STEEL STRUCTURES - DESIGN OF THE JOINTS

BOLTED CONNECTIONS

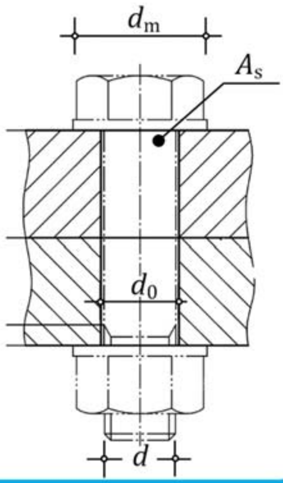
Strength (nominal values)

Nominal values of the **yield strength (f_{yb})** and **ultimate tensile strength (f_{ub})**

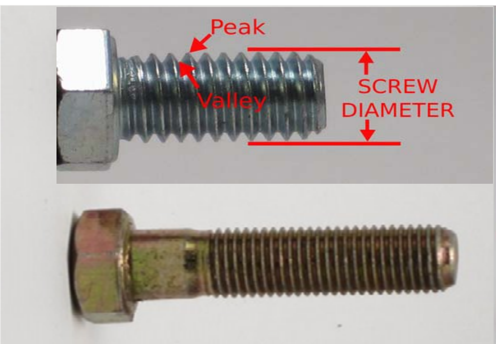
Bolt class	4.6	4.8	5.6	5.8	6.8	8.8	10.9
f_{yb} (MPa)	240	320	300	400	480	640	900
f_{ub} (MPa)	400	400	500	500	600	800	1000

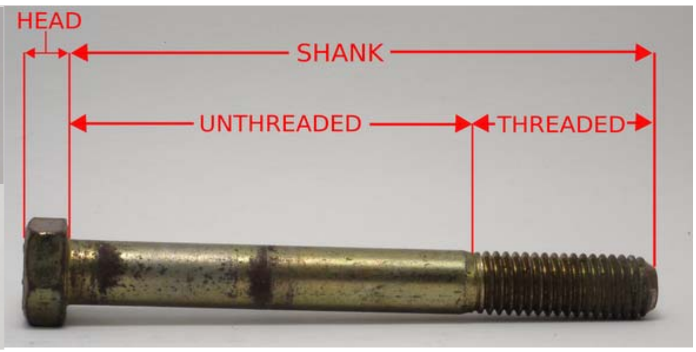
Preloaded bolts – Only bolts of classes 8.8 and 10.9 may be used.

	M12	M16	M20	M24	M27	M30
d [mm]	12	16	20	24	27	30
d_0 [mm]	13	18	22	26	30	33
A_s [mm^2]	84,3	157	245	353	459	561
d_m [mm] – non preloaded	18,5	23,2	29,2	35,0	40,0	45,0
d_m [mm] – preloaded	21,2	27,0	32,0	41,0	46,0	50,0

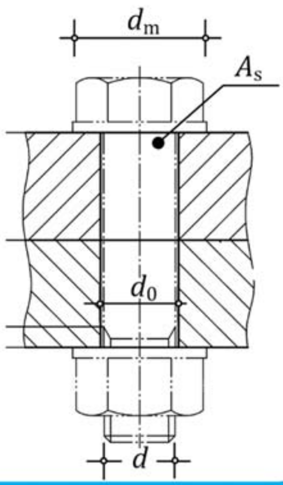


STEEL STRUCTURES - DESIGN OF THE JOINTS





	M12	M16	M20	M24	M27	M30
d [mm]	12	16	20	24	27	30
d_0 [mm]	13	18	22	26	30	33
A_s [mm^2]	84,3	157	245	353	459	561
d_m [mm] – non preloaded	18,5	23,2	29,2	35,0	40,0	45,0
d_m [mm] – preloaded	21,2	27,0	32,0	41,0	46,0	50,0



STEEL STRUCTURES - DESIGN OF THE JOINTS

Categories of bolted connections

Shear connections	**Category A**: Bearing type Neither preloading nor special provisions for the contact surfaces are required	$F_{\mathrm{v,Ed}} \leq \min\{F_{\mathrm{v,Rd}}\ ;\ F_{\mathrm{b,Rd}}\}$
	Category B: Slip-resistant at SLS Preloaded bolts should be used.	$F_{\mathrm{v,Ed}} \leq \min\{F_{\mathrm{v,Rd}}\ ;\ F_{\mathrm{b,Rd}}\}$ $F_{\mathrm{v,Ed,ser}} \leq F_{\mathrm{s,Rd,ser}}$
	Category C: Slip-resistant at ULS Preloaded bolts should be used.	$F_{\mathrm{v,Ed}} \leq F_{\mathrm{s,Rd}}$
Tension connections	**Category D**: non-preloaded **Category E**: preloaded	$F_{\mathrm{t,Ed}} \leq \min\{F_{\mathrm{t,Rd}}\ ;\ B_{\mathrm{p,Rd}}\}$

Note 1: The value of $F_{\mathrm{t,Ed}}$ should include the effect of prying action, where relevant.

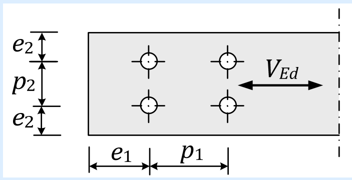
Note 2: Bolts subjected to combined shear and tensile forces should also satisfy an additional condition (interaction).

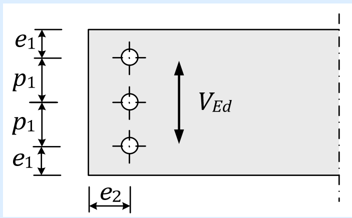
Note 3: Bolted tension connections that are frequently subjected to variations of loading should be preloaded (category E). However, connections designed to resist normal wind loads may be non-preloaded (category D).

STEEL STRUCTURES - DESIGN OF THE JOINTS

Formulas for obtaining the design resistances:

Tension	$F_{\mathrm{t,Rd}} = 0{,}9\, A_{\mathrm{s}} \cdot f_{\mathrm{ub}} / \gamma_{\mathrm{M2}}$
Punching shear	$B_{\mathrm{p,Rd}} = 0{,}6\, \pi\, d_{\mathrm{m}} \cdot t_{\mathrm{p}} \cdot f_{\mathrm{u}} / \gamma_{\mathrm{M2}}$
Shear (for one shear plane)	$F_{\mathrm{v,Rd}} = \alpha_{\mathrm{v}} \cdot A_{\mathrm{s}} \cdot f_{\mathrm{ub}} / \gamma_{\mathrm{M2}}$
Bearing resistance	$F_{\mathrm{b,Rd}} = \alpha_{\mathrm{b}} \cdot k_1 \cdot d \cdot t_{\mathrm{p}} \cdot f_{\mathrm{u}} / \gamma_{\mathrm{M2}}$





$$\alpha_{\mathrm{b}} = \min\left\{\frac{e_1}{3d_0}\ ;\ \frac{p_1}{3d_0} - 0{,}25\ ;\ \frac{f_{\mathrm{ub}}}{f_{\mathrm{u}}}\ ;\ 1{,}0\right\} \qquad k_1 = \min\left\{2{,}8\,\frac{e_2}{d_0} - 1{,}7\ ;\ 1{,}4\,\frac{p_2}{d_0} - 1{,}7\ ;\ 2{,}5\right\}$$

Shear in the unthreaded section $\alpha_{\mathrm{v}} = 0{,}6$

Shear in the threaded portion:
- $\alpha_{\mathrm{v}} = 0{,}6$ bolts from classes 4.6, 5.6 e 8.8
- $\alpha_{\mathrm{v}} = 0{,}5$ bolts from classes 4.8, 5.8, 6.8 e 10.9

Partial factor: $\gamma_{\mathrm{M2}} = 1{,}25$

STEEL STRUCTURES - DESIGN OF THE JOINTS

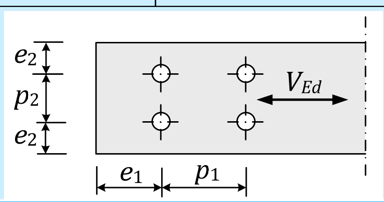
Tension resistance $F_{t,Rd}$ [kN]		M12	M16	M20	M24	M27	M30
	4.6	24,3	45,2	70,6	101,7	132,2	161,6
	5.6	30,3	56,5	88,2	127,1	165,2	202,0
	8.8	48,6	90,4	141,1	203,3	264,4	323,1
	10.9	60,7	113,0	176,4	254,2	330,5	403,9

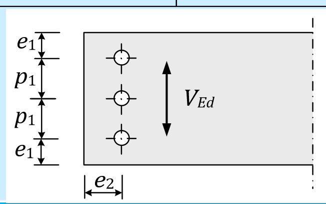
Shear resistance – $F_{v,Rd}$ [kN]			M12	M16	M20	M24	M27	M30
	single shear	(n = 1)	M12	M16	M20	M24	M27	M30
		4.6	16,2	30,1	47,0	67,8	88,1	107,7
		5.6	20,2	37,7	58,8	84,7	110,2	134,6
		8.8	32,4	60,3	94,1	135,6	176,3	215,4
		10.9	33,7	62,8	98,0	141,2	183,6	224,4
	double shear	(n = 2)	M12	M16	M20	M24	M27	M30
		4.6	32,4	60,3	94,1	135,6	176,3	215,4
		5.6	40,5	75,4	117,6	169,4	220,3	269,3
		8.8	64,7	120,6	188,2	271,1	352,5	430,8
		10.9	67,4	125,6	196,0	282,4	367,2	448,8

STEEL STRUCTURES - DESIGN OF THE JOINTS

Positioning of holes for bolts

End and edge distances; spacings	**Minimum**	**Normal values**		
		Compact detailing	Normal detailing	No reduction
End distance, e_1	$1,2\ d_0$	$e_1 \approx 1,9d$	$e_1 \approx 2,5d$	$e_1 \geq 3d_0$
Edge distance, e_2		$e_2 \approx 1,5d$	$e_2 \approx 1,8d$	$e_2 \geq 1,5d_0$
Spacing p_1	$2,2\ d_0$	$p_1 \geq \min\begin{cases} e_1 + 0,75d_0 \\ 3,75d_0 \end{cases}$;	$p_2 \geq \min\begin{cases} 2e_2 \\ 3d_0 \end{cases}$	$p_1 \geq 3,75d_0$
Spacing p_2	$2,4\ d_0$			$p_2 \geq 3d_0$





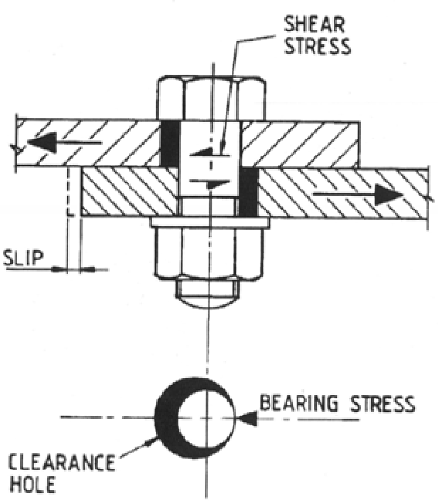
STEEL STRUCTURES - DESIGN OF THE JOINTS

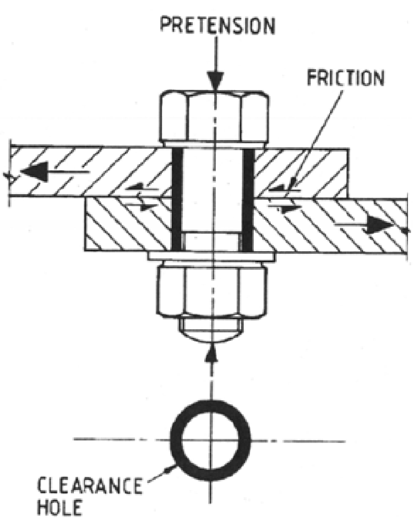
Bearing resistance – $F_{b,Rd}$ [kN] for $t_p = 10$ mm		(t_p= 10 mm)	M12	M16	M20	M24	M27	M30
	Detailing1 (compact)	e_1 [mm]	25	30	40	45	50	55
		e_2 [mm]	20	25	30	35	40	45
		$p_{1,min}$ [mm]	35	44	57	65	73	80
		$p_{2,min}$ [mm]	39	50	60	70	80	90
		S235	55,4	56,0	73,9	82,5	87,8	101,7
		S275	63,1	63,8	84,2	94,0	100,0	115,8
		S355	72,3	73,2	96,5	107,7	114,7	132,7
		(t_p= 10 mm)	M12	M16	M20	M24	M27	M30
	Detailing 2 (“normal”)	e_1 [mm]	35	45	55	65	75	85
		e_2 [mm]	25	30	35	40	45	50
		$p_{1,min}$ [mm]	45	59	72	85	98	110
		$p_{2,min}$ [mm]	39	54	66	78	90	99
		S235	77,5	96,0	120,0	144,0	162,0	185,5
		S275	88,3	109,3	136,7	164,0	184,5	211,2
		S355	101,2	125,3	156,7	188,0	211,5	242,1

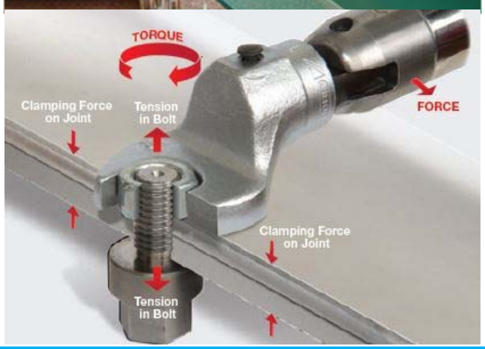
The values given for $F_{b,Rd}$ correspond to $t_p = 10$ **mm** and two distinct detailing sets: compact detailing 1 and “normal” detailing 2, and so more resistant than the former; both cases assume $f_{ub} \geq f_u$.

STEEL STRUCTURES - DESIGN OF THE JOINTS

✓ **Preloaded bolts**







STEEL STRUCTURES - DESIGN OF THE JOINTS

Slip resistance per friction plane

(for preloaded bolts with normalized holes)

$$F_{s,Rd,ser} = k_s \cdot \mu \cdot F_{p,C} / \gamma_{M3,ser}$$

$$F_{s,Rd} = k_s \cdot \mu \cdot F_{p,C} / \gamma_{M3}$$

Where $k_s = 1{,}0$ for bolts in normalizes holes ($< 1{,}0$ in oversized or slotted holes),
$F_{p,C} = (0{,}7 f_{ub} \cdot A_s)$ is the preloading force and μ (the slip factor)
$\gamma_{M3,ser} = 1{,}10$ and $\gamma_{M3} = 1{,}25$

Class of friction surface	A	B	C	D
μ (slip factor)	0,5	0,4	0,3	0,2

$\mu \geq 0{,}5$ class A – surfaces blasted with shot or grit, with loose rust removed, not pitted; surfaces blasted with shot or grit, spray-metallized with aluminium or a zinc based product;

$\mu \geq 0{,}4$ class B – alkali-zinc silicate paint with a thickness of 50-80 μm applied on shot- or grit-blasted surfaces;

$\mu \geq 0{,}3$ class C – surfaces cleaned by wire-brushing or flame cleaning, with loose rust removed;

$\mu \geq 0{,}2$ class D – surfaces not treated.

STEEL STRUCTURES - DESIGN OF THE JOINTS

NON-PRELOADED BOLTS – Punching shear resistance $t_{Bp,min}$ [mm]

Steel	Bolt class	M12	M16	M20	M24	M27	M30
S235	4.6	2,4	3,6	4,5	5,4	6,1	6,6
	5.6	3,0	4,5	5,6	6,7	7,6	8,3
	8.8	4,8	7,2	8,9	10,7	12,2	13,2
	10.9	6,0	9,0	11,1	13,4	15,2	16,5
S275	4.6	2,1	3,2	3,9	4,7	5,3	5,8
	5.6	2,7	3,9	4,9	5,9	6,7	7,3
	8.8	4,2	6,3	7,8	9,4	10,7	11,6
	10.9	5,3	7,9	9,8	11,7	13,4	14,5
S355	4.6	1,9	2,7	3,4	4,1	4,7	5,1
	5.6	2,3	3,4	4,3	5,1	5,8	6,3
	8.8	3,7	5,5	6,8	8,2	9,3	10,1
	10.9	4,6	6,9	8,5	10,2	11,7	12,7

$t_{Bp,min}$ – Plate thickness which provides $B_{p,Rd} \geq F_{t,Rd}$ (considering hexagon bolts and head diameter d_m given in previous table)

PRELOADED BOLTS – Punching shear $t_{Bp,min}$ [mm]

Steel	Bolt class	M12	M16	M20	M24	M27	M30
S235	8.8	4,2	6,2	8,1	9,1	10,6	11,9
	10.9	---	7,7	10,2	11,4	13,2	14,9
S275	8.8	3,7	5,4	7,1	8,0	9,3	10,5
	10.9	---	6,8	8,9	10,0	11,6	13,1
S355	8.8	3,2	4,7	6,2	7,0	8,1	9,1
	10.9	---	5,9	7,8	8,7	10,1	11,4

STEEL STRUCTURES - DESIGN OF THE JOINTS

Slip resistance – SLS $F_{s,Rd,ser}$ [kN/plane]	$(n = 1)$	μ	M12	M16	M20	M24	M27	M30
	8.8	0,2	8,6	16,0	24,9	35,9	46,7	57,1
		0,3	12,9	24,0	37,4	53,9	70,1	85,7
		0,4	17,2	32,0	49,9	71,9	93,5	114,2
		0,5	21,5	40,0	62,4	89,9	116,8	142,8
	10.9	0,2	---	20,0	31,2	44,9	58,4	71,4
		0,3	---	30,0	46,8	67,4	87,6	107,1
		0,4	---	40,0	62,4	89,9	116,8	142,8
		0,5	---	50,0	78,0	112,3	146,0	178,5

Slip resistance – ULS $F_{s,Rd}$ [kN/plane]	$(n = 1)$	μ	M12	M16	M20	M24	M27	M30
	8.8	0,2	7,6	14,1	22,0	31,6	41,1	50,3
		0,3	11,3	21,1	32,9	47,4	61,7	75,4
		0,4	15,1	28,1	43,9	63,3	82,3	100,5
		0,5	18,9	35,2	54,9	79,1	102,8	125,7
	10.9	0,2	---	17,6	27,4	39,5	51,4	62,8
		0,3	---	26,4	41,2	59,3	77,1	94,2
		0,4	---	35,2	54,9	79,1	102,8	125,7
		0,5	---	44,0	68,6	98,8	128,5	157,1

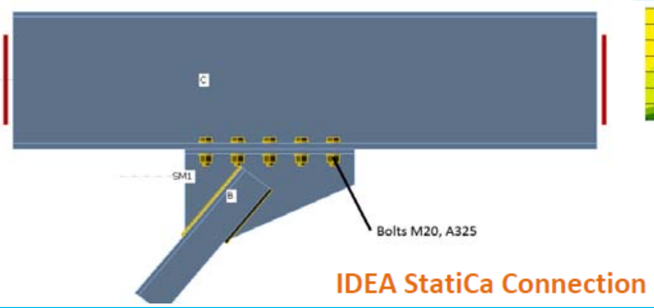
STEEL STRUCTURES - DESIGN OF THE JOINTS

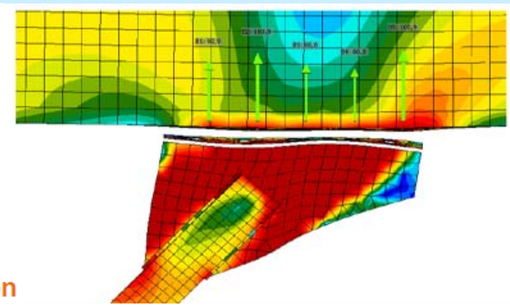
Combined shear and tension

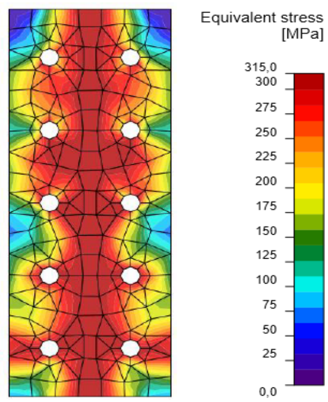
Connection of type "A+D" or "B+E" $\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1,4\,F_{t,Rd}} \leq 1,0$ $\frac{F_{t,Ed}}{F_{t,Rd}} \leq 1,0$

Connection of type "B+E" $F_{s,Rd,ser} = k_s \cdot \mu \cdot \left(F_{p,C} - 0,8\,F_{t,Ed,ser}\right)/\gamma_{M3,ser}$ $\gamma_{M3,ser} = 1,10$

Connection of type "C+E" $F_{s,Rd} = k_s \cdot \mu \cdot \left(F_{p,C} - 0,8\,F_{t,Ed}\right)/\gamma_{M3}$, $\gamma_{M3} = 1,25$







STEEL STRUCTURES - DESIGN OF THE JOINTS

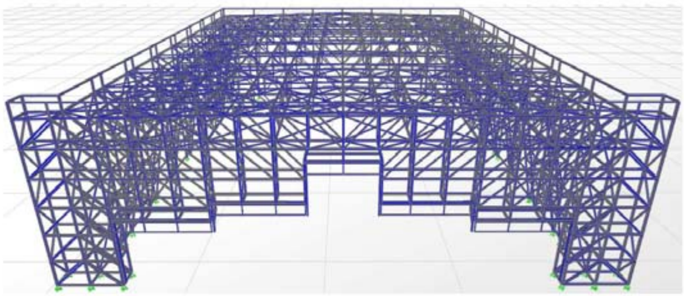


Figure 12 – Hangar Structure – 3D perspective (North view)

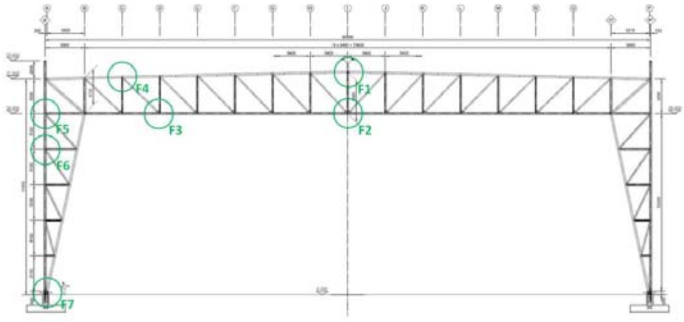
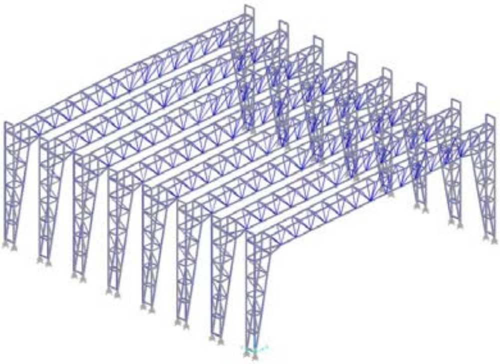


Figure 32 – Typical portal frame joints location.



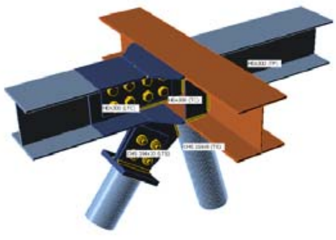


Figure 33 – Detail F1 model

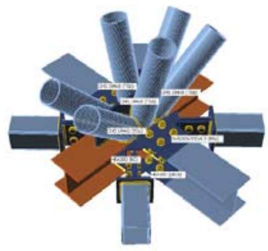


Figure 34 – Detail F2 model

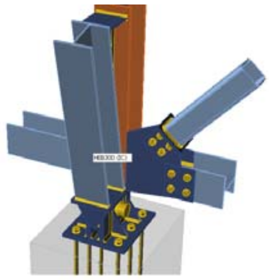
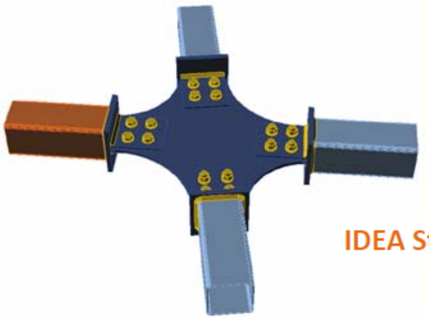


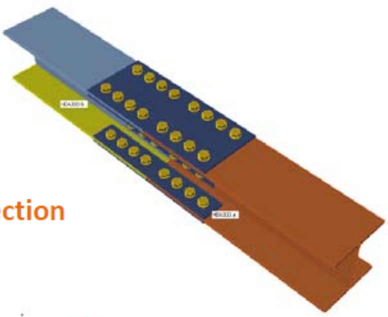
Figure 39 – Detail F7 model

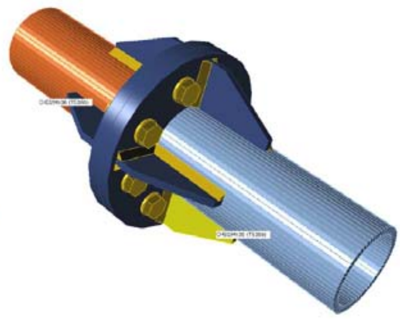
IDEA StatiCa Connection

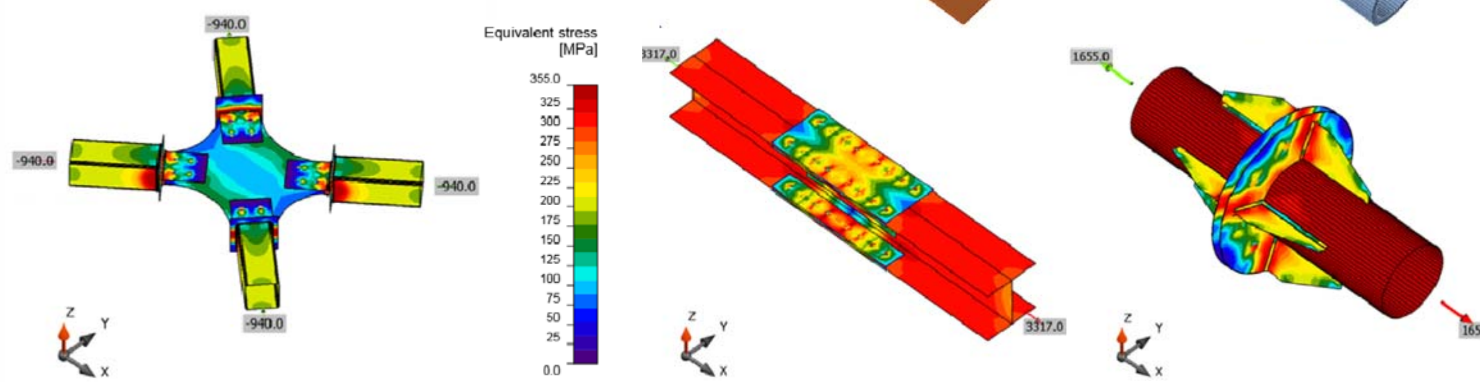
STEEL STRUCTURES - DESIGN OF THE JOINTS



IDEA StatiCa Connection





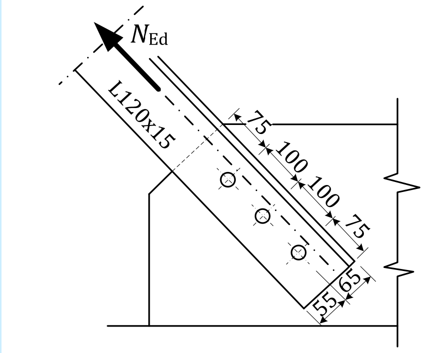


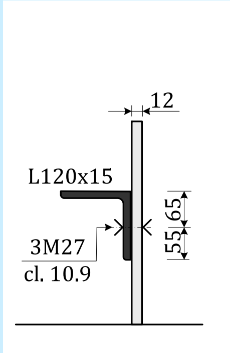
STEEL STRUCTURES - DESIGN OF THE JOINTS

Example 1 – Bolted connection, category A, single shear

$N_{\mathrm{Ed}} = 538\ \mathrm{kN}$

angle L120x120x15 and
gusset plate $t = 12$ mm –
steel S355





Bolted connection (category A), 3 M27 grade 10.9 (**single shear**), using "normal" detailing – 2

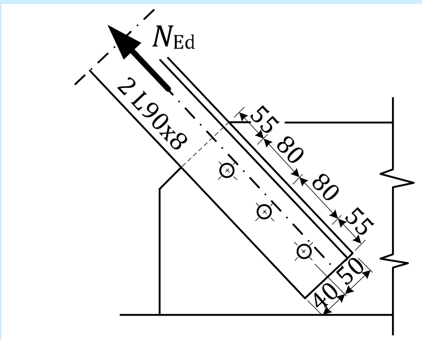
$$\begin{cases} \text{M27 cl10.9} - \textit{single shear} \rightarrow F_{\mathrm{v,i,Rd}} = \boxed{183{,}6\ \mathrm{kN}} \\ \text{“normal” detailing} - 2 \rightarrow F_{\mathrm{b,i,Rd}} \geq \boxed{211{,}5} \times \dfrac{12}{10} = 253{,}8\ \mathrm{kN} \end{cases} \rightarrow F_{\mathrm{Rd}} = 3 \times 183{,}6 = 551\ \mathrm{kN}\ \checkmark$$

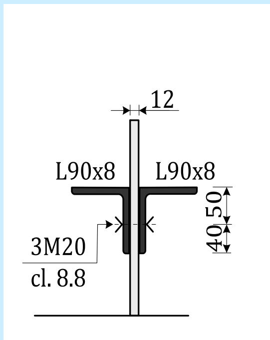
STEEL STRUCTURES - DESIGN OF THE JOINTS

Example 2 – Bolted connection, category A, double shear

$N_{\mathrm{Ed}} = 538\ \mathrm{kN}$

2 x angles L90x8 and
a gusset plate $t = 12$ mm –
steel S355





Bolted connection (category A), 3 M20 grade 8.8 (**double shear**), using "normal" detailing – 2

$$\begin{cases} \text{M20 cl 8.8} - \textit{double shear} \rightarrow F_{\mathrm{v,i,Rd}} = \boxed{188{,}2\ \mathrm{kN}} \\ \text{“normal” detailing} - 2 \rightarrow F_{\mathrm{b,i,Rd}} \geq \boxed{156{,}7} \times \dfrac{12}{10} = 188{,}0\ \mathrm{kN} \end{cases} \rightarrow F_{\mathrm{Rd}} = 3 \times 188{,}0 = 564\ \mathrm{kN}\ \checkmark$$