Metal Structures

Lecture XIX

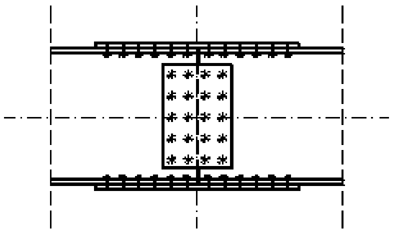
Rigid joints

Contents

Bolts in joints

There are two types of rigid joint between I-members: shear joint and tension joint.

Example of shear joint – each loads act perpendicular to axis of bolts (Design Project #2).



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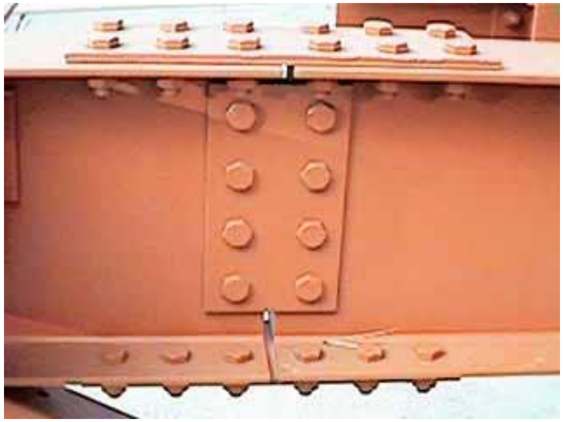

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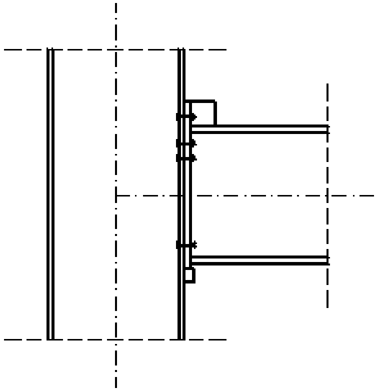
Example of tension joint – loads acts mainly parallel to axis of bolts, but for part of bolts, forces can act simultaneously in parallel and perpendicular direction (Design Project #3).



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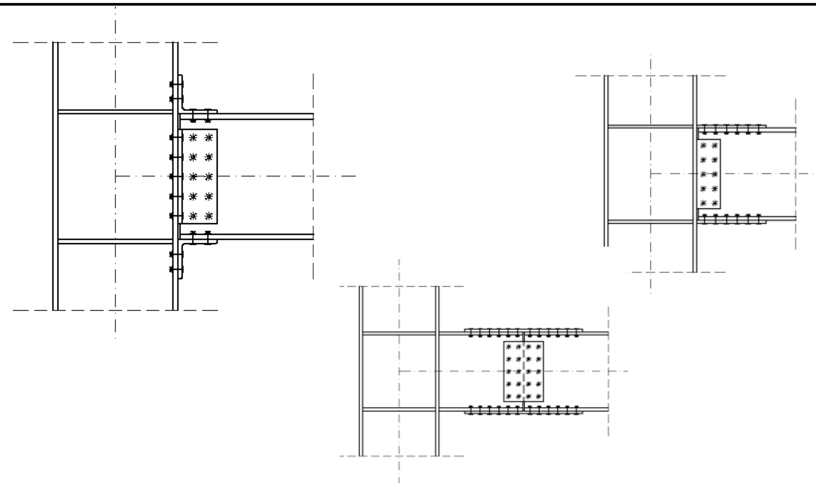
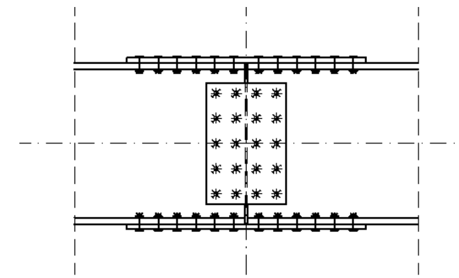
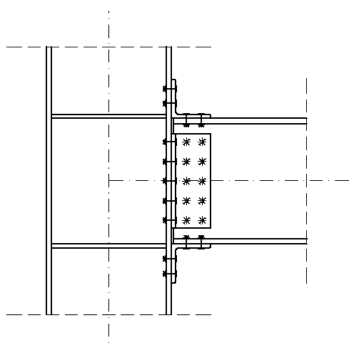
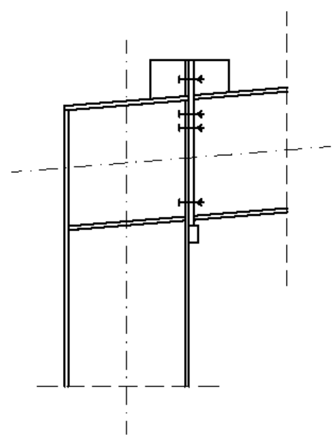
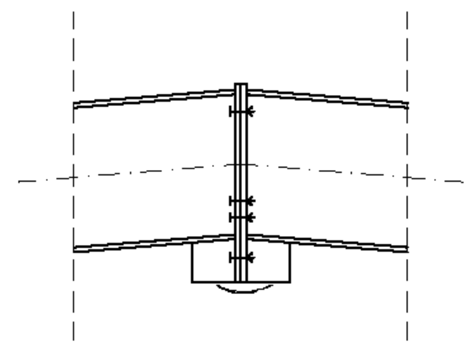
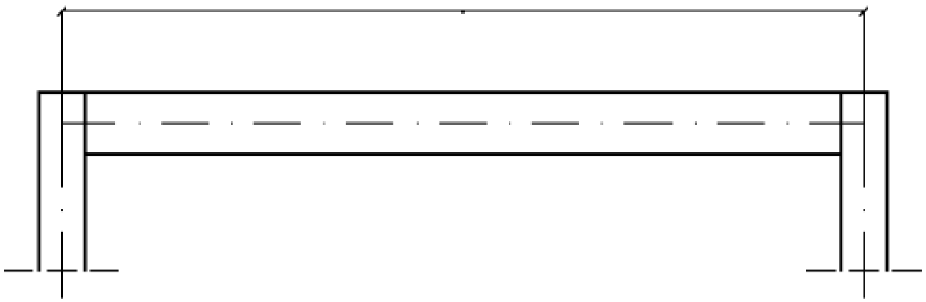
Examples

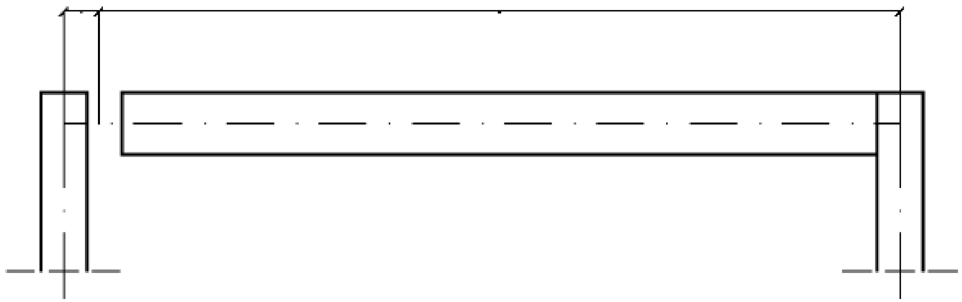
	Beam-column	Beam-beam
Shear joint		
Tension joint	  Photo: Author	

Because of imperfections, real positions of columns and real distances between columns can be different than theoretical distances in design project. Length of beam should be few milimeters smaller than theoretical distances to avoid collision betweem real position of column and end of beam.

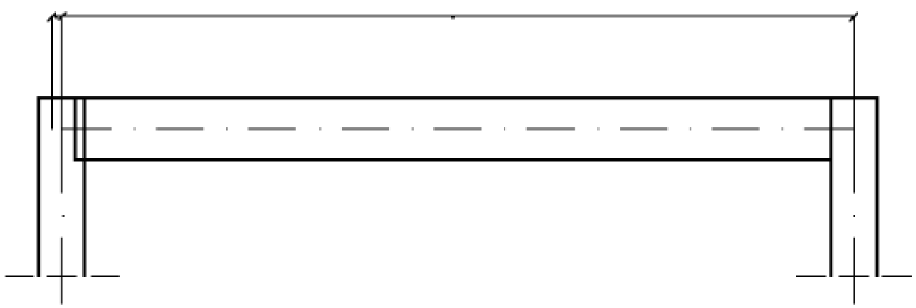
Theory (ideal situation):



Imperfected position of column (additional gap):



Imperfected position of column (collision):



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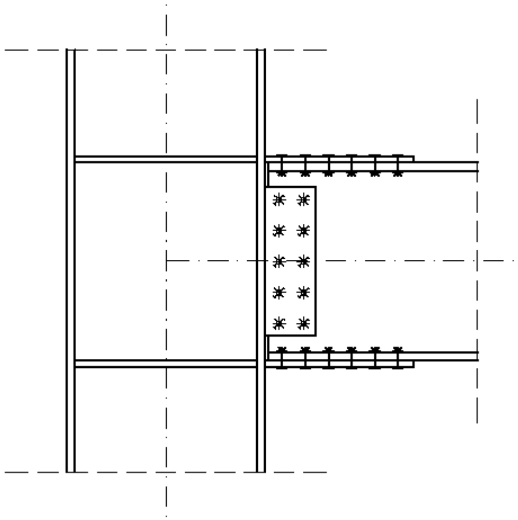
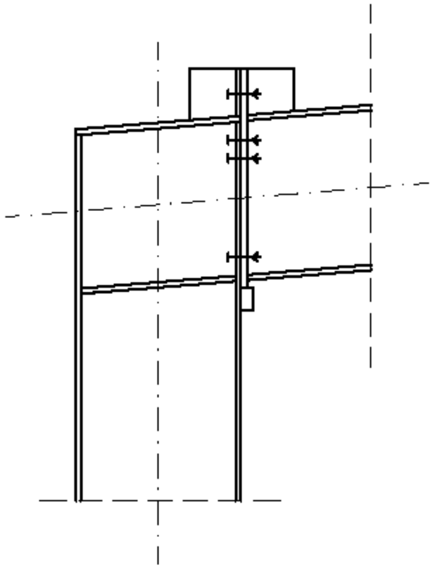
	Imperfections	Time of calculations	Time of erection (number of bolts)
Shear joint	Real distance between columns could be longer, equal or shorter in comparison to theorethical length of beam		
Tension joint	Real distance between columns can’t be shorter or longer in comparison to theorethical length of beam		





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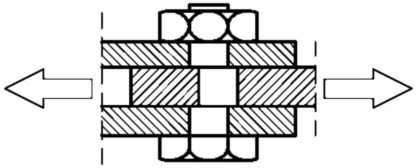
$F_{v,\,Ed}$ - shear force acts on bolt
$F_{V,\,Rd}$ - shear resistance of bolt



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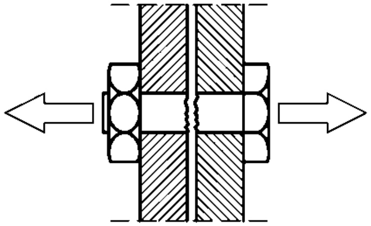


$F_{t,\,Ed}$ - tensile force acts on bolt
$F_{t,\,Rd}$ - tensile resistance of bolt

$$F_{v,\,Ed} / F_{v,\,Rd} \leq 1{,}0$$

or

$$F_{t,\,Ed} / F_{t,\,Rd} \leq 1{,}0$$

If both forces act on bolts simultaneously:

$$F_{v,\,Ed} / F_{v,\,Rd} \leq 1{,}0$$

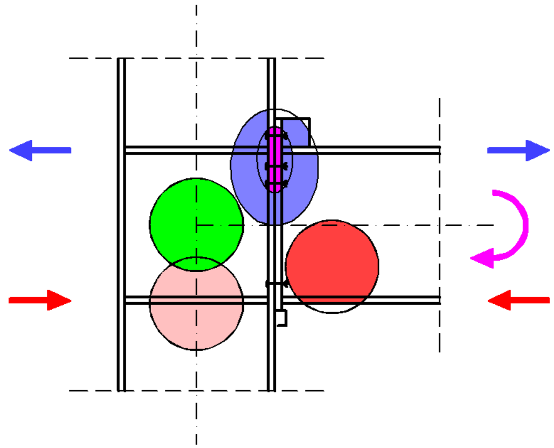
and

$$F_{t,\,Ed} / F_{t,\,Rd} \leq 1{,}0$$

and

$$F_{v,\,Ed} / F_{v,\,Rd} + F_{t,\,Ed} / (1{,}4\, F_{t,\,Rd}) \leq 1{,}0$$

Component method: resistance and stiffness of joint is effect of resistance and stiffness its components.



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→ #14 / 17

For stifness, joint is analysed as a complex of springs.

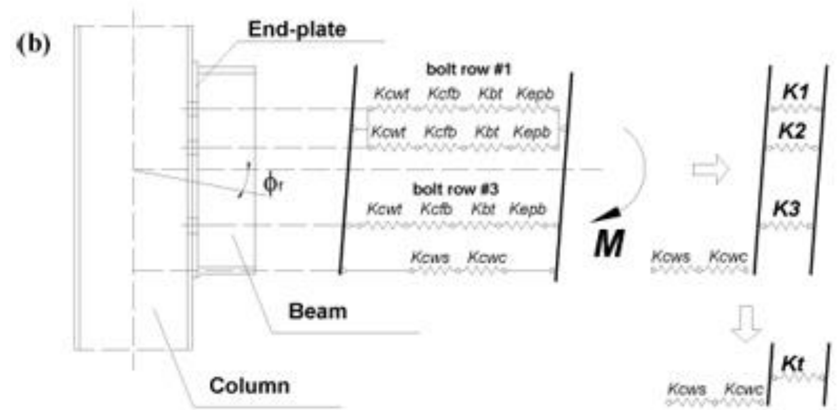


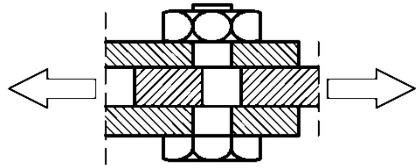
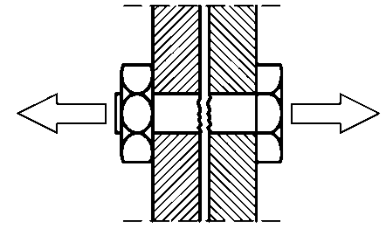
Figure 2. (a) Active components for bolted beam-to-column end-plate connections and (b) joint rotational stiffness according to EC3-1.8 (2003).

Photo: scielo.br

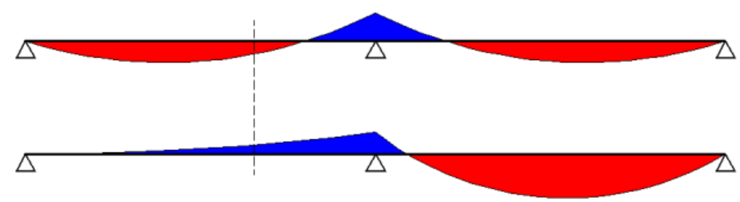
For resistance, the most important is the weaknest component (the weaknest link).

Photo: dynamicbusiness.com.au

Categories of bolted joints and loads

					
Categories of bolted joint	A	B	C	D	E
Types of loads	Static without changing the direction of the bending moments; aerodynamic	Static with changing the direction of the bending moments; aerodynamic	Dynamic	Static; aerodynamic	Dynamic
Types of bolts	„normal”	preloaded		„normal”	preloaded

Changing the direction of the bending moment:
various combinations of loads



→ #15 / 13

Photo: Author

Shear joint

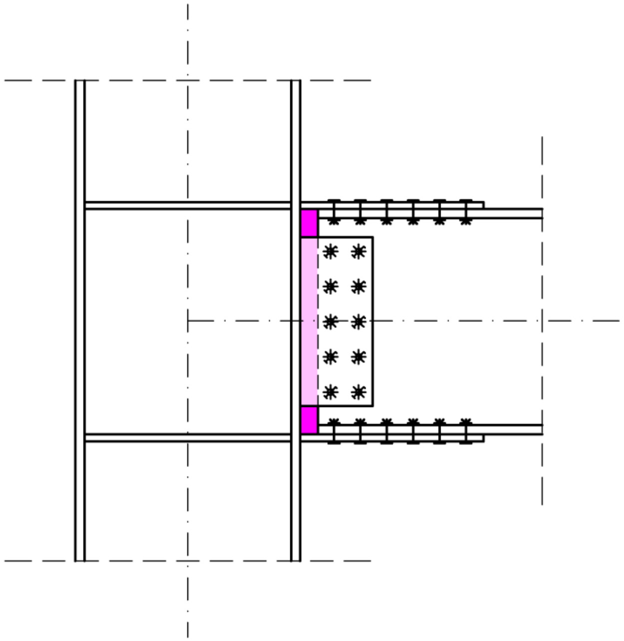


Photo: Author

Because of little gap between beam and column (≈ 20mm), both types of imperfection can be compensate. If distance betwen columns is bigger than in design project, gap will be wider. In opposite case (distance smaller than in design project), gap allows to compensate its imperfection.

According to results of experiments, we can assume, that there are always pinned joints, if:

- web only is supported;
- for bolts are applied slotted holes.

→ #14 / 42

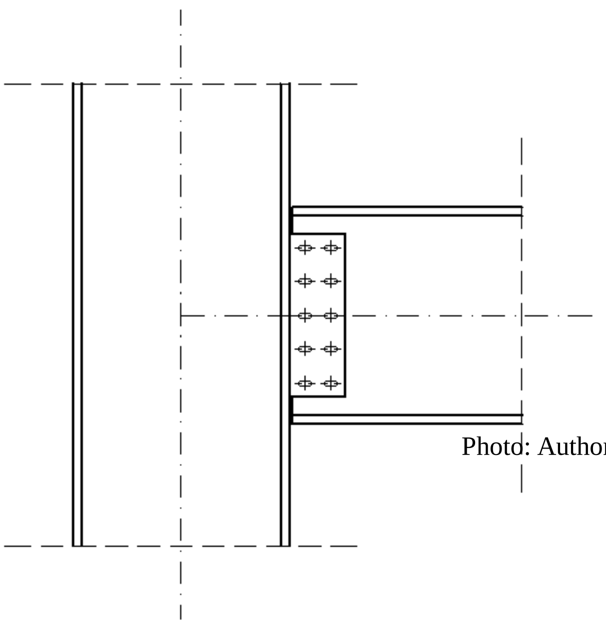


Photo: Author

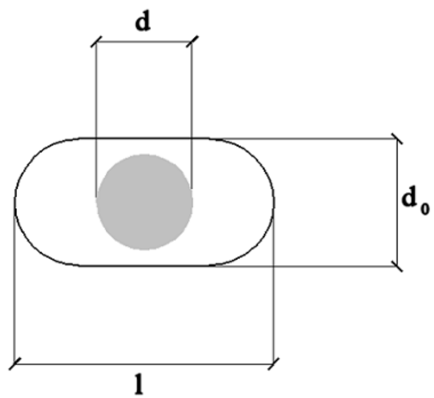
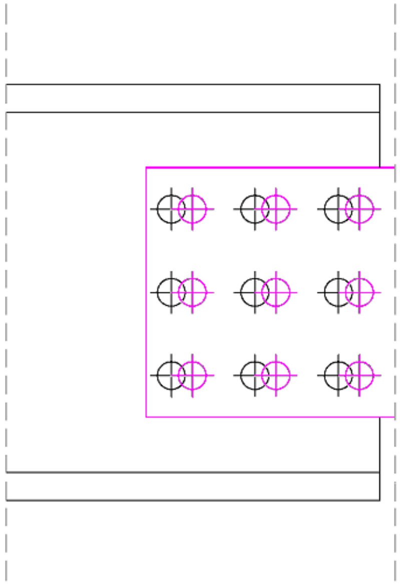


Photo: tekla-detailed-structural-fabrication.com

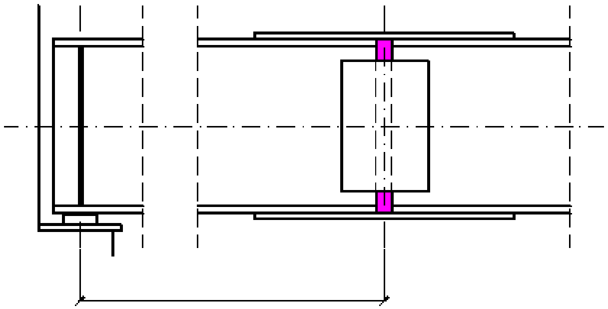
Of course, slotted holes can be used for compensation of imperfection during erection of structures. The technical solutions used at that time are heading towards the development of a rigid joint.

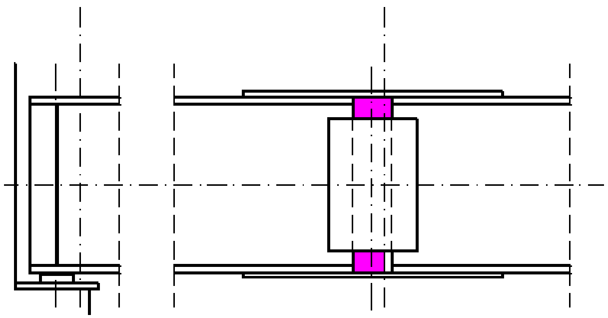
But other solutions allow to get an pinned joint with them.

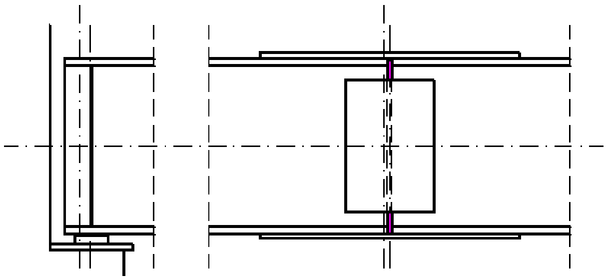


→ #14 / 43

Photo: Author







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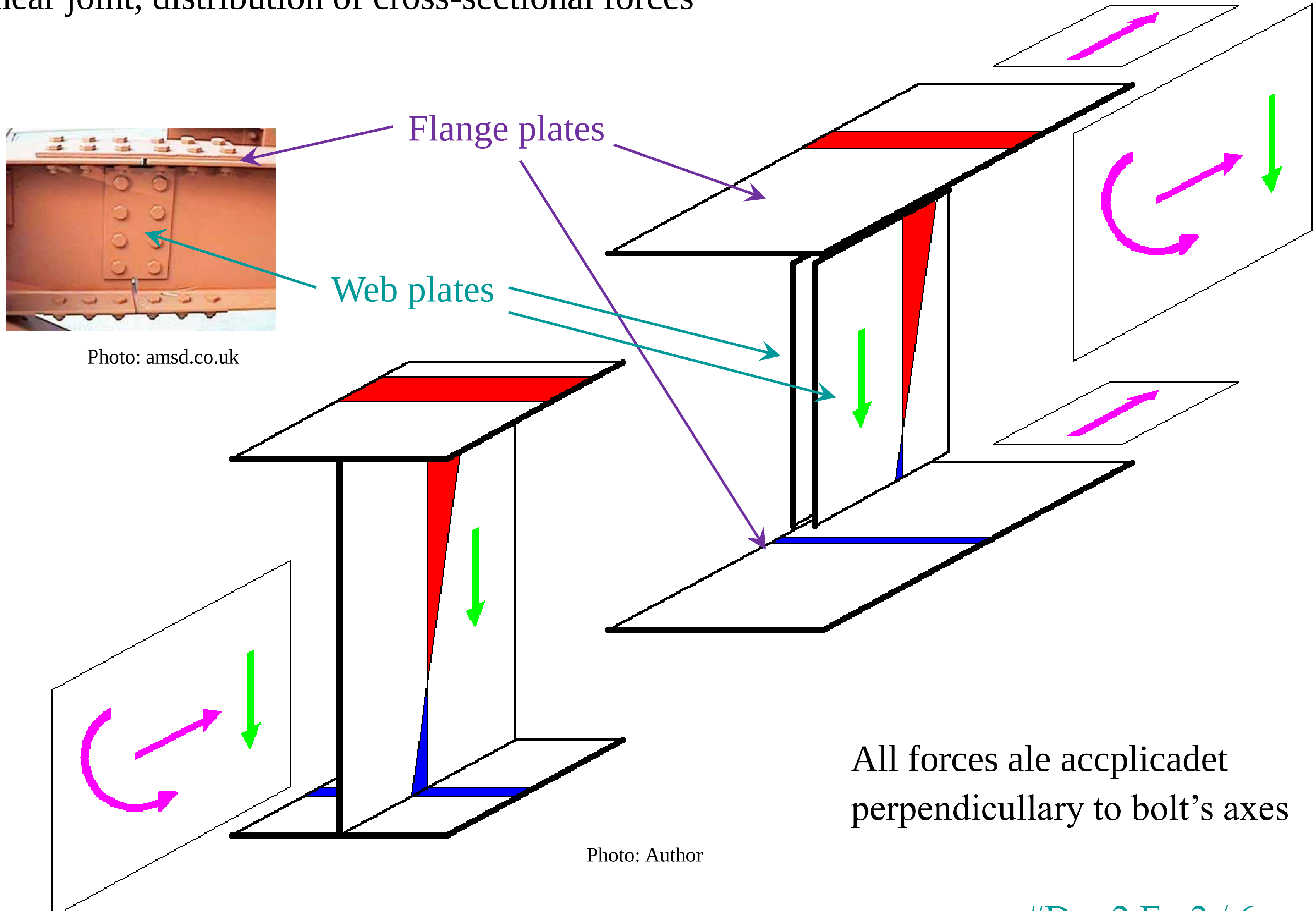
Shear joint, distribution of cross-sectional forces



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All forces ale accplicadet perpendicullary to bolt's axes

→ #Des 2 Ex 2 / 6

Initial asumptions of dimensions

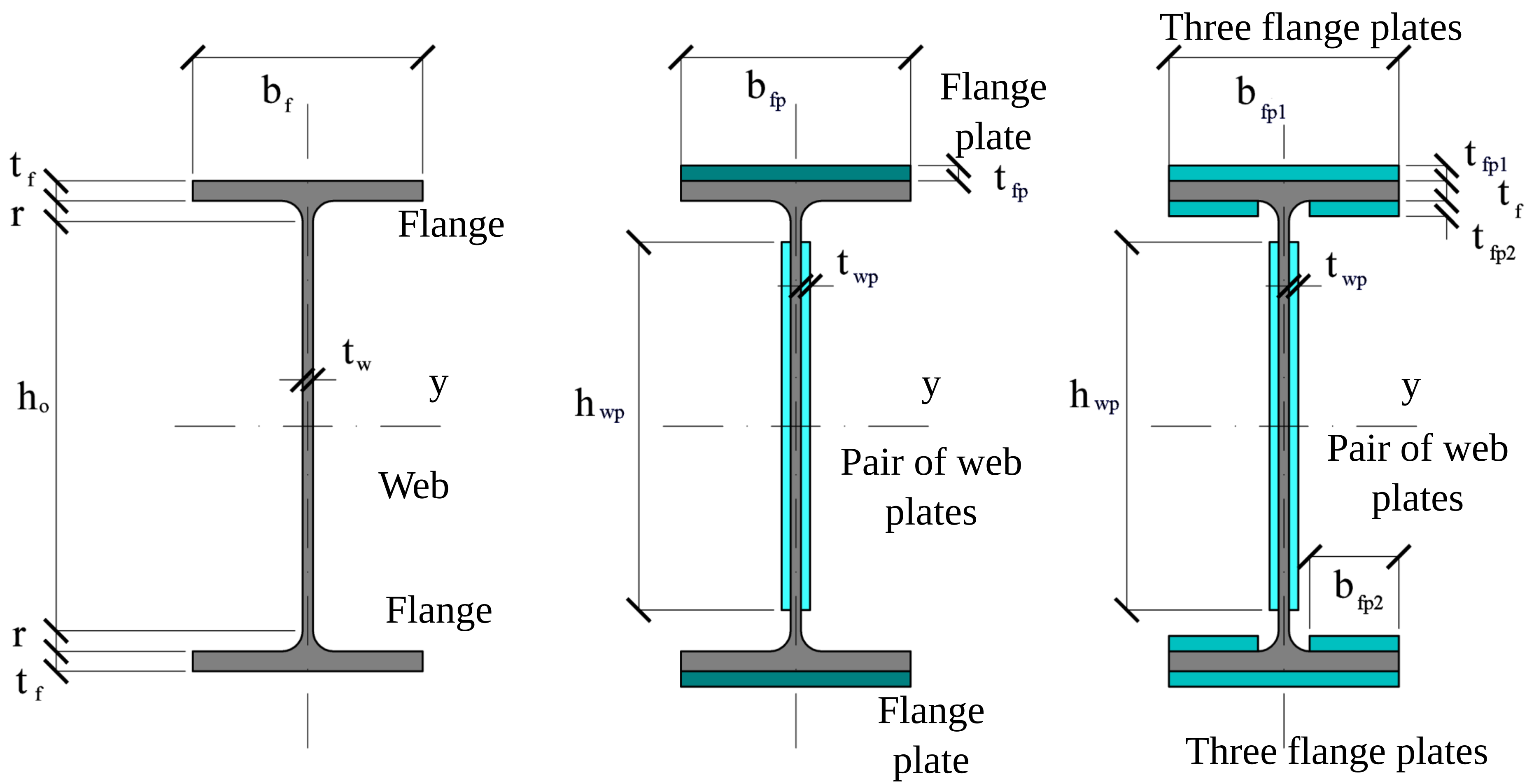


Photo: Author

I Method, II Method

III Method, VI Method

	No influence of low climatic temperature	Important influence of low climatic temperature
Two various methods of initial verification of dimensions (below table)	I Method	III Method
	II Method	VI Method

Methods I and III:

$0{,}8\ J_{I,\,y} \leq J_{fp,\,y}$

$J_{fp,\,y} \geq 10\ J_{wp,\,y}$

Methods II and IV:

$J_{f,\,y} \approx J_{fp,\,y}$

$J_{w,\,y} \approx J_{wp,\,y}$

Example of calculations for II Project: Method I.

Indexes:

$_I$ – total cross-section of I-beam

$_f$ – geometrical characteristic for both flanges only

$_w$ – geometrical characteristic for web only

$_{fp}$ – geometrical characteristic for both / six flange plates

$_{wp}$ – geometrical characteristic for both web plates

Initial assumptions:

Method I and II
(one flange plate for each flange)

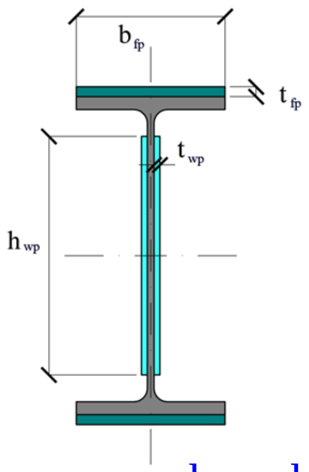


Photo: Author

$b_{fp} = b_f$

$t_f \leq t_{fp} \leq 2t_f$

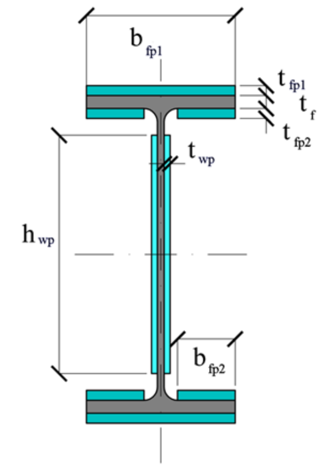
$t_{wp} \leq t_w \leq 2t_{wp}$

$t_{wp} \geq 8$ mm

$h_{wp} \approx 0{,}8\ h_0$

Method II and IV
(three flange plates)

Photo: Author



$b_{fp1} = b_f$

$b_{fp2} = (b_f - 2r - t_w) / 2$

$t_{fp2} = t_{max}$

$b_{fp1}\ t_{fp1}\ (t_f + t_{fp1}) / 2 = 2\ b_{fp2}\ t_{fp2}\ (t_f + t_{fp2}) / 2$

$t_{wp} \leq t_w \leq 2t_{wp}$

$t_{wp} \geq 8$ mm

$h_{wp} \approx 0{,}8\ h_0$

Influence of low temperature: too fat elements are prohibitet

Steel grade	Sub-grade	KV at T [°C]	KV J_{min}	Reference temperature T_{Ed} [°C]																	
				10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-2
				$\sigma_{Ed} = 0{,}75\, f_y(t)$							$\sigma_{Ed} = 0{,}50\, f_y(t)$							$\sigma_{Ed} = 0,$			
S235	JR	20	27	60	50	40	35	30	25	20	90	75	65	55	45	40	35	135	115	100	8
	J0	0	27	90	75	60	50	40	35	30	125	105	90	75	65	55	45	175	155	135	11
	J2	-20	27	125	105	90	75	60	50	40	170	145	125	105	90	75	65	200	200	175	15
S275	JR	20	27	55	45	35	30	25	20	15	80	70	55	50	40	35	30	125	110	95	8
	J0	0	27	75	65	55	45	35	30	25	115	95	80	70	55	50	40	165	145	125	11
	J2	-20	27	110	95	75	65	55	45	35	155	130	115	95	80	70	55	200	190	165	14
	M,N	-20	40	135	110	95	75	65	55	45	180	155	130	115	95	80	70	200	200	190	16
	ML,NL	-50	27	185	160	135	110	95	75	65	200	200	180	155	130	115	95	230	200	200	20
S355	JR	20	27	40	35	25	20	15	15	10	65	55	45	40	30	25	25	110	95	80	7
	J0	0	27	60	50	40	35	25	20	15	95	80	65	55	45	40	30	150	130	110	9

EN 1993-1-10 tab 2.1

If

- structure is exposed to low temperature (no thermal isolation on structure);

and

- thickness of flange plate t_{fp} according to initial assumptions (→ #t / 16, Method I on II) is too fat in comparison to accepted thickness (EN 1993-1-10 tab. 2.1)

then Methods III or IV must be taken into consideration.

Distribution of global cross-sectional forces (M_{Ed} , N_{Ed} , V_{Ed}) between flange plates and web plates:

$M_{fp} = M_{Ed} J_{1,y} / (J_{1,y} + J_{2,y})$

$M_{wp} = M_{Ed} J_{2,y} / (J_{1,y} + J_{2,y})$

$N_{fp} = N_{Ed} A_1 / (A_1 + A_2)$

$N_{wp} = N_{Ed} A_2 / (A_1 + A_2)$

$V_{fp} = 0$

$V_{wp} = V_{Ed}$

Characteristics	Method A	Method B
$A_1 =$	A_{fp}	A_f
$A_2 =$	A_{wp}	A_w
$J_{1,y} =$	$J_{fp,y}$	$J_{f,y}$
$J_{2,y} =$	$J_{wp,y}$	$J_{w,y}$

Example of calculations for II Project: Method B.

Axial force in flange plate(s) - arm of action for bending moemnt:

Method	A	B
I	$x = x_1$	$x = x_2$
II	$x = x_1$	$x = x_2$
III	$x = x_2$	$x = x_2$
IV	$x = x_2$	$x = x_2$

$$x_1 = h + t_{fp} / 2 + t_{fp} / 2$$

$$x_2 = h - t_f / 2 - t_f / 2$$

The same directions of vectors

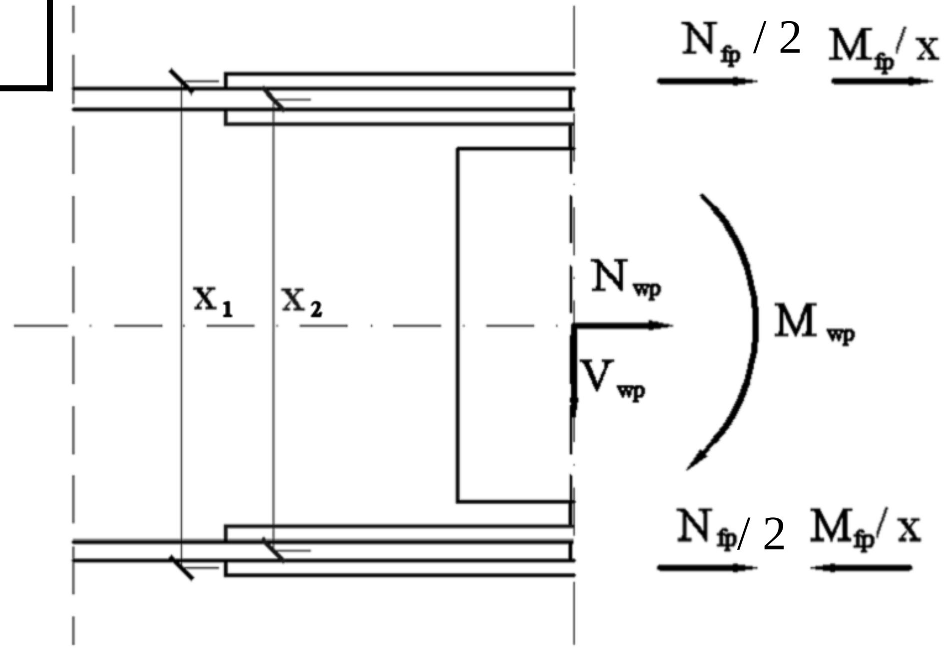


Photo: Author

Opposite directions of vectors

F_{fp} = max (the same direction of vectors, opposite directions of vectors) =

$$= \max (F_{fp,\ top} \quad ; \quad F_{fp,\ bottom}) =$$

$$= | N_{fp} | / 2 + | M_{fp} | / x$$

I-beam, welded joints; additional rules

Recommendation:

$b_1 \approx b - 30$ mm

$b_2 \approx b + 30$ mm

$t_1 = t_2\, b_2 / b_1$

For distribution of cross-section forces:

$t = (t_1 + t_2) / 2$

$b = (b_1 + b_2) / 2$

$A_{fp} = t\, b$

$J_{fp} = 2\, [b\, t^3 / 12 + b\, t\, (h / 2)^2]$

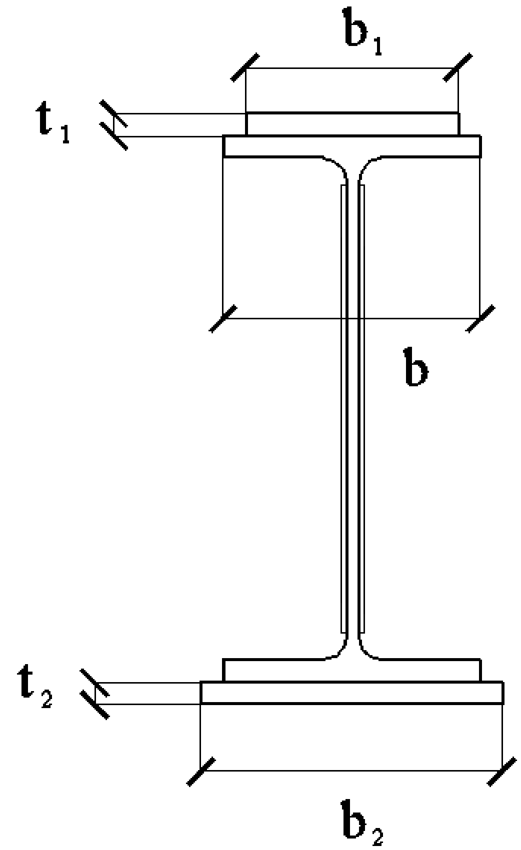
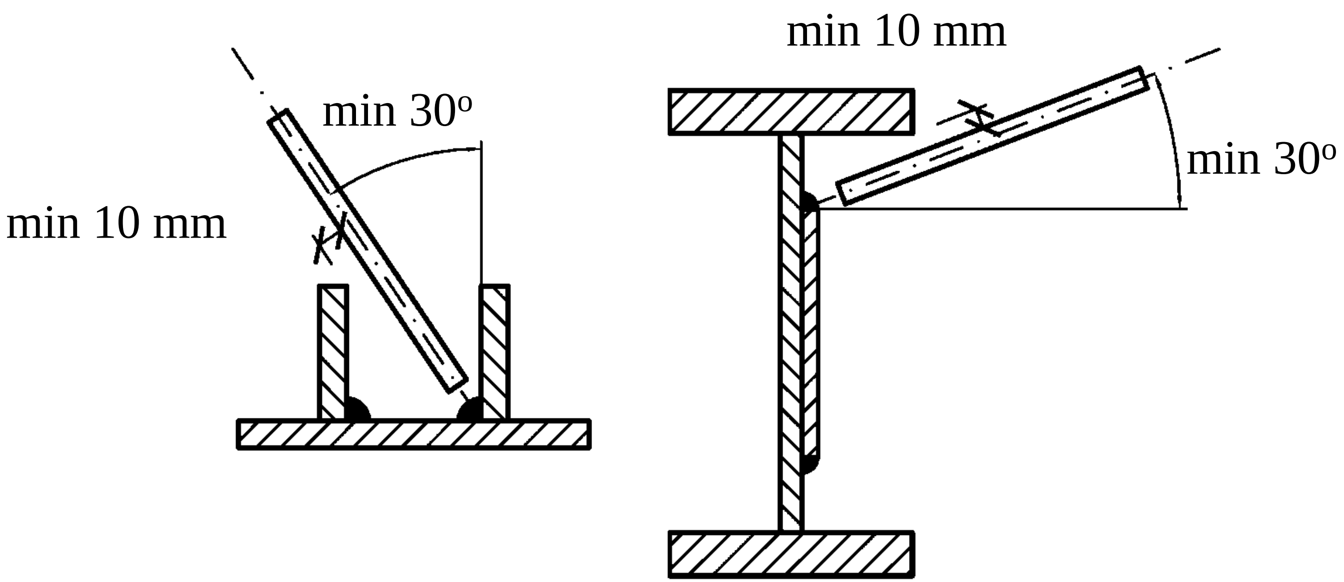


Photo: Author

Various width of plates is effect of ergonomy of welding processes: the best position of welding electrode during welding is downward 30° – 60°.

→ #16 / 30



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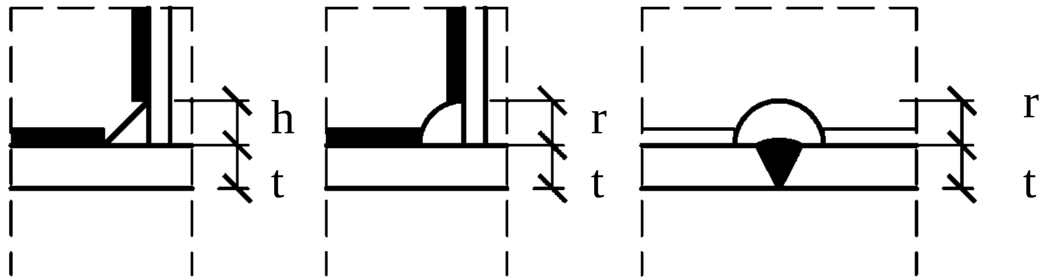


$h \geq 25$ mm; $h \geq 3\ t$

$r \geq 25$ mm; $r \geq 3\ t$

Number of bolts on web plate

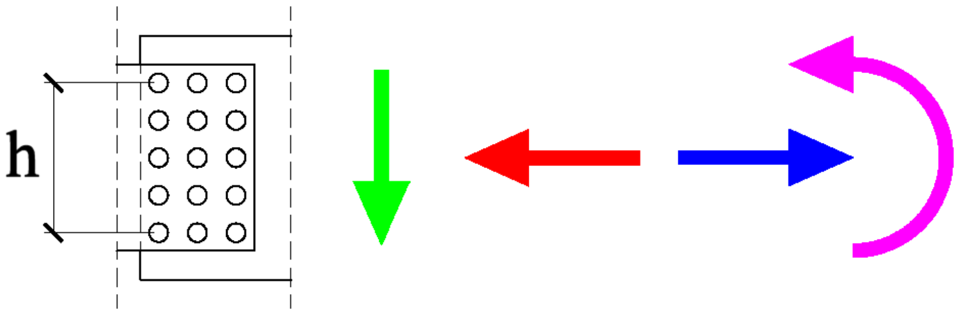


Photo: Author

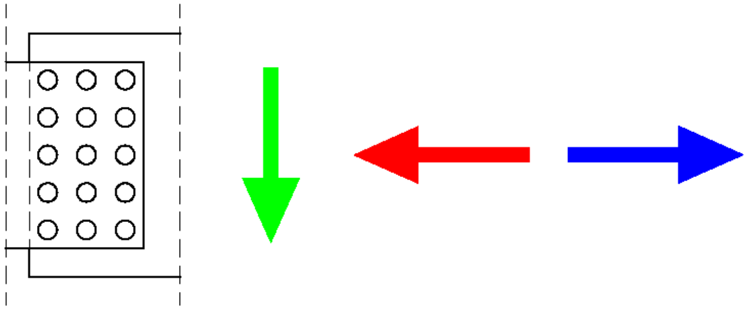
$$n = \max\left[5{,}2\, M_{Ed} / (h\, F_{Rd}) \quad ; \quad 4\right]$$

F_{Rd} = shear resistance for category A and B; slip resistance for category C

If $M_{Ed} = 0$, n could be smaller than 4, but not smaller than 2.

Shear joint – forces act evenly on each bolts;

Force for one bolt = global force / number of bolts.



$V_{Fi} = F_V / n$

$H_{Fi} = F_H / n$

Photo: Author

Shear joint – bending moment acts unequally on each bolts;

Force for bolt #i is proportionally to distance between bolt and centre of gravity for bolts; vector of force is perpendicular to arm of action

Centre of gravity for bolts ≠ centre of gravity for plate.

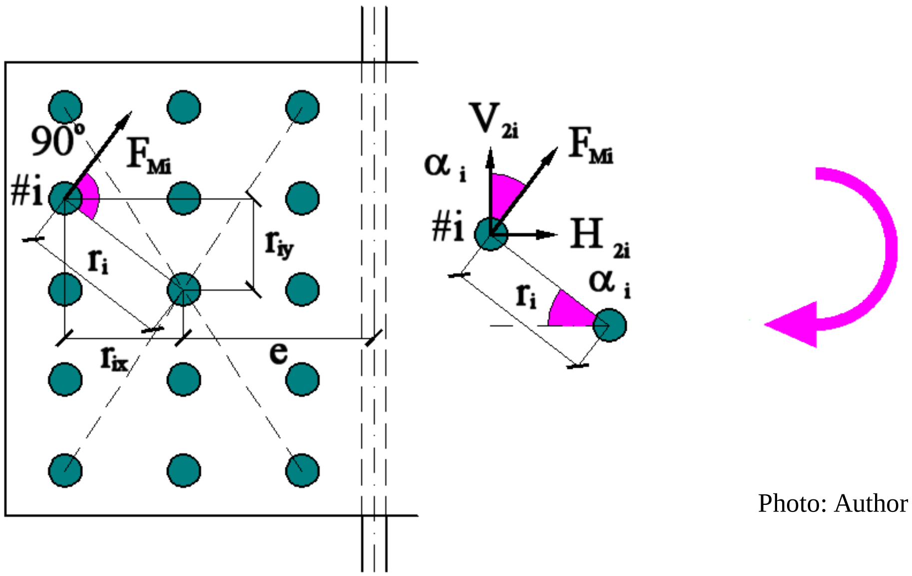


Photo: Author

$F_{Mi} = \psi\, r_i$; $F_{Mi} \perp r_i$ (from experiments and experience)

$M_i = F_{Mi}\, r_i = \psi\, (r_i)^2$

$M_{Ed} = \Sigma\, M_i = \psi\, \Sigma\, (r_i)^2 \rightarrow \psi = M_{Ed} / \Sigma\, (r_i)^2$

$F_{Mi} = \psi\, r_i = M_{Ed}\, r_i / \Sigma\, (r_i)^2 \rightarrow V_{Mi} = F_{Mi} \cos \alpha_i$; $H_{Mi} = F_{Mi} \sin \alpha_i$

Shear joint – forces and bending moment;

Loads cause horizontal and vertical component forces;

Horizontal and vertical forces for one bolt are effects of horizontal and vertical global forces F (→ #t / 19) and horizontal and vertical effects of global bending

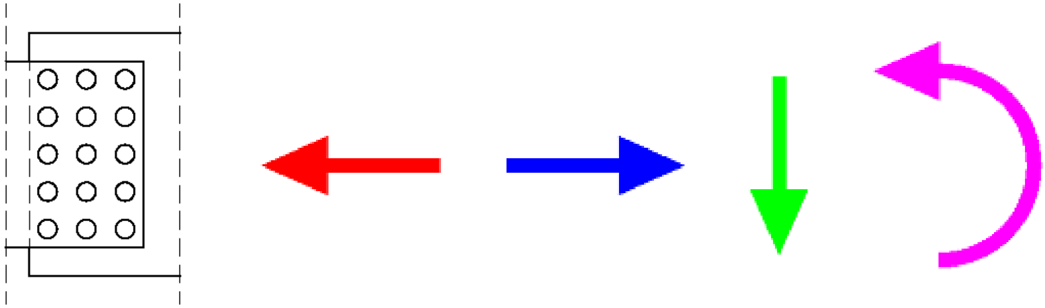


Photo: Author

$$F_{V,\ total,\ i} = V_{Fi} + V_{Mi}$$
$$F_{H,\ total,\ i} = H_{Fi} + H_{Mi}$$

Analysis of the weaknest component for shear joint:

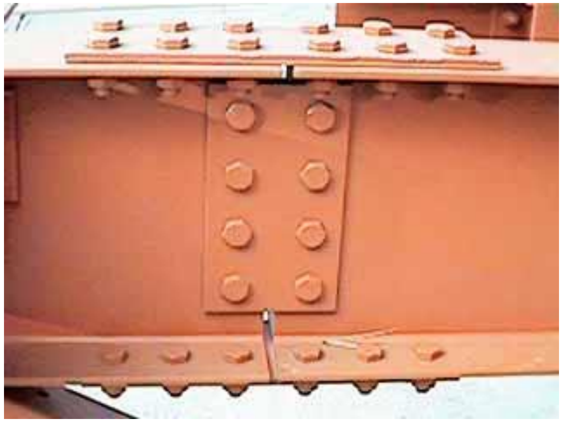


Photo: amsd.co.uk

1. Forces act on one bolt are compared with resistance of this bolt for shear force (A, B). If resistance is too small, bigger diameter of bolt or higher class of bolt should be taken into consideration.

2. Forces act on one bolt are compared with bearing resistance of plate (A, B, C). If resistance is too small, fatter plate on other positions of bolts shoul be taken into consideration.

3. Forces act on one bolt are compared with slip-resistant (B, C). If resistance is too small, higher friction coefficient or bigger preloaded force (bigger diameter of bolt or higher class of bolt is needed for bigger preloaded force) should be taken into consideration.

4. Preloaded force is compared with punching resistance (B, C) and resistance fo tensile force (A, B, C). If resistance is too small, fatter plates should be taken into consideration.

5. Global forces are compared with netto resistance / block tearing resistance (A, B, C). If resistance is too small, fatter plates or smaller diameters of holes (smaller diameter of holes means smaller resistance of bolts; higher class must be applied in this case) should be taken into consideration.

Gorup of requirements must be checked in case of shear joint. These requirements can be easily divided into:

- resistance of connection (resistance of shank of bolt under shear force and tensile force);
- resistance of joint in case of contact bolt-element (bearing resistance, punching resistance);
- resistance of joint not related to contact bolt-element (slip-resistant, netto resistance / block tearing resistance).

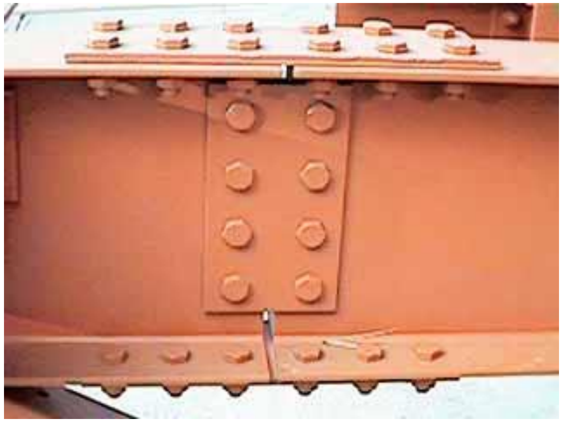


Photo: amsd.co.uk

For each requirement is very easy to point out the weaknest element and it is very easy to find out way to increase resistance of the weaknest element.

Tension joint

Recommendation for tension joint: beams should be made a little shorter (≈ 20mm) than theoretical distance betwen columns, to compensate imperfection during erection of column (too close position of columns).

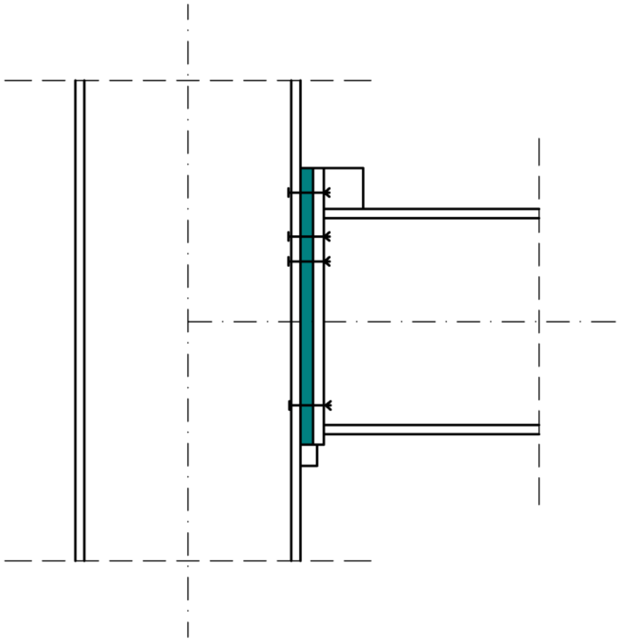


Photo: Author

Fundamental requirement for such type of joint: **full contact** between column (flange) and beam (end plate). A little shorter beam makes gap, filled by additional packing plate. Thickness of packing plates must be selected on the construction site, after measuring the actual position of column and actual length of beams.

Stresses in bolted tensile joint

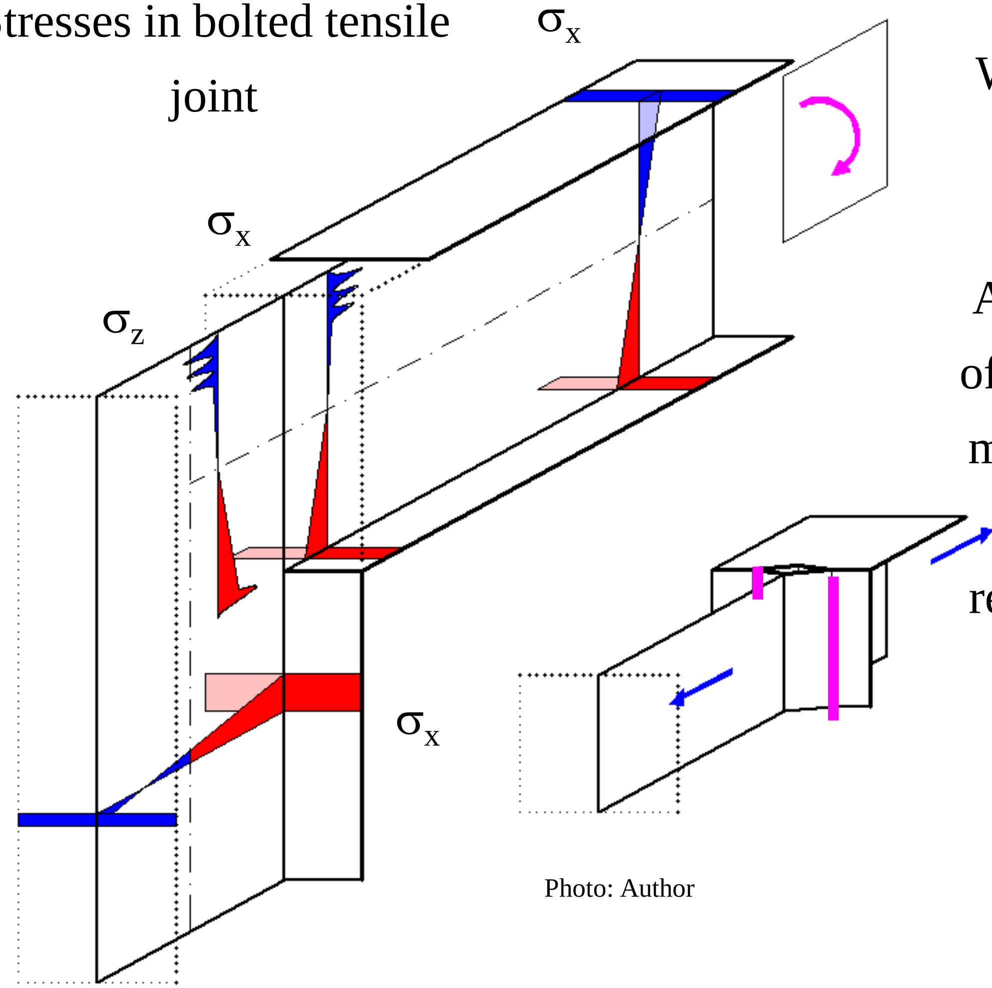


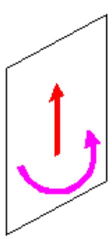
Photo: Author

We have a full set of cross-sectional forces in beam: M_{Ed} , N_{Ed} , V_{Ed} .

Axial force is taken into account only in form of stipulation in EN 1993-1-8 6.2.7.1 (2) that it must not exceed 5% of beam's resistance; it is then neglected in calculations. This requirement is another condition to be met for beam.

Shear force is traditionally applied by calculation to compressed zone only.

→ #15 / 15



Shear force in column don't affected on joint.

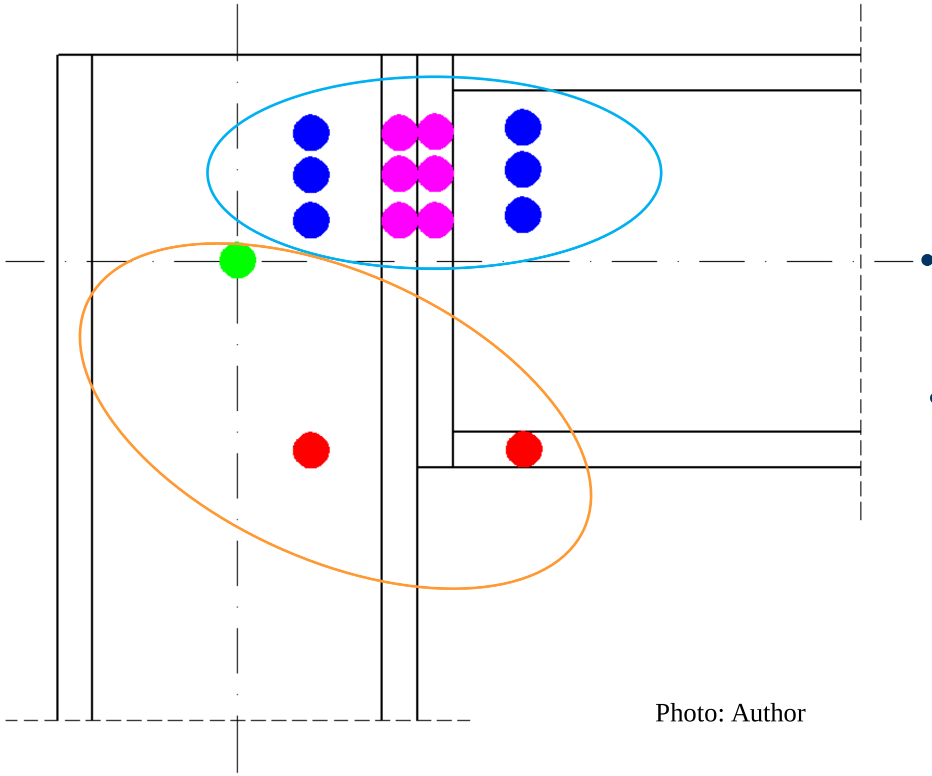


Photo: Author

Various resistances for various rows of bolts:

- Local transverse tension of column's web around I, II, III row of bolts;
- Local bending of column's flange around I, II, III row of bolts;
- Local bending of end plate around I, II, III row of bolts;
- Local longitudinal tension of beam's web around I, II, III row of bolts;

Tensed zone

The same resistance for each row of bolts:

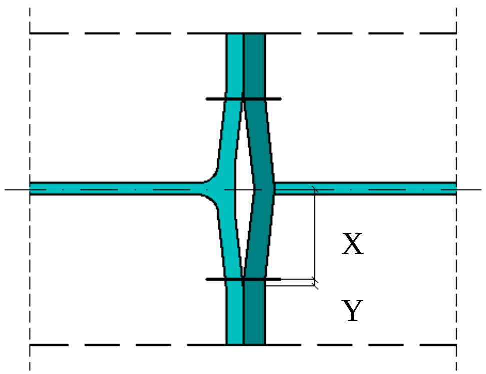
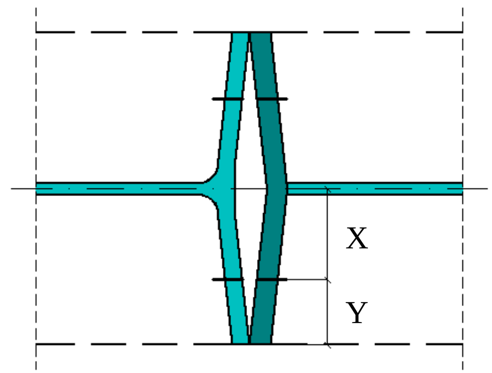
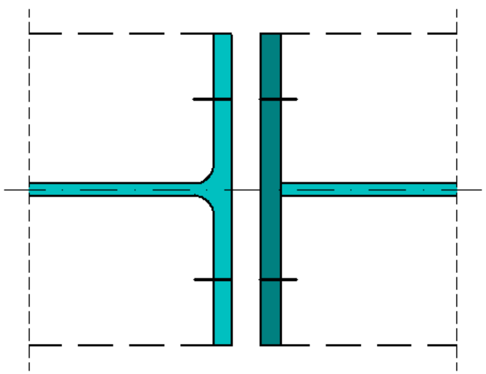
- Local transverse compression of beam's flange;
- Local transverse compression of column's web under global longitudinal compression;
- Local shearing of column's web between "scissors" of compressed and tensed zones;

Shear zone is included in compressed zone.

→ #15 / 16

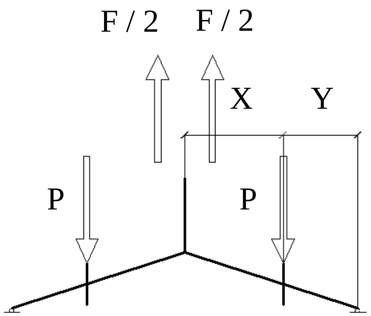
Photo: Author

3 models of destruction must be analysed in bended zone.

<table>
<tr><td>Model 1 – complete yielding of flange / end plate</td><td>Model 2 – bolt failure with (partial) yelding of flange / eng plate</td><td>Model 3 – bolt failure</td></tr>
<tr><td colspan="2">Thin column’s flange / end plate – prying action</td><td>Fat column’s flange / end plate</td></tr>
<tr><td>
</td><td>
</td><td></td></tr>
<tr><td colspan="2">Force in bolt = P
Total force in tensed zone = F

$P\,Y = (F / 2)\,(X + Y)$ → #15 / 17

$P = (F / 2)\;(X + Y) / Y$

$(X + Y) / Y > 2 \;\rightarrow\; P > F$ (!!!)

</td><td>Force in bolt = P
Total force in tensed zone = F

$P = F / 2$</td></tr>
</table>

Prying action - when it can occur?

EN 1993-1-8 tab. 6.2

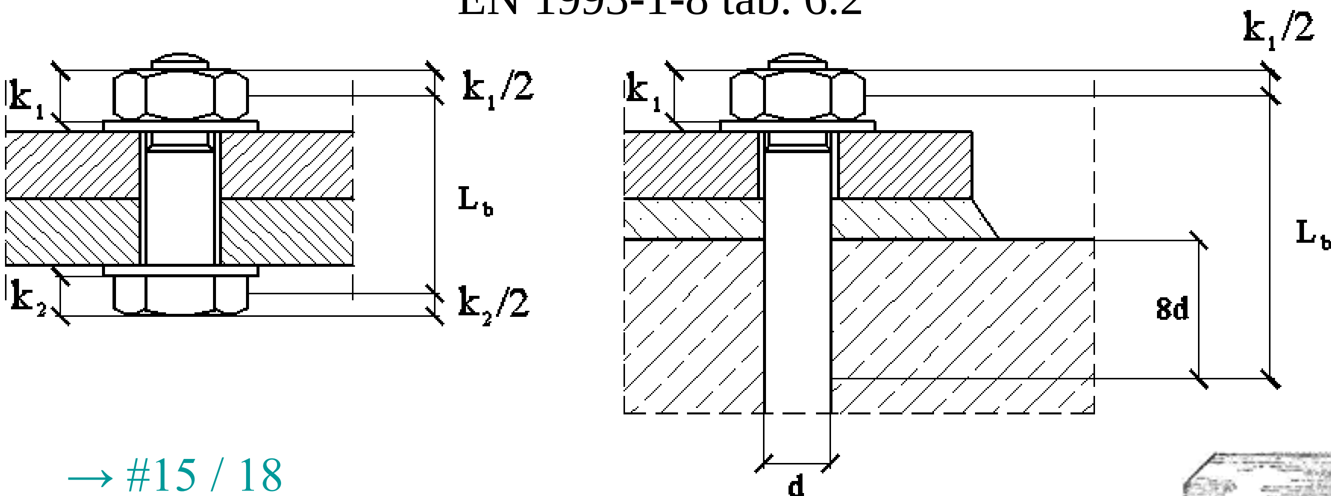


Photo: Author

→ #15 / 18

$L_b \leq L_b^*$ → Prying forces

$L_b > L_b^*$ → No prying forces

$L_b^* = 8{,}8\ m^3 A_s / (\Sigma l_{eff}\ t_f^3)$

A_s – area of bolt cross-section in threated portion

t_f – the thickness of the thinnest plate

m → #15 / 6

Σl_{eff} → #15 / 23 – 25, #15 / 27

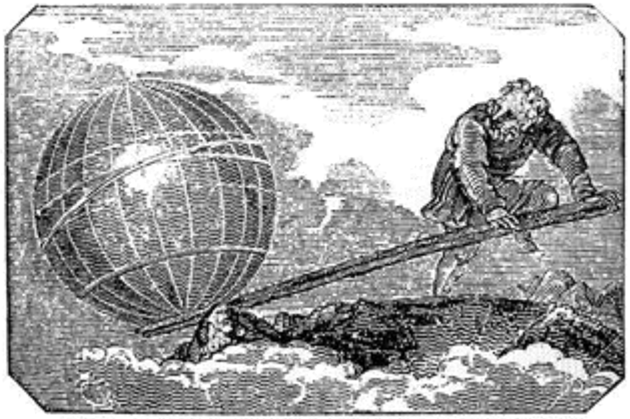
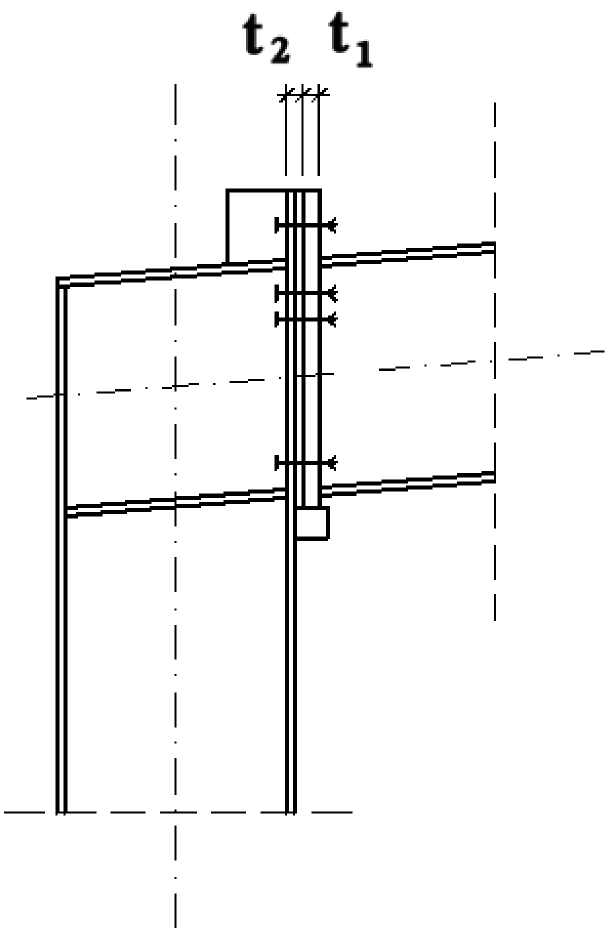


Photo: physics.weber.edu

Give me the place to stand, and I shall move the Earth

Tension joint – thickness of end plate (t_1) and additional plate for column flange ($t_2 = t_{flange} + t_{additional\ plate}$)



$\min(t_1 ; t_2) \geq t$

Bolted joint cathegory D:

$t = 2{,}0 \sqrt{\{c\, F_{t,Rd} / [f_y (2c + d)]\}}$

Bolted joint cathegory E:

$t = 1{,}25\, d\ \sqrt[3]{\{f_{ub} / 1\,000\ [MPa]\}}$

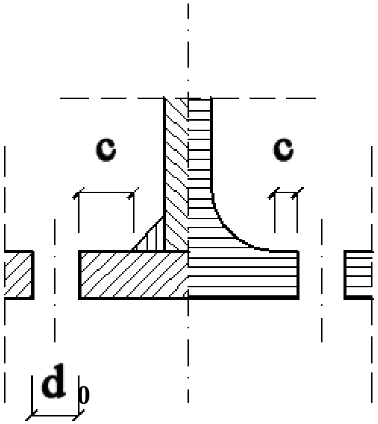
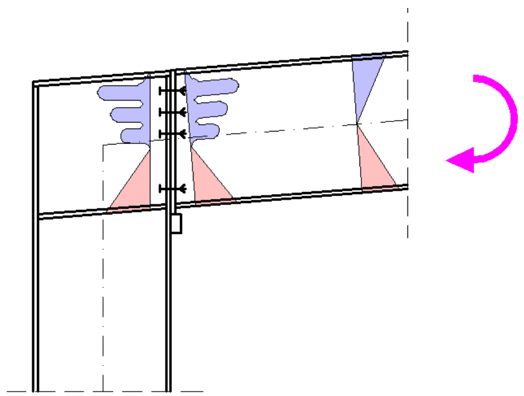


Photo: Author



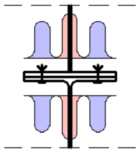
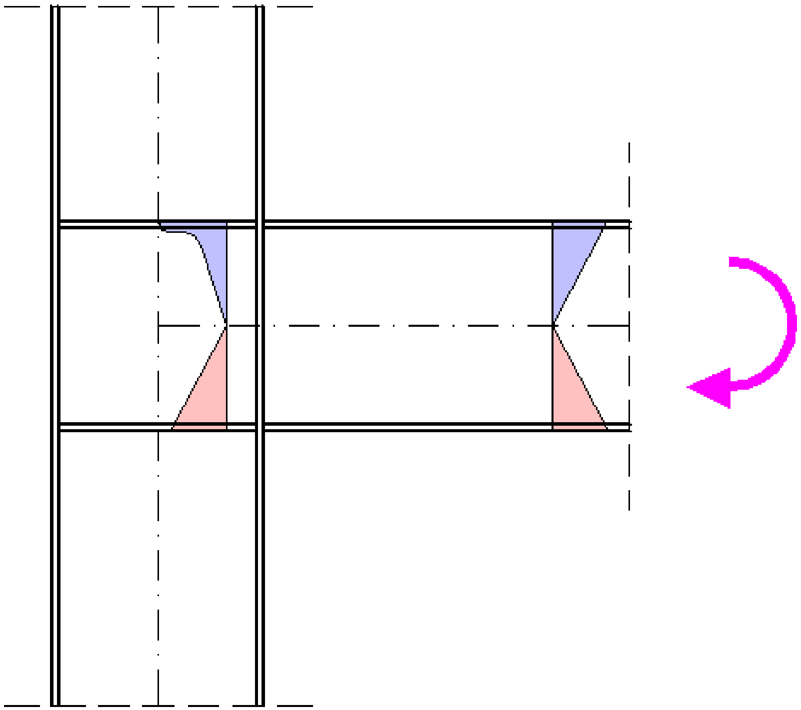


Photo: microstran.com.au



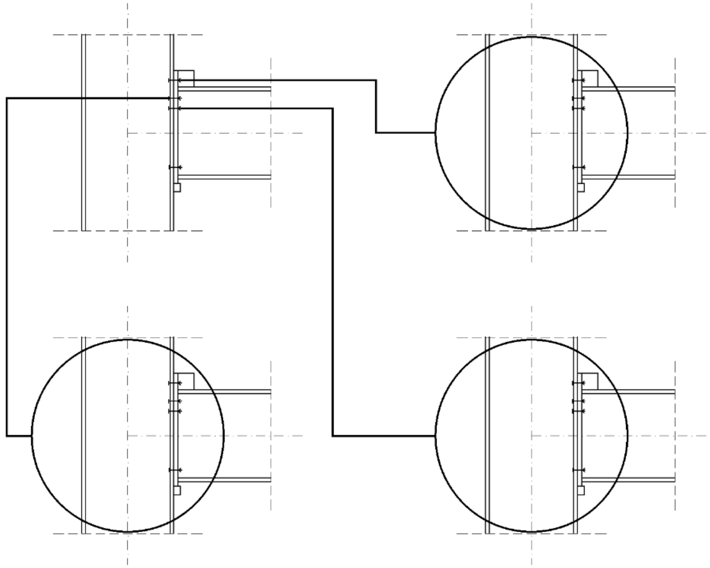
Welded joint - other shape of concentration of stresses than for bolted joint.

Photo: Author

General assumptions for analysis of bolted tension joint:

For bending moment and shear force from beam:

- bending moment is presented as couple of forces; tensile force acts on bolts in tensed part of joint, compressive one acts on compressed part of joint;
- shear force acts on compressed part of joint;
- resistance for bending moment is calculated as efect of equivalent resistances of rows of bolts;
- resistances depends on category of joint (D / E);



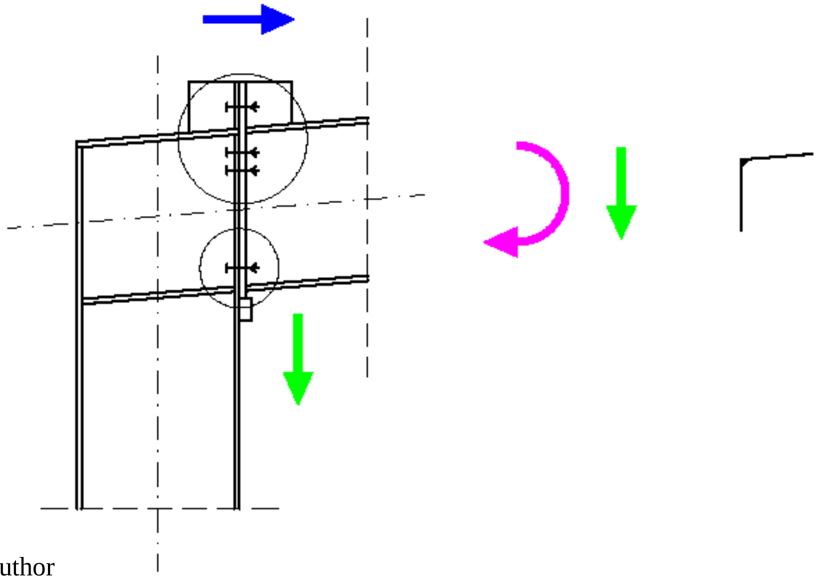
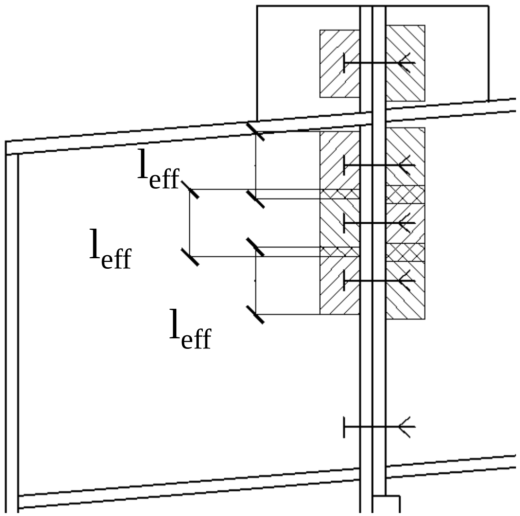


Photo: Author

Calculation model: effective area of stress concentration - effective length

Flange, plate → l_{eff}

Web → b_{eff} (other symbol, but value the same as for flange / plate l_{eff})



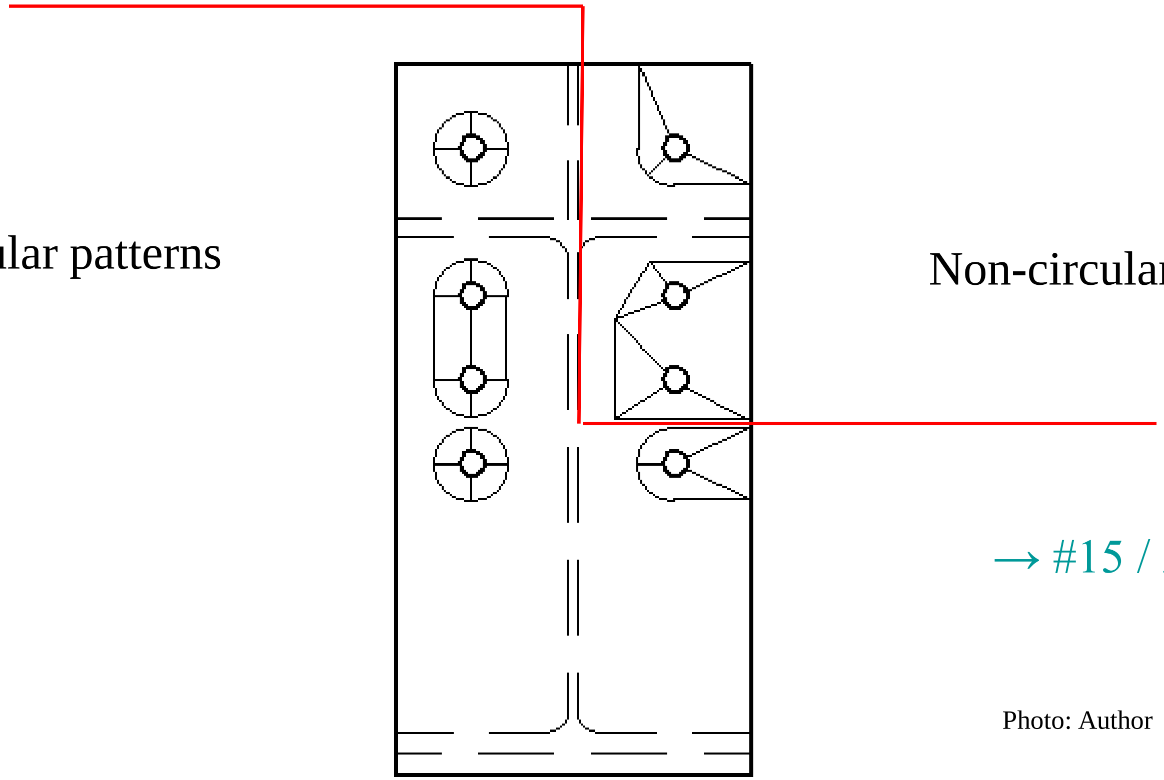
→ #15 / 19

Photo: Author

There is possible, that effective areas from two row of bolts would be common. In this situation we must analysed group of bolts Σl_{eff} , not separate bolts l_{ef} .

Σl_{eff} is important for resistance only, l_{ef} is important for resistance and stiffness.

Generally, breakage of plate / flange is possible by two ways:



Circular patterns

Non-circular patterns

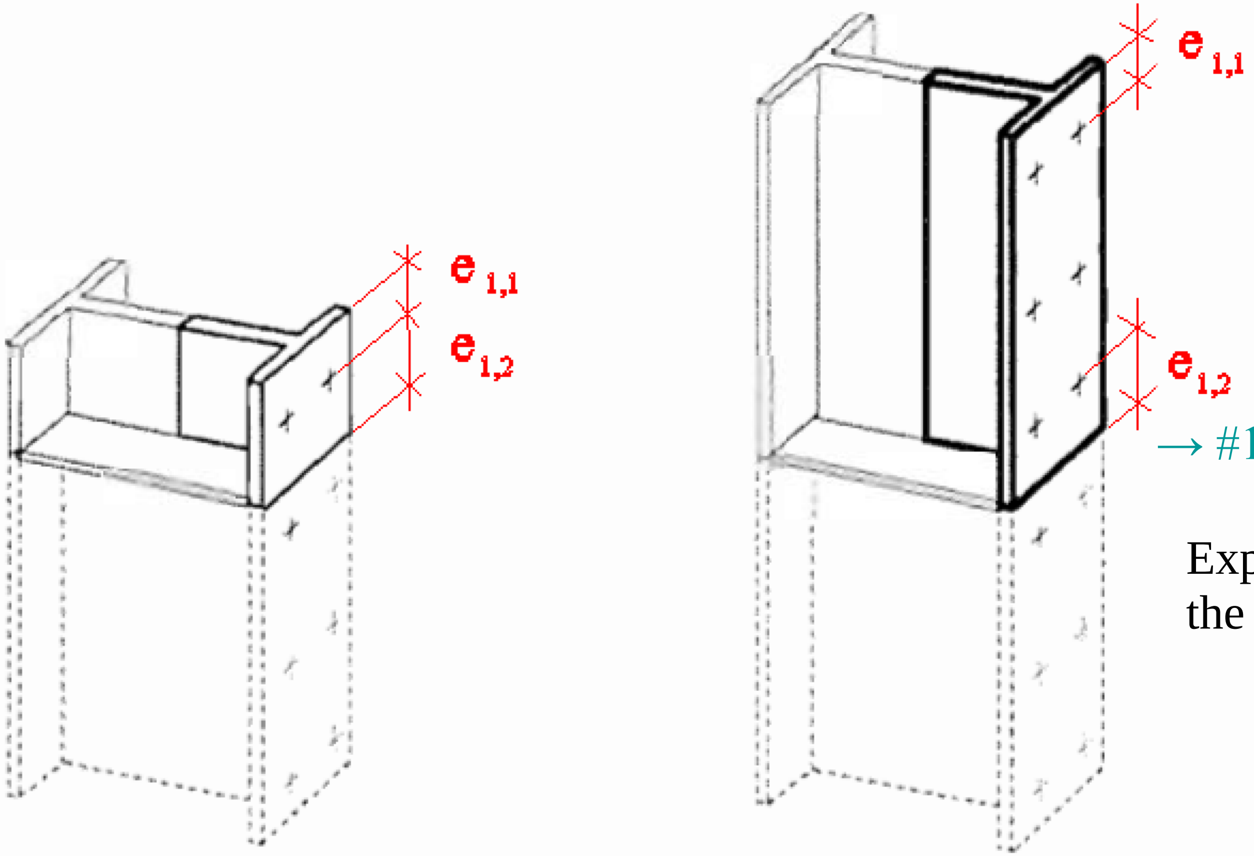
→ #15 / 20

Photo: Author

There are different values of l_{eff} for both. We must calculate l_{eff} for both and take into following consideration less of them.

$e_{1,1}$ – distance from bolt to end of column's flange

Photo: Author



→ #15 / 21

Explanation is not given in the Polish version of EN

$e_{1,2}$ – the least distance from bolt to the nearest stiffener

The information in the Eurocode (row name) ↔ (location) is not completely clear; other interpretations can also be found in the literature

Analysis of literature and Eurocode indicates existence of 4 differently working rows of bolts. Descriptions from EN 1993-1-8 will be given for these four series.

One over flange of beam / column stiffener
First below flange of beam / column stiffener
Next below flange of beam / column stiffener
Last below flange of beam / column stiffener

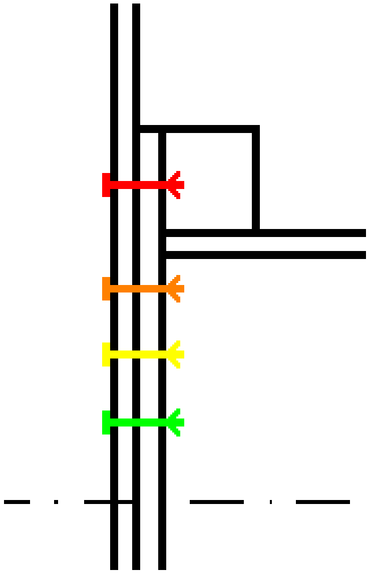
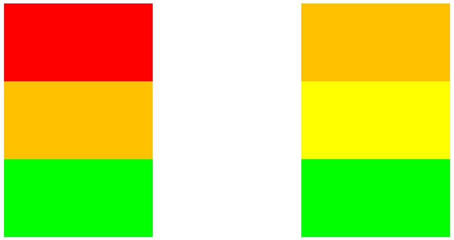


Photo: Author

The most often, one of two situations is applicated:



→ #15 / 22

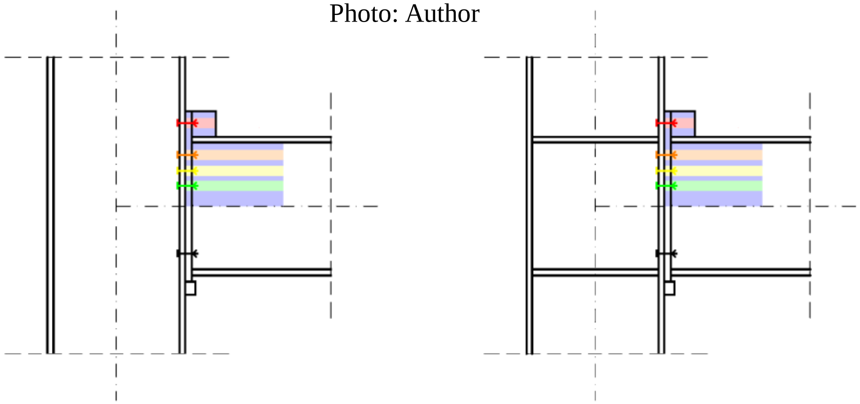
End-plate / beam web

(Web stiffeners doesn't matter)

→ #15 / 23

EN 1993-1-8 tab. 6.6

Photo: Author



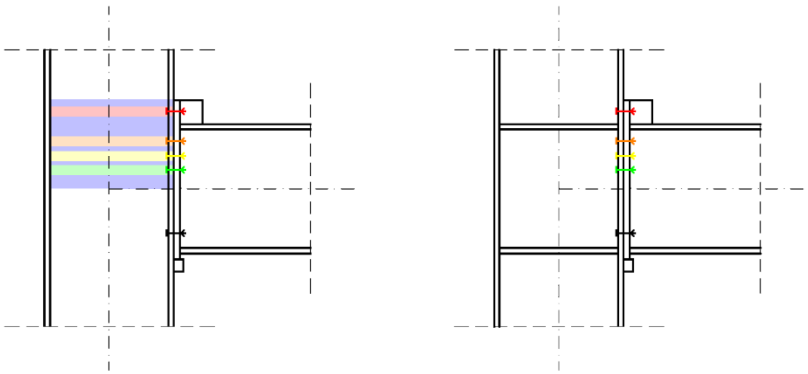
Bolt-row location	Bolt-row considered individually		As part of a group of bolt-rows	
	Circular $l_{eff,\,cp}$	Non-circular $l_{eff,\,nc}$	Circular $\Sigma l_{eff,\,cp}$	Non-circular $\Sigma l_{eff,\,nc}$
Bolt-row outside tension flange of beam	min ($2\pi m_x$; $\pi m_x + w$; $\pi m_x + 2e$)	min ($4m_x + 1{,}25e_x$; $e + 2m_x + 0{,}625e_x$; $0{,}5b_p$; $0{,}5w + 2m_x + 0{,}625e_x$)	-	-
First bolt-row below tension flange of beam	$2\pi m$	αm	$\pi m + p$	$0{,}5p + \alpha m - 2m - 0{,}625e$
Other inner bolt-row	$2\pi m$	$4m + 1{,}25e$	$2p$	p
Other end row-bolt	$2\pi m$	$4m + 1{,}25e$	$\pi m + p$	$2m + 0{,}625e + 0{,}5p$

Unstiffened column flange / unstiffened column web

→ #15 / 24

EN 1993-1-8 tab. 6.4

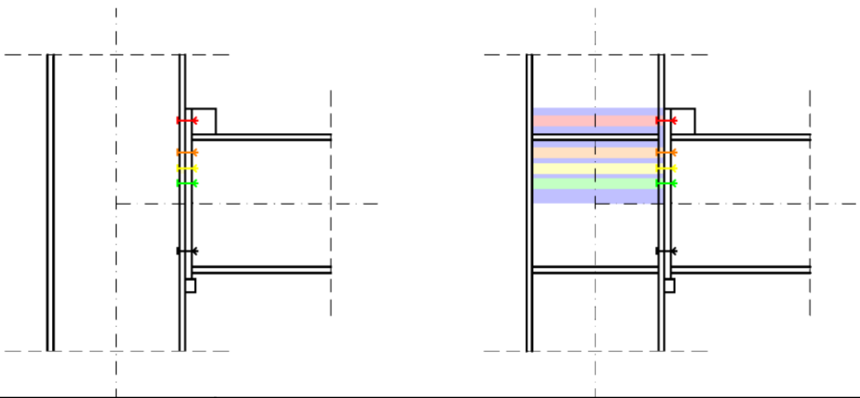
Photo: Author



Bolt-row location	Bolt-row considered individually		As part of a group of bolt-rows	
	Circular $l_{eff,\,cp}$	Non-circular $l_{eff,\,nc}$	Circular $\Sigma l_{eff,\,cp}$	Non-circular $\Sigma l_{eff,\,nc}$
(Top) end row bolt	$\min(2\pi m\ ;\ \pi m + 2e_{1,1})$	$\min(4m + 1{,}25e\ ;\ 2m + 0{,}625e + 2e_{1,1})$	$\min(\pi m + p\ ;\ 2e_{1,1} + p)$	$\min(2m + 0{,}625e + 0{,}5p\ ;\ e_{1,1} + 0{,}5p)$
Inner bolt-row	$2\pi m$	$4m + 1{,}25e$	$2p$	p
(Bottom) end bolt row	$\min(2\pi m\ ;\ \pi m + 2e_{1,b})$	$\min(4m + 1{,}25e\ ;\ 2m + 0{,}625e + 2e_{1,b})$	$\min(\pi m + p\ ;\ 2e_{1,b} + p)$	$\min(2m + 0{,}625e + 0{,}5p\ ;\ e_{1,b} + 0{,}5p)$

Part not completely clear in Eurocode; $e_{1,1}$ according to #15 / 21 ; $e_{1,b}$ could be problably taken as distance to bottom end of column or to joint in lower lewel of frame

Photo: Author



Stiffened column flange / stiffened column web

→ #15 / 25

EN 1993-1-8 tab. 6.5

Bolt-row location	Bolt-row considered individually		As part of a group of bolt-rows	
	Circular $l_{eff, cp}$	Non-circular $l_{eff, nc}$	Circular $\Sigma l_{eff, cp}$	Non-circular $\Sigma l_{eff, nc}$
End bolt-row adjacent to a stiffener	min $(2\pi m\ ;\ \pi m + 2e_{1,1})$	min $(e_{1,1} + \alpha m - 2m - 0{,}625e\ ;\ \alpha m)$	-	-
Bolt-row adjacent to a stiffener	$2\pi m$	αm	$\pi m + p$	$0{,}5p + \alpha m - 2m - 0{,}625e$
Other inner bolt-row	$2\pi m$	$4m + 1{,}25e$	$2p$	p
Other end bolt-row	min $(2\pi m\ ;\ \pi m + 2e_{1,2})$	min $(4m + 1{,}25e\ ;\ 2m + 0{,}625e + 2e_{1,2})$	min $(\pi m + p\ ;\ 2e_{1,2} + p)$	min $(2m + 0{,}625e + 0{,}5p\ ;\ e_{1,2} + 0{,}5p)$

Recommendation in literature

Flange cleat

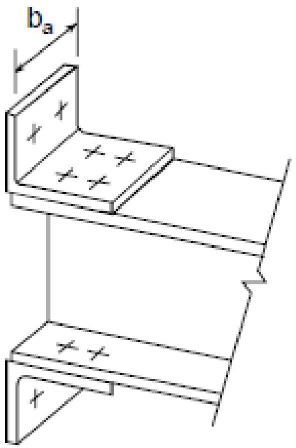


Photo: EN 1993-1-8 fig. 6.12

$$l_{eff} = b_a / 2$$

Photo: Behaviour of stiffened flange cleat joints, D. SkejicD. Dujmovic, D. Beg

<u>Informal</u> remarks on the effect of the reinforcing rib above the beam flange

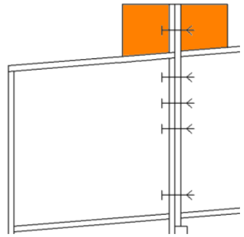
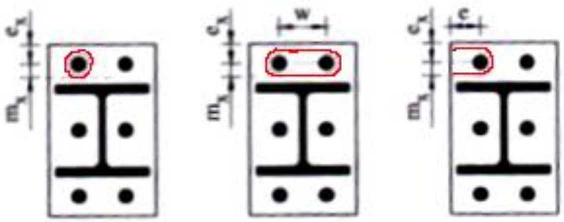


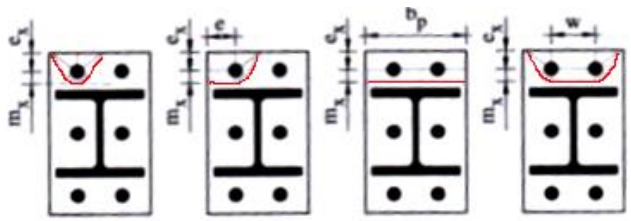
Photo: Author

Circular patterns

Non-circular patterns



1 2 3



1 2 3 4

Photo: J. Goczek, Ł. Supeł, M. Gajdzicki, Przykłady obliczeń konstrukcji stalowych, Politechnika Łódzka 2011

→ #15 / 26

Formulas for effective lengths given, in the table, apply to specific failure mechanisms. Reinforcement of plate over beam flange by a vertical rib (→ #15 / 4) will make **second** mechanism in circular ($\pi m_x + w$) and **third** + **fourth** mechanisms in non-circular ones ($e + 2m_x + 0{,}625e_x$; $0{,}5b_p$) impossible (rib will prevent collapse involving both bolts at the same time). These formulas can be omitted from calculations.

Effective areas in compressed part of column web

→ #15 / 28

EN 1993-1-8 6.2.6.2

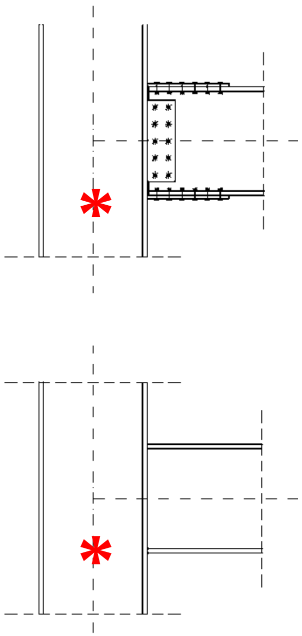
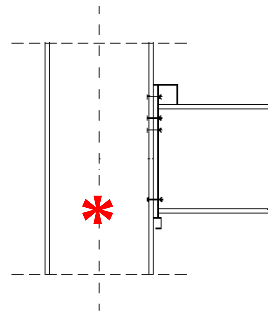
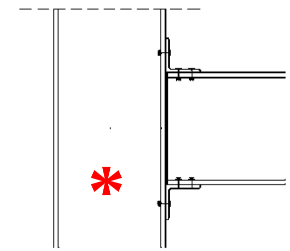
			
$b_{eff,\,c,\,wc}$	$t_{fb} + 2\sqrt{2}\,a_b + 5(t_{fc} + s)$	$t_{fb} + 2\sqrt{2}\,a_p + 5(t_{fc} + s) + s_p$	$2t_a + 0{,}6\,r_a + 5(t_{fc} + s)$

Photo: Author

Effective areas in compressed part of column's web

→ #15 / 29

Column:	s_p	s	d_{wc}
Welded I-beam	min $(t_p + c\ ;\ 2t_p)$	$\sqrt{2}\, a_c$	$h_c - 2(t_{fc} + \sqrt{2}\, a_c)$
Hot rolled I-beam		r_c	$h_c - 2(t_{fc} + r_c)$

c – length of end-plate out off bottom flange of beam

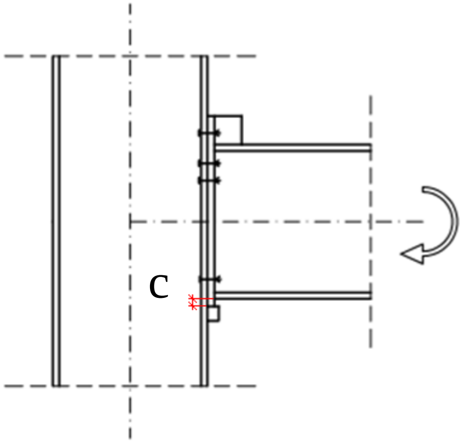


Photo: Author

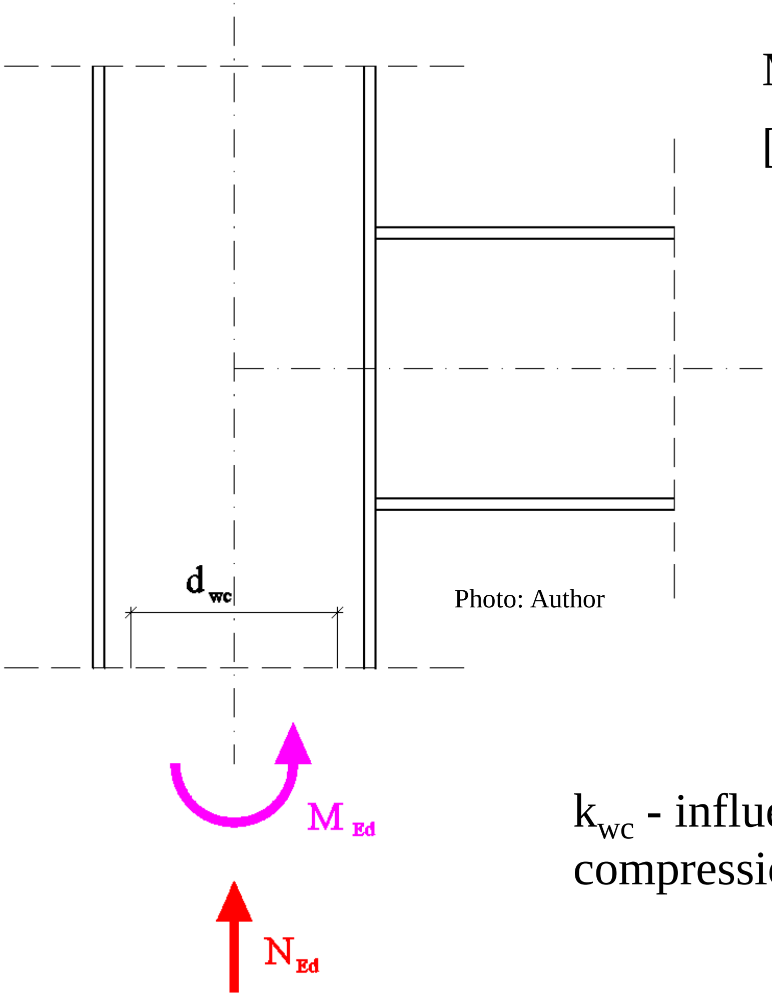
EN 1993-1-8 6.2.6.2

$\bar{\lambda}_p$	ρ
$\leq 0{,}72$	1,0
$> 0{,}72$	$(\bar{\lambda}_p - 0{,}2) / (\bar{\lambda}_p)^2$

$$\bar{\lambda}_p = 0{,}932 \sqrt{[\,(b_{eff,\,c,\,wc}\, d_{wc}\, f_{y,\,wc}) / (E\, t_{wc}^2)\,]}$$

ρ - simplified calculation of instability in compressed part of web - without full calculation of instability factor (χ), only reduction factor.

Effective areas in compressed part of column's web



Max compression for plane part of web (d_{dwc}):

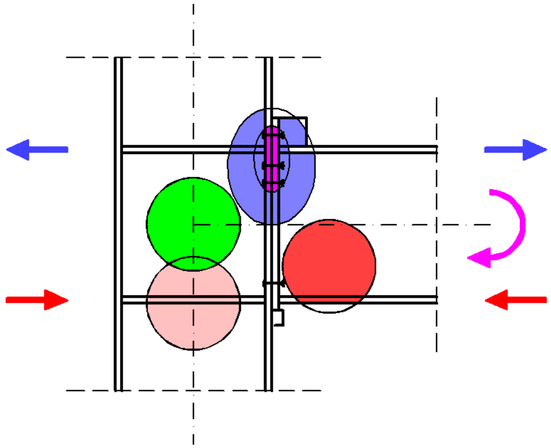
$[\, \sigma\, (N_{ed} + M_{Ed})\,]_{dwc} = \sigma_{com,\, Ed}$

$\sigma_{com,\, Ed} / f_{y,\, wc}$	k_{wc}
$\leq 0{,}7$	1,0
$> 0{,}7$	$1{,}7 - \sigma_{com,\, Ed} / f_{y,\, wc}$

EN 1993-1-8 6.2.6.2

k_{wc} - influence of double - transverse and longitudinal - compression of the column flange

Sub-parts of tension joint



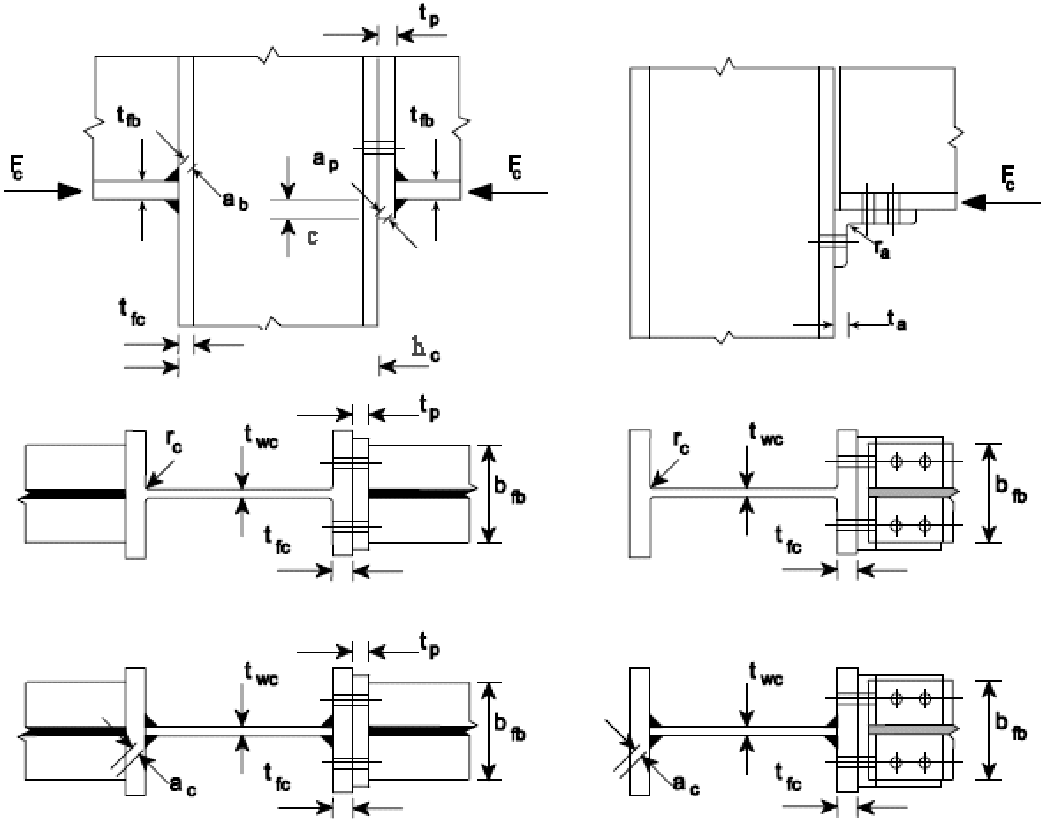
For these sub-parts are calculated equivalnent resistances

Photo: Author

Bolted joint	Welded joint
Column web in tension → #t / 58, 60	Column web in tension → #t / 59-60
Beam web in tension → #t / 61	
Column flange in bending → #t / 62-65	Column flange in bending → #t / 66
End-plate in bending → #t / 67	
Column web in shear → #t / 55-57	
Column web in transverse compression → #t / 54	
Beam flange and web in compression → #t / 53	

→ #15 / 5

Dimensions



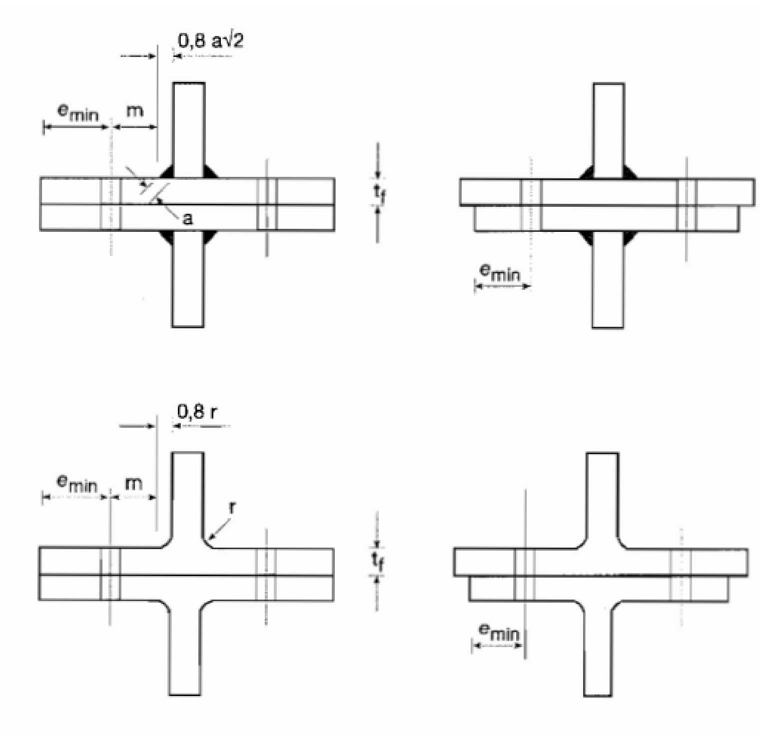
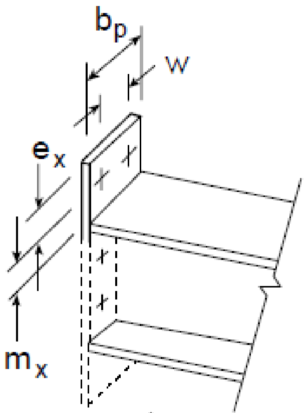
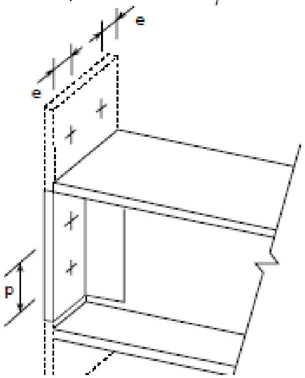


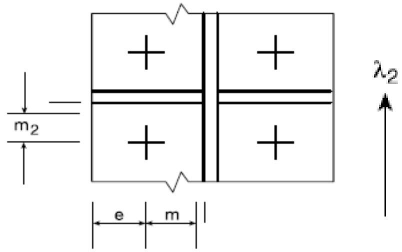
Photo: EN 1993-1-8 fig. 6.2 , fig. 6.6

→ #15 / 6

Dimensions

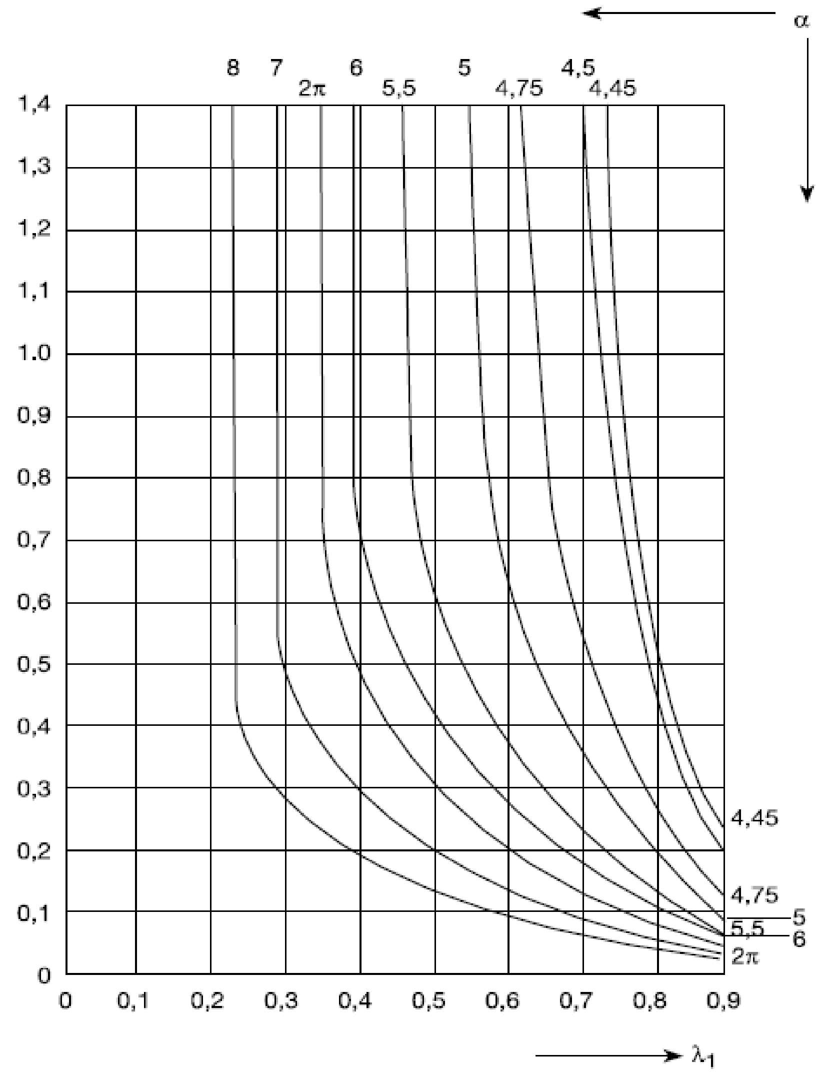


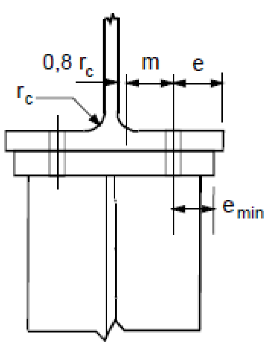




$$\lambda_1 = \frac{m}{m + e}$$

$$\lambda_2 = \frac{m_2}{m + e}$$





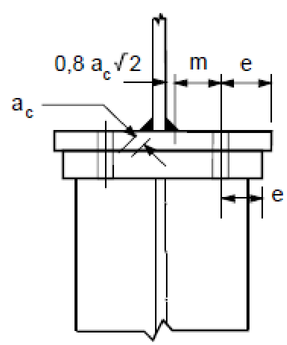
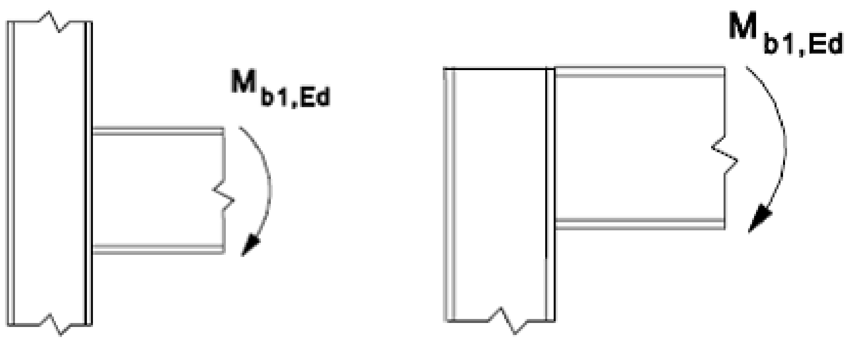
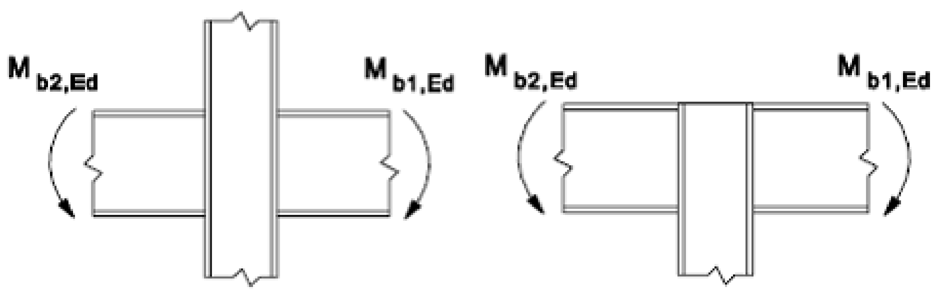


Photo: EN 1993-1-8 fig 6.8, 6.10. 6.11

→ #15 / 10

Beam-column geometry

EN 1993-1-8 tab. 5.4

<table>
<tr><th>Type of joint configuration</th><th>Action</th><th>Ttransformation parameter β</th></tr>
<tr><td>
</td><td>$M_{b1,\ Ed}$</td><td>$\beta \approx 1$</td></tr>
<tr><td rowspan="4">
</td><td>$M_{b1,\ Ed} = M_{b2,\ Ed}$</td><td>$\beta = 0$ *)</td></tr>
<tr><td>$M_{b1,\ Ed} = M_{b2,\ Ed} > 0,0$</td><td>$\beta \approx 1$</td></tr>
<tr><td>$M_{b1,\ Ed} = M_{b2,\ Ed} < 0,0$</td><td rowspan="2">$\beta \approx 2$</td></tr>
<tr><td>$M_{b1,\ Ed} + M_{b2,\ Ed} = 0,0$</td></tr>
<tr><td colspan="3">*) in this cane the value of β is the exact value rater than an approximation</td></tr>
</table>

→ #15 / 11

EN 1993-1-8 tab. 6.3

β	ω
$0{,}0 \leq \beta \leq 0{,}5$	$\omega = 1{,}0$
$0{,}5 \leq \beta < 1{,}0$	$\omega = \omega_1 + 2(1 - \beta)\,(1 - \omega_1)$
$\beta = 1{,}0$	$\omega = \omega_1$
$1{,}0 < \beta < 2{,}0$	$\omega = \omega_1 + 2(1 - \beta)\,(\omega_2 - \omega_1)$
$\beta = 2{,}0$	$\omega = \omega_2$

$$\omega_1 = 1 / \sqrt{[1 + 1{,}3(b_{eff,\,c,\,wc}\ t_{wc} / A_{vc})^2]}$$

$$\omega_2 = 1 / \sqrt{[1 + 5{,}2(b_{eff,\,c,\,wc}\ t_{wc} / A_{vc})^2]}$$

$$A_{vc} = A_{vc,\,column}\ \ (\approx h_w\ t_w)$$

β , ω - two ways to take into account shape of join (one beam to column / two beams to column…)

Beam flange and beam web in compression

The same rules for welded and bolted joints

EN 1993-1-8 (6.21)

$$F_{c,\,fb,\,Rd} = M_{c,\,Rd} / (h - t_{fp})$$

$M_{c,\,Rd}$ – resistance of beam

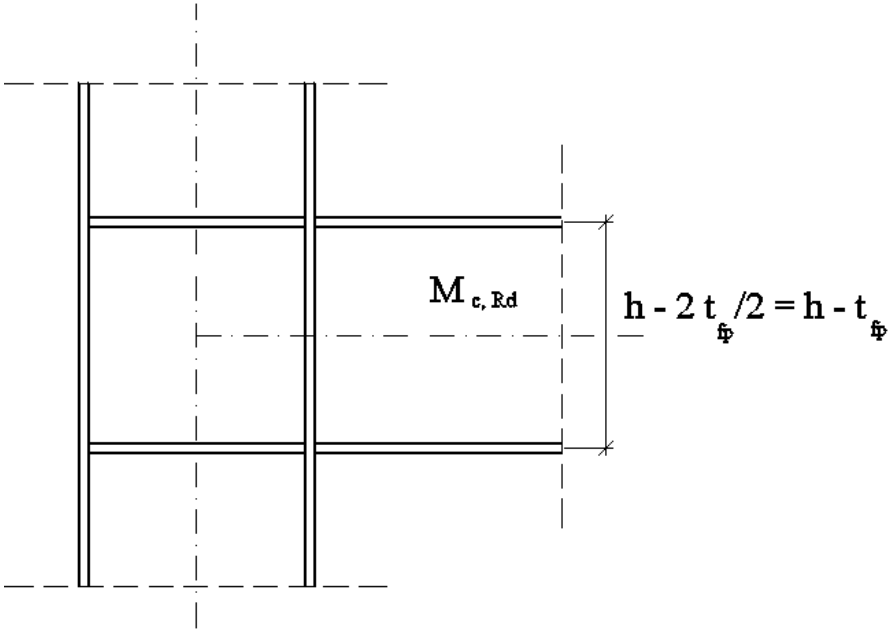
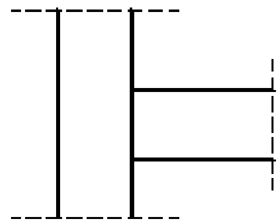
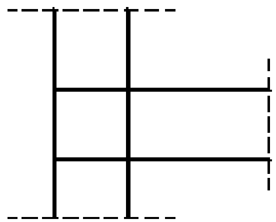


Photo: Author

Column web in transverse compression

The same rules for welded and bolted joints

EN 1993-1-8 6.2.6.2

		
$F_{c,\,wc,\,Rd}$	$\min(1\ \omega\ k_{wc}\ b_{eff,\,c,\,wc}\ t_{wc}\ f_{y,\,wc}\ /\ \gamma_{M0}\ ;$ $\rho\ \omega\ k_{wc}\ b_{eff,\,c,\,wc}\ t_{wc}\ f_{y,\,wc}\ /\ \gamma_{M0}) =$ $= \min(1\ ;\ \rho)\ \omega\ k_{wc}\ b_{eff,\,c,\,wc}\ t_{wc}\ f_{y,\,wc}\ /\ \gamma_{M0}$	= resistance of stiffener (→ lecture #21)

$b_{eff,\,c,\,wc}$ – effecive with of column web in compression → #t / 45

ρ – reduction factor for plate buckling → #t / 46

k_{wc} – reduction factor for longitudinal compression in column web→ #t / 47

ω – reduction factor for interaction → #t / 52

t_{wc} – thickness of column web

$\gamma_{M0} = 1{,}0$

Photo: Author

Column web in shear

The same for welded and bolted joints

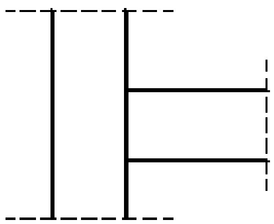
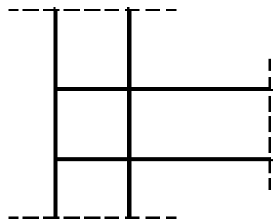
EN 1993-1-8 6.2.6.1

$$V_{wp,\,Rd} = [(0{,}9\ f_{y,\,wc}\ A_{vc}) / (\gamma_{M0}\ \sqrt{3})] + V_{wp,add,\,Rd}$$

$\beta \rightarrow$ #t / 51-52

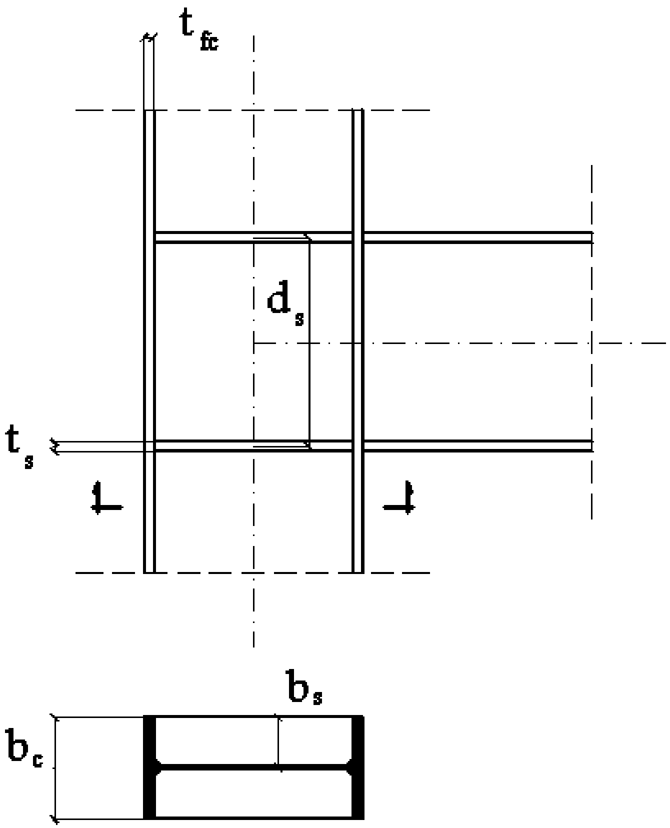
A_{vc} – active area of web forshear force $\rightarrow$ #t / 52

Photo: Author

		
$V_{wp,add,\,Rd}$	0	$\min [\ 4M_{pl,\,fc,\,Rd} / d_s\ ;\ (2M_{pl,\,fc,\,Rd} + 2M_{pl,\,st,\,Rd}) / d_s\ ]$

$M_{pl,\,fc,\,Rd}$, $M_{pl,\,st,\,Rd}$, $d_s \rightarrow$ #t / 56

EN 1993-1-8 6.2.6.1



$$M_{pl,\,fc,\,Rd} = 0{,}25\, b_c\, t_{fc}^2\, f_{y,\,fc} / \gamma_{M0}$$

$$M_{pl,\,st,\,Rd} = 0{,}50\, b_s\, t_s^2\, f_{y,\,s} / \gamma_{M0}$$

$$\gamma_{M0} = 1{,}0$$

Photo: Author

If slenderness web: $d_{wc} / t_{wc} > 69\varepsilon \rightarrow$ supplementary web plates are needed (EN 1993-1-8 6.2.6.1)

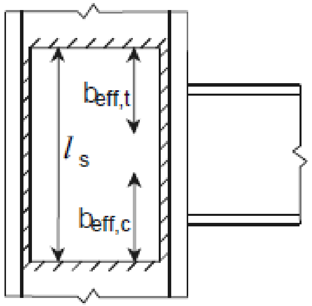
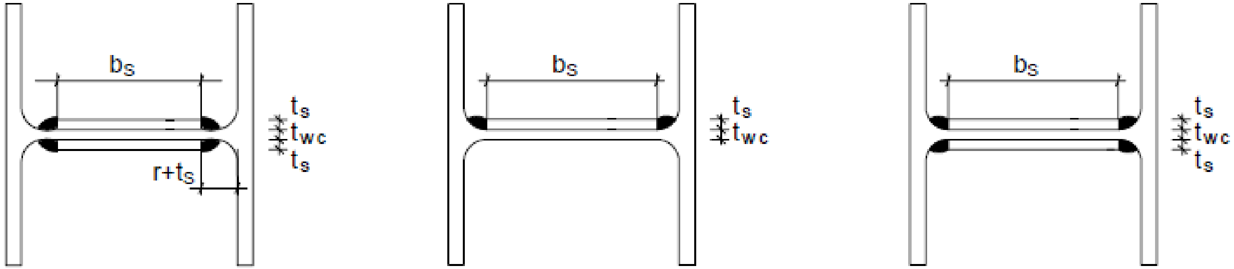


Photo: EN 1993-1-8 fig. 6.5



Requirements for additional plates:

$$b_s / t_s \leq 40\varepsilon;$$

$$b_s \geq d_{wc}$$

$$t_s \geq t_{wc}$$

$$f_{y,\,s} = f_{y,\,wc}$$

Influence on resistance: always there are taken into consideration only one plate (even if there are two supplementary plates)

$$A_{vc,\,new} = A_{vc} + b_s\, t_{wc}$$

Column web in tension

There are different rules for bolted and welded joints

EN 1993-1-8 6.2.6.3

Bolted joint:

Column: $F_{t,\ wc,\ Rd} = \omega\ b_{eff,\ t,\ wc}\ t_{wc}\ f_{y,\ wc}\ /\ \gamma_{M0}$

$b_{eff,\ t,\ wc} = l_{eff,\ c} \rightarrow$ #t / 41, 42

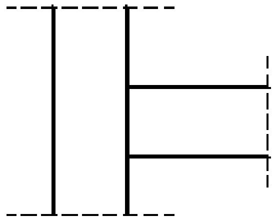
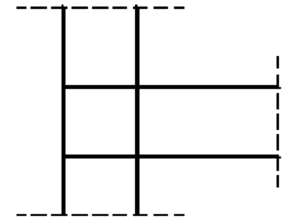
$\omega \rightarrow$ #t / 52

t_{wc} – thickness of column web

$\gamma_{M0} = 1{,}0$

Welded joint:

EN 1993-1-8 6.2.6.3

		Photo: Author 
$F_{t,\ wc,\ Rd}$	$\omega\ b_{eff,\ t,\ wc}\ t_{wc}\ f_{y,\ wc}\ /\ \gamma_{M0}$	If $t_s \geq t_{fb}$ and $R_{web} \geq R_s \rightarrow \infty$ this is resistance of stiffener (→ lecture #21)

$b_{eff,\ t,\ wc} = t_{fb} + 2\sqrt{2}\ a_b + 5(t_{fc} + s)$

$\omega \rightarrow$ #t / 52

t_{wc} – thickness of column web

$\gamma_{M0} = 1{,}0$

t_{fb} – thickness of beam flange

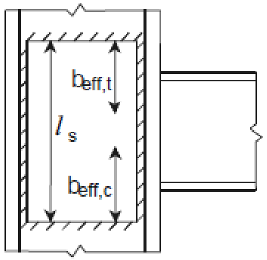
a_b – thickness of weld

$s \rightarrow$ #t / 46

t_{fc} – thickness of column flange

Column web tension, supplementary web plates, influence on resistance

EN 1993-1-8 6.2.6.3



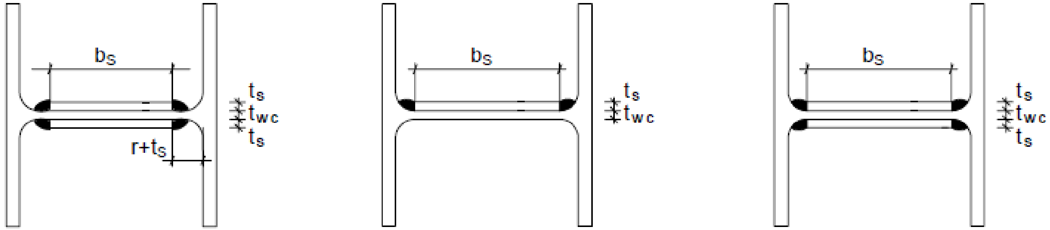


Photo: EN 1993-1-8 fig. 6.5

New value of t_{wc} in formula on #t / 68:	Supplementary web plate:	Full penetration butt welds between web and supplementary plate, $a \geq t_s$	Filled welds between web and supplementary plate, $a \geq t_s / \sqrt{2}$	
			S235, S275, S355	S420, S460
$t_{wc,\ eff}$ =	One side	1,5 t_{wc}	1,4 t_{wc}	1,3 t_{wc}
	Both sides	2,0 t_{wc}		

The same rules for bolted and welded joints

Beam web in tension

Part important for bolted joint only

EN 1993-1-8 6.2.6.3

$$F_{t,\,wb,\,Rd} = \omega \; b_{eff,\,t,\,wb} \; t_{wb} \; f_{y,\,wb} \;/\; \gamma_{M0}$$

$b_{eff,\,t,\,wb} = l_{eff,\,b} \rightarrow$ #t / 40

$\omega \rightarrow$ #t / 52

t_{wb} thickness of beam web

$\gamma_{M0} = 1{,}0$

Column flange in bending

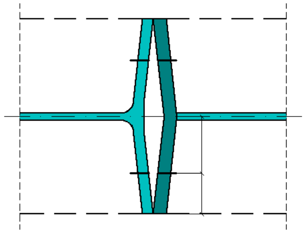
There are different rules for bolted and welded joints

Bolted joint:

We must analyse three different mechanism of destruction, according to prying actions phenomenon

Generally, we must analyse three different mode of destruction; 1st and 2nd with or without prying force and 3rd without prying force.

Mode 2 – plate / flange destruction and bolts destruction



Mode 1 – plate / flange destruction, no bolt destruction

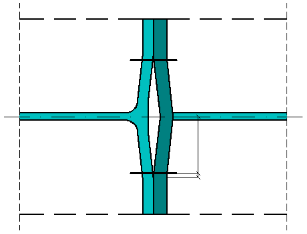
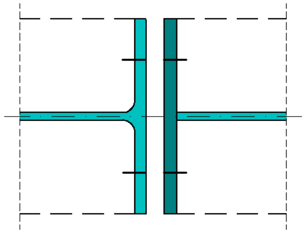


Photo: Author

Mode 3 – bolts destruction, no plate destruction



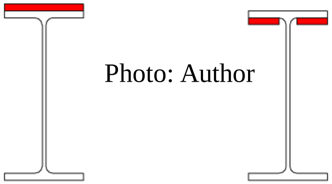
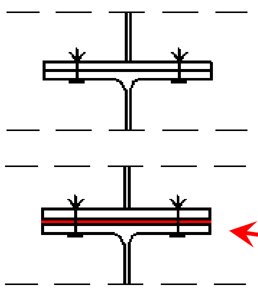
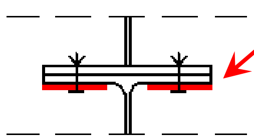


Photo: Author

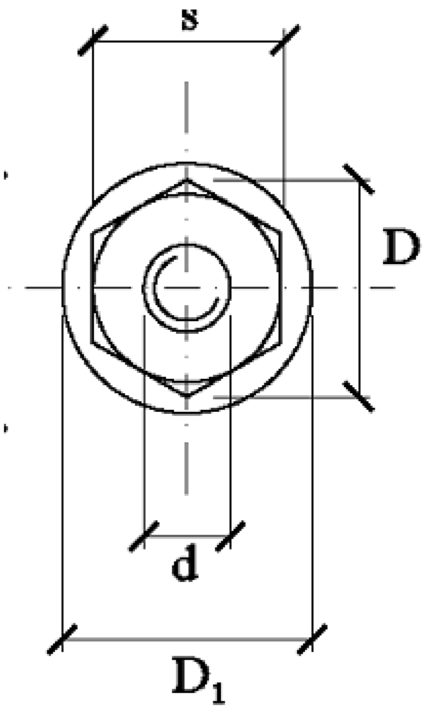
There are two possibilities of flange reinforcement by additional plates. The first is more effective, the second could be easier.

Resistances

Photo: Author	Prying forces		No prying forces: $F_{T,\ 1\text{-}2,\ Rd}$
Mode 1: $F_{T,\ 1,\ Rd} = \min(1.1\ ;\ 1.2)$	Method 1.1	Method 1.2	
	$4\ M_{pl,\ 1,\ Rd} / m$	$(8n - 2e_w)\ M_{pl,\ 1,\ Rd}$ / $[2mn - e_w(m + n)]$	$2\ M_{pl,\ 1,\ Rd} / m$
 Reinforcing by additional plate(s)	$(4\ M_{pl,\ 1,\ Rd} + 2M_{bp,\ Rd}) / m$	$[(8n - 2e_w)\ 4\ M_{pl,\ 1,\ Rd} + 4n\ M_{bp,\ Rd}]$ / $[2mn - e_w(m + n)]$	
Mode 2: $F_{T,\ 2,\ Rd}$	$(2\ M_{pl,\ 2,\ Rd} + n\ \Sigma F_{t,\ Rd}) / (m + n)$		
Mode 3: $F_{T,\ 3,\ Rd}$	$\Sigma F_{t,\ Rd}$		

EN 1993-1-8 tab 6.2

Symbols → #t / 65



$m \rightarrow$ #t / 56

$n = \min(e_{min} \;;\; 1{,}25m)$

$e_w = d_w / 4$

$d_w = D$ or D_1

$l_{eff,\,1} = \min(l_{eff,\,cp} \;;\; l_{eff,\,nc})$

$\Sigma l_{eff,\,1} = \min(\Sigma l_{eff,\,cp} \;;\; \Sigma l_{eff,\,nc})$

$l_{eff,\,2} = l_{eff,\,nc}$

$\Sigma l_{eff,\,2} = \Sigma l_{eff,\,nc}$

Photo: Author

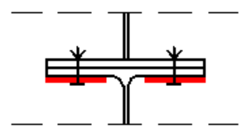
$\Sigma F_{t,\,Rd} \rightarrow$ #t / 80

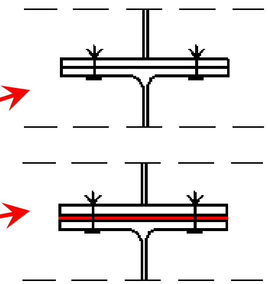
t_{fc} – thickness of column's flange

t_{bp} – thickness of addidional plates

$l_{eff} \rightarrow$ #t / 41, 42

$\Sigma l_{eff} \rightarrow$ #t / 41, 42





$t_{fc} = t_{fc,\,true}$ or $t_{fc,\,true} + t_{bp}$

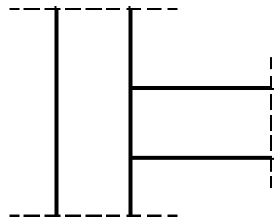
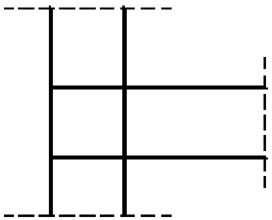
	Bolt-row considered individually	As part of a group of bolt-rows
$M_{pl,\,1,\,Rd}$	$0{,}25\; l_{eff,\,1}\; t_{fc}^2\; f_y \;/\; \gamma_{M0}$	$0{,}25\; \Sigma l_{eff,\,1}\; t_{fc}^2\; f_y \;/\; \gamma_{M0}$
$M_{pl,\,2,\,Rd}$	$0{,}25\; l_{eff,\,2}\; t_{fc}^2\; f_y \;/\; \gamma_{M0}$	$0{,}25\; \Sigma l_{eff,\,2}\; t_{fc}^2\; f_y \;/\; \gamma_{M0}$
$M_{bp,\,Rd}$	$0{,}25\; l_{eff,\,1}\; t_{bp}^2\; f_{y,\,bp} \;/\; \gamma_{M0}$	$0{,}25\; \Sigma l_{eff,\,1}\; t_{bp}^2\; f_{y,\,bp} \;/\; \gamma_{M0}$

EN 1993-1-8 tab 6.2

Photo: Author

Welded joint

EN 1993-1-8 4.10

		
$F_{t,\ wc,\ Rd}$	$b_{eff,\ b,\ fc}\ \ t_{fc}\ \ f_{y,\ fc}\ /\ \gamma_{M0}$	If $t_s \geq t_{fb}$ and $R_{web} \geq R_s \rightarrow \infty$ this is resistance of stiffener ($\rightarrow$ lecture #21)

$b_{eff,\ t,\ fc} = t_{wc} + 2s + 7\ k\ t_{fc}$

$k = \min\ [\ (t_{fc} / t_{bp}) \cdot (f_{y,\ f} / f_{y,\ p})\ ;\ 1{,}0\ ]$

$s \rightarrow$ #t / 46

Photo: Author

t_{fc} – thickness of column flange

t_{bp} – thickness of end plate of beam

End plate in bending

Part important for bolted joint only.

The same rules and formulas as for column flange in bending;

Important change:

- l_{eff} , Σl_{eff} according to #t / 40;
- Instead t_{fc} (thickness of column flange) is calculated t_p (thickness of end plate);
- No influence of additional plates.

Analysis of the weaknest component for tension joint is more complicated than for shear joint.

Cooperation of sub-parts of tension joint is completely other type as in case of shear joint. For tension joint we can't divided requirements into resistance of shank (connection) and resistance of contact or resistance of elements.

Photo: uwyo.edu

For tension joint:

- we take into consideration rows of bolt (the most often composed of two bolts);
- for each row of bolts analise these sub-parts of joint, which cooperated directly with considered row;
- for each these sub-parts (shank of bolts, plates, elements…) analise their resistance;
- the weaknest sub-part (the smallest resistance) is equivalent resistance of considered row of bolt.

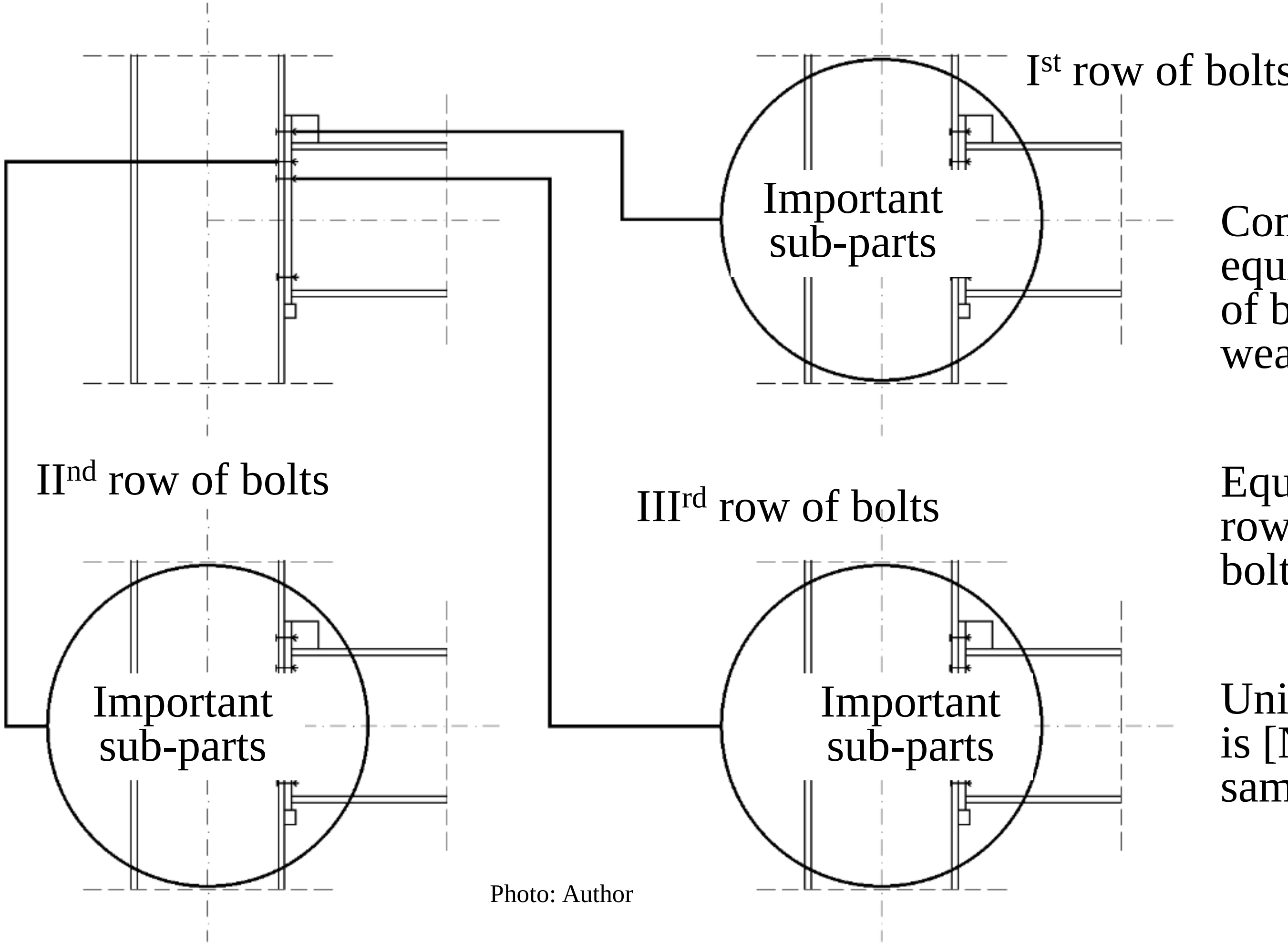


Photo: Author

Component method: equivalent resistance of row of bolt = resistance of the weaknest link.

Equivalent resistance of Ist row of bolts, IInd row of bolts, IIIrd row of bolts…

Unit of equivalent resistance is [N] (unit of force – the same unit as for shear joint).

Resistance of joint = Σ [(equivalent resistance of nth row of bolts) · (their arm of action)]

Global bending moment / Resistance ≤ 1,0

Dimensions

Arms of actions: → #15 / 8

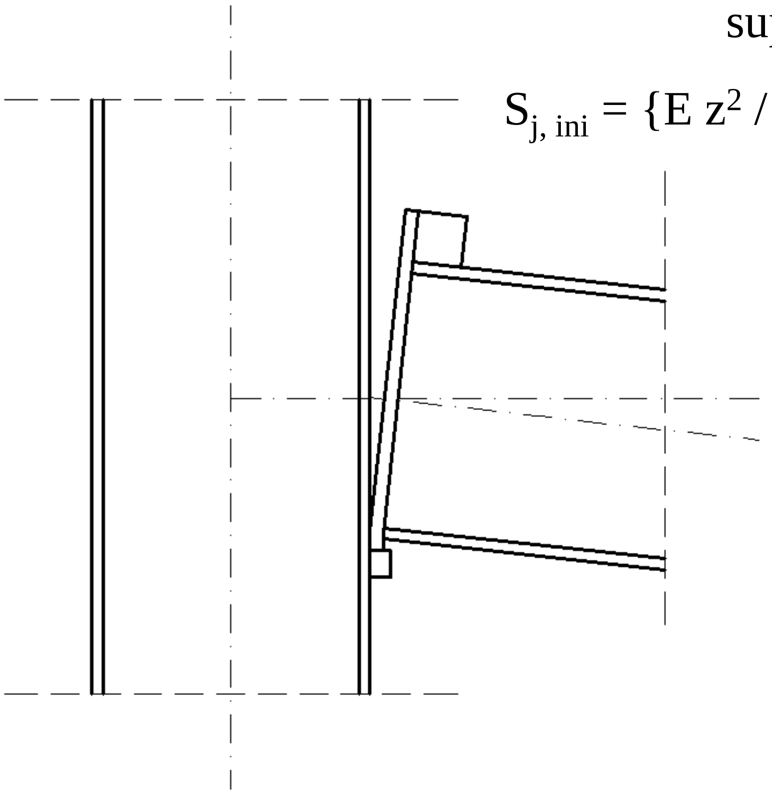
"frame" joints:

$$S_{j,\ ini} = E\ z^2 / [\ S\ (1 / k_i)]$$

support joints:

$$S_{j,\ ini} = \{E\ z^2 / [\ S\ (1 / k_i)]\}\ e / (e + e_k)$$

Photo: Author



Theoretical situation: no bolts in joint – rotation of beam around bottom part of compressed zone. Theoretical axis of rotation: centre of gravity (CoG) of compressed beam's flange.

Arm of action z is defined as distance between CoG of bottom flange to CoG of top flange or axis of bolt (AoB):

→ #15 / 9

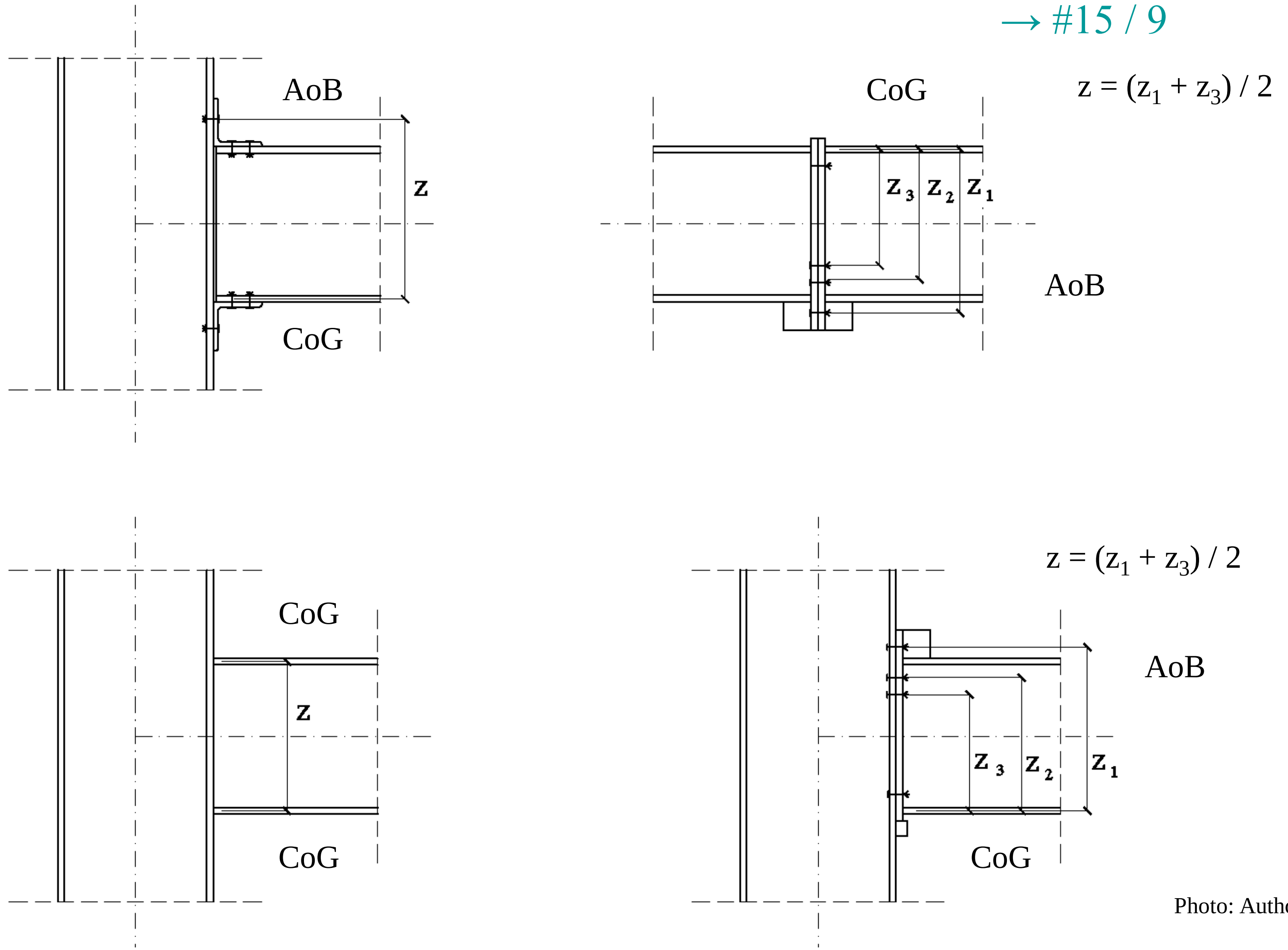


Photo: Author

Often misunderstanding during calculation of tension joint: identification of **equivalent resistance** of row of bolts with **real resistance** of row of bolts.

Photo: uwyo.edu

Equivalent resistance = min (**real resistance** of row of bolts, resistance of web of column, resistance of flange of column, resistance of end-plate, resistance of web of beam…)

Real resistance of row of bolt could be much more bigger than **equivalent resistance**. Equivalent resistance could be, for example, resistance of web of column (if web of column is the weaknest link). For such situation, increasing of resistance of bolts will no incerase resistance of joint: small resistance of web still will be small.

Shear joint – 5 easy requirements (→ #t / 26), the weaknest element can be found very quickly, after checking each of requirement.

Tension joint – one complicated global requirement (bending moment / resistance). Failure of this condition will be noticed only after long time of calculation. This means the weaknest element will be identified only after long time of calculation.

Equivalent resistance = min (real resistance of row of bolts, resistance of web of column, resistance of flange of column, resistance of end-plate, resistance of web of beam…)

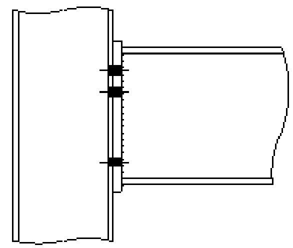
Equivalent resistance: in most cases it is not strength of bolt

Various phenomena are important for various sub-parts of joint. Three phenomena, regarding directly resistance of tension joint, were detaily presented on Lecture #18: tension resistance of shank of bolt. Preloading force and punching resistance. At now, information about local bending of flange of column and end plate, and local tension of webs of column and beam will be presented.

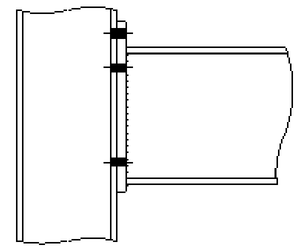
For analisis of local bending, very important is prying action.

Additional rules

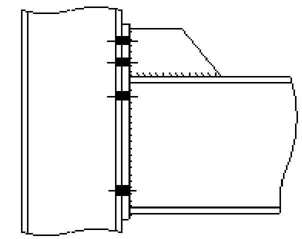
There are four main types of bolted joint for beam-column joint:



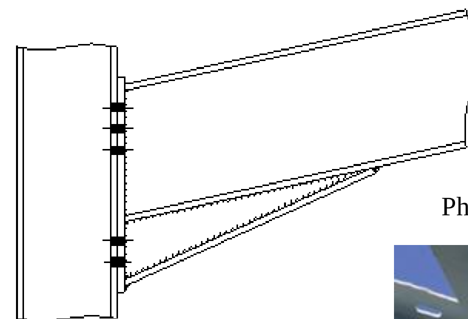
Full depth end plate



Extended end plate



Stiffened depth end plat



Haunched beam (may also be exten

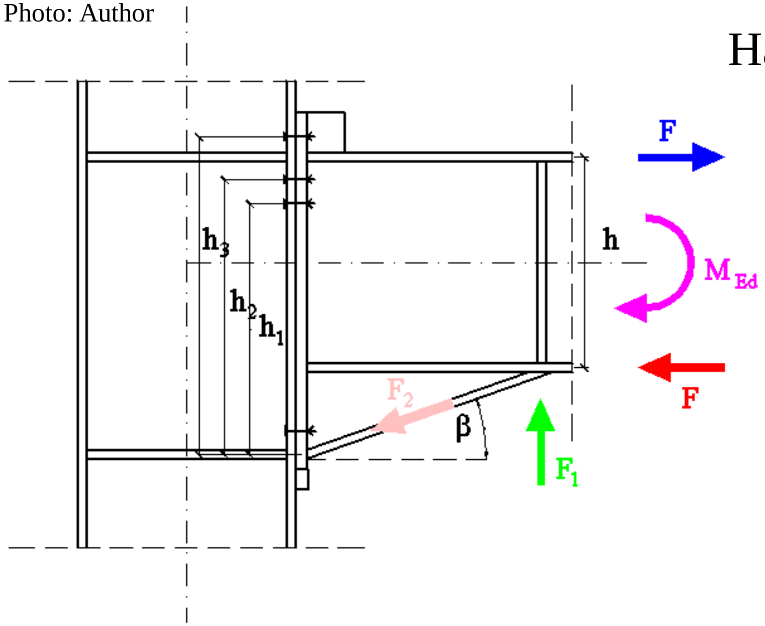
Photo: steelconstruction.info

Photo: uwyo.edu

Photo: lusas.com

Photo: gic-edu.com

Photo: Author



Haunched beam - way to increase arms of action → increase resistance $M_{j,\,Rd}$

Requirement:

$\beta \leq 45^{o}$

EN 1993-1-8 p.6.2.6.7

There are transverse compression of beam web (F_1) and compression of haunched flange (F_2):

$$F = M_{Ed} / h$$

$$F_1 = F \, tg \, \beta$$

$$F_2 = F / \cos \beta$$

Calculations of resistance are the same as for transverse compression of web and compression of flange.

EN 1993-1-8   6.2.7.2 (7)

Balance between **compressed zone** and **tensed zone**:

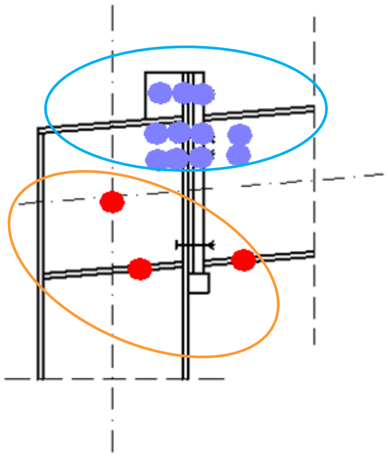


Photo: Author

$$\Sigma F_{t,\,Rd} \leq F_{c,\,Rd} = \min\left(F_{c,\,wc,\,Rd} \;\; ; \;\; F_{c,\,fb,\,Rd} \;\; ; \;\; V_{wp,\,Rd} / \beta\right)$$

$\Sigma F_{t,\,Rd}$ = total resistance of all bolts in tensed zone, i.e. :

$\Sigma_{i=1\text{-}3}$ min (column web tensed around row #i; column flange bending around row #i; end-plate bending around row #i; beam web tensed around row #i)

If condition is not met, we reduce equivealne resistance of bolt rows computationally, starting from bolt closest to compression zone:

$$F_{t,\,3,\,Rd} = F_{c,\,Rd} - F_{t,\,1,\,Rd} - F_{t,\,2,\,Rd}$$

or even

$$F_{t,\,3,\,Rd} = 0 \;\; ; \;\; F_{t,\,2,\,Rd} = F_{c,\,Rd} - F_{t,\,1,\,Rd}$$

EN 1993–1–8   6.2.7.2 (8)

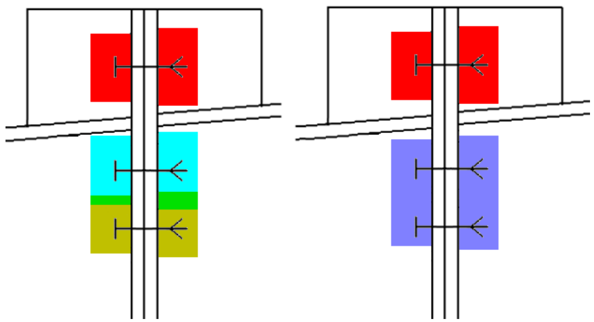
Condition for tensed zone:

$\Sigma F_{t, r, Rd\ (individual)} \leq \Sigma\ F_{t, r, Rd\ (group)}$

$F_{t, r, Rd\ (individual)} = F_{t, r, Rd}\ (l_{eff})$

$F_{t, r, Rd\ (group)} = F_{t, r, Rd}\ (\Sigma\ l_{eff})$

Photo: Author



If condition is not met, we **once again** reduce equivealne resistance of bolt rows computationally, starting from bolt closest to compression zone:

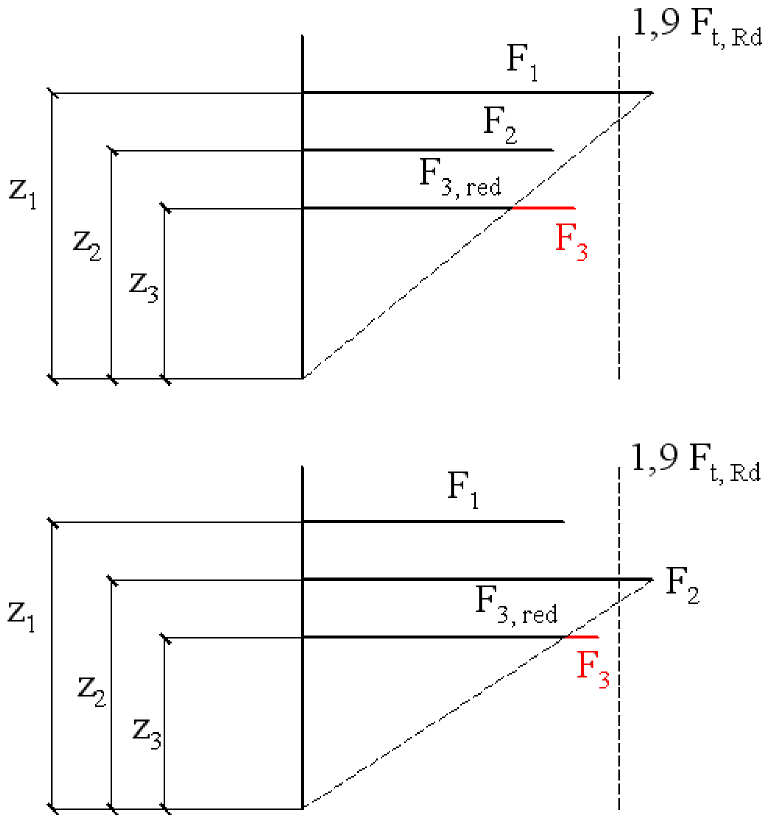
$$F_{t, 3, Rd} = \Sigma\ F_{t, r, Rd\ (group)} - F_{t, 1, Rd} - F_{t, 2, Rd}$$

or even

$$F_{t, 3, Rd} = 0 \quad ; \quad F_{t, 2, Rd} = \Sigma\ F_{t, r, Rd\ (group)} - F_{t, 1, Rd}$$

EN 1993-1-8 6.2.7.2 (9)

If for any row of bolts its equivalent resistance is greater than 1,9 resistance of bolt for axial force, equivalent resistances lower rows of bolt must be reduced by linear way.



$$F_{3,\ red} = F_1\ z_3\ /\ z_1$$

$$F_{3,\ red} = F_2\ z_3\ /\ z_2$$

Photo: Author

NA 5: recommended for joints exposed to impact and vibration only

Mounting corbel / mounting bracket

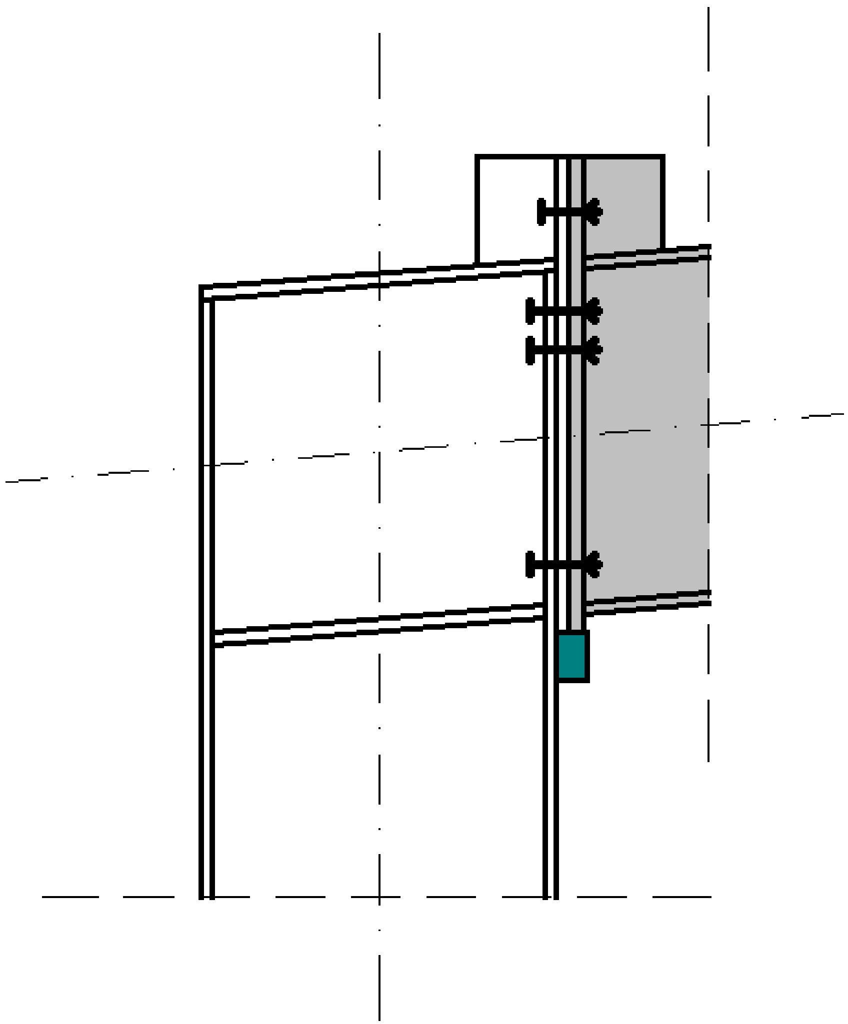


Photo: Author

Fat rectangular bar, welded transversally to column flange. This is mounting support for beams and girders. It supports beam when bolts are installed. Beam is stationary - we avoid swaying beam suspended from crane.

Category	**D** („normal”)	**E** (preloaded)
Phenomena	Girder’s flange axial compression, column’s web transversal compression, column’s web shear, column’s web transversal tension, column’s flange bending (prying action), end-plate bending (prying action), girder’s web axial tension	
Tensed zone (forces parallel to bolt’s axes)	Formula → #t / 65: $\Sigma F_{t,\,Rd} = \Sigma \min (F_{t,\,Rd}\ ;\ B_{p,Rd})$ (tensile force resistance ; punching resistance)	Formula → #t / 65: $\Sigma F_{t,\,Rd} = \Sigma \min (F_{p,C}\ ;\ B_{p,Rd})$ (preloaded force ; punching resistance)
Compressed part (global shear forces perpendicular to bolt’s axes)	As for category **A** (shear, bearing, bolck tearing…);	As for category **C** (bearing, slip resistance, block tearing…);
Notices	Only 3 highest rows are taken into account when checking stiffness and resistance.	Bolts are evenly distributed over entire height of joint (there may be significantly more than 3 rows); Only 3 highest rows are taken into account when checking the stiffness and resistance.

Summation

Elements that „go beyond” „standard set” (column – end-plate – girder) influence stiffness and resistance of joint in different ways.

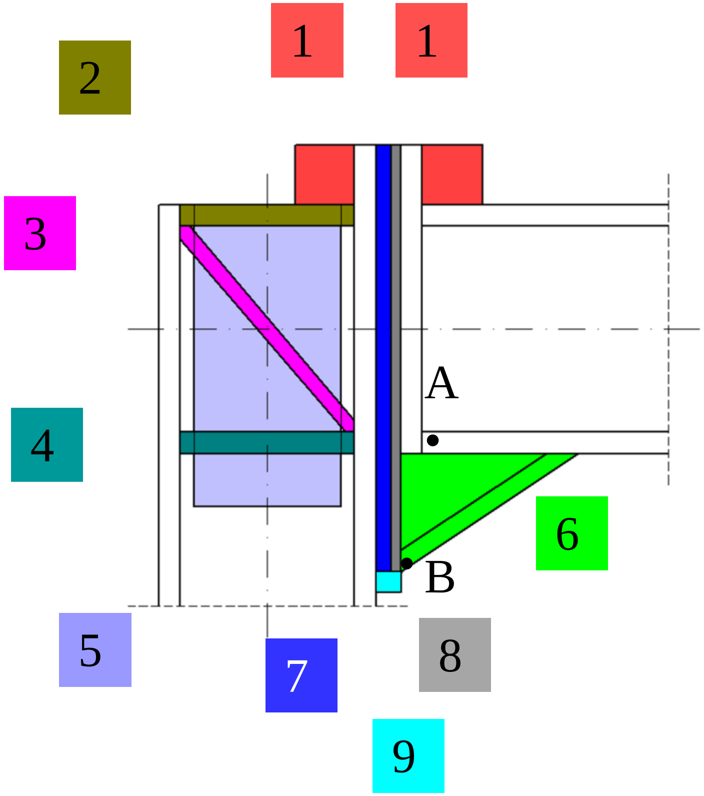


Photo: Author

1. Additional vertical rib over top flange;
2. Horizontal stiffener in axis of top beam’s flange;
3. Diagonal stiffener;
4. Horizontal stiffener in axis of bottom beam’s flange;
5. Additional plate for column’s web;
6. Haunched beam;
7. Additional plate for column’s flange;
8. Packing plate;
9. Mounting corbel

Element	Influence
1	Informally – it prevents appearance of specific circular and non-circular mechanisms; corresponding effective lengths are not taken into account in calculations. Inconsistently, Eurocode gives lengths for end plate without vertical rib and for column flange with a vertical element (rib / distal part of web). In case of rib above beam / girder, some effective lengths should be omitted. In case of column with flange not supported by web (rare but possible situation), additional mechanisms should be considered, similar to those for end plate.
2	Changes column from unstifened to stifened; effective lengths around bolts are calculated differently. Contradictory descriptions in literature; some sources allow adding stiffener's resistance to tensed zone resistance, which, however, seems unadvised (stiffener's axis does not coincide with bolt axes).
3	Role is unclear: not described in the Eurocode and poorly recognized in literature. Probably only combined presence of 2+3+4 allows assumption of stiffness for shear zone of column web tending to infinity; in case of resistance, local resistance of stiffener should probably be added to resistance of shear web. In arrangement shown in figure, \ is compressed; it strengthens more effectively than tensioned / .

Element	Influence
4	Role is unclear: unclearly described in Eurocode and presented differently in literature. Probably presence of this element allows assumption that stiffness of compressed zone of column web tending to infinity; in case of resistance, local resistance of stiffener should probably be added to resistance of compressed web.
5	Increases web thickness in shear and tensed zones (although this is taken into account in different ways in both zones); increases stiffness and resistance of web in these zones. It should include compressed zone (if 6 exists – must be much lower than in photo); Eurocode does not specify whether it strengthens compressed zone. Only alternatively possible: 5 ↔ (2, 3, 4).
6	Increases arm of action for subsequent bolt rows (theoretical axis of rotation moves from point A to B); the simplest way to increase stiffness and resistance of joint.
7	Increases thickness of column flange, can prevent prying actions; increases stiffness and resistance of bending column flange.
8	Eliminates gaps due to imperfections in beam dimensions and column position; without affecting stiffness and resistance.
9	Supporting beam / girder during assembly.

Complex load

Above procedure is dedicated to situation, whem only bending moment acts on joint. What happened, if only axial force / axial force and bending moment act on joint?

According to EN 1993-1-8 6.2.7.1 (2), we can calculate joints, only when axial force in beam $N_{Ed} \leq 0{,}05\ N_{Rd}$ of beam. If this requirement is not satisfied, according to EN 1993-1-8 6.2.7.1 (2) we calculate resistance of joint according to formula:

$$M_{j,\,Ed} / M_{j,\,Rd} + N_{j,\,Ed} / N_{j,\,Rd} \leq 1{,}0$$

But there is no information about:

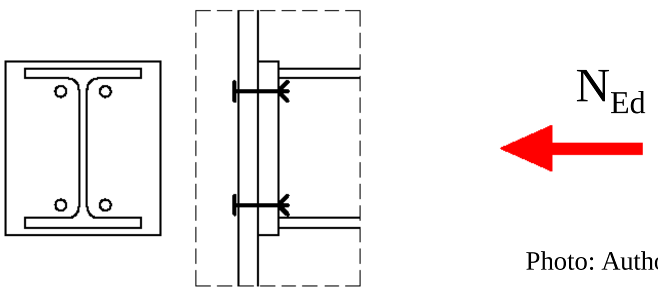
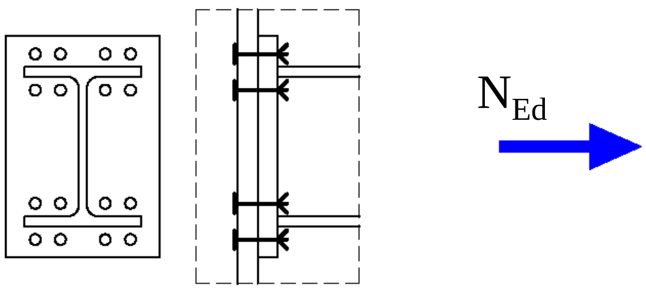
- what means $N_{j,\,Rd}$;
- whether $M_{j,\,Rd}$ is calculated according the same way as for cause $N_{Ed} \leq 0{,}05\ N_{Rd}$.

Assumptions for case $N_{Ed} > 0{,}05\ N_{Rd}$:

First proposal of calculation: calculations for joint as whole

$M_{j,\,Rd}$ is calculated according the same formulas as for $N_{Ed} \leq 0{,}05\ N_{Rd}$;

$N_{j,\,Rd}$ depends on direction of force:

 Photo: Author	
$N_{j,\,Rd}$ = min (column web in compression, beam flange in compression, column web in shear); effect of uneven web compression/tension	$N_{j,\,Rd}$ = min [min$_{\text{first row of bolt}}$ (column web in tension, beam web in tension, column flange in bending, end plate in bending) + min$_{\text{second row of bolt}}$ (...) + ... + min$_{\text{last row of bolt}}$ (...), column web in shear]

Second possibility of calculation: separated calculation for bolts around top and bottom flange

Axial force and bending moment are reducted to forces in flanges's centres of gravity.

Resistances of both parts (top and bottom) are calculated separately (as for only tensed and only compressed part). Resistances of both parts are calculated according to the same way as on previous page.

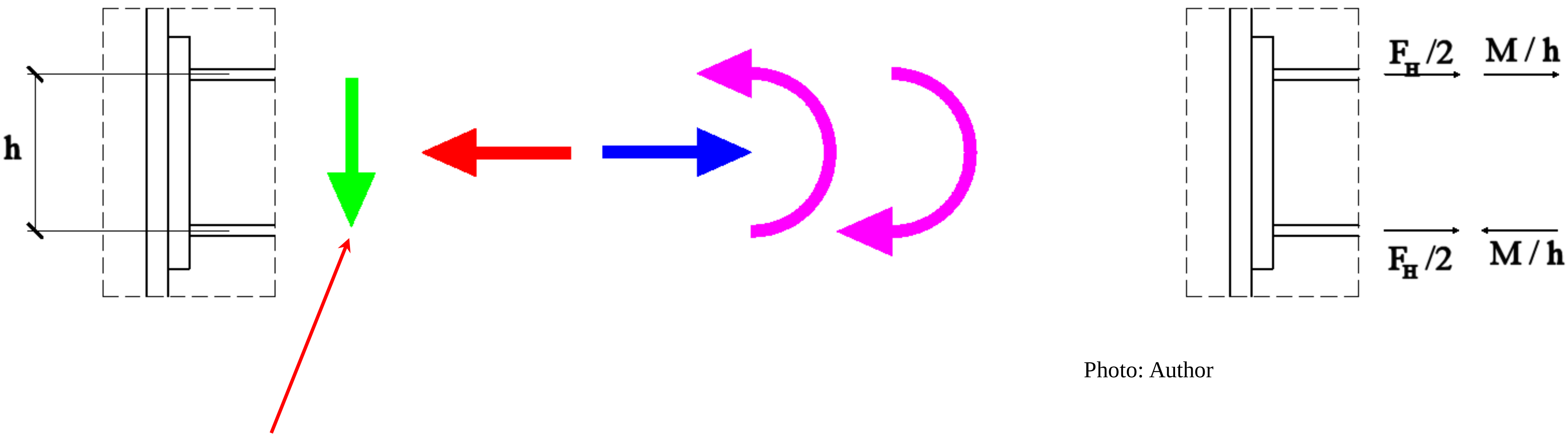


Photo: Author

Shear force always existed in such type of joint. This is effect of gravity and dead weight of elements.

Bending moment, axial force, shear force – bending moment and axial force applied to flanges as complex of forces (#t / 86). Next step depends on values of forces in both flanges:

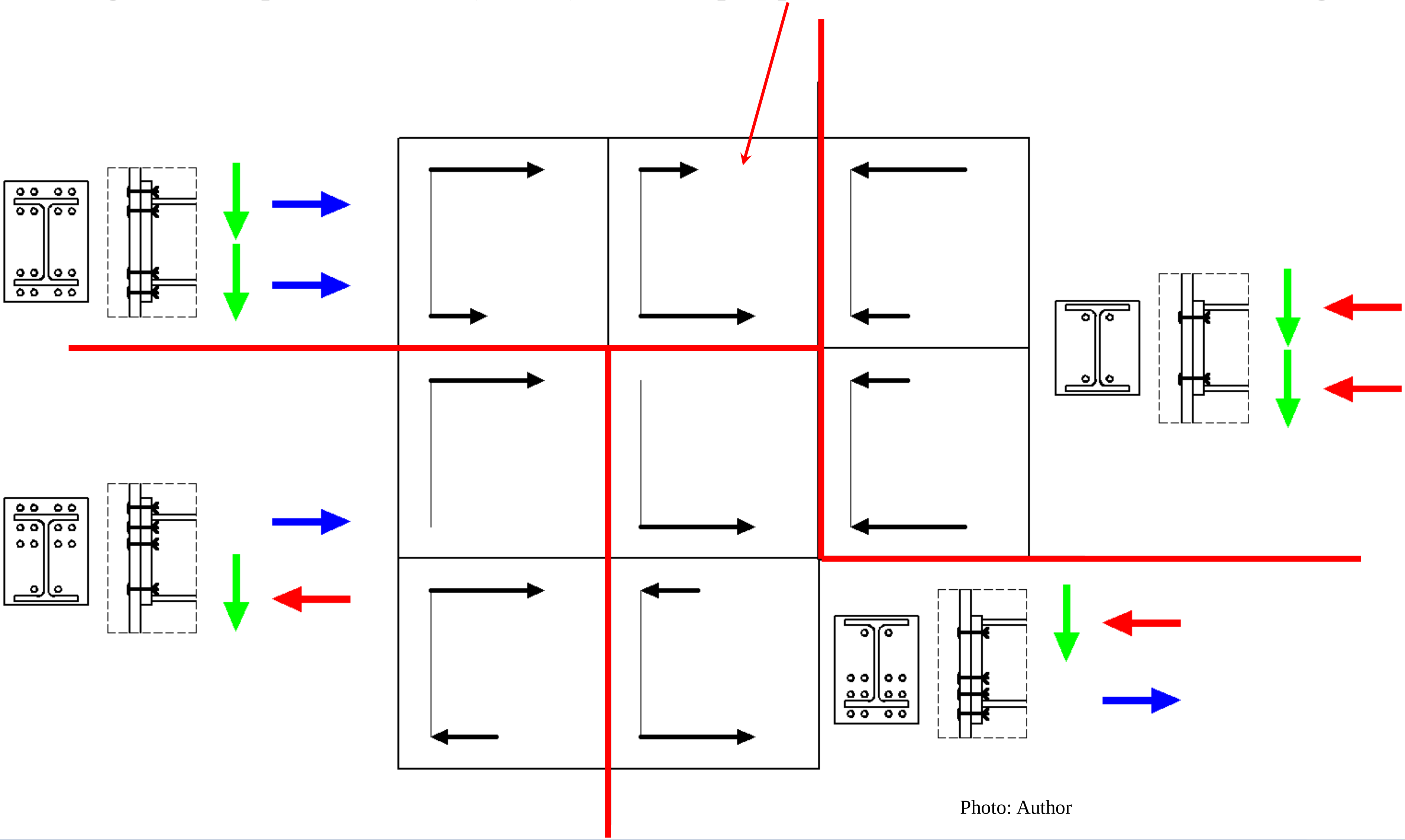


Photo: Author

- Tension joint - shear force only or shear force and compressive force;
- Top and bottom part of joint calculated separately (various horizontal stiffeners?);
- Shear force for one bolt = global shear force / number of bolts;
- Compressive force not acts on bolts.

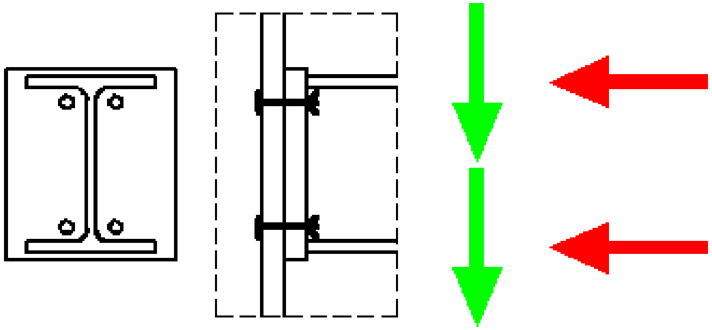


Photo: Author

Compressive force: resistance of joint calculated according to #t / 85

Additionally, for shear force, resistance according to #t / 80

- Tension joint - shear force and tensile force;
- Top and bottom part of joint calculated separately (various numbers of bolts?);
- Shear force for one bolt = global shear force / number of bolts;
- Tensile force for one bolt = global tensile force / number of bolts.

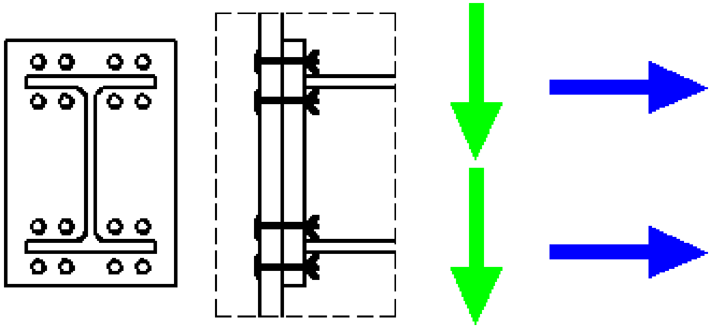


Photo: Author

Tensile force: resistance of joint calculated according to #t / 85

Additionally, for shear force, resistance according to #t / 80

Additionally, due to both forces act on bolt, shank of bolt is checked (EN 1993-1-8 tab. 3.4):

$$F_{v,\,Ed} / F_{v,\,Rd} + F_{t,\,Ed} / (1{,}4\, F_{t,\,Rd}) \leq 1{,}0$$

- Tension joint - shear force, tensile and compressive forces;
- Top and bottom part of joint calculated separately (tension / compression);
- Shear force for one bolt = global shear force / number of bolts;
- Tensile force for one bolt = global tensile force / number of bolts.

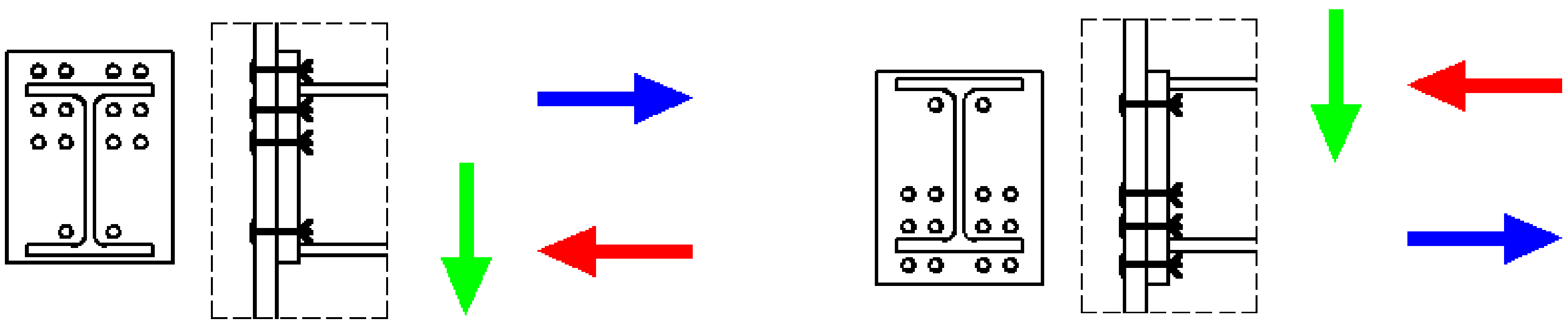


Photo: Author

Tensile force: resistance of joint calculated according to #t / 85

Compressive force: resistance of joint calculated according to #t / 85

Additionally, for shear force, resistance according to #t / 80

Specific type of joint with compressive force is joint column-column.

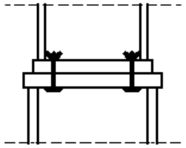
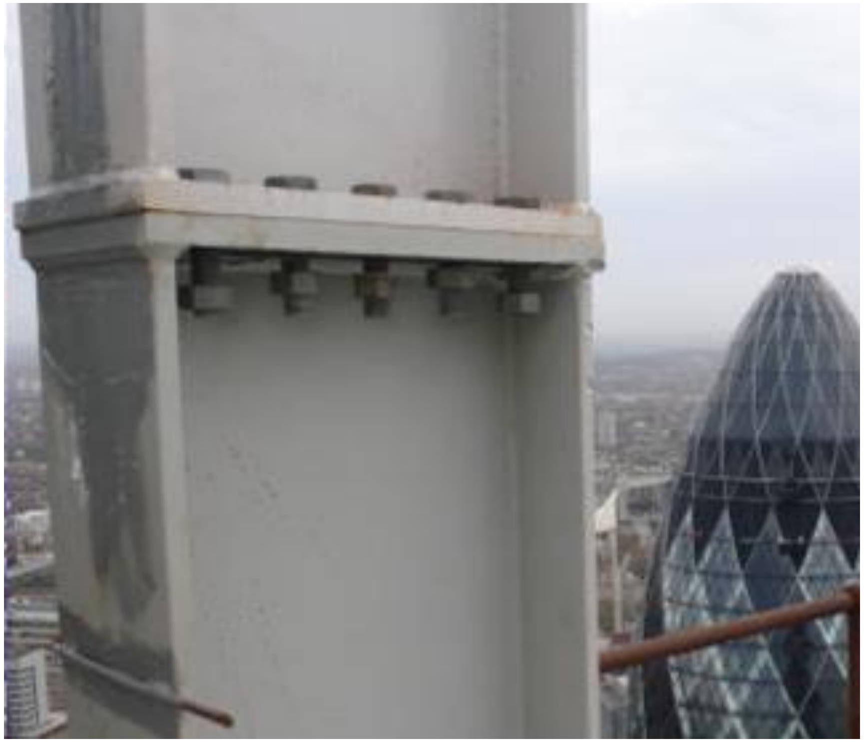


Photo: Author

Photo: steelconstruction.info



Column-column – there is no beam.

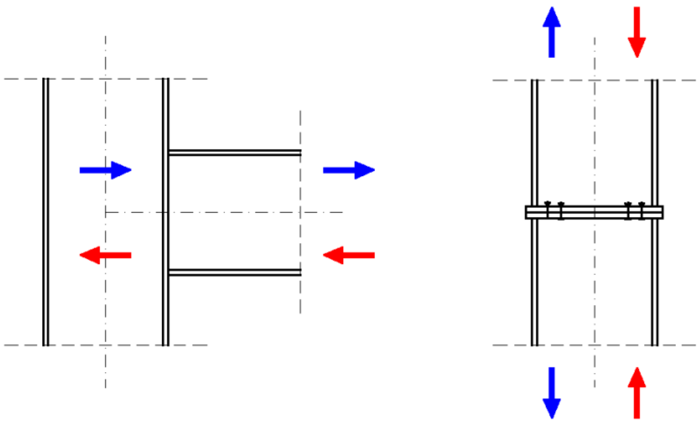


Photo: Author

In bolted joint beam-column, forces are applied longitudinally to beam and transversally to column. In joint column-column, forces are applied longitudinally to both parts of column.

Because of this wal of force application, resistance of such type of joint is calculated based on formulas for beams (resistance of beam web in tension, resistance of beam flange in compression, contact plate in local bending).

Way of calculations depends on shape of stresses in joint.

Relatively small bending moment to compressive axial force → compression only → no tension in web, no bending in contact plates → bolts calculated only for shear force.

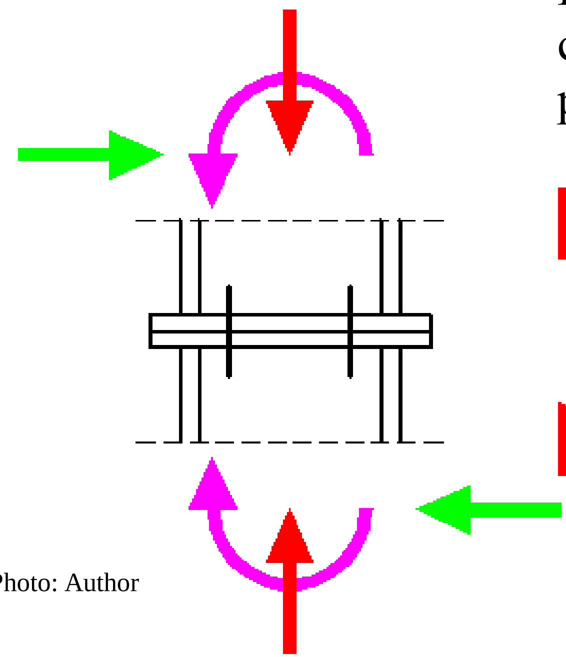
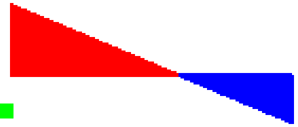


Photo: Author



Relatively big bending moment to compressive axial force → compression and tension → classical tension joint → bolts calculated for tensile force and shear force.

Photo: hoverdale.com

Both surfaces of contact plates should be grinded smoothly to ensure full contact in compressed part of joint.

Important notice: for various combinations of actions, there are possible different distributions of forces in top and bottom flanges.

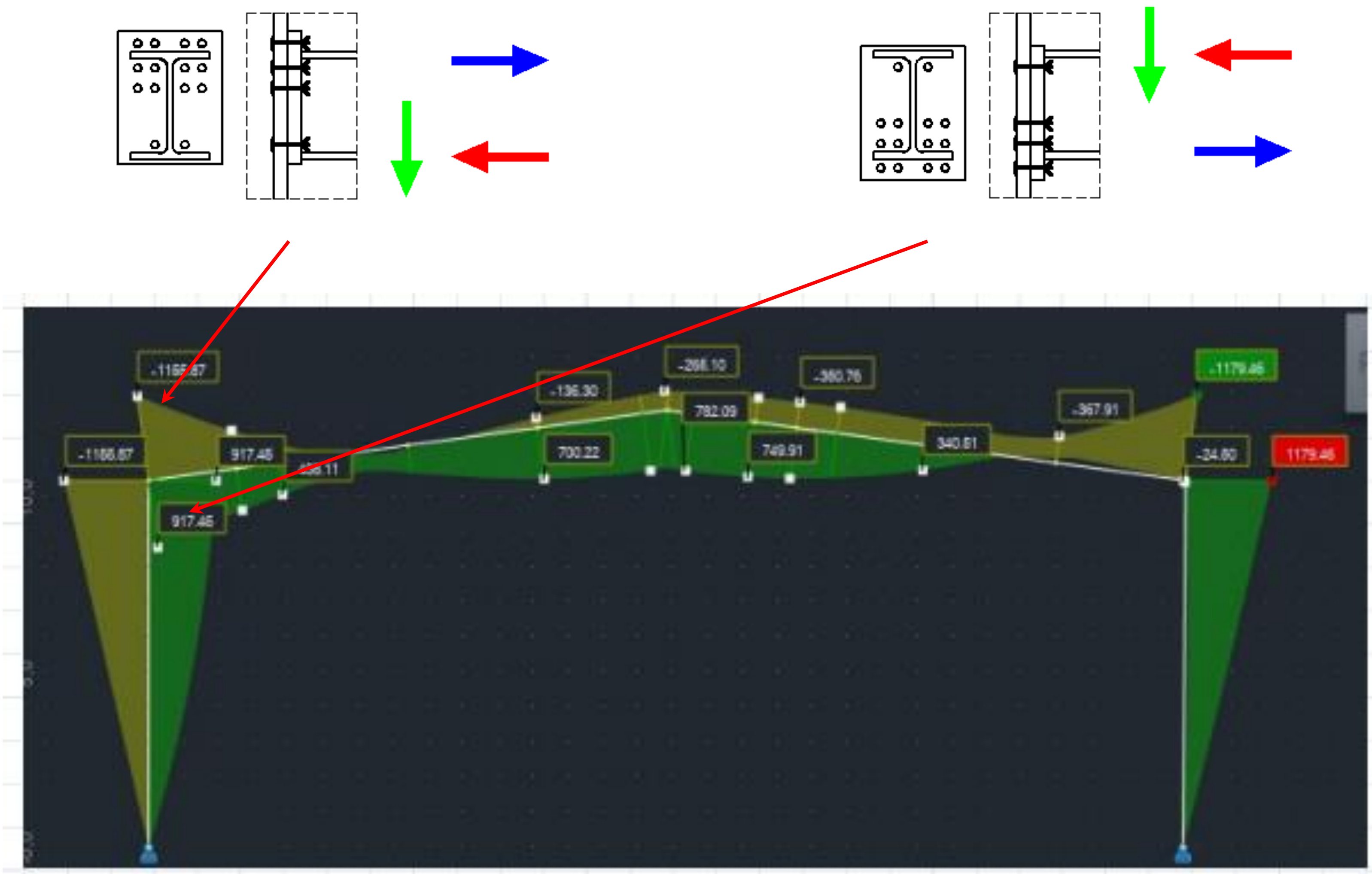


Photo: Author

Examination issues

Shear joint and tension joint – similiarities and differences

Redistribution of load in shear joint

Similiarities and differences for cathegories of bolted joints D, E

Parameters important for cathegories of bolted joints D, E

Sub-parts important for resistance

Shear (bolted) joints - połączenia (śrubowe) zakładkowe
Tension (bolted) joints - połączenia (śrubowe) doczołowe
Bearing resistance - nośność na docisk
Block tearing - rozerwanie blokowe
Slip-resistant - nośność na poślizg
Punching resistance - nośność na przeciąganie łba
Prying actions - efekt dźwigni
Cleat - nakładka z kątownika
Floor girder - ruszt
Rigging screw - śruba rzymska
Resin - żywica
Elongation length - baza wydłużalności
Grip length - grubość skleszczenia
Circular pattern - kołowy mechanizm zniszczenia
Backing plates - płytki usztywniające
Torque spanner / tension wrench - klucz dynamometryczny
Mounting corbel / mounting bracket – stolik montażowy

Thank you for attention

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