1. Stiffening glass facade fin

Design and check glass facade fin see Fig. 1.1 in Ultimate limit state and Serviceability limit state. For the assessment, use the procedures in German DIN 18008-1 [1] and Australian Standard AS 1288 [2]. Consider only the wind load on the facade panels, which are semi-rigid glued joint attached to a glass fin.

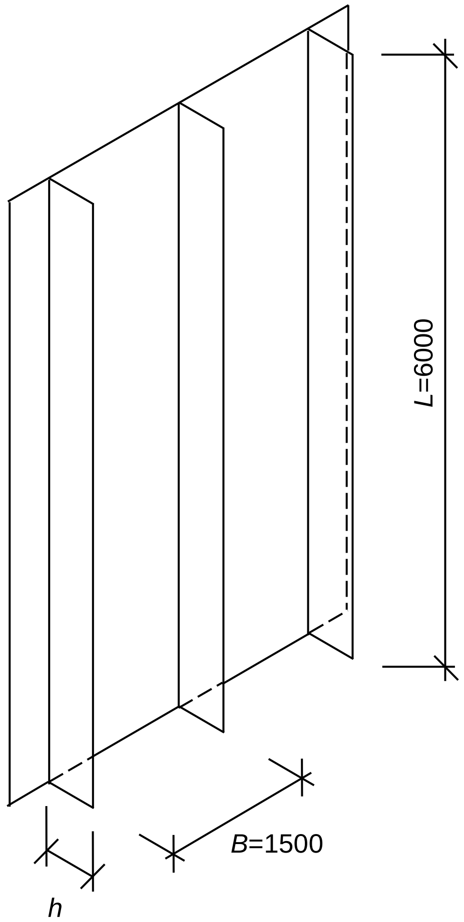

Fig. 1.1: Structure scheme

The fin is designed from 2 x 10 mm double-layer, heat-tempered glass with a PVB film of thickness. 0.76 mm see Fig. 1.2. The check is made for an accidental situation in which one of the panes is broken, i.e. in a static calculation, only one glass pane is considered. The fin simply supported on the upper and lower edges acts as a simple beam.

Fin length	L = 6000 mm
Distance between fins	B = 1500 mm
Pane thickness	t_1 = 10 mm
Fin thickness	$2 \cdot t_1 + 0{,}76 = 20{,}76$ mm
Fin depth	h

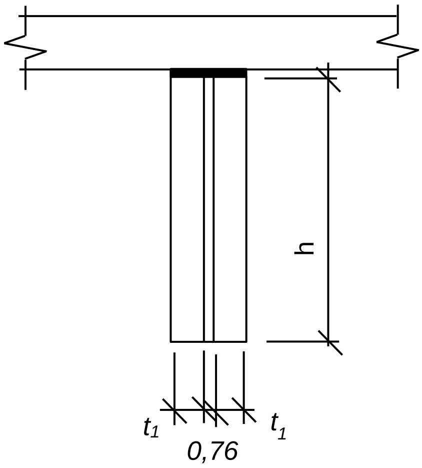

Fig. 1.2: Fin cross-section

1.1 Loading

The loading of the facade is assumed by wind load. Glass facade is located in the 2nd wind area and 4th terrain category according to EN 1991-1-4, [3]. Characteristic peak velocity pressure is $\boldsymbol{q_p(6\ m)}$ **= 0,46 kN/m²**. The external pressure coefficient for the windward face is (with solidity ratio φ = 1,0) $\boldsymbol{c_{pe,10,pressure}}$ **= 0,8**. The external pressure coefficient for the leeward face is $\boldsymbol{c_{pe,10,suction}}$ **= - 0,7**. Plane perpendicular wind load is therefore considered to be in a characteristic value for the pressure $\boldsymbol{w_{k,pressure}}$ **= 0,37 kN/m²** and for suction $\boldsymbol{w_{k,suction}}$ **= - 0,32 kN/m²**.

In addition to considered wind loads, self weight of the glass fin could be neglected.

Tab. 1.1: Combination of actions

Number	Designation	Limit state
KZ1	$\gamma_Q \cdot w_{k,pressure}$	ULS
KZ2	$\gamma_Q \cdot w_{k,suction}$	
KZ3	$\gamma_Q \cdot w_{k,pressure}$	SLS
KZ4	$\gamma_Q \cdot w_{k,suction}$	

1.2 Material characteristics of glass

The minimum characteristic strength of tempered soda-lime glass is according to EN 12150-1, [4] $\boldsymbol{f_{b,k}}$ **= 120 N/mm²**. Standard EN 572-1, [5] sets Young's modulus of elasticity as ***E* = 70 GPa**. The shear modulus is then determined as:

$$G = \frac{E}{2 \cdot (1+\nu)} = \frac{70}{2 \cdot (1+0{,}23)} = 28{,}46 \cdot 10^3\ MPa$$

where ν is Poisson´s ratio.

The glass design strength determination was established according to the procedure in DIN 18008-1, [1]:

$$f_{b,d} = \frac{k_{mod} \cdot k_c \cdot f_{b,k}}{\gamma_M} = \frac{1 \cdot 1 \cdot 120}{1{,}5} = 80\ MPa$$

where $f_{b,d}$ is design bending strength;

$f_{b,k}$ characteristic bending strength;

γ_M partial factors for material properties (for tempered glass γ_M = 1,5);

k_{mod} modification factor (for tempered glass is not considered);

k_c construction factor (k_c = 1,0).

1.3 Ultimate limit state

The distance between fins equals to the load width of one fin and is assumed as ***B* = 1,5 m**, see Fig. 1.1.

Characteristic value of wind load for pressure and suction:

$$q_{k,pressure} = B \cdot w_k = 1{,}5 \cdot 0{,}36 = 0{,}540\ kN/m$$

$$q_{k,suction} = B \cdot w_k = 1{,}5 \cdot 0{,}32 = 0{,}480\ kN/m$$

where q_k is characteristic value of wind load;

w_k plane wind load;

B load width.

Design load values:

$$q_{d,pressure} = \gamma_Q \cdot q_{k,pressure} = 1{,}5 \cdot 0{,}540 = 0{,}810\ kN/m$$

$$q_{d,suction} = \gamma_Q \cdot q_{k,suction} = 1{,}5 \cdot 0{,}480 = 0{,}720\ kN/m$$

where q_d is design wind load;

γ_Q partial load factor for variable load ($\gamma_Q = 1{,}5$).

Internal forces for pressure:

$$M_{Ed,pressure} = \frac{1}{8} \cdot q_{d,pressure} \cdot L^2 = \frac{1}{8} \cdot 0{,}810 \cdot 6000^2 = 3{,}65\ \cdot 10^6\ Nmm = 3{,}65\ kNm$$

$$V_{Ed,pressure} = \frac{1}{2} \cdot q_{d,pressure} \cdot L = \frac{1}{2} \cdot 0{,}810 \cdot 6000 = 2{,}43 \cdot 10^3\ N = 2{,}43\ kN$$

and for suction:

$$M_{Ed,suction} = \frac{1}{8} \cdot q_{d,suction} \cdot L^2 = \frac{1}{8} \cdot 0{,}720 \cdot 6000^2 = 3{,}24\ \cdot 10^6\ Nmm = 3{,}24\ kNm$$

$$V_{Ed,suction} = \frac{1}{2} \cdot q_{d,suction} \cdot L = \frac{1}{2} \cdot 0{,}720 \cdot 6000 = 2{,}16\ \cdot 10^3\ N = 2{,}16\ kN$$

o design the depth of the fin *h*, we will use the conditions for the ultimate limit state:

$$M_{Ed} \leq M_{Rd} = W_y \cdot \frac{f_{b,k}}{\gamma_M}$$

where M_{Ed} is bending moment caused by load;

W_y section modulus with respect to y axis;

M_{Rd} design bending resistance.

Section modulus for rectangular crosssection is calculated as:

$$W_y = \frac{1}{6} \cdot t_1 \cdot h^2$$

where t_1 is pane thickness;

h fin depth.

By numerical substitution into these upper formulas we can obtain the minimal fin height fullfilling the ULS condition. For M_{Ed} we consider higher bending moment from both loading cases. In this case, wind pressure is considered:

$$h \geq \sqrt{\frac{6 \cdot M_{Ed} \cdot \gamma_M}{f_{b,k} \cdot t}} = \sqrt{\frac{6 \cdot 3{,}55 \cdot 10^6 \cdot 1{,}5}{120 \cdot 10}} = 163\ mm$$

Chosen dimensions:

$$t_1 = 10\ mm \qquad h = 200\ mm$$

Calculation of cross-sectional characteristics for this slim rectangular cross-section:

$$I_y = \frac{1}{12} \cdot t_1 \cdot h^3 = \frac{1}{12} \cdot 10 \cdot 200^3 = 6{,}67 \cdot 10^6 \; mm^4$$

$$I_z = \frac{1}{12} \cdot h \cdot {t_1}^3 = \frac{1}{12} \cdot 200 \cdot 10^3 = 1{,}67 \cdot 10^4 \; mm^4$$

$$I_k = \frac{1}{3} \cdot h \cdot {t_1}^3 \cdot \left(1 - 0{,}63 \cdot \frac{t_1}{h}\right) = \frac{1}{3} \cdot 200 \cdot 10^3 \cdot \left(1 - 0{,}63 \cdot \frac{10}{200}\right) = 6{,}46 \cdot 10^4 \; mm^4$$

where I_y is moment of inertia with respect to y axis;

I_z moment of inertia with respect to z axis;

I_k torsional moment of inertia.

The fin is connected to the glass facade panels by semi-rigid glued joint, which prevents lateral displacement of the beam and reduces the critical moment. The calculation of the critical torque M_{cr} for the fin, which is elastically supported at the load point, is carried out in accordance with AS 1288, [2] as:

$$M_{cr} = \frac{\pi^2}{L^2} \cdot \frac{\left[E \cdot I_z \cdot \left(\frac{h^2}{12} + {c_z}^2\right) + G \cdot I_k\right]}{2 \cdot c_z + z_a}$$

where M_{cr} is critical buckling moment;

c_z distance between the gravity center and the lateral restraint, see Fig. 1.4;

z_a location of the loading point regarding the gravity center, see Fig. 1.4;

$$M_{cr,suction} = \frac{\pi^2}{6000^2} \cdot \frac{\left[70 \cdot 10^3 \cdot 1{,}67 \cdot 10^4 \cdot \left(\frac{200^2}{12} + 100^2\right) + 28{,}46 \cdot 10^3 \cdot 6{,}46 \cdot 10^4\right]}{2 \cdot 100 + 100} = 6{,}14 \cdot 10^6 \; Nmm$$

$$M_{cr,suction} = 6{,}14 \; kNm$$

$$M_{cr,pressure} = \frac{\pi^2}{6000^2} \cdot \frac{\left[70 \cdot 10^3 \cdot 1{,}67 \cdot 10^4 \cdot \left(\frac{200^2}{12} + 100^2\right) + 28{,}46 \cdot 10^3 \cdot 6{,}46 \cdot 10^4\right]}{2 \cdot 100 - 100} = 18{,}57 \cdot 10^6 \; Nmm$$

$$M_{cr,pressure} = 18{,}57 \; kNm$$

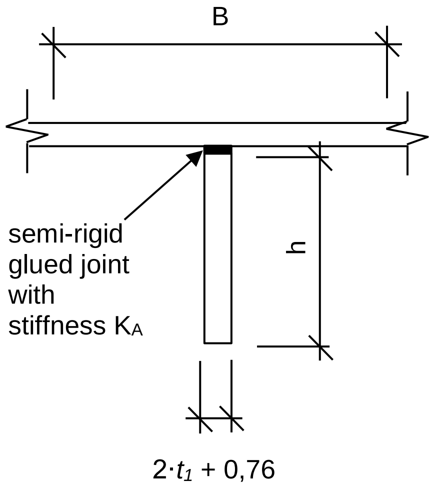

Fig. 1.3: Semi-rigid connection of the fin to the facade

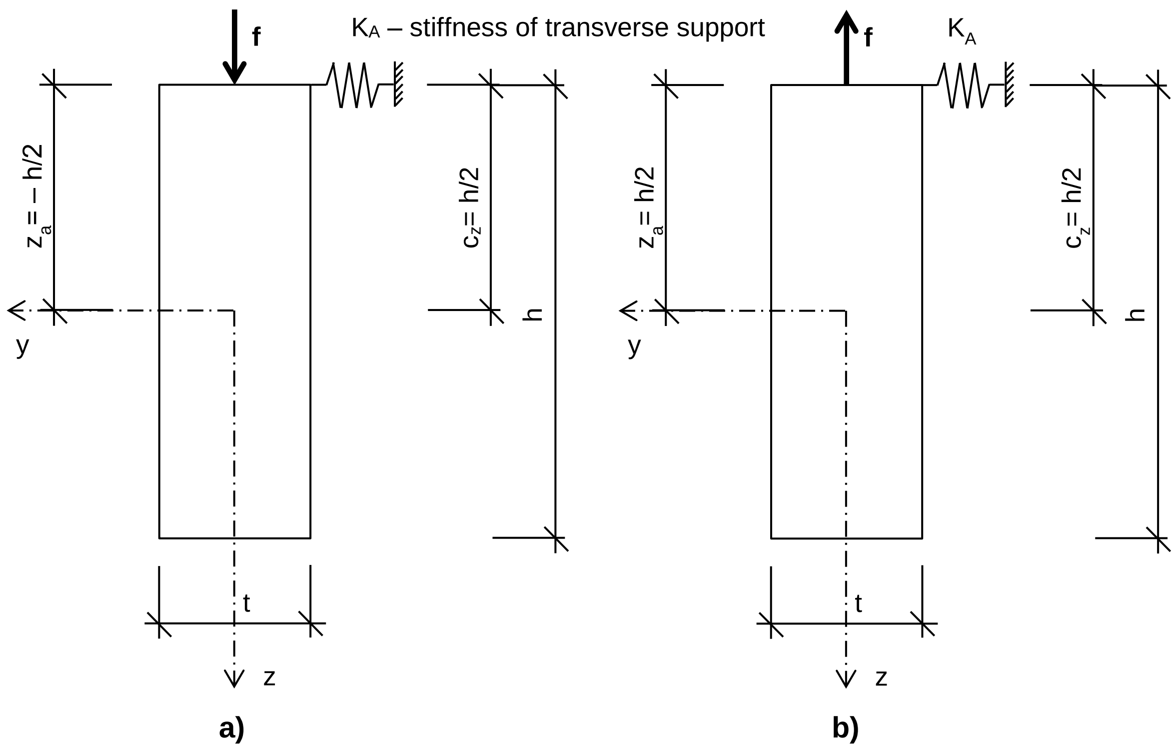

Fig. 1.4: Determination of variables za and cz for the load position in the direction of the cross section (wind pressure) (a) and out of the cross section (wind suction) (b)

The reinforcing fin can be simplified assessed in the ULS for bending with loss of lateral and torsional stability according to the following formula:

$$M_{Ed} \leq M_{Rd} = \frac{M_{cr}}{\gamma}$$

where M_{Rd} is bending resistance;

γ safety factor ($\gamma = 1{,}7$).

Bending resistence for combination KZ1 – wind pressure is:

$$M_{Rd,pressure} = \frac{18{,}57}{1{,}7} = 10{,}92\ kNm$$

Bending resistence for combination KZ2 – wind suction is:

$$M_{Rd,suction} = \frac{6{,}19}{1{,}7} = 3{,}64\ kNm$$

Assessment:

$$M_{Ed,pressure} = 3{,}65\ kNm\ \leq 10{,}92\ kNm = \ M_{Rd,pressure}\ \ \Rightarrow\ \ SATISFACTORY$$

$$M_{Ed,suction} = 3{,}24\ kNm\ \leq 3{,}64\ kNm = \ M_{Rd,suction}\ \ \Rightarrow\ \ SATISFACTORY$$

The vin is at ULS **satisfactory** for the applied load.

1.4 Serviceability limit state

In the SLS, fin deflection will be investigated. The standard EN 1993-1-1, [6] for the design of steel structures defines the maximum horizontal deflection as 1/300 of the span for columns and pillars of glazed walls.

Design load values:

$$q_{d,pressure} = \gamma_Q \cdot q_{k,pressure} = 1{,}0 \cdot 0{,}540 = 0{,}540\ kN/m$$

$$q_{d,suction} = \gamma_Q \cdot q_{k,suction} = 1{,}0 \cdot 0{,}480 = 0{,}480\ kN/m$$

where q_d is design wind load;

γ_Q partial load factor for variable load ($\gamma_Q = 1{,}0$).

Deflection of a simply supported beam for combination KZ3 – wind pressure is:

$$\delta_{pressure} = \frac{8}{384} \cdot \frac{q_{d,pressure} \cdot L^4}{E \cdot I_y} = \frac{5}{384} \cdot \frac{0{,}540 \cdot 6000^4}{70 \cdot 10^3 \cdot 6{,}67 \cdot 10^6} = 19{,}52\ mm$$

Deflection of a simply supported beam for combination KZ4 – wind suction is:

$$\delta_{suction} = \frac{8}{384} \cdot \frac{q_{d,suction} \cdot L^4}{E \cdot I_y} = \frac{5}{384} \cdot \frac{0{,}480 \cdot 6000^4}{70 \cdot 10^3 \cdot 6{,}67 \cdot 10^6} = 17{,}36\ mm$$

Assessment:

$$\delta_{pressure} = 19{,}52\ mm\ \leq \delta_{lim} = \frac{L}{300} = \frac{6000}{300} = 20\ mm\ \Rightarrow\ \ SATISFACTORY$$

$$\delta_{suction} = 17{,}36\ mm\ \leq \delta_{lim} = \frac{L}{300} = \frac{6000}{300} = 20\ mm\ \Rightarrow\ \ SATISFACTORY$$

The beam is at SLS **satisfactory** for the applied load.

1.5 Literature

[1] DIN 18008-1, *Glas im Bauwesen – Bemessungs- und Konstruktionsregeln: Teil 1: Begriffe und allgemeine Grundlagen*, 2010. Berlin: Deutsches Institut für Normung

[2] AS 1288, *Glass in buildings: Section and installation*, 2006. Sydney: Standards Association of Australia

[3] ČSN EN 1991-1-4, *Eurokód 1: Zatížení konstrukcí: Část 1-4: Obecná zatížení – Zatížení větrem*, 2013. Ed. 2. Úřad pro technickou normalizaci, metrologii a státní zkušebnictví

[4] ČSN EN 12150-1, *Sklo ve stavebnictví – Tepelně tvrzené sodnovápenatokřemičité bezpečnostní sklo: Část 1: Definice a popis*, 2016. Úřad pro technickou normalizaci, metrologii a státní zkušebnictví

[5] ČSN EN 572-1:2012*: Sklo ve stavebnictví – Základní výrobky ze sodnovápenatokřemičitého skla – Část 1: Definice a obecné fyzikální a mechanické vlastnosti*, 2012. Úřad pro technickou normalizaci, metrologii a státní zkušebnictví

[6] ČSN EN 1993-1-1, *Eurokód 3: Navrhování ocelových konstrukcí: Část 1-1: Obecná pravidla a pravidla pro pozemní stavby*, 2011. Ed. 2. Úřad pro technickou normalizaci, metrologii a státní zkušebnictví