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είδος μελέτης : Στατικά στάδιο μελέτης : Οριστική Μελέτη χρόνος μελέτης : 2021	αριθμός τεύχους : Σ.4/4
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θέμα τεύχους : Στατική μελέτη μεταλλικής δοκού τάνυσης μεμβράνης

σφραγίδα & υπογραφή μελετητή :	
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1 Περιεχόμενα

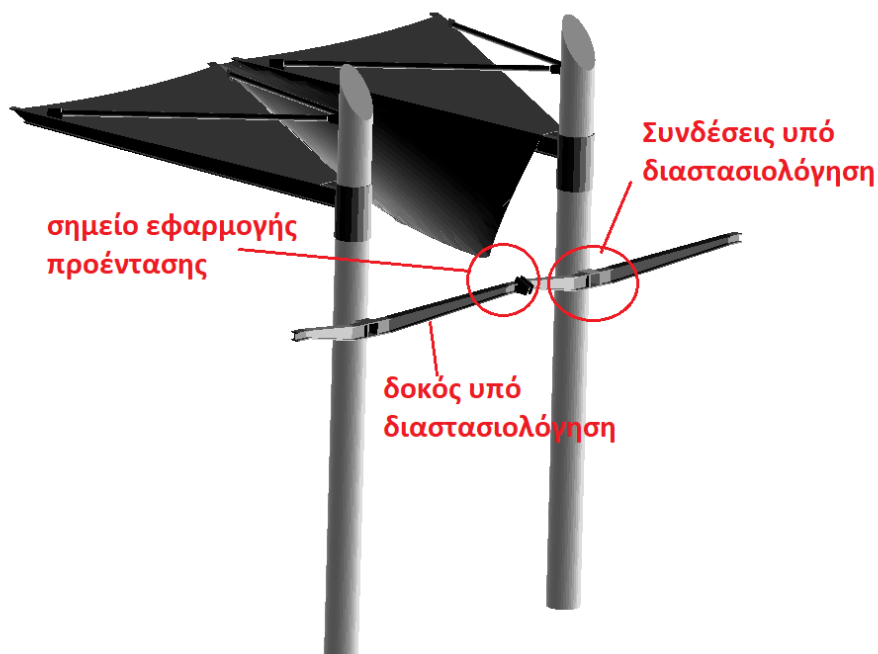
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2 Τεχνική έκθεση

Η παρούσα τεχνική έκθεση αφορά την ανάλυση και διαστασιολόγηση των συνδέσεων μεταλλικής δοκού επί της οποίας ασκούνται τα φορτία τάνυσης/προέντασης επιφανειακής μεμβράνης κάλυψης στεγάστρου. Πιο συγκεκριμένα διαστασιολογούνται τα παρακάτω:

- Η διατομή της δοκού επί της οποία ασκείται η δύναμη της προέντασης.
- Η σύνδεση της μεταλλικής δοκού σε μεταλλικό φουρούσι

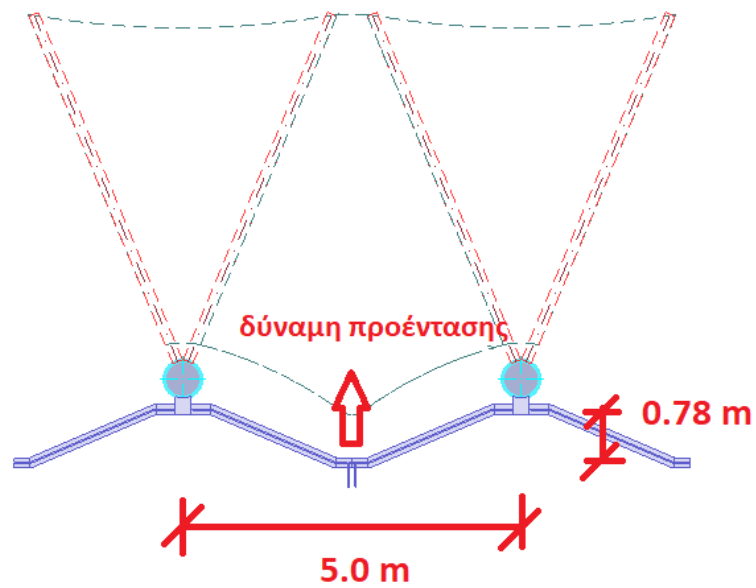
Παρακάτω εμφανίζονται ενδεικτικώς ο φορέας καθώς και τα σημεία εφαρμογής των συνδέσεων. Οι παρακάτω εικόνες είναι αποσπάσματα των αρχιτεκτονικών σχεδίων πριν την εφαρμογή των αποτελεσμάτων της υφιστάμενης μελέτης.



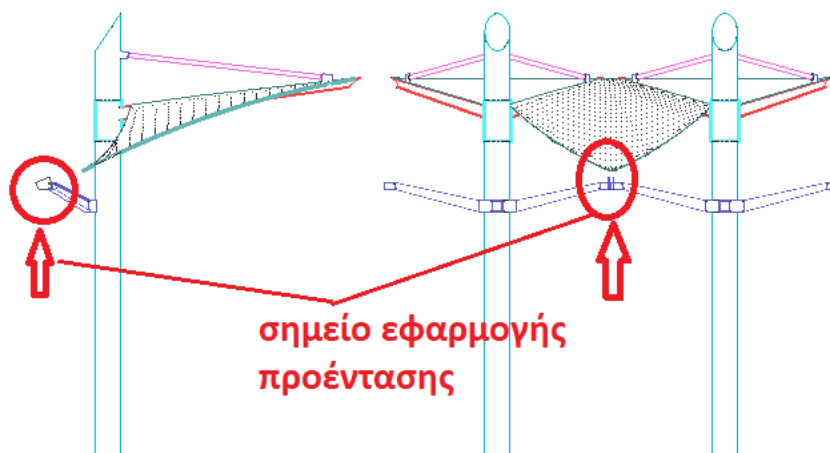
Εικόνα 1: Γραφική απεικόνιση των υπό εξέταση στοιχείων

3 Διαστασιολόγηση μεταλλικής δοκού

Παρακάτω παρουσιάζεται με μεγαλύτερη λεπτομέρεια η υπό εξέταση δοκός.



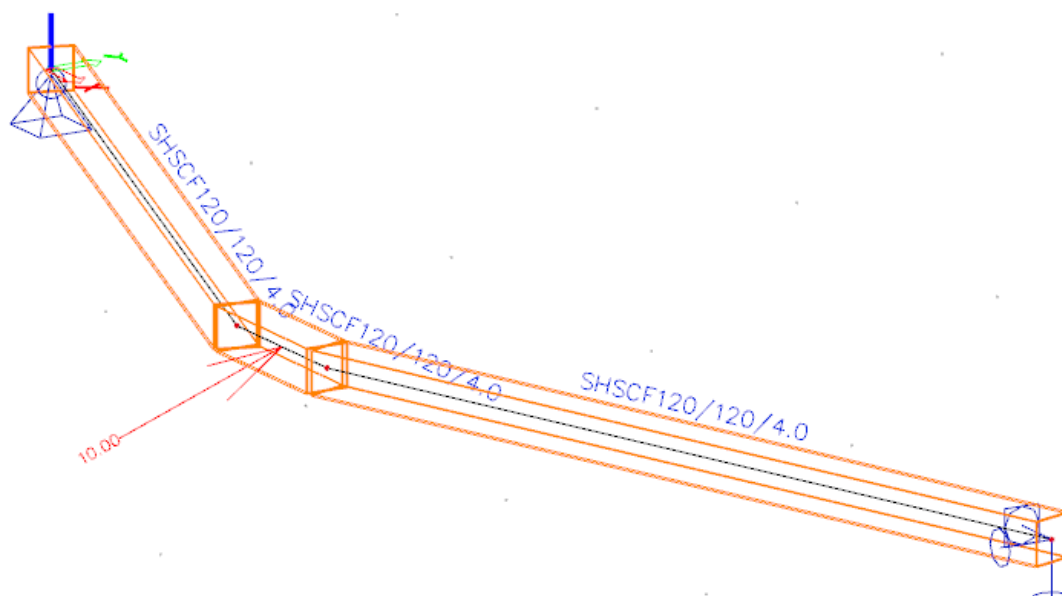
Εικόνα 2: Κάτοψη



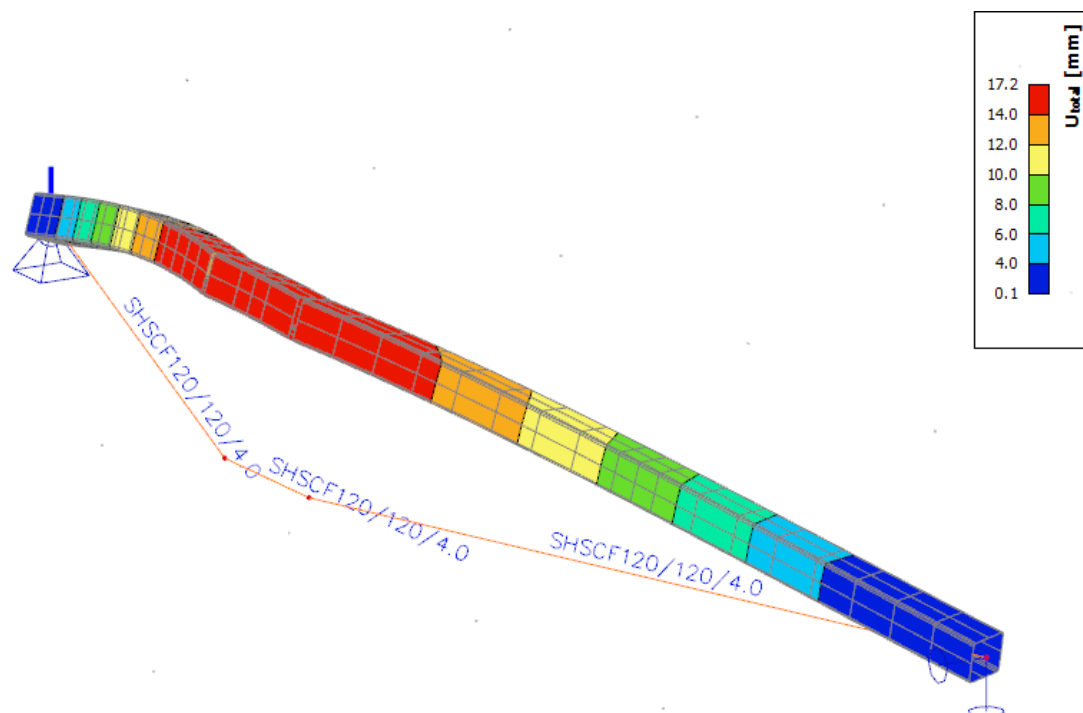
Εικόνα 3: Όψεις

Δύναμη προέντασης: 10 kN (1 tonnes)

Παρακάτω εμφανίζεται το ενδεικτικό προσομοίωμα:

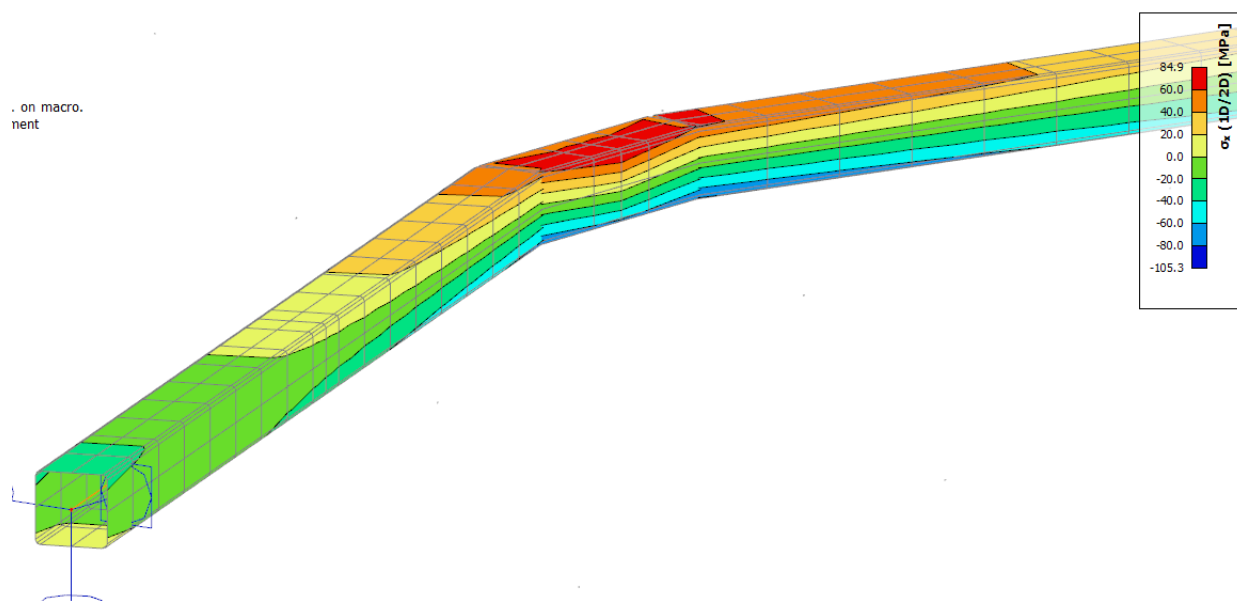


Οι παραμορφώσεις του παραπάνω προσομοιώματος είναι ίσες με:



Η παραπάνω τιμή πλησιάζει την οριακή τιμή $L/250 = 20$ mm και ως εκ τούτου αποφασίζεται να υιοθετηθεί μια τάξη διατομής παραπάνω SHS160x6

Η μέγιστη τάση κατά την οριακή κατάσταση αστοχίας εμφανίζεται παρακάτω:



Σύμφωνα με την παραπάνω εικόνα, η μέγιστη τάση δεν ξεπερνάει τα 85.0MPa και ως εκ τούτου η οριακή κατάσταση αστοχίας ικανοποιείται.

Θεωρώντας πακτώσεις στα άκρα του μέλους (συντηρητική παραδοχή για τις αντιδράσεις) έχουμε τις παρακάτω αντιδράσεις

Reactions

Linear calculation

Combination: ELU

System: Global

Extreme: Global

Selection: All

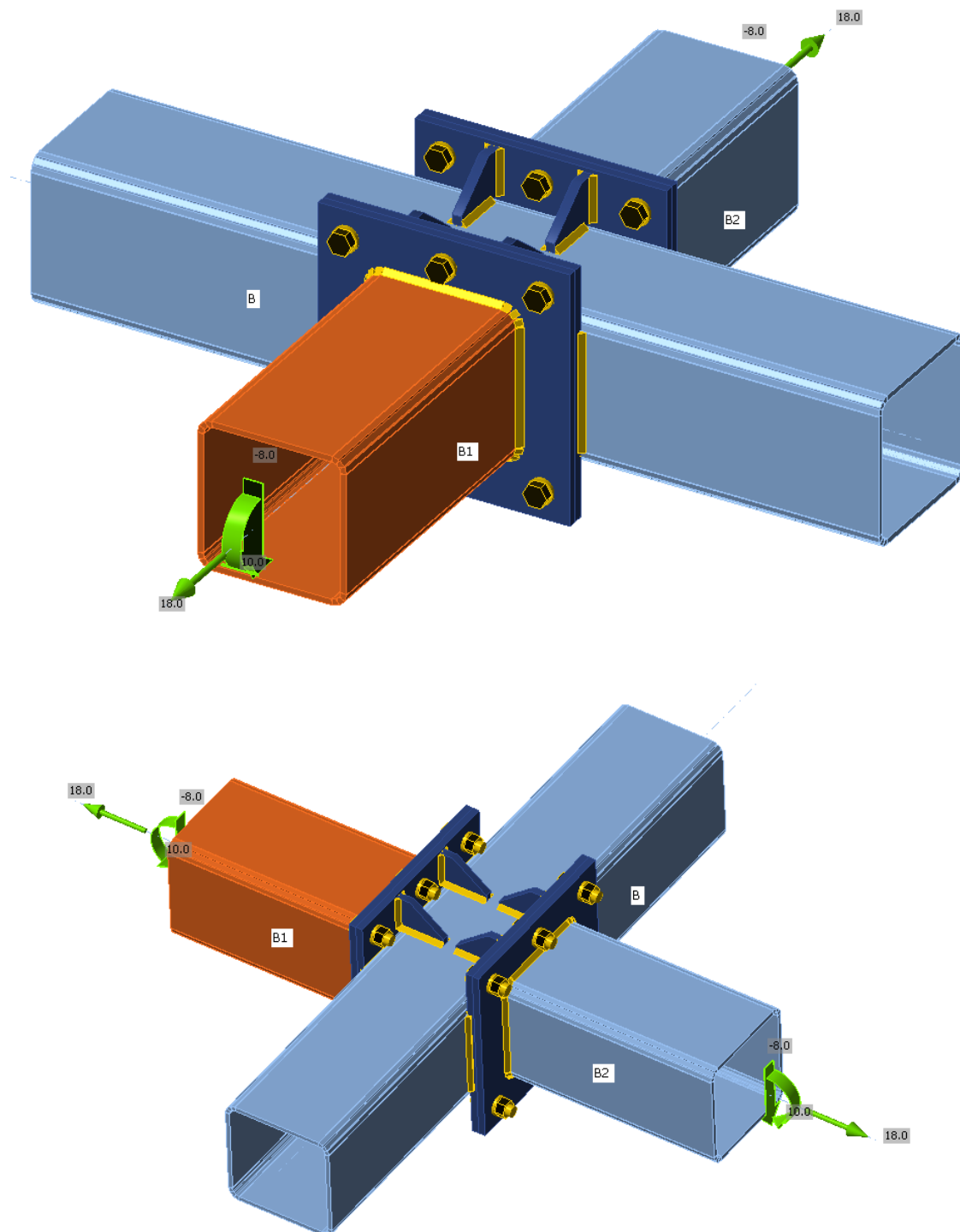
Nodal reactions

Name	Case	R _x [kN]	R _y [kN]	R _z [kN]	M _x [kNm]	M _y [kNm]	M _z [kNm]	e _x [mm]	e _y [mm]
Sn2/N2	ELU/1	-18.19	-6.34	-1.81	1.59	-2.59	0.19	-877.3	1427.4
Sn1/N1	ELU/1	18.19	-6.34	-1.81	1.59	2.59	-0.19	-877.3	-1427.4

Name	Combination key
ELU/1	1.35*SW + 1.35*Poentasi

4 Σύνδεση δοκού σε φουρούσι

4.1 Γεωμετρία



4.2 Αποτελέσματα ανάλυσης & διαστασιολόγησης – Ενδεικτικά σχέδια επιμέρους στοιχείων

Project data

Project name
Project number
Author
Description
Date 12/3/2021
Design code EN

Material

Steel S 235
Concrete C25/30

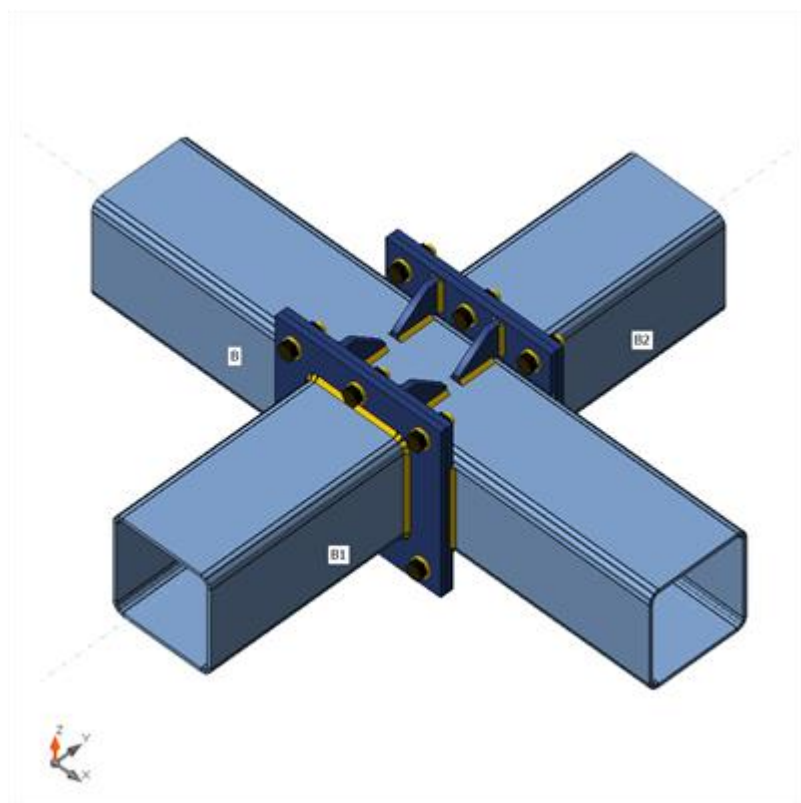
Project item CON1

Design

Name CON1
Description
Analysis Stress, strain/ simplified loading

Beams and columns

Name	Cross-section	β – Direction [°]	γ – Pitch [°]	α – Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]	Forces in
B	1 - SHS160/160/6.3	0.0	0.0	0.0	0	0	0	Node
B1	1 - SHS160/160/6.3	-90.0	0.0	0.0	0	0	0	Bolts
B2	1 - SHS160/160/6.3	90.0	0.0	0.0	0	0	0	Bolts



Cross-sections

Name	Material
1 - SHS160/160/6.3	S 235

Bolts

Name	Bolt assembly	Diameter [mm]	f_u [MPa]	Gross area [mm ²]
M16 8.8	M16 8.8	16	800.0	201

Load effects (equilibrium not required)

Name	Member	N [kN]	V _y [kN]	V _z [kN]	M _x [kNm]	M _y [kNm]	M _z [kNm]
LE1	B1	18.0	0.0	-8.0	0.0	10.0	0.0
	B2	18.0	0.0	-8.0	0.0	10.0	0.0

Check

Summary

Name	Value	Status
Analysis	100.0%	OK
Plates	0.1 < 5.0%	OK
Bolts	53.7 < 100%	OK
Welds	97.3 < 100%	OK

Buckling	Not calculated	
GMNA	Calculated	

Plates

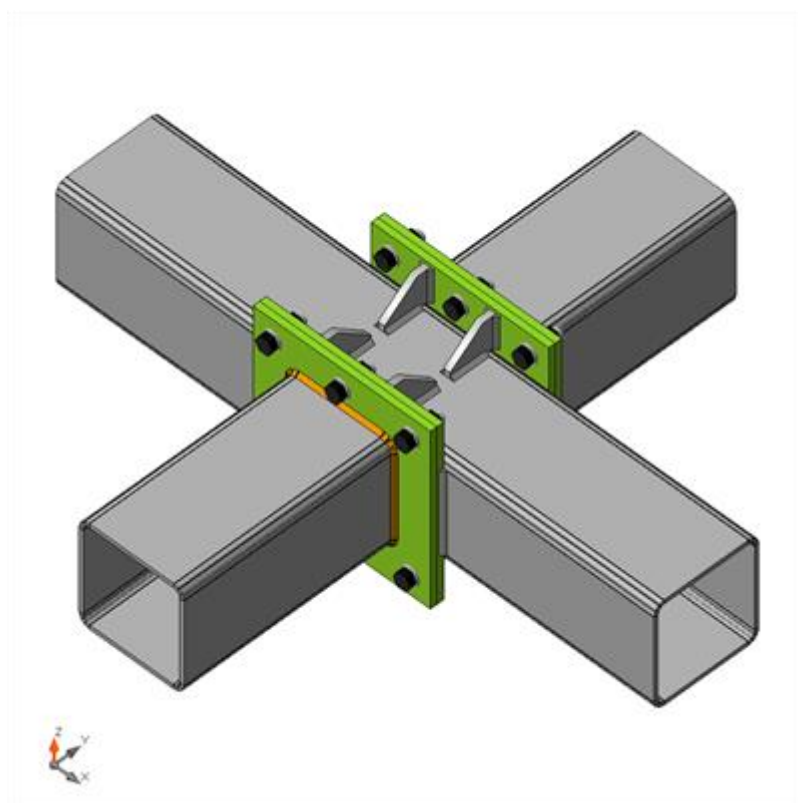
Name	Thickness [mm]	Loads	σ_{Ed} [MPa]	ϵ_{Pl} [%]	σ_{CEd} [MPa]	Status
B	6.3	LE1	207.2	0.0	0.0	OK
B1	6.3	LE1	182.5	0.0	0.0	OK
B2	6.3	LE1	182.6	0.0	0.0	OK
SP1	10.0	LE1	235.1	0.1	35.1	OK
SP2	10.0	LE1	216.1	0.0	35.1	OK
SP3	10.0	LE1	235.1	0.1	35.1	OK
SP4	10.0	LE1	216.7	0.0	35.1	OK
Stiff	10.0	LE1	131.1	0.0	0.0	OK
Stiff_2	10.0	LE1	113.4	0.0	0.0	OK
SP7	10.0	LE1	130.5	0.0	0.0	OK
SP8	10.0	LE1	114.0	0.0	0.0	OK
SP9	10.0	LE1	85.8	0.0	0.0	OK
SP10	10.0	LE1	85.4	0.0	0.0	OK
SP11	10.0	LE1	83.6	0.0	0.0	OK
SP12	10.0	LE1	83.5	0.0	0.0	OK

Design data

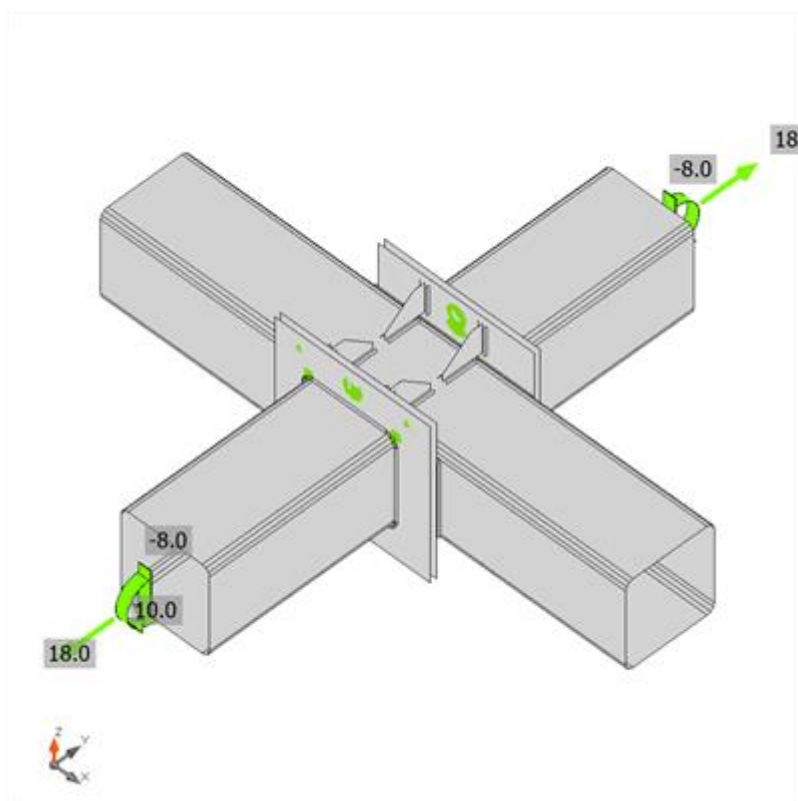
Material	f_y [MPa]	ϵ_{lim} [%]
S 235	235.0	5.0

Symbol explanation

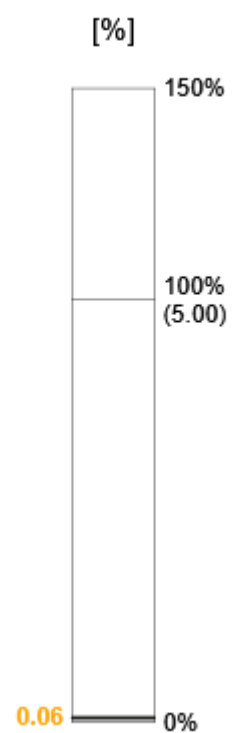
ϵ_{Pl}	Strain
σ_{Ed}	Eq. stress
σ_{CEd}	Contact stress
f_y	Yield strength
ϵ_{lim}	Limit of plastic strain

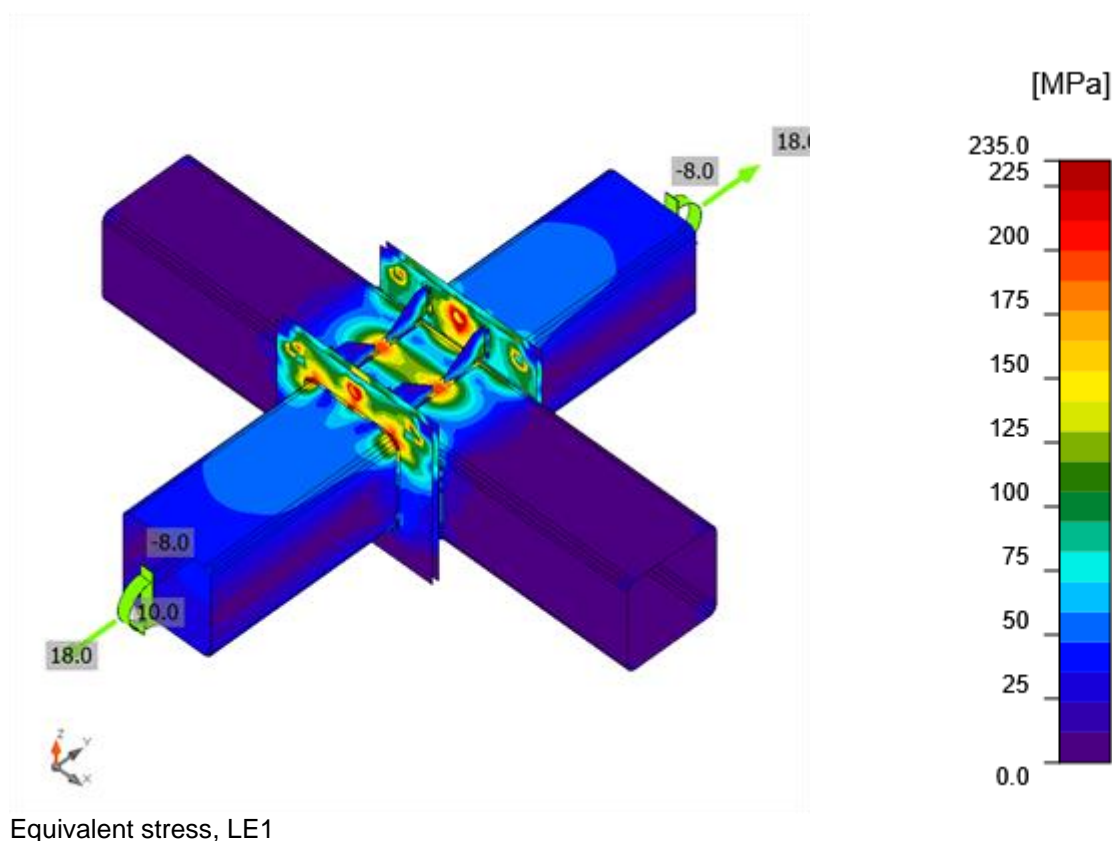


Overall check, LE1



Strain check, LE1





Bolts

	Name	Loads	$F_{t,Ed}$ [kN]	V [kN]	$U_{t,t}$ [%]	$F_{b,Rd}$ [kN]	$U_{t,s}$ [%]	$U_{t,ts}$ [%]	Status
	B1	LE1	0.0	1.2	0.0	64.0	2.0	2.0	OK
	B2	LE1	28.0	1.6	30.9	64.0	2.7	24.8	OK
	B3	LE1	0.0	1.1	0.0	64.0	1.9	1.9	OK
	B4	LE1	48.5	1.6	53.6	64.0	2.7	41.0	OK
	B5	LE1	0.0	1.2	0.0	64.0	2.0	2.0	OK
	B6	LE1	28.0	1.6	31.0	64.0	2.7	24.8	OK
	B7	LE1	0.0	1.2	0.0	64.0	2.0	2.0	OK
	B8	LE1	28.1	1.6	31.1	64.0	2.7	24.9	OK
	B9	LE1	0.0	1.1	0.0	64.0	1.9	1.9	OK
	B10	LE1	48.6	1.6	53.7	64.0	2.7	41.1	OK
	B11	LE1	0.0	1.2	0.0	64.0	2.0	2.0	OK
	B12	LE1	28.1	1.6	31.1	64.0	2.7	24.9	OK

Design data

Name	$F_{t,Rd}$ [kN]	$B_{p,Rd}$ [kN]	$F_{v,Rd}$ [kN]
M16 8.8 - 1	90.4	135.7	60.3

Symbol explanation

$F_{t,Rd}$ Bolt tension resistance EN 1993-1-8 tab. 3.4

$F_{t,Ed}$ Tension force

$B_{p,Rd}$	Punching shear resistance
V	Resultant of shear forces V_y, V_z in bolt
$F_{v,Rd}$	Bolt shear resistance EN_1993-1-8 table 3.4
$F_{b,Rd}$	Plate bearing resistance EN 1993-1-8 tab. 3.4
U_t	Utilization in tension
U_s	Utilization in shear

Detailed result for B10

Tension resistance check (EN 1993-1-8 tab 3.4)

$$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}} = 90.4 \text{ kN} \geq F_t = 48.6 \text{ kN}$$

where:

$k_2 = 0.90$	– Factor
$f_{ub} = 800.0 \text{ MPa}$	– Ultimate tensile strength of the bolt
$A_s = 157 \text{ mm}^2$	– Tensile stress area of the bolt
$\gamma_{M2} = 1.25$	– Safety factor

Punching resistance check (EN 1993-1-8 tab 3.4)

$$B_{p,Rd} = \frac{0.6 \pi d_m t_p f_u}{\gamma_{M2}} = 135.7 \text{ kN} \geq F_t = 48.6 \text{ kN}$$

where:

$d_m = 25 \text{ mm}$	– The mean of the across points and across flats dimensions of the bolt head or the nut, whichever is smaller
$t_p = 10 \text{ mm}$	– Thickness
$f_u = 360.0 \text{ MPa}$	– Ultimate strength
$\gamma_{M2} = 1.25$	– Safety factor

Shear resistance check (EN 1993-1-8 tab 3.4)

$$F_{v,Rd} = \frac{\beta_p \alpha_v f_{ub} A}{\gamma_{M2}} = 60.3 \text{ kN} \geq V = 1.6 \text{ kN}$$

where:

$\beta_p = 1.00$	– Reducing factor
$\alpha_v = 0.60$	– Reducing factor
$f_{ub} = 800.0 \text{ MPa}$	– Ultimate tensile strength of the bolt
$A = 157 \text{ mm}^2$	– Tensile stress area of the bolt
$\gamma_{M2} = 1.25$	– Safety factor

Bearing resistance check (EN 1993-1-8 tab 3.4)

$$F_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}} = 64.0 \text{ kN} \geq V = 1.6 \text{ kN}$$

where:

$k_1 = \min(2.8 \frac{e_2}{d_0} - 1.7, 1.4 \frac{p_2}{d_0} - 1.7, 2.5) = 2.50$	– Factor for edge distance and bolt spacing perpendicular to the direction of load transfer
$e_2 = 135 \text{ mm}$	– Distance to the plate edge perpendicular to the shear force
$p_2 = 105 \text{ mm}$	– Distance between bolts perpendicular to the shear force
$d_0 = 18 \text{ mm}$	– Bolt hole diameter

$$a_b = \min\left(\frac{e_1}{3d_0}, \frac{p_1}{3d_0} - \frac{1}{4}, \frac{f_{ub}}{f_u}, 1\right) = 0.56$$

$$e_1 = 30 \text{ mm}$$

$$p_1 = \infty \text{ mm}$$

$$f_{ub} = 800.0 \text{ MPa}$$

$$f_u = 360.0 \text{ MPa}$$

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

$$t = 10 \text{ mm}$$

$$\gamma_{M2} = 1.25$$

– Factor for end distance and bolt spacing in direction of load transfer

– Distance to the plate edge in the direction of the shear force

– Distance between bolts in the direction of the shear force

– Ultimate tensile strength of the bolt

– Ultimate strength

– Nominal diameter of the fastener

– Thickness of the plate

– Safety factor

Interaction of tension and shear (EN 1993-1-8 tab 3.4)

$$U_{ts} = \frac{F_{t,Ed}}{F_{t,Rd}} + \frac{F_{s,Ed}}{1.4F_{s,Rd}} = 41.1 \%$$

Utilization in tension

$$U_{tt} = \frac{F_{t,Ed}}{\min(F_{t,Rd}; B_{p,Rd})} = 53.7 \%$$

Utilization in shear

$$U_{ts} = \frac{V_{Ed}}{\min(F_{v,Rd}; F_{b,Rd})} = 2.7 \%$$

Welds (Plastic redistribution)

Item	Edge	Throat th. [mm]	Length [mm]	Loads	$\sigma_{w,Ed}$ [MPa]	ε_{PI} [%]	σ_{\perp} [MPa]	τ_{\parallel} [MPa]	τ_{\perp} [MPa]	Ut [%]	Ut _c [%]	Status
SP2	B1	4.0	592	LE1	309.5	0.1	252.1	54.8	-88.0	97.3	28.6	OK
SP4	B2	4.0	592	LE1	309.9	0.1	252.1	-55.3	-88.1	97.3	28.5	OK
B-w 4	SP1	4.0	129	LE1	62.7	0.0	-30.7	18.0	-25.9	17.4	13.2	OK
B-w 4	SP1	4.0	129	LE1	62.7	0.0	-30.6	-18.1	-25.9	17.4	13.2	OK
SP1	B-w 4	4.0	270	LE1	163.0	0.0	62.1	-82.7	26.8	45.3	26.2	OK
SP1	B-w 4	4.0	270	LE1	91.3	0.0	-9.0	0.3	-52.5	25.4	16.3	OK
B-w 2	SP3	4.0	129	LE1	63.9	0.0	-30.8	18.7	26.4	17.7	13.2	OK
B-w 2	SP3	4.0	129	LE1	63.8	0.0	-30.8	-18.9	26.2	17.7	13.2	OK
SP3	B-w 2	4.0	270	LE1	162.4	0.0	66.1	82.1	24.4	45.1	25.5	OK
SP3	B-w 2	4.0	270	LE1	88.8	0.0	-13.1	-0.4	-50.7	24.7	15.5	OK
SP1	Stiff	4.0	50	LE1	197.9	0.0	71.2	-84.2	-65.5	55.0	28.6	OK
		4.0	50	LE1	134.8	0.0	35.6	62.7	41.2	37.4	19.1	OK
B-w 3	Stiff	4.0	70	LE1	129.6	0.0	38.5	-51.7	49.3	36.0	17.1	OK
		4.0	70	LE1	140.3	0.0	28.0	76.3	-21.8	39.0	19.1	OK
B-w 3	Stiff_2	4.0	54	LE1	124.0	0.0	45.7	31.1	58.8	34.5	19.0	OK
		4.0	54	LE1	141.6	0.0	26.1	-78.0	-19.3	39.3	23.0	OK
SP1	SP7	4.0	50	LE1	131.9	0.0	34.2	-61.8	-39.9	36.7	19.1	OK
		4.0	50	LE1	195.2	0.0	70.2	83.3	64.2	54.2	28.6	OK
SP3	Stiff_2	4.0	50	LE1	142.9	0.0	70.9	-46.2	54.7	39.7	25.3	OK
		4.0	50	LE1	85.4	0.0	23.9	25.3	-40.0	23.7	15.8	OK
B-w 3	SP8	4.0	54	LE1	141.4	0.0	26.1	77.9	19.3	39.3	22.9	OK
		4.0	54	LE1	123.9	0.0	45.7	-30.9	-58.9	34.4	19.0	OK
B-w 3	SP7	4.0	70	LE1	140.3	0.0	28.0	-76.3	21.9	39.0	19.1	OK
		4.0	70	LE1	129.1	0.0	38.6	51.1	-49.4	35.9	17.1	OK
B-w 1	SP9	4.0	54	LE1	98.2	0.0	-35.9	38.1	-36.6	27.3	14.0	OK

		▲4.0▲	54	LE1	104.6	0.0	-37.6	-42.6	36.9	29.1	16.3	OK
B-w 1	SP10	▲4.0▲	54	LE1	104.4	0.0	-37.7	42.3	-37.0	29.0	16.3	OK
		▲4.0▲	54	LE1	98.0	0.0	-36.0	-37.8	36.6	27.2	14.0	OK
SP3	SP8	▲4.0▲	50	LE1	86.8	0.0	24.4	-27.1	39.8	24.1	15.8	OK
		▲4.0▲	50	LE1	144.7	0.0	70.4	48.1	-54.9	40.2	25.3	OK
SP1	SP11	▲4.0▲	50	LE1	150.4	0.0	-66.9	-43.6	64.4	41.8	17.7	OK
		▲4.0▲	50	LE1	139.8	0.0	-58.4	40.9	-60.9	38.8	16.0	OK
SP1	SP12	▲4.0▲	50	LE1	139.2	0.0	-57.8	-41.8	60.0	38.7	15.9	OK
		▲4.0▲	50	LE1	149.9	0.0	-65.8	44.7	-63.6	41.6	17.7	OK
SP3	SP9	▲4.0▲	50	LE1	97.3	0.0	-48.1	-11.0	-47.6	27.0	15.9	OK
		▲4.0▲	50	LE1	87.2	0.0	-40.4	13.6	42.5	24.2	14.2	OK
SP3	SP10	▲4.0▲	50	LE1	86.7	0.0	-40.3	-12.8	-42.4	24.1	14.1	OK
		▲4.0▲	50	LE1	96.9	0.0	-47.5	12.1	47.2	26.9	15.9	OK
B-w 1	SP11	▲4.0▲	70	LE1	76.6	0.0	-23.2	-33.5	-25.5	21.3	12.2	OK
		▲4.0▲	70	LE1	83.1	0.0	-13.6	46.1	10.7	23.1	13.6	OK
B-w 1	SP12	▲4.0▲	70	LE1	83.1	0.0	-13.5	-46.1	-10.6	23.1	13.6	OK
		▲4.0▲	70	LE1	76.0	0.0	-23.4	33.0	25.6	21.1	12.1	OK

Design data

	β_w [-]	$\sigma_{w,Rd}$ [MPa]	0.9σ [MPa]
S 235	0.80	360.0	259.2

Symbol explanation

ϵ_{Pl}	Strain
$\sigma_{w,Ed}$	Equivalent stress
$\sigma_{w,Rd}$	Equivalent stress resistance
σ_{\perp}	Perpendicular stress
$\tau_{ }$	Shear stress parallel to weld axis
τ_{\perp}	Shear stress perpendicular to weld axis
0.9σ	Perpendicular stress resistance - $0.9 \cdot f_u / \gamma_{M2}$
β_w	Corelation factor EN 1993-1-8 tab. 4.1
U_t	Utilization
U_{tc}	Weld capacity utilization

Detailed result for SP4 B2

Weld resistance check (EN 1993-1-8 4.5.3.2)

$$\sigma_{w,Rd} = f_u / (\beta_w \gamma_{M2}) = 360.0 \text{ MPa} \geq \sigma_{w,Ed} = [\sigma_{\perp}^2 + 3(\tau_{\perp}^2 + \tau_{||}^2)]^{0.5} = 309.9 \text{ MPa}$$

$$\sigma_{\perp,Rd} = 0.9 f_u / \gamma_{M2} = 259.2 \text{ MPa} \geq |\sigma_{\perp}| = 252.1 \text{ MPa}$$

where:

$f_u = 360.0 \text{ MPa}$	– Ultimate strength
$\beta_w = 0.80$	– appropriate correlation factor taken from Table 4.1
$\gamma_{M2} = 1.25$	– Safety factor

Stress utilization



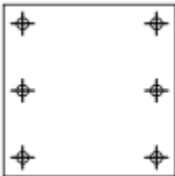



$$U_t = \max\left(\frac{\sigma_{xx}}{\sigma_{xx,Rd}}, \frac{|\sigma_{\perp}|}{\sigma_{\perp,Rd}}\right) = 97.3 \quad \%$$







Buckling

Buckling analysis was not calculated.

Bill of material

Manufacturing operations

Name	Plates [mm]	Shape	Nr.	Welds [mm]	Length [mm]	Bolts	Nr.
SP1	P10.0x270.0-270.0 (S 235)		1			M16 8.8	6
SP2	P10.0x270.0-270.0 (S 235)		1			M16 8.8	6
CUT1				Fillet: a = 4.0	592.3		
SP3	P10.0x270.0-270.0 (S 235)		1			M16 8.8	6
SP4	P10.0x270.0-270.0 (S 235)		1			M16 8.8	6
CUT2				Fillet: a = 4.0	592.3		
Stiff	P10.0x50.0-70.0 (S 235)		1	Double fillet: a = 4.0	50.0		
Stiff_2	P10.0x50.0-70.0 (S 235)		1				

SP7	P10.0x50.0-70.0 (S 235)		1	Double fillet: a = 4.0	50.0		
SP8	P10.0x50.0-70.0 (S 235)		1				
SP9	P10.0x50.0-70.0 (S 235)		1				
SP10	P10.0x50.0-70.0 (S 235)		1				
SP11	P10.0x50.0-70.0 (S 235)		1	Double fillet: a = 4.0	50.0		
SP12	P10.0x50.0-70.0 (S 235)		1	Double fillet: a = 4.0	50.0		

Welds

Type	Material	Throat thickness [mm]	Leg size [mm]	Length [mm]
Fillet	S 235	4.0	5.7	1184.5
Fillet	S 235	4.0	5.7	1594.0
Double fillet	S 235	4.0	5.7	897.0

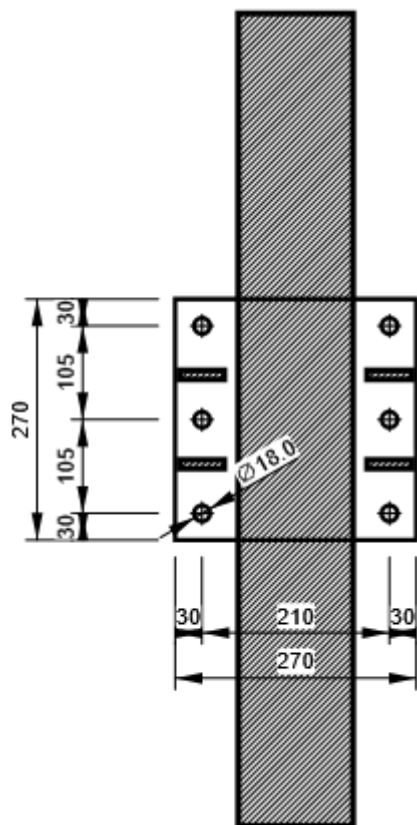
Bolts

Name	Grip length [mm]	Count
M16 8.8	20	12

Drawing

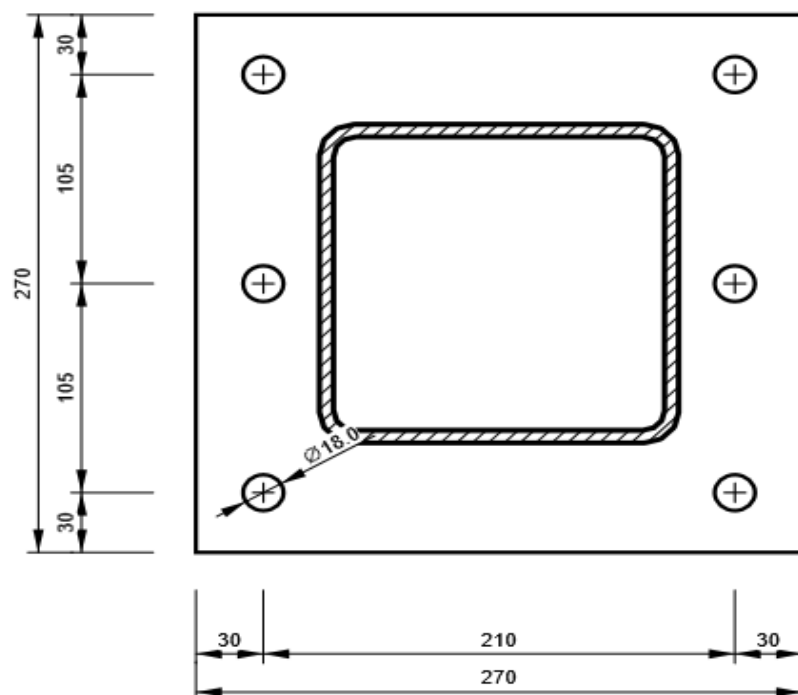
SP1

P10.0x270-270 (S 235)



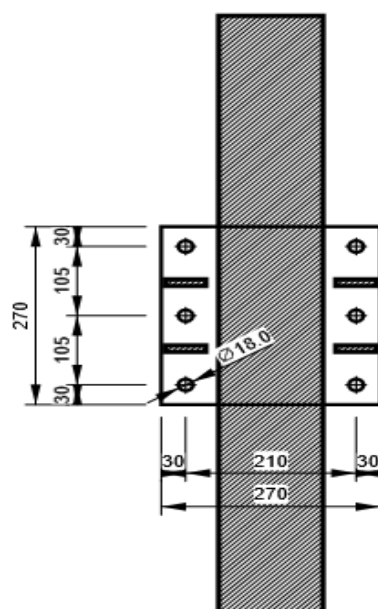
SP2

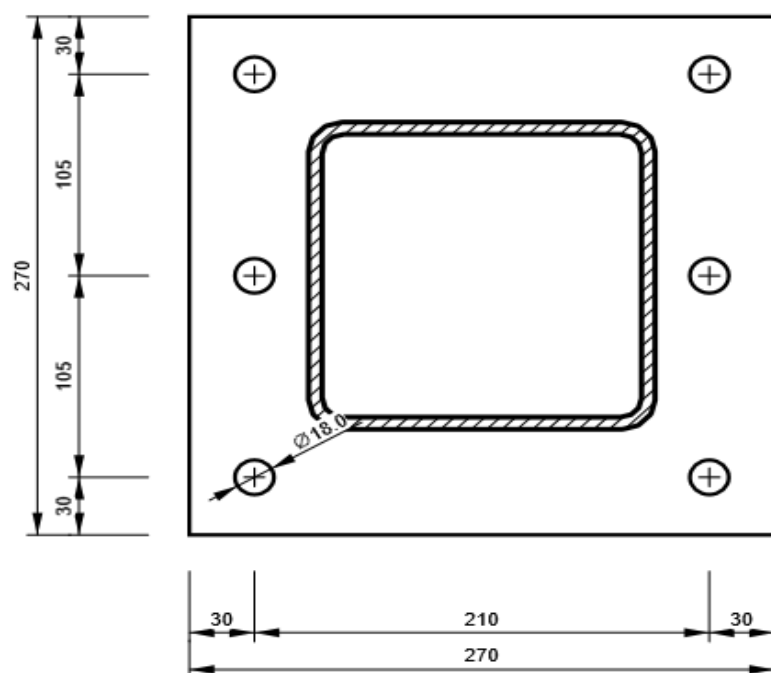
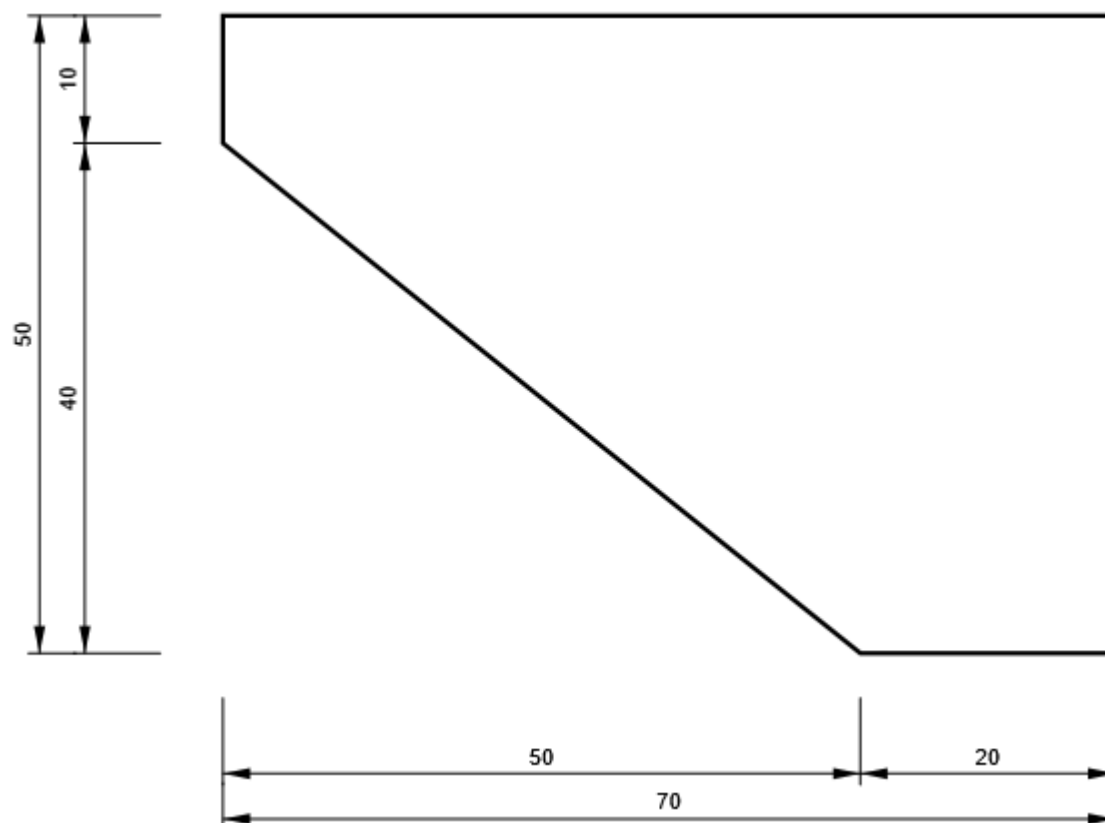
P10.0x270-270 (S 235)



SP3

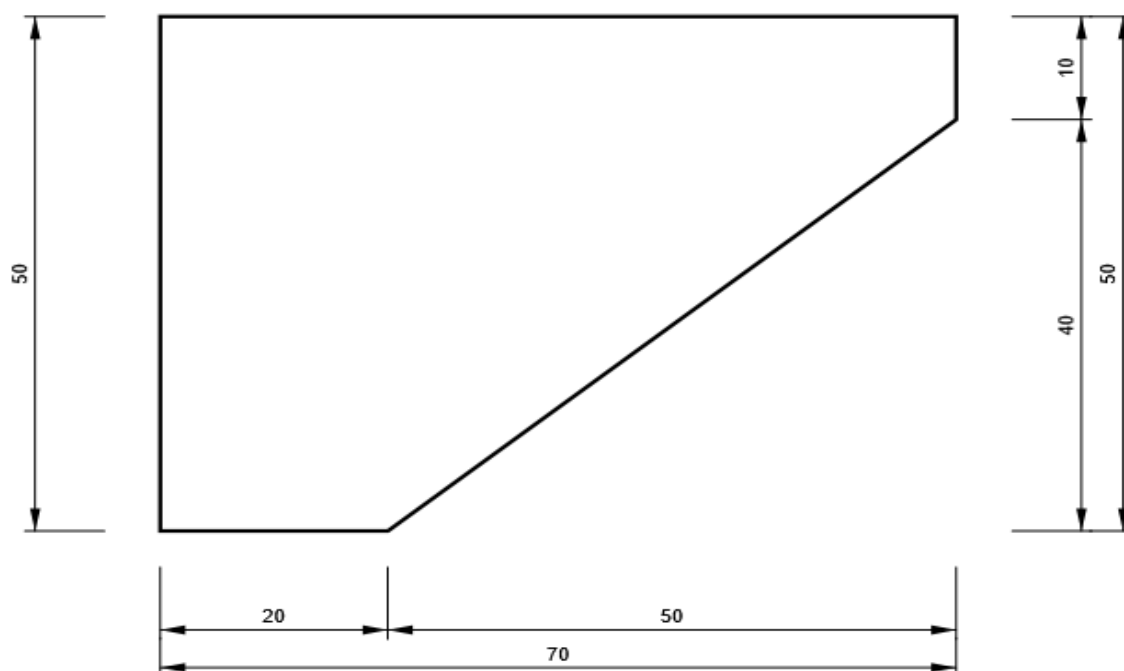
P10.0x270-270 (S 235)



SP4**P10.0x270-270 (S 235)****Stiff****P10.0x70-50 (S 235)**

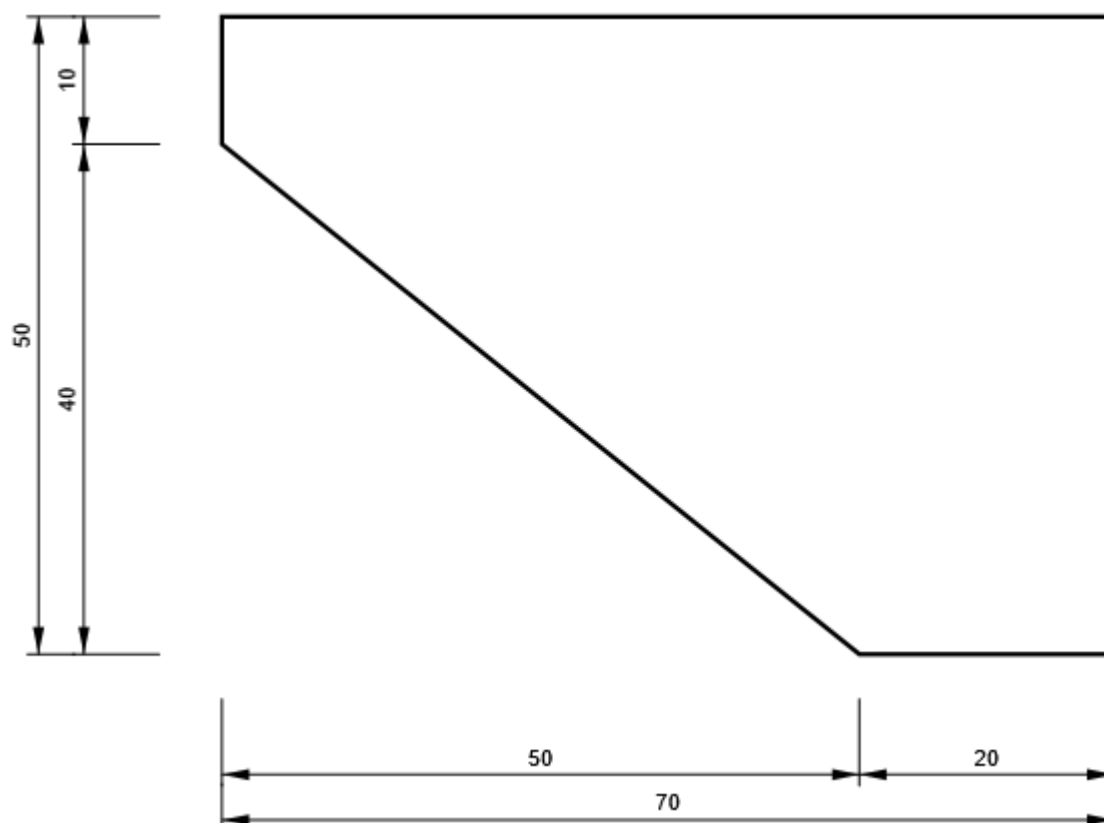
Stiff_2

P10.0x70-50 (S 235)



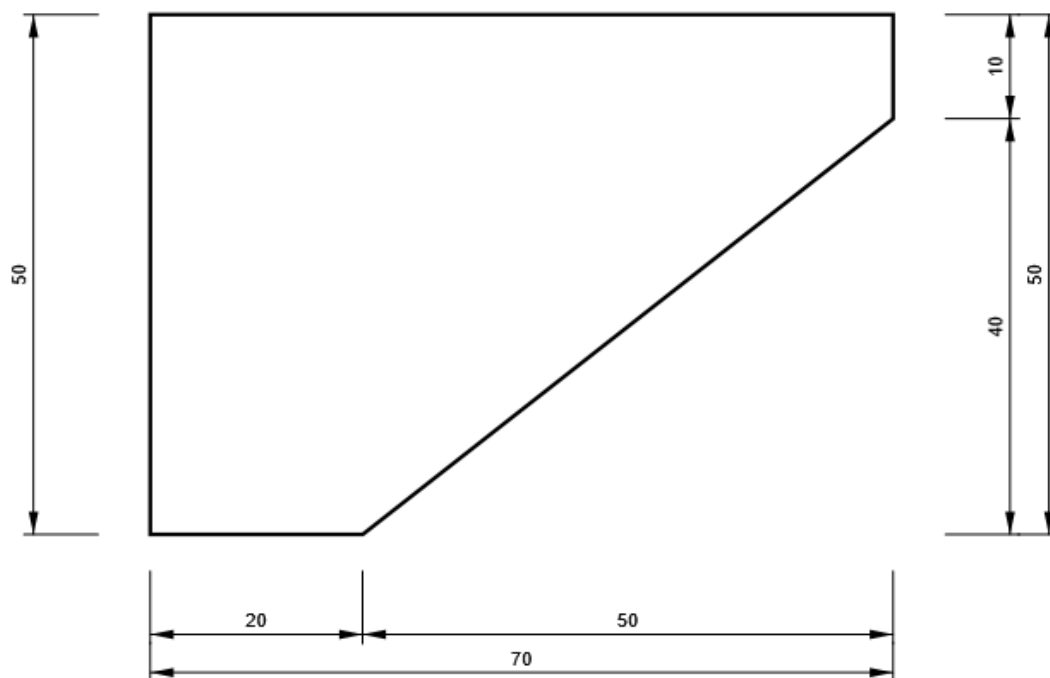
SP7

P10.0x70-50 (S 235)



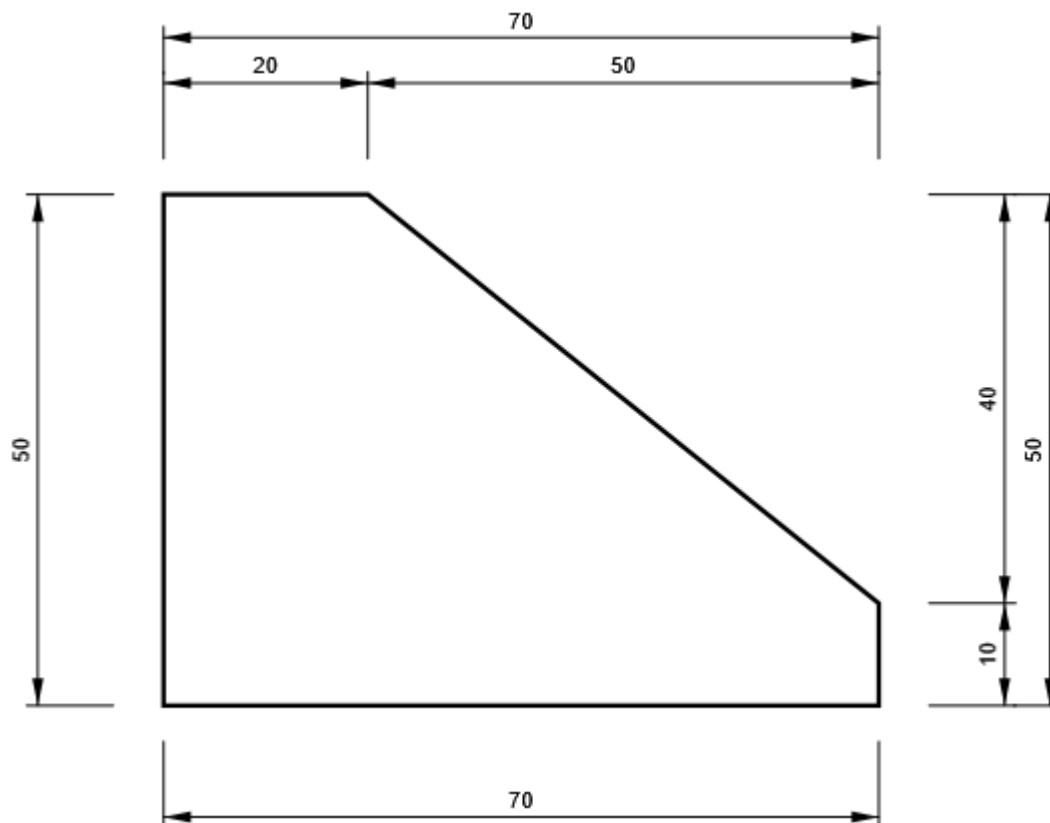
SP8

P10.0x70-50 (S 235)



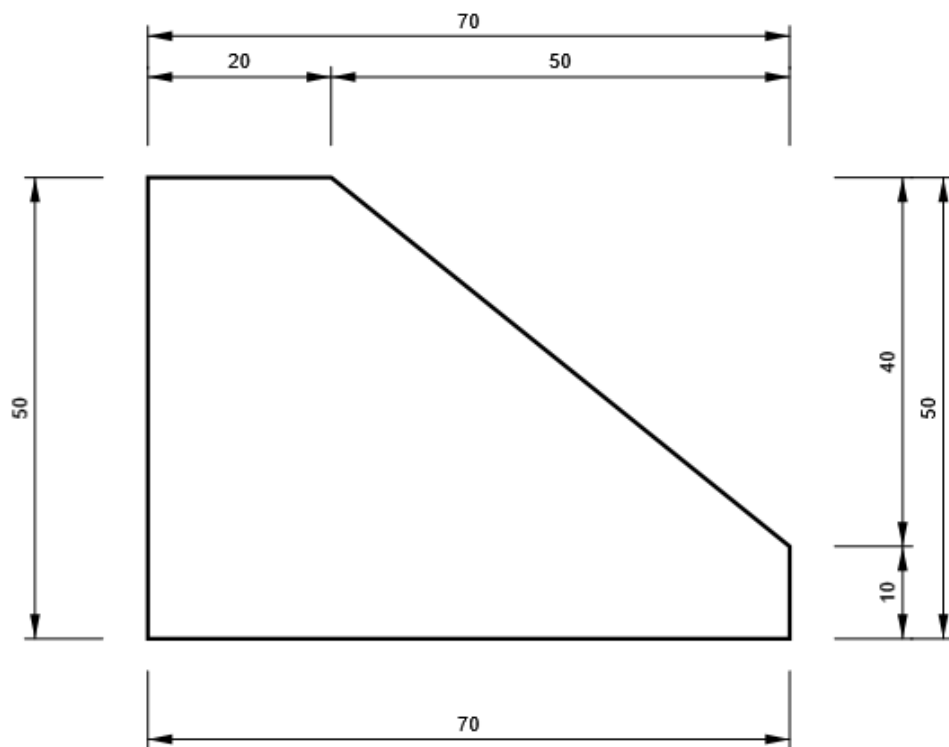
SP9

P10.0x70-50 (S 235)



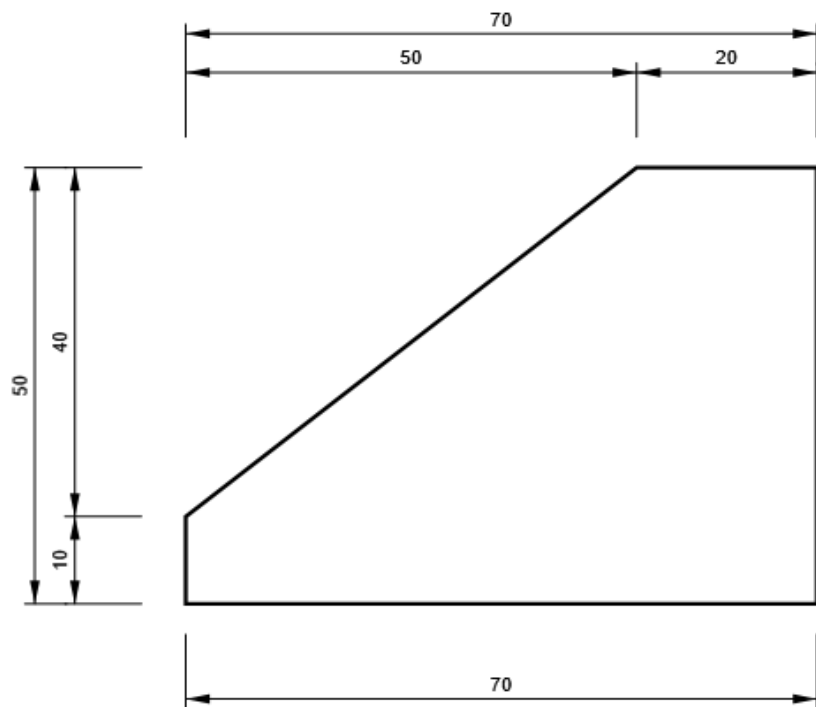
SP10

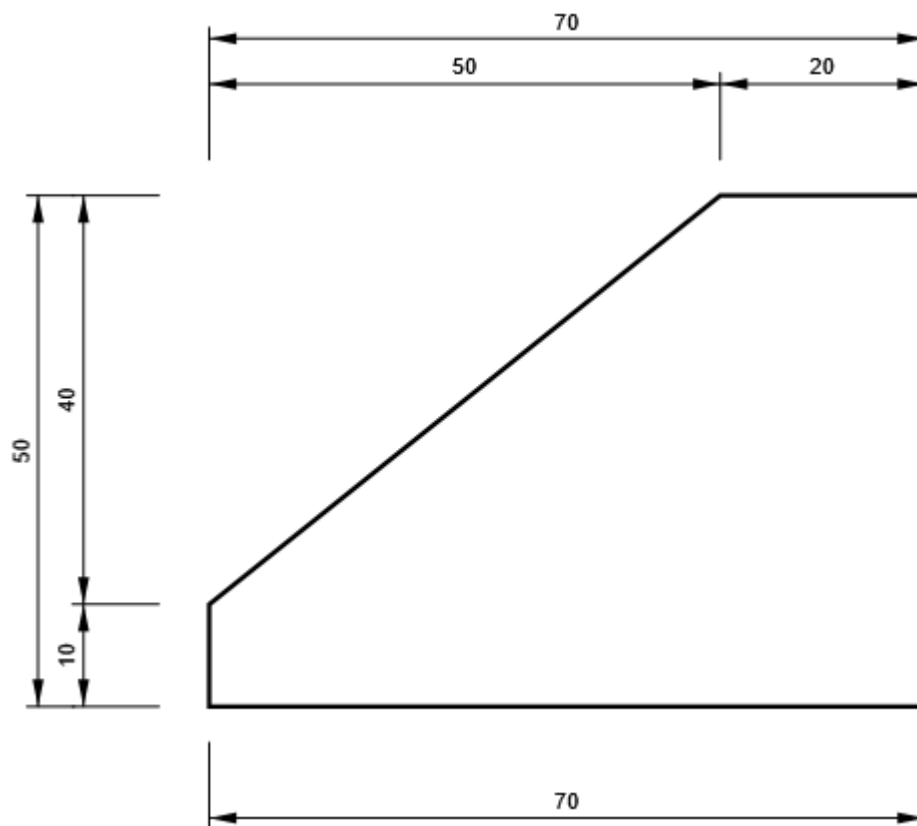
P10.0x70-50 (S 235)



SP11

P10.0x70-50 (S 235)



SP12**P10.0x70-50 (S 235)**

Code settings

Item	Value	Unit	Reference
γ_{M0}	1.00	-	EN 1993-1-1: 6.1
γ_{M1}	1.00	-	EN 1993-1-1: 6.1
γ_{M2}	1.25	-	EN 1993-1-1: 6.1
γ_{M3}	1.25	-	EN 1993-1-8: 2.2
γ_C	1.50	-	EN 1992-1-1: 2.4.2.4
γ_{Inst}	1.20	-	EN 1992-4: Table 4.1
Joint coefficient β_j	0.67	-	EN 1993-1-8: 6.2.5
Effective area - influence of mesh size	0.10	-	
Friction coefficient - concrete	0.25	-	EN 1993-1-8
Friction coefficient in slip-resistance	0.30	-	EN 1993-1-8 tab 3.7
Limit plastic strain	0.05	-	EN 1993-1-5
Weld stress evaluation	Plastic redistribution		
Detailing	No		
Distance between bolts [d]	2.20	-	EN 1993-1-8: tab 3.3
Distance between bolts and edge [d]	1.20	-	EN 1993-1-8: tab 3.3
Concrete breakout resistance	Both		EN 1992-4: 7.2.1.4 and 7.2.2.5

check			
Use calculated α_b in bearing check.	Yes		EN 1993-1-8: tab 3.4
Cracked concrete	Yes		EN 1992-4
Local deformation check	No		CIDECT DG 1, 3 - 1.1
Local deformation limit	0.03	-	CIDECT DG 1, 3 - 1.1
Geometrical nonlinearity (GMNA)	Yes		Analysis with large deformations for hollow section joints
Braced system	No		EN 1993-1-8: 5.2.2.5