

A Simplified Design Method for All-Glass Balustrades

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An all-glass balustrade's continuous handrail enables a horizontal load transfer from more flexible glass panes into adjacent elements with higher stiffness and thereafter – as the case may be – into even more rigid parts of the structure. As all the glass units are interconnected thus supporting each other mutually, a safe and economic design either requires taking a holistic view of the entire structural system or to make appropriate assumptions for the boundary conditions of the handrail in order to assess precisely the stress state of a single element of an all-glass railing. The idea of the method presented is to set elastic springs at the ends of the single element's rail to simulate the stiffness of the adjacent glazing. As these elements are usually charged by wind or horizontal live load, too, the additional supports must not be applied for the entire load and are therefore divided in up to three parts. Each part is put onto a corresponding model of the considered single element and glass stresses are calculated subsequently. Finally, the superposition principle leads to the actual maximum stress. Within a parameter study the new method is compared to former methods and to the results of calculations done with extended FEA-models that comprise the neighbouring structure. The new approach shows a good accordance with the latter and exceeds the former methods by far. Hence it contributes to a more economic glass design.

Keywords: free-standing glass protective barriers, calculation method, economic glass dimensioning

1. Introduction – all-glass balustrades

1.1. Definition, design specificity and normative status in Germany

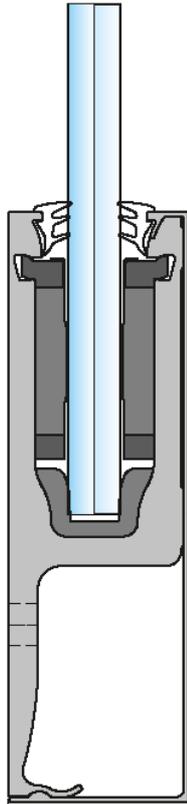
All-glass balustrades constitute a peculiarity among glass railings insofar as their glazing units are exclusively clamped at the bottom edge and there are no vertical balusters sequenced in-between as otherwise usual with infill panels. Nonetheless, a slender handrail is continuously attached to all the glass panes' top edges with the consequence that an external load is not only diverted into the supporting construction by a solely stressed element itself but also by its entire connected neighboring structure – therefore, all glazing units support each other mutually. Referring to the static principles, according to which all components of a system are charged, such a horizontal load transfer only takes effect if two adjacent glass panes are differently strained or have varying stiffness values. The causes of such discrepancies in the load-bearing and deformation behavior are for example end-side connections of the handrail to the building or higher wind loads at the balustrade periphery. Furthermore, the German body of standards prescribes, that the failure of a layer of a single laminated glass unit must be considered in a separate static calculation, whereby only one sound but also considerably more flexible glass ply remains. For the purpose of a more economical glass dimensioning the hereafter introduced computing method was developed on the basis of fundamental mechanical principles, which shall moreover offer the advantage of a moderate modelling effort compared to extended FE simulations of the entire system.



Fig. 1 End-side angled all-glass balustrade with cp-1402 model from Pauli + Sohn Ltd.

Introduced by the German building supervisory authorities in the years 2010 and 2013 the currently binding series of technical standards for structural glass engineering is the DIN 18008 with the title: “Glass in Building”, which is composed of five parts. Part four specifically addresses the additional requirements for protective barriers and imposes rules concerning their design and construction. Therein, a distinction is made between three categories depending on the demanded load-bearing capacity. All-glass balustrades – preferentially used amongst architects for in- and outdoor fall-proof barriers – form a separate class, the middle category B. This indicates again that the glazing units of all-glass balustrades do not have to carry off loads completely autonomously but merely partially and biaxially due to the assistance of their neighboring structure resulting from the bending and shear stiffness of the continuous handrail.

1.2. Constructive specifications according to DIN 18008-4 and industrial handling



To ensure a residual resistance in case of breakage, part 4 of DIN 18008 stipulates the use of laminated safety glass (LSG) as the only permissible building product for all-glass balustrades. The application possibilities of float glass are very limited because of its low mechanical strength. Instead, in common practice, the LSG is manufactured from thermally toughened (FTG) or heat strengthened glass (HSG) with typical thicknesses of 8, 10 or 12 mm depending on the load level, whereas the standard thickness of the interlayer amounts to 1,52mm, so that the units' overall dimensions add up to 17,52, 21,52 or 25,52 mm. Although the German standard provides some requirements for which an all-glass balustrade and its components can be considered shockproof without further evidence – such as pane widths of two meters at most, maximum cantilever lengths of 1,1 meters or a minimum LSG-thickness of 21,52mm, the solutions distributed by most system suppliers may exceed those limits, as they were granted a technical approval after passing the pendulum impact test under the control of a certified testing laboratory. By that way the companies either strive to achieve competitive advantages or at least try to remain on equal terms with others.

Nevertheless, the functional principles of the clamping systems available on the market are often similar and only some minor details differ. Fig. 2 exemplarily illustrates a cross section through the cp-1402 support model from company Pauli + Sohn Ltd. (Germany). Basis therefore is always an aluminum profile that is screwed onto the substructure. Inside the profile an elastomer bottom rail is installed on which the glass pane rests. Clamping jaws or rods inserted on both side of the glass generate a firm wedging, completed by gaskets or silicone sealings on the upper end. Ignoring the attached handrail, statically seen, the system corresponds to a short single span beam inside the profile with a large cantilever arm jutting out. Thereby, the bending moment is split into two opposing forces at the line supports, which in turn are transferred from there on into the profile walls. Considering the stabilizing effect of the handrail, a statically indeterminate system results. The components' stiffness influence the load flow so that computer-aided FEM calculations are necessary in order to thoroughly assess the internal stress state of an element of an all-glass railing.

Fig. 2 Pauli + Sohn Ltd. system profile set cp-1402 for side mounting

2. German design concept pursuant to DIN 18008 and DIN EN 1990 respectively

2.1. Actions on all-glass balustrades

The glazing units of all-glass railings are only subjected to self-weight, uniformly distributed wind pressure (if erected outdoors) and especially horizontal, linear live loads imposed by persons leaning against the beam or also pulling at it. Thanks to guidelines given in Eurocode 1, the procedure for the determination of actions is in principle the same throughout all European Union nations. Merely the values defined in the National Annexes (NA) may vary. Referring to the German version of DIN EN 1991-1-1/NA, the Nationally Determined Parameters (NDP) for characteristic beam loads, for example, are 0,5, 1,0 or in extreme cases 2,0 kN/m according to the usage category.

2.2. Analysis to be provided

As the stability of the balustrade under percussive loading is confirmed with the certificate issued by the accredited testing laboratory, the structural analyses must be conducted only under static loads – no dynamic verification is needed. In addition, the German DIN 18008 does not request any binding deflection criterion to be fulfilled, which means that a serviceability limit state computational check is not required either. However, the ultimate limit state involves not one but two scenarios: On the one hand, the permanent and temporary design situation in which all glass panes of a balustrade are wholly intact and the acting loads operate in full as normal. On the other hand, as stated previously, an accidental design situation exists, where a partial destruction of a single laminated safety glass unit is to be taken into account. In the course of this calculation, only reduced loads are applied. An overview of potential action combinations and an explanation of how to create them is provided on the next page. Those pertaining to the persistent and transient design situation are certainly already familiar to most structural engineers since the safe and correct handling of load combinations constitutes a focal point of the daily work. Quite on the contrary, the accidental design situation is most probably an unknown domain.

2.3. Action combinations in the ultimate limit state

- persistent and transient design situation:

Dead weight always acts as an independent permanent load. Conversely, the independent variable wind pressure and beam loads both may occur as leading actions with the respective other one as an accompanying action. While the main action appears with its characteristic variable value, for the secondary load the relevant rare combination coefficient is additionally brought into the formula to determine its combination value. All three representative values need to be multiplied by their corresponding partial safety factor to get their design values. By this, two combination possibilities need to be analyzed to obtain the governing main tensile stresses E_d within the characteristic situation.

$$E_{d,1} = E\{\gamma_{G,sup} \cdot G_k \oplus \gamma_Q \cdot q_k \oplus \gamma_Q \cdot \psi_0 \cdot w_k\} \quad (1)$$

$$E_{d,2} = E\{\gamma_{G,sup} \cdot G_k \oplus \gamma_Q \cdot w_k \oplus \gamma_Q \cdot \psi_0 \cdot q_k\} \quad (2)$$

Based on Eurocode 0/NA, partial safety factors of $\gamma_G = 1.35$ for permanent loads and one of $\gamma_Q = 1.50$ for changeable loads are demanded for the basic combination. The reduction coefficients are to be set to $\psi_0 = 0,70$ for beam loads and $\psi_0 = 0,60$ for wind loads. Thereby the equations (1) and (2) can be written as follows:

$$E_{d,1} = E\{1,35 \cdot G_k \oplus 1,50 \cdot q_k \oplus 1,5 \cdot 0,6 \cdot w_k\} \quad (3)$$

$$E_{d,2} = E\{1,35 \cdot G_k \oplus 1,50 \cdot w_k \oplus 1,5 \cdot 0,7 \cdot q_k\} \quad (4)$$

Note: Likewise, the sufficient bearing capacity of clamping device and handrail must be proved in calculation, too.

- Accidental design situation:

Accidental design situations must either contain an accidental load of the structure responsible for this scenario or a situation following an exceptional event. The difference is that in the second case the element A_d disappears in equation (5). Upon explicit request of DIN 18008-4 beam loads are to be treated as an accidental load using its design value, meaning that for wind load its frequent combination coefficient has to be considered to transform it to its accompanying value. The representative values of own weight and wind pressure are not multiplied with a partial safety factor. Thus, in contrast to the permanent and temporary design situation, there is only one combination possibility within this frequent situation:

$$E_{dA} = E\{G_k \oplus A_d (= \gamma_A \cdot q_k) \oplus \psi_1 \cdot w_k\} \quad (5)$$

Based on Eurocode 0/NA, the partial safety factor for an accidental action is $\gamma_A = 1,00$ and the combination coefficient $\psi_1 = 0,20$ should be taken for wind loads. In this case, the equation (5) can be expressed as:

$$E_{dA} = E\{G_k \oplus 1,00 \cdot q_k \oplus 0,2 \cdot w_k\} \quad (6)$$

Note: Such decreased load levels do not necessarily imply diminished strains as the area moment of inertia of the laminated safety glass is also reduced by at least a half because to the breakage of one of the two glass layers.

2.4. Resistance to static loads in the ultimate limit state

The European product standards specify the material resistance of heat strengthened and thermally toughened safety glass with characteristic values f_k of 70 N/mm² or 120 N/mm² respectively. Detailed information on how to determine the design values of the flexural strength are provided in the first part of DIN 18008. The general equation reads:

$$R_d = k_{mod} \cdot k_c \cdot f_k \cdot k_{LSG} \cdot k_{edge} / \gamma_M \quad (7)$$

The multiplication factors k_{mod} and k_{edge} which take account of load duration and lower tensile strengths at the edges relate exclusively to non-tempered glasses and can therefore be neglected. Using thermal tempered glass products, the partial safety factor becomes $\gamma_M = 1,5$, while the structural factor has the value $k_c = 1,0$. The last remaining factor k_{LSG} represents the higher load-bearing capacity of laminated safety glass which is due to a slight shear coupling generated by the laminate. In Germany, a flat-rate plus of 10 percent may be added ($k_{LSG} = 1,1$). Making use of this surcharge is only valid as long as no shear modulus of the interlayer is entered into the FEM program for the subsequent numerical stress analysis. Hence, the above-mentioned equation (7) can be shown in simplified form:

$$R_d = f_k \cdot k_{LSG} / \gamma_M \quad (8)$$

With regard to the accidental design situation in which only one glass layer remains intact, the factor k_{LSG} must, of course, be erased from equations (7) and (8).

In summary, the resulting design values of the resistance are depicted in the following table.

Table 1 Design values for the resistance of heat strengthened and thermally toughened safety glass

Rd [N/mm ²]	persistent and transient design situation		accidental design situation
	interlayer shear modulus G = 0	interlayer shear modulus G ≠ 0	
FTG	88,00	80,00	80,00
HSG	51,33	46,67	46,67

The design criteria to comply with in the end reads as known from other Eurocodes:

$$E_{d(A)}/R_d \leq 1,0 \tag{9}$$

Thus, the basic information required to carry out a full static proof according to DIN 18008 is described.

3. A simplified design method for all-glass balustrades

3.1. Design problem

The finite-element software SJ Mepla is frequently used to perform static and dynamic calculations of glass structures because of its numerous advantages. Nevertheless, it only allows to model one glazing of a system. By reason of the mutually supportive effect between all elements, appropriate assumptions for the boundary conditions of the handrail need to be made in most cases to guarantee an economical dimensioning. Otherwise, without modelling any adjoining parts, the internal glass stresses might be overestimated and conservative resulting in uneconomic glass thicknesses.

The idea of the method presented is to simulate the higher stiffness of the adjacent glazing units by cutting apart the system into single plates and by placing elastic springs in the upper corners of the more flexible glass-pane being, i.e. because of the partial destruction. The major problem is to quantify this supportive effect adequately. It is taken advantage of the linear-elastic material behavior of glass: As the spring constant describes the ratio of an applied external force to the elongation (Hooke’s Law), it appears logical and proper to determine the equivalent stiffness of a neighboring element by applying a single unit force \bar{F} in its corresponding upper corner and to compute its displacement \bar{u} . The quotient then serves as the spring rate – formulated more briefly:

$$c = \bar{F}/\bar{u} \tag{10}$$

It is important to note, that stresses calculated that way are not correct. By using elastic springs deduced in that manner without making further adjustments, the fact in turn is ignored that the neighboring structural components are charged by wind or horizontal live load, too and are deformed themselves. So, the additional supports must not be applied for the entire load as otherwise the supportive effect would be overestimated and tensile stresses would be too low. In consequence, a simplified interpolation method with a still sufficient quality of results was aimed for.

3.2. Distinction of the different support condition situations for a balustrade element

The glazing units of a balustrade can be given short abbreviations, which contain information on the constructive continuation on both of their sides. Free ends of a boundary element carry the token “0”. Ends with angled handrail arrangements or ends connected to the walls are labelled as “1” – the element is supported there. The token “C” signals that another lateral glass pane follows, with which the original element will mutually interact.

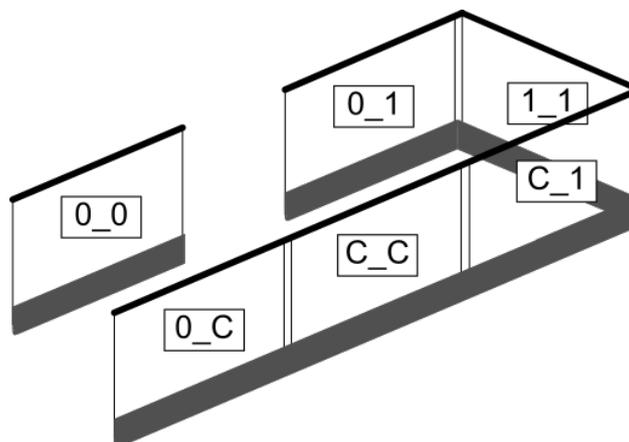


Fig. 3 Distinction of the different support condition situations for a balustrade element

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3.3. Geometric parameters and modelling assumptions of the chosen example

The method's essential steps are being exemplarily clarified with the aid of a symmetric three-glazing-balustrade-system, whose middle LSG pane is partly destroyed (a single intact ply is left). Installation location is an indoor area, for instance an office gallery. Thus, merely horizontal live load is acting. Its value is $q_k = 1,0 \text{ kN/m}$. Both ends of the attached handrail are connected to the rigid building structure – so, situation C_C is applicable, with the special feature that both springs have an identical stiffness. The glass widths are chosen to be two meters, the freely-projecting cantilever length is one meter. A single ply's thickness measures 10 mm. Hence, the overall dimensions of the lateral intact LSG-elements amount to 21,52 mm. The shear modulus of the interlayer is set to zero.

The modelling assumptions go back to the popular design practices of most system suppliers: The clamping height is ten centimeters. Two horizontal line supports, each with a width of two centimeters and a thickness of five millimeters, are placed inside this range, each sitting flush with the upper and lower margins. In this example, the elastic modulus of the elastomer strip supports are set to be $E = 200 \text{ N/mm}^2$ - the maximum value for EPDM according to DIN 18008-3. This guarantees a safe design as higher stiffnesses naturally attract loads to a greater extent. Moreover, the glass panes need to be and are supported in-plane via two rigid springs at the bottom corners, whereas an edge beam simulates the attached handrail. Its cross section values are calculated at $A = 124 \text{ mm}^2$ and $I_z = 18981 \text{ mm}^4$. Those Fig.s gain importance for the holistic FEM analyses conducted subsequently that comprises the entire balustrade.

3.4. Proceeding strategy of the simplified design method

Arising from the specifications described in the previous chapter, the following Fig. shows the whole structural system as well as the single pane systems for the simplified design method.

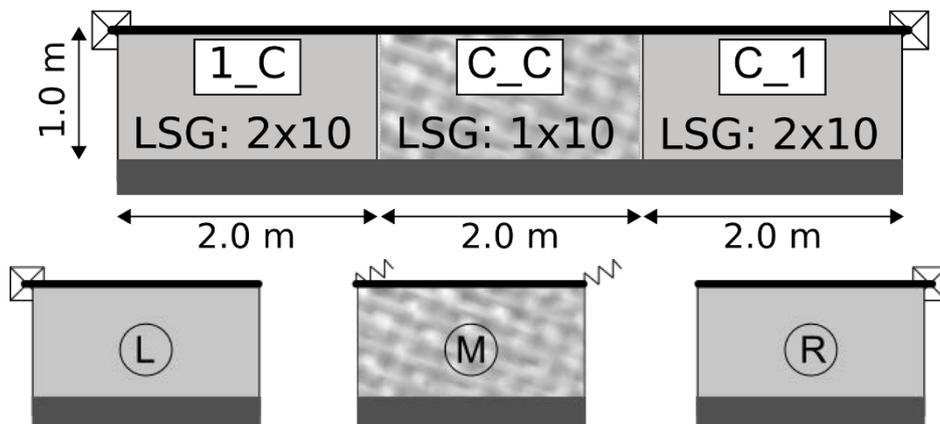


Fig. 4 Overview of the selected system and the single pane systems for the simplified design method.

As a first step, stresses are calculated excluding any supportive effects emerging from the neighboring elements. The middle glass pane M is viewed in isolation. As indicated above, very conservative results will be obtained this way.

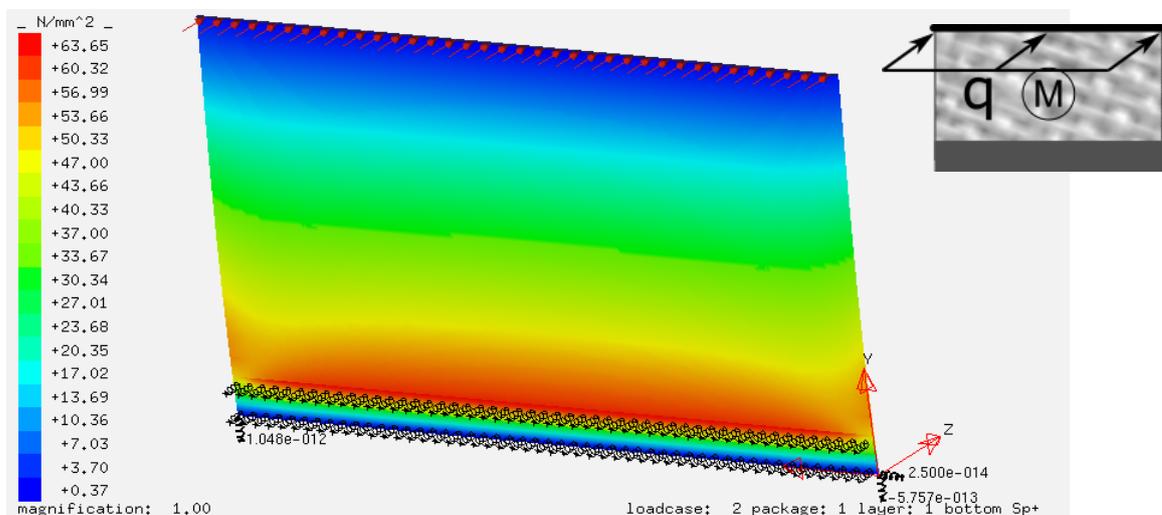


Fig. 5 Stress determination for the middle element M, situation "0_0" simulated with SJ MEPLA®

➤ $E_{dA,0} = 63,65 \text{ N/mm}^2$

In the next step, the adjacent glazing units R and L are transformed into single elastic compression springs with an equivalent stiffness following the instructions made in chapter 3.1: The deformation caused by a single force of $\bar{F} = 1000 \text{ N}$ is $\bar{u} = 33,5 \text{ mm}$. Inserted into equation (10), a spring rate of $c_{L,M} = c_{R,M} = 29,84 \text{ N/mm}$ results.

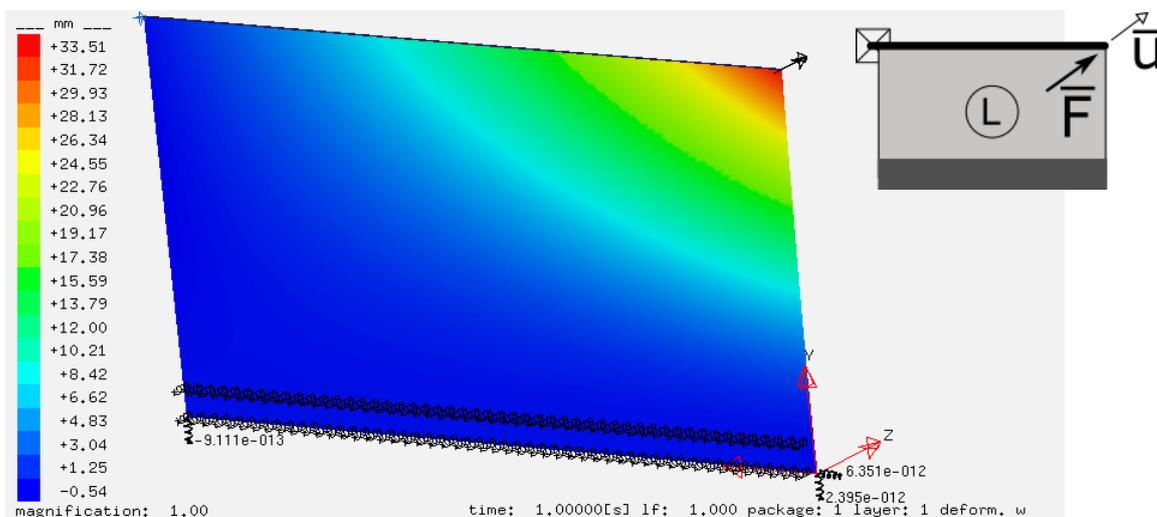


Fig. 6 Determination of the spring constant for both lateral elements simulated with SJ MEPLA®

The springs are to be positioned at the cutaway ends of the handrail, which are synonymous with the upper right and upper left corner of the partially broken middle unit M. As also explained before, this leads to underestimated strains and therefore unsafe results. For that reason, this deficient practice is henceforth called the excessive approach.

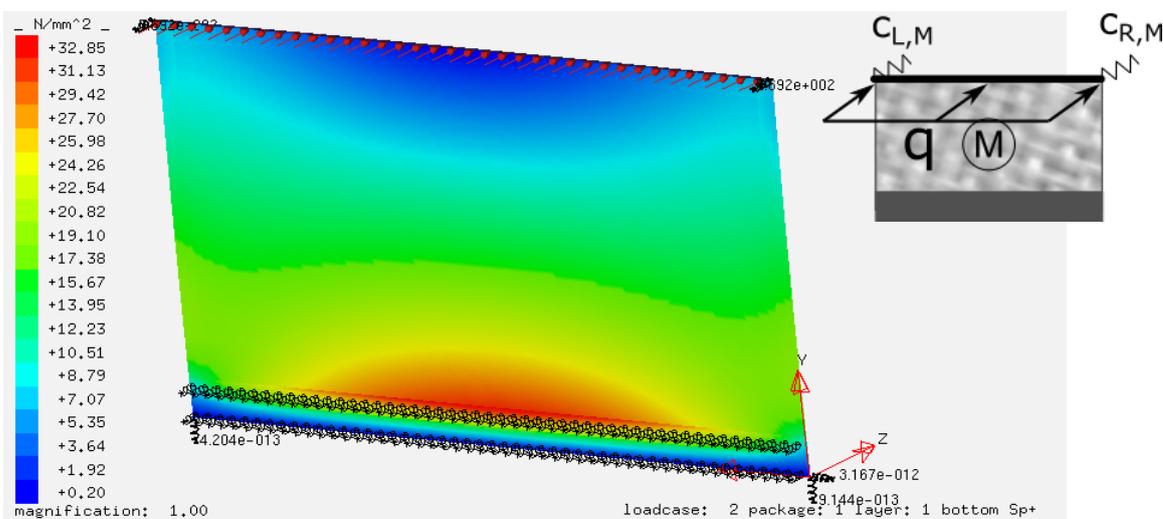


Fig. 7 Stress determination for the middle element, situation "C_C" simulated with SJ MEPLA®

➤ $E_{dA,C} = 32,85 \text{ N/mm}^2$

$E_{dA,0}$ and $E_{dA,C}$ can be interpreted as maximum and minimum limit values. The actual decisive stresses will take on intermediate values. To find appropriate ratio factors for the linear interpolation, the focus is directed at the deflection of all three separated elements under the real type of loading – the border load of $q_k = 1,0 \text{ kN/m}$ in this case. Fig. 8 qualitatively demonstrates their deformation behavior. The free-standing semi-broken middle element M is, of course, more flexible ($u_M = 60,28 \text{ mm}$ in the top right hand corner of the plate) than its adjacent glazing units that are in intact condition plus also connected to the rigid walls ($u_L = u_R = 26,83\text{mm}$).

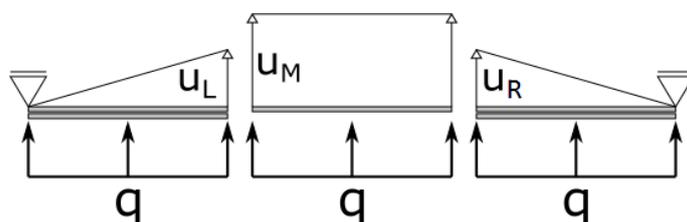


Fig. 8 Qualitative deformation Figs of the balustrade's three elements in top view

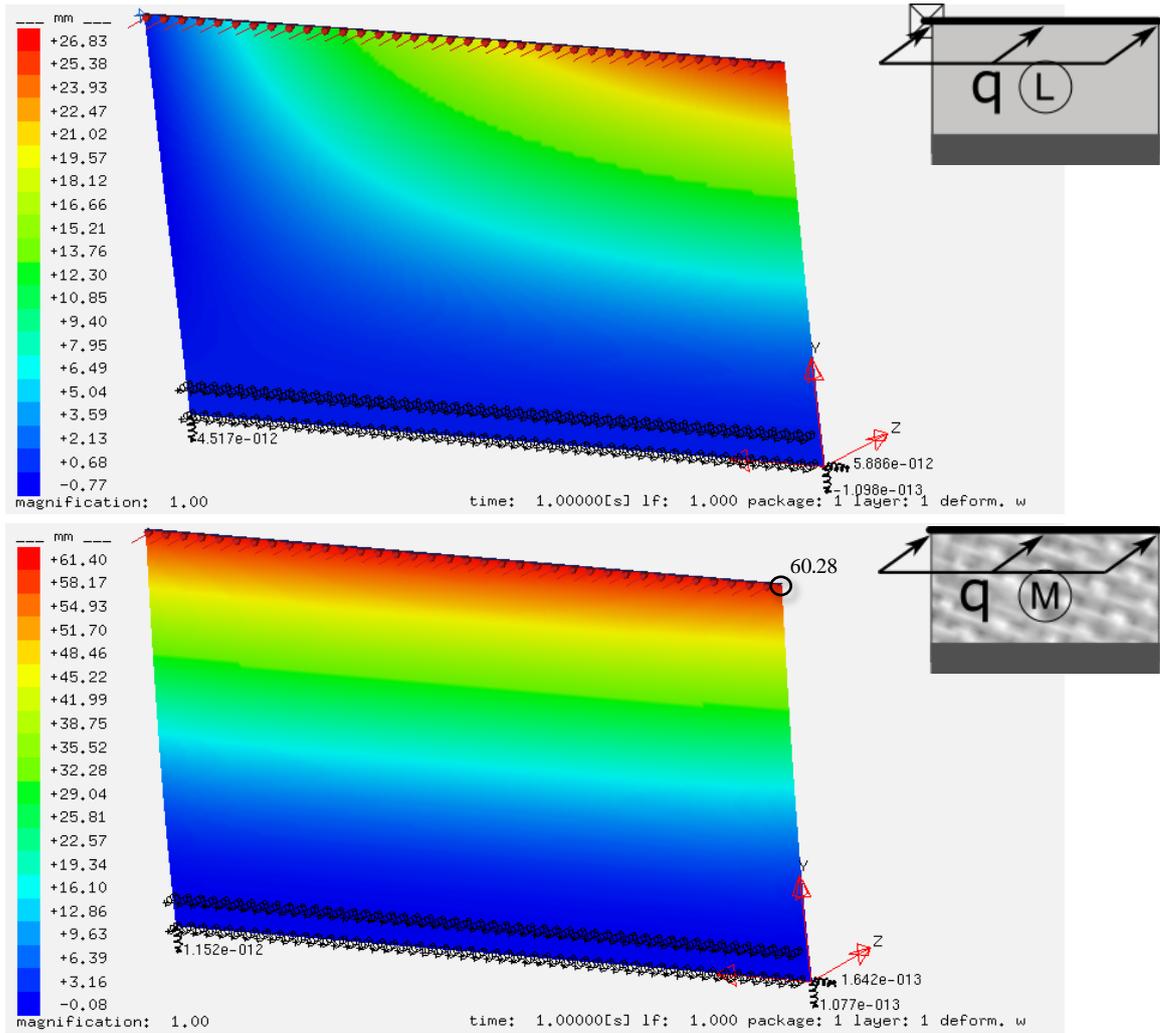


Fig. 9 Determination of the displacements for the two different elements simulated with SJ MEPLA®

A comparison between the deflections of the corners of two neighboring plates suggests the proportion to which the stresses $E_{dA,0}$ and $E_{dA,C}$ have to be summed up. It is assumed, that the monolithic ply M acts completely independently until reaching the final deformation of the stiffer two LSG-elements of the balustrade periphery. The supportive effect starts to make its contribution only for displacements exceeding the measurement of 26,83mm. This means, that an assistance of springs is only valid for the difference of the two deflections. Expressed in mathematical terms, equations (11) and (12) serve to determine the interpolation factors.

$$f_0 = u_L / u_M \quad (11)$$

$$f_C = (u_M - u_L) / u_M = 1 - f_0 \quad (12)$$

Substituting $u_L = 26,83\text{mm}$ and $u_M = 60,28\text{ mm}$ into the formulas above, $f_0 = 0,45$ and $f_C = 0,55$ are yielded. So, in this case, the value of the stress resultants will lay about midway between $E_{dA,0}$ and $E_{dA,C}$.

In the present case the general interpolation formula can be rearranged to a simplified form:

$$E_{dA} = E_{dA,0} \cdot f_0 + E_{dA,C} \cdot f_C \quad (13)$$

By implementing this approximate calculation method into the structural analyses, the obtained main tensile stresses could be lowered to $E_{dA} = 46,56\text{ N/mm}^2$. This corresponds to a reduction of 28,4 % compared to a conservative design without any assistance from the lateral components.

The obvious question arises of how reliable this value is. To be able to consolidate, classify and discuss these findings, a FE-simulation of the entire railing system using the same input data was performed, as stresses computed that way can be accepted as most accurate. A comparison between these results and those of the other approaches are depicted in tabular form following afterwards.

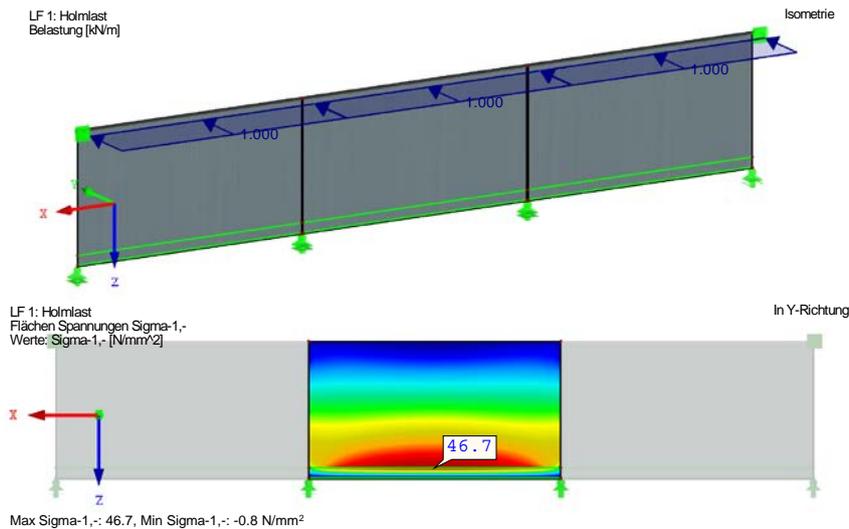


Fig. 10 Stress determination by modelling the entire railing system with Dlubal RFEM®

As can be seen in Table 2, the approximation works out very well in this example. Although the results are marginally on the unsafe side in this case, the deviation from the exact solution computed with Dlubal RFEM® makes up just 0,3 %. As part of a parameter study carried out for a large number of varying geometric conditions, such as differing glass heights, widths or thicknesses, it could be observed that stresses calculated with the aid of this very simplified method mostly show a good correlation with those of extended FE-analysis and are in nearly all cases on the safe side – and if not, they are never outside a tolerance range of only a few percentages. Despite – or perhaps because of – the limited complexity and modelling effort, the approach seems to be promising. A big advantage is that the method is applicable to any clamping construct. With some minor modifications and amendments, the procedure can likewise be transferred to systems with two different spring stiffnesses and, of course, interacting wind pressure and beam loads.

In order to demonstrate the benefits of even low spring rates, a second calculation was performed. The safe assumption is made that both lateral elements are only one meter wide and not connected to the building structure because this leads to a minimal stiffness. No changes are made to the partially broken middle pane. Thereby, the spring rates change to $c_{L,M} = c_{R,M} = 14,56 \text{ N/mm}$ – less than half as much as in the previous example. However, by following all the steps described before, the maximum main tensile stress rises to just $E_{dA} = 49,68 \text{ N/mm}^2$, a plus of only 6,7 % compared to $E_{dA} = 46,56 \text{ N/mm}^2$. This underlines how big the influence of supportive springs is.

Table 2 Comparison between the different calculation methods

method	main tensile stresses E_{dA} [N/mm ²]	convergence [%]	modelling effort
conservative approach (0_0)	63,65	+ 36,4	low
excessive approach (C_C)	32,85	- 29,7	irrelevant
approximative approach - simplified	49,68	+ 6,4	medium
approximative approach - detailed	46,56	- 0,3	medium
exact solution	46,70	reference	high

4. Conclusion and outlook

Due to the complex interplay between glazing units and handrail with regard to the load transfer, special considerations and idealizations are necessary for static analysis on the basis of one-plate-models so that proper statements can be given about the internal stress level inside the glass. The simplified calculation method presented enhances the limited possibilities of FEM-software like SJ Mepla and shall guarantee an economic dimensioning by using simple structural systems. As the proceeding is kept simple, the approach offers some starting-points for optimization, so that the real load-carrying behavior of the glasses and the flow of forces inside the components can be detected more precisely. The key aspect is the abstraction of basic mechanical mechanisms: By cutting the handrail apart at the gaps but solely considering its shear stiffness and therefore applying pure translational springs, the rotational stiffness is completely neglected yet. From that perspective, the beams are connected by hinges and no moments are transmitted. The impact becomes more considerable the larger the torsional angle between the upper edges of two adjacent glazing units get. Hence, the method has a more positive effect on free end elements rather than on glass panes with end-side supports. As those units are often the governing ones, this approach can be of high importance for an economic dimensioning.

A desirable ongoing work would be to create tables e.g. for a wide variety of possible boundary conditions, from which the matching substitute spring rate could easily be read off.

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References

- Spyra, T.: "Investigations on the numerical simulation of free-standing glass protective barriers", Technical University of Munich, 2017.
- P+S Ltd. product brochure: "Frameless Glass Balustrades – system profiles for top and fascia mounting", Pauli + Sohn GmbH, Waldbröl, 2015
- DIN German Institute for Standardization e.V., „DIN 18008-1: Glass in Building – Design and construction rules – Part 1: Terms and general bases“ Beuth Verlag GmbH, Berlin, 2010.
- DIN German Institute for Standardization e.V., „DIN 18008-3: Glass in Building – Design and construction rules – Part 3: Point fixed glazing“ Beuth Verlag GmbH, Berlin, 2013.
- DIN German Institute for Standardization e.V., „DIN 18008-4: Glass in Building – Design and construction rules – Part 4: Additional requirements for barrier glazing“ Beuth Verlag GmbH, Berlin, 2013.
- DIN German Institute for Standardization e.V., „DIN EN 1990: Eurocode: Basis of structural design;“ Beuth Verlag GmbH, Berlin, 2010.
- DIN German Institute for Standardization e.V., „DIN EN 1990/NA: National Annex – Nationally determined parameters - Eurocode: Basis of structural design“ Beuth Verlag GmbH, Berlin, 2010.
- DIN German Institute for Standardization e.V., „DIN EN 1991-1-1/NA: National Annex – Nationally determined parameters - Eurocode 1: Actions on structures – Part 1-1: General actions – Densities, self-weight, imposed loads for buildings“ Beuth Verlag GmbH, Berlin, 2010.
- DIN German Institute for Standardization e.V., „DIN EN 1863-1:2012-02: Glass in building - Heat strengthened soda lime silicate glass - Part 1: Definition and description“ Beuth Verlag GmbH, Berlin, 2012.
- DIN German Institute for Standardization e.V., „DIN EN 12150-1:2015-12: Glass in building - Thermally toughened soda lime silicate safety glass - Part 1: Definition and description“ Beuth Verlag GmbH, Berlin, 2015.

