4. Laminated glass floor slab situated in a museum

Assess laminated glass floor slab situated in a museum. The assessment must be performed in accordance with the principles of european standards system in cooperation with german standarts for load bearing capacity and usability.
Laminated glass slabs with the dimensions ***b* = 1000 mm** and ***a* = 900 mm**, see Fig. 4.1, are simply laid on the steel grid of the ceiling structure. The axial distance of the supporting beams is identical to the dimensions of the plate. These beams are considered to be sufficiently rigid and are able to provide rigid peripheral support to each slab. The slabs will be laid on the upper flanges of the beams through a rubber elastic pad preventing the contact between the glass and steel, see Fig. 4.2. The floor slab is made of three-layered glass in a composition of: heat strengthened float glass (TVG) of thickness **t_1 = 10 mm**, PVB foil of thickness **t_{PVB} = 0,76 mm** + heat strengthened float glass (TVG) of thickness **t_2 = 10 mm**, PVB foil + heat toughened float glass (ESG) of thickness **t_3 = 6 mm**, see Fig. 4.3.

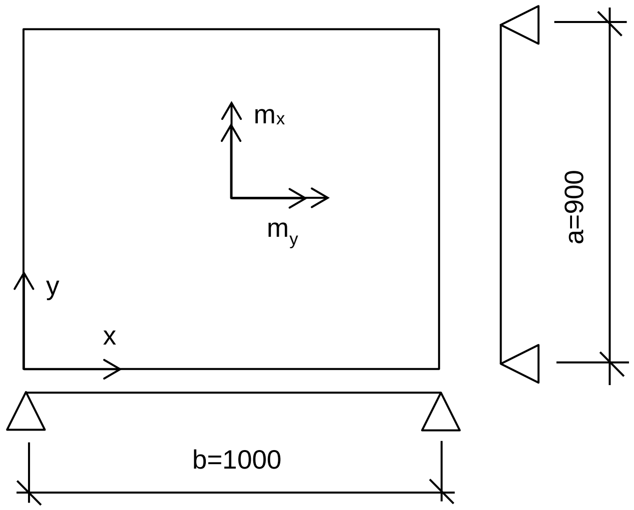

Fig. 4.1: Peripheral dimensions of the slab and its local coordinates

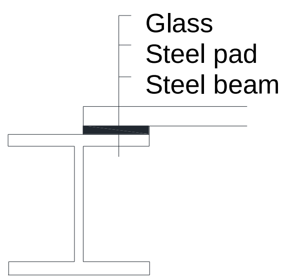

Fig. 4.2: Detail of floor slab with supporting beam´s flange contact

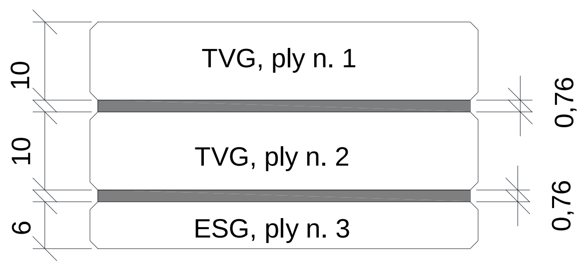

Fig. 4.3: Laminated glass composition

4.1 Loading cases

- **Self weight of construction – ZS 1**

Glass bulk density is $\boldsymbol{\rho_G}$ **= 2500 kg/m³** (**25 kN/m³**).
Uniformly distributed loading is:

$$g_k = \rho_G \cdot (t_1 + t_2 + t_3) = 25 \cdot (0{,}006 + 0{,}01 + 0{,}01) = 0{,}65\ kN/m^2$$

where g_k is characteristic value of uniformly distributed load;
t_1 upper glass thickness;
t_2 middle glass thickness;
t_3 lower glass thickness.

- **Uniformly distributed utility loading – ZS2**

Characteristic value of uniformly distributed loading is determined according to EN 1991-1-1, [1] and it is set into category C3 – floor is in a museum.
Characteristic value of uniformly distributed loading is $\boldsymbol{q_k}$ **= 5,0 kN/m²**

- **Local utility load – ZS3**

According to the standart EN 1991-1-1, [1], or DIN 18008-5, [2] the slab must be assessed for local load.
Characteristic value of local loading is $\boldsymbol{Q_k}$ **= 2,0 kN** and acts on the area of **50 x 50 mm**. The local load must evoke maximum actions, it is therefore placed in the middle of the slab., see Fig. 4.4.

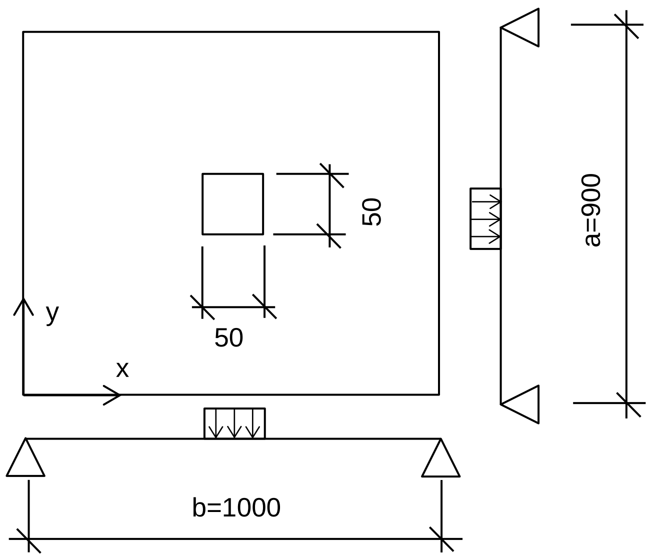

Fig. 4.4: Local load position on the slab

- **Unequal vertical deflections in supports**

The unequal vertical deflections of the steel beams are negligible for our designed slab. But in practice, the unequal vertical deflections of the supporting beams may be significant and should be thoroughly verified.

4.2 Loading cases combinations

- **ULS loading cases combinations**

These combinations are in correlation with EN 1990, [3] and are shown in Tab. 4.1.

Tab. 4.1: ULS loading cases combinations

Number	Combination key	Combination factor for permanent loading γ_G [-]	Combination factor for utility loading γ_Q [-]
KZ1	$\gamma_G \cdot g_k + \gamma_Q \cdot q_k$	1,35	1,50
KZ2	$\gamma_G \cdot g_k + \gamma_Q \cdot Q_k$	1,35	1,50

- **ULS loading cases combinations – accidental situation**

Whether the upper layer of the whole laminate is damaged (glass surface impact, etc.), the accidental situation must be considered in the calculation. This means that the lower glass layers must be able to carry themselves and a part of the variable loading too, see Tab. 4.2.

Tab. 4.2: ULS loading cases combinations – accidental situation

Number	Combination key	Combination factor for permanent loading γ_G [-]	Combination factor for utility loading γ_Q [-]
KZ3	$\gamma_G \cdot g_k + \gamma_Q \cdot q_k$	1,0	0,5
KZ4	$\gamma_G \cdot g_k + \gamma_Q \cdot Q_k$	1,0	0,5

- **SLS loading cases combinations**

Verification of horizontal deflections of the floor slab in SLS is required. According to [3], there is characteristic value of loading considered. Considered loading combinations may be found in Tab. 4.3.

Tab. 4.3: SLS loading cases sombinations

Number	Combination key	Combination factor for permanent loading γ_G [-]	Combination factor for utility loading γ_Q [-]
KZ5	$\gamma_G \cdot g_k + \gamma_Q \cdot q_k$	1,0	1,0
KZ6	$\gamma_G \cdot g_k + \gamma_Q \cdot Q_k$	1,0	1,0

4.3 Material properties

Characteristic strength of heat toughened glass in tension is according to EN 12150-1, [4] $\boldsymbol{f_{b,k}}$ **= 120 N/mm^2**. Characteristic strength of heat strengthened glass in tension is according to EN 1863-1, [5] $\boldsymbol{f_{g,k}}$ **= 70 N/mm^2**. Material properties of glass and PVB foil are shown in Tab. 4.4. Standart EN 572-1, [6] determines Young´s modulus of elasticity of glass as $\boldsymbol{E}$ **= 70 GPa**. Poisson´s ratio of glass $\boldsymbol{\nu}$ **= 0,23**. All modules are considered for long lasting load.

Modulus of elasticity in shear is 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.

Glass design strength value determination:

$$f_{b,d} = \frac{k_{mod} \cdot k_c \cdot f_{b,k}}{\gamma_M} = \frac{1 \cdot 1 \cdot 70}{1{,}5} = 46{,}67\ MPa$$

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

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

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

Characteristic strength of a thermally toughened float glass in bending is determined as:

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

Tab. 4.4: Material properties of the individual layers

Material	**Modulus of elasticity E [MPa]**	**Shear modulus G [MPa]**	**Poisson´s ratio ν [-]**	**Bulk weight γ [kN/m³]**
Glass	70000	28460	0,23	25
PVB foil	0,03	0,01	0,499	10,7

4.4 ULS assessment

For normal stresses calculation, it is necessary to determine the specific bending moments m_x and m_y. For the calculation of these moments, it is conservatively considered that the individual glass plies in the laminate will not co-operate. Imposed load is according to DIN 18008-2, [7] uniformly distributed between the individual plies proportionally to their stiffness. Stiffness proportional factor δ_i is defined as:

$$\delta_i = \frac{I_i}{I_1 + I_2 + I_3} = \frac{t_i^3}{t_1^3 + t_2^3 + t_3^3},$$

where I_i is moment of inertia of 1 ply meter;

For the individual plies then:

$$\delta_1 = \delta_2 = \frac{t_1^3}{t_1^3 + t_2^3 + t_3^3} = \frac{10^3}{10^3 + 10^3 + 6^3} = 0{,}45$$

$$\delta_3 = \frac{t_3^3}{t_1^3 + t_2^3 + t_3^3} = \frac{6^3}{10^3 + 10^3 + 6^3} = 0{,}1$$

One glass ply specific section modulus for the normal stress calculation:

$$W_1 = W_2 = \frac{t_1^2}{6} = \frac{10^2}{6} = 16{,}7\ mm^3/mm$$

$$W_3 = \frac{t_3^2}{6} = \frac{6^2}{6} = 6{,}0\ mm^3/mm$$

To determine the bending moments across the whole laminate, it is necessary to subtract the coefficients for the load distribution η_x and η_y. Moreover, these coefficients depend on the applied load and in our example are taken from charts in Glasbau-Praxis publication, [8]. The length of the floor slab is considered *b* = 1,0 m and the width of the slab is assumed to be *a* = 0,9 m. The graphs with the values of the load distribution η_x a η_y in ULS are shown in Fig. 4.5 and Fig. 4.7 for the local load and in Fig. 4.6 for the uniformly distributed load. The intermediate values can be linearly interpolated. The orientation of the coordinate system in the graphs is the same as the coordinate system of our solved slab.
Ratio *b*/*a* is determined as:

$$\frac{b}{a} = \frac{1{,}0}{0{,}9} = 1{,}11$$

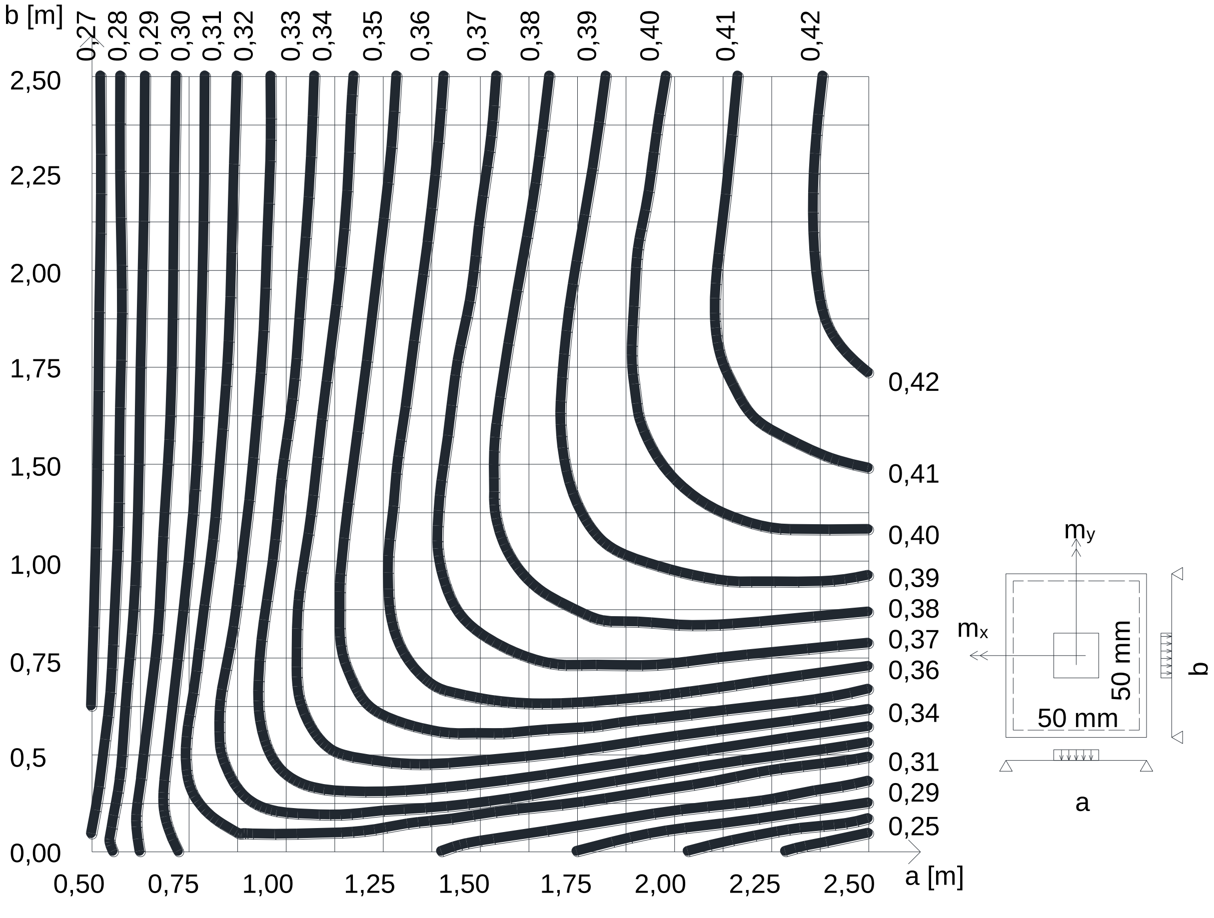

Fig. 4.5: Graph with load distribution coefficients $\eta_{x,Q}$ for the local load, [8]

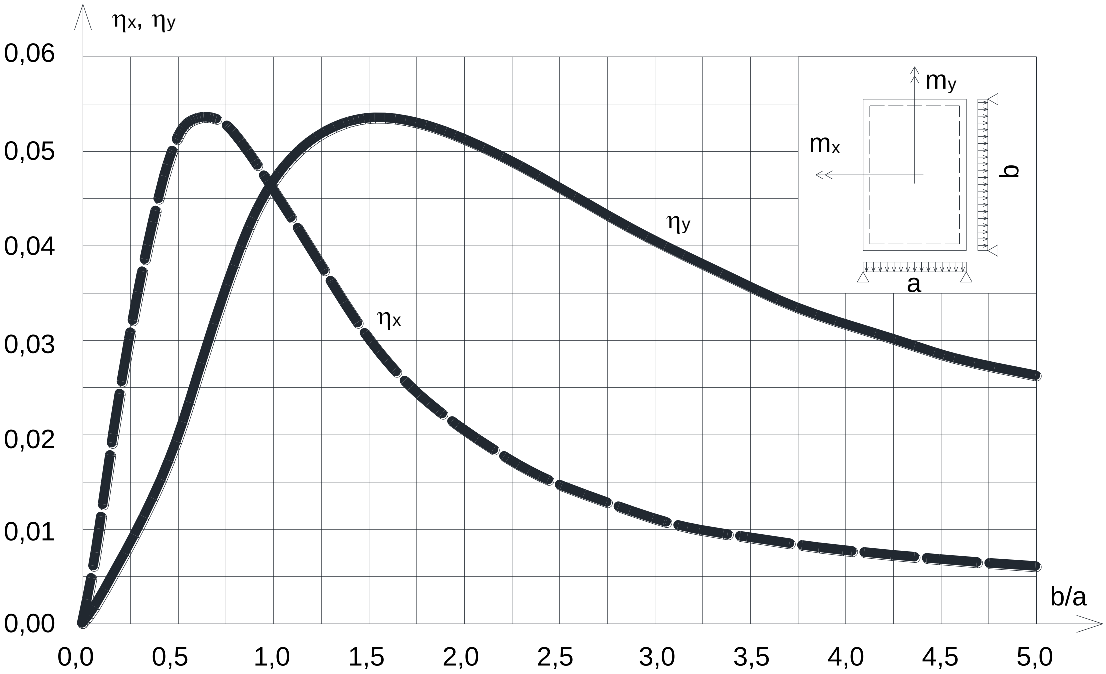

Fig. 4.6: Graph with load distribution coefficients η_x a η_y for the uniform loading, [8]

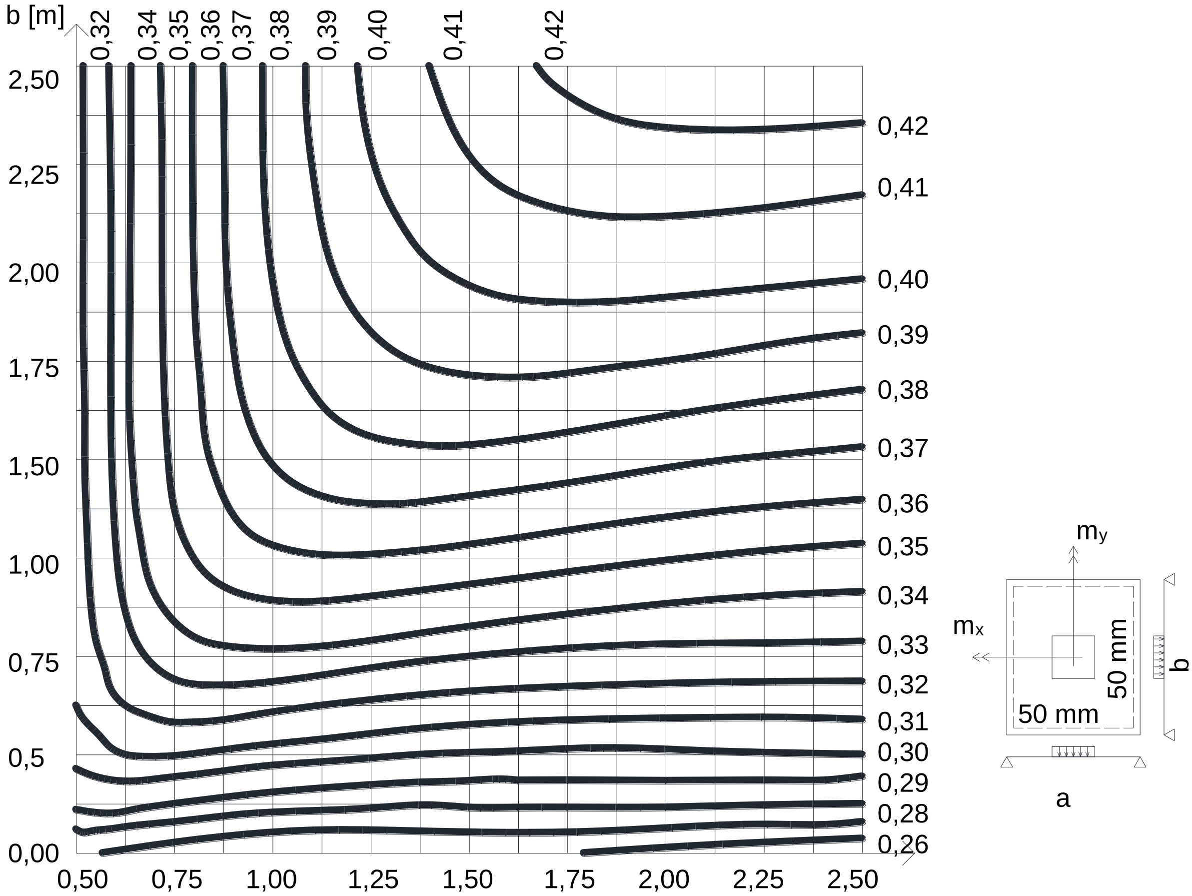

Fig. 4.7: Graph with load distribution coefficients $\eta_{y,Q}$ for the local load, [8]

The following values of coefficients for our designed slab:

- Uniform loading

$$\eta_x = 0{,}042$$

$$\eta_y = 0{,}048$$

- Local load

$$\eta_{x,Q} = 0{,}33$$

$$\eta_{x,Q} = 0{,}34$$

- **Combination KZ1**

Design value of uniformly distributed load:

$$f_d = \gamma_G \cdot g_k + \gamma_Q \cdot q_k = 1{,}35 \cdot 0{,}65 + 1{,}5 \cdot 5 = 8{,}4\ kN/m^2$$

Specific bending moment for the whole laminate in the middle of the span is determined as:

$$m_{x,Ed} = \eta_x \cdot a \cdot b \cdot f_d = 0{,}042 \cdot 900 \cdot 1000 \cdot 8{,}4 \cdot 10^{-3} = 317{,}5\ Nmm/mm$$

$$m_{y,Ed} = \eta_y \cdot a \cdot b \cdot f_d = 0{,}048 \cdot 900 \cdot 1000 \cdot 8{,}4 \cdot 10^{-3} = 362{,}8\ Nmm/mm$$

Specific bending moment distribution between the individual plies is determined as:

$$m_{x,Ed,1} = m_{x,Ed,2} = m_{x,Ed} \cdot \delta_1 = 317{,}5 \cdot 0{,}45 = 142{,}9\ Nmm/mm$$

$$m_{x,Ed,3} = m_{x,Ed} \cdot \delta_3 = 317{,}5 \cdot 0{,}10 = 31{,}8\ Nmm/mm$$

$$m_{y,Ed,1} = m_{y,Ed,2} = m_{y,Ed} \cdot \delta_1 = 362{,}8 \cdot 0{,}42 = 163{,}2\ Nmm/mm$$

$$m_{y,Ed,3} = m_{y,Ed} \cdot \delta_3 = 362{,}8 \cdot 0{,}10 = 36{,}3\ Nmm/mm$$

Normal stress for the individual plies caused by these specific bending moments is determined as:

$$\sigma_{x,Ed,1,2} = \frac{m_{x,Ed,1,2}}{W_{1,2}} = \frac{142{,}9}{16{,}7} = 8{,}55\ MPa$$

$$\sigma_{x,Ed,3} = \frac{m_{x,Ed,3}}{W_3} = \frac{31{,}8}{6} = 5{,}3\ MPa$$

$$\sigma_{y,Ed,1,2} = \frac{m_{y,Ed,1,2}}{W_{1,2}} = \frac{163{,}26}{16{,}7} = 9{,}77\ MPa$$

$$\sigma_{y,Ed,3} = \frac{m_{y,Ed,3}}{W_3} = \frac{36{,}3}{6} = 6{,}0\ MPa$$

Assessment:

$$\sigma_{x,Ed,1,2} = 8{,}55\ MPa\ \leq 46{,}6\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{x,Ed,3} = 5{,}3\ MPa\ \leq 80{,}0\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{y,Ed,1,2} = 9{,}77\ MPa\ \leq 46{,}6\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{y,Ed,3} = 6{,}0\ MPa\ \leq 80{,}0\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

- **Combination KZ2**
- Self weight contribution

Design value of uniformly distributed loading:

$$f_d = \gamma_G \cdot g_k = 1{,}35 \cdot 0{,}65 = 0{,}88\ kN/m^2$$

Specific bending moment for the whole laminate in the middle of the span is determined as:

$$m_{x,Ed} = \eta_x \cdot a \cdot b \cdot f_d = 0{,}042 \cdot 900 \cdot 1000 \cdot 0{,}88 \cdot 10^{-3} = 33{,}26\ Nmm/mm$$

$$m_{y,Ed} = \eta_y \cdot a \cdot b \cdot f_d = 0{,}048 \cdot 900 \cdot 1000 \cdot 0{,}88 \cdot 10^{-3} = 38{,}02\ Nmm/mm$$

Specific bending moment distribution between the individual plies is executed according to:

$$m_{x,Ed,1} = m_{x,Ed,2} = m_{x,Ed} \cdot \delta_1 = 33{,}26 \cdot 0{,}45 = 14{,}97\ Nmm/mm$$

$$m_{x,Ed,3} = m_{x,Ed} \cdot \delta_3 = 33{,}26 \cdot 0{,}10 = 3{,}33\ Nmm/mm$$

$$m_{y,Ed,1} = m_{y,Ed,2} = m_{y,Ed} \cdot \delta_1 = 38{,}02 \cdot 0{,}45 = 17{,}11\ Nmm/mm$$

$$m_{y,Ed,3} = m_{y,Ed} \cdot \delta_3 = 38{,}02 \cdot 0{,}10 = 3{,}80\ Nmm/mm$$

- Local load contribution

Design value of the local load:

$$Q_d = \gamma_q \cdot Q_k = 1{,}5 \cdot 2{,}0 = 3{,}0\ kN$$

Specific bending moment for the whole laminate in the middle of the span is determined as:

$$m_{x,Ed} = \eta_{x,Q} \cdot Q_d = 0{,}33 \cdot 3{,}00 \cdot 10^3 = 990\ Nmm/mm$$

$$m_{y,Ed} = \eta_{y,Q} \cdot Q_d = 0{,}34 \cdot 3{,}00 \cdot 10^3 = 1020\ Nmm/mm$$

Specific bending moment distribution between the individual plies is executed according to:

$$m_{x,Ed,1} = m_{x,Ed,2} = m_{x,Ed} \cdot \delta_1 = 990 \cdot 0{,}45 = 445{,}5\ Nmm/mm$$

$$m_{x,Ed,3} = m_{x,Ed} \cdot \delta_3 = 990 \cdot 0{,}10 = 99{,}0\ Nmm/mm$$

$$m_{y,Ed,1} = m_{y,Ed,2} = m_{y,Ed} \cdot \delta_1 = 1020 \cdot 0{,}45 = 459{,}0\ Nmm/mm$$

$$m_{y,Ed,3} = m_{y,Ed} \cdot \delta_3 = 1020 \cdot 0{,}10 = 102{,}0\ Nmm/mm$$

Normal stress for the individual plies caused by these specific bending moments is determined as:

$$\sigma_{x,Ed,1,2} = \frac{m_{x,Ed,1,2,q} + m_{x,Ed,1,2,Q}}{W_{1,2}} = \frac{14{,}97 + 445{,}5}{16{,}7} = 27{,}57\ MPa$$

$$\sigma_{x,Ed,3} = \frac{m_{x,Ed,3,q} + m_{x,Ed,3,Q}}{W_3} = \frac{3{,}33 + 99{,}0}{6} = 17{,}06\ MPa$$

$$\sigma_{y,Ed,1,2} = \frac{m_{y,Ed,1,2,q} + m_{y,Ed,1,2,Q}}{W_{1,2}} = \frac{17{,}11 + 459{,}0}{16{,}7} = 28{,}50\ MPa$$

$$\sigma_{y,Ed,3} = \frac{m_{y,Ed,3,q} + m_{y,Ed,3,Q}}{W_3} = \frac{3{,}8 + 102{,}0}{6} = 17{,}63\ MPa$$

Assessment:

$$\sigma_{x,Ed,1,2} = 27{,}57\ MPa\ \leq 46{,}6\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{x,Ed,3} = 17{,}06\ MPa\ \leq 80{,}0\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{y,Ed,1,2} = 28{,}5\ MPa\ \leq 46{,}6\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{y,Ed,3} = 17{,}63\ MPa\ \leq 80{,}0\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

4.5 ULS assessment – accidental situation

When the upper glass ply is broken, lower glass plies (TVG+ESG) are still able to carry the load. These must be satisfactory for accidental loading combination. Resulting bending moments are divided between remaining glass plies proportionally to their stiffness by δ_i coefficients as:

$$\delta_2 = \frac{10^3}{10^3 + 6^3} = 0{,}82$$

$$\delta_3 = \frac{6^3}{10^3 + 6^3} = 0{,}18$$

- **Combination KZ3**

Design value of uniformly distributed loading:

$$f_d = \gamma_G \cdot g_k + \gamma_Q \cdot q_k = 1{,}0 \cdot 0{,}65 + 0{,}5 \cdot 5{,}0 = 3{,}15\ kN/m^2$$

Specific bending moment for the whole laminate in the middle of the span is determined as:

$$m_{x,Ed} = \eta_x \cdot a \cdot b \cdot f_d = 0{,}042 \cdot 900 \cdot 1000 \cdot 3{,}15 \cdot 10^{-3} = 119{,}1\ Nmm/mm$$

$$m_{y,Ed} = \eta_y \cdot a \cdot b \cdot f_d = 0{,}048 \cdot 900 \cdot 1000 \cdot 3{,}15 \cdot 10^{-3} = 136{,}1\ Nmm/mm$$

Specific bending moment distribution for the ply number 2 is executed according to:

$$m_{x,Ed,2} = m_{x,Ed} \cdot \delta_2 = 119{,}1 \cdot 0{,}82 = 97{,}6\ Nmm/mm$$

$$m_{y,Ed,2} = m_{y,Ed} \cdot \delta_2 = 136{,}1 \cdot 0{,}82 = 111{,}6\ Nmm/mm$$

Specific bending moment distribution for the ply number 3 is executed according to:

$$m_{x,Ed,3} = m_{x,Ed} \cdot \delta_3 = 119{,}1 \cdot 0{,}18 = 21{,}4\ Nmm/mm$$

$$m_{y,Ed,3} = m_{y,Ed} \cdot \delta_3 = 136{,}1 \cdot 0{,}18 = 24{,}5\ Nmm/mm$$

Normal stress for the individual plies caused by these specific bending moments is determined as:

$$\sigma_{x,Ed,2} = \frac{m_{x,Ed,2}}{W_2} = \frac{97{,}6}{16{,}7} = 5{,}84\ MPa$$

$$\sigma_{x,Ed,3} = \frac{m_{x,Ed,3}}{W_3} = \frac{21{,}4}{6} = 3{,}57\ MPa$$

$$\sigma_{y,Ed,2} = \frac{m_{y,Ed,2}}{W_2} = \frac{111{,}6}{16{,}7} = 6{,}70\ MPa$$

$$\sigma_{y,Ed,3} = \frac{m_{y,Ed,3}}{W_3} = \frac{24{,}5}{6} = 4{,}08\ MPa$$

Assessment:

$$\sigma_{x,Ed,2} = 5{,}84\ MPa\ \leq 46{,}6\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{x,Ed,3} = 3{,}57\ MPa\ \leq 80{,}0\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{y,Ed,2} = 6{,}70\ MPa\ \leq 46{,}6\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{y,Ed,3} = 4{,}08\ MPa\ \leq 80{,}0\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

- **Combination KZ4**
- Self-weight contribution

Design value of uniformly distributed loading:

$$g_d = \gamma_G \cdot g_k = 1{,}0 \cdot 0{,}65 = 0{,}65\ kN/m^2$$

Specific bending moment for the whole laminate in the middle of the span is determined as:

$$m_{x,Ed} = \eta_x \cdot a \cdot b \cdot g_d = 0{,}042 \cdot 900 \cdot 1000 \cdot 0{,}65 \cdot 10^{-3} = 24{,}57\ Nmm/mm$$

$$m_{y,Ed} = \eta_y \cdot a \cdot b \cdot g_d = 0{,}048 \cdot 900 \cdot 1000 \cdot 0{,}65 \cdot 10^{-3} = 28{,}08\ Nmm/mm$$

Specific bending moment distribution for the ply number 2 is executed according to:

$$m_{x,Ed,2} = m_{x,Ed} \cdot \delta_2 = 24{,}57 \cdot 0{,}82 = 20{,}1\ Nmm/mm$$

$$m_{y,Ed,2} = m_{y,Ed} \cdot \delta_2 = 28{,}08 \cdot 0{,}82 = 23{,}0\ Nmm/mm$$

Specific bending moment distribution for the ply number 3 is executed according to:

$$m_{x,Ed,3} = m_{x,Ed} \cdot \delta_3 = 24{,}57 \cdot 0{,}18 = 4{,}4\ Nmm/mm$$

$$m_{y,Ed,3} = m_{y,Ed} \cdot \delta_3 = 28{,}08 \cdot 0{,}18 = 5{,}0\ Nmm/mm$$

- Local load contribution

Design value of local load:

$$Q_d = \gamma_q \cdot Q_k = 0{,}5 \cdot 2{,}0 = 1{,}0\ kN$$

Specific bending moment for the whole laminate in the middle of the span is determined as:

$$m_{x,Ed} = \eta_{x,Q} \cdot Q_d = 0{,}33 \cdot 1{,}00 \cdot 10^3 = 330\ Nmm/mm$$

$$m_{y,Ed} = \eta_{y,Q} \cdot Q_d = 0{,}34 \cdot 1{,}00 \cdot 10^3 = 340\ Nmm/mm$$

Specific bending moment distribution for the ply number 2 is executed according to:

$$m_{x,Ed,2} = m_{x,Ed} \cdot \delta_2 = 330 \cdot 0{,}82 = 270{,}6\ Nmm/mm$$

$$m_{y,Ed,2} = m_{y,Ed} \cdot \delta_2 = 340 \cdot 0{,}82 = 278{,}8\ Nmm/mm$$

Specific bending moment distribution for the ply number 3 is executed according to:

$$m_{x,Ed,3} = m_{x,Ed} \cdot \delta_3 = 330 \cdot 0{,}18 = 59{,}4\ Nmm/mm$$

$$m_{y,Ed,3} = m_{y,Ed} \cdot \delta_3 = 340 \cdot 0{,}18 = 61{,}2\ Nmm/mm$$

Normal stress for the individual plies caused by these specific bending moments is determined as:

$$\sigma_{x,Ed,2} = \frac{m_{x,Ed,q,2} + m_{x,Ed,Q,2}}{W_2} = \frac{20,1 + 270,6}{16,7} = 17,40\ MPa$$

$$\sigma_{x,Ed,3} = \frac{m_{x,Ed,q,3} + m_{x,Ed,Q,3}}{W_3} = \frac{4,4 + 59,4}{6} = 10,63\ MPa$$

$$\sigma_{y,Ed,2} = \frac{m_{y,Ed,q,2} + m_{y,Ed,Q,2}}{W_2} = \frac{23,0 + 278,8}{16,7} = 18,07\ MPa$$

$$\sigma_{y,Ed,3} = \frac{m_{y,Ed,q,3} + m_{y,Ed,Q,3}}{W_3} = \frac{5,0 + 61,2}{6} = 11,04\ MPa$$

Assessment:

$$\sigma_{x,Ed,2} = 17,4\ MPa\ \leq 46,6\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{x,Ed,3} = 10,63\ MPa\ \leq 80,0\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{y,Ed,2} = 18,07\ MPa\ \leq 46,6\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

$$\sigma_{y,Ed,3} = 11,04\ MPa\ \leq 80,0\ MPa = f_{b,d}\ \Rightarrow\ SATISFACTORY$$

4.6 SLS assessment

Vertical deflection, which is accoring to DIN 18008-2, [7] limited as ***w_{lim}* = L/200**, will be assessed in terms of SLS verification. The load distribution coefficient for vertical deflection resulting from uniform loading η_f is shown in Fig. 4.8 and from local loading $\eta_{f,Q}$ is shown in Fig. 4.9. The intermediate values can be linearly interpolated. The orientation of the coordinate system in the graphs is the same as the coordinate system of our solved slab. Ratio b/a = 1/0,9 = 1,11

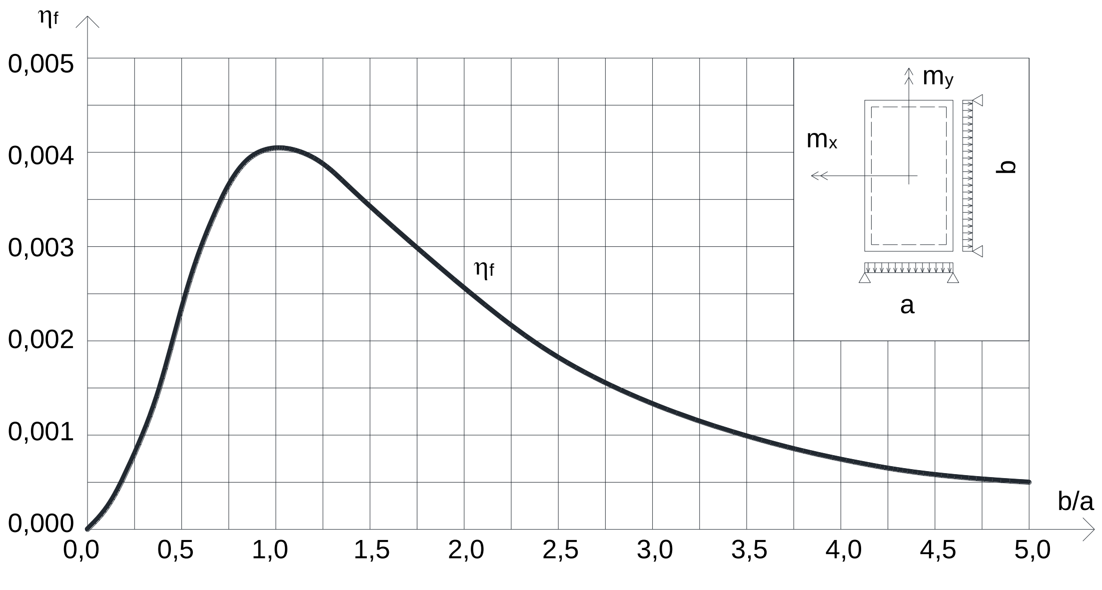

Fig. 4.8: Graph with η_f coefficient for vertical deflection determination caused by uniform loading, [8]

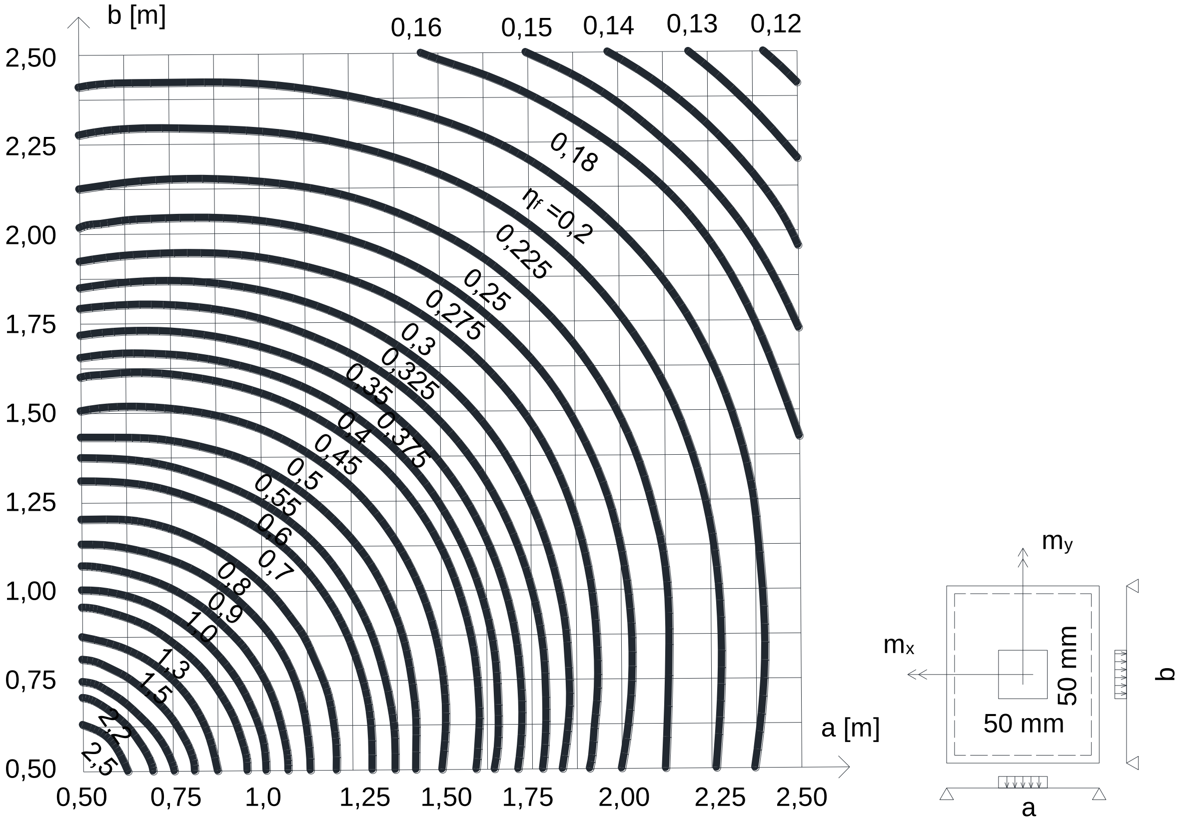

Fig. 4.9: Graph with $\eta_{f,Q}$ coefficient for vertical deflection determination caused by local load, [8]

Coefficient values for vertical deflections calculations in our case

- Uniform loading

$$\eta_f = 0{,}004$$

- Local load

$$\eta_{f,Q} = 0{,}80$$

- **Combination KZ5**

Characteristic value of uniformly distributed load:

$$f_k = \gamma_G \cdot g_k + \gamma_Q \cdot q_k = 1{,}0 \cdot 0{,}65 + 1{,}0 \cdot 5 = 5{,}65\ kN/m^2$$

Referenced thickness $t^*$of the monolithic slab having the same deflection as the entire laminate:

$$t^* = \sqrt[3]{\sum_{k=1}^{n} t_k^3} = \sqrt[3]{10^3 + 10^3 + 6^3} = 13{,}0\ mm$$

Stiffness K of the monolithic glass slab with the thickness t^*:

$$K = \frac{E \cdot t^{*3}}{12 \cdot (1 - \nu^2)} = \frac{70000 \cdot 13^3}{12 \cdot (1 - 0{,}23^2)} = 1{,}353.10^7\ Nmm$$

Deflection of this monolithic slab can be calculated as:

$$w = \frac{a^2 \cdot b^2}{K} \cdot \eta_f \cdot f_k = \frac{900^2 \cdot 1000^2}{1{,}353 \cdot 10^7} \cdot 0{,}004 \cdot 5{,}65 \cdot 10^{-3} = 1{,}35\ mm$$

Assessment:

$$w = 1{,}35\,mm \le w_{lim} = \frac{900}{200} = 4{,}5\,mm \Rightarrow \ SATISFACTORY$$

- **Combination KZ6**

Total deflection will be calculated as the sum of the deflections resulting from the uniformly distributed load and local load. Linear calculation allows superposition of loading effects thus the individual load states effects can be summed.

- Self weight contribution

The deflection of the slab with the referenced thickness t^* and stiffness K having the same deflection as the whole laminate is determined by:

$$w_1 = \frac{a^2 \cdot b^2}{K} \cdot \eta_f \cdot g_k = \frac{900^2 \cdot 1000^2}{1{,}353 \cdot 10^7} \cdot 0{,}004 \cdot 0{,}65 \cdot 10^{-3} = 0{,}16\,mm$$

- Local load contribution

Locally concentrated load 2,0 kN acting on the area of 50 x 50 mm in the middle of the span is going to be converted into the uniform load. It allows vertical deflection calculation. The conversion is executed as:

$$q_k = \frac{Q_k}{A} = \frac{2{,}0}{0{,}05 \cdot 0{,}05} = 800\ kN/m^2$$

The deflection resulting from locally concentrated load can then be calculated for the slab with the reference thickness t^*:

$$w_2 = \frac{1}{25000} \frac{a^2 \cdot b^2}{K} \cdot \eta_{f,Q} \cdot q_k = \frac{1}{25000} \frac{900^2 \cdot 1000^2}{1{,}353 \cdot 10^7} \cdot 0{,}8.800 \cdot 10^{-3} = 1{,}53\,mm$$

Total value of deflection is set as:

$$w_c = w_1 + w_2 = 0{,}16 + 1{,}53 = 1{,}7\,mm$$

Deflection assessment:

$$w_c = 1{,}7\,mm \le w_{lim} = \frac{a}{200} = \frac{900}{200} = 4{,}5\,mm \Rightarrow \ SATISFACTORY$$

4.7 Literature

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