1, α_2 conversion factors of the weld joint [-]

Meaning of used variables:

F_z axial force [N, lb]
F_n normal force [N, lb]
F_t shear force [N, lb]
A throat area of the weld [mm^2, in^2]
T torque [Nm, lb ft]
M_1, M_2 bending moments [Nm, lb ft]
s plate thickness [mm, in]
W section modulus of throat area of the weld [mm^3, in^3]
α_1, α_2 conversion factors of the weld joint [-]

Throat area of butt weld

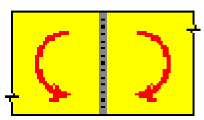
Weld design	*Throat area of butt weld A [mm ^{2}, in ^{2}]* for full weld length	for load-bearing (active) weld length
	$A = s\,L$	$A = s\,(L - 2\,s)$
	$A = s \cdot \frac{L}{\cos\delta}$	$A = s \cdot \left(\frac{L}{\cos\delta} - 2 \cdot s\right)$
	$A = s\,L$	$A = s\,(L - 2\,s)$
	$A = \pi\, s\,(D - s)$	-

Meaning of used variables:

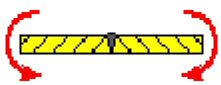
D tube outer diameter [mm, in]
L weld length [mm, in]
s thickness of thinner joined part [mm, in]
δ weld direction angle [°]

Section modulus of throat area of butt weld

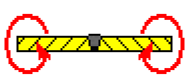
Weld design — *Section modulus of throat area of butt weld W [mm ^{3}, in ^{3}]*
for full weld length — for load-bearing (active) weld length



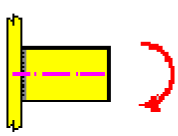
$$W = \frac{s \cdot L^2}{6} \qquad W = \frac{s \cdot L^2}{6}$$



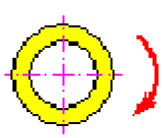
$$W = \frac{s^2 \cdot L}{6} \qquad W = \frac{s^2 \cdot (L - 2 \cdot s)}{6}$$



$$W = \frac{s^2 \cdot L^2}{3 \cdot L + 1.8 \cdot s} \qquad W = \frac{s^2 \cdot (L - 2 \cdot s)^2}{3 \cdot (L - 2 \cdot s) + 1.8 \cdot s}$$



$$W = \frac{s \cdot L^2}{6} \qquad W = \frac{s \cdot (L - 2 \cdot s)^2}{6}$$



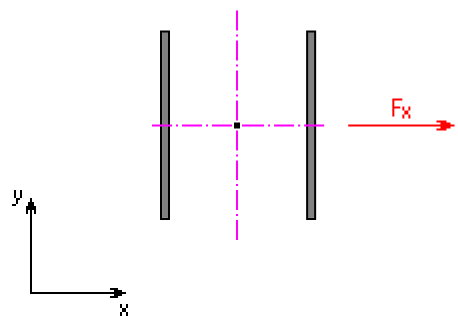
$$W = \frac{\pi}{2} \cdot s \cdot (D - s)^2$$

Meaning of used variables:

D tube outer diameter [mm, in]
L weld length [mm, in]
s thickness of thinner joined part [mm, in]

Calculation of fillet welds loaded in the plane of part joining

1. Loading by axial force F x



Resultant Shear Stress

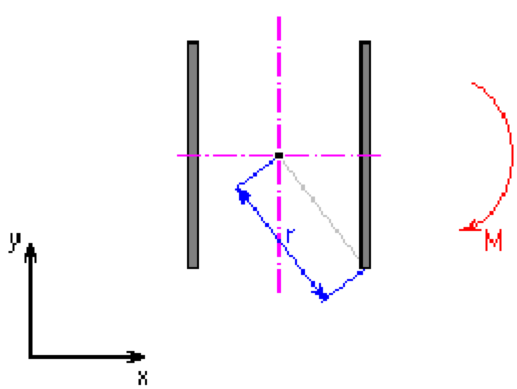
$$\tau = \frac{F_x}{A} \qquad [\mathrm{MPa, psi}]$$

where:

F_x axial force [N, lb].

A throat area of the weld group [mm^2, in^2].

2. Loading by bending moment M



Shear stress in the weld investigated point

$$\tau = \frac{u \cdot M \cdot r}{J} \qquad [MPa, psi]$$

where:

u constant

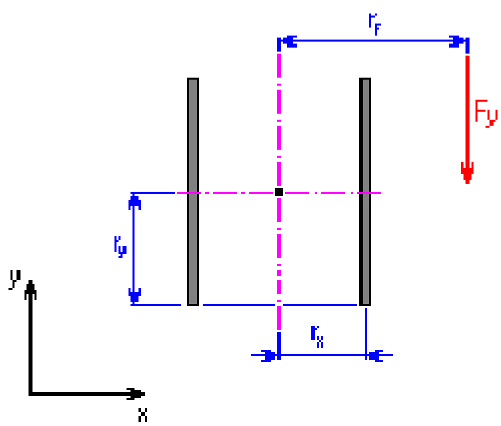
- for calculation in metric units u = 1000
- for calculation in English units u = 12

M bending moment [Nm, lb ft]

r radius vector of investigated weld point related to the weld group center of gravity [mm, in]

J polar moment of inertia of weld group [mm^4, in^4]

3. Loading by bending force F_Y



In any weld point, a stress caused by shearing force F_Y and bending moment M_F originates. Its size determines the formula:

$M_F = F_Y r_F$ [Nmm, lb in]

where:

F_Y bending shearing force [N, lb]

r_F arm of bending force to the weld group center of gravity [mm, in].

Shear stress caused by shearing force

$$\tau_Y = \frac{F_Y}{A} \qquad [\mathrm{MPa, psi}]$$

where:

F_Y bending shearing force [N, lb]

A throat area of the weld group [mm ^{2}, in ^{2}].

Shear stress caused by bending moment

- stress x-component

$$\tau_{XM} = \frac{M_F \cdot r_Y}{J} \qquad [\mathrm{MPa, psi}]$$

- stress y-component

$$\tau_{YM} = \frac{M_F \cdot r_X}{J} \qquad [\mathrm{MPa, psi}]$$

where:

M_F bending moment [Nmm, lb in]

r_Y distance of investigated weld point to the weld group center of gravity in the y-axis direction [mm, in]

r_X distance of investigated weld point to the weld group center of gravity in the x-axis direction [mm, in]

J polar moment of inertia of weld group [mm ^{4}, in ^{4}]

Resultant shear stress in the investigated point of weld

$$\tau = \sqrt{\tau_{XM}^{\,2} + (\tau_Y \pm \tau_{YM})^2} \qquad [\mathrm{MPa, psi}]$$

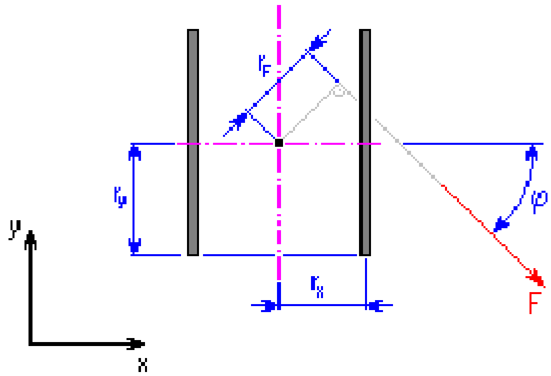
where:

τ_{XM} x-component of shear stress caused by bending moment [MPa, psi]

τ_Y shear stress caused by shearing force F_Y' [MPa, psi]

τ_{YM} y-component of shear stress caused by bending moment [MPa, psi]

4. Loading by common force F



In any weld point, a common force F causes adequate stress to the stress which would arise by combined loading from bending moment M_F and the pair of shearing forces F_X', F_Y' with action point in the weld group center of gravity, while applies:

$M_F = F\ r_F$ [Nmm, lb in]

$F_{X'} = F \cos \phi$ [N, lb]

$F_{Y'} = F \sin \phi$ [N, lb]

where:

F acting force [N, lb]

r_F arm of bending force to the weld group center of gravity [mm, in]

φ direction angle of acting force [°]

Shear stress caused by shearing force $F_{X'}$

$$\tau_X = \frac{F'_X}{A} \qquad [\text{MPa,psi}]$$

Shear stress caused by shearing force $F_{Y'}$

$$\tau_Y = \frac{F'_Y}{A} \qquad [\text{MPa,psi}]$$

where:

A throat area of the weld [mm^2, in^2]

Shear stress caused by bending moment

- stress x-component

$$\tau_{XM} = \frac{M_F \cdot r_Y}{J} \qquad [MPa, psi]$$

- stress y-component

$$\tau_{YM} = \frac{M_F \cdot r_X}{J} \qquad [MPa, psi]$$

where:

M_F	bending moment [Nmm, lb in]
r_Y	distance of investigated weld point to the weld group center of gravity in the y-axis direction [mm, in]
r_X	distance of investigated weld point to the weld group center of gravity in the x-axis direction [mm, in]
J	polar moment of inertia of weld group [mm^4, in^4]

Resultant shear stress in the investigated point of weld

$$\tau = \sqrt{(\tau_X \pm \tau_{XM})^2 + (\tau_Y \pm \tau_{YM})^2} \qquad [MPa, psi]$$

where:

τ_X shear stress caused by shearing force $F_{X'}$ [MPa, psi]

τ_{XM} x-component of shear stress caused by bending moment [MPa, psi]

τ_Y shear stress caused by shearing force F_Y' [MPa, psi]

τ_{YM} y-component of shear stress caused by bending moment [MPa, psi]

5. Calculation of comparative stress σ_S

Comparative stress is determined from calculated partial stresses according to the formula:

$$\sigma_S = \sqrt{\left(\frac{\tau_X \pm \tau_{XM}}{\alpha_X}\right)^2 + \left(\frac{\tau_Y \pm \tau_{YM}}{\alpha_Y}\right)^2} \qquad [MPa, psi]$$

while for the x-component of stress that actuates in the investigated point of weld, perpendicularly to the weld direction, the $\alpha_X = \alpha_3$ formula is applied. In the opposite case $\alpha_X = \alpha$

$_4$. The same applies for the y-component of the stress actuating perpendicularly to the weld direction, that is $\alpha_Y = \alpha_3$ or $\alpha_Y = \alpha_4$.

where:

τ_X shear stress caused by shearing force $F_{X'}$ [MPa, psi]

τ_{XM} x-component of shear stress caused by bending moment [MPa, psi]

τ_Y shear stress caused by shearing force F_Y ' [MPa, psi]

τ_{YM} y-component of shear stress caused by bending moment [MPa, psi]

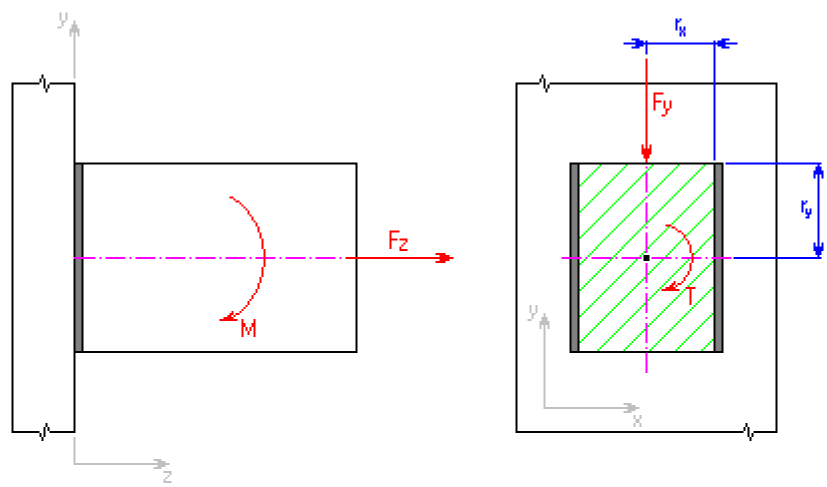
α_3 conversion factor of weld joint for fillet end weld [-]

α_3 conversion factor of weld joint for fillet end weld [-]

alculation of fillet welds loaded in the plane perpendicular to the plane of part joining

Standard Calculation Procedure

1. Common solution for combined loading



Loading in the plane perpendicular to the weld plane induces a tensile or pressure stress σ in the weld.

Normal stress caused by axial force F_Z

$$\sigma_F = \frac{F_Z}{A} \qquad [MPa, psi]$$

where:

F_Z axial force [N, lb].

A throat area of the weld group [mm^2, in^2].

Normal stress caused by bending moment M

$$\sigma_M = \frac{u \cdot M \cdot r_Y}{I} \qquad [MPa, psi]$$

where:

u constant

- for calculation in metric units u = 1000
- for calculation in English units u = 12

M bending moment [Nm, lb ft]

r_Y distance of investigated weld point from the weld group center of gravity in the y-axis direction [mm, in]

I moment of inertia of weld group to the neutral x-axis [mm^4, in^4]

Total normal stress

$\sigma = \sigma_F \pm \sigma_M$ [MPa, psi]

where:

σ_F normal stress caused by the axial force F_Z [N, lb]

σ_M normal stress caused by the bending moment M [mm, in]

Loading in the weld plane induces a shear stress τ in the weld:

Shear stress caused by shearing force F_Y

$$\tau_Y = \frac{F_Y}{A} \quad [\mathrm{MPa, psi}]$$

where:

F_Y shearing force [N, lb]

A throat area of the weld group [mm^2, in^2]

Shear stress caused by torsion moment T

- x-component of stress

$$\tau_{XT} = \frac{u \cdot T \cdot r_Y}{J} \quad [\mathrm{MPa, psi}]$$

- y-component of stress

$$\tau_{YT} = \frac{u \cdot T \cdot r_X}{J} \qquad [MPa, psi]$$

where:

u constant

- for calculation in metric units u = 1000

- for calculation in English units u = 12

T torque [Nm, lb ft]

r_X distance of investigated weld point to the weld group center of gravity in the y-axis direction [mm, in]

r_Y distance of investigated weld point to the weld group center of gravity in the y-axis direction [mm, in]

J polar moment of inertia of weld group [mm ^{4}, in ^{4}]

Total shear stress

$$\tau = \sqrt{\tau_{XT}^2 + (\tau_Y + \tau_{YT})^2} \qquad [MPa, psi]$$

where:

τ_{XT} x-component of shear stress caused by torque T [MPa, psi]

τ_Y shear stress caused by shearing force F_Y' [MPa, psi]

τ_{YT} y-component of shear stress caused by torque T [MPa, psi]

Resultant shear stress in the investigated point of weld

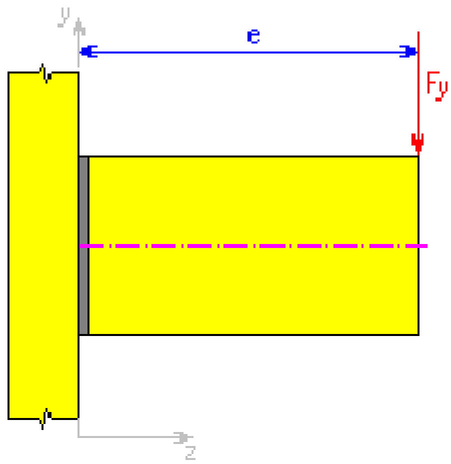
$$\sigma_R = \sqrt{\sigma^2 + 3 \cdot \tau^2} \qquad [MPa, psi]$$

where:

σ total normal stress [MPa, psi]

τ total shear stress [MPa, psi]

2. Loading with bending force F_Y



For calculation purposes, the bending force can be substituted by the combination of shearing force F_Y acting in the weld plane and the bending moment M acting in the plane perpendicular to the weld plane. Then the stress in the weld can be calculated using the previously mentioned procedure.

The bending moment is defined by a formula:

$$M = \frac{F_Y \cdot e}{u} \qquad [Nm, lbft]$$

where:

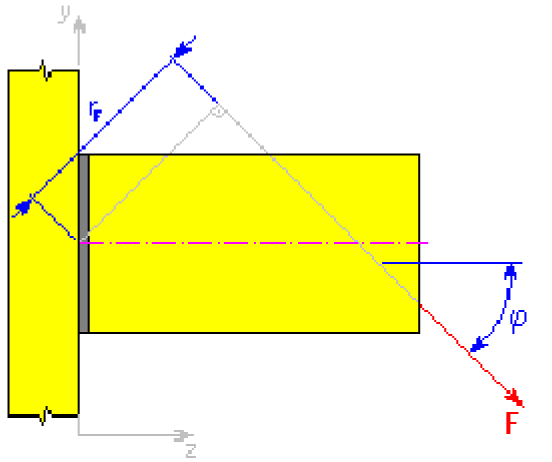
F_Y shearing force [N, lb]

e arm of bending force [mm, in]

u constant

- for calculation in metric units u = 1000
- for calculation in English units u = 12

3. Loading with common force F_Y



For calculation purposes, the common force F can be substituted by the combination of shearing force F_Y acting in the weld plane with the axial force F_Z and the bending moment M acting in the plane perpendicular to the weld plane. Then the stress in the weld for so defined loading can be calculated using the above mentioned procedure.

The particular components of the loading are defined by formulas:

- bending moment

$$M = \frac{F \cdot r_F}{u} \qquad [Nm, lbft]$$

- axial force

$F_Z = F \cos \phi$ [N, lb]

- shearing force

$F_Y = F \cos \phi$ [N, lb]

where:

F acting force [N, lb]

r_F force arm related to the weld group center of gravity [mm, in]

u constant

- for calculation in metric units u = 1000

- for calculation in English units u = 12

φ direction angle of acting force [°]

Method of Comparative Stresses

1. Common solution for combined loading

Compared with the standard calculation method, the method of comparative stresses approaches a different way to calculate stresses caused by the axial force or bending moment that actuate in the plane perpendicular to the weld plane. Generally the stress in fillet welds has normal and tangential components. The method of comparative stresses is based on the fact that the shear strength of weld metal is lower than the tensile strength. To simplify the calculation, weld joints are only checked for shear stresses. But the calculation method is the same as in the standard calculation method. Used calculation formulas are also similar.

Loading in the perpendicular plane to the weld plane:

Shear stress caused by axial force F_Z

$$\tau_Z = \frac{F_Z}{A} \qquad [\mathrm{MPa, psi}]$$

where:

F_Z axial force [N, lb].

A throat area of the weld group [mm^2, in^2].

Shear stress caused by bending moment M

$$\tau_{ZM} = \frac{u \cdot M \cdot r_Y}{I} \qquad [\mathrm{MPa, psi}]$$

where:

M bending moment [Nm, lb ft]

r_Y distance of investigated weld point from the weld group center of gravity in the y-axis direction [mm, in]

u constant

- for calculation in metric units u = 1000

- for calculation in English units u = 12

I moment of inertia of weld group to the neutral x-axis [mm^4, in^4]

Loading in the weld plane:

Shear stress caused by shearing force F_Y

$$\tau_Y = \frac{F_Y}{A} \qquad [MPa, psi]$$

where:

F_Y shearing force [N, lb]

A throat area of the weld group [mm^2, in^2]

Shear stress caused by torque T

- stress x-component

$$\tau_{XT} = \frac{u \cdot T \cdot r_Y}{J} \qquad [MPa, psi]$$

- stress y-component

$$\tau_{YT} = \frac{u \cdot T \cdot r_X}{J} \qquad [MPa, psi]$$

where:

T torque [Nm, lb ft]

u constant

- for calculation in metric units u = 1000
- for calculation in English units u = 12

r_Y distance of investigated weld point to the weld group center of gravity in the y-axis direction [mm, in]

r_X distance of investigated weld point to the weld group center of gravity in the x-axis direction [mm, in]

J polar moment of inertia of weld group [mm^4, in^4]

Total shear stress in the investigated point of weld

$$\tau = \sqrt{\tau_{XT}^2 + (\tau_Y + \tau_{YT})^2 + (\tau_Z \pm \tau_{ZM})^2} \qquad [MPa, psi]$$

where:

τ_{XT} x-component of shear stress caused by torque T [MPa, psi]

τ_Y shear stress caused by shearing force F_Y' [MPa, psi]

τ_{YT} y-component of shear stress caused by torque T [MPa, psi]

τ_Z shear stress caused by shearing force F_Z [MPa, psi]

τ_{ZM} shear stress caused by bending moment M [MPa, psi]

2. Calculation of comparative stress σ_s

The comparative stress is determined from calculated partial stresses according to the formula.

$$\sigma_S = \sqrt{\left(\frac{\tau_{XT}}{\alpha_X}\right)^2 + \left(\frac{\tau_Y + \tau_{YT}}{\alpha_Y}\right)^2 + \left(\frac{\tau_Z \pm \tau_{ZM}}{\alpha_3}\right)^2} \qquad \text{[MPa,psi]}$$

while for the x-component of stress that actuates in the investigated point of weld, perpendicularly to the weld direction, the $\alpha_X = \alpha_3$ formula is applied. In the opposite case $\alpha_X = \alpha_4$. The same applies for the y-component of the stress actuating perpendicularly to the weld direction, that is $\alpha_Y = \alpha_3$ or $\alpha_Y = \alpha_4$.

τ_{XT} shear stress x-component caused by torque T [MPa, psi]

τ_Y shear stress caused by shearing force F_Y [MPa, psi]

τ_{YT} shear stress y-component caused by torque T [MPa, psi]

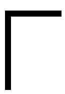
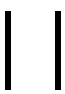
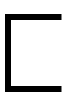
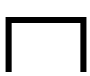
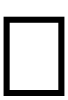
τ_Z shear stress caused by shearing force F_Z [MPa, psi]

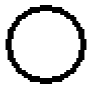
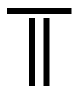
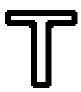
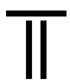
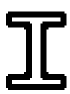
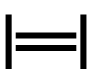
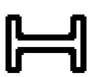
τ_{ZM} shear stress caused by bending moment M [MPa, psi]

α_3 conversion factor of weld joint for fillet end weld [-]

α_4 conversion factor of weld joint for fillet end weld [-]

Throat area of fillet weld

Weld design	*Throat area of fillet weld A [mm ^{2}, in ^{2}]* for full weld length	for load-bearing (active) weld length
	A = a L	A = a (L - 2 a)
	A = a (H + B)	A = a (H + B - 2 a)
	A = a 2 H	A = a 2 (H - 2 a)
	A = a 2 B	A = a 2 (B - 2 a)
	A = a (H + 2 B)	A = a (H + 2 B - 2 a)
	A = a (2 H + B)	A = a (2 H + B - 2 a)
	A = a 2 (H + B)	-
	A = 2 π a (r + a / 2)	-

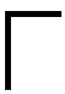
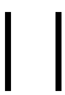
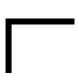
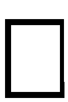
		
	A = a 2 L	A= a 2 (L - 2 a)
	A = a (2 H + B), A = a (2 H + B - 2 t)	A = a (2 H + B - 6 a), A = a (2 H + B - 2 t - 6 a)
	A = a 2 (H + B)	-
	A = a 2 (H + B), A = a 2 (H + B - 2 t)	A = a 2 (H + B - 4 a), A = a 2 (H + B - 2 t - 4 a)
	A = a 2 (H + 2 B), A = a 2 (H +2 B - s)	-
	A = a 2 (H + B), A = a 2 (H + B - 2 t)	A = a 2 (H + B - 4 a), A = a 2 (H + B - 2 t - 4 a)
	A = a 2 (2 H + B), A = a 2 (2 H + B - s)	-

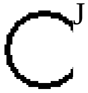
Meaning of used variables:

a fillet weld height [mm, in]
B width of weld group [mm, in]
H height of weld group [mm, in]
L weld length [mm, in]
r weld radius [mm, in]
s web thickness [mm, in]

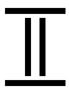
t flange thickness [mm, in]

Polar moment of inertia for filet weld

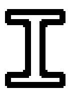
Weld design	*Polar moment of inertia of fillet weld J [mm ^{4}, in ^{4}]*	*Position of center of gravity of weld group section*
	$J = a \cdot \frac{L^3}{12}$	$\bar{X} = \frac{L}{2}$ $\quad \bar{Y} = \frac{a}{2}$
	$J = a \cdot \left(\frac{(H+B)^4 - 6 \cdot H^2 \cdot B^2}{12 \cdot (H+B)} \right)$	$\bar{X} = \frac{B^2}{2 \cdot (H+B)}$ $\quad \bar{Y} = \frac{2 \cdot H \cdot B + H^2}{2 \cdot (H+B)}$
	$J = a \cdot \left(\frac{H \cdot (3 \cdot B^2 + H^2)}{6} \right)$	$\bar{X} = \frac{B}{2}$ $\quad \bar{Y} = \frac{H}{2}$
	$J = a \cdot \left(\frac{H \cdot (3 \cdot B^2 + H^2)}{6} \right)$	$\bar{X} = \frac{B}{2}$ $\quad \bar{Y} = \frac{H}{2}$
	$J = a \cdot \left(\frac{(8 \cdot B^3 + 6 \cdot B \cdot H^2 + H^3}{12} - \frac{B^4}{2 \cdot B + H} \right)$	$\bar{X} = \frac{B^2}{2 \cdot B + H}$ $\quad \bar{Y} = \frac{H}{2}$
	$J = a \cdot \left(\frac{(8 \cdot H^3 + 6 \cdot H \cdot B^2 + B^3}{12} - \frac{H^4}{2 \cdot H + B} \right)$	$\bar{X} = \frac{B}{2}$ $\quad \bar{Y} = \frac{H^2}{2 \cdot H + B}$
	$J = a \cdot \frac{(H+B)^3}{6}$	$\bar{X} = \frac{B}{2}$ $\quad \bar{Y} = \frac{H}{2}$

 $J = 2 \pi a (r + a / 2)^3$ -

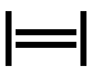
Weld design — *Polar moment of inertia of fillet weld J [mm⁴, in⁴]*



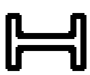
$$J = a \cdot \left(\frac{H^3 + B^3}{6} + \frac{B \cdot H^2}{2} \right)$$



$$J = a \cdot \left(\frac{H^3 + 2 \cdot B^3}{6} + B \cdot H^2 \right)$$



$$J = a \cdot \left(\frac{H^3 + B^3}{6} + \frac{H \cdot B^2}{2} \right)$$

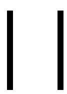
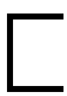
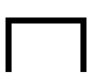
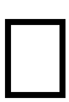
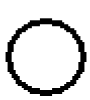


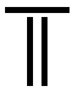
$$J = a \cdot \left(\frac{B^3 + 2 \cdot H^3 - s^3}{6} + H \cdot B^2 + \frac{B \cdot s^2 - s \cdot B^2}{2} - 2 \cdot (H - \right.$$

Meaning of used variables:

a fillet weld height [mm, in]
B width of weld group [mm, in]
H height of weld group [mm, in]
L weld length [mm, in]
r weld radius [mm, in]
s web thickness [mm, in]
t flange thickness [mm, in]

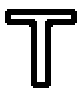
Moment of inertia for fillet weld

Weld design	*Moment of inertia of fillet weld J [mm ^{4}, in ^{4}]*	*Position of center of gravity of weld group section*
	$I = a \cdot \frac{L^3}{12}$	$\overline{Y} = \frac{L}{2}$
	$I = a \cdot \frac{H^3}{6}$	$\overline{Y} = \frac{H}{2}$
	$I = a \cdot \frac{B \cdot H^2}{2}$	$\overline{Y} = \frac{H}{2}$
	$I = a \cdot \frac{(6 \cdot B + H) \cdot H^2}{12}$	$\overline{Y} = \frac{H}{2}$
	$I = a \cdot \left(\frac{2 \cdot H^3}{3} - 2 \cdot \overline{Y} \cdot H^2 + (B + 2 \cdot H) \cdot \overline{Y}^2 \right)$	$\overline{Y} = \frac{H^2}{2 \cdot H + B}$
	$I = a \cdot \frac{(3 \cdot B + H) \cdot H^2}{6}$	$\overline{Y} = \frac{H}{2}$
	$J = \pi a (r + a / 2)^3$	-



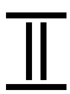
$$I = a \cdot \left(\frac{2 \cdot H^3}{3} - 2 \cdot \bar{Y} \cdot H^2 + (B + 2 \cdot H) \cdot \bar{Y}^2 \right) \qquad \bar{Y} = \frac{H^2}{2 \cdot (H + B)}$$

$$\bar{Y} = \frac{H^2}{2 \cdot H + B} \qquad \bar{Y} = \frac{H^2 - t^2}{2 \cdot H + B - 2 \cdot t}$$



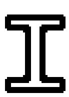
$$I = a \cdot \left(\frac{2 \cdot H^3}{3} - 2 \cdot \bar{Y} \cdot H^2 + 2 \cdot (B + H) \cdot \bar{Y}^2 \right) \qquad \bar{Y} = \frac{H^2}{2 \cdot (H + B)}$$

$$I = a \cdot \left(\frac{2 \cdot H^3}{3} - 2 \cdot \bar{Y} \cdot H^2 + 2 \cdot (B + H) \cdot \bar{Y}^2 - B \cdot t \cdot (2 \cdot \bar{Y} - t) \right) \qquad \bar{Y} = \frac{H^2 + B \cdot t}{2 \cdot (H + B)}$$



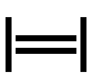
$$I = a \cdot \frac{(3 \cdot B + H) \cdot H^2}{6}$$

$$I = a \cdot \left(\frac{(H - 2 \cdot t)^3}{6} + \frac{B \cdot H^2}{2} \right) \qquad \bar{Y} = \frac{H}{2}$$



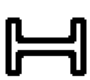
$$I = a \cdot \left(\frac{H^3}{6} + B \cdot H^2 \right)$$

$$I = a \cdot \left(\frac{H^3}{6} + B \cdot H^2 - \frac{s \cdot H^2}{2} - 2 \cdot H \cdot t \cdot (B - s) + 2 \cdot t^2 \cdot (B - s) \right) \qquad \bar{Y} = \frac{H}{2}$$



$$I = a \cdot \frac{H^3}{6}$$

$$I = a \cdot \left(\frac{H^3}{6} + \frac{(B - 2 \cdot t) \cdot s^2}{2} \right) \qquad \bar{Y} = \frac{H}{2}$$



$$I = a \cdot \frac{H^3}{3} \qquad \bar{Y} = \frac{H}{2}$$

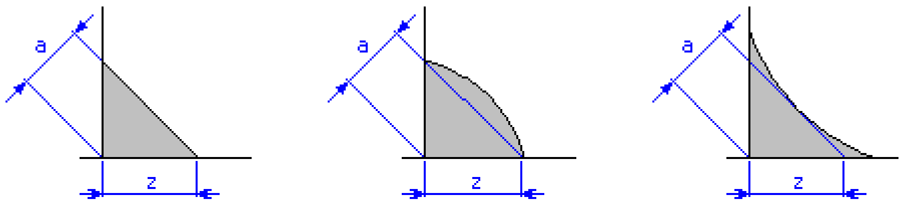
$$I = a \cdot \left(\frac{H^3}{3} + \frac{B \cdot s^2}{2} - \frac{s^3}{6} \right)$$

Meaning of used variables:

a fillet weld height [mm, in]
B width of weld group [mm, in]
H height of weld group [mm, in]
L weld length [mm, in]
r weld radius [mm, in]
s web thickness [mm, in]
t flange thickness [mm, in]

Active height of fillet weld

The active height (thickness) of a fillet weld is specified by the height of the biggest isosceles triangle inscribed into the weld section without penetration. The following image illustrates different weld designs.

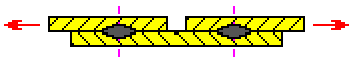


The size of fillet weld height approximately specifies the = 0.7 formula, where z is the fillet weld width. Minimum fillet weld height is selected according to the thickness of the thicker welded part and according to the material. The following table presents the values of the recommended minimum fillet weld height.

Thickness of welded part [mm]		*Minimum thickness of fillet weld a [mm] for steels of the strength series*	
over	up to	370 and 420 MPa	520 MPa
-	10	3	4
10	20	4	5
20	30	6	7
30	50	7	9
50	-	9	10

Formulas for calculating spot (resistance) welds

One-shear joint loaded with shear



Shear loading of a point

$$\tau_1 = \frac{4 \cdot F}{i \cdot \pi \cdot d^2} \qquad \text{[MPa,psi]}$$

Tear loading of a point along the cylindrical surface

$$\tau_2 = \frac{F}{i \cdot \pi \cdot d \cdot s} \qquad \text{[MPa,psi]}$$

Comparative stress

$$\sigma_S = \max\left\langle \frac{\tau_1}{\alpha}, \frac{\tau_2}{\alpha} \right\rangle \qquad \text{[MPa,psi]}$$

Meaning of used variables

F acting force [N, lb]

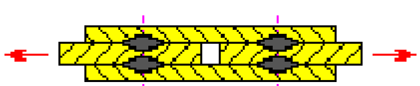
d diameter of spot weld [mm, in]

i number of welds [-]

s plate thickness [mm, in]

α conversion factor of weld joint [-]

Double-shear joint loaded with shear



Shear loading of a point

$$\tau_1 = \frac{2 \cdot F}{i \cdot \pi \cdot d^2} \qquad \text{[MPa,psi]}$$

Tear loading of a point along the cylindrical surface

$$\tau_2 = \frac{F}{2 \cdot i \cdot \pi \cdot d \cdot s} \qquad \text{[MPa,psi]}$$

Comparative stress

$$\sigma_S = \max\left\langle \frac{\tau_1}{\alpha}, \frac{\tau_2}{\alpha} \right\rangle \qquad \text{[MPa,psi]}$$

Meaning of used variables

F acting force [N, lb]

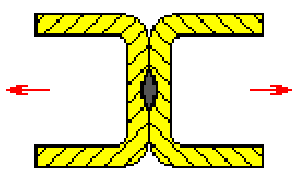
d diameter of spot weld [mm, in]

i number of welds [-]

s plate thickness [mm, in]

α conversion factor of weld joint [-]

Spot weld joint loaded with tear-off



Tear-off loading of a point

$$\tau = \frac{4 \cdot F}{i \cdot \pi \cdot d^2} \qquad \text{[MPa,psi]}$$

Comparative stress

$$\sigma_S = \frac{\tau}{\alpha} \qquad \text{[MPa,psi]}$$

Meaning of used variables

F acting force [N, lb]

d diameter of spot weld [mm, in]

i number of welds [-]

s plate thickness [mm, in]

α conversion factor of weld joint [-]

Formulas for calculating plug welds

Comparative stress for all types of plug and spot welds

$$\sigma_S = \max\left\langle \frac{\tau_Z}{\alpha}, \frac{\tau_O}{\alpha} \right\rangle \qquad [MPa, psi]$$

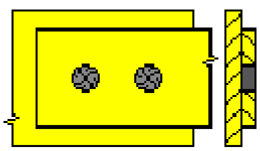
where:

τ_Z shear stress in the weld base area [MPa, psi]

τ_0 shear stress in the weld peripheral area [MPa, psi]

α conversion factor of weld joint [-]

Plug weld - perpendicular



Shear stress in the weld base area

$$\tau_Z = \frac{F}{0.5 \cdot d^2 \cdot i} \qquad [MPa, psi]$$

Shear stress in the weld peripheral area

$$\tau_O = \frac{F}{2.2 \cdot d \cdot s \cdot i} \qquad [MPa, psi]$$

where:

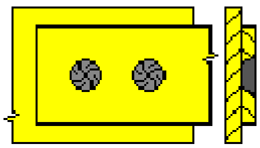
Facting force [N, lb]

ddiameter of plug weld [mm, in]

i number of welds [-]

s plate thickness [mm, in]

Plug weld - with bevel



Shear stress in the weld base area

$$\tau_Z = \frac{F}{0.8 \cdot d^2 \cdot i} \qquad [MPa, psi]$$

Shear stress in the weld peripheral area

$$\tau_O = \frac{F}{3.1 \cdot d \cdot s \cdot i} \qquad [MPa, psi]$$

where:

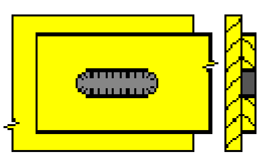
Facting force [N, lb]

d diameter of plug weld [mm, in]

i number of welds [-]

s plate thickness [mm, in]

Groove weld - perpendicular



Shear stress in the weld base area

$$\tau_Z = \frac{F}{0.7 \cdot b \cdot L \cdot i} \qquad [MPa, psi]$$

Shear stress in the weld peripheral area

$$\tau_0 = \frac{F}{1.4 \cdot s \cdot L \cdot i} \qquad [MPa, psi]$$

where:

Facting force [N, lb]

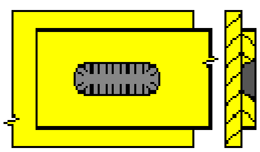
b groove weld width [mm, in]

Lgroove weld length [mm, in]

i number of welds [-]

s plate thickness [mm, in]

Groove weld - with bevel



Shear stress in the weld base area

$$\tau_Z = \frac{F}{b \cdot L \cdot i} \qquad [MPa, psi]$$

Shear stress in the weld peripheral area

$$\tau_0 = \frac{F}{2 \cdot s \cdot L \cdot i} \qquad [MPa, psi]$$

Meaning of used variables:

F acting force [N, lb]
d diameter of plug weld [mm, in]
b groove weld width [mm, in]
L groove weld length [mm, in]
i number of welds [-]
s plate thickness [mm, in]
τ_Z shear stress in the weld base area [MPa, psi]
τ_0 shear stress in the weld peripheral area [MPa, psi]
α conversion factor of weld joint [-]

Fatigue strength of weld joint

Conventional check procedures at fatigue loaded weld joints (based on the ultimate or yield strength of material) do not provide sufficient guarantee of safe joint design, so the fatigue strength of joints is used to check fatigue loaded joints.

1. Specifying an endurance limit

In the first step the calculation determines the endurance limit at constant strength σ_e or τ_e for the specified type, design, loading, and material of weld joint.

2. Specifying finite-life fatigue limit

The finite-life fatigue limit σ_f or τ_f is calculated for the specified joint life that is in the ($N < 10^6$ cycles) range of timed strength. Calculation continues with this finite-life fatigue limit.

3. Calculation of parameters of particular fatigue loadings

Mean values for given upper and lower cycle loadings are calculated their mean values according to the following formulas. It is done for all specified loadings.

$$F_m = \frac{F_h + F_n}{2},\ F_a = \frac{F_h - F_n}{2}$$

$$M_m = \frac{M_h + M_n}{2},\ M_a = \frac{M_h - M_n}{2}$$

4. Effect of strokes

If strokes effect the joint besides the fatigue loading, their influence must be included into the calculation. This calculation is implemented by using the dynamic stroke factor in the formula for determining the maximum calculated loading:

$F_{max} = F_m + \eta\, F_a$ or $M_{max} = M_m + \eta\, M_a$

5. Calculation of actuating stress in the weld joint

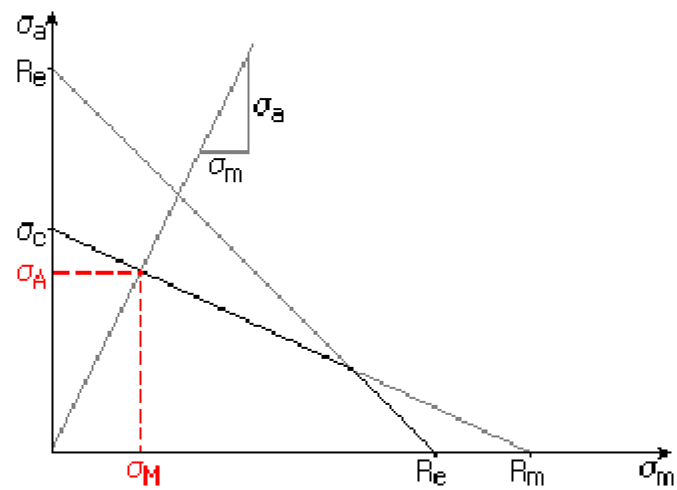
Mean cycle stress σ_m or τ_m and upper cycle stress σ_h or τ_h are calculated for the specified mean cycle loading F_m, M_m and maximum calculated loading F_{max}, M_{max} with the formulas used in static calculation. These stresses are used for calculation of cycle amplitude according to the formula:

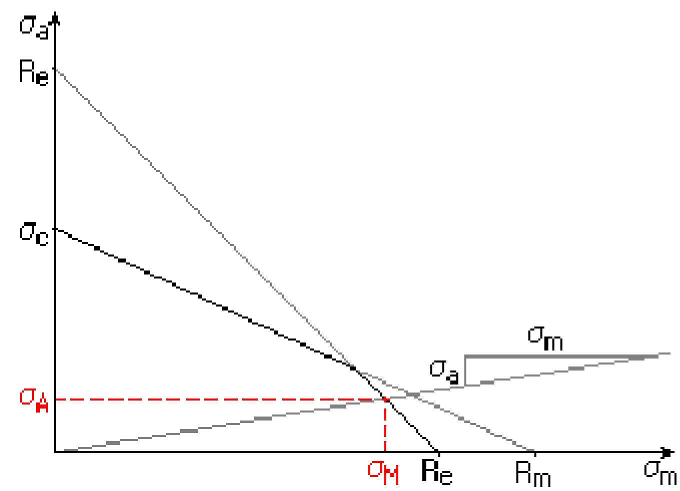
$\sigma_a = \sigma_h - \sigma_m$ or $\tau_a = \tau_h - \tau_m$

6. Specifying fatigue strength of joint

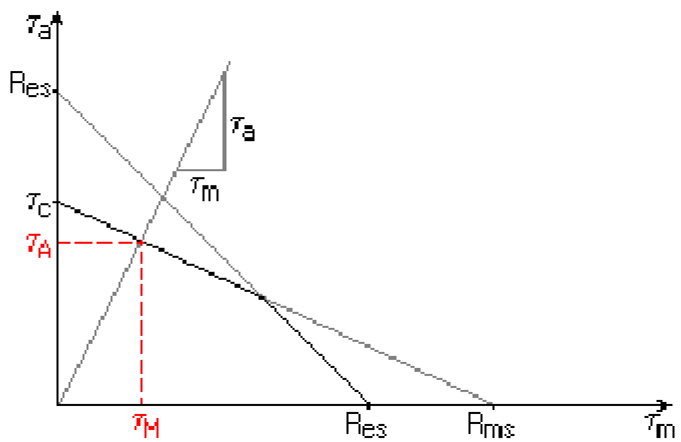
For calculated stress and known endurance limit, the resulting strength of fatigue joint is easily determined according to the selected fatigue curve. The procedure of fatigue strength determination for both normal and shear stresses is obvious from the following pictures.

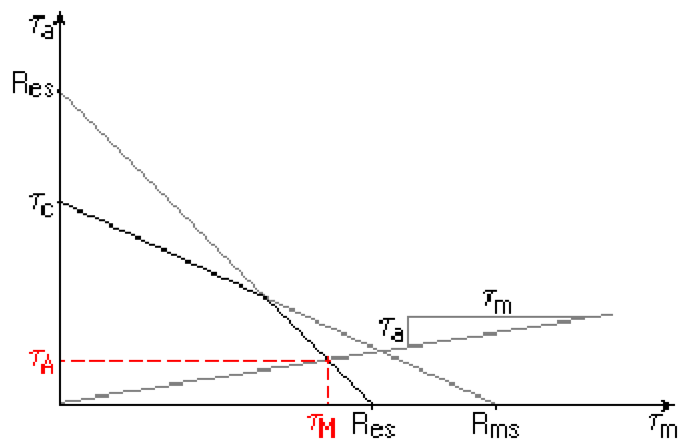
Haigh charts of normal stress for different σ_a / σ_m ratio (modified Godman fatigue curve is used):





Haigh charts of normal stress for different τ_a / τ_m ratio (modified Godman fatigue curve is used):





7. Joint check

In the last step the program calculates the joint safety factor $n_C = \sigma_A / \sigma_a$ and compares it with the required safety degree. For convenient weld joint, the condition $n_f \leq n_C$ must be satisfied.

Endurance limits for weld joints

Corrected endurance limit at the constant strength σ_e or τ_e of the bolted connection is determined for the selected type, design, material, and joint loading from the formula:

$\sigma_e = \sigma'_e k_a k_b k_c k_d k_e k_f$ [MPa, psi]

where:

σ'_e basic endurance limit of a test bar from the selected material [MPa, psi].

k_a surface factor [-].

k_b size factor [-].

k_c reliability factor [-].

k_d operation temperature factor [-].

k_e modified factor of stress concentration [-].

k_f factor of miscellaneous effects [-].

1. Basic endurance limit σ'_e

If you do not have available results of material tests of the selected weld joint material and do not know the exact value of basic endurance limit, you can estimate its value. The calculation designs the basic endurance limit using the following empirical formulas:

$\sigma'_e \approx 0.5\ S_U$ - for reversed bending

$\sigma'_e \approx 0.4\ S_U$ - for reversed traction - pressure

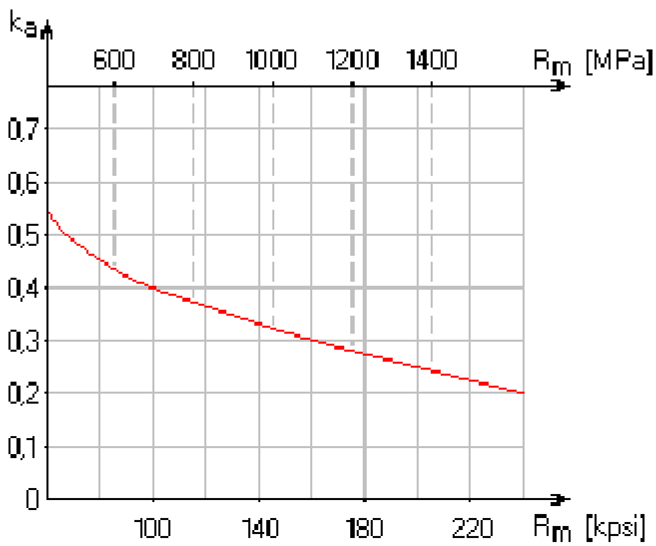
$\sigma'_e \approx 0.28\ S_U$ - for reversed torsion (shear)

S_u ultimate tensile strength [MPa, psi]

2. Surface factor k_a

To describe the dependence of endurance limit on the surface quality, the fatigue strength of fatigue loaded part increases with the increasing surface quality. This effect is more distinctive for the high quality materials. Use experimental curves to describe the effect of surface quality on the endurance limit according to material strength and for variously machined surface.

The following curve for standard quality weld joints is used for the ka factor determination.



3. Size factor k $_b$

The joint size has no effect on the fatigue strength at weld joints loaded with reversed traction - pressure. Therefore, the size factor for this type of loading is $k_b = 1$.

When the joint is loaded with reversed bending or torsion (shear), the joint size can substantially affect its fatigue strength. The strength reduces when joint dimensions increase.

Determination of exact relation of weld size to the joint fatigue strength can only be done by intricate experimental fatigue tests of the specified weld joint. It is practically impossible. Therefore, a simplified theoretic procedure was worked out. The procedure originates from experimental fatigue tests made at smooth test bars of different diameters. This procedure estimates the approximate size of k_b factor according to the theory that the corresponding virtual comparative diameter of test bar can be assigned for the particular weld section.

The following are the calculation formulas for the k_b factor determination.

$$k_b = 0.869 \cdot \bar{d}^{-0.097}$$ - English units

$$k_b = 1.189 \cdot \bar{d}^{-0.097}$$ - metric units

while the following must be followed:

$k_b \geq 0.6$

$k_b = 1$ for

$\bar{d} < 0.3$ [in], $\bar{d} < 8$ [mm]

where a formula is used for calculation of virtual comparative diameter:

$$\bar{d} \approx \sqrt{\frac{0.06 \cdot A}{0.0766}}$$

4. Reliability factor k_c

This factor expresses the influence of required joint reliability in operation to the value of fatigue strength. The factor value is in the<0.5 ... 1> range and the factor is reduced when a requirement for reliability grows. The $k_c = 1$ value corresponds with the 50percent reliability, that is the 50 percent probability of failure of a weld joint loaded with specified fatigue loading.

In common mechanical praxis, the 95 percent reliability of mechanical parts is usual. If a joint failure can threaten human lives or cause substantial financial losses, the weld joint must be designed for greater reliability.

5. Operating temperature factor k_d

The effect of operation temperature on the endurance limit substantially depends on the properties of used material. Commonly used structural steels working in the approximate range of -20 to 200°C do not have the endurance limit much dependent on the temperature and the $k_d = 1$ factor can be used.

Design that considers fatigue failure at high temperatures is a complex problem, because generally the interactions of creep, fatigue and metallurgical instabilities occur. Theoretic information describing this problem are not complete and sufficient. Use the results of experimental tests for good determination of k_d factor.

6. Modified factor of stress concentration k_e

High local stress concentrations originate in a joint when the weld joint is fatigue loaded because of weld notch effect. These concentrations considerably reduce the joint fatigue strength. Modified factor of stress concentration is determined from the $k_e = 1/K$ formula, where the fatigue-strength reduction factor K depends on the weld type, shape, design, weld quality, and the weld joint loading. The following are the recommended values of stress concentration factor for the selected weld types and weld loadings.

Weld type, method of loading	*K*
Butt end weld loaded with bend and traction - pressure	1.2
Butt end weld loaded with torsion (shear)	1.8
T-joint with double-sided butt weld	2.0
Fillet weld with loading perpendicular	1.5
Fillet weld with loading parallel to the weld axis	2.7

When considering the arousal of local stress concentrations, the most hazardous parts of weld joint are transitions between the weld and the basic material. For this reason, take care to use a suitable weld design and perfect machining of transition faces if the weld joints are fatigue loaded. Badly welded root of butt weld or unwedded gap in the root of fillet weld have unfavorable influence on the weld fatigue life. Consider the quality of weld design when setting a factor of stress concentration size.

7. Factor of miscellaneous effects k_f

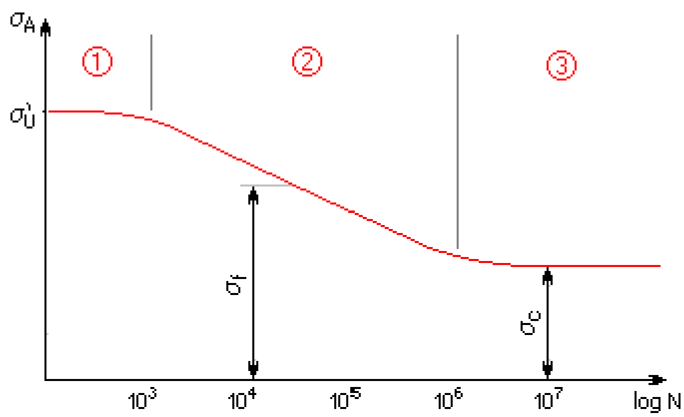
All other effects that can reduce or increase the fatigue strength of weld joint (the influence of corrosion, for example) are included in this factor.

Endurance limit in the scope of timed strength

Consider required joint life you determine fatigue strength of weld joints. The joint strength can be divided into three distinctive areas according to the number of cycles:

- Area of low-cycle strength (for $N \le 10^3$ cycles approximately) - joint strength is roughly constant, independent on cycles, static calculation is sufficient for check of the joint.
- Area of timed strength (for $10^4 \le N \le 10^6$ cycles approximately) - joint strength decreases when the cycle number increases.
- Area of permanent strength (for $N > 10^6$ cycles approximately) - joint strength is again roughly constant, the endurance limit se or te is used for determining the fatigue strength of joint.

Dependence of joint fatigue strength σ_A or τ_A on the number of cycles N for symmetrical reversed loading is displayed in the following image:



If the weld joint is calculated on the condition of finite life in the area of timed strength, the finite-life fatigue limit σ_f or τ_f must be known for determining the joint strength. An empirical formula $\sigma_f = 10^Y N_X$ is used for calculation of this limit if the endurance limit se is known. Exponents are calculated according to:

$$X = -\frac{1}{3} \cdot \log\left(\frac{\sigma'_U}{\sigma_e}\right)$$

$$Y = \log\left(\frac{\sigma'^2_U}{\sigma_e}\right)$$

while:

$\sigma'_U \approx 0.9\ S_U$ - for reversed bending
$\sigma'_U \approx 0.75\ S_U$ - for traction - pressure
$\sigma'_U \approx 0.72\ S_U$ - for reversed torsion (shear)

Fatigue curves

Different types of fatigue curves can be used for determining the fatigue strength of weld joints. The following are formulas for individual curves of normal and shear stress.

1. Method of virtual mean stress

$$\left(\frac{\sigma_a}{\sigma_e}\right) + \left(\frac{\sigma_m}{\sigma_F}\right) = 1, \qquad \left(\frac{\tau_a}{\tau_e}\right) + \left(\frac{\tau_m}{\tau_F}\right) = 1$$

where:

σ_a, τ_a amplitude of normal (shear) stress [MPa, psi].

σ_e, τ_e endurance limit at the constant strength [MPa, psi]

σ_m, τ_m mean cycle stress [MPa, psi].

virtual mean stress [MPa, psi]

σ_F, τ_F $\sigma_F = \frac{\sigma_e}{\psi}, \tau_F = \frac{\tau_e}{\psi}$

Ψ factor of Haigh diagram narrowing [-]

depends on the joint material - recommended values - for traction and bending Ψ<0.15...0.3>

- for shear Ψ <0.1...0.25>.

2. Modified Godman method

$$\left(\frac{\sigma_a}{\sigma_e}\right) + \left(\frac{\sigma_m}{S_u}\right) = 1, \qquad \left(\frac{\tau_a}{\tau_e}\right) + \left(\frac{\tau_m}{S_{us}}\right) = 1$$

where:

σ_a, τ_a amplitude of normal (shear) stress [MPa, psi].

σ_e, τ_e endurance limit at the constant strength [MPa, psi]

σ_m, τ_m mean cycle stress [MPa, psi].

S_U ultimate tensile strength [MPa, psi]

S_{US} ultimate shear strength [MPa, psi]

while $S_{US} \approx 0.8\ S_U$

3. Quadratic (Elliptic) method

$$\left(\frac{\sigma_a}{\sigma_e}\right)^2 + \left(\frac{\sigma_m}{S_U}\right)^2 = 1, \qquad \left(\frac{\tau_a}{\tau_e}\right)^2 + \left(\frac{\tau_m}{S_{US}}\right)^2 = 1$$

for explanation of variables see the item 2 - Modified Godman method

4. Gerber parabolic method

$$\left(\frac{\sigma_a}{\sigma_e}\right) + \left(\frac{\sigma_m}{S_U}\right)^2 = 1, \qquad \left(\frac{\tau_a}{\tau_e}\right) + \left(\frac{\tau_m}{S_{US}}\right)^2 = 1$$

for explanation of variables see the item 2 - Modified Godman method

5. Method by Keccecioglu, Chester, and Dodge

$$\left(\frac{\sigma_a}{\sigma_e}\right)^a + \left(\frac{\sigma_m}{S_U}\right)^2 = 1, \qquad \left(\frac{\tau_a}{\tau_e}\right)^a + \left(\frac{\tau_m}{S_{US}}\right)^2 = 1$$

where:

σ_a, τ_a amplitude of normal (shear) stress [MPa, psi].

σ_e, τ_e endurance limit at the constant strength [MPa, psi]

σ_m, τ_m mean cycle stress [MPa, psi].

S_U ultimate tensile strength [MPa, psi]

S_{US} ultimate shear strength [MPa, psi]

while $S_{US} \approx 0.8\ S_U$

a exponent depending on the joint material [-]

recommended values a <2.6...2.75>

6. Method by Bagci

$$\left(\frac{\sigma_a}{\sigma_e}\right) + \left(\frac{\sigma_m}{S_Y}\right)^4 = 1, \qquad \left(\frac{\tau_a}{\tau_e}\right) + \left(\frac{\tau_m}{S_{YS}}\right)^4 = 1$$

where:

σ_a , τ_a amplitude of normal (shear) stress [MPa, psi].

σ_e , τ_e endurance limit at the constant strength [MPa, psi]

σ_m , τ_m mean cycle stress [MPa, psi].

S_Y yield tensile strength [MPa, psi]

S_{YS} yield shear strength [MPa, psi]

while $S_{YS} \approx 0.577\ S_Y$

7. Soderberg Method

$$\left(\frac{\sigma_a}{\sigma_e}\right) + \left(\frac{\sigma_m}{S_Y}\right) = 1, \qquad \left(\frac{\tau_a}{\tau_e}\right) + \left(\frac{\tau_m}{S_{YS}}\right) = 1$$

for explanation of variables see the item 6 - Method by Bagci

Safety factor of statically loaded weld joint

Required minimum safety factor of weld joint during static loading n_s represents a ratio of allowable stress and the yield strength of joint material $n_S = S_Y / \sigma_{Al}$ or $n_S = S_Y / \tau_{Al}$.

Required safety of weld joint is affected by method and quality of weld design (shape and machining of the weld surface, weld reinforcement, weld homogeneity, penetrations, and so on), operation conditions, requirements for joint reliability, and potential threat to human life at weld breaking. Many other effects must be considered when setting its value.

Calculation procedures do not consider possible sudden brittle fractures and change of material mechanical values due to the temperature and residual stress. Only the nominal stress is set by the calculation in a certain section for given loading. Stress concentrations and internal stresses are not considered. Consider all these facts when you are setting a required minimum joint safety.

Used calculation method must be considered when specifying the safety factor. Both calculation methods of statically loaded welds solve the weld safety in a different manner.

Standard calculation procedure

The allowable weld loading is compared directly with the calculated normal, shear, or resulting reduced stress to find whether the weld is satisfactory. This comparison is made according to the weld type and design and the way of loading. It is obvious that the required weld safety depends on the type and direction of stress that arises in the weld joint. It is also necessary to specify different safety factors for different type, shape, and design of welds and for various load combinations. Informative values of recommended minimum safety factor values for different weld types are presented in the following table.

Weld type, loading	n_S
Butt welds loaded with traction	1.6 ... 2.2
Butt welds loaded with bend	1.5 ... 2.0
Butt welds loaded with shear	2.0 ... 3.0
Butt welds loaded with loading	1.4 ... 2.7
Fillet welds loaded in the plane of joining the part	2.0 ... 3.0
Fillet welds loaded spatially	1.4 ... 2.7
Plug and groove welds	2.0 ... 3.0
Plug (resistant) welds loaded with shear	1.6 ... 2.2
Plug (resistant) welds loaded with tearing	2.5 ... 3.3

Method of comparative stresses

Compares allowable weld loading with the auxiliary comparative stress. This comparative stress is obtained from calculated partial stresses by means of conversion factors of weld joint. The effects of different types of stresses, which arise in weld joint, to safety of weld joint, are considered in the safety factor. You need only one common safety factor for any type, shape, and design of weld and arbitrary combination of loading. The recommended minimum value of safety factor is given in the n_S =<1.25...2> range.

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