Exercise: Construction with pultruded GFRP Profiles

1 Static system

Figure 1 shows a beam with the hangers A and B and the loading (excluding beam self weight).

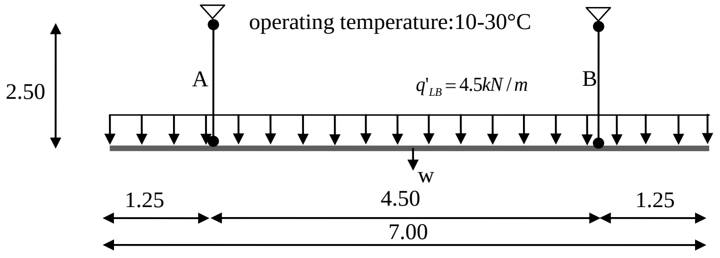

Figure 1: Static system and loading of longitudinal beam with hangers [m]

2 Tasks

Task 1: Choose a profile for the longitudinal beam of Figure 1. The mid-span deflection $w_{d,SLS}$ (consider the hangers as rigid) should not exceed $w_{\lim} = l/500$ under Serviceability Limit State loads ($q'_{SLS} = 1.0 \cdot q'_{LB}$). Material properties and profiles are listed in Appendix A and Appendix B, respectively.

> Note: You will have to develop a detail (Task 3) for the connection between the longitudinal beam and the hanger. Consider this by choosing the profile for the longitudinal beam.

Task 2: Verify the Ultimate Limit State of the longitudinal beam,

a) for the *short*-term load with the (global) load factor $\gamma_{Q,short} = 1.45$ for q'_{LB} and dead load factor $\gamma_G = 1.35$ for the beam self weight

b) for the *long*-term load with $\gamma_{Q,long} = 1.0$ and $\gamma_G = 1.35$

and the partial coefficients γ_m according to Table 1. Stability problems do not have to be considered (stability is given by the construction)

Task 3: Choose a profile for the hangers and develop an appropriate detail (dimensioning and sketching the detail to scale!) for the connection between the chosen longitudinal beam and the hangers. Use steel as little as possible. Guidelines for the design of bolted joints are given in Appendix C. **Do not use details similar to those in** Figure 2 **(no bending moments with tensile stresses perpendicular to the fibres are allowed!)**:

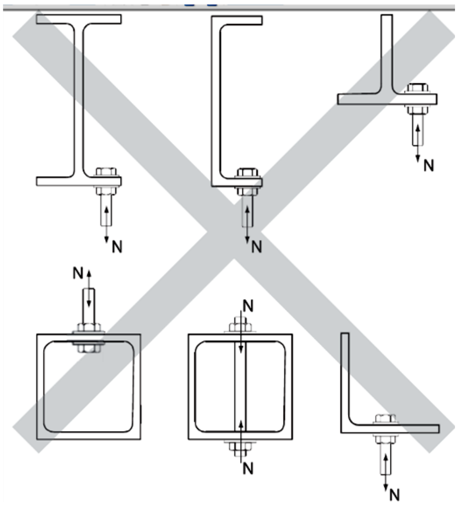

Figure 2: These details are not allowed, since tensile forces perpendicular to the fibers are not allowed.

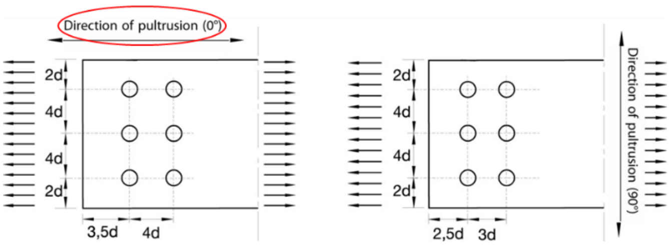

Figure 3: Minimum distances for bolts. d = bolt diameter.

Respect the minimum distances as a function of the direction of pultrusion = direction of fibres (Figure 3).

Table 1: Partial coefficients (values in parentheses are for profiles in vinylester)

Operating temperature (°C) dry condition	$\gamma_m = \gamma_{m.1}\,\gamma_{m.2}\,\gamma_{m.3}\,\gamma_{m.4}$	
	Short-tem load	Long-term load
-20	1.3	3.2
60 (80)	1.3	3.2
80 (100)	1.6	4.0

3 Documents

Extractions of Fiberline Design Manual (2003), see attached pages. More information can be found at www.fiberline.com (registration necessary)

4 Assignment due date

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5 Contact

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6 Appendix A: Material properties

Typical strength values		
		[MPa]
Flexural strength, 0°	$f_{b,0°}$	240
Flexural strength, 90°	$f_{b,90°}$	100
Tensile strength, 0°	$f_{t,0°}$	240
Tensile strength, 90°	$f_{t,90°}$	50
Compressive strength, 0°	$f_{c,0°}$	240
Comprehensive strength, 90°	$f_{c,90°}$	70
Shear strength	f_{τ}	25
Pin-bearing strength, longitudinal direction	$f_{cB,0°}$	150
Pin-bearing strength, transverse direction	$f_{cB,90°}$	70

Typical stiffness figures and transverse contraction			
		[MPa]	[--]
Modulus of elasticity	$E_{0°}$	23 000 / 28 000	
Modulus of elasticity	$E_{90°}$	8 500	
Modulus in shear	G	3 000	
Poisson's ratio	$\nu_{0°,90°}$		0.23
Poisson's ratio	$\nu_{90°,0°}$		0.09

Table 2.2

The E-modulus of the profiles varies from 23 to 28 GPa, depending on the geometry and reinforcement. See the relevant values in the section on the load-bearing capacities of the individual profiles.

7 Appendix B: Profiles

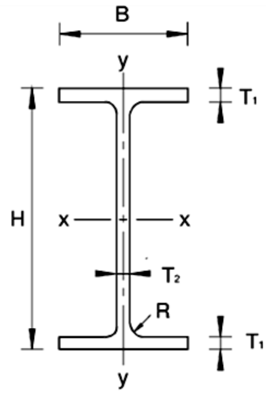


Table 2.5: I-profiles

I-profile HxBxT[1)]	H mm	B mm	T_1 mm	T_2 mm	R mm	A mm^2	$A_{k,y}$ mm^2	$A_{k,x}$ mm^2	g kg/m	I_{xx} mm^4	W_{xx} mm^3	I_{yy} mm^4	W_{yy} mm^3	$E_{0°}$ MPa	$E_{0°}\cdot I_{xx}$ Nmm^2
factor	1	1	1	1	1	10^3	10^3	10^3	1	10^6	10^3	10^6	10^3	10^3	10^9
I 120x60x6	120	60	6	6	7.5	1.42	0.68	0.58	2.55	3.10	51.7	0.22	7.30	23	71.30
I 160x80x8	160	80	8	8	8	2.49	1.22	1.02	4.48	9.66	121	0.69	17.3	28	270.5
I 200x100x10	200	100	10	10	10	3.89	1.90	1.60	6.99	23.6	236	1.69	33.7	28	660.8
I 240x120x12	240	120	12	12	12	5.60	2.74	2.30	10.1	48.9	408	3.50	58.3	28	1369
I 300x150x15	300	150	15	15	15	8.74	4.28	3.60	15.7	119	796	8.54	114	28	3332
I 360x180x18	360	180	18	18	18	12.6	6.16	5.18	22.7	248	1376	17.7	197	28	6944

Table values must be multiplied by the factors listed at the top of the table. ([1)] $T = T_1 = T_2$)

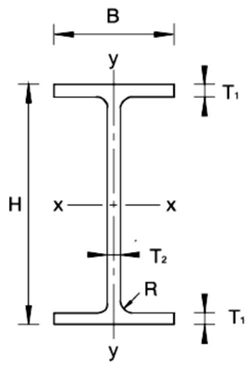


Table 2.6: IL-profiles

IL-profile $HxBxT_1 / T_2$	H mm	B mm	T_1 mm	T_2 mm	R mm	A mm^2	$A_{k,y}$ mm^2	$A_{k,x}$ mm^2	g kg/m	I_{xx} mm^4	W_{xx} mm^3	I_{yy} mm^4	W_{yy} mm^3	$E_{0°}$ MPa	$E_{0°}\cdot I_{xx}$ Nmm^2
factor	1	1	1	1	1	10^3	10^3	10^3	1	10^6	10^3	10^6	10^3	10^3	10^9
IL 120x60x5/5	120	60	5	5	5,0	1.17	0.570	0.480	2.11	2.60	43.36	0.181	6.05	23	59.80
IL 160x80x8/5	160	80	8	5	8,0	2,05	0.760	1.024	3.70	8.76	109.5	0.685	17.1	28	245.3
IL 200x100x8/5	200	100	8	5	8,0	2,57	0.950	1.280	4.63	17.4	174.4	1.336	26.7	28	487.2
IL 240x120x10/7	240	120	10	7	10,0	4,03	1.596	1.920	7.25	38.1	317.8	2.888	48.1	28	1067
IL 300x150x12/8	300	150	12	8	12,0	5,93	2.280	2.880	10.7	90.2	606.5	6.768	90.2	28	2526
IL 360x180x15/10	360	180	15	10	15,0	8,89	3.420	4.320	16.0	195.8	1088	14.62	162	28	5482

Table values must be multiplied by the factors listed at the top of the table.

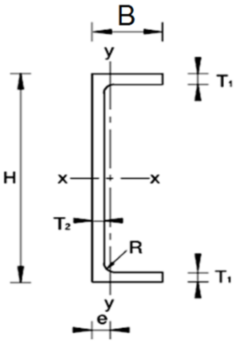


Table 2.7: U-profiles

U-profile	H	B	T_1	T_2	R	A	$A_{k,y}$	$A_{k,x}$	g	I_{xx}	W_{xx}	I_{yy}	W_{yy}	e	$E_{0°}$	$E_{0°} \cdot I_{xx}$
HxBxT[1)]	mm	mm	mm	mm	mm	mm^2	mm^2	mm^2	kg/m	mm^4	mm^3	mm^4	mm^3	mm	MPa	Nmm^2
factor	1	1	1	1	1	10^3	10^3	10^3	1	10^6	10^3	10^6	10^3	1	10^3	10^9
U 120x50x6	120	50	6	6	7.5	1.27	0.648	0.510	2.29	2.65	44.1	0.279	7.63	13.5	23	60.95
U 140x40x5	140	40	5	5	5	1.06	0.630	0.340	1.91	2.78	39.8	0.131	4.23	9.1	23	63.94
U 160x48x8	160	48	8	8	8	1.95	1.15	0.653	3.51	6.57	82.1	0.338	9.38	12.0	28	184.0
U 200x60x10	200	60	10	10	10	3.04	1.80	1.02	5.48	16.0	160	0.825	18.3	15.0	28	448.0
U 240x72x8	240	72	8	8	8	2.97	1.73	0.98	5.35	23.3	194	1.23	22.1	16.5	28	652.4
U 240x72x12	240	72	12	12	12	4.38	2.59	1.47	7.89	33.2	277	1.71	31.7	18.0	28	929.6
U 300x90x15	300	90	15	15	15	6.85	4.05	2.30	12.3	81.2	541	4.18	61.9	22.4	28	2274
U 360x108x18	360	108	18	18	18	9.86	5.83	3.31	17.8	168	935	8.67	107	26.9	28	4704

Table values must be multiplied by the factors listed at the top of the table. ([1)] $T = T_1 = T_2$)

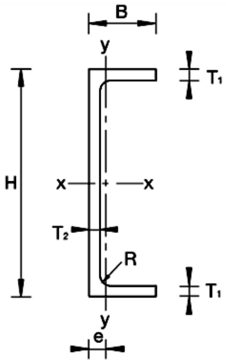
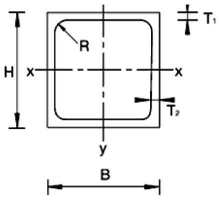


Table 2.8: UL-profiles

UL -profile	H	B	T_1	T_2	R	A	$A_{k,y}$	$A_{k,x}$	g	I_{xx}	W_{xx}	I_{yy}	W_{yy}	e	$E_{0°}$	$E_{0°} \cdot I_{xx}$
$HxBxT_1 / T_2$	mm	mm	mm	mm	mm	mm^2	mm^2	mm^2	kg/m	mm^4	mm^3	mm^4	mm^3	mm	MPa	Nmm^2
factor	1	1	1	1	1	10^3	10^3	10^3	1	10^6	10^3	10^6	10^3	1	10^3	10^9
UL 120x50x5/5	120	50	5	5	5.0	1.06	0.540	0.425	1.91	2.239	37.33	0.238	6.469	13.1	23	51.52
UL 160x48x8/5	160	48	8	5	8.0	1.40	0.720	0.653	2.52	5.664	70.80	0.299	8.934	14.6	28	158.6
UL 200x60x8/5	200	60	8	5	8.0	1.75	0.900	0.816	3.16	11.32	113.2	0.603	14.29	17.8	28	317.0
UL 240x72x10/7	240	72	10	7	10.0	2.77	1.512	1.224	5.40	24.93	207.7	1.316	25.69	20.8	28	698.0
UL 300x90x12/8	300	90	12	8	12	4.43	2.160	1.836	7.97	59.96	399.8	3.317	50.32	24.1	28	1679
UL 360x108x15/10	360	108	15	10	15.0	6.64	3.240	2.754	11.9	128.9	716.3	7.127	90.27	29.0	28	3610

Table values must be multiplied by the factors listed at the top of the table.



Profile	H	B	T_1	T_2	R	A	$A_{K,y}$	$A_{K,x}$	g	I_{xx}	W_{xx}	I_{yy}	W_{yy}	$E_{0°}$	$E_{0°} \cdot I_{xx}$
HxBxT[1)]	mm	mm	mm	mm	mm	mm^2	mm^2	mm^2	kg/m	mm^4	mm^3	mm^4	mm^3	MPa	Nmm^2
factor	1	1	1	1	1	10^3	10^3	10^3	1	10^6	10^3	10^6	10^3	10^3	10^9
50x50x5	50	50	5	5	2	0.90	0.45	0.45	1.63	0.31	12.4	0.31	12.4	23	7.130
60x60x5	60	60	5	5	4	1.11	0.54	0.54	2.00	0.57	18.9	0.57	18.9	23	13.11
80x60x5	80	60	5	5	4	1.31	0.72	0.54	2.36	1.15	28.7	0.72	24.0	23	26.45
100x60x8	80	60	8	8	4	2.32	1.44	0.86	4.18	2.85	57.0	1.21	40.3	23	65.55
100x100x6	100	100	6	6	4	2.27	1.08	1.08	4.09	3.36	67.2	3.36	67.2	23	77.28
100x100x8	100	100	8	8	4	2.96	1.44	1.44	5.32	4.21	84.2	4.21	84.2	23	96.83
120x120x6	120	120	6	6	4	2.75	1.30	1.30	4.95	5.98	99.7	5.98	99.7	23	137.5
120x120x8	120	120	8	8	4	3.60	1.73	1.73	6.48	7.57	126	7.57	126	23	174.1
160x160x8	160	160	8	8	8	4.92	2.30	2.30	8.85	19.1	238	19.1	238	23	437.0
200x200x10	200	200	10	10	10	7.69	3.60	3.60	13.84	46.5	465	46.5	465	23	1070
240x240x12	240	240	12	12	12	11.1	5.18	5.18	20.0	96.5	804	96.5	804	23	2217

Table values must be multiplied by the factors listed at the top of the table.

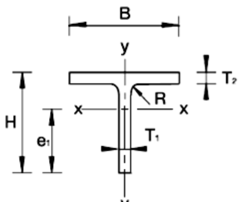
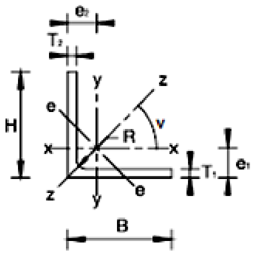


Table 2.11: T-profiles

T-profile	H	B	T_1	T_2	R	A	$A_{K,y}$	$A_{K,x}$	g	I_{xx}	W_{xx}	I_{yy}	W_{yy}	e_1	$E_{0°}$	$E_{0°} \cdot I_{xx}$
$HxBxT_1xT_2$	mm	mm	mm	mm	mm	mm^2	mm^2	mm^2	kg/m	mm^4	mm^3	mm^4	mm^3	mm	MPa	Nmm^2
factor	1	1	1	1	1	10^3	10^3	10^3	1	10^6	10^3	10^6	10^3	1	10^3	10^9
T 60x60x6x6	60	60	6	6	7	0.70	0.342	0.288	1.27	0.23	5.46	0.109	3.65	43.1	23	5.290
T 90x72x11x10	90	72	11	10	7	1.62	0.941	0.576	2.92	1.28	21.2	0.321	8.92	60.5	23	29.44

Table values must be multiplied by the factors listed at the top of the table.



L-profile	R	A	$A_{s,y}$	$A_{s,z}$	g	I_{xx}	W_{xx}	I_{yy}	W_{yy}	I_{zz}	I_{ee}	e_1	e_2	v	$E_{0°}$	$E_{0°}\cdot I_{xx}$
HxBxT[1)]	mm	mm^2	mm^2	mm^2	kg/m	mm^4	mm^3	mm^4	mm^3	mm^4	mm^4	mm	mm	Grd.	MPa	Nmm^2
factor	1	10^3	10^3	10^3	1	10^6	10^3	10^6	10^3	10^6	10^6	1	1	1	10^3	10^9
L 50x50x6	7	0.57	0.27	0.27	1.03	0.13	3.72	0.13	3.72	0.21	0.057	14.6	14.6	-450	23	2.990
L 50x50x8	7	0.75	0.36	0.36	1.34	0.17	4.79	0.17	4.79	0.26	0.071	15.3	15.3	-45.0	23	3.910
L 75x75x6	7	0.87	0.40	0.40	1.57	0.47	8.69	0.47	8.69	0.74	0.203	20.8	20.8	-45.0	23	10.81
L 75x75x8	7	1.15	0.54	0.54	2.06	0.60	11.3	0.60	11.3	0.95	0.256	21.6	21.6	-45.0	23	13.80
L 80x80x8	7	1.23	0.58	0.58	2.21	0.74	12.9	0.74	12.9	1.16	0.313	22.8	22.8	-45.0	23	17.02
L 100x100x8	7	1.55	0.72	0.72	2.78	1.49	20.6	1.49	20.6	2.34	0.626	27.8	27.8	-45.0	23	34.27
L 100x100x10	7	1.91	0.90	0.90	3.44	1.80	25.3	1.80	25.3	2.85	0.757	28.6	28.6	-45.0	23	41.40
L 100x100x12	7	2.27	1.08	1.08	4.08	2.10	29.8	2.10	29.8	3.32	0.883	29.3	29.3	-45.0	23	48.30
L 150x100x8	7	1.95	1.08	0.72	3.50	4.57	44.7	1.67	21.6	5.27	0.971	47.8	22.9	-23.8	23	105.1
L 150x100x10	7	2.41	1.35	0.90	4.34	5.59	55.1	2.03	26.6	6.44	1.180	48.6	23.7	-23.7	23	128.6
L 150x100x12	7	2.87	1.62	1.08	5.16	6.57	65.3	2.37	31.3	7.56	1.380	49.4	24.5	-23.6	23	151.1
L 150x150x8	7	2.35	1.08	1.08	4.22	5.21	47.5	5.21	47.5	8.24	2.170	40.3	40.3	-45.0	23	119.8
L 150x150x10	7	2.91	1.35	1.35	5.24	6.38	58.6	6.38	58.6	10.1	2.650	41.1	41.1	-45.0	23	146.7
L 150x150x12	7	3.47	1.62	1.62	6.24	7.51	69.4	7.51	69.4	11.9	3.110	41.9	41.9	-45.0	23	172.7

Table values must be multiplied by the factors listed at the top of the table. ([1)] $T = T_1 = T_2$)

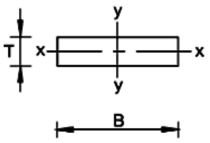


Table 2.13: Flat profiles, plates and sheets

Profile	B	T	A	$A_{x,y}$	$A_{x,x}$	g	I_{xx}	W_{xx}	I_{yy}	W_{yy}
BxT	mm	mm	mm^2	mm^2	mm^2	kg/m	mm^4	mm^3	mm^4	mm^3
factor	1	1	10^3	10^3	10^3	1	10^6	10^3	10^6	10^3
30x6	30	6	0.18	0.12	0.12	0.32	0.0005	0.18	0.013	0.90
50x6	50	6	0.30	0.20	0.20	0.54	0.0009	0.30	0.062	2.50
50x10	50	10	0.50	0.33	0.33	0.90	0.0042	0.83	0.104	4.17
100x6	100	6	0.60	0.40	0.40	1.08	0.0018	0.60	0.500	10.0
100x10	100	10	1.00	0.67	0.67	1.80	0.0083	1.67	0.833	16.7
140x10	140	10	1.40	0.93	0.93	2.52	0.0117	2.33	2.290	32.7
200x10	200	10	2.00	1.33	1.33	3.60	0.0167	3.33	6.670	66.7
300x10	300	10	3,00	2.00	2.00	5.40	0.0250	5.00	22.50	150
1220x6	1220	6	7.32	4.88	4.88	13.18	0.0220	7.32	907.9	1488
1220x8	1220	8	9.76	6.51	6.51	17.57	0.0521	13.0	1211	1985
1220x10	1220	10	12.2	8.13	8.13	21.96	0.1020	20.3	1513	2480
1220x12	1220	12	14.6	9.76	9.76	26.35	01757	29.3	1816	2977

Table values must be multiplied by the factors listed at the top of the table.

The elasticity modulus 23,000 MPa is not valid for flat profiles and sheets.

8 Appendix C: Design of bolts according to Fiberline Manual 2002

FIBERLINE COMPOSITES

Load-bearing capacity of bolts - shear in the longitudinal direction (0°)

The approximate distribution of tension in the laminate around a bolt subjected to shear is described in Figure 4.5.

The load-bearing capacity of a bolt subjected to shear will be sufficient if the stress which occurs does not exceed the relevant strengths.

The shear for a bolt can be determined as

$$P_{B,D} = \frac{d \cdot t \cdot 150\ \text{MPa}}{\gamma_m} = d \cdot t \cdot 115{,}4\ \text{MPa}$$

in which
γ_m = 1,3
d = nominal diameter of the bolt
t = thickness of the laminate

The values are based on
$a = 3{,}5 \cdot d$
$b = 1{,}0 \cdot d$
$c = 2{,}0 \cdot d$

Theoretical derivatives for load-bearing capacity terms

Geometry:

- a — Distance from the centre line of the bolt to the edge in the direction of force (longitudinal direction).
- b — Width of area in front of the bolt where interlaminar forces occur.
- c — Distance from the centre line of the bolt to the edge perpendicular to the direction of force.
- d — Diameter of bolt.
- v — Angle of inclined pressure: tan(v) = [c/2+d/4]/[a-b/2]
- t — Thickness of laminate.

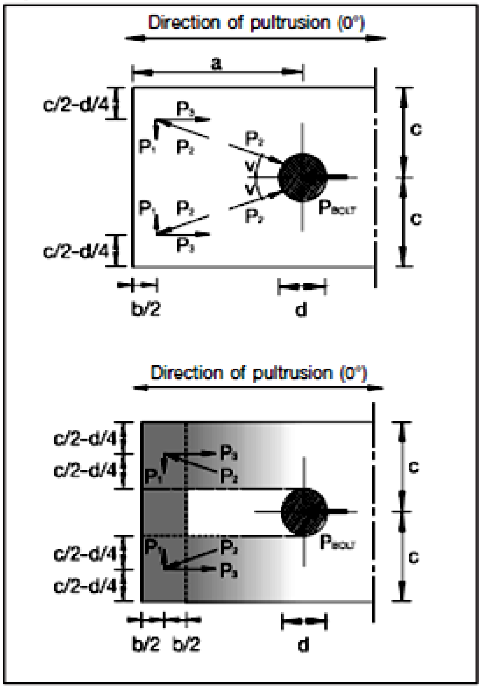
Static conditions:

$$P_1 = \tfrac{1}{2} \cdot P_{Bolt} \cdot \tan(v)$$

$$P_2 = \frac{P_{Bolt}}{2 \cdot \cos(v)}$$

$$P_3 = \tfrac{1}{2} \cdot P_{Bolt}$$

Figure 4.5



Stress-related conditions:

The force diagrams for the various conditions are illustrated in the figures below. The line of fracture is also illustrated.

Condition 1 : Tensile stress in the longitudinal direction next to bolt

$$\frac{P_3}{\left(\frac{c-d}{2}\right)\cdot t}$$

Fibre in 0° overloaded
See Figure 4.6

Load-bearing capacity $P_{Bolt} \leq 720\ \text{MPa}\cdot t\cdot d$

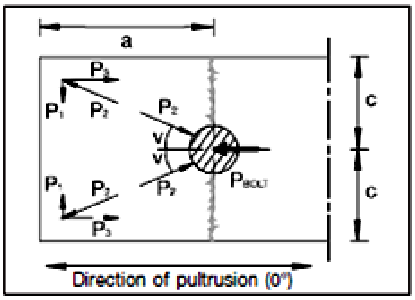


Figure 4.6

Condition 2 : Cleavage stress in area in front of bolt

$$\frac{P_1}{b\cdot t}$$

Fibre in 90° overloaded
See Figure 4.7

Load-bearing capacity $P_{Bolt} \leq 240\ \text{MPa}\cdot t\cdot d$

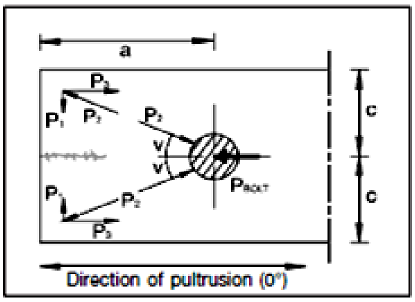


Figure 4.7

Condition 3 : Tearing of laminate in front of bolt

$$\frac{P_{Bolt}}{2\cdot\left(a-\frac{d}{2}\right)\cdot t}$$

shear stress exceeded in the lines of fracture shown
See Figure 4.8

Load-bearing capacity $P_{Bolt} \leq 150\ \text{MPa}\cdot t\cdot d$

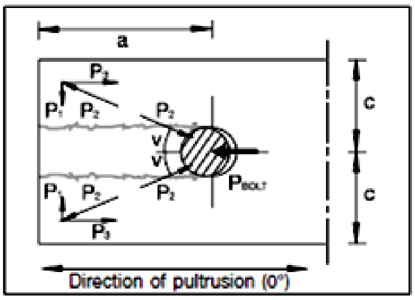


Figure 4.8

Condition 4 : Inclined distribution in front of bolt

$$\frac{P_2}{d \cdot t}$$

The compression stress in the inclined failure surface exceeds the compression strength.
See Figure 4.9

Load-bearing capacity: $P_{Bolt} \leq 240 \text{ MPa} \cdot t \cdot d$

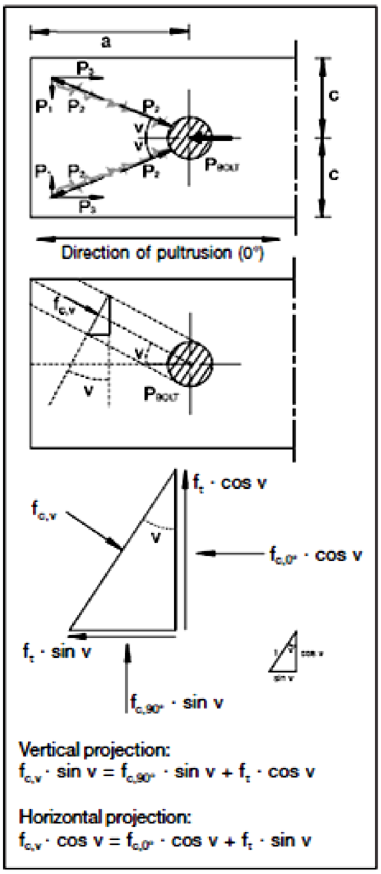


Figure 4.9
Strength $f_{c,v}$ in inclined forces

Condition 5 : Laminate compresses in front of bolt

$$\frac{P_{Bolt}}{d \cdot t}$$

Contact compression between bolt and laminate exceeds the compression strength, so the bolt "eats" into the laminate.
See Figure 4.10

Load-bearing capacity: $P_{Bolt} \leq 240 \text{ MPa} \cdot t \cdot d$

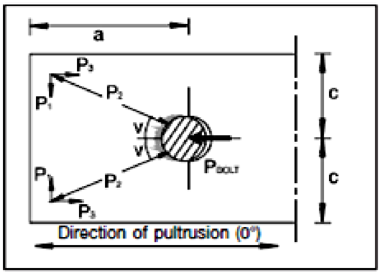


Figure 4.10

Load-bearing capacity of bolts - shear in the transverse direction (90°)

The approximate distribution of stress in the laminate around a bolt subjected to shear can be described as shown in Figure 4.11.

The load-bearing capacity of a bolt subjected to shear, if the stress does not exceed the relevant strengths.

Calculation of shear strength:

$$P_{B,d} = \frac{d \cdot t \cdot 70\,\text{MPa}}{\gamma_m} = d \cdot t \cdot 53{,}8\,\text{MPa}$$

in which
γ_m = 1,3
d = nominal diameter of bolt
t = thickness of laminate

Values are based on
a = 3,5 · d
b = 1,0 · d
c = 2,0 · d

Theoretical derivatives for load-bearing capacity terms

Geometry:

a Distance from centre line of bolt to edge in direction of force (transverse direction)

b Width of area in front of bolt where interlaminar forces occur

c Distance from centre line of bolt to edge perpendicular to direction of force

d Bolt diameter

v Angle of inclined pressure: tan(v) = [c/2+d/4]/[a-b/2]

t Thickness of laminate

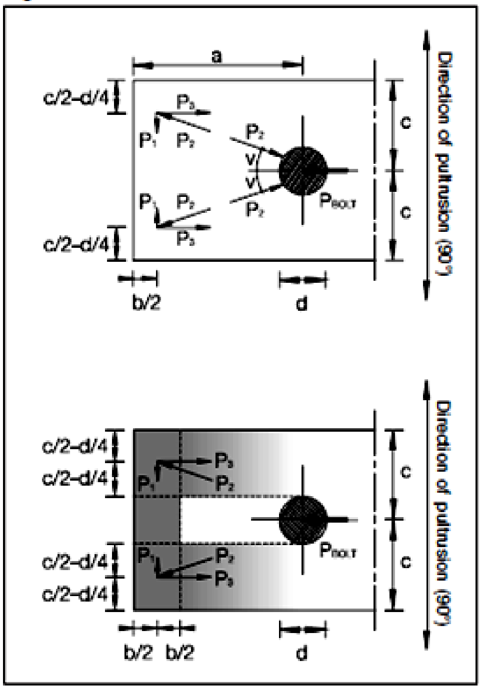
Static conditions:

$$P_1 = \tfrac{1}{2} \cdot P_{Bolt} \cdot \tan(v)$$

$$P_2 = \frac{P_{Bolt}}{2 \cdot \cos(v)}$$

$$P_3 = \tfrac{1}{2} \cdot P_{Bolt}$$

Figure 4.11



Stress-related conditions:

The force diagrams for the various conditions are illustrated in the figures below. The line of fracture is also illustrated.

Condition 1 : $\frac{P_3}{(c - \frac{d}{2}) \cdot t}$

Tensile force in longitudinal direction next to bolt. See Figure 4.12

Load-bearing capacity $P_{Bolt} \leq 150 \text{ MPa} \cdot t \cdot d$

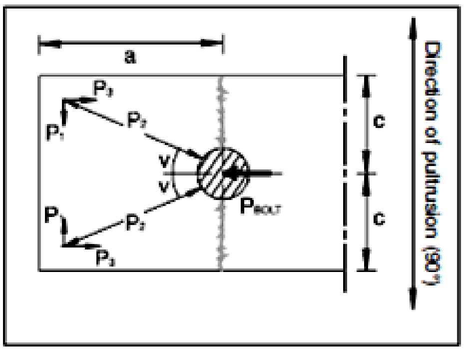


Figure 4.12

Condition 2 : $\frac{P_1}{b \cdot t}$

Cleavage in area in front of bolt. Fibre in 90° overloaded. See Figure 4.13

Load-bearing capacity $P_{Bolt} \leq 768 \text{ MPa} \cdot t \cdot d$

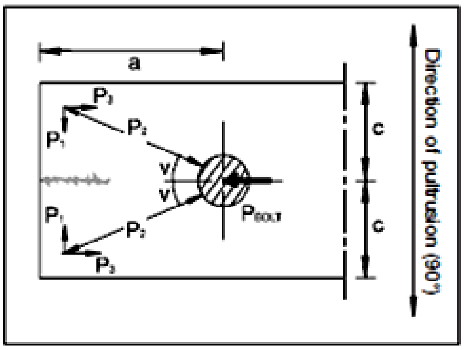


Figure 4.13

Condition 3 : $\frac{P_{Bolt}}{2 \cdot (a - \frac{d}{2}) \cdot t}$

Tearing of laminate in front of bolt. The strength of shear is exceeded in the illustrated lines of fracture. See Figure 4.14

Load-bearing capacity $P_{Bolt} \leq 100 \text{ MPa} \cdot t \cdot d$

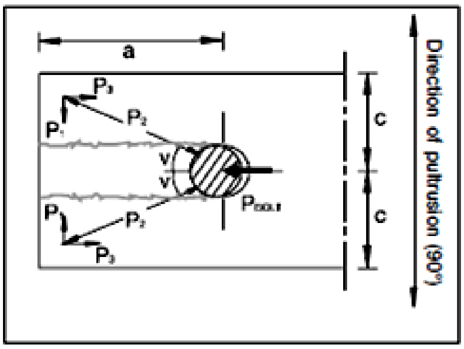


Figure 4.14

Condition 4 : $\frac{P_2}{d \cdot t}$

Inclined distribution in front of bolt. Compression stress in the inclined failure surface exceeds the compression strength.
See Figure 4.15

Load-bearing capacity

The following geometric parameters:

a = 2,5 · d
b = 1,0 · d
c = 2,0 · d

are to be put into the conditions listed above to find:

$P_{Bolt} \leq 145$ MPa · t · d

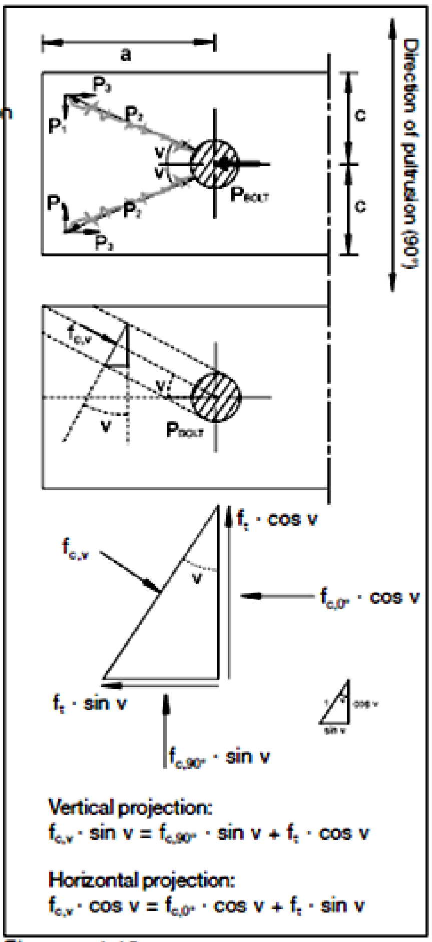


Figure 4.15
Strength $f_{c,v}$ in inclined forces

Condition 5 : $\frac{P_{Bolt}}{d \cdot t}$

Pressure deformation of laminate in front of bolt.

The contact compression between the bolt and laminate exceeds the pin-bearing strength, so the bolt 'eats' into the laminate.
See Figure 4.16.

Load-bearing capacity

$P_{Bolt} \leq 70$ MPa · t · d

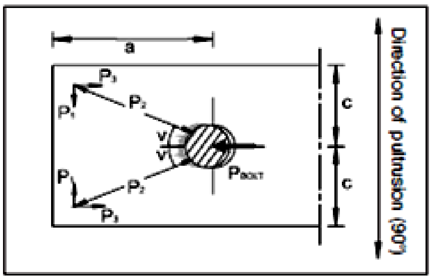


Figure 4.16