

Metal Structures

Lecture XVIII

Bolts

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Joints and connections

→ #14 / 5

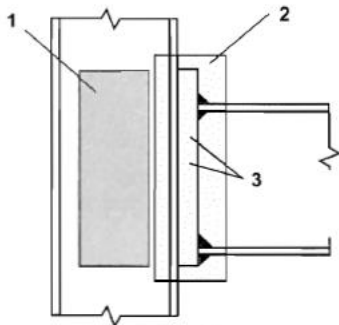
1.4.2 connection

Location at which two or more elements meet. For design purposes it is the assembly of the basic components required to represent the behaviour during the transfer of the relevant internal forces and moments at the connection.

EN 1993-1-8 1.4.2,
1.4.4

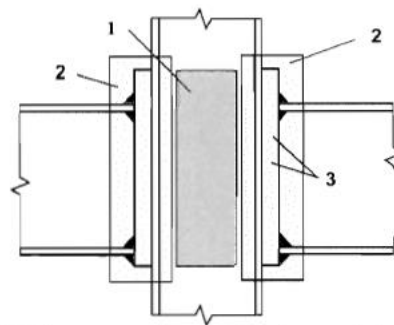
1.4.4 joint

Zone where two or more members are interconnected. For design purposes it is the assembly of all the basic components required to represent the behaviour during the transfer of the relevant internal forces and moments between the connected members. A beam-to-column joint consists of a web panel and either one connection (single sided joint configuration) or two connections (double sided joint configuration), see Figure 1.1.



Joint = web panel in shear + connection

a) Single-sided joint configuration



Left joint = web panel in shear + left connection

Right joint = web panel in shear + right connection

b) Double-sided joint configuration

- 1 web panel in shear
- 2 connection
- 3 components (e.g. bolts, endplate)

Photo: EN 1993-1-8 Fig. 1.1

Connection: Location... ...the assembly of the basic components...

Joint: Zonethe assembly of **all** the basic components...

Nodes on steel structure always consist on bolts or welds and additional plates (stiffeners, gusset plates). Local concentration of stresses and forces reveals on each node.

Because of it local concentration, short parts of connecting members (short part cooperated with subelements of node) must be taken into consideration. Specific local phenomena, resulting form concentration and cooperation, must be detaily analysed.

In simplification: the most important parts of node are weld and shank of bolts. Because of this, they coul be named „connections” – in opposite to „rest part of node”, i.e. stiffeners, gusset plates and cooperated parts of members.

→ #14 / 6

Resistance of **connections** are resistance of welds and resistance of shank of bolts

→ #14 / 12



Photo: researchgate.net



Photo: ceprofs.civil.tamu.edu

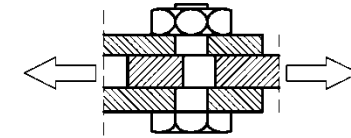


Photo: Author

- exceeding stresses in the weld;
- shearing of the bolt;
- tearing of the bolt;

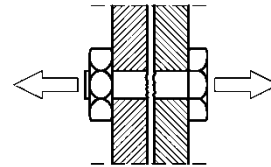


Photo: Author



Photo: forgemag.com

Behaviour of **joint** could be divided into two groups:

- Interaction between plates/elements and connections;
- Interaction between plates/elements each other.

→ #14 / 13



Photo: ascelibrary.org

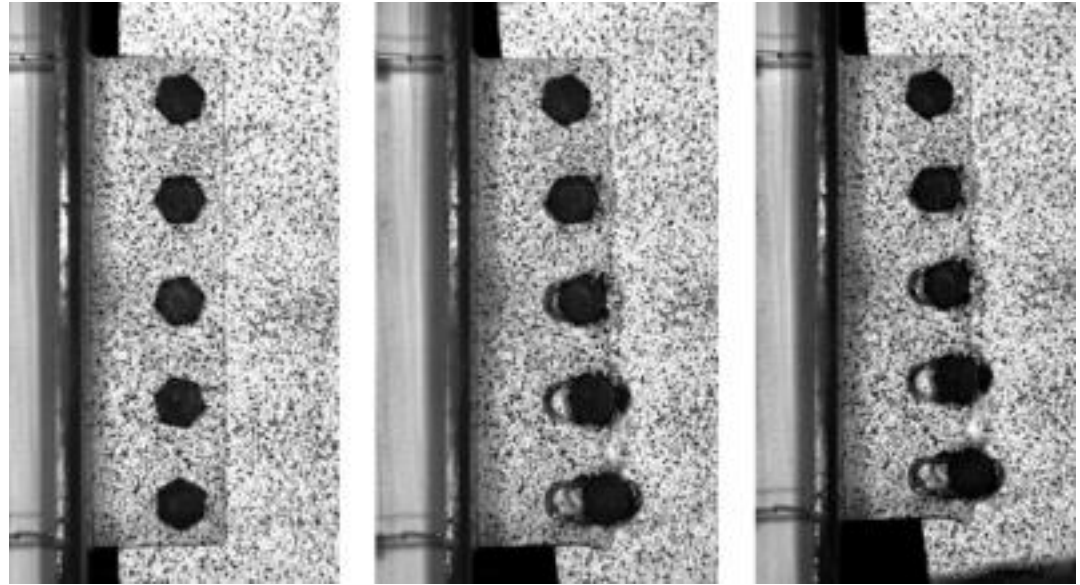


Photo: ascelibrary.org

Example for interaction plate-shank: bearing resistance: deformation or destruction of plate as the effect of interaction between shank of bolt and plate.

Other examples of destruction as the effect of interaction and contact between shank of bolt and plates:

- punching;
- local bending of plate around bolts under tension.

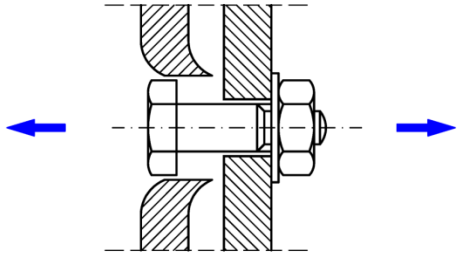


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Photo: knkmpk.blogspot.com

Photo: Author

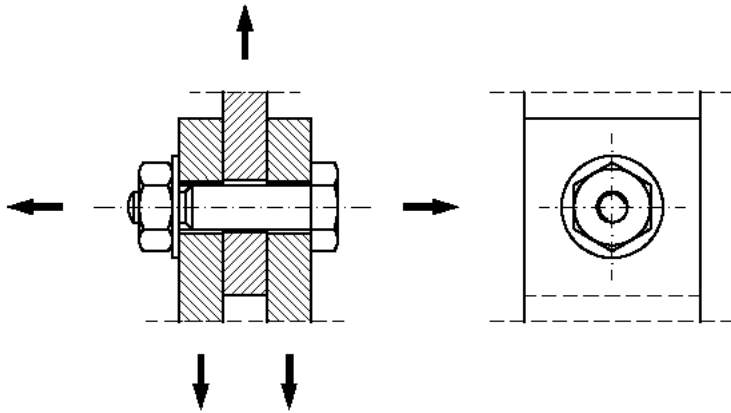
→ #14 / 14

This type of destruction occurs only as effect of interaction/contact between bolt and plate/element, not between weld and plate/element.

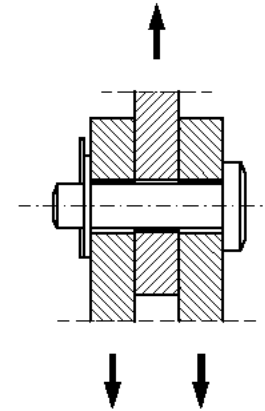
Quasi-bolted joints (→ Lec # 18)



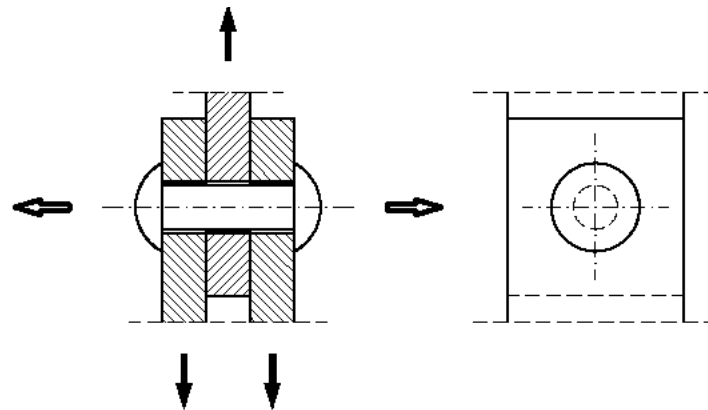
Photo: ventia.pl



Bolt



Pin



Rivet

Photo: Author

Pin - round shank with cup; fixed - cotter pin and washer



Photo: elgo-srubby.pl

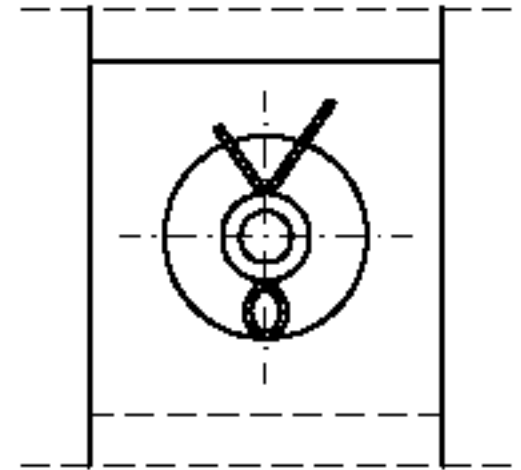
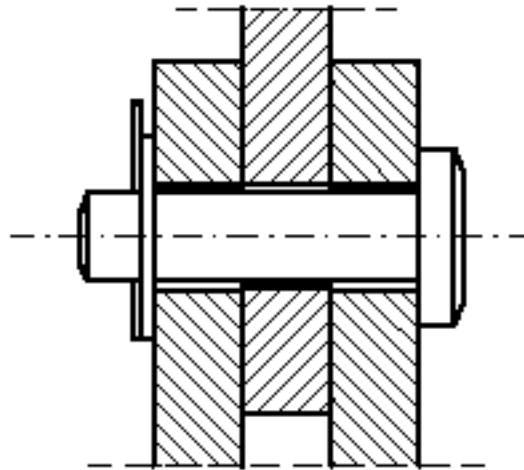


Photo: Author

Cotter pin - very very very ... very weak element - there are no acceptable axial forces



Photo: warszawa.naszemiasto.pl

For temporary structures:

temporary bridge
crane mast

Photo:demotywatory.pl



Rivet - round shank with cup; fixed - cold deformation of shank (close up rivet)



Photo: ferrodopoznan.com.pl

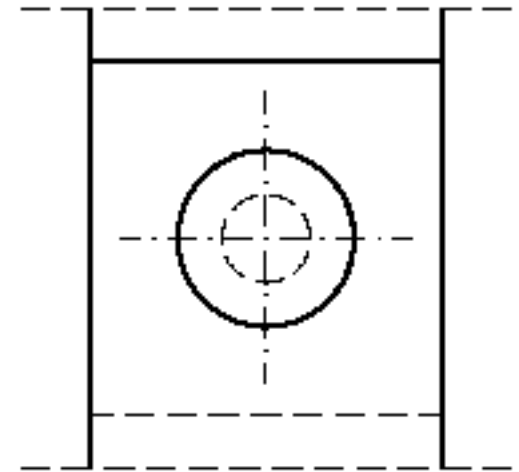
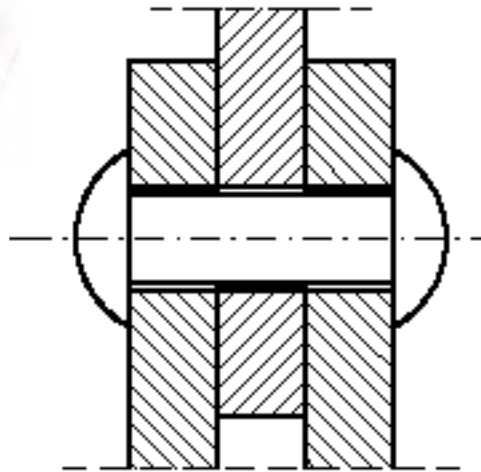


Photo: Author



Photo: .pinterest.com

Used +100 years ago and today for aesthetic reason.

Photo: mostypolskie.pl



Most im. Ignacego Mościckiego w Puławach
fot.: Katarzyna Janikowska

Photo: mbgrafikuje.pl

Bolt - round threaded shank with hex cup; fastening by tightening hex nut.



Photo: ventia.pl

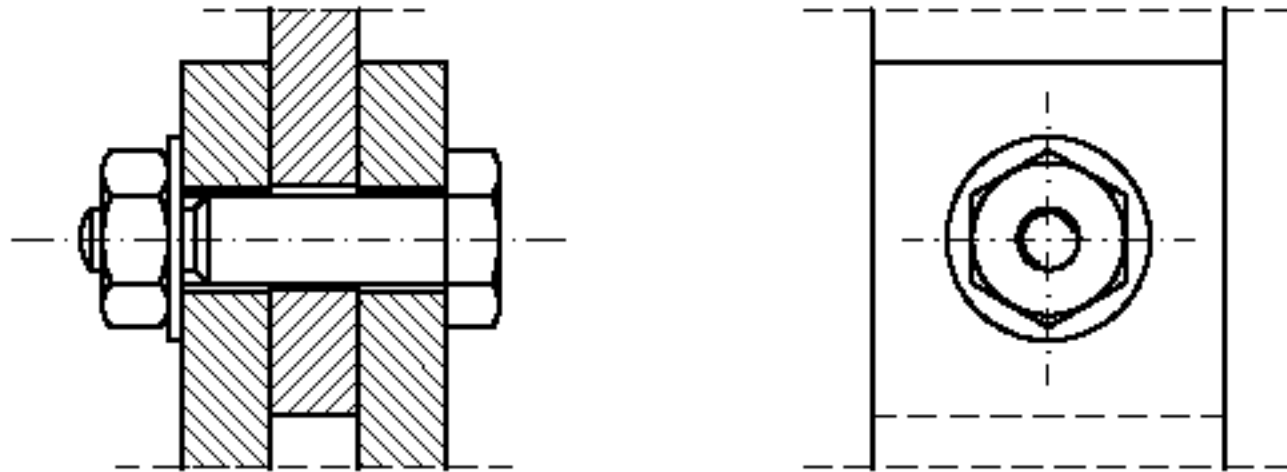


Photo: Author

Today more than 95% of quasi-bolted joint.

From bar to bolt - plastic cold working and machining



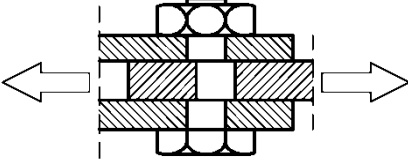
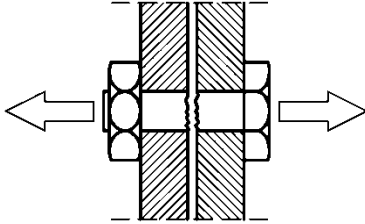
Photo: wbisia.prz.edu.pl

Technical requirements

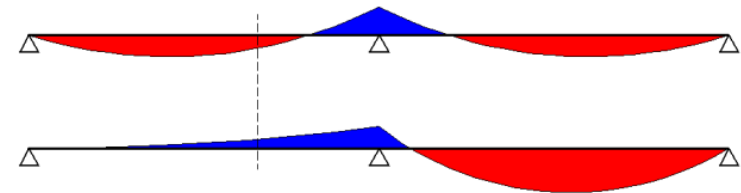
In each situation, we must fulfill few requirements:

- ◆ We must be sure, that the bolt is dedicated to steel structure - this means accepted are only bolts described in EN 14 399 and EN 15 048;
- ◆ Diameters less than 16 mm are recommended rather to fastened roofing and housing;
- ◆ When we use different diameters of bolt, we should avoid too similar diameters.

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

Bolts:

Symbol:

M16 \rightarrow $d = 16\text{mm}$

Category	Class	Diameter
A, D	4.6, 4.8	$d = 16\text{ mm}$
	5.6, 5.8, 6.8	$d = 20 - 24\text{ mm}$
	8.8, 10.9	$d \geq 24\text{ mm}$
B	8.8, 10.9	$d \geq 24\text{ mm}$
C, E		

Class: X.Y

$$X = f_{ub} / 100 \rightarrow f_{ub} = 100 X$$

$$Y = 10 f_{yb} / f_{ub} \rightarrow f_{yb} = 10 X Y$$

Class: 4.8

$$f_{ub} = 400\text{ MPa}$$

$$f_{yb} = 320\text{ MPa}$$

\rightarrow #Des 2 Ex 1 / 43

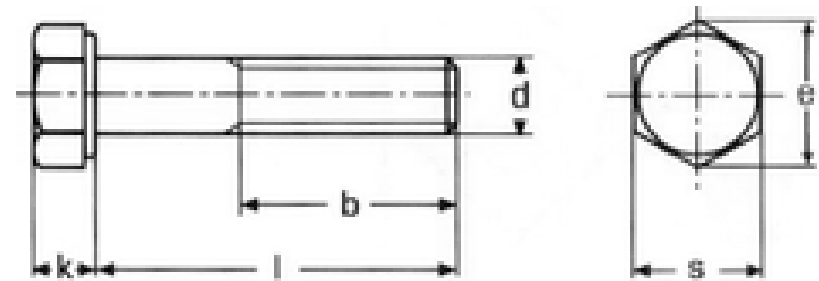


Photo: Author

There are used only few diameters of bolts for steel structures:

M 5 M 6 M 8 M 10

M 12 M 16 M 20 M 22 M 24 M 27 M 30 M 33 M 36

M 39 M 42 M 45 M 48 M 52

M 56 M 64 M 72 M 80 M 90 M 100 M 110 M 125 M 140 M 160

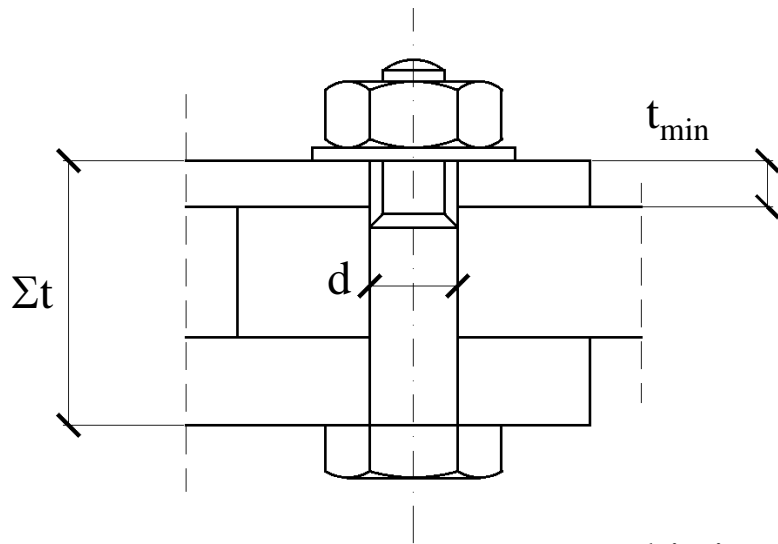
Recommended - to fastened roofing and housing only;

Recommended - to main joints;

Not recommended (too small diameter or too similar to other);

Rarely used / not produced;

Recommendation, diameter of bolts: function of thickness of elements



$$1,5 t_{\min} \leq d \leq 2,5 t_{\min}$$

$$A, D: \Sigma t \leq 5d$$

$$B, C, E: \Sigma t \leq 8d$$

$$f_{ub} > f_u$$

Photo: Author

This is a universal recommendation for all types of bolts.

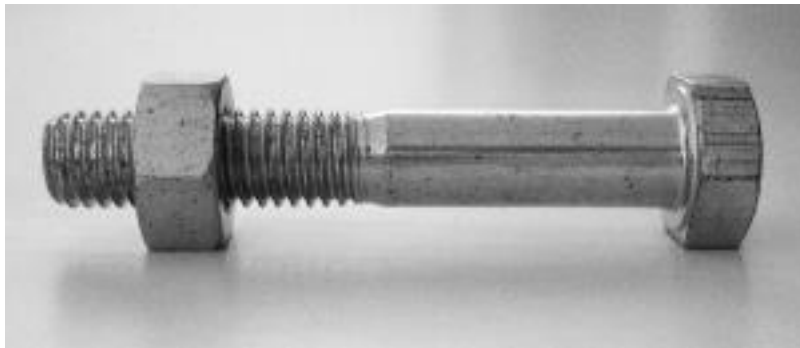
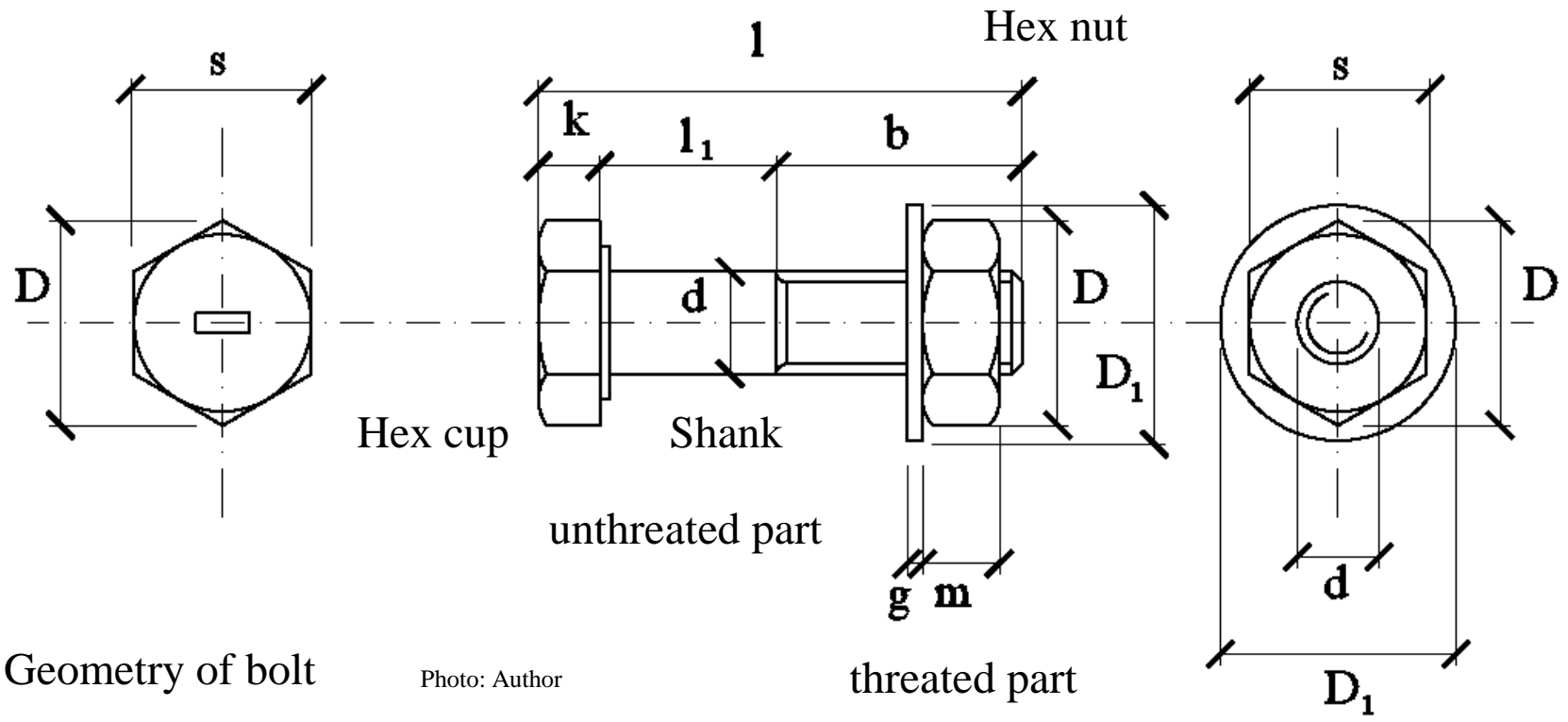


Photo: wikipedia



Photo: parkersteel.co.uk

Washer



Geometry of bolt

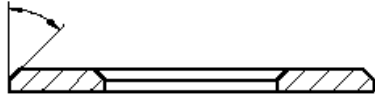
Photo: Author

threaded part

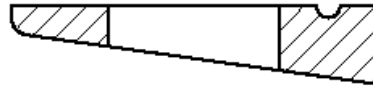
Washers

Photo: Author

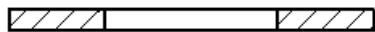
For preloaded bolts



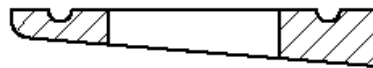
For IPN



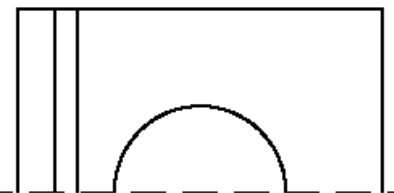
IPN, C-section and C_E-sections have various inclination of flange; the same washers for these cross-sections.



For „normal” bolts



For C-sections



For C_E-sections

Imperfections as effect of drilling:

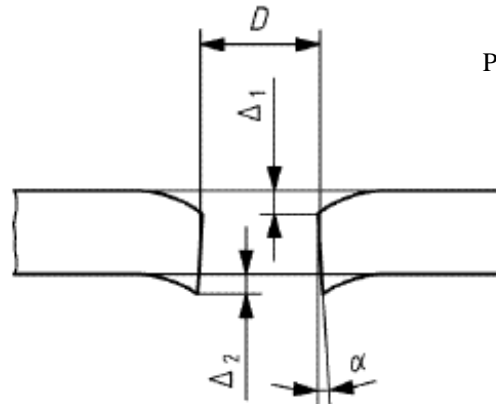


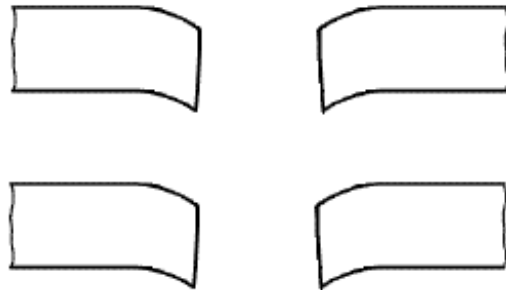
Photo: EN 1090-2 fig. 1.

$$D = (d_{\min} + d_{\max}) / 2$$

$$\max (\Delta_1 ; \Delta_2) \leq \max (D / 10 ; 1 \text{ mm})$$

$$\alpha \leq 4^\circ = 7\%$$

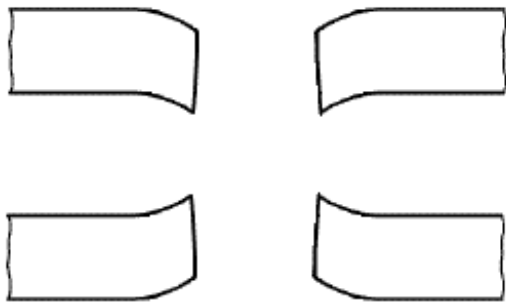
Accepted position of pair imperfected members:



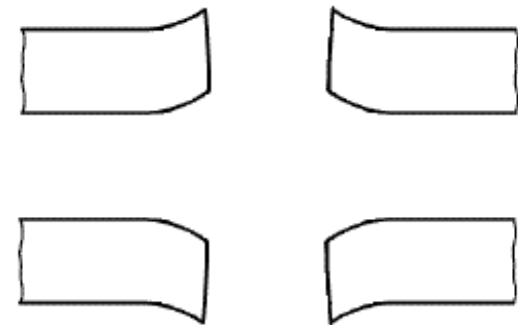
Well

Flange / flange plate, web / web plate, etc -
 Δ in one direction

Photo: Author



Wrong

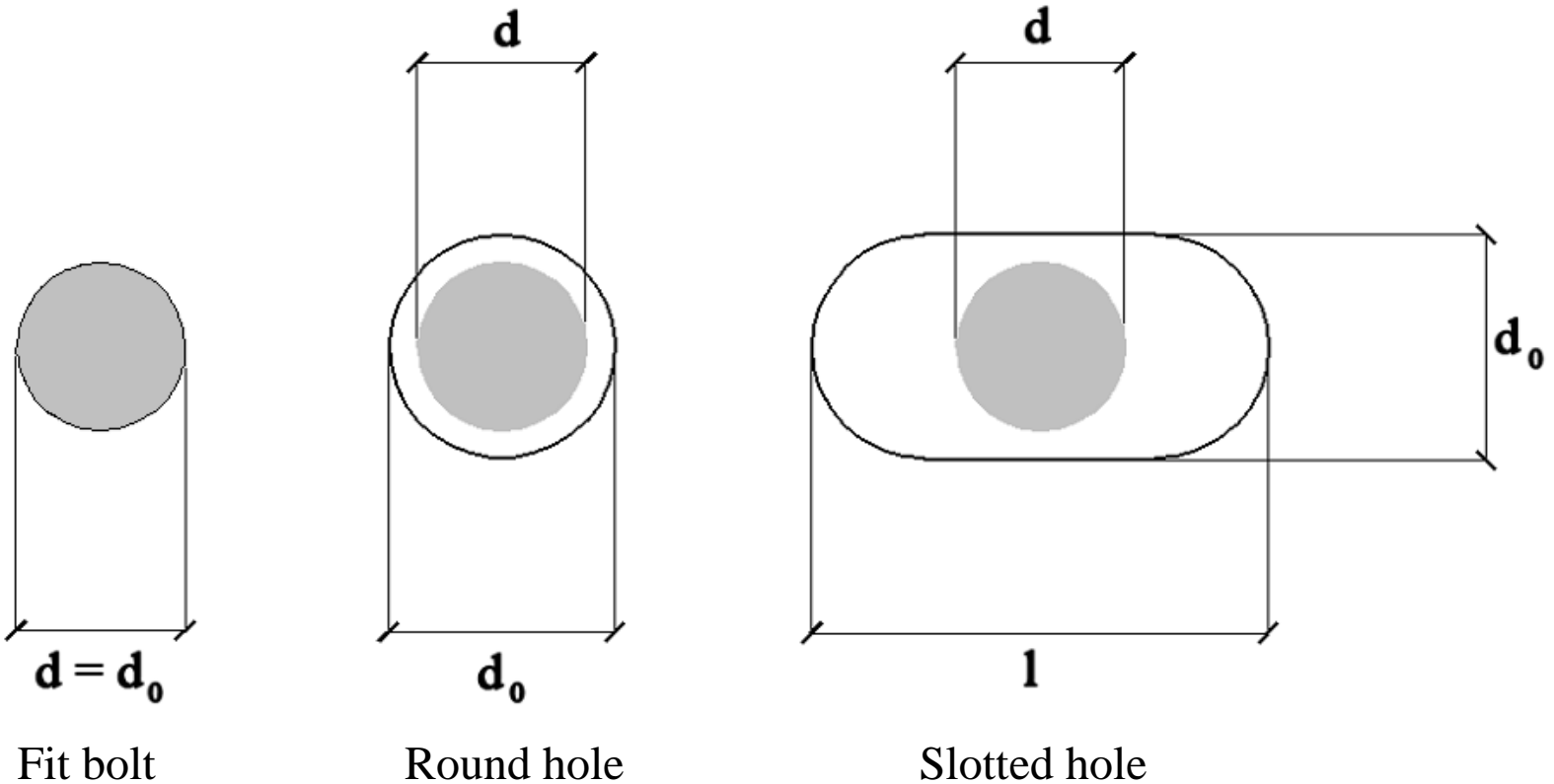


Wrong

d_0, l – diameters of hole

Photo: Author

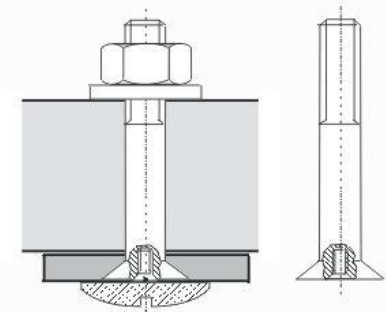
d – diameter of bolt



Differences between two diameters: $d_0 - d =$ or $l - d =$ [mm]

Bolts or pins:		M 12, M 14	M16, M 18, M 20, M 22	M 24	M 27, M 30 ...
Fit bolts		0			
Normal <u>round</u> holes		1 (0,5) 2	2 (1,5)		3 (2,5)
Oversize <u>round</u> holes		3	4	6	8
Short <u>slotted</u> holes	d_0	1 2	2		3
	1	4	6	8	10
Long <u>slotted</u> holes	d_0	1 2	2		3
	1	1,5 d			

EN 1090-2 tab 11
(mast, towers)
countersunk bolts



Rivets - nominal hole diameter shall be specified individually in each design project

Photo: zeglarstwo.sail-ho.pl

Hole diameter is related to grades of making bolts. There are three grades:

- A - high grade (fit bolt);
- B - mid-range grade;
- C - coarse grade.

Grade	Diameter of shank	Hole	Notices
A	Diameter of hole bigger of 0,2-0,3 mm, the highest level of accuracy (the smallest imperfections in comparison to B and C)	Make on assembly room with the smaller diameter and drilled on construction site to target diameter	Fit bolts, expensive, rarely used, used when it is very important to limit the clearances in joint; recommended for preloaded bolts
B	The same diameter of hole as shank, but accuracy of made for C is lower (bigger imperfections are accepted)	Make on assembly room with the target diameter	Most often used, can be used in any situation
C			Used in weakly loaded joints (no dynamic actions) and joints without significant structural importance, the cheapest

Bolts for steel structures are described by
 EN 14 399
 EN 15 048

Categories of bolted joint	A	B	C	D	E
Standard	EN 15 048	EN 14 399	EN 14 399	EN 15 048	EN 14 399
System of bolts	SB	HV	HV	SB	HR

System SB is dedicated to bolted joints A and D, where can be applied „normal” bolts. In case of joints B, C, and E, specific type of bolts, preloaded bolts, are applied. In general, HR and HV come from old national standards of different countries (France and Germany) and differ slightly in dimensions. Main difference concerns length of thread along shank of bolt.

Bolts can be divided into two types: with a thread along part of shank length and with a thread along entire shank length.

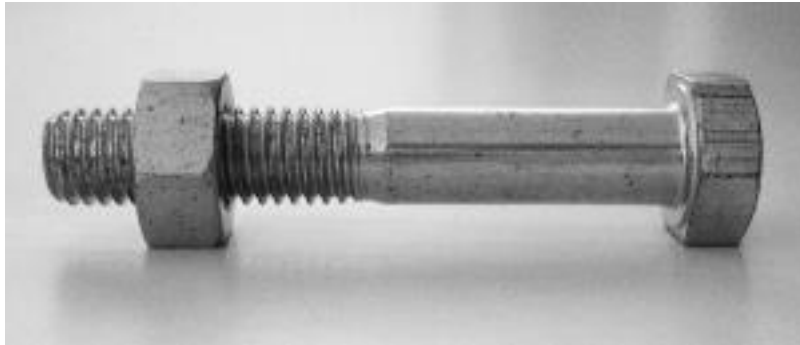


Photo: wikipedia



Photo: parkersteel.co.uk

Recommendation

Category	A	B	C	D	E
Bolt	Part	Part	Part	Entire	Entire

Bolt dimensions for different categories may vary

Bolt set includes bolt, nut and washer.

Categories of bolted joint		A	B	C	D	E
General standard		EN 15 048	EN 14 399		EN 15 048	EN 14 399
Bolt	Grade A	EN ISO 4014	EN 14 399-8		EN ISO 4017	Not recommended
	Grade B		EN 14 399-4			EN 14 399-3
	Grade C		Not recommended			Not recommended
Nut		EN ISO 4032	EN ISO 4033		EN ISO 4032	EN ISO 4033
Washer		EN 14399-5	EN 14399-6		EN 14399-5	EN 14399-6

Bolts and washers

Recommendation



Photo: parkersteel.co.uk

Categories A and D: one washer under nut



Photo: fxaball.co.uk

Categories B, C and E: two washers, under cup and nut

Pitch of bolt

Recommendation

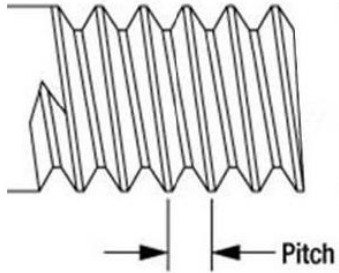


Photo: u-bolts-r-us.co.uk

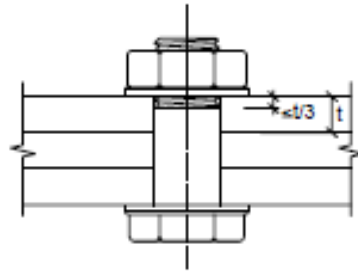


Photo: EN 1993-1-8 fig. 3.2

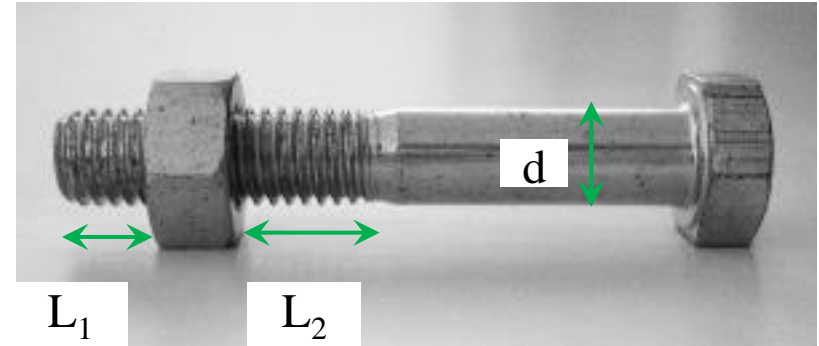


Photo: wikipedia

Categories:		A	D	B, C, E
L ₁	min	1P		2P, rounded up to full multiples of 5 mm
	max	d		d
L ₂	min	1P	Not applicable	4P
	max	1/3 of thickness of adjacent plate		1/3 of thickness of adjacent plate

Distance between axis of bolts

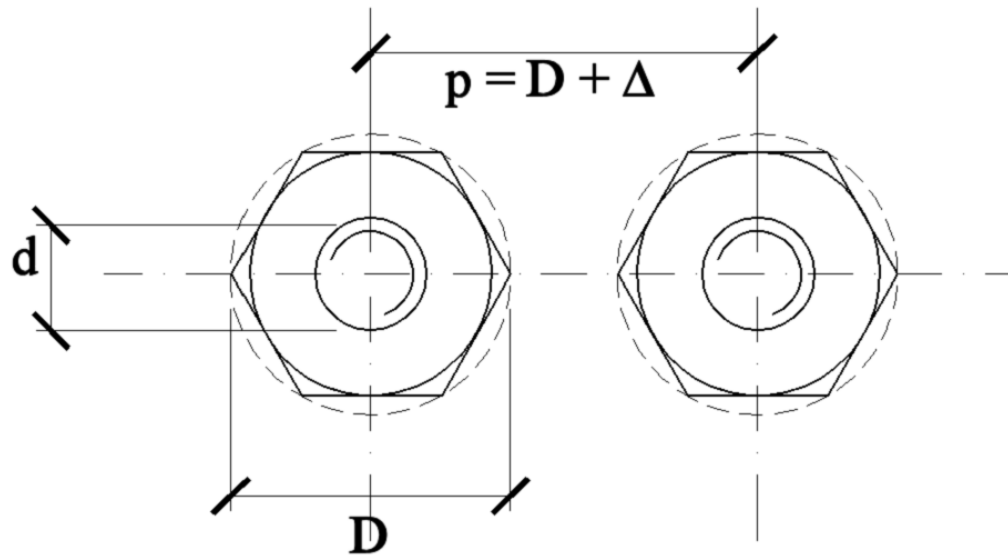
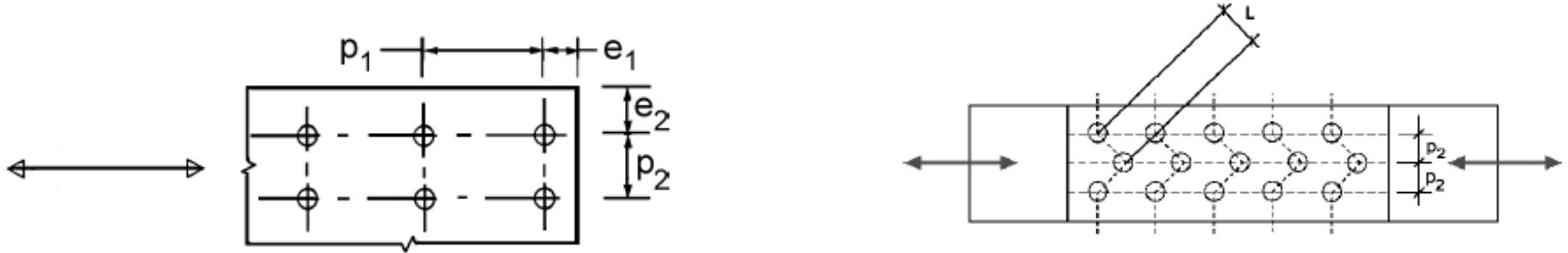


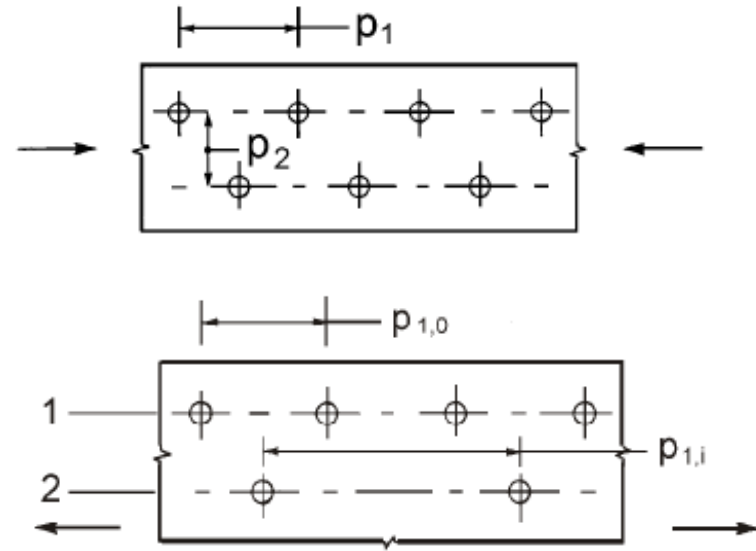
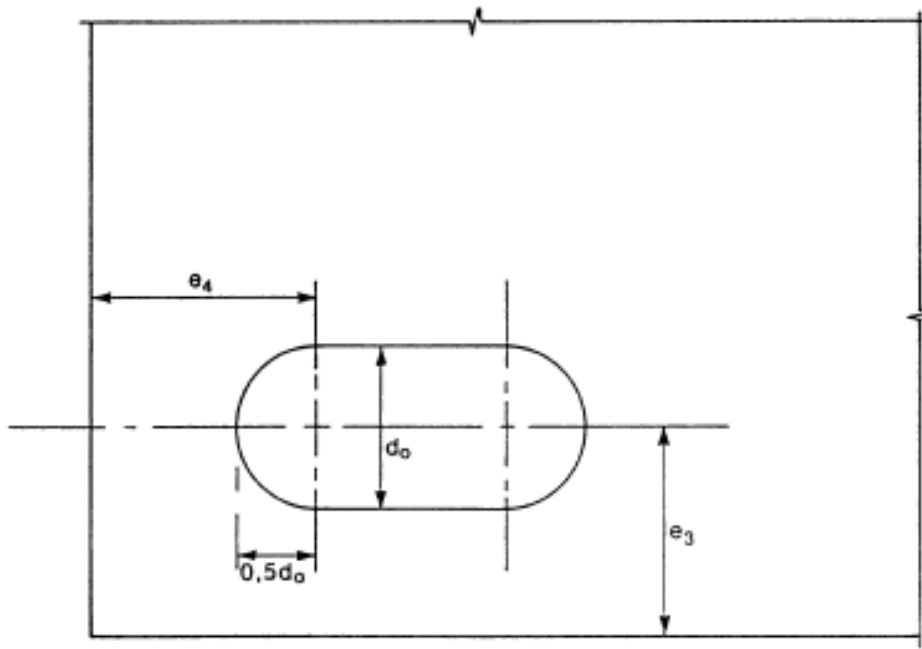
Photo: Author

M 12 - M 48: $D / d = 1,75 - 1,85 \rightarrow p \geq 1,9 d$

Recommendation: $p = 2,5 d + 5 \text{ mm}$



Distances according to EN 1993-1-8 fig. 3.1



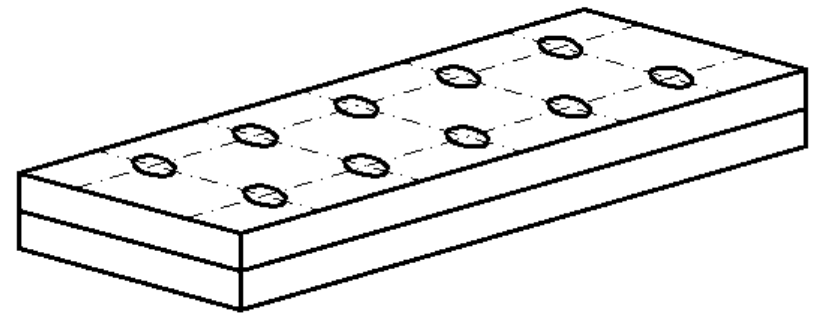
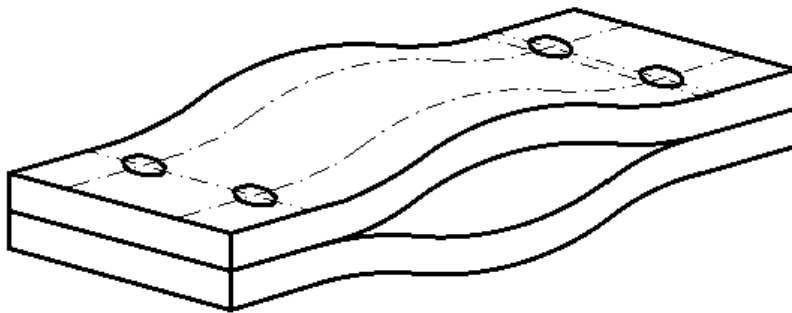
Dimensions	Minimum	Maximum		
		„Normal” steels		Stainless steels
		Steel exposed to the weather / corrosion influences	Not exposed	
e_1	$1,2 d_0$	$4 t_{e, \min} + 40 \text{ mm}$		$\max(8 t_{e, \min} ; 125 \text{ mm})$
e_2	$1,2 d_0$	$4 t_{e, \min} + 40 \text{ mm}$		$\max(8 t_{e, \min} ; 125 \text{ mm})$
e_3	$1,5 d_0$			
e_4	$1,5 d_0$			
p_1	$2,2 d_0$	$\min(14 t_{e, \min} ; 200 \text{ mm})$	$\min(14 t_{e, \min} ; 200 \text{ mm})$	$\min(14 t_{\min} ; 175 \text{ mm})$
$p_{1,0}$		$\min(14 t_{e, \min} ; 200 \text{ mm})$		
$p_{1,i}$		$\min(14 t_{e, \min} ; 200 \text{ mm})$		
p_2	$2,4 d_0$ ($1,2 d_0$ and $L \geq 2,4 d_0$)	$\min(14 t_{e, \min} ; 200 \text{ mm})$	$\min(14 t_{e, \min} ; 200 \text{ mm})$	$\min(14 t_{\min} ; 175 \text{ mm})$

Min distance: prevention of problems of too small distance between caps / nuts of bolts (collision), prevention of cracking between hols for bolts during drilling.

Max distance: function of type of steel („normal” / stainless) and exposition for corrosion influences.

Because of imperfection, there are no ideal flat plates in real world. Imperfections can make space between plates.

Photo: Author



In case of big distance between bolts, crevice corrosion can occurs in space between plates.

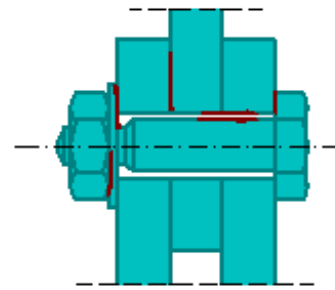
Big number of bolts make plates more straight, eliminate spaces between plates and prevent from crevice corrosion.

Crevice

Photo: Author



Photo: epg.science.cmu.ac.th



Limited air circulation and limited oxygen access, uneven distribution of sparingly and easily soluble salts on the surface of gap, increased aggressiveness of environment inside gap

→ #7 / 18

Contact (bimetallic): different chemical composition of alloys or contact of different metals. In presence of water/electrolyte, galvanic cell and directed movement of electrons is created. As a result, less noble metal corrodes in the presence of a more noble metal.



Photo: wikipedia

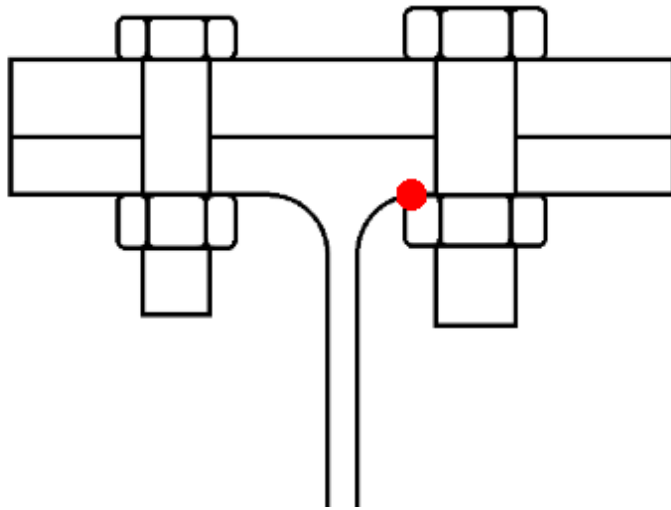


Photo: Author

Additional problems: cooperation between bolt and member

Too big diameter of bolt = collision between nut and cross-section. Bolt can't be completely close.

Slip resistant = 0

Bearing resistance smaller than according to formulas in EN 1993-1-8

Probability of bending in shank of bolt = shear resistance smaller than according to formulas in EN 1993-1-8.

Recommended distances between axis of bolts and plates or bolts and welds

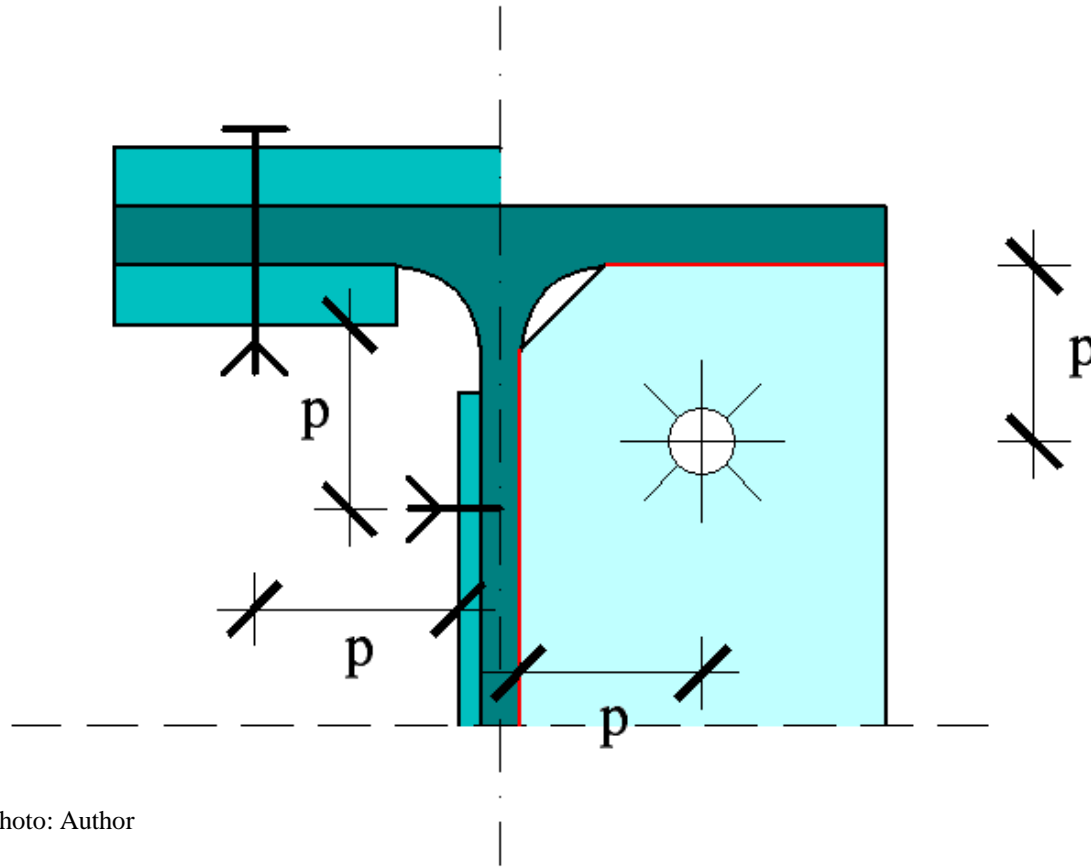
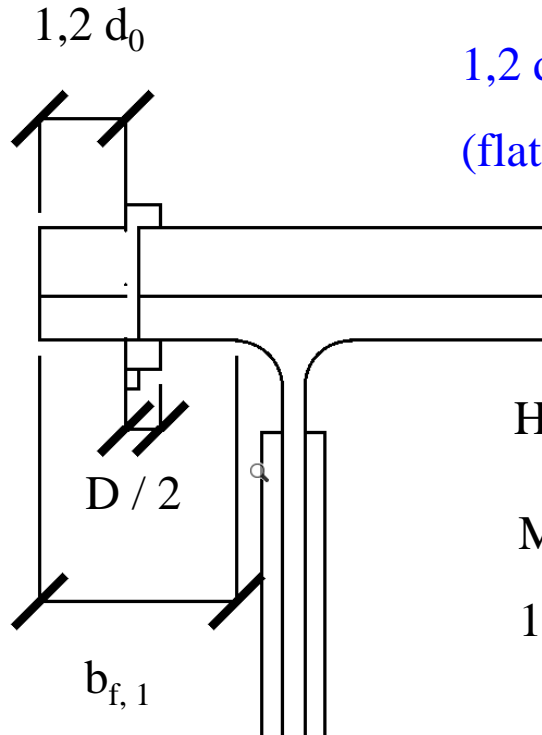


Photo: Author

p according to #t / 34

Additional limit: enough space on flange



$$1,2 d_0 + D / 2 + 5 \text{ mm} \leq b_{f,1}$$

(flat part of flange)

HEA 650: $b_{f,1} = (300 - 2 \cdot 27 - 13,5) / 2 = 116 \text{ mm}$

M24: $1,2 d_0 = 31,2 \text{ mm}$; $D / 2 = 20,8 \text{ mm}$

$1,2 d_0 + D / 2 + 5 \text{ mm} = 57 \text{ mm} \leq b_{f,1}$ **OK**

Photo: Author

Otherwise, we risk that nut will get stuck on rounded part between web and flange and we will not be able to tighten bolt.

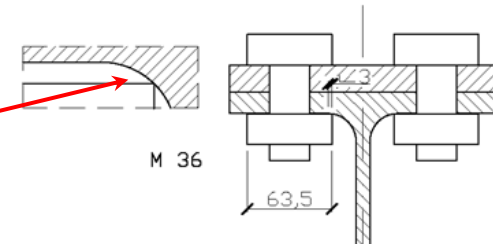


Photo: Author

Gap b between two part of I-beam (10 - 20 mm) - compensation of imperfection on support

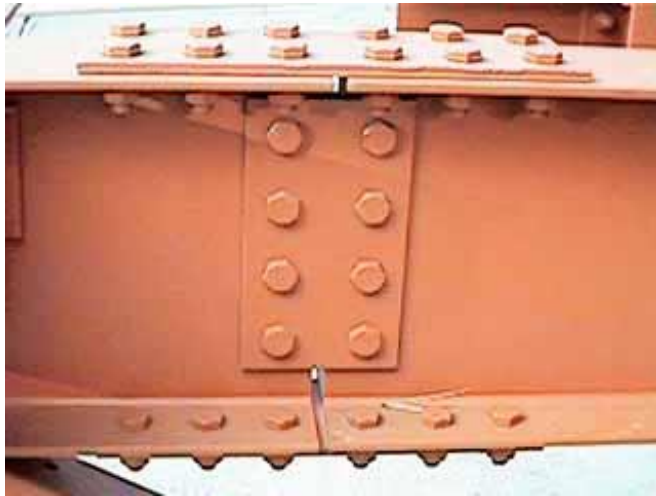


Photo: amsd.co.uk

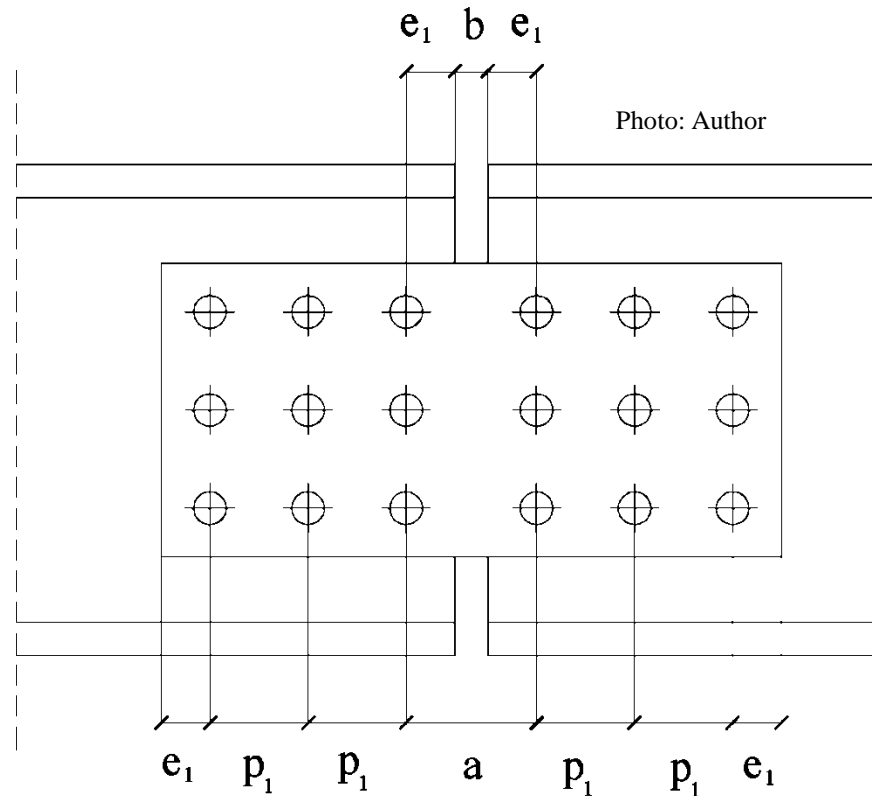


Photo: Author

$a = 2 e_1 + b$ can't be bigger than $\max p_1$ according to #t / 34

Too big distance between bolts parallel to direction of force (p_1) in not recommended.

$p_1 / t \geq 9\varepsilon$ and compressive force \rightarrow local buckling of plate (EN 1993-1-8 tab. 3.3)

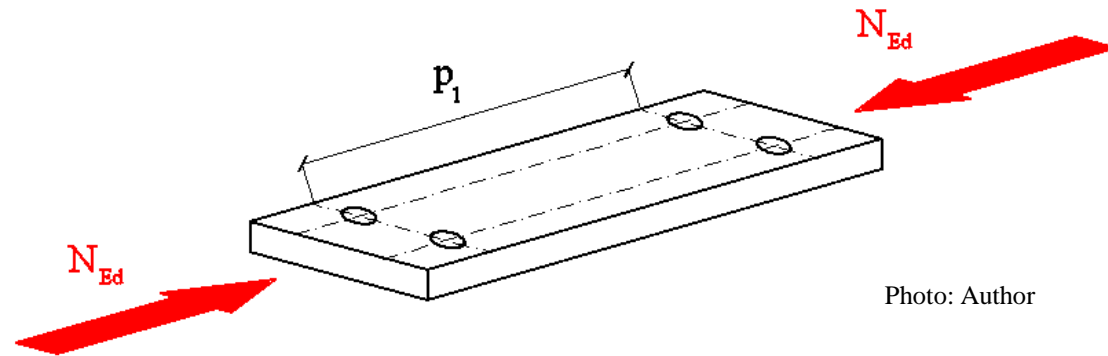
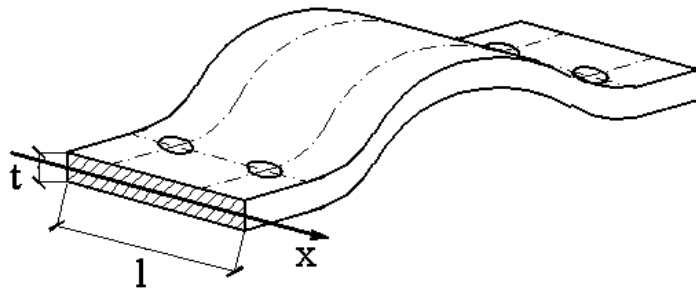


Photo: Author



$$N_{Ed} / (\chi_x N_{Rd}) \leq 1,0$$

$$N_{Rd} = A f_y$$

$$A = t \cdot 1 \quad ; \quad J_x = 1 \cdot t^3 / 12 \quad ;$$

$$i_x = \sqrt{(J_x / A)} = t / (2 \sqrt{3})$$

$$L_{cr} = 0,6 p_1$$

$$\chi_x = \chi_x (L_{cr} \quad ; \quad i_x \quad ; \quad c)$$

Resistances

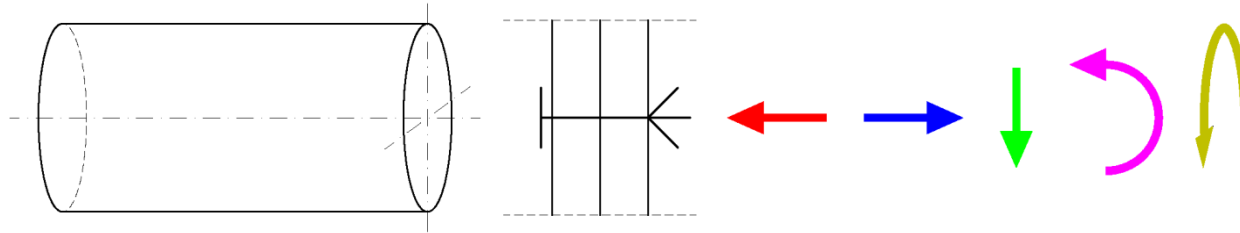


Photo: Author

Shank – long circular cylinder, sometimes (for bolts) with thread.

There is few different types of loads, applied to the shank, and, additionally, few combinations of forces. We must use different types of formula for different types of connection element (bolt - rivet - pin).

Besides resistance of shank, there are important different types of interactions between shank and plates / part of members.

Type	Connection	Joint		
		→ #14 / 18		
		Stiffness	Resistance	
Contact / interaction between connections (shank of bolt) and other elements	Contact / interaction between other elements			
Welded	EN 1993-1-8 chapter 4 (welds) <u>Lecture #16, 17</u>	EN 1993-1-8 chapter 5 and 6 <u>Lecture #14,15</u>	No phenomenons	EN 1992-1-1 chapter 6 EN 1993-1-5 chapter 5, chapter 9 EN 1993-1-8 chapter 4, chapter 6, chapter 7 EN 1995-1-5 chapter 9 <u>Lecture #19, 20, 21</u>
Bolted	EN 1993-1-8 chapter 3 (shanks) <u>Lecture #18</u>		EN 1993-1-8 chapter 3, chapter 6 <u>Lecture #18, 19, 21</u>	EN 1993-1-8 chapter 4, chapter 6 <u>Lecture #18, 19, 20, 21</u>

Type of bolts			Connection (→ #t / 43)		Rest part of joint (→ #t / 43)
			Shear resistance	Tension resistance	Different types of interactions
			→ #t / 51-56, 58-59	→ #t / 50, 57	
Shear	"normal"	A	✓		✓
	preloaded	B	✓	(✓)	✓
		C		(✓)	✓
Tension	"normal"	D	(✓)	✓	✓
	preloaded	E		(✓)	✓

Shear resistance and tension resistance are important for different categories of joints.

(✓) – sometimes important; more information → #t / 96 and #19

EN 1993-1-8 tab. 3.2

Interaction / contact bolt-element

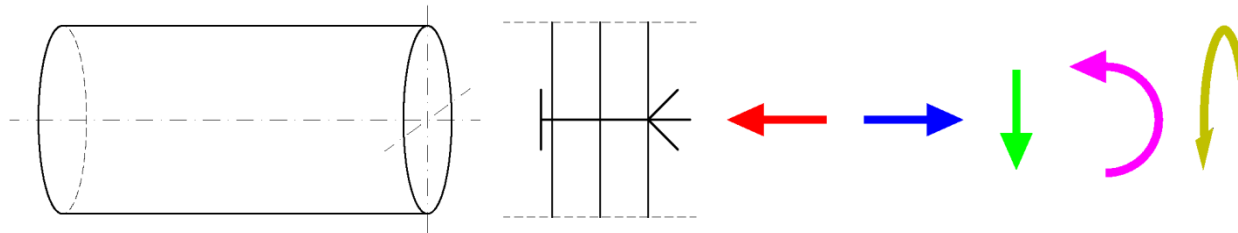
Type of bolts			Bearing resistance	Base plates shearing	Punching resistance	Prying actions	Plate / flange in bending	Web in tension
			→ #t / 62-76	→ lec #20	→ #t / 95	→ lec #19	→ lec #19	→ lec #19
Shear	"normal"	A	✓	✓				
	preloaded	B	✓		(✓)			
		C	✓		(✓)			
Tension	"normal"	D	(✓)		✓	✓	✓	✓
	preloaded	E	(✓)		✓	✓	✓	✓






Interaction / contact elements-elements

Type of bolts			Weakening by holes			Instability of plate	Slip-resistant
			„Classical” net area	Block tearing	L section		
Shear	"normal"	A	✓	✓	✓	✓	
	preloaded	B	✓	✓	✓	✓	✓
		C	✓	✓	✓	✓	✓
Tension	"normal"	D	(✓)	(✓)		(✓)	
	preloaded	E	(✓)	(✓)		(✓)	(✓)

Resistance of shank

Photo: Author



					
Bolts	by contact of plates	calculation of resistance	calculation of resistance	destruction	while tightening only
Rivets	by contact of plates	calculation of resistance	calculation of resistance	destruction	not occurs
Pins	by contact of plates	destruction	calculation of resistance	calculation of resistance	not occurs

Generally, we have two mechanisms of shank destruction for bolts, rivets and pins:



Photo: ceprofs.civil.tamu.edu

Photo: forgemag.com

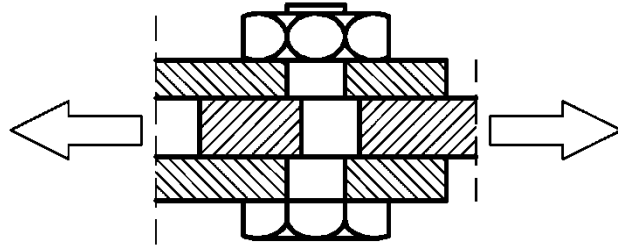


Photo: Author

Shear
(shear force)

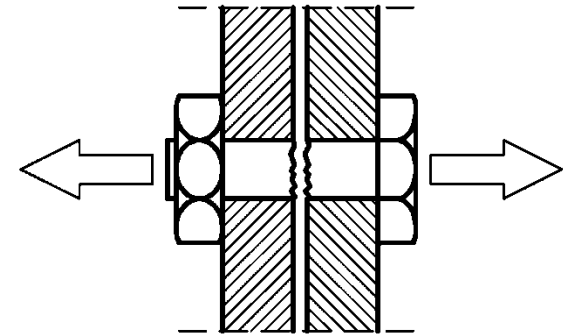


Photo: Author




Tearing
(tensile force)

For pins we must analyse resistance for bending moment, too.

Resistances

Photo: Author

There are only black part in EN 1993-1-8 tab 3.4 or 3.10. **Red part** is given in other points of EN.

	 $F_{t,Rd}$ (tension)	 $F_{v,Rd, total}$ (shear)	 M_{Rd}
Bolts	$k_2 f_{ub} A_s / \gamma_{M2}$ → #t / 50	$n \beta_{12-14} \beta_{Lf} \beta_p \alpha_v f_{ub} A_{(s)} / \gamma_{M2}$ → #t / 51-56	
Rivets	$0,6 f_{ur} A_0 / \gamma_{M2}$ → #t / 57	$n \beta_{Lf} \beta_p 0,6 f_{ur} A_0 / \gamma_{M2}$ → #t / 58	
Pins		$n \beta_{Lf} 0,6 f_{up} A / \gamma_{M2}$ → #t / 59	$1,5 f_{up} W_{el} / \gamma_{M0}$ („normal” pins) $0,8 f_{up} W_{el} / \gamma_{M6,ser}$ (replaced pins) → #t / 60-61

Bolts, tensile force

$$F_{t,Rd} = k_2 f_{ub} A_s / \gamma_{M2}$$

$k_2 = 0,90$ (or 0,63 for countersunk bolts)

f_{ub} - according to class of bolt $\rightarrow \#t / 17$

A_s - area of threaded portion of bolt

$\gamma_{M2} = 1,25$



Photo: forgemag.com

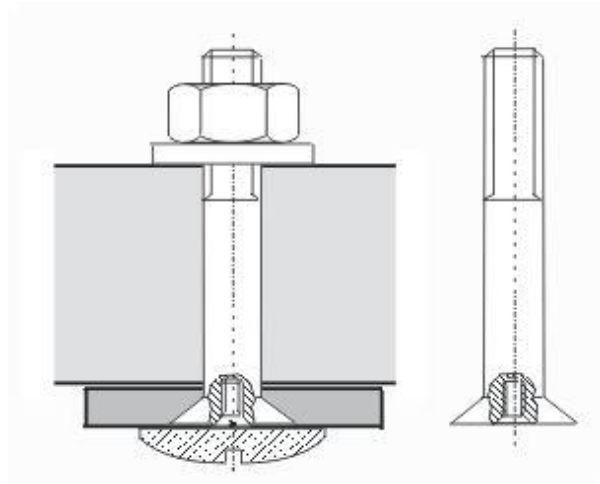


Photo: zeglarstwo.sail-ho.pl

Bolts, shear force

$$F_{v,Rd, total} = n \beta_{12-14} \beta_{Lf} \beta_p \alpha_V f_{ub} A_{(s)} / \gamma_{M2}$$



Photo: ceprofs.civil.tamu.edu

n - number of shear planes \rightarrow #t / 52

β_{12-14} - factor for bolts M12 and M14 \rightarrow #t / 53

β_{Lf} - factor for long joints \rightarrow #t / 54-55

β_p - factor for packing plates \rightarrow #t / 53

α_V - factor for shear resistance \rightarrow #t / 53

f_{ub} - according to class of bolt \rightarrow #t / 17

$A_{(s)}$ - area of threaded or unthreaded portion of bolt \rightarrow #t / 56

$\gamma_{M2} = 1,25$

Number of shear planes

Shear force $F_{v, Ed}$ acts evenly on each shear planes ($F_{v, Ed} / n$; n – number of shear planes).

For each plane effect of loads can't be greater than resistance ($F_{v, Ed} / n \leq F_{v, Rd}$).

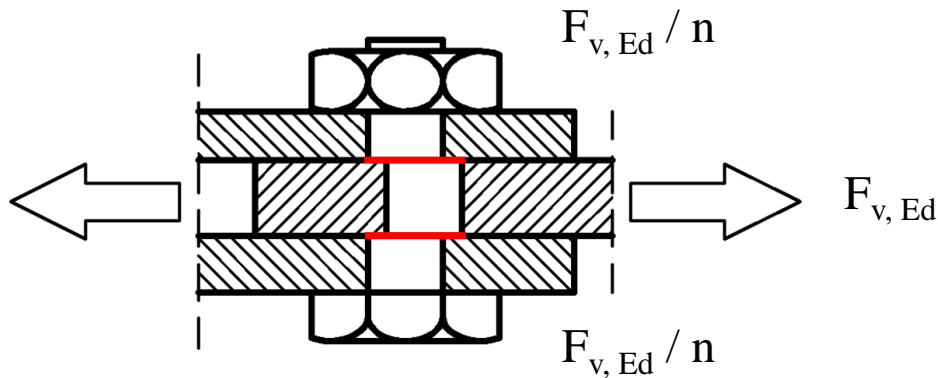


Photo: Author

$$F_{v, Ed} / n \leq F_{v, Rd} \rightarrow F_{v, Ed} \leq n F_{v, Rd}$$

EN 1993-1-8 tab. 3.4

$\alpha_V :$

A = A _s			A = A			
4.6	5.6	8.8	4.8	5.8	6.8	10.9
0,6			0,5			

EN 1993-1-8 tab. 3.4

$\beta_{12-14} :$

$d_0 - d =$

2 mm					1 mm	
4.8	5.8	6.8	8.8	10.9	4.6	5.6
0,85					1,00	

EN 1993-1-8 p.3.6.1.(5)

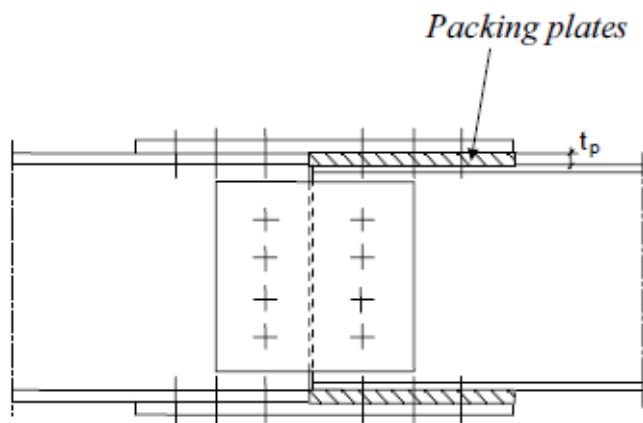


Photo: EN 1993-1-8 fig 3.4

When thickness / depth of elements is not the same:

$$3 t_p \geq d \rightarrow \beta_p = \min [9 d / (8 d + 3 t_p) ; 1,0]$$

EN 1993-1-8 (3.3)

Condition 1: $\sqrt{[(\sigma_{\perp})^2 + 3(\tau_{\parallel}^2 + \tau_{\perp}^2)]} \leq \beta_{LW} f_u / (\beta_w \gamma_{M2})$

Condition 2: $\sigma_{\perp} \leq 0,9 \beta_{LW} f_u / \gamma_{M2}$

→ #17 / 69

Values of β_{LW} for different types and lengths of welds:

Length of weld:	0 - ∞		
Between flange and web in welded I-beam	1,0		
Length of weld:	L < 1,700 m	1,700 m < L < 8,500 m	L > 8,500 m
Between transverse stiffeners and plates in welded I-beam	1,0	1,1 - L / 17	0,6
Length of weld:	L < 150 a	150 a < L < 900 a	L > 900 a
All other cases	1,0	1,2 - 0,2 L / (150 a)	0,0

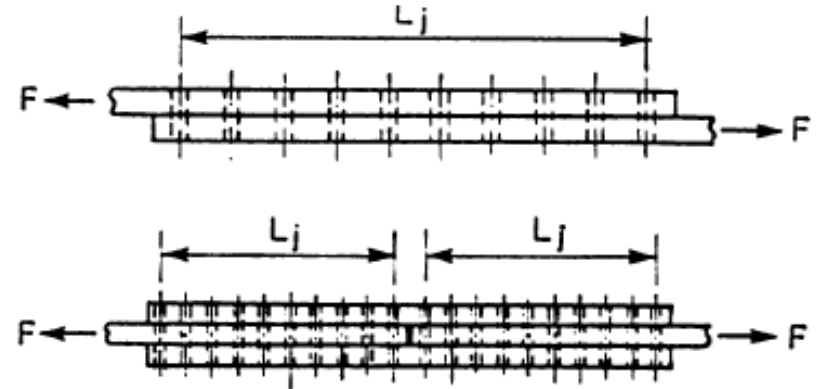
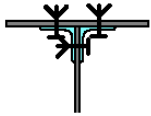
EN 1993-1-8 (4.9), (4.10)

In full analogy to welds: long joints for bolted joint:

Photo: EN 1993-1-8 fig. 3.7

EN 1993-1-8 3.8

Photo: Author



β_{Lf} :

	$L_j \leq 15 d$	$15 d \leq L_j \leq 65 d$	$L_j \geq 65 d$
Uniform distribution of force transfer over the length of the joint (flange-web)	1,00		
All other cases	1,00	$1 - (L_j - 15 d) / (200 d)$	0,75

Shear plane can go through threaded or unthreaded part of bolt.

→ #Des 2 Ex 1 / 60

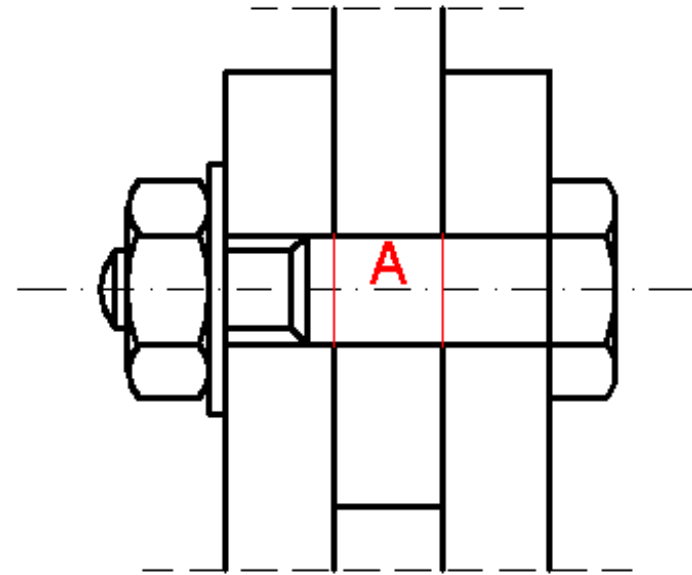
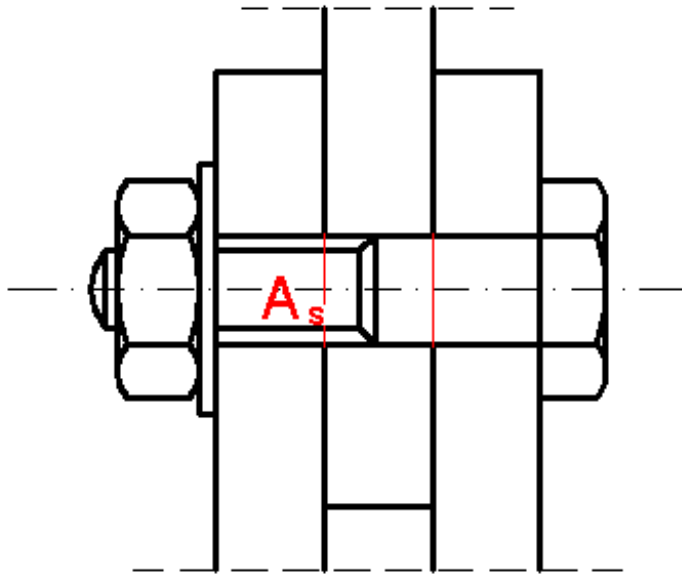


Photo: Author

It is necessary to check bolt length (length of thread along part of shank) now, and not - as in the previous project - only at the very end.

Rivets, tensile force

$$F_{t,Rd} = 0,6 f_{ur} A_0 / \gamma_{M2}$$

f_{ur} - specified ultimate tensile strength of rivet (according to National Standards)

A_0 - area of rivet hole

$$\gamma_{M2} = 1,25$$

Rivets, shear force

$$F_{v,Rd, total} = n \beta_{Lf} \beta_p 0,6 f_{ur} A_0 / \gamma_{M2}$$

n - number of shear planes $\rightarrow \#t / 52$

β_{Lf} - factor for long joints $\rightarrow \#t / 54-55$

β_p - factor for packing plates $\rightarrow \#t / 53$

f_{ur} - specified ultimate tensile strength of rivet (according to National Standards)

A_0 - area of rivet hole

$\gamma_{M2} = 1,25$

Pins, shear force

$$F_{v,Rd, total} = n \beta_{Lf} 0,6 f_{up} A / \gamma_{M2}$$

n - number of shear planes \rightarrow #t / 52

β_{Lf} - factor for long joints \rightarrow #t / 54-55

f_{up} - ultimate tensile strength of pin (according to National Standards)

A - area of pin

$$\gamma_{M2} = 1,25$$

Pins, bending moment

$$M_{Rd} = 1,5 f_{up} W_{el} / \gamma_{M0}$$

(„normal” pins)

$$M_{Rd,ser} = 0,8 f_{up} W_{el} / \gamma_{M6,ser}$$

(replaced pins)

f_{up} - ultimate tensile strength of pin (according to National Standards)

W_{el} - sectional modulus for pin's cross-section

$$\gamma_{M0} = 1,00$$

$$\gamma_{M6,ser} = 1,00$$

There is no clear, what means "replaced pin" and, in opposite to this, "normal pin". Certainly "normal pins" are used in hinge supports. More information will be presented in Lec #21.

Bending moment, which acts on pins, it is secondary effect of clearances between elements; it is not external bending moment.

EN 1993-1-8 tab 3.10, fig. 3.11:

$$M_{Ed} = F_{Ed} (b + 4c + 2a) / 8$$

shear force and bending moment always act on pin simultaneously:

$$(M_{Ed} / M_{Rd})^2 + (F_{v,Ed} / F_{v,Rd})^2 \leq 1,0$$

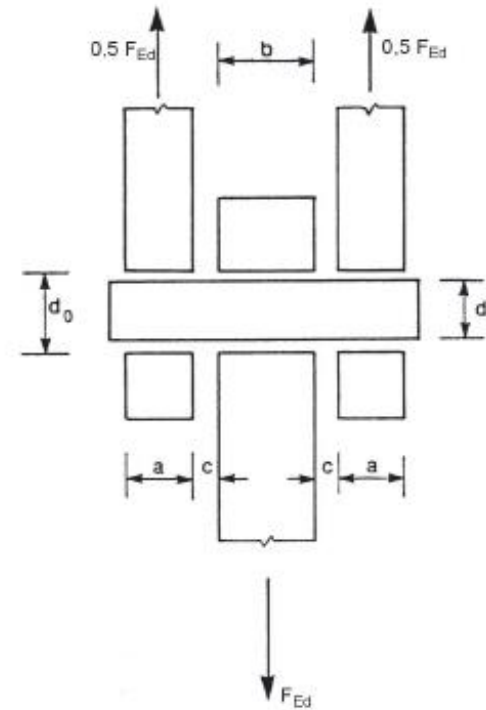
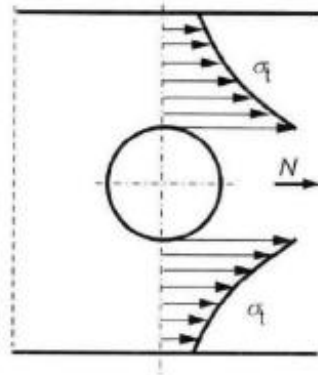
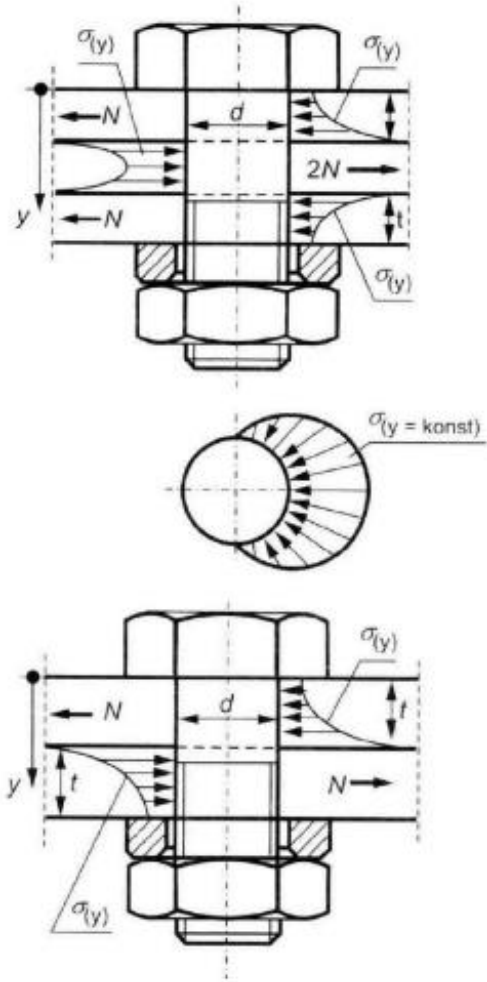


Photo: EN 1993-1-8 fig. 3.11

Bearing resistance



Deformation or destruction of plates as the effect of contact with shank of bolt.

Photo: A. Biegus, Projektowanie konstrukcji stalowych według Eurokodów, Politechnika Wroclawska

→ #Des 2 Examp 1 / 68

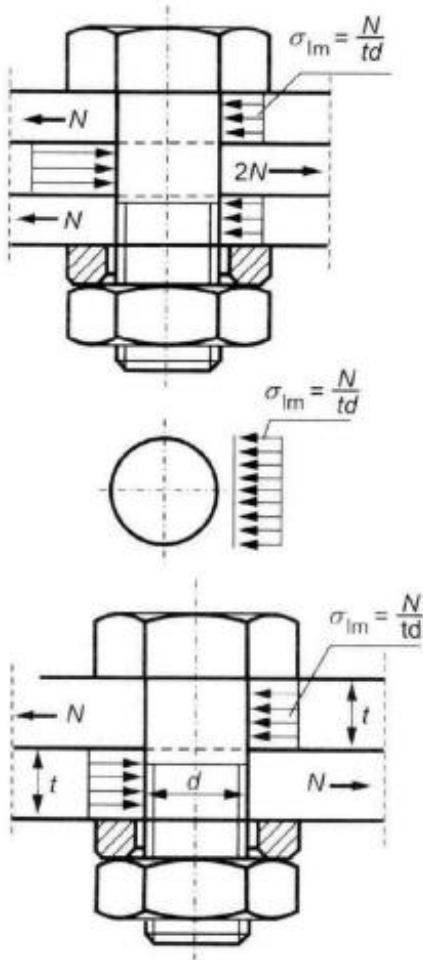


Photo: ascelibrary.org

We assume linear stresses in calculation model.

Photo: A. Biegus, Projektowanie konstrukcji stalowych według Eurokodów, Politechnika Wroclawska

Local deformation or destruction - but no global destruction (block tearing)

→ #Des 2 Ex 1 / 69

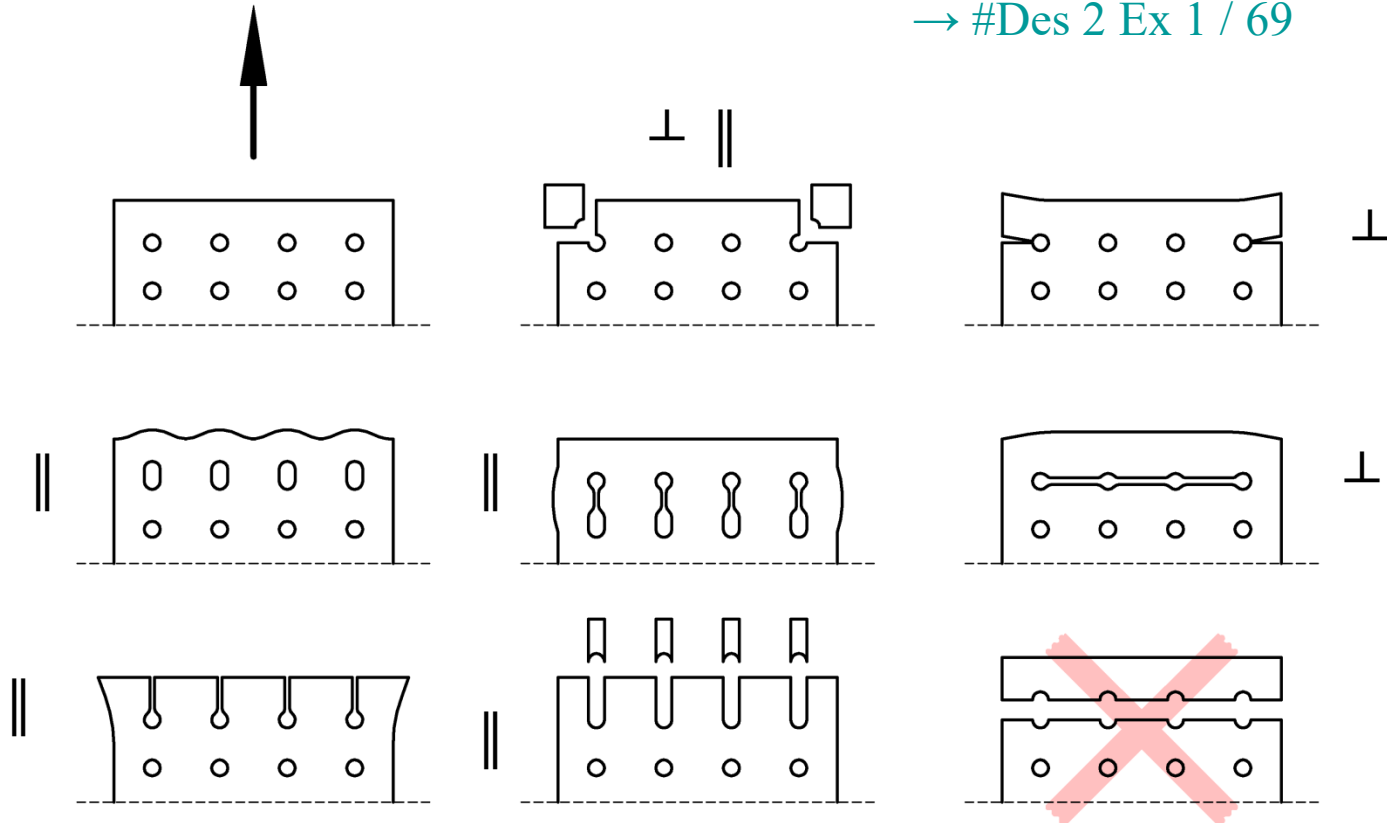
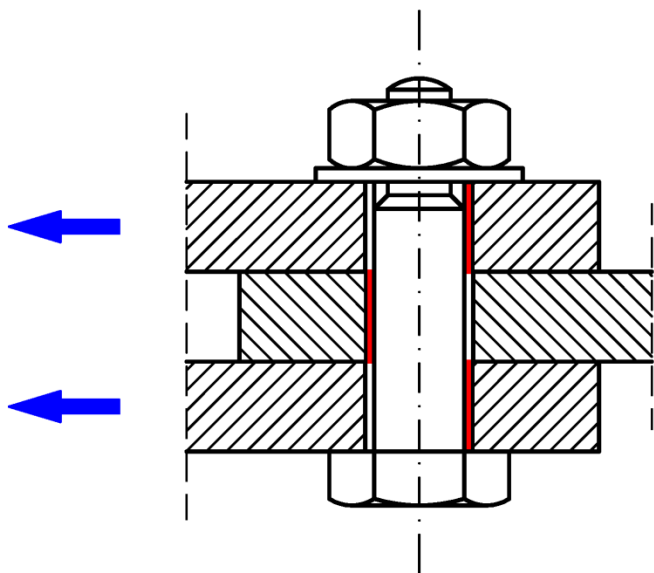


Photo: Author



→ Des #2 Ex 1 / 70

$$F_{b,Rd} = \beta_b k_1 \alpha_b f_u d t_{min} / \gamma_{M2}$$

Photo: Author

EN 1993-1-8 tab 3.4, **red part** is given in bottom part of table.

β_b – parameter of shape of hole → Des#2Ex#1 / 71

k_1 – parameter for phenomenons in direction perpendicular \perp to force → Des#2Ex#1 / 72

α_b – parameter for phenomenons in direction parallel \parallel to force → Des#2Ex#1 / 71, 72

f_u – ultimate strength of plate

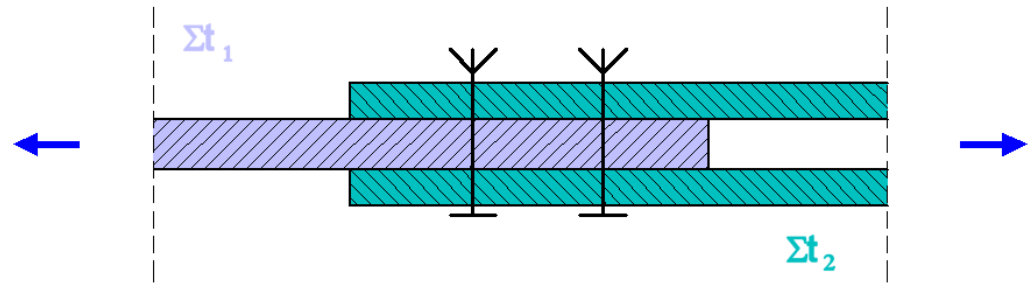
d – dimension of bolt

t_{min} – minimum total thickness of plate → Des#2Ex#1 / 71

$$\gamma_{M2} = 1,25$$

$$\alpha_b = \min (\alpha_d ; f_{ub} / f_u ; 1,0)$$

$$t_{min} = \min (\Sigma t_1 ; \Sigma t_2)$$



→ #Des 2 Ex 1 / 71

Photo: Author

Intentionally: no resistance, allowing free movement along hole's axis. This allows beam to rotate, as in an ideal hinge. After bolt has moved, it may possibly come into contact with plate. Then coefficient can be assumed as for an enlarged round hole 0,8 (to avoid damage of plate).

	β_b	
Fit bolts	1,0	
Normal round holes		
Oversized round holes	0,8	
Slotted holes	0,6	

EN 1993-1-8 tab 3.4

k_1 – parameter for phenomenons in direction perpendicular to force \perp

α_b – parameter for phenomenons in direction paralell to force \parallel

$$\alpha_b = \min (\alpha_d ; f_{ub} / f_u ; 1,0)$$

→ #Des 2 examp 1 / 72

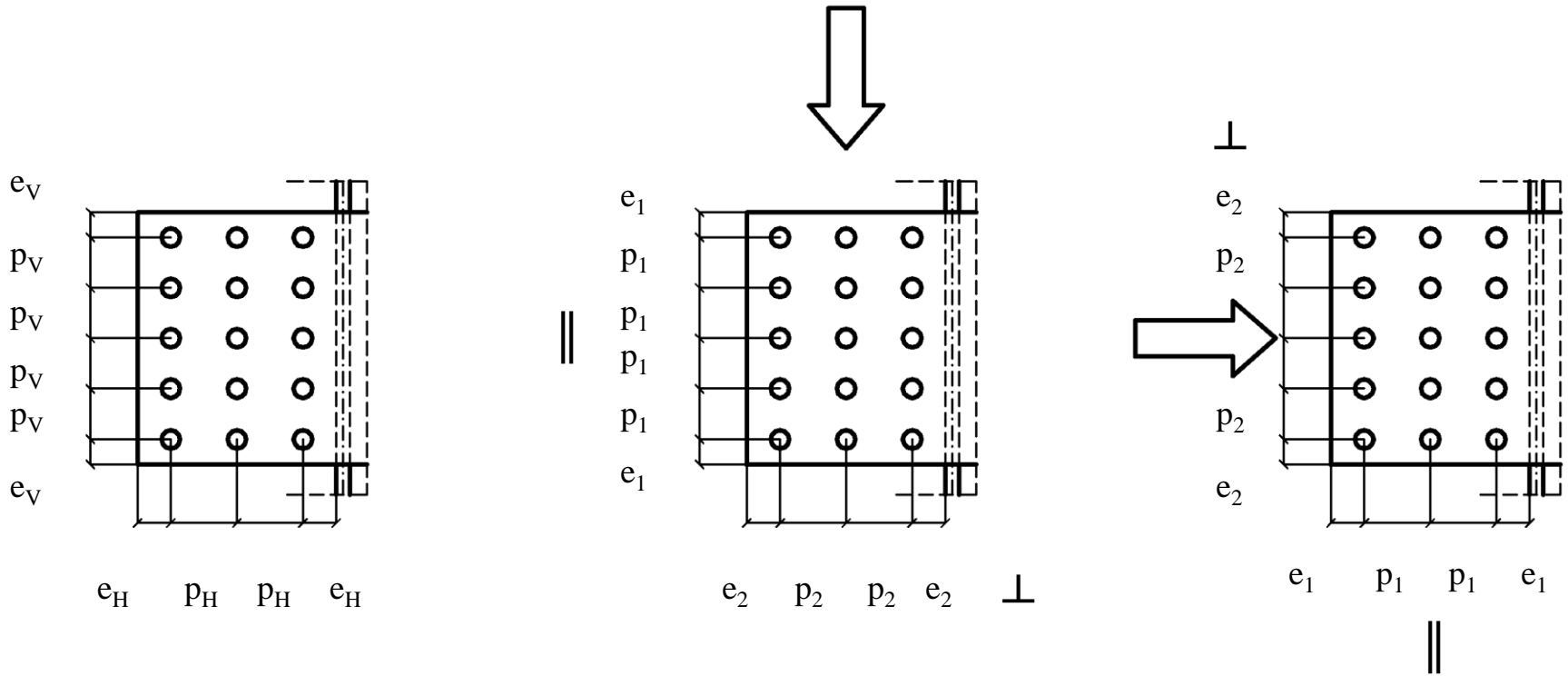
EN 1993-1-8 tab 3.4

d_0 – diameter of hole

	$k_1 \perp$ Direction perpendicular to force
Inner	$\min (1,4 p_2 / d_0 - 1,7 ; 2,5)$
Edge	$\min (2,8 e_2 / d_0 - 1,7 ; 2,5)$

	$\alpha_d \parallel$ Direction parallel to force
Inner	$p_1 / 3d_0 - 0,25$
End	$e_1 / 3d_0$

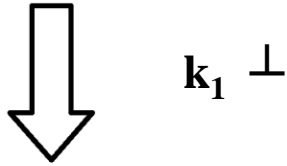
Index 1 and 2 in symbols e_1 e_2 p_1 p_2 - there are no horizontal and vertical directions, but always paralell (1) and perpendicular (2) to direction of force:



→ #Des 2 examp 1 / 73

Photo: Author

	$k_1 \perp$	Notice
Inner	$\min(1,4 p_2 / d_0 - 1,7 ; 2,5)$	Neighboring bolts on both sides \perp to force
Edge	$\min(2,8 e_2 / d_0 - 1,7 ; 2,5)$	Neighboring bolts on one side only



$k_1 \perp$

→ #Des 2 Ex 1 / 74

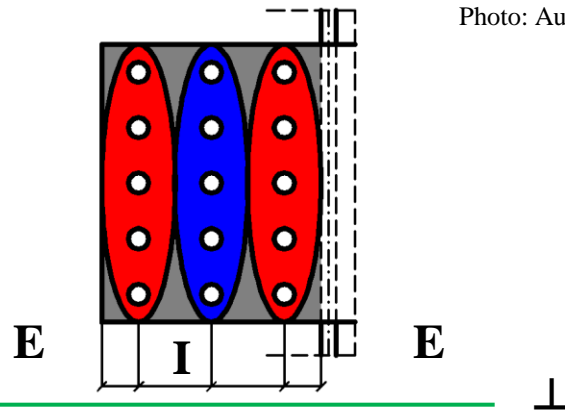
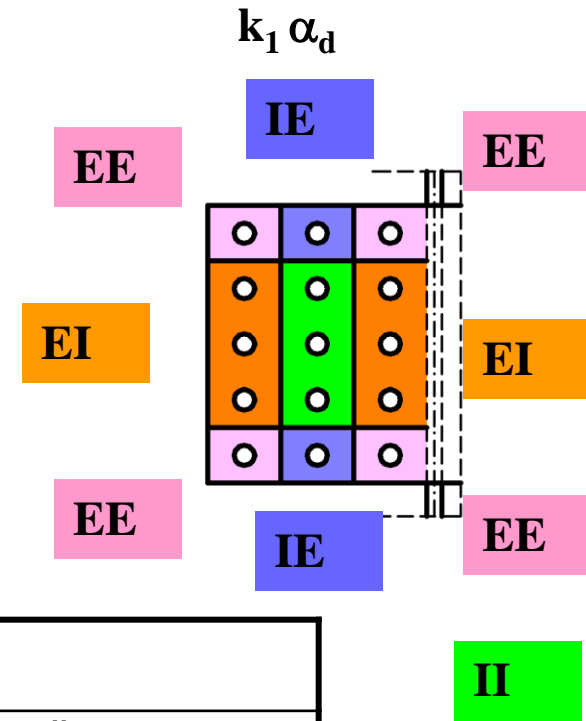
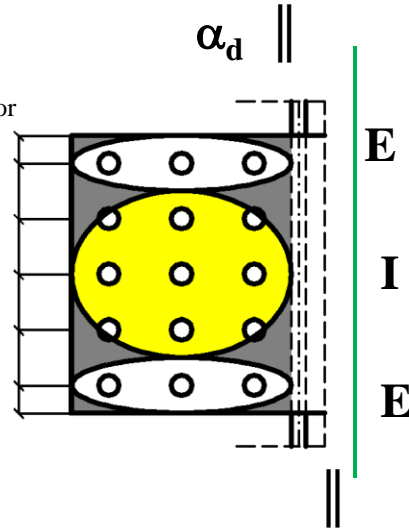


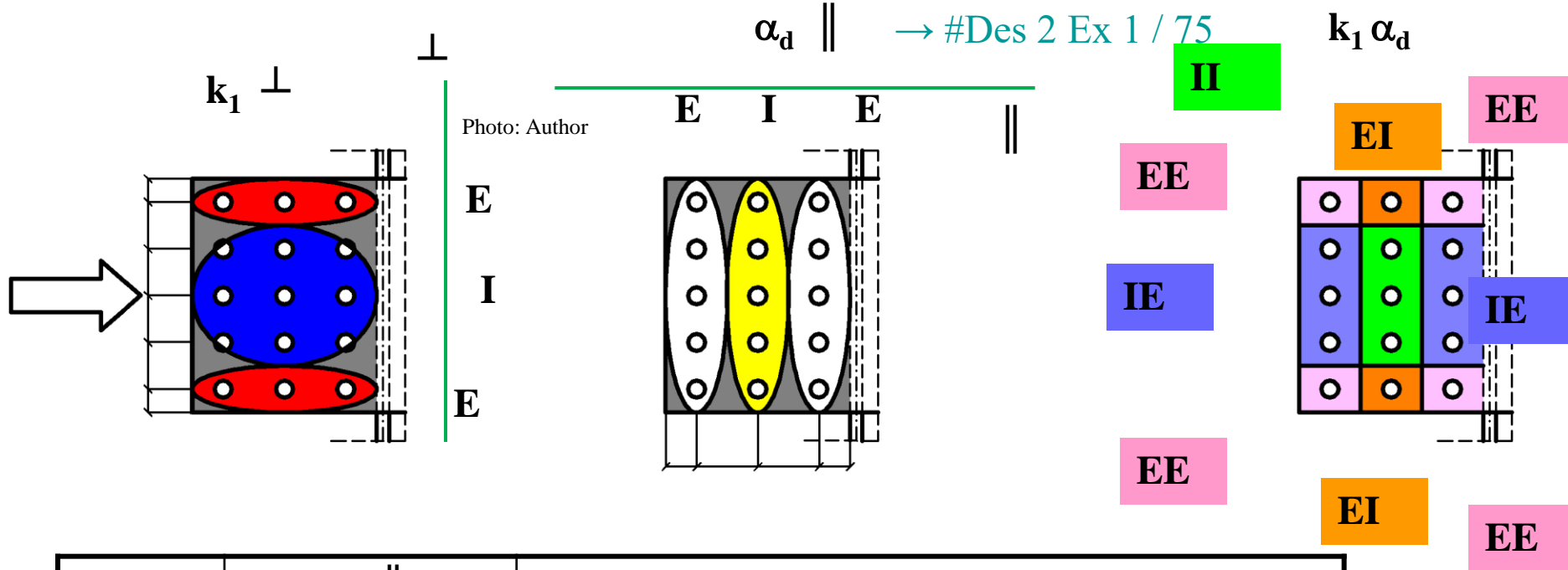
Photo: Author



	$\alpha_d \parallel$	Notice
Inner	$p_1 / 3d_0 - 0,25$	Neighboring bolts on both sides \parallel to force
End	$e_1 / 3d_0$	Neighboring bolts on one side only

II

	$k_1 \perp$	Notice
Inner	$\min(1,4 p_2 / d_0 - 1,7 ; 2,5)$	Neighboring bolts on both sides \perp to force
Edge	$\min(2,8 e_2 / d_0 - 1,7 ; 2,5)$	Neighboring bolts on one side only



	$\alpha_d \parallel$	Notice
Inner	$p_1 / 3d_0 - 0,25$	Neighboring bolts on both sides \parallel to force
End	$e_1 / 3d_0$	Neighboring bolts on one side only

Only one row, separated specification (EN 1993-1-8 (3.2)):

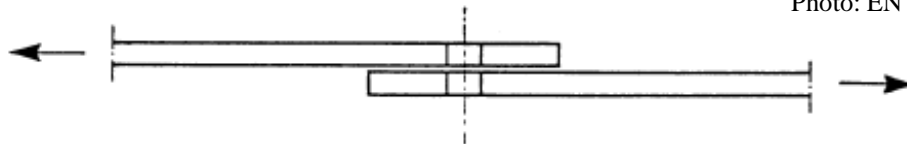


Photo: EN 1993-1-8 fig. 3.3

$$F_{b,Rd} = \min [\beta_b k_1 \alpha_b f_u d t_{\min} / \gamma_{M2} ; \beta_b 1,5 f_u d t_{\min} / \gamma_{M2}] =$$

$$= \min (k_1 \alpha_b ; 1,5) \cdot \beta_b f_u d t_{\min} / \gamma_{M2}$$

Symbols according to #t / 65

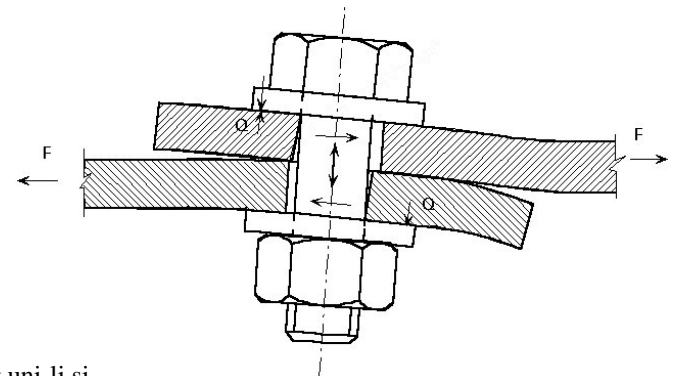


Photo: fgg.uni-lj.si

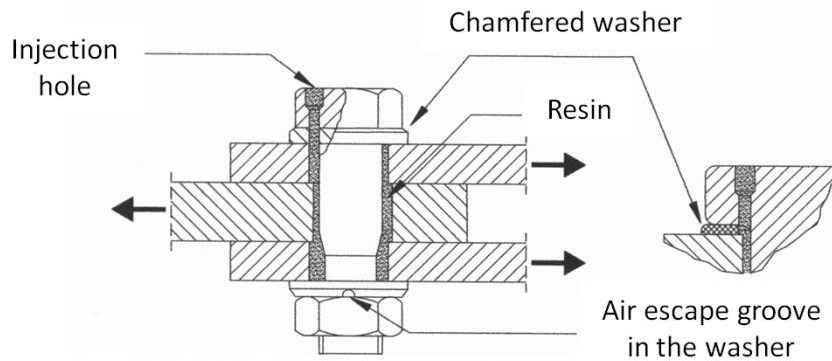


Photo: researchgate.net

Bearing of injection bolts:

EN 1993-1-8 (3.4)

$$F_{b,Rd, resin} = k_t k_s d t_{b, resin} \beta f_{b, resin} / \gamma_{M4}$$

k_t - coefficient of limit states $\rightarrow \#t / 73$

k_s - diameter of hollow shape $\rightarrow \#t / 73$

d - diameter of bolt

$t_{b, resin}$ - effective bearing thickness $\rightarrow \#t / 74$

β - coefficient of thickness ratio $\rightarrow \#t / 74$

$f_{b, resin}$ - bearing strength of resin \rightarrow information from manufactures

$$\gamma_{M4} = 1,0$$

	ULS	SLS
k_t	1,2	1,0

EN 1993-1-8 3.6.2.2.(5)

	k_s
Fit bolts	No space for resin
Normal round holes	1,0
Oversized round holes	1,0 - 0,1 ($d_0 - d$)
Slotted holes	1,0 - 0,05 ($1 - d_0$)

$l ; d_0 ; d$ [mm]

EN 1993-1-8 3.6.2.2.(5)

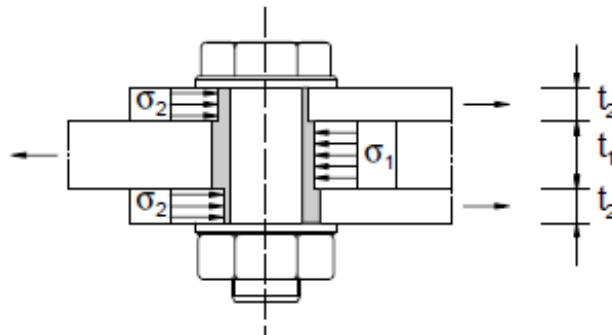


Photo: EN 1993-1-8 fig 3.5

	β	$t_{b, \text{resin}}$
$t_1 / t_2 \leq 1,0$	1,33	min (t_1 ; 1,5d)
$1,0 \leq t_1 / t_2 \leq 2,0$	$1,66 - 0,33 (t_1 / t_2)$	
$t_1 / t_2 \geq 2,0$	1,0	min ($2t_2$; 1,5d)

EN 1993-1-8 tab 3.5

Pins

Geometrical requirements for pin ended members

EN 1993-1-8 tab 3.9

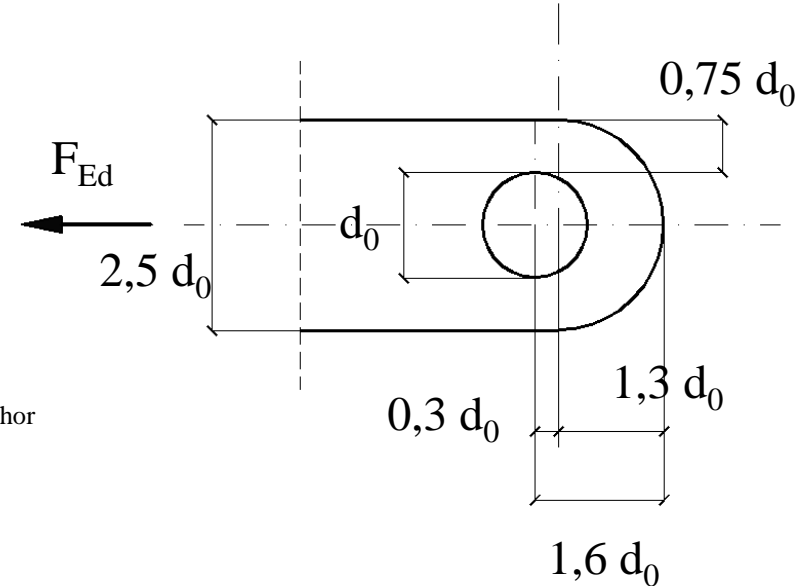
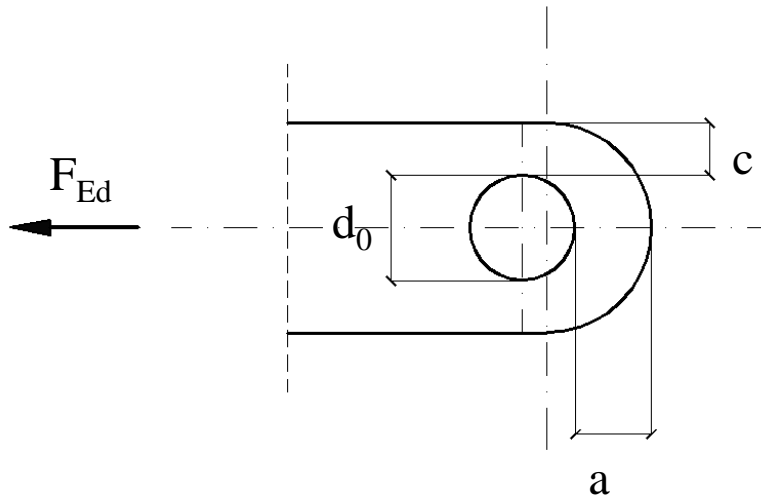


Photo: Author

When thickness t of plate is given:

$$a \geq [F_{Ed} \gamma_{M0} / (2 t f_y)] + 2 d_0 / 3$$

$$c \geq [F_{Ed} \gamma_{M0} / (2 t f_y)] + d_0 / 3$$

When diameter d_0 is given:

$$t \geq 0,7 \sqrt{[F_{Ed} \gamma_{M0} / f_y]}$$

$$d_0 \leq 2,5 t$$

Contact bearing stress for pins

EN 1993-1-8 3.13.2

$$\sigma_{h, Ed} / f_{h, Rd} \leq 1,0$$

$$\sigma_{h, Ed} = 0,591 \sqrt{[E F_{Ed, ser} (d_0 - d) / (d^2 t)]}$$

$$f_{h, Rd} = 2,5 f_y / \gamma_{M6, ser}$$

Weakening of the cross-section by holes

Cross-section without holes for bolts



Photo: quora.com



Rys: quora.com

"Classical" netto area

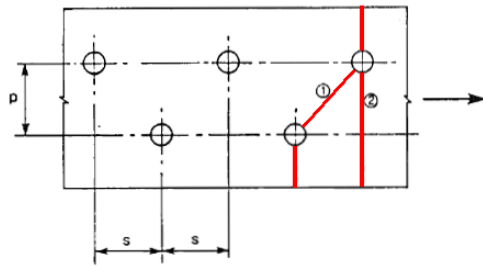


Photo: EN 1993-1-8 fig. 3.1

Block tearing

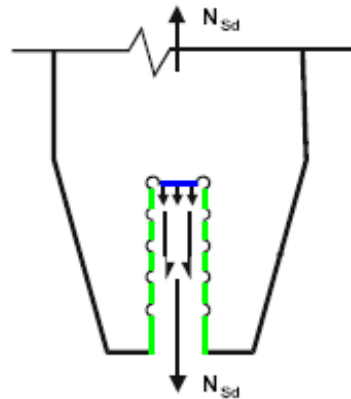


Photo: EN 1993-1-8 fig. 3.8

L section (separated rules)

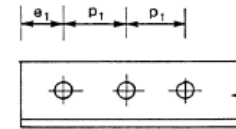


Photo: EN 1993-1-8 fig. 3.9

- ◆ straight or nearly straight line;
- ◆ different cross-sections (except L section);
- ◆ different loads (forces, bending moment, interactions);

- ◆ broken line;
- ◆ flat part of elements / plates;
- ◆ only one force;

- ◆ additional rules for L section „classical” netto area only;
- ◆ tensile axial force only;

"Classical" netto area

EN 1993-1-1 chapter 6

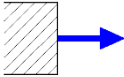

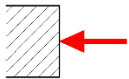
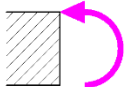
Force	Type	Fit bolts	Normal round holes	Oversized round holes	Slotted holes
	A, B	$N_{u,Rd} = 0,9 A_{net} f_u / \gamma_{M2}$ (recommendation: $N_{u,Rd} > A f_y / \gamma_{M0}$)			
	C	$N_{net,Rd} = A_{net} f_y / \gamma_{M0}$			
	A, B, C	Impact of holes can be neglected			

Photo: Author

Force	Type	Fit bolts	Normal round holes	Oversized round holes	Slotted holes
	A, B, C		Impact of holes can be neglected		
	A, B, C		Impact of holes can be neglected	If $0,9 A_{\text{comp, net}} f_u / \gamma_{M2} \geq A_{\text{comp}} f_y / \gamma_{M0}$ then can be neglected	

No information in Eurocode. It could mean, that such solution is not recommended / prohibited.

Block tearing – total destruction of web

→ #Des 2 Ex 1 / 83

EN 1993-1-8 3.10.2

Shear

Tension

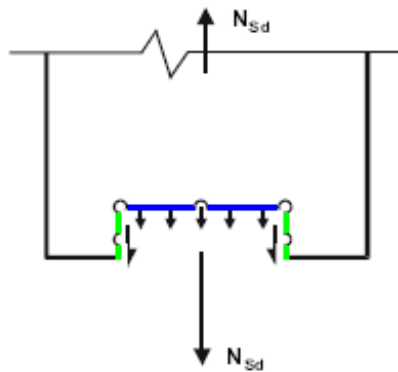
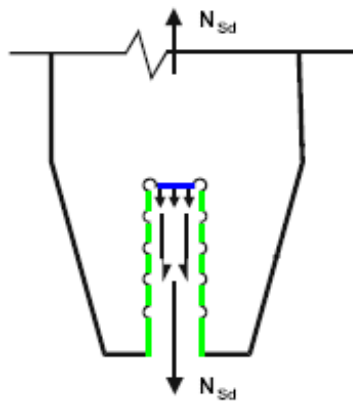
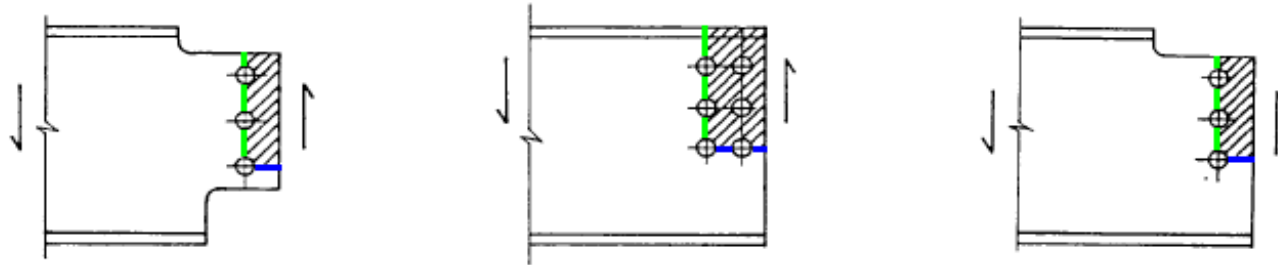
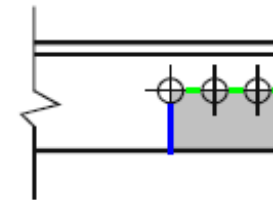


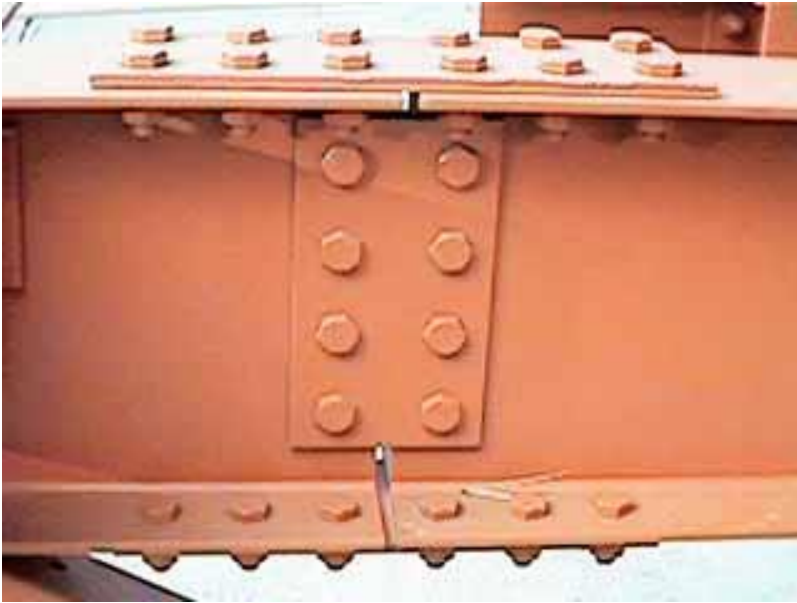
Photo: EN 1993-1-8 fig. 3.8



$$V_{\text{eff}, 1, R_d} = f_u A_{\text{nt}} / \gamma_{M2} + f_y A_{\text{nv}} / (\sqrt{3} \gamma_{M0}) \quad | \quad 0,5 f_u A_{\text{nt}} / \gamma_{M2} + f_y A_{\text{nv}} / (\sqrt{3} \gamma_{M0})$$

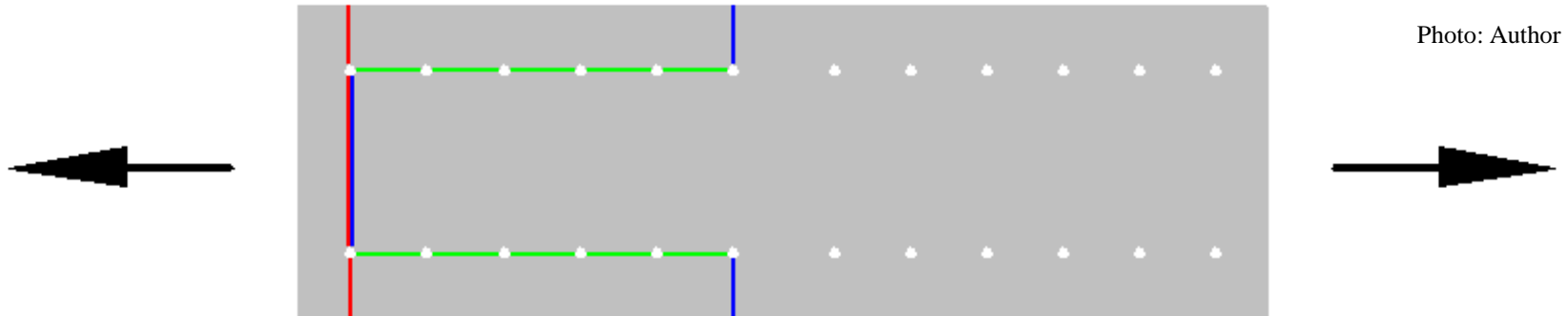
$$\gamma_{M0} = 1,00; \quad \gamma_{M2} = 1,25$$

Photo: amsd.co.uk



Example for calculation of net area: flange, flange plate, web, web plate

→ #Des 2 Ex 2 / 76



Flange plate, axial force only. According to #Des 2Ex1 / 78 we should calculate block tearing (**tension part** and **shear part**), but the smallest area is for **red** cross-section for netto area effect. Netto resistance for tensile axial force:

$$N_{u,Rd} = \min [0,9 A_{\text{net}} f_u / \gamma_{M2} ; A f_y / \gamma_{M0}]$$

→ #Des 2 Ex 2 / 77

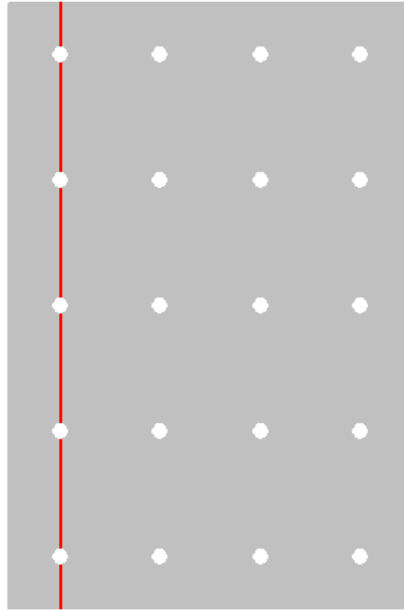


Photo: Author

Web plate, bending moment, shear force and, optionally, axial force.

$$\sigma(N_{fp}) = N_{fp} / A_{netto}$$

$$\sigma(M_{fp}) = M_{fp} / W_{netto}$$

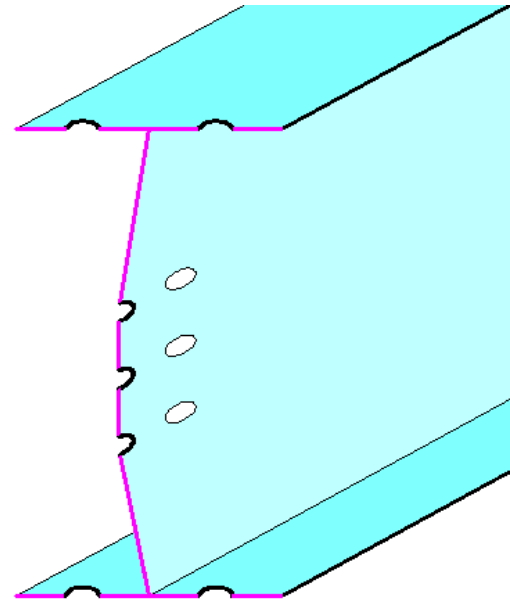
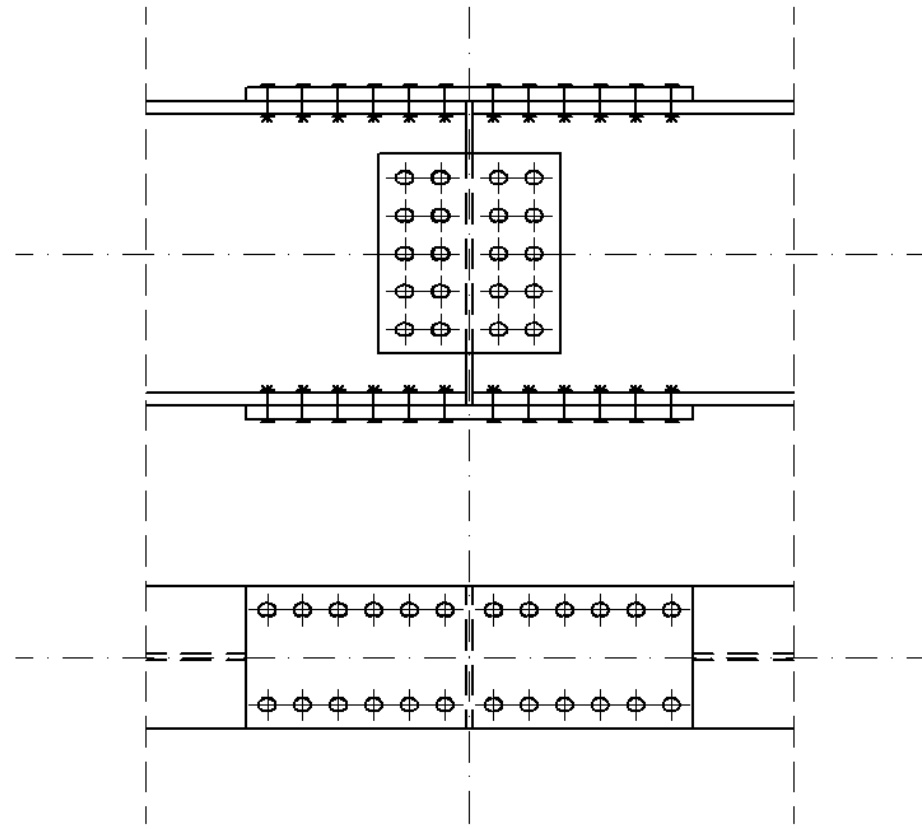
$$\tau(V_{fp}) = V_{fp} / A_{total}$$

$$\sqrt{\{ [\sigma(N_{fp}) + \sigma(M_{fp})]^2 + 3[\tau(V_{fp})]^2 \}} \leq f_y$$

Web, flange - uniform cross-section, not two separate part. We should analysed destruction of whole netto cross-section.

→ #Des 2 Ex 2 / 78

Photo: Author



$$\sigma(M_{fp}) = M_{Ed} / W_{netto}$$

$$\tau(V_{fp}) = V_{Ed} / (h_w t_w)$$

$$\sqrt{\{ [\sigma(M_{fp})]^2 + 3[t(V_{fp})]^2 \}} \leq f_y$$

L section (axial force) – separated rules
EN 1993-1-8 3.10.3

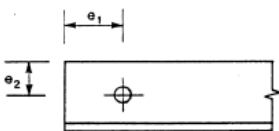
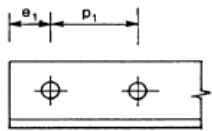
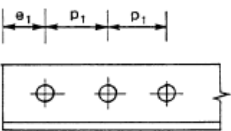
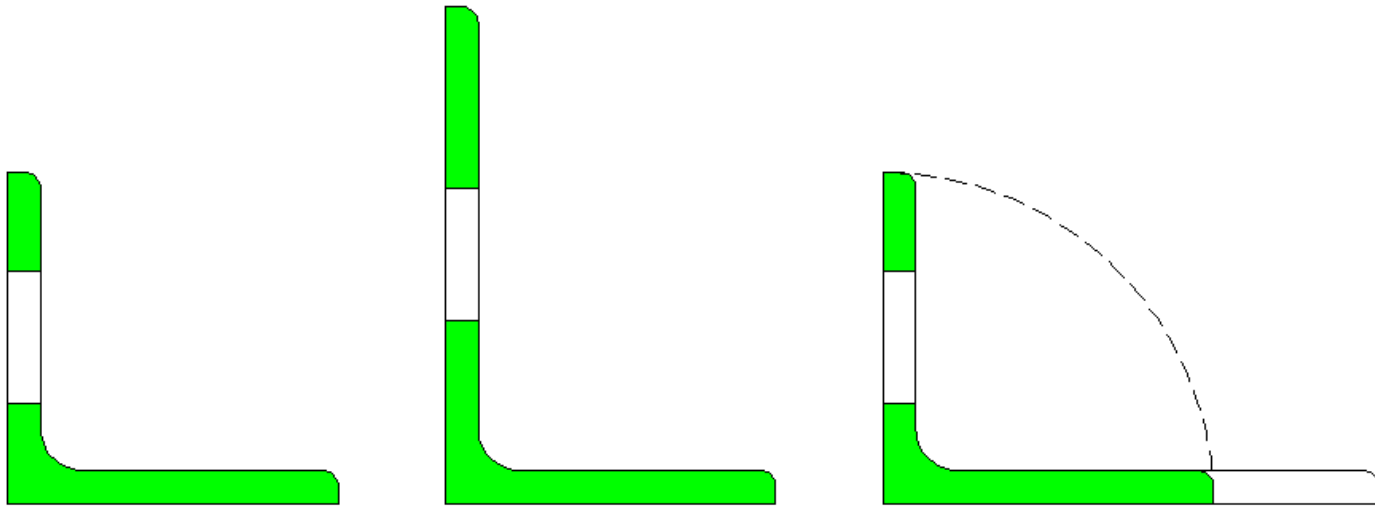
	$N_{u, Rd} =$	β		
		$p_1 / d_0 \leq 2,5$	$2,5 < p_1 / d_0 < 5,0$	$p_1 / d_0 \geq 5,0$
	$2 (e_1 - 0,5 d_0) t f_u / \gamma_{M2}$			
	$\beta A_{net} f_u / \gamma_{M2}$	0,4	$0,4 + 0,12 (p_1 / d_0 - 2,5)$	0,7
		0,5	$0,5 + 0,08 (p_1 / d_0 - 2,5)$	0,7

Photo: EN 1993-1-8 fig. 3.9



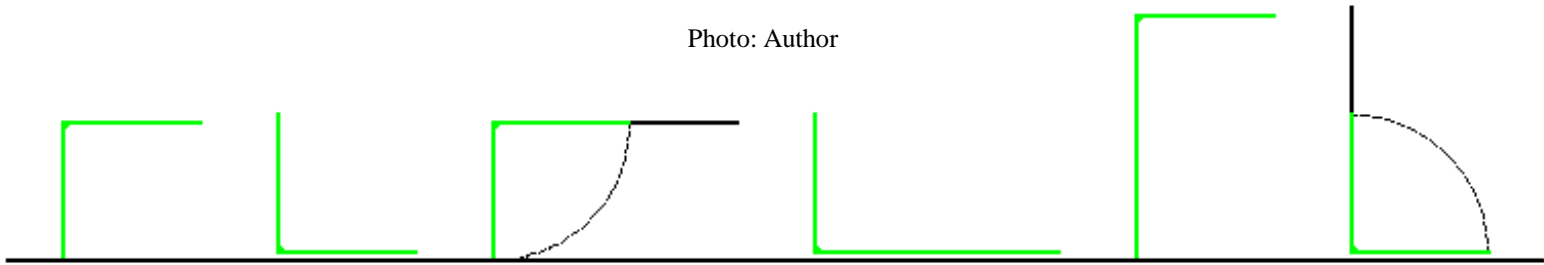
A_{net}

Photo: Author

L - section; additional rules for welds

The same philosophy as for bolts

Photo: Author



Resistance of L section, connected by one leg:

$$N_{Rd} = A_{eff} f_y / \gamma_{M1}$$

Slip-resistant

Preloaded bolt – special types of bolts: preloading force (due to strong tightening of nut) causes friction; loads can't be greater than friction.

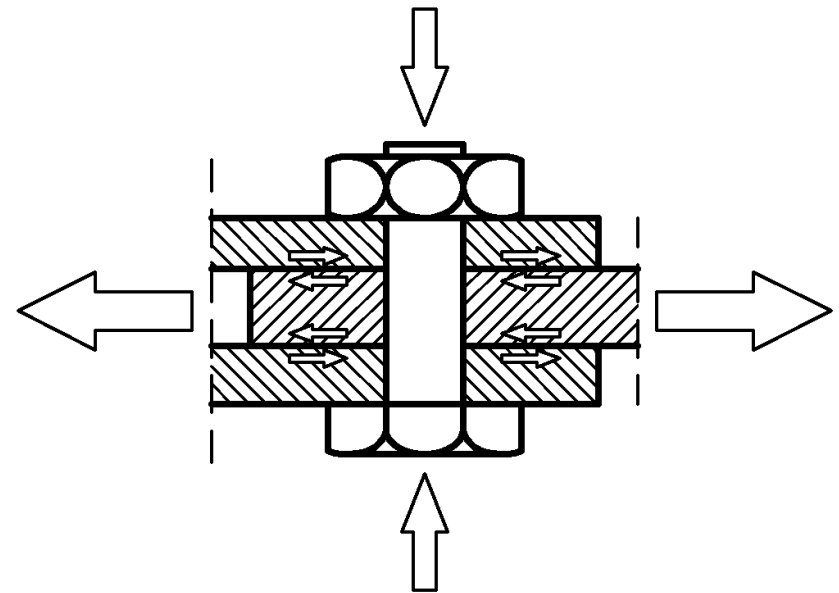
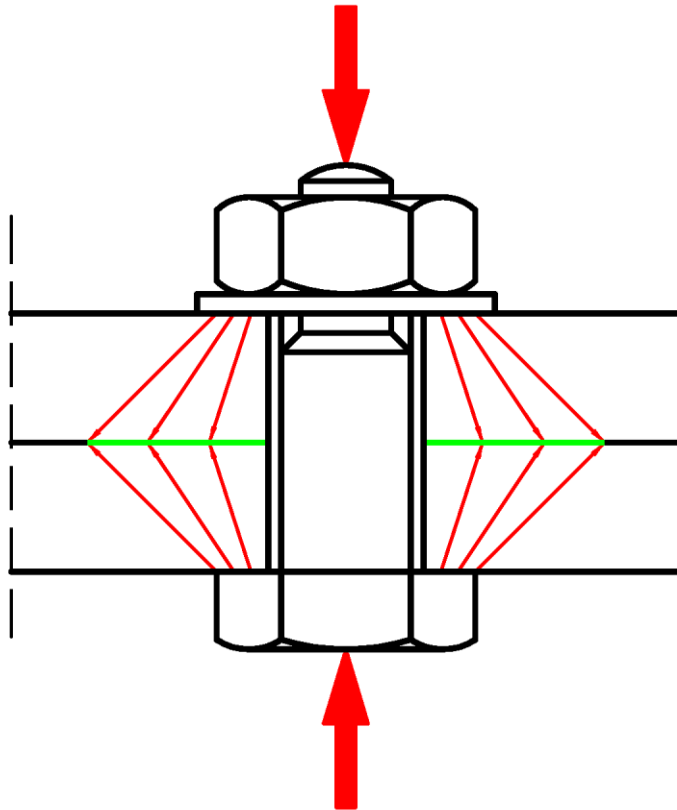


Photo: Author

Resistance

EN 1993-1-8 (3.7, 3.8a, 3.8b)

Type	F _{s,Rd}		Condition
	F _{t,Ed} = 0	F _{t,Ed} ≠ 0	
B	k _s n μ F _{p,C} / γ _{M3}	k _s n μ [F _{p,C} - 0,8 F _{t,Ed, ser} (q _k)] / γ _{M3,ser}	F _{Ed} (q _k) / F _{s,Rd} ≤ 1,0
C		k _s n μ [F _{p,C} - 0,8 F _{t,Ed} (q)] / γ _{M3}	F _{Ed} (q) / F _{s,Rd} ≤ 1,0

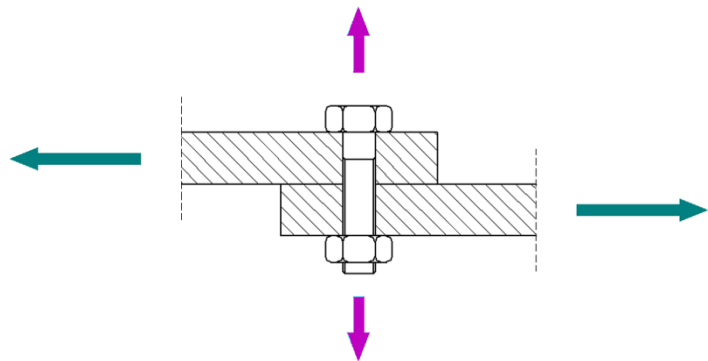


Photo: Author

F_{t,Ed} - additional external load (in case of joint category E)

k_s - coefficient of hollow shape → #t / 90

n - number of friction planes

μ - friction coefficient → #t / 91






F_{p,C} - preloading force → #t / 90

γ_{M3} = 1,25 γ_{M3,ser} = 1,10

$$F_{p,C} = 0,7 f_{ub} A_s / \gamma_{M7} = 0,636 f_{ub} A_s = 88\% \text{ tensile force resistance} = 0,720 f_{ub} A_s$$

$$\gamma_{M7} = 1,1$$

EN 1993-1-8 (3.7)

Type of holes		Force	k_s
Round	Fit		1,0
	Normal		1,0
	Oversized		0,85
Slotted	Short		0,76
			0,85
	Long		0,63
			0,70

→ #Des 2 Ex 2 / 66

EN 1993-1-8 tab. 3.6

Photo: Author

Class of friction surfaces	Friction coefficient μ	Surface treatment
A	0,5	Surface blasted with shot or grit with loose rust removed, not pitted;
B	0,4	Surfaces blasted with shot or grit: <ul style="list-style-type: none"> ◆ spray-metallized with a aluminum or zinc based product; ◆ with alkali-zinc silicate paint with a thickness of 50 μm to 80 μm;
C	0,3	Surfaces cleaned by wire-brushing or flame cleaning, with loose rust removed;
D	0,2	Surfaces as rolled;

Torque spanner for preloaded bolts – we must know value of preloaded force.



Photo: narzedzia.pl

Relation torque moment M_r – preloading force $F_{p,C}$ for preloaded bolts (diameter d)

$$M_r = k_m d F_{p,C}$$

EN 1090-2 p.8.5.2

$k_m = 0,15 \sim 0,18$ according to EN 14 399

WHO DETERMINES THE STRENGTH OF A BOLT?



Photo: home.jtan.com

By unfortunate coincidence, three completely different things are marked in the same way:

- **Category of bolted joint:** A, B, C, D, E (\rightarrow #t / 16);
- **Grade of bolt:** A, B, C (\rightarrow #t / 26);
- **Class of friction surface:** A, B, C, D (\rightarrow #t / 91).

Category	Grade	Friction
	(this part is recommendation only)	
A („normal”, shear)	Recommended B, acceptable C only for class of bolt not higher than 5.6	It doesn't matter for this category
B (partly preloaded, shear)	Recommended A, acceptable B	A, B, C, D – decision of designer
C (preloaded, shear)		
D („normal”, tension)	Recommended B, acceptable C only for class of bolt not higher than 5.6	It doesn't matter for this category
E (preloaded, tension)	Recommended B	A, B, C, D – decision of designer

Punching resistance

Too big axial force (or preloading force) can destruct too thin plates

$$B_{p,Rd} = 0,6 \pi d_m t_p f_u / \gamma_{M2}$$

$$d_m = (D + s) / 2$$

t_p - thickness of plate

f_u - strength of plate

$$\gamma_{M2} = 1,25$$

Categories B, C, E → checking: $F_{p,C} / B_{p,Rd} \leq 1,0$

Categories D, E → checking: tensile axial force / $B_{p,Rd} \leq 1,0$

EN 1993-1-8 tab. 3.4

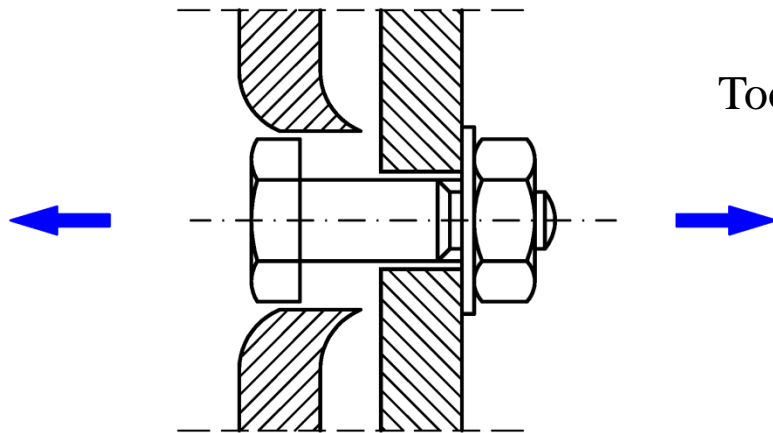


Photo: Author

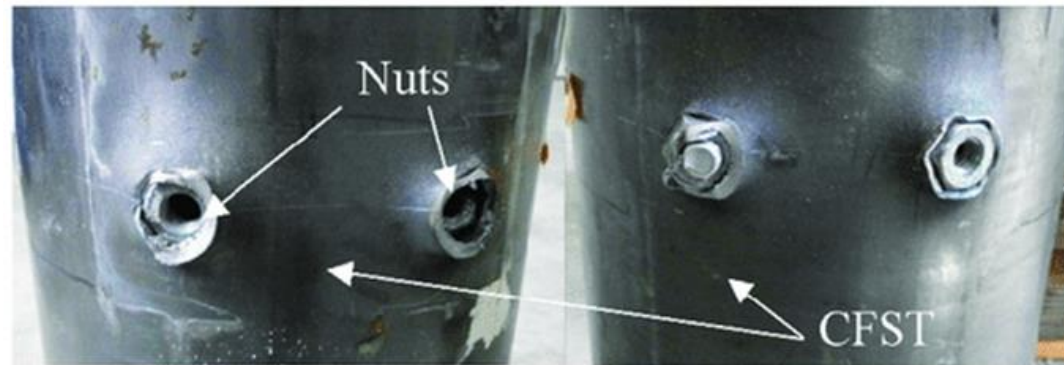
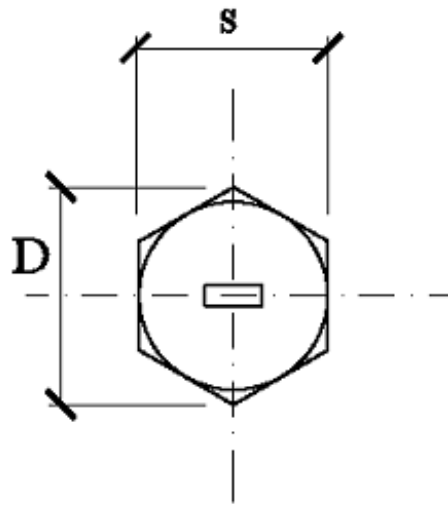
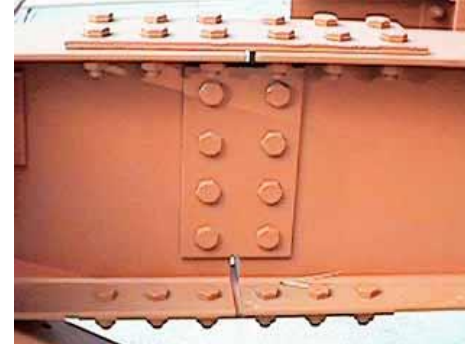


Photo: Moment Resisting Connection with Curved Endplates: Behaviour Study, A. Mudrow & all

Summary of shear joints (shear bolts)

Photo: amsd.co.uk



Category	A („normal”)	B (partly preloaded)	C (preloaded)
Shear resistance (→ #t / 51-56)	Yes		No
Bearing resistance (→ #t / 62-74)	Yes		
Slip-resistant (→ #t / 88-94)	No	Yes (loads in characteristic values)	Yes (loads in design values)
Netto area (→ #t / 77-79)	Yes		
Block tearing (→ #t / 80)	Yes		
Tensile resistance (→ #t / 50)	No	Reference level for preloading force	
Punching resistance (→ #t / 95)	No	Yes (preloading force can't be bigger than punching resistance)	

Examination issues

Similarities and differences for categories of bolted joints A, B, C

Parameters important for resistance of categories of bolted joints A, B, C

Relations between: category of bolted joint, grade of bolt and class of friction

Bolt - śruba
Rivet - nit
Pin - sworzeń
Hex cap – sześciokątny łeb (śruby)
Hex nut – nakrętka (sześciokątna)
Shank – trzpień
Thread – gwint
Preloaded bolts - śruby do sprężania
Fit bolts - śruby pasowane
Slotted holes - otwory owalne
Packing plate - przekładka
Washer - podkładka
Clearances - prześwity
Countersunk bolts - śruby z łbem wpuszczanym
Machining - obróbka skrawaniem
Plastic cold working - obróbka plastyczna na zimno

Thank you for attention

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tmichal@pk.edu.pl