Hitsien taloudellinen mitoitus perusaineen kestävyyden mukaan

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26.8.2021 Heikki Holopainen

Sumitomo SHI FW

Abstrakti

- On helppoa tehdä hitsien mitoitus ylimalkaisesti määrityksellä ”tasalujat hitsit”. Käytännössä tämä voi onnistua kuitenkin vain läpihitsattujen liitosten tapauksessa. Läpihitsatut liitokset eivät yleensä ole taloudellisin ratkaisu. On toki paljon tapauksia, joissa läpihitsaus puoltaa paikkansa, mutta suurin osa hitseistä kannattaa toteuttaa muutoin, esim. pienoilla. **On erittäin epätodennäköistä, että suunnitelmalla ”tasalujat hitsit” syntyy oikean kokoiset pienat**.

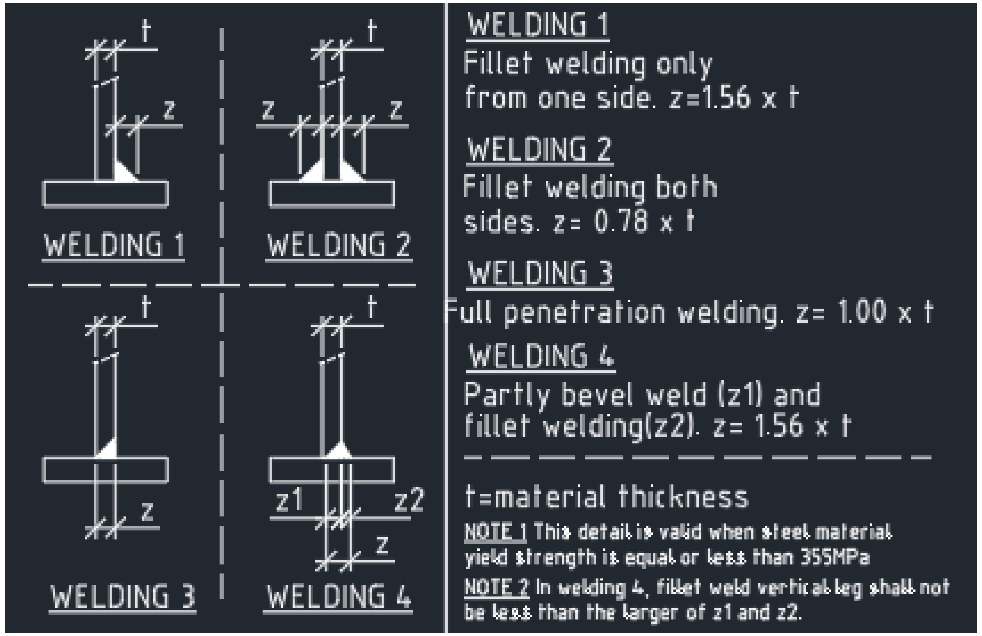
- Vain rakennesuunnittelijalla on hyvät mahdollisuudet tietää kunkin hitsin lujuustekninen olemassaolon tarkoitus siihen liittyvine kuormituksen suuntineen. **Eri suuntaisille kuormille myös taloudellisen hitsin tyyppi ja koko poikkeavat toisistaan**. Jopa a-mitan määritelmä on osittain puutteellinen taloudellisimman lopputuloksen tavoittelussa. Vaikka suunnittelunormi antaa a-mitalle määritelmän, se ei sulje pois suunnittelijan itse määrittämän poikkileikkauksen mahdollisuutta. Tällä tavalla **avautuu uusia taloudellisuuden mahdollisuuksia, vaikka tarvitaankin tavallista enemmän suunnittelutunteja**.

- **Hitsien neliöjuuriluokittelu** tarjoaa helpon pääsyn optimaalisimman hitsikoon tavoitteluun. Menetelmän avulla tunnistetaan ensin hitsin tarkoitus välittää tietyn suuntaista voimaa. Sen jälkeen **hitsille saadaan taloudellinen koko joko voiman tai perusaineen kestävyyden mukaan**.

- Hitsien mitoitusstandardeissa on kuitenkin puutteita ja tulkinnanvaraisuuksia. Esimerkiksi Eurocoden EN 1993-1-8 tulkinnasta riippuen hitsille voidaan saada erilaisia mittoja. Tulkinnanvaraa on erityisesti yhdeltä puolelta toteutettujen hitsien tapauksissa. Vaikka yleensä on suositeltavaa toteuttaa hitsit molemmilta puolilta hitsattuina, **on paljon tapauksia, joissa yhdeltä puolelta hitsaaminen on joko väistämätöntä tai riittävää**.

Equal Strength Welds

Load Bearing Joints



- The following kind of details are usually applicable:
  - For all force directions
  - Vertical tension is the governing direction
- For single side PJP, it may be necessary to increase weld size, if plate rotation isn't restrained by other parts of the same joint
  - EN 1993-1-8 chapter 4.12
- Although the welds would be sized as equally strong with the attached parts, the base metal itself may be necessary to stiffen in joint areas
  - EN 1993-1-8 chapters 4.10 and 7
  - AISC 360-16 chapter "K. Additional Requirements for HSS and Box-section Connections"
- Usual BeamFEA calculations do not apply on joint areas at all

CJP = Complete Joint Penetration

PJP = Partial Joint Penetration

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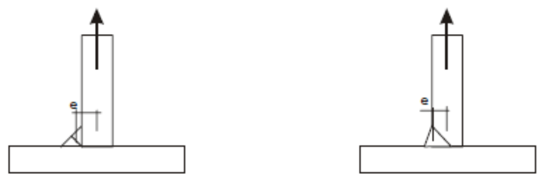
Equal Strength Welds

Hollow Structural Sections (HSS, RHS, CHS)

EN 1993-1-8 Figure 4.9:



(b) Tensile force produces tension at the root of the weld

- Hollow sections are normally welded with one side fillet weld or PJP
- As obvious, there isn't only single flange welded at the end of HSS, but all flanges are welded
- The neighboring flange restraints the rotation of plate otherwise producing tension at the root of the weld, see EN 1993-1-8, Figure 4.9(b). The phenomenon is the same for CHS (circular hollow sections)
- There are formulas in EN 1993-1-8 chapter 7 for HSS joints
  - Formulas are based on yield line theory with assumption of equal strength welds
- The welds should be sized as equal strength weld for axial load in the flanges
  - See EN 1993-1-8 clause 7.3.1(4): "*The design resistance of the weld, per unit length of perimeter of a brace member, should not normally be less than the design resistance of the cross-section of that member per unit length of perimeter*"
  - There is possible release in clause 7.3.1(6) but it could be utilized only with shell or solid element models
- For S355 or lower strength, the size of fillet weld is usually adequate as $a = 1.1 \times s$

Capacity based sizing of welds

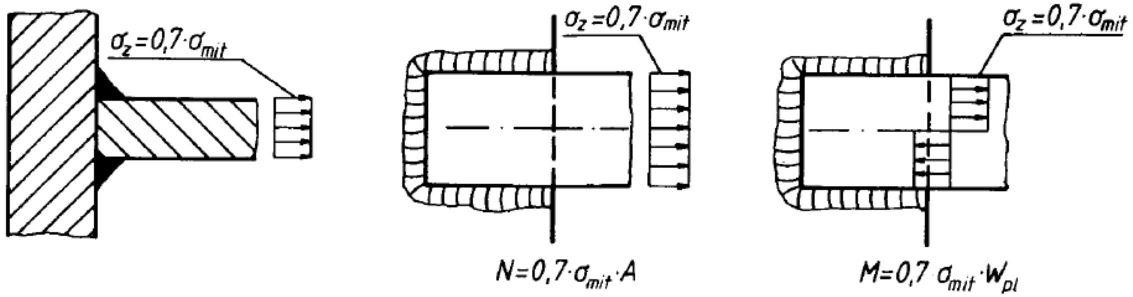
Three approaches

- It is not directly clear what is the criteria to size welds based on capacity of base metal
- The following approaches can be identified:
  A. Welds are sized to maintain plastic deformability
  B. Welds are sized to transfer as much load as base metal can be sized to transfer
  C. Welds are sized to transfer as much load as load path may transfer after excessive yielding
- The purpose of approach A is to make base metal to yield before rupture in weld
- The purpose of approach B is to fulfill A and to enable load independent weld sizing method
- The purpose of approach C is to make specified section in the load path to yield excessively before rupture anywhere in the load path

Approach A 1/2

Welds sized to maintain plastic deformability

- The purpose of approach A is to make base metal to yield before rupture in weld
- SFS 2373 specified that yield capacity of weld should be at least 70 % of yield capacity of base metal
  - SFS 2373 chapter 7.1, page 11:
  - ”Staattisesti määräämättömissä rakenteissa mitoitetaan hitsit vähintään niin lujiksi, että heikompi liitettävistä osista myötää ennen hitsin murtumista”
  - ”Kuvan 13 tapauksissa a) ja b) riittää muodonmuutoskyky, kun hitsit mitoitetaan oletetun vetojännityksen $\sigma_z = 0{,}7 \cdot \sigma_{mit}$ aiheuttamalle kuormitukselle”



Approach A 2/2

Welds sized to maintain plastic deformability

- The purpose of approach A is to make base metal to yield before rupture in weld
- ENV 1993-1-1 specified that rupture capacity of weld associated with gamma 1.25 should be at least 80 % of yield capacity of base metal associated with gamma 1.0:
  - SFS ENV 1993-1-1:1992 chapter 6.6.4, page 230:
  - ”(6) Muissa liitoksissa, joissa vaaditaan mahdollisen liiallisen venymisen ja liitoksen kiertymisen takia muodonmuutoskykyä, hitseiltä vaaditaan riittävää lujuutta, jotta ne eivät murru ennen viereisen perusmateriaalin yleistä myötäämistä”
  - ”(7) Yleensä tämä ehto täyttyy, jos hitsin kestävyyden mitoitusarvo on vähintään 80 % heikomman liitettävän osan kestävyyden mitoitusarvosta”
- In current Eurocodes, there isn’t anymore percentage criteria given

Approach C

Welds are sized to transfer as much load as load path may transfer after excessive yielding

- The purpose of approach C is to make specified section in the load path to yield excessively before rupture anywhere in the load path
- Approach C is necessary when excessive yielding must be able to happen without rupture
- This is necessary for example for earthquake loads if the structure is sized with dissipative concept
- In dissipative concept, the members are sized for much smaller loads compared to loads from design earthquake
- Small members can provide flexibility and better ultimate resistance for earthquakes once the details in load paths are sized with **expected** yield capacity of specified yielding section
- When the yielding location is selected, its expected capacity is calculated by multiplying its proof yield by factor like Ry specified in AISC 341. Eurocode 8 introduces similar factor but fails to give its magnitudes.
- The main purpose of Ry is to account for possible strength deviations in different raw materials
- It may not be necessary to apply Ry within the members of same melting of raw material from steel mill

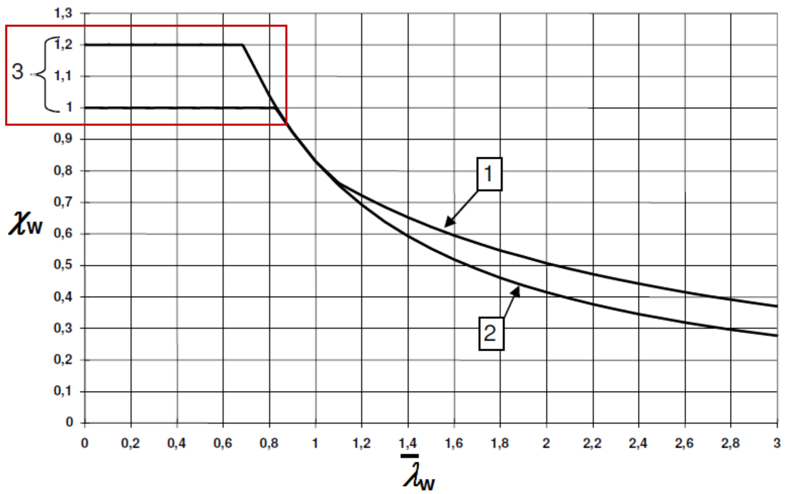
Approach B

Welds are sized to transfer as much load as base metal can be sized to transfer

- The purpose of approach B is to make base metal to yield before rupture in weld, and to enable load independent weld sizing method
- In load independent weld sizing method, the welds can be sized based on
  - Geometry
  - Materials
  - Directions of loads
- Actual loads in members are not necessary. Also directions may not be necessary, but then the design isn’t usually the most economical
- Approach B utilizes rupture strength of welds in two ways:
  - Strength of weld is based on rupture strength of base metal with γ_{M2} = 1.25
  - Strength of weld is increased with factor β_w
- It may be questionable to try more. In this presentation, all examples are with approach B

Base metal shear capacity

- It is necessary to make judgement for factor η that may be used to increase shear strength based on strain hardening
- Factor η is mentioned in EN 1993-1-1 clause 6.2.6(3). It's range is 1,0 – 1,2
- Figure 5.2 of Shear buckling factor χ_w in EN 1993-1-5:2006:



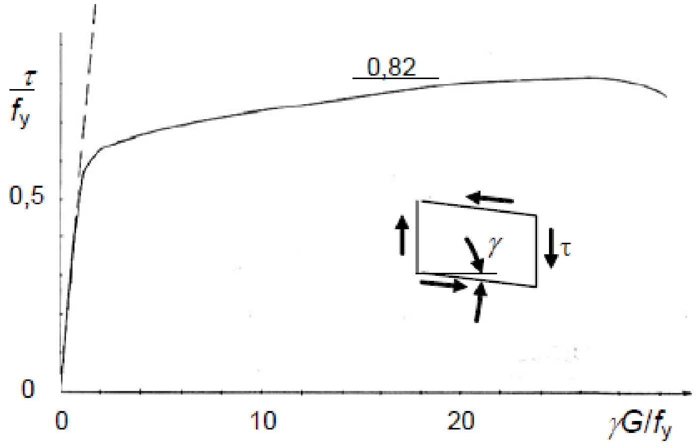
3 Range of recommended η

- Factor η is given only for webs whose shear capacity has contribution from flanges
- In this presentation, η is present also in cases that appear as individual plates. Real joints are usually with more plates.

Base metal shear capacity

Justification for factor *η*

- Extract from commentary[1] of EN 1993-1-5, chapter 5.2.1, page 62:
  - “The reasons why *η* can be taken larger than 1 may be explained as follows…One reason for this is strain hardening of steel, which can be utilized because it does not give excessive deformations”



- If the one who has selected base metal dimensions may have utilized *η*, this should be accounted for by the one who sizes the welds with approach B

1) Commentary and Worked Examples to EN 1993-1-5 “Plated Structural Elements”, can be downloaded freely in internet

Capacity based sizing of welds

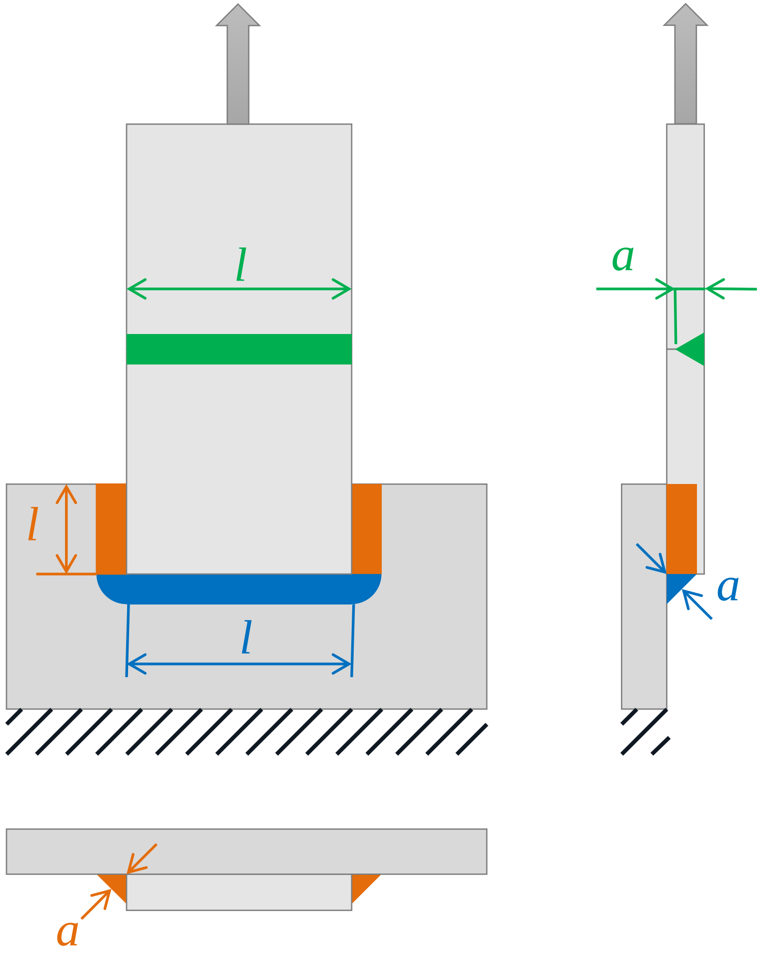
Square Root Classification of Welds

- There is need to classify welds according to directions they are designed to transfer loads
- Classification can be based on square root term in strength formula

Square root one welds $F_{w.Rd} = \Sigma al \cdot f_{yd.w} / \sqrt{1}$

Square root two welds $F_{w.Rd} = \Sigma al \cdot f_{yd.w} / \sqrt{2}$

Square root three welds $F_{w.Rd} = \Sigma al \cdot f_{yd.w} / \sqrt{3}$



$f_{yd.w} = f_u/(\beta_w \gamma_{M2})$ for √2- and √3-welds

$f_{yd.w} = 0.9 f_u/\gamma_{M2}$ for √1-welds (partial penetration)

Square Root Classification of Welds

Symbols

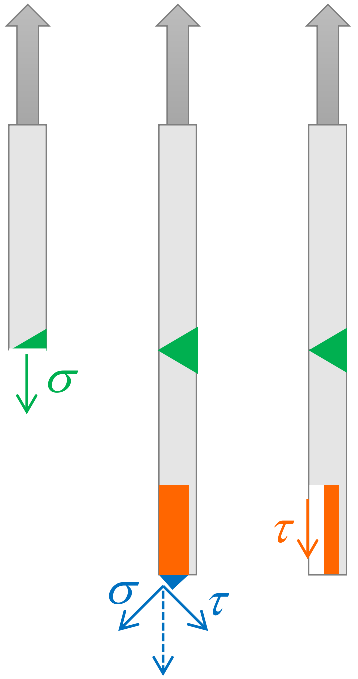
- Symbols are based on standard EN 1993-1-8: Eurocode 3: Design of steel structures. Part 1-8: Design of joints

a	weld effective throat thickness
f_u	ultimate tensile strength of parent metal (MPa)
f_y	yield strength of parent metal (MPa)
γ_{M0}	partial safety factor for parent metal
γ_{M2}	partial safety factor for welds
β_w	correlation factor for fillet welds, see EN 1993-1-8, table 4.1
$f_{yd.w}$	design yield strength of weld (MPa)
F_{Rd}	design resistance (kN)

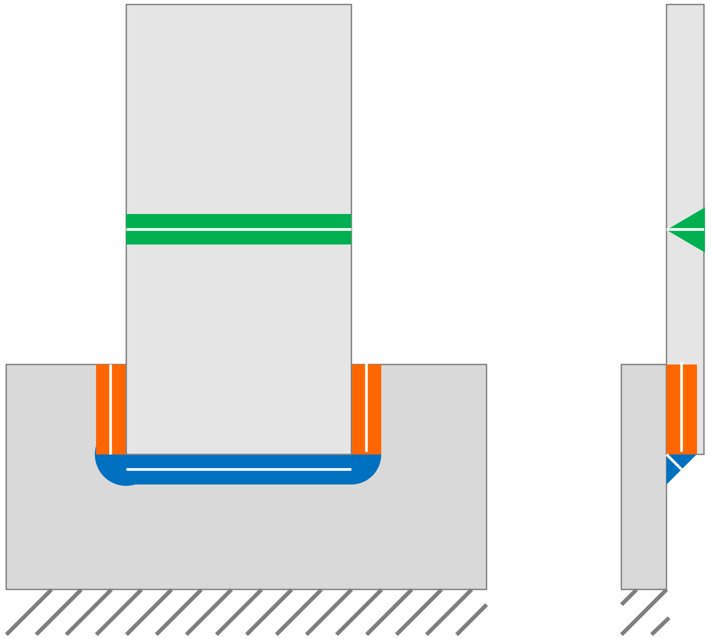
- Load factors are not discussed in this presentation. Generally maximum permissible load is F_{Rd} / 1.5 if the type of load case is not specified
- In examples, there isn't included overstrength factor that may be necessary in case of dissipative members for earthquake

How to classify

- Classification is based on primary stress type in weld throat
  - √1-weld: only normal stress σ
  - √2-weld: half-and-half normal stress σ and shear stress τ
  - √3-weld: only shear stress τ
- Stresses are used only for classification, not for calculations



weld throats are marked with white color



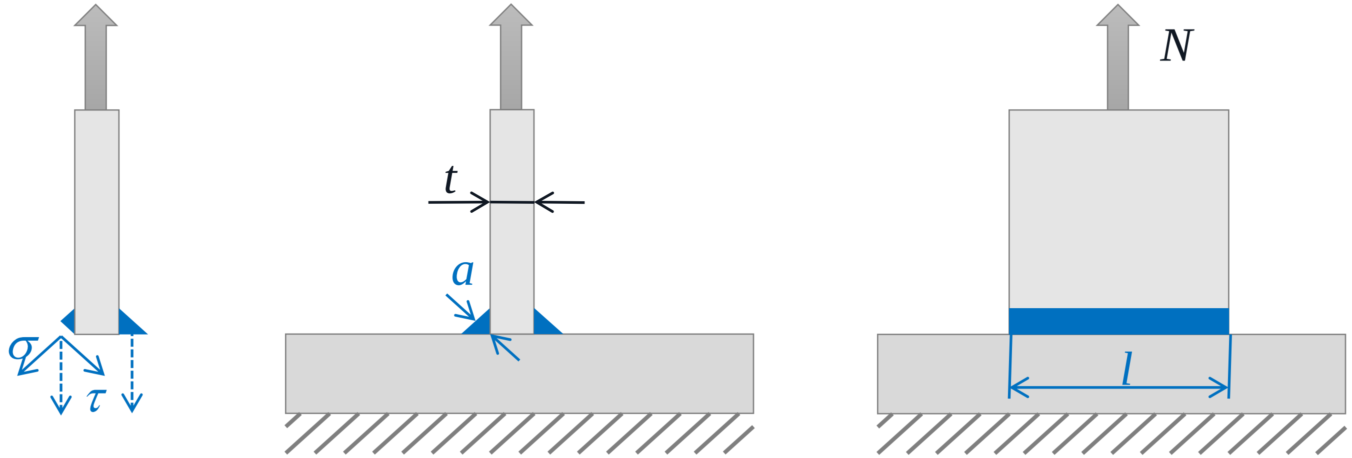
Calculation example of square root two weld

- Define throat thickness for equal strength weld, for which $F_{w.Rd} \geq N_{p.R}$ not utilizing γ_{M0}
- Strength of √2-weld $F_{w.Rd} = \Sigma\, al \cdot f_{yd.w} / \sqrt{2}$ $f_{yd.w} = f_u/(\beta_w \gamma_{M2})$
- Tensionstrength of plate $N_{p.R} = tl \cdot f_y$

$$2al \cdot f_u / (\beta_w \gamma_{M2}) / \sqrt{2} \geq tl \cdot f_y$$

$$a \geq \sqrt{2} \cdot f_y / f_u \cdot (\beta_w \gamma_{M2})\, t / 2$$

- For S355 $a \geq \sqrt{2} \cdot 355\text{MPa} / 510\text{MPa} \cdot (0.9 \cdot 1.25)\, t / 2$
  $a \geq 0.55t$



Calculation example of square root three weld

- Define throat thickness for equal strength weld, for which $F_{w.Rd} \geq V_{p.R}$ not utilizing γ_{M0}
- Strength of √3-weld $F_{w.Rd} = \Sigma\, al \cdot f_{yd.w} / \sqrt{3}$ $f_{yd.w} = f_u/(\beta_w \gamma_{M2})$
- Shear strength of plate $V_{p.R} = \eta \cdot tl \cdot f_y / \sqrt{3}$

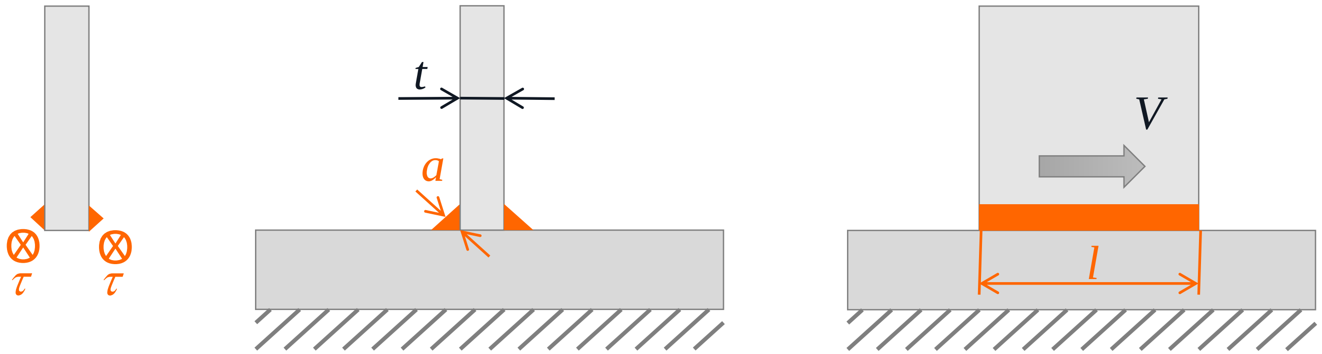
$$2al \cdot f_u / (\beta_w \gamma_{M2}) / \sqrt{3} \geq \eta \cdot tl \cdot f_y / \sqrt{3}$$

$$a \geq \eta \cdot f_y / f_u \cdot (\beta_w \gamma_{M2})\, t / 2$$

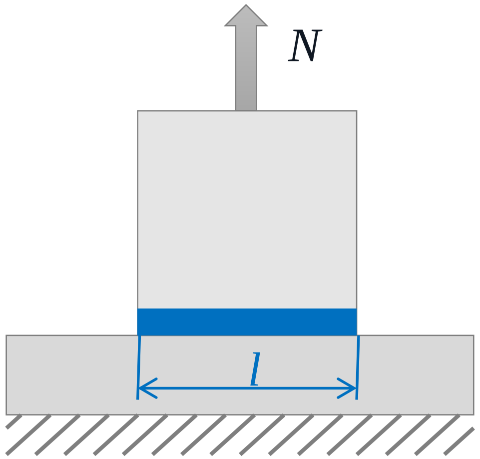
- For S355 $a \geq \eta \cdot 355\text{MPa} / 510\text{MPa} \cdot (0.9 \cdot 1.25)\, t / 2$

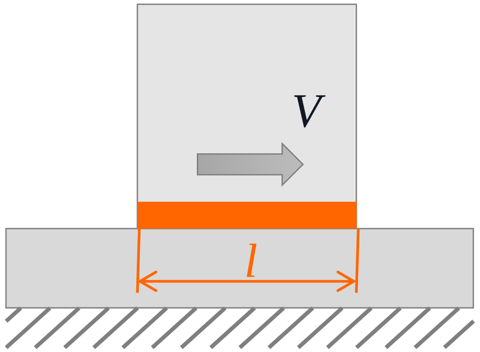
$$a \geq \eta \cdot 0.39t$$

Eurocode gives η only for webs whose shear capacity has contribution from flanges. This example is made with assumption that real 3D joints are usually with more plates than illustrated in 2D.



Summary of calculation examples





$a \geq \sqrt{2} \cdot f_y / f_u \cdot (\beta_w \gamma_{M2})\ t / 2$

$a \geq \sqrt{2} \cdot 355\text{MPa} / 510\text{MPa} \cdot (0.9 \cdot 1.25)\ t / 2$

$a \geq 0.55t$

$a \geq \eta \cdot f_y / f_u \cdot (\beta_w \gamma_{M2})\ t / 2$

$a \geq \eta \cdot 355\text{MPa} / 510\text{MPa} \cdot (0.9 \cdot 1.25)\ t / 2$

$a \geq \eta \cdot 0.39t$

- The size of √3 weld is the size of √2 weld multiplied by $\eta / \sqrt{2}$

Combined tension and shear

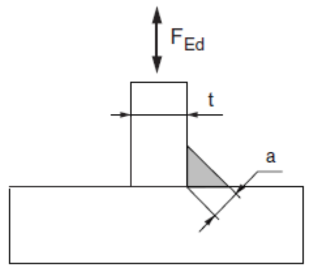
- The shear need not to be considered in the parent metal sizing in the same way like for weld sizing according to EN 1993-1-8
- EN 1993-1-1 6.2.8 manipulates combined tension and shear in different way:

(2) Where the shear force is less than half the plastic shear resistance its effect on the moment resistance may be neglected except where shear buckling reduces the section resistance, see EN 1993-1-5.

- This can easily cause oversizing of welds as can happen for example with handbook SSAB Domex Tube Structural Hollow Sections:

SSAB DOMEX TUBE STRUCTURAL HOLLOW SECTIONS **Chapter 3**

Table 3.9 The required throat thickness for an equal strength fillet weld made around the perimeter of the hollow section which is subject to axial tension, compression and/or bending



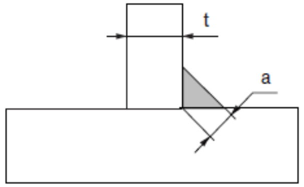
Steel grade	Yield strength a) f_y (N/mm^2)	Ultimate tensile strength a) f_u (N/mm^2)	Throat thickness of the weld b)
S235H	235	360	0,92·t
S275H	275	430	0,96·t
S355H	**355**	**510**	**1,11·t**
S275NH	275	370	1,12·t
S355NH	355	470	1,20·t
S460NH	460	550	1,48·t
S275MH	275	360	1,15·t
S355MH	355	470	1,20·t
S420MH	**420**	**500**	**1,48·t**
S460MH	460	530	1,53·t

+22.5 %

$\sqrt{3} / \sqrt{2} =$ 1.225

SSAB DOMEX TUBE STRUCTURAL HOLLOW SECTIONS **Chapter 3**

Table 3.10 The required throat thickness for an at least equal strength fillet weld made around the perimeter of the hollow section which is subject to axial tension, compression, bending and/or shear



Steel grade	Yield strength a) f_y (N/mm^2)	Ultimate tensile strength a) f_u (N/mm^2)	Throat thickness of the weld b)
S235H	235	360	1,13·t
S275H	275	430	1,18·t
S355H	**355**	**510**	**1,36·t**
S275NH	275	370	1,37·t
S355NH	355	470	1,47·t
S460NH	460	550	1,81·t
S275MH	275	360	1,41·t
S355MH	355	470	1,47·t
S420MH	**420**	**500**	**1,82·t**
S460MH	460	530	1,88·t

Example of combined tension and shear

- Define throat thickness for equal strength weld not utilizing γ_{M0} for

$N_{Ed} / N_R = 100\ \%$

$V_{Ed} / V_R = 50\ \%$

$\eta = 1.2$

$$\sigma_{eq} = \sqrt{\sigma_\perp^{\,2} + 3\tau_\perp^{\,2} + 3\tau_\parallel^{\,2}} = \sqrt{\frac{N_{Ed}}{2al/\sqrt{2}}^{2} + 3\left(\frac{N_{Ed}}{2al/\sqrt{2}}\right)^{2} + 3\left(\frac{V_{Ed}}{2al}\right)^{2}}$$

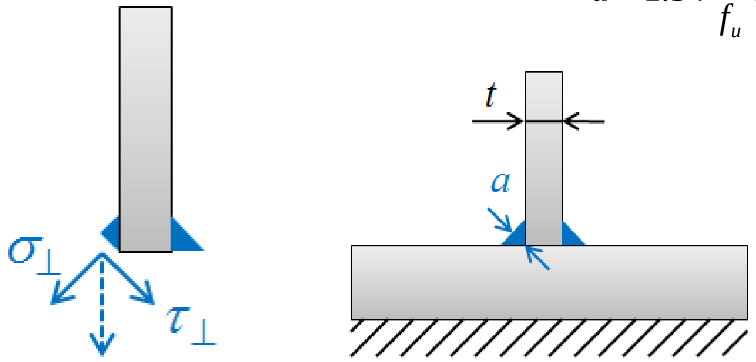
$$= \sqrt{2\left(\frac{N_{Ed}}{2al}\right)^{2} + 3\left(\frac{V_{Ed}}{2al}\right)^{2}} = \sqrt{2\left(\frac{100\% \cdot tl \cdot f_y}{2al}\right)^{2} + 3\left(\frac{50\% \cdot 1.2tl \cdot f_y/\sqrt{3}}{2al}\right)^{2}}$$

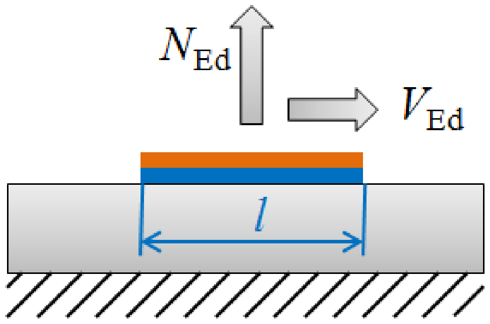
$$= \sqrt{2\left(\frac{100\% \cdot tf_y}{2a}\right)^{2} + \left(\frac{50\% \cdot 1.2tf_y}{2a}\right)^{2}} = \sqrt{0.59}\,\frac{tf_y}{a}$$

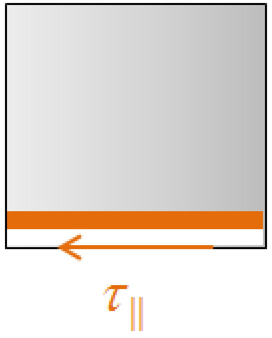
$$0.768\frac{tf_y}{a} = \frac{f_u}{\beta_w \gamma_{M2}}$$

$$a = 1.54\frac{f_y}{f_u}\left(\beta_w \gamma_{M2}\right) \cdot s/2$$

this is 8.6 % bigger than √2-weld for N_R



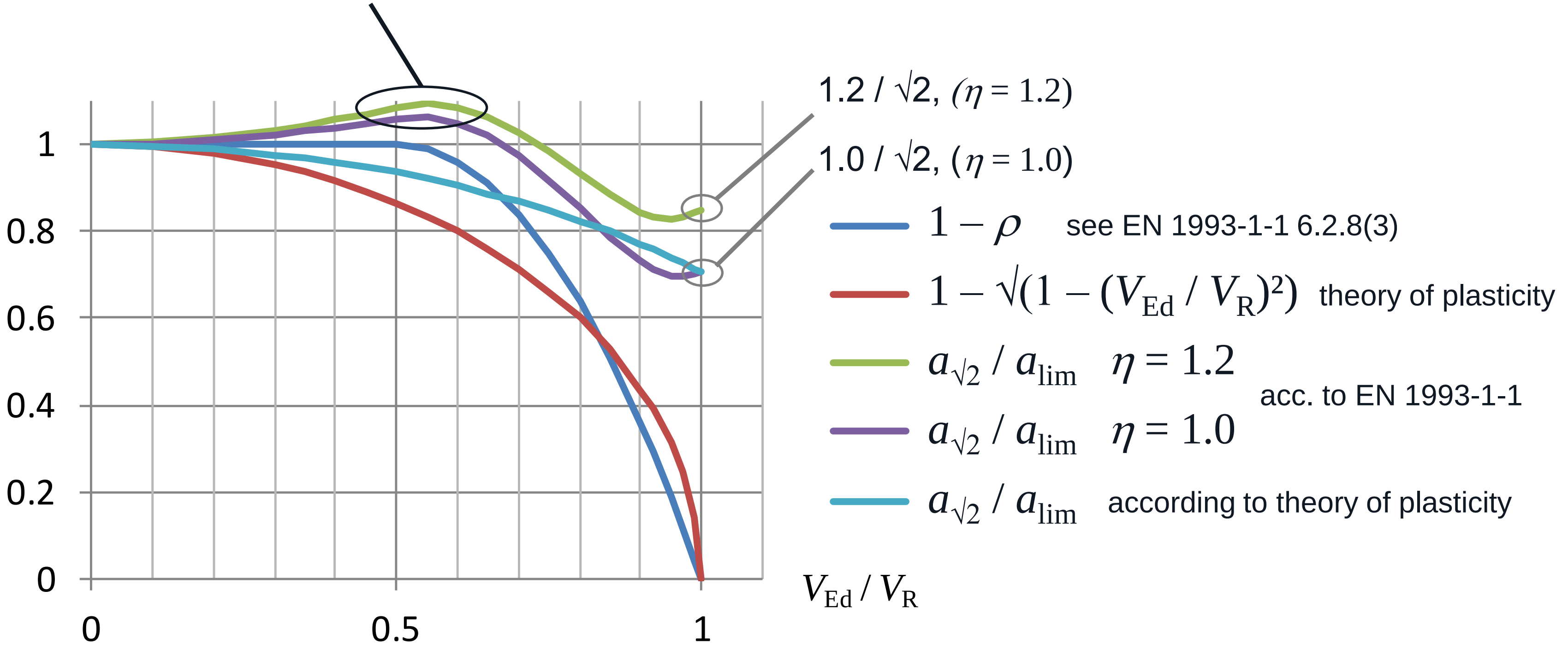




Combined tension and shear

<u>area of interest</u> for η = 1.2
+8.6 % when V_{Ed}/V_R = 50 %
max +9.4 % when V_{Ed}/V_R = 55 %

When parent metal is sized according to theory of plasticity, the $a_{\sqrt{2}} / a_{lim}$ is always less than or equal to 1. In this case, square root two weld defined for N_R is enough for all combinations of N_{Ed} and V_{Ed}.



$a_{\sqrt{2}}$ = throat thickness of equal strength √2 weld for N_R

a_{lim} = limiting throat thickness weld for condition $N_{Ed} / N_{V.R}$ = 100 %

$N_{V.R}$ = normal force resistance reduced due to the shear

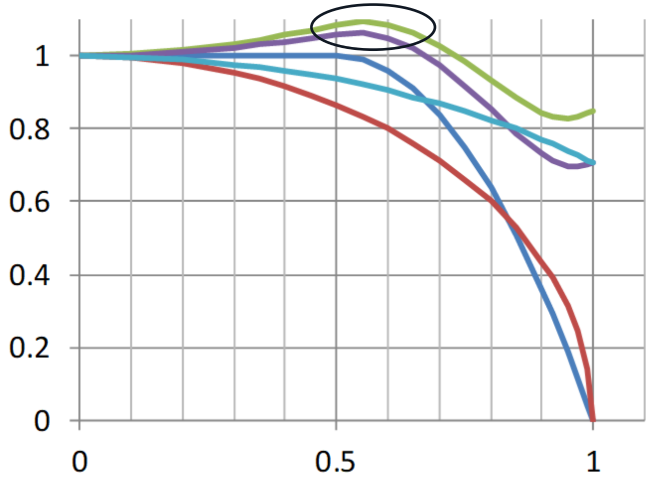
Combined tension and shear

Conclusions

- For example SSAB handbook suggests to increase throat thickness 22.5 % compared to size for pure tension
- But it is enough to increase it
  - max 9 % if η = 1.2 (not applicaple for hollow sections acc. to EN 1993-1-1 clause 6.2.6(3))
  - max 6 % if η = 1.0
- Usually the ratio of *N* of *V* is at the range where increasing is not necessary at all

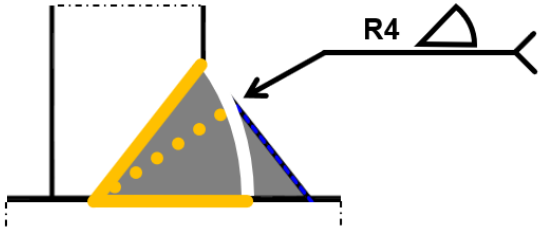
<u>area of interest</u>

max +9 % when V_{Ed}/V_R = 55 % and η = 1.2
max +6 % when V_{Ed}/V_R = 55 % and η = 1.0

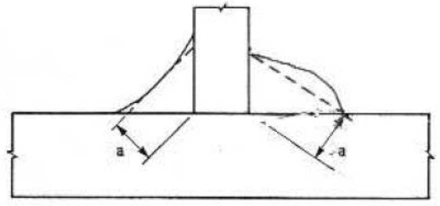


Optimal weld shapes for static loads

- It is quite easy to find optimum weld shapes with SQRT-classification
- Usually the optimal shape for static strength is
  - Combined partial bevel and fillet weld
  - Convex surface



- Eurocode EN 1993-1-8 chapter 4.5.2(1) specifies throat thickness as following:
  - "The effective throat thickness, a, of a fillet weld should be taken as the height of the largest **triangle** (with equal or unequal legs) that can be inscribed within the fusion faces and the weld surface, measured perpendicular to the outer side of this triangle, see Figure 4.3"

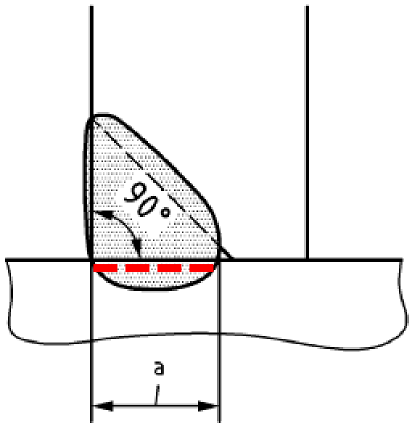


- This definition does not account for the benefits of convex surface. It is common that standard maker must give this kind of limitations to keep the scope of standard as finite
- In this presentation, the convex surface is utilized. This requires more precise calculations and drawing details compared to standard practice.

Optimal weld shapes for static loads

Weld factor β_w

- Eurocode allows to utilize weld factor β_w for all welds
- It is often heard that β_w is based on the usual condition where the strenght of weld metal is higher than strength of base metal
- This justification is clear in the middle volume of weld metal, but in standard there is no limitation to apply it also in the border of weld metal and base metal



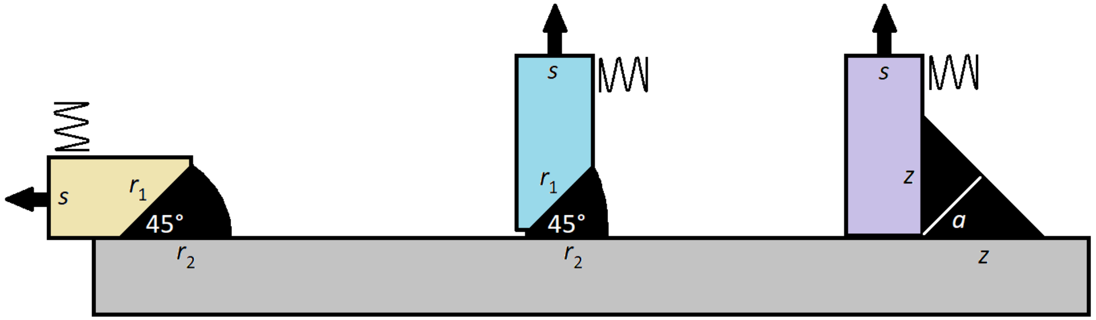
Draft of new version of EN 1993-1-8 shows this application even more clearly with this new figure with traditional clause:

”The design resistance of partial penetration butt welds should be determined using the method for fillet welds…”

Critical section at the border of weld and base metals. Factor β_w is active for shear.

Optimal weld shapes for static loads

- In the following pages, there are given the optimal shapes for welds
- Convex shapes are extending standard boundaries, but this is done with more precise calculation compared to standard practice
- There aren't standard weld symbols for given shapes, but manually drawn weld details would be necessary
- Factor β_w is utilized in all sections as per standard practice
- Factor 0.9 in equation 4.1 of EN 1993-1-8 to check $\sigma_\perp$ is considered for partial penetration
- Parameters used: f_u = 510 MPa, f_y = 355 MPa, β_w = 0.9, γ_{M2} = 1.25



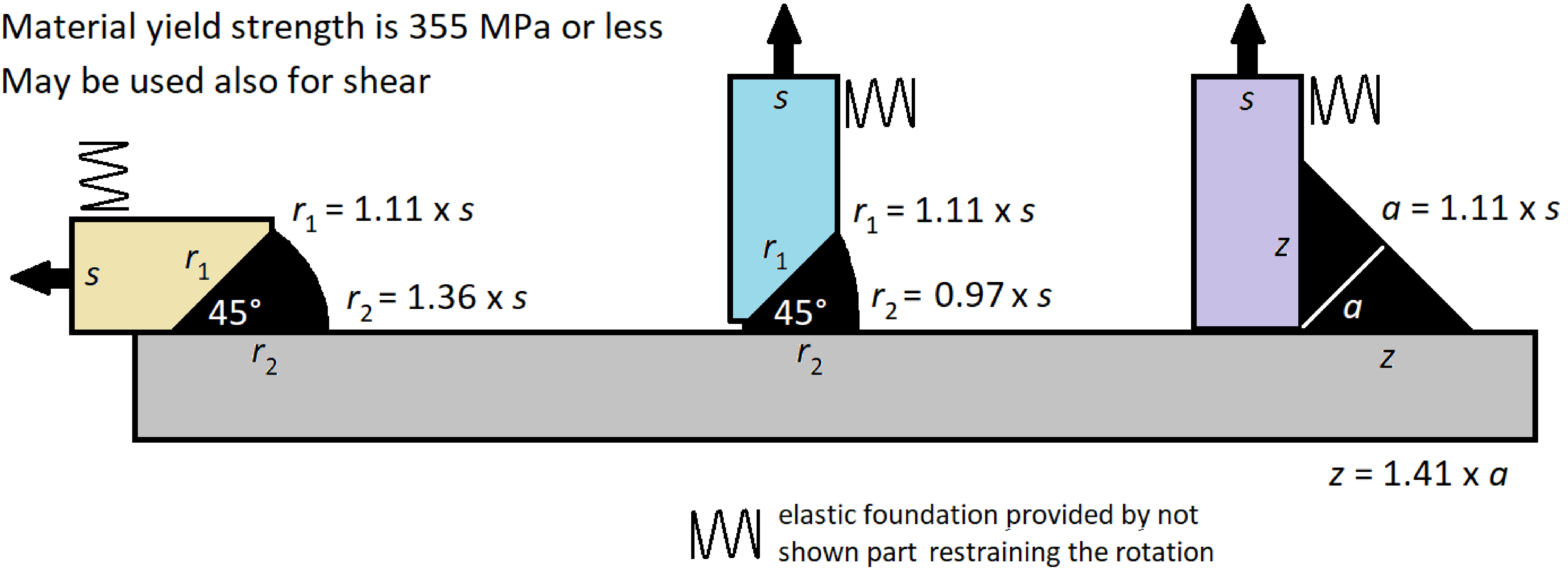
Equal Strength Welds

Axial Load in the Flange of Profile

Rotation of plate is restained with other parts indicated with spring symbol

Material yield strength is 355 MPa or less

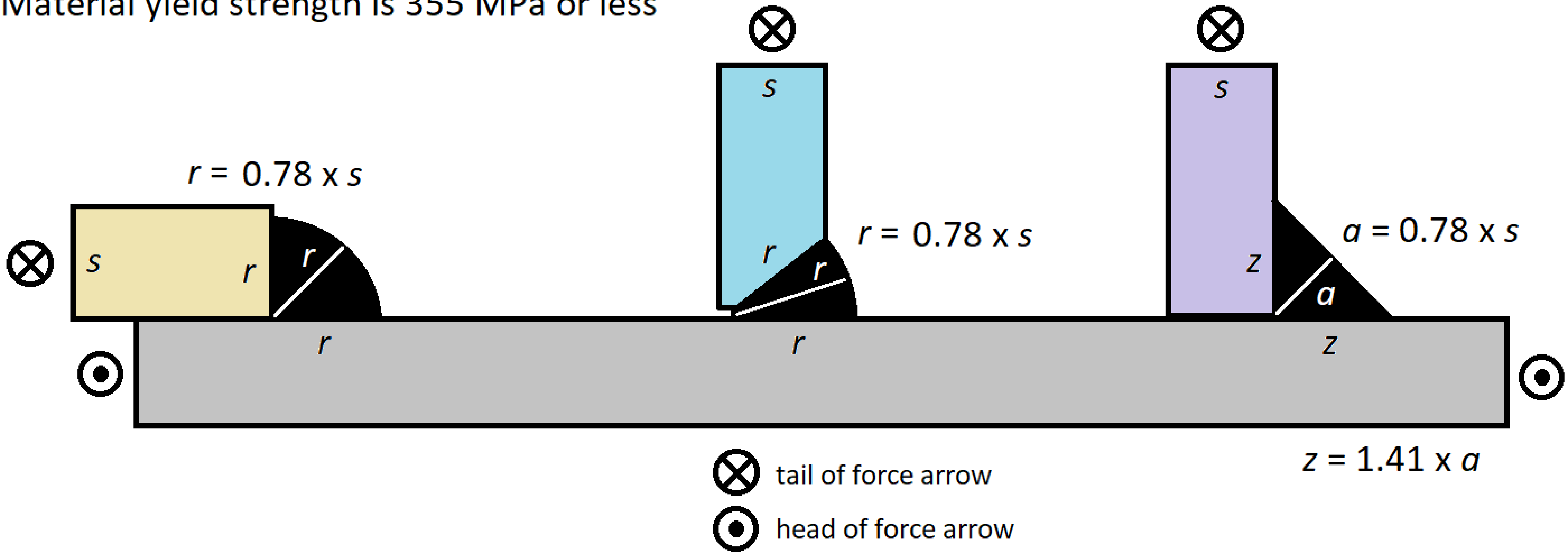
May be used also for shear



Equal Strength Welds

Shear Load

It is assumed that strain hardening is not utilized in base metal
Material yield strength is 355 MPa or less



Equal Strength Welds for Plate Bending

Single Side Load Bearing Joints

- Current wording in EN 1993-1-8:

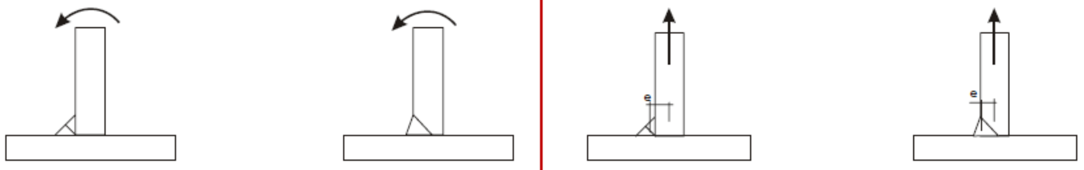
4.12 Eccentrically loaded single fillet or single-sided partial penetration butt welds

(1) Local eccentricity should be avoided whenever it is possible.

(2) Local eccentricity (relative to the line of action of the force to be resisted) should be taken into account in the following cases:

- Where a bending moment transmitted about the longitudinal axis of the weld produces tension at the root of the weld, see Figure 4.9(a);
- Where a tensile force transmitted perpendicular to the longitudinal axis of the weld produces a bending moment, resulting in a tension force at the root of the weld, see Figure 4.9(b).

(3) Local eccentricity need not be taken into account if a weld is used as part of a weld group around the perimeter of a structural hollow section.



(a) Bending moment produces tension at the root of the weld

(b) Tensile force produces tension at the root of the weld

Figure 4.9: Single fillet welds and single-sided partial penetration butt welds

- In current **draft** of next version of EN 1993-1-8 there is added the following clause for cases (a) and (b) in Figure 4.9:
  - “the weld should be designed according to elastic design rules”

Equal Strength Welds for Plate Bending

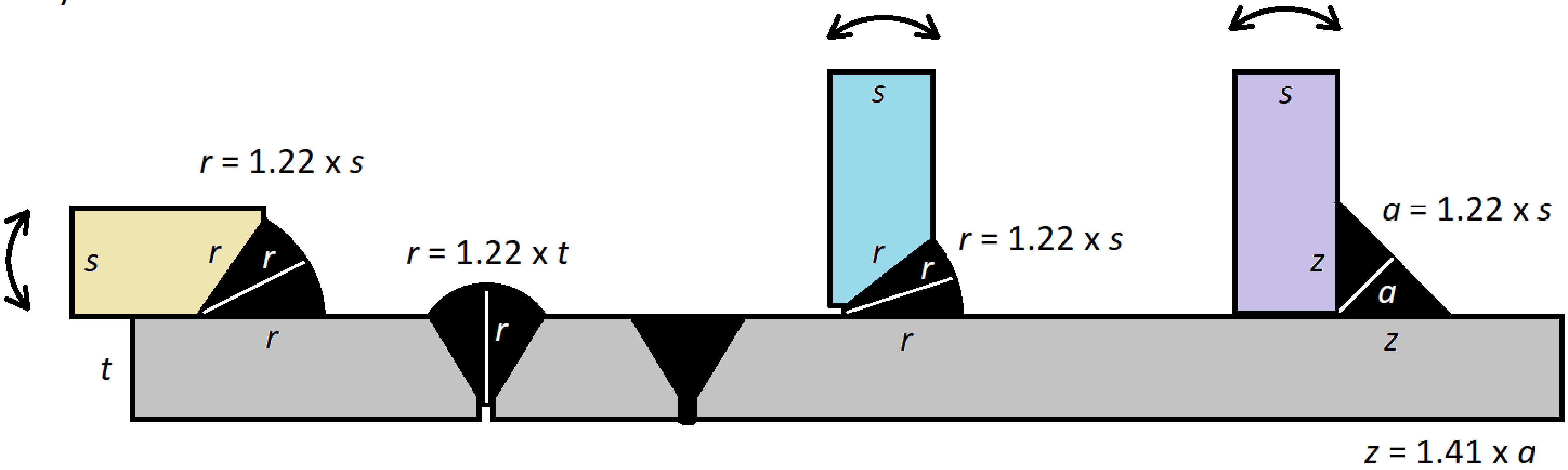
Single Side Load Bearing Joints

- The tension at the root of the weld should be avoided
  - As given in EN 1993-1-8, clause 4.12(1)
- If root tension cannot be avoided, the weld throat should be sized to stay elastic for plastic bending capacity of base metal. In this presentation, this is done with the following criteria:
  - Not utilizing β_w nor f_u
  - Partial safety factor γ_M is 1.0 for f_y
- This means that elastic section modulus of throat should be made 1.5 times bigger compared to elastic section modulus of plate in case of plate bending
  - For plate, plastic section modulus is 1.5 times bigger compared to elastic one
- Plate bending resistance increases in power two of thickness
  - Throat thickness should be $\sqrt{1.5} = 1.22$ greater than plate thickness

Equal Strength Welds for Plate Bending

Single Side Load Bearing Joints

May be used also for shear



Equal Strength Welds for Plate Bending

Non-load Bearing Joints

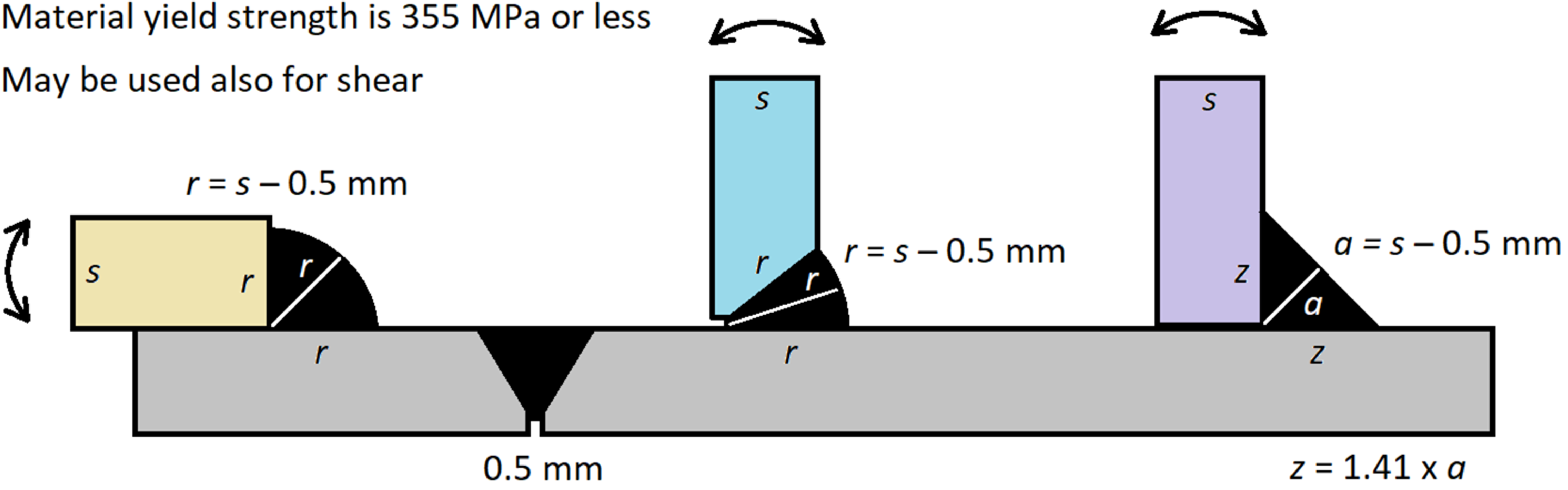
- Lots of plated structures are used in industry in various types of casings, ducts, hoppers, vessels
- It is good to consider if their non-loadbearing welds should be sized as equal strength welds
- This can prevent failures caused by secondary actions like thermal expansion differences
- In this presentation, it is considered enough to size **non-loadbearing** welds equally strong with plate bending resistance
- In case of S355, weld strength is 510/355/0.9/1.25 = 1.28 times more compared to base metal
  - Where f_u = 510 MPa, f_y = 355 MPa, β_w = 0.9, γ_{M2} = 1.25
- Plate bending resistance increases in power two of thickness. For **0.5** mm lacking welds:
  - 6 mm wall: 1.28 × (6 – **0.5**)^2 / 6^2 = 1.08 (ok)
  - 5 mm wall: 1.28 × (5 – **0.5**)^2 / 5^2 = 1.04 (ok)
  - 4 mm wall: 1.28 × (4 – **0.5**)^2 / 4^2 = 0.98 (border line case)

Equal Strength Welds for Plate Bending

Non-load Bearing Joints

Thickness *s* is 4 mm or greater
Material yield strength is 355 MPa or less

May be used also for shear



Summary

- Hollow structural sections must be sized as equally strong to keep joint sizing methods valid
- Equal strength sizing enables load independent weld sizing method
- Factor η for shear strength of base metal has contribution to capacity based sizing of welds
- Direct adoption of weld size from handbooks can cause about 20 % too big throat thickness
- Eurocode based sizing of parent metal can cause need for slightly bigger fillet weld size for combined tension and shear than necessary for pure tension
- Usually the optimal shape for static strength is combined partial bevel and fillet weld with convex surface
- Eurocode allows to utilize weld factor β_w also at the border of weld and base metals
- If root tension cannot be avoided, the weld throat should be sized to stay elastic

THANK YOU

Heikki Holopainen
Chief Engineer, Structural Engineering
Sumitomo SHI FW Energia Oy
Relanderinkatu 2, PO. Box 201
FI-78201 Varkaus, Finland
M +358 40 556 0798
heikki.holopainen@shi-g.com

Sumitomo SHI FW

shi-fw.com