5. Clamped railing slab made of laminated glass

Assess clamped railing slab made of laminated glass, see Fig. 5.1. according to valid european standarts ČSN EN and DIN.

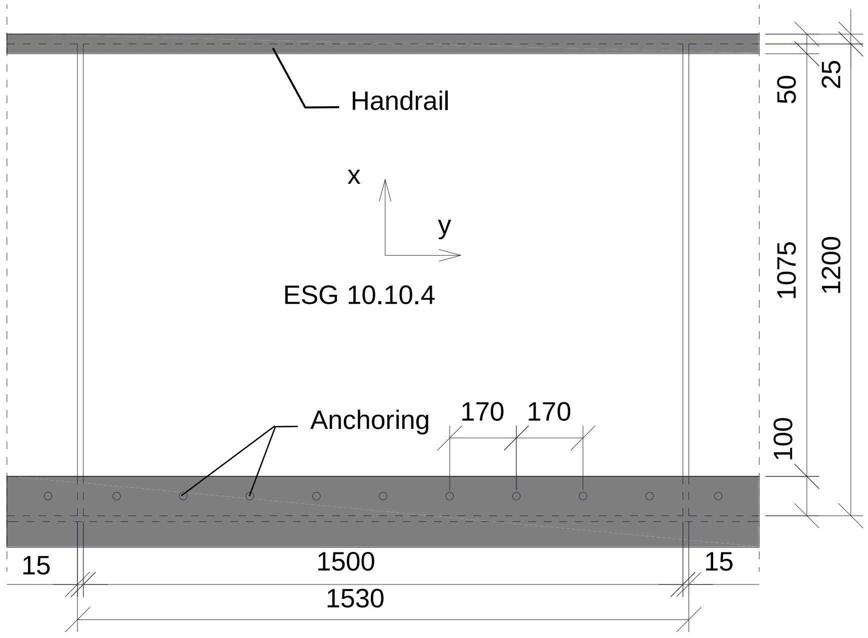

Fig. 5.1: Railing-front view

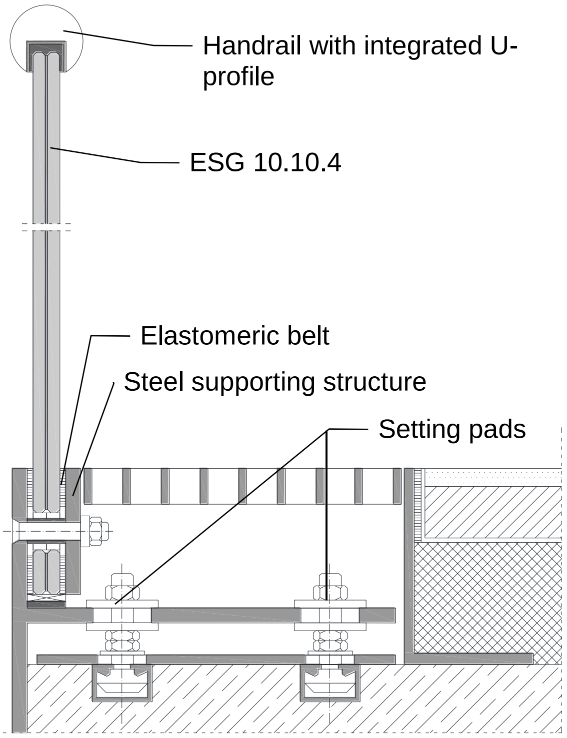

Fig. 5.2: Railing-transversal cross section

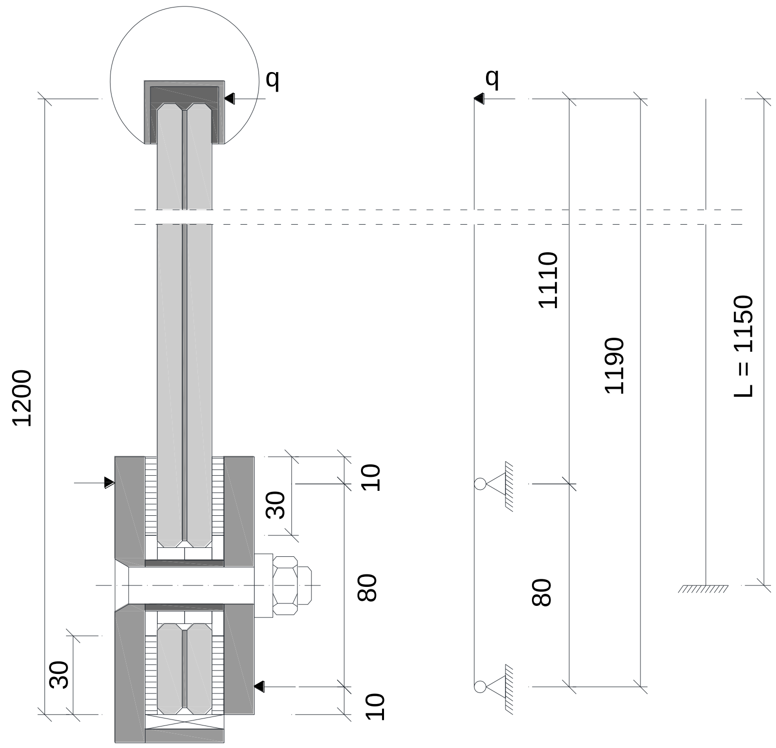

Fig. 5.3: Railing slab anchoring detail, vertical dimensions

The subject of this simplified design is two-layer clamped railing glass slab made of thermally thoughened glass with dimensions of **1500 x 1200 mm** situated in a museum. One glass ply thickness is ***t* = 10 mm** and PVB interlayer thickness is **1,52 mm**. This slab is clamped into steel supporting structure using bolts M20, check Fig. 5.2. Handrail attaching all individual slabs is on the upper edge of each slab. Fig. 5.3 shows considered static schema of railing slab with its loading and reactions positions. The length of a cantilever for slab assessment is conservatively considered as ***L* = 1,15 m**. Fig. 5.4 shows laminated glass composition in detail.

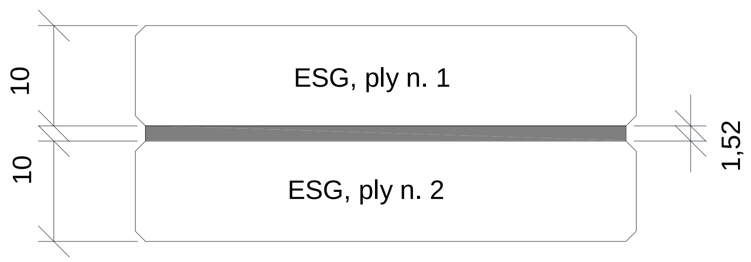

Fig. 5.4: Laminated glass composition

The railing is assumed as continous. The assessment will be therefore executed for 1 m length.

5.1 Loading

- **Self weight of railing**

The board self weight acts in the midline plane of the slab. To make it simple, in this case it will be neglected.

- **Utility loading**

The railing structure is situated in a museum. According to EN 1991-1-1, [1] , the museum is classified with category C3 in terms of utility loading. The characteristic value of the horizontal constant loading at the handrail level is **q_k = 1.0 kN/m**. Railing slabs susceptible to falling body impacts must be assessed for dynamic loading according to DIN 18008-4, [2].

- **Climatic loading**

Due to the location of the board inside the museum, no climatic loads will be considered.

5.2 Loading combinations

This handrail is only exposed to the utility load. In order to verify its resistance in ULS, the load will be increased by the coefficient γ_q = 1,5. In order to verify its SLS, the characteristic value of the load will be considered, i.e. γ_q = 1,0, see Tab. 5.1.

Tab. 5.1: Loading combinations

Number	Combination	Limit state
KZ1	$\gamma_q \cdot q_k$	ULS
KZ2	$\gamma_q \cdot q_k$	SLS

5.3 Material characteristics of glass

This railing slab is made of thermally toughened float glass. The minimum characteristic strength of a thermally toughened float glass is according to EN 12150-1, [3] ***$f_{b,k}$* = 120 MPa**. Young's modulus of elasticity as **E = 70 GPa** and Poisson´s ratio as **ν = 0,23**. The modulus of shear elasticity is then defined as:

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

Glass strength design value determination was done using the procedure in DIN 18008-1, [4] as:

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

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

$f_{b,k}$ characteristic value of strength;

γ_M partial factor of material (for thermally toughened glass $\gamma_M = 1{,}5$);

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

k_c construction factor ($k_c = 1{,}0$).

5.4 Ultimate limit state

For the internal forces calculation, the railing slab is considered to be clamped into the supporting structure in the anchoring bolts level. Regarding the loading direction at the level of the handrail, unilateral strain and uniformly distributed normal stress along the cross section in the anchoring is considered in a simple way. There is zero shear stress in the board's extreme fibers, calculated normal stresses can thus be considered as the main ones. For the normal stress calculation, the shear coupling between the individual layers of the slab must be neglected with respect to DIN 18008-1, [4] The normal stress calculation in the slab anchoring will therefore be considered separately for each individual glass ply. Bending moment will be divided between the individual glass plates in the ratio of their bending stiffness, 1:1 because the slab is composed of two individual plies having the same thickness. In the calculation, there will be substituted in N, mm and MPa.

Design bending moment in the anchoring of the individual glass plate for 1 m length:

$$m_{x,Ed} = \frac{1}{2} \cdot q_k \cdot \gamma_Q \cdot L \cdot b = \frac{1{,}0 \cdot 1{,}5 \cdot 1150 \cdot 1000}{2} = 0{,}860 \cdot 10^6\ Nmm = 0{,}86\ kNm$$

One glass plate section modulus for 1 m length:

$$W = \frac{b \cdot t^2}{6} = \frac{1000 \cdot 10^2}{6} = 16{,}666 \cdot 10^3\ mm^3$$

Normal stress in the extreme fibers:

$$\sigma_{x,Ed} = \frac{m_{x,Ed}}{W} = \frac{0{,}860 \cdot 10^6}{16{,}666 \cdot 10^3} = 51{,}6\ MPa$$

Assessment:

$$\sigma_{x,Ed} = 51{,}6\ MPa \leq 80\ MPa = f_{b,d} \ \Rightarrow\ \ SATISFACTORY$$

5.5 Accidental situation

In case of one glass ply breakage, the remaining plate must be capable of transferring the characteristic utility loading according to DIN 18008-1, [4]. There is loading coefficient $\gamma_q = 1{,}0$ considered in the accidental situation.

Design bending moment for 1 m of the remaining glass plate anchoring:

$$m_{x,EdA} = q_k \cdot \gamma_q \cdot L \cdot b = 1{,}0 \cdot 1{,}0 \cdot 1150.1000 = 1{,}150 \cdot 10^6\ Nmm = 1{,}15\ kNm$$

Normal stress in the extreme fibers of the remaining glass plate:

$$\sigma_{x,EdA} = \frac{m_{x,EdA}}{W} = \frac{1{,}150 \cdot 10^6}{16{,}666 \cdot 10^3} = 69{,}0\ MPa$$

Assessment:

$$\sigma_{x,Ed} = 69{,}0\ MPa \leq 80\ MPa = f_{b,d} \ \Rightarrow\ \ SATISFACTORY$$

5.6 Serviceability limit state

There are no recommendations and limits in all parts of DIN 18008 restraining the value of the horizontal deflection caused by the characteristic utility loading. The calculation of the horizontal deflection will be again performed for one slab of 1 m length. No shear coupling is again provided by the interlayer. The horizontal load is therefore divided between both glass plates regarding their bending stiffness (for two plates of the same thickness in the ratio of 1:1). The favorable shear stiffness of the interlayer film will be in according to DIN 18008-1, [4] neglected.

Individual plate moment of inertia of 1 m railing´s length for the horizontal deflection calculation:

$$I = \frac{b \cdot t^3}{12} = \frac{1000 \cdot 10^3}{12} = 8{,}3333.10^4\ mm^4$$

Horizontal deflection of a cantilever loaded by vertical force on its edge can be calculated a:

$$w_z = \frac{0{,}5 \cdot q_k \cdot b \cdot L^3}{3 \cdot E \cdot I} = \frac{0{,}5 \cdot 1{,}0 \cdot 1000 \cdot 1150^3}{3 \cdot 70000 \cdot 8{,}3333 \cdot 10^4} = 43{,}0\ mm$$

Assessment:

$$w_z = 43\ mm\ > w_{lim} = \frac{L}{50} = \frac{1150}{50} = 23\ mm\ \Rightarrow\ DISATISFACTORY$$

Calculated vertical deflection corresponds to 1/27 of the console length. The handrail can significantly reduce calculated horizontal deflection values in many cases. Recommended value of horizontal deflection in the handrail level is 1/50 of the railing´s high which isn´t fullfilled in our case. To reduce calculated horizontal deflection, it becomes necessary to increase glass thickness.

5.7 Literature

[1] ČSN EN 1991-1-1. *Eurokód 1: Zatížení konstrukcí: Část 1-1: Obecná zatížení - Objemové tíhy, vlastní tíha a užitná zatížení pozemních staveb*. 2004. Český normalizační institut

[2] DIN 18008-4. *Glas im Bauwesen - Bemessungs und Konstruktionsregeln: Teil 4: Zusatzanforderungen an absturzichernde Verglasungen*. Berlin: Deutsches Institut für Normung, 2013

[3] 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

[4] DIN 18008-1. *Glas im Bauwesen – Bemessungs- und Konstruktionsregeln –: Teil 1: Begriffe und allgemeine Grundlagen*. Berlin: Deutsches Institut für Normung, 2011