NOVATOP OPEN

Preliminary Design – Calculation Examples

The calculation examples complement the preliminary design tables included in the NOVATOP OPEN technical documentation. This document presents a detailed calculation for a load-bearing NOVATOP OPEN element, including an assessment carried out in accordance with ČSN EN 1995-1-1 + A1 + A2 (05/2015). Verification of ultimate and serviceability limit states is performed.

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Technical Documentation
NOVATOP OPEN

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CALCULATION EXAMPLES – VERTICAL

1. 1. GENERAL INFORMATION

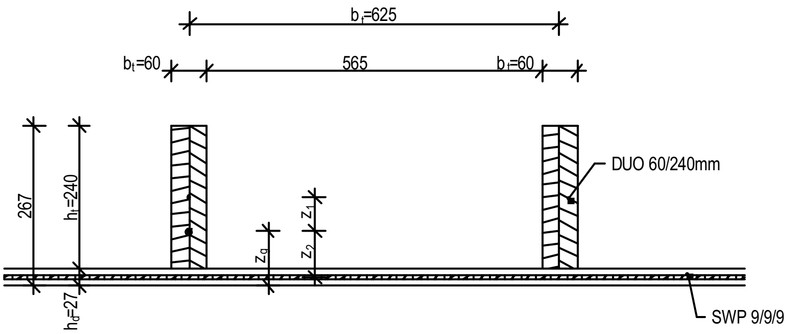
In the following document, a detailed calculation and assessment according to the standard ČSN EN 1995-1-1 + A1 + A2 (05/2015) is shown on the bearing element (the direction of the fibres of the surface layers of the boards are in the direction of the span). Assessment of limit states of load capacity and applicability is carried out.

2. 2. SYSTEM AND LOAD

2.1. Material

NOVATOP OPEN – bearing element – height of 267 mm
Bearing ribs – beams DUO 60 x 240 mm (bt x ht)
Rib pitch bf = 625 mm
Board on the bottom surface – SWP 9/9/9 – hd= 27 mm
Span of the simple beam L = 6.0 m
30° slope (girders in the slope direction)

Diagram of the panel thickness of 267 mm:



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Solid wood panel (SWP):

Property	---	The testing method	Class / Category of use / Numerical value [1]			
Panels with butted joints in the middle layers						
Mechanical behaviour in the plane of the SWP						
Composition of panels			6/15/6	9/9/9	9/15/9	9/42/9
Bending strength $f_{m,0}$	N/mm^2	ČSN EN 789	13,9	20,3	16,8	9,7
Bending strength $f_{m,90}$			8,6	5,3	7,1	10,7
Tensile strength $f_{t,0}$			9,3	13,6	11,2	6,5
Tensile strength $f_{t,90}$			5,7	3,6	4,7	7,1
Compression strength $f_{c,0}$			13,9	20,3	16,8	9,7
Compression strength $f_{c,90}$			8,6	5,3	7,1	10,7
Resistance to shear f_v			3,0	3,0	3,0	3,0
Modulus of elasticity $E_{m,0}$			5300	7800	6400	3700
Modulus of elasticity $E_{m,90}$			3300	2050	2700	4100
Shear modulus of elasticity G			600	600	600	600
Mechanical behaviour perpendicular to the plane of the SWP						
Bending strength $f_{m,0}$	N/mm^2	ČSN EN 789	25,0	28,9	27,3	20,1
Bending strength $f_{m,90}$			5,4	3,1	4,1	7,8
Modulus of elasticity $E_{m,0}$			9600	11100	10500	7700
Modulus of elasticity $E_{m,90}$			1150	400	710	2100
Shear modulus of elasticity G			90	90	90	90
Resistance to shear f_v			1,1	1,1	1,1	1,1
The glued joint between the rib and the flange						
Resistance to shear $f_{v, k, glue, KVH}$	N/mm^2	ETAG 019	1,10			
Resistance to shear $f_{v, k, glue, LVL}$			4,40			
Resistance to shear $f_{v, k, DUO, TRIO, I\text{-}nosníky}$			1,10			
Resistance to shear $f_{v, k, glue, BSH}$			3,50			

DUO girders:

		KVH	DUO-TRIO
Quality class		S10TS	S10TS
Strength class according to ČSN EN 1194: 1999		C24	C24
Characteristic values of strength in N/mm²			
Bending strength	$f_{m,k}$	24	24
Tensile strength parallel to the fibres	$f_{t,0,k}$	14	14
Tensile strength perpendicular to the fibres	$f_{t,90,k}$	0,5	0,4
Compressive strength parallel to the fibres	$f_{c,0,k}$	21	21
Compressive strength perpendicular to the fibres	$f_{c,90,k}$	2,5	2,5
Shear strength	$f_{v,k}$	2,5	2
Characteristic values of elasticity in kN/mm²			
The average value of the modulus of elasticity parallel to the fibre direction	$E_{0, mean}$	11	11,6
5% of quantiles of the modulus of elasticity parallel to the fibres	$E_{0,05}$	7,4	-
The average value of the modulus of elasticity perpendicular to the fibres	$E_{90, mean}$	0,37	0,37
The average value of the modulus of elasticity in shear	G_{mean}	0,69	0,69
Density in kg/m³			
Density	ρ_k	350	350

Cross-sectional characteristics:

Co-acting panel width $b_1 = \min (b_f; L/10) = 0{,}6 \text{ m} = 600 \text{ mm}$

Effective substitute cross-section:

$b_{eff} = (E_2/E_1) \cdot b_1 = (7800/11600) \times 0{,}6 = 0{,}403 \text{ m}$

$A_{t,eff} = 0{,}06 \times 0{,}24 = 0{,}0144 \text{ m}^2$

$A_{d,eff} = b_{eff} \times 0{,}027 = 0{,}010893 \text{ m}^2$

$z_g = (A_{t,eff} \times (h_d + h_t/2) + A_{d,eff} \times h_d/2) / (A_{t,eff} + A_{d,eff}) =$

$(0{,}0144 \times 0{,}147 + 0{,}010893 \times 0{,}0135) / (0{,}0144 + 0{,}010893) = 0{,}090 \text{ m}$

$z_1 = 0{,}057 \text{ m}$

$z_2 = 0{,}076 \text{ m}$

$$I_{y,eff} = \frac{1}{12} \times b_t \times h_t^3 + A_{t,eff} \times z_1^2 + \frac{1}{12} \times b_{eff} \times h_d^3 + A_{d,eff} \times z_2^2 =$$

$$\frac{1}{12} \times 0{,}06 \times 0{,}24^3 + 0{,}0144 \times 0{,}057^2 + \frac{1}{12} \times 0{,}403 \times 0{,}027^3 + 0{,}010893 \times 0{,}076^2 = 180{,}3 \times 10^{-6} \text{ m}^4$$

$$i_{y,eff} = \sqrt{\frac{I_{y,eff}}{A_{eff}}} = \sqrt{\frac{180{,}3 \times 10^{-6}}{0{,}0253}} = 0{,}084 \text{ m}$$

2.2. Load

Operation class	1
Dead load of the element	$g_1 = 0{,}25 \text{ kN/m}^2$
Other permanent load	$g_k = 1{,}00 \text{ kN/m}^2$
Imposed load	$g_k = 0{,}75 \text{ kN/m}^2$
Snow load	$s_k = 1{,}00 \text{ kN/m}^2$
Wind load (pressure)	$w_k = 0{,}25 \text{ kN/m}^2$
⇨	$k_{mod} = 0{,}9$
	$\Psi_2 = 0{,}60$

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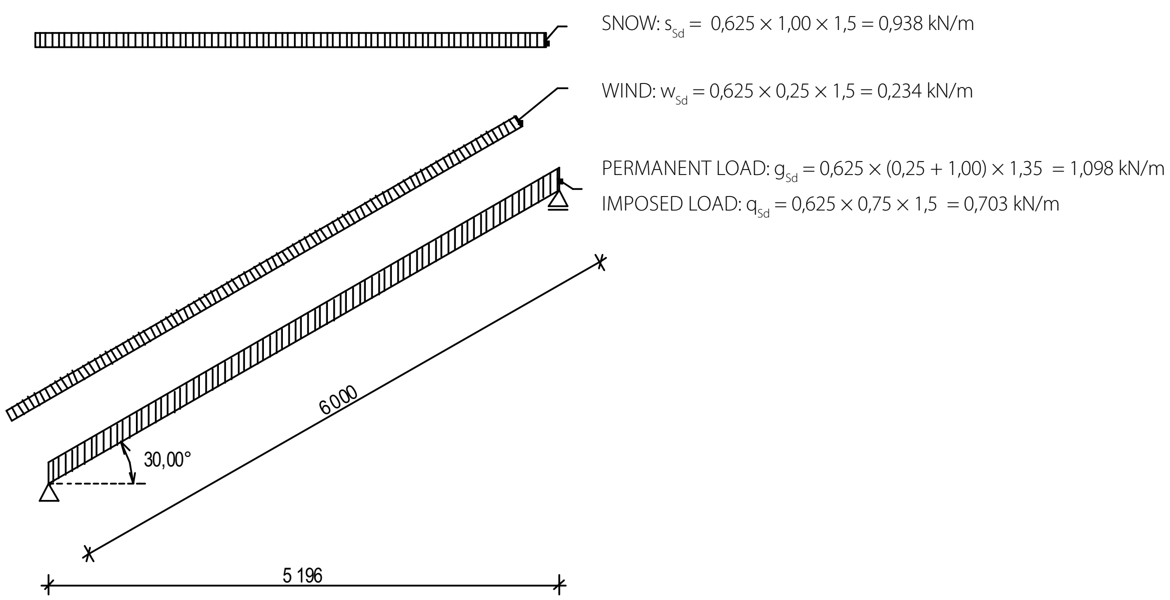
2.3. Assessment of limit states of load capacity
2.3.1 Static scheme

Load in the direction perpendicular to the plane of the element:



2.3.2 Maximum internal forces

The values of the maximum internal forces are calculated, for example, using suitable software for static analysis of structures, or by manual calculation:

$$M_{y,Sd} = \frac{1}{8} \times (g_{sd} + q_{sd}) \times L \times L_p + \frac{1}{8} \times s_{sd} \times Lp^2 + \frac{1}{8} \times w_{sd} \times L^2$$

$$= \frac{1}{8} \times (1{,}098 + 0{,}703) \times 6{,}0 \times 5{,}196 + \frac{1}{8} \times (0{,}938 \times 5{,}196^2) + \frac{1}{8} \times 0{,}234 \times 6{,}0^2 = 11{,}237 \text{ kNm}$$

$$V_{Sd} = \frac{1}{2} \times (g_{sd} + q_{sd}) \times L \times \cos 30° + \frac{1}{2} \times s_{sd} \times L_p \times \cos 30° + \frac{1}{2} \times w_{sd} \times L$$

$$= \frac{1}{2} \times (1{,}098 + 0{,}703) \times 6{,}0 \times \cos 30° + \frac{1}{2} \times 0{,}938 \times 5{,}196 \times \cos 30° + \frac{1}{2} \times 0{,}234 \times 6{,}0 = 7{,}492 \text{ kN}$$

$$N_{Sd} = (g_{sd} + q_{sd}) \times L \times \sin 30° - s_{sd} \times L_p \times \sin 30°$$

$$= -(1{,}098 + 0{,}703) \times 6{,}0 \times \sin 30° - 0{,}938 \times 5{,}196 \times \sin 30° = -7{,}840 \text{ kN}$$

(**Note:** this is pressure)

2.3.3 Assessment of bending stress in upper fibres under compression

$$W_{y,d} = \frac{I_{y,eff}}{((h_t + h_d) - z_g)} = \frac{180{,}3 \times 10^{-6}}{((0{,}24+0{,}027) - 0{,}090} = 1{,}019 \times 10^{-3}\ m^3$$

$$\sigma_{1,c} = \frac{M_{Sd}}{W_{y,h}} = \frac{11{,}237}{1{,}019 \times 10^{-3}} = 11027\ kPa$$

$$f_{c,0,d} = k_{mod} \times \frac{f_{c,0,k}}{\gamma_M} = 0{,}9 \times \frac{21000}{1{,}3} = 14538\ kPa$$

$$\frac{\sigma_{1,c}}{f_{c,0,d}} = \frac{11027}{14538} = 0{,}76 < 1{,}0$$

✓ SUITABLE

2.3.4 Assessment of bending stress in lower fibres under tension

$$W_{y,d} = \frac{I_{y,eff}}{z_g} = \frac{180{,}3 \times 10^{-6}}{0{,}090} = 2{,}003 \times 10^{-3}\ m^3$$

$$\sigma_{m,d} = \frac{M_{Sd}}{W_{y,d}} = \frac{11{,}237}{2{,}003 \times 10^{-3}} = 5610\ kPa$$

$$f_{m,y,0,d} = k_{mod} \times \frac{f_{m,y,0,d}}{\gamma_M} = 0{,}9 \times \frac{20300}{1{,}3} = 14054\ kPa$$

$$\frac{\sigma_{m,d}}{f_{m,y,0,d}} = \frac{5610}{14054} = 0{,}40 < 1{,}0$$

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2.3.5 Assessment of the combination of compressive and bending stresses (with the effect of the strut)

Note: A conservative cross-section of 60 x 267 mm is considered for the calculation of the strut perpendicular to the „z" axis

$$W_{y,min} = 1{,}019 \times 10^{-3}\ m^3$$

$$\sigma_{m,crit} = \frac{0{,}78 \times b^2}{h \times l_{ef}} \times E_{0,05} = \frac{0{,}78 \times 0{,}06^2}{0{,}267 \times 2{,}0} \times {}^{7}400000 = 38912\ kPa$$

$$\lambda_{rel,m} = \sqrt{\frac{f_{m,k}}{\sigma_{m,crit}}} = \sqrt{\frac{24000}{38912}} = 0{,}785\ m$$

$$k_{crit} = 1{,}56 - 0{,}75 \times \lambda_{rel,m} = 1{,}56 - 0{,}75 \times 0{,}785 = 0{,}97$$

$$\sigma_{m,d} = \frac{M_{Sd}}{W_{y,min}} = \frac{11{,}237}{1{,}019 \times 10^{-3}} = 11027\ kPa$$

Strut:

$$\lambda_y = \frac{L_{y,eff}}{i_{y,eff}} = \frac{6{,}0}{0{,}084} = 71{,}428$$

$$\lambda_z = \frac{L_{z,eff}}{i_z} = \frac{2{,}0}{(0{,}06/\sqrt{12})} = 115{,}5$$

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Buckling perpendicular to the „z" axis is decisive

$$\lambda_{rel,z} = \quad \times \sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{115,5}{\pi} \times \sqrt{\frac{21000}{7400000}} = 1,959$$

$$k_z = 0,5 \times (1 + \beta_c \times (\lambda_{rel,z} - 0,3) + \lambda_{rel,z}{}^2)$$
$$= 0,5 \times (1 + \beta_c \times (1,959 - 0,3) + 1,959^2) = 2,584$$

$$k_{c,z} = \frac{1}{k_z + \sqrt{k_z{}^2 - \lambda_{rel,z}{}^2}} = \frac{1}{2,584 + \sqrt{2,584^2 - 1,959^2}} = 0,234$$

$$\sigma_{c,0,d} = \frac{N_{Sd}}{A_c} = \frac{7,840}{0,267 \times 0,06} = 489,4 \text{ kPa}$$

$$\left(\frac{\sigma_{m,d}}{k_{crit} \times f_{m,y,d}}\right)^2 + \frac{\sigma_{c,0,d}}{k_{c,y} \times f_{c,0,d}} = \left(\frac{11027}{0,97 \times 14054}\right)^2 + \frac{489,4}{0,234 \times 14538} = 0,798$$

✓ SUITABLE

2.3.6 Assessment of tensile stress in the centre of gravity of the bottom panel

$$W_{y,2} = \frac{I_{y,eff}}{z_2} = \frac{180,3 \times 10^{-6}}{0,076} = 2,372 \times 10^{-3} \text{ m}^3$$

$$\sigma_{m,2,d} = \frac{M_{y,Sd}}{W_{y,2}} = \frac{11,237}{2,372 \times 10^{-3}} = 4737 \text{ kPa}$$

$$f_{t,0,d} = k_{mod} \times \frac{f_{t,0,k}}{\gamma_M} = 0,9 \times \frac{13600}{1,3} = 9415 \text{ kPa}$$

$$\frac{\sigma_{m,2,d}}{f_{t,0,d}} = \frac{4737}{9415} = 0,50 < 1,0$$

✓ SUITABLE

2.3.7 Assessment of shear stress in the centre of gravity of the cross-section

$$S_1 = b_{eff} \times h_d \times z_2 + b_t \times (z_g - h_d)^2 \times 0,5$$
$$= 0,403 \times 0,027 \times 0,076 + 0,06 \times (0,090 - 0,027)^2 \times 0,5$$
$$= 9,460 \times 10^{-4} \text{ m}^3$$

$$\tau_{v,d} = \frac{V_{S,d} \times S_1}{I_{eff} \times k_{cr} \times b_t} = \frac{7,492 \times 9,460 \times 10^{-4}}{180,3 \times 10^{-6} \times 0,67 \times 0,06} = 977,8 \text{ kPa}$$

$$f_{v,d} = k_{mod} \times \frac{f_{v,k}}{\gamma_M} = 0,9 \times \frac{2000}{1,3} = 1385 \text{ kPa}$$

$$\frac{\tau_{v,d}}{f_{v,d}} = \frac{977,8}{1385} = 0,71 < 1,0$$

✓ SUITABLE

2.3.8 Assessment of shear stress in the panel at the glued joint

Note: Failure mode 1 in shear according to ETA-11/0310. Failure of surface lamellas adjacent to the glued joint in the shear is expected.

$$S_2 = b_{eff} \times h_d \times (z_g - h_d \times 0{,}5) = 0{,}403 \times 0{,}027 \times (0{,}090 - 0{,}027 \times 0{,}5) = 8{,}279 \times 10^{-4}\ m^3$$

$$\tau_{v,d,2} = \frac{V_{S,d} \times S_2}{I_{eff} \times t_2} = \frac{7{,}492 \times 8{,}279 \times 10^{-4}}{180{,}3 \times 10^{-6} \times 2 \times 0{,}009} = 1911{,}2\ kPa$$

$$f_{v,d,2} = k_{mod} \times \frac{f_{v,k,2}}{\gamma_M} = 0{,}9 \times \frac{3000}{1{,}3} = 2076{,}92\ kPa$$

$$\frac{\tau_{v,d,2}}{f_{v,d,2}} = \frac{1911{,}2}{2076{,}92} = 0{,}92 < 1{,}0$$

✓ SUITABLE

2.3.9 Assessment of shear stress at the glued joint

Note: Failure mode 2 in shear according to ETA-11/0310.

$$S_2 = b_{eff} \times h_d \times (z_g - h_d \times 0{,}5) = 0{,}403 \times 0{,}027 \times (0{,}090 - 0{,}027 \times 0{,}5) = 8{,}279 \times 10^{-4}\ m^3$$

$$\tau_{v,d,3} = \frac{V_{S,d} \times S_2}{I_{eff} \times b_t} = \frac{7{,}492 \times 8{,}279 \times 10^{-4}}{180{,}3 \times 10^{-6} \times 0{,}06} = 573{,}36\ kPa$$

$$f_{v,d,glue} = k_{mod} \times \frac{f_{v,k,glue}}{\gamma_M} = 0{,}9 \times \frac{1100}{1{,}3} = 761{,}54\ kPa$$

$$\frac{\tau_{v,d,3}}{f_{v,d,glue}} = \frac{573{,}36}{761{,}54} = 0{,}75 < 1{,}0$$

✓ SUITABLE

2.4 Assessment of applicability limit states

2.4.1 Flexible immediate deflection (characteristic combination)

Proportion of the bend:

$$w_{m,g,inst} = \frac{5}{384} \times \frac{g_{s,k} \times L^4}{E \times I_{eff}} = \frac{5}{384} \times \frac{0{,}781 \times 6{,}0^4}{11600000 \times 180{,}3 \times 10^{-6}} = 0{,}0063\ m$$

$$w_{m,q,inst} = \frac{5}{384} \times \frac{q_{s,k} \times L^4}{E \times I_{eff}} = \frac{5}{384} \times \frac{0{,}469 \times 6{,}0^4}{11600000 \times 180{,}3 \times 10^{-6}} = 0{,}0038\ m$$

$$w_{m,s,inst} = \frac{5}{384} \times \frac{s_{s,k} \times L^4}{E \times I_{eff}} = \frac{5}{384} \times \frac{0{,}625 \times 6{,}0^4}{11600000 \times 180{,}3 \times 10^{-6}} = 0{,}0050\ m$$

$$w_{m,w,inst} = \frac{5}{384} \times \frac{w_{s,k} \times L^4}{E \times I_{eff}} = \frac{5}{384} \times \frac{0{,}156 \times 6{,}0^4}{11600000 \times 180{,}3 \times 10^{-6}} = 0{,}0013\ m$$

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Proportion of the shear:

$$w_{v,g,inst} = \frac{1}{8} \times \frac{g_{s,k} \times L^2}{G \times A} = \frac{1}{8} \times \frac{0{,}781 \times 6{,}0^2}{690000 \times 0{,}0144} = 0{,}0004 \text{ m}$$

$$w_{v,q,inst} = \frac{1}{8} \times \frac{q_{s,k} \times L^2}{G \times A} = \frac{1}{8} \times \frac{0{,}469 \times 6{,}0^2}{690000 \times 0{,}0144} = 0{,}0002 \text{ m}$$

$$w_{v,s,inst} = \frac{1}{8} \times \frac{s_{s,k} \times L^2}{G \times A} = \frac{1}{8} \times \frac{0{,}625 \times 6{,}0^2}{690000 \times 0{,}0144} = 0{,}0003 \text{ m}$$

$$w_{v,w,inst} = \frac{1}{8} \times \frac{q_{w,k} \times L^2}{G \times A} = \frac{1}{8} \times \frac{0{,}156 \times 6{,}0^2}{690000 \times 0{,}0144} = 0{,}0001 \text{ m}$$

Immediate deflection from permanent load::

$$W_{g,inst} = W_{m,g,inst} + W_{v,g,inst} = 0{,}0063 + 0{,}0004 = 0{,}0067 \text{ m}$$

Immediate deflection from imposed load:

$$W_{q,inst} = W_{m,q,inst} + W_{v,q,inst} = 0{,}0038 + 0{,}0002 = 0{,}0040 \text{ m}$$

Immediate deflection from snow:

$$W_{s,inst} = W_{m,s,inst} + W_{v,s,inst} = 0{,}0050 + 0{,}0003 = 0{,}0053 \text{ m}$$

Immediate deflection from wind:

$$W_{w,inst} = W_{m,w,inst} + W_{v,w,inst} = 0{,}0013 + 0{,}0001 = 0{,}0014 \text{ m}$$

Flexible immediate deflection (characteristic combination):

$$W_{inst} = W_{g,inst} + W_{q,inst} + W_{s,inst} + W_{w,inst} = 0{,}0067 + 0{,}0040 + 0{,}0053 + 0{,}0014 = 0{,}0174 \text{ m}$$

2.4.2 Final deflection (quasi-stable combination)

$$W_{fin} = W_{g,inst} \times (1 + k_{def}) + W_{q,inst} \times (1 + \psi_{2,1} \times k_{def}) + W_{s,inst} \times (1 + \psi_{2,2} \times k_{def}) + W_{w,inst} \times (1 + \psi_{2,3} \times k_{def}) =$$

$$0{,}0067 \times (1 + 0{,}6) + 0{,}0040 \times (1 + 0 \times 0{,}6) + 0{,}0053 \times (1 + 0 \times 0{,}6) + 0{,}0014 \times (1 + 0 \times 0{,}6) = 0{,}0214 \text{ m}$$

2.4.3 Check of recommended values

$$W_{inst} = 0{,}0174 \text{ m} > \frac{L}{300} = \frac{6}{300} = 20{,}0 \rightarrow$$ ✓ SUITABLE

$$W_{fin} = 0{,}0214 \text{ m} > \frac{L}{250} = \frac{6}{250} = 24{,}0 \rightarrow$$ ✓ SUITABLE

Conclusion: A girder with a span of 6.0 m is sufficient for the expected load. This combination is not shown in the preliminary design tables, as the tables simply consider all variable loads in one (most unfavourable) direction. So the aforementioned calculation is more accurate.

1. GENERAL INFORMATION

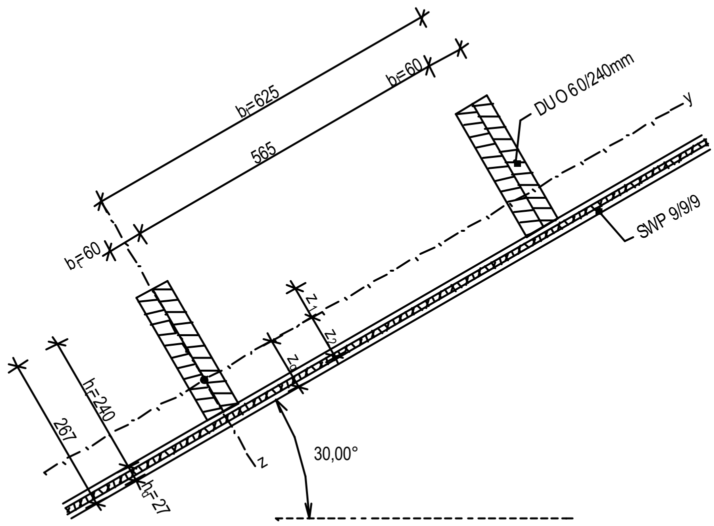
In the following document, a detailed calculation and assessment according to the standard ČSN EN 1995-1-1 + A1 + A2 (05/2015) is shown on the bearing element (the direction of the fibres of the surface layers of the boards are in the direction of the span). Assessment of limit states of load capacity and applicability is carried out.

2. SYSTEM AND LOAD

2.1. Material

NOVATOP OPEN – bearing element – height of 267 mm
Bearing ribs – beams DUO 60 x 240 mm (bt x ht)
Rib pitch bf= 625 mm
Board on the bottom surface – SWP 9/9/9 – hd= 27 mm
Span of the simple beam L = 6.0 m
30° slope (girders in the slope direction)

Diagram of the panel thickness of 267 mm:



NOVATOP OPEN
CALCULATION EXAMPLES – HORIZONTAL

Solid wood panel (SWP):

Property	---	The testing method	Class / Category of use / Numerical value [1]			
Panels with butted joints in the middle layers						
Mechanical behaviour in the plane of the SWP						
Composition of panels			6/15/6	9/9/9	9/15/9	9/42/9
Bending strength $f_{m,0}$	N/mm^2	ČSN EN 789	13,9	20,3	16,8	9,7
Bending strength $f_{m,90}$			8,6	5,3	7,1	10,7
Tensile strength $f_{t,0}$			9,3	13,6	11,2	6,5
Tensile strength $f_{t,90}$			5,7	3,6	4,7	7,1
Tensile strength $f_{c,0}$			13,9	20,3	16,8	9,7
Tensile strength $f_{c,90}$			8,6	5,3	7,1	10,7
Resistance to shear f_v			3,0	3,0	3,0	3,0
Modulus of elasticity $E_{m,0}$			5300	7800	6400	3700
Modulus of elasticity $E_{m,90}$			3300	2050	2700	4100
Shear modulus of elasticity G			600	600	600	600
Mechanical behaviour perpendicular to the plane of the SWP						
Bending strength $f_{m,0}$	N/mm^2	ČSN EN 789	25,0	28,9	27,3	20,1
Bending strength $f_{m,90}$			5,4	3,1	4,1	7,8
Modulus of elasticity $E_{m,0}$			9600	11100	10500	7700
Modulus of elasticity $E_{m,90}$			1150	400	710	2100
Shear modulus of elasticity G			90	90	90	90
Resistance to shear f_v			1,1	1,1	1,1	1,1
The glued joint between the rib and the flange						
Resistance to shear $f_{v, k, glue, KVH}$	N/mm^2	ETAG 019	1,10			
Resistance to shear $f_{v, k, glue, LVL}$			4,40			
Resistance to shear $f_{v, k, DUO, TRIO, I\text{-}nosníky}$			1,10			
Resistance to shear $f_{v, k, glue, BSH}$			3,50			

DUO girders:

		KVH	DUO-TRIO
Quality class		S10TS	S10TS
Strength class according to ČSN EN 1194: 1999		C24	C24
Characteristic values of strength in N/mm²			
Bending strength	$f_{m,k}$	24	24
Tensile strength parallel to the fibres	$f_{t,0,k}$	14	14
Tensile strength parallel to the fibres	$f_{t,90,k}$	0,5	0,4
Compressive strength parallel to the fibres	$f_{c,0,k}$	21	21
Compressive strength perpendicular to the fibres	$f_{c,90,k}$	2,5	2,5
Shear strength	$f_{v,k}$	2,5	2
Characteristic values of elasticity in kN/mm²			
The average value of the modulus of elasticity parallel to the fibre direction	$E_{0,\,mean}$	11	11,6
5% of quantiles of the modulus of elasticity parallel to the fibres	$E_{0,05}$	7,4	-
The average value of the modulus of elasticity perpendicular to the fibres	$E_{90,\,mean}$	0,37	0,37
The average value of the modulus of elasticity in shear	G_{mean}	0,69	0,69
Density in kg/m³			
Density	ρ_k	350	350

Cross-sectional characteristics:

Co-acting panel width $b_1 = \min(b_f; L/10) = 0{,}6\ m = 600\ mm$

Effective substitute cross-section:

$b_{eff} = (E_2/E_1) \cdot b_1 = (7800/11600) \times 0{,}6 = 0{,}403\ m$

$A_{t,eff} = 0{,}06 \times 0{,}24 = 0{,}0144\ m^2$

$A_{d,eff} = b_{eff} \times 0{,}027 = 0{,}010893\ m^2$

$z_g = (A_{t,eff} \times (h_d + h_t/2) + A_{d,eff} \times h_d/2) / (A_{t,eff} + A_{d,eff}) =$

$(0{,}0144 \times 0{,}147 + 0{,}010893 \times 0{,}0135) / (0{,}0144 + 0{,}010893) = 0{,}090\ m$

$z_1 = 0{,}057\ m$

$z_2 = 0{,}076\ m$

$$i_{y,eff} = \sqrt{\frac{I_{y,eff}}{A_{eff}}} = \sqrt{\frac{180{,}3 \times 10^{-6}}{0{,}0253}} = 0{,}084\ m$$

$$I_{y,eff} = \frac{1}{12} \times h_t \times b_t^3 + \frac{1}{12} \times h_d \times b_{eff}^3 = \frac{1}{12} \times 0{,}24 \times 0{,}06 + \frac{1}{12} \times 0{,}027 \times 0{,}403^3 = 151{,}6 \times 10^{-6}\ m^4$$

$$I_{z,eff} = \sqrt{\frac{I_{z,eff}}{A_{eff}}} = \sqrt{\frac{151{,}6 \times 10^{-6}}{0{,}0253}} = 0{,}077\ m$$

2.2. Load

Operation class	1
Dead load of the element	$g_1 = 0{,}25\ kN/m^2$
Other permanent load	$g_k = 1{,}00\ kN/m^2$
Imposed load	$g_k = 0{,}75\ kN/m^2$
Snow load	$s_k = 1{,}00\ kN/m^2$
Wind load (pressure)	$w_k = 0{,}25\ kN/m^2$
⇨	$k_{mod} = 0{,}9$
	$\Psi_2 = 0{,}60$

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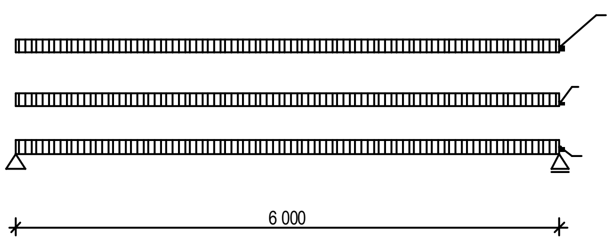
The element is rotated by 30°, so the load is distributed as follows:

- Dead load of the element, other permanent load, imposed load – load width of 625 mm, distributed in the direction perpendicular to the plane of the element and parallel to the plane of the element
- Snow load – load width of 625mm*cos 30° = 541 mm, distributed in the direction perpendicular to the plane of the element and parallel to the plane of the element
- Wind load – load width of 625mm, acts only in the direction perpendicular to the plane of the element

2.3. Assessment of limit states of load capacity
2.3.1 Static scheme

Load in the direction perpendicular to the plane of the element:



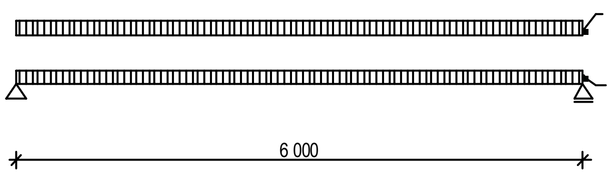
WIND: $w_{Sd} = 0{,}625 \times 0{,}25 \times 1{,}5 = 0{,}234$ kN/m

SNOW: $s_{Sd} = 0{,}541 \times 1{,}00 \times 1{,}5 \times \cos 30° = 0{,}703$ kN/m

PERMANENT LOAD: $g_{Sd} = 0{,}625 \times (0{,}25 + 1{,}00) \times 1{,}35 \times \cos 30° = 0{,}913$ kN/m

IMPOSED LOAD: $q_{Sd} = 0{,}625 \times 0{,}75 \times 1{,}5 \times \cos 30° = 0{,}609$ kN/m

Load in the direction of the plane of the element:



SNOW: $s_{Sd} = 0{,}541 \times 1{,}00 \times 1{,}5 \times \sin 30° = 0{,}406$ kN/m

PERMANENT LOAD: $g_{Sd} = 0{,}625 \times (0{,}25 + 1{,}00) \times 1{,}35 \times \sin 30° = 0{,}527$ kN/m

IMPOSED LOAD: $q_{Sd} = 0{,}625\ 0{,}75 \times 1{,}5 \times \sin 30° = 0{,}352$ kN/m

2.3.2 Maximum internal forces

The values of the maximum internal forces are calculated, for example, using suitable software for static analysis of structures, or by manual calculation:

$$M_{y,Sd} = \frac{1}{8} \times f_{yd} \times L^2 = \frac{1}{8} \times 2{,}459 \times 6{,}0^2 = 11{,}066 \text{ kNm}$$

$$V_{y,Sd} = \frac{1}{2} \times f_{yd} \times L = \frac{1}{2} \times 2{,}459 \times 6{,}0 = 7{,}377 \text{ kNm}$$

$$M_{z,Sd} = \frac{1}{8} \times f_{zd} \times L^2 = \frac{1}{8} \times 1{,}285 \times 6{,}0^2 = 5{,}783 \text{ kNm}$$

$$V_{z,Sd} = \frac{1}{2} \times f_{zd} \times L = \frac{1}{2} \times 1{,}285 \times 6{,}0 = 3{,}855 \text{ kNm}$$

2.3.3 Assessment of bending stress in lower fibres under tension – perpendicular to the plane of the element

$$W_{y,d} = \frac{I_{y,eff}}{z_g} = \frac{180{,}3 \times 10^{-6}}{0{,}090} = 2{,}003 \times 10^{-3}\ m^3$$

$$\sigma_{m,y,d} = \frac{M_{y,Sd}}{W_{y,d}} = \frac{11{,}066}{2{,}003 \times 10^{-3}} = 5525\ kPa$$

$$f_{m,y,0,d} = k_{mod} \times \frac{f_{m,y,0,d}}{\gamma_M} = 0{,}9 \times \frac{20300}{1{,}3} = 14054\ kPa$$

$$\frac{\sigma_{m,y,d}}{f_{m,y,0,d}} = \frac{5525}{14054} = 0{,}39 < 1{,}0$$

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2.3.4 Assessment of bending stress in lower fibres under tension – perpendicular to the plane of the element (with the effects of stability)

Distance of transverse struts – $L_{vz} = 2{,}0$ m
$W_{y,d} = 2{,}003 \times 10^{-3}\ m^3$

$$\sigma_{m,crit} = \frac{0{,}78 \times b^2}{h \times l_{ef}} \times E_{0,05} = \frac{0{,}78 \times 0{,}06^2}{0{,}267 \times 2{,}0} \times 7400000 = 38912\ kPa$$

$$\lambda_{rel,m} = \sqrt{\frac{f_{m,k}}{\sigma_{m,ctit}}} = \sqrt{\frac{2400}{38912}} = 0{,}785$$

$$k_{crit} = 1{,}56 - 0{,}75 \times \lambda_{rel,m} = 1{,}56 - 0{,}75 \times 0{,}785 = 0{,}97$$

$$\sigma_{m,y,d} = \frac{M_{y,Sd}}{W_{y,d}} = \frac{11{,}066}{2{,}003 \times 10^{-3}} = 5525\ kPa$$

$$f_{m,y,0,d} = k_{mod} \times \frac{f_{m,y,0,k}}{\gamma_M} = 0{,}9 \times \frac{20300}{1{,}3} = 14054\ kPa$$

$$\frac{\sigma_{m,y,d}}{k_{crit} \times f_{m,y,,d}} = \frac{5525}{0{,}97 \times 14054} = 0{,}41$$

2.3.5 Assessment of bending stress in lower fibres under tension – parallel to the plane of the element

$$W_{z,d} = \frac{I_{y,eff}}{b_{eff} / 2} = \frac{151{,}6 \times 10^{-6}}{0{,}202} = 7{,}523 \times 10^{-4}\ m^3$$

$$\sigma_{m,z,d} = \frac{M_{z,Sd}}{W_{z,d}} = \frac{5{,}783}{7{,}523 \times 10^{-4}} = 7687{,}1\ kPa$$

$$f_{m,z,0,d} = k_{mod} \times \frac{f_{m,z,0,k}}{\gamma_M} = 0{,}9 \times \frac{20300}{1{,}3} = 14054\ kPa$$

$$\frac{\sigma_{m,z,d}}{f_{m,z,0,d}} = \frac{7687{,}1}{14054} = 0{,}55 < 1{,}0$$

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2.3.6 Assessment of bending stress – combination of both main directions

$$\frac{\sigma_{m,y,d}}{k_{crit} \times f_{m,y,d}} + k_m \frac{\sigma_{m,z,d}}{f_{m,z,d}} = \frac{5525}{0,97 \times 14054} + \frac{7687,1}{14054} = 0,94 < 1,0$$

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2.3.7 Assessment of tensile stress in the centre of gravity of the bottom panel

$$W_{y,2} = \frac{I_{y,eff}}{z_2} = \frac{180,3 \times 10^{-6}}{0,076} = 2,372 \times 10^{-3}\ m^3$$

$$\sigma_{m,2,d} = \frac{M_{y,Sd}}{W_{y,2}} = \frac{11,066}{2,372 \times 10^{-3}} = 4665,3\ kPa$$

$$f_{t,0,d} = k_{mod} \times \frac{f_{t,0,k}}{\gamma_M} = 0,9 \times \frac{13600}{1,3} = 9415\ kPa$$

$$\frac{\sigma_{m,2,d}}{f_{t,0,d}} = \frac{4665,3}{9415} = 0,50 < 1,0$$

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2.3.8 Assessment of shear stress in the centre of gravity of the cross-section

$$S_y = b_{eff} \times h_d \times z_2 + b_t \times (z_g - h_d)^2 \times 0,5$$
$$= 0,403 \times 0,027 \times 0,076 + 0,06 \times (0,090 - 0,027)^2 \times 0,5$$
$$= 9,460 \times 10^{-4}\ m^3$$

$$\tau_{v,y,d} = \frac{V_{S,y,d} \times S_y}{I_{y,eff} \times k_{cr} \times b_t} = \frac{7,377 \times 9,460 \times 10^{-4}}{180,3 \times 10^{-6} \times 0,67 \times 0,06} = 962,8\ kPa$$

$$S_z = h_d \times \frac{b_{eff}}{2} \times \frac{b_{eff}}{4} + h_t \times \frac{b_t}{2} \times \frac{b_t}{4} = 0,027 \times 0,202 \times 0,101 + 0,24 \times 0,03 \times 0,015$$
$$= 6,561 \times 10^{-4}\ m^3$$

$$\tau_{v,z,d} = \frac{V_{S,z,d} \times S_z}{I_{z,eff} \times k_{cr} \times (h_{t+} h_d)} = \frac{3,855 \times 6,561 \times 10^{-4}}{151,6 \times 10^{-6} \times 0,67 \times 0,267} = 93,3\ kPa$$

$$f_{v,d} = k_{mod} \times \frac{f_{v,k}}{\gamma_M} = 0,9 \times \frac{2000}{1,3} = 1385\ kPa$$

$$\frac{\tau_{v,y,d}}{f_{v,d}} + \frac{\tau_{v,z,d}}{f_{v,d}} = \frac{962,8}{1385} + \frac{93,3}{1385} = 0,76 < 1,0$$

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2.3.9 Assessment of shear stress in the panel at the glued joint

Note: Failure mode 1 in shear according to ETA-11/0310. Failure of surface lamellas adjacent to the glued joint in the shear is expected.

$$S_2 = b_{eff} \times h_d \times (z_g - h_d \times 0{,}5) = 0{,}403 \times 0{,}027 \times (0{,}090 - 0{,}027 \times 0{,}5) = 8{,}279 \times 10^{-4}\ m^3$$

$$\tau_{v,d,2} = \frac{V_{S,d} \times S_2}{I_{eff} \times t_2} = \frac{7{,}377 \times 8{,}279 \times 10^{-4}}{180{,}3 \times 10^{-6} \times 2 \times 0{,}009} = 1881{,}9\ kPa$$

$$f_{v,d,2} = k_{mod} \times \frac{f_{v,k,2}}{\gamma_M} = 0{,}9 \times \frac{3000}{1{,}3} = 2076{,}92\ kPa$$

$$\frac{\tau_{v,d,2}}{f_{v,d,2}} = \frac{1881{,}9}{2076{,}92} = 0{,}91 < 1{,}0$$

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2.3.10 Assessment of shear stress at the glued joint

Note: Failure mode 2 in shear according to ETA-11/0310.

$$S_2 = b_{eff} \times h_d \times (z_g - h_d \times 0{,}5) = 0{,}403 \times 0{,}027 \times (0{,}090 - 0{,}027 \times 0{,}5) = 8{,}279 \times 10^{-4}\ m^3$$

$$\tau_{v,d,3} = \frac{V_{y,S,d} \times S_2}{I_{y,eff} \times b_t} + \frac{V_{z,S,d}}{b_t} = \frac{7{,}377 \times 8{,}279 \times 10^{-4}}{180{,}3 \times 10^{-6} \times 0{,}06} + \frac{3{,}855}{0{,}06} = 628{,}8\ kPa$$

$$f_{v,d,glue} = k_{mod} \times \frac{f_{v,k,glue}}{\gamma_M} = 0{,}9 \times \frac{1100}{1{,}3} = 761{,}54\ kPa$$

$$\frac{\tau_{v,d,3}}{f_{v,d,glue}} = \frac{628{,}8}{761{,}54} = 0{,}83 < 1{,}0$$

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2.4 Assessment of applicability limit states

(In a simplified manner, we consider the deflection perpendicular to the plane of the element. To calculate the deflection in global coordinates, we recommend using appropriate software)

2.4.1 Flexible immediate deflection (characteristic combination)

Proportion of the bend:

$$w_{m,g,inst} = \frac{5}{384} \times \frac{g_{s,k} \times L^4}{E \times I_{eff}} = \frac{5}{384} \times \frac{0{,}677 \times 6{,}0^4}{11600000 \times 180{,}3 \times 10^{-6}} = 0{,}0055\ m$$

$$w_{m,q,inst} = \frac{5}{384} \times \frac{q_{s,k} \times L^4}{E \times I_{eff}} = \frac{5}{384} \times \frac{0{,}406 \times 6{,}0^4}{11600000 \times 180{,}3 \times 10^{-6}} = 0{,}0033\ m$$

$$w_{m,s,inst} = \frac{5}{384} \times \frac{s_{s,k} \times L^4}{E \times I_{eff}} = \frac{5}{384} \times \frac{0{,}469 \times 6{,}0^4}{11600000 \times 180{,}3 \times 10^{-6}} = 0{,}0038\ m$$

$$w_{m,w,inst} = \frac{5}{384} \times \frac{w_{s,k} \times L^4}{E \times I_{eff}} = \frac{5}{384} \times \frac{0{,}156 \times 6{,}0^4}{11600000 \times 180{,}3 \times 10^{-6}} = 0{,}0013\ m$$

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Proportion of the shear:

$$w_{v,g,inst} = \frac{1}{8} \times \frac{g_{s,k} \times L^2}{G \times A} = \frac{1}{8} \times \frac{0{,}677 \times 6{,}0^2}{690000 \times 0{,}0144} = 0{,}0003 \text{ m}$$

$$w_{v,q,inst} = \frac{1}{8} \times \frac{q_{s,k} \times L^2}{G \times A} = \frac{1}{8} \times \frac{0{,}406 \times 6{,}0^2}{690000 \times 0{,}0144} = 0{,}0002 \text{ m}$$

$$w_{v,s,inst} = \frac{1}{8} \times \frac{s_{s,k} \times L^2}{G \times A} = \frac{1}{8} \times \frac{0{,}469 \times 6{,}0^2}{690000 \times 0{,}0144} = 0{,}0002 \text{ m}$$

$$w_{v,w,inst} = \frac{1}{8} \times \frac{q_{w,k} \times L^2}{G \times A} = \frac{1}{8} \times \frac{0{,}156 \times 6{,}0^2}{690000 \times 0{,}0144} = 0{,}0001 \text{ m}$$

Immediate deflection from permanent load:

$$W_{g,inst} = W_{m,g,inst} + W_{v,g,inst} = 0{,}0055 + 0{,}0003 = 0{,}0058 \text{ m}$$

Immediate deflection from imposed load:

$$W_{q,inst} = W_{m,q,inst} + W_{v,q,inst} = 0{,}0033 + 0{,}0002 = 0{,}0035 \text{ m}$$

Immediate deflection from snow:

$$W_{s,inst} = W_{m,s,inst} + W_{v,s,inst} = 0{,}0038 + 0{,}0002 = 0{,}0040 \text{ m}$$

Immediate deflection from wind:

$$W_{w,inst} = W_{m,w,inst} + W_{v,w,inst} = 0{,}0013 + 0{,}0001 = 0{,}0014 \text{ m}$$

Flexible immediate deflection (characteristic combination):

$$W_{inst} = W_{g,inst} + W_{q,inst} + W_{s,inst} + W_{w,inst} = 0{,}0058 + 0{,}0035 + 0{,}0040 + 0{,}0014 = 0{,}0147 \text{ m}$$

2.4.2 Final deflection (quasi-stable combination)

$$W_{fin} = W_{g,inst} \times (1 + k_{def}) + W_{q,inst} \times (1 + \psi_{2,1} \times k_{def}) + W_{s,inst} \times (1 + \psi_{2,2} \times k_{def}) + W_{w,inst} \times (1 + \psi_{2,3} \times k_{def}) =$$

$$0{,}0058 \times (1 + 0{,}6) + 0{,}0035 \times (1 + 0 \times 0{,}6) + 0{,}0040 \times (1 + 0 \times 0{,}6) + 0{,}0014 \times (1 + 0 \times 0{,}6) = 0{,}0182 \text{ m}$$

2.4.3 Check of recommended values

$$W_{inst} = 0{,}0147 \text{ m} > \frac{L}{300} = \frac{6}{300} = 20{,}0 \rightarrow$$ ✓ SUITABLE

$$W_{fin} = 0{,}0182 \text{ m} > \frac{L}{250} = \frac{6}{250} = 24{,}0 \rightarrow$$ ✓ SUITABLE

Conclusion: A girder with a span of 6.0 m is sufficient for the expected load.

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