New products with structural silicone bonding

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Abstract

New products ideas with structural silicone adhesives. Due to the lack of understanding of the load-bearing behaviour of silicone under tensile stress with constrained transverse strain, adhesive joints may only be used with an aspect ratio of 1/3. Through specific research at the Institute for Statics and Construction at the University of Darmstadt, a general material model was developed within the framework of a dissertation. Glas Trösch supported this research work with test specimens. Further investigations within the framework of the building authority approval "SWISSRAILING FLAT" showed that the applicability of the "Nelder-Drass material model" for 2 k silicones is given. With the additionally introduced design concept, it is now possible for Glas Trösch to design any structural bonded joints.

Keywords

structural silicone, hydrostatic stress stage, silicone thin layer bonding, SWISSRAILING FLAT, full glass balustrade

1. Einführung

Structural adhesive bonds are an essential component in structural glass construction. Practically all structural bonding is carried out with silicones. The reason for this is the excellent durability of silicones and their comparatively safe application. Structural 2-component bonding has proven itself for decades, but no further progress has been made by the manufacturers in this area with regard to the strength or the expansion of the geometric design of glued joints. The regulation by ETAG 002-1 sets very narrow limits in which structural silicone can be used so far. In particular, the ratio of the width to the height of the adhesive joint ensures that a geometric change in the shape of the silicone is possible under tensile stress in order to exclude hydrostatic stress conditions as far as possible. Thus, a structural application of silicone has so far been reduced to linear bonding, as is known from SSG facades.

However, it would be quite possible in many areas to use the proven structural silicones for more advanced applications. From experience in practical work with the material, it is known that this is possible. This however requires to change the strict geometrical specifications of ETAG 002-1, respectively to allow the occurrence of hydrostatic stress states. This requires a comprehensive understanding of the load-bearing behaviour of silicone, i.e. a material model that is capable of correctly representing the material behaviour even under hydrostatic stress conditions.

Examples of conceivable new applications of structural silicone are:

- One-sided restraints of glass, e.g. in the form of a full glass balustrade (SWISSRAILING FLAT),
- Point fixing connections e.g. for forming an all-glass corner,
- Correct dimensioning of very wide edge bonding of insulating glass pan-els, as it occurs e.g. with cylindrical insulating glass along the curved edge,
- more precise dimensioning of the silicone of insulating glass with "toggle fixings",
- Local connection points on the glass, e.g. for shading systems and others.

2. Previous thin-layer silicone bondings

In addition to the general structural silicones, for some time now there has been a silicone adhesive that is deliberately used for thin-film bonding. One manufacturer has tried to establish a highly transparent structural silicone, which is known on the market as TSSL (Transparent Structural Sealant). However, the application of the material by means of an auto-clave process has proved to be too complex to be as successful as the standard structural silicone adhesives. Nevertheless, various universities have investigated the material very closely, as the strength and also the durability of the material are excellent.

3. Transfer of the material model from TSSL to Two-component silicones

Glas Trösch has supported two major studies on the load-bearing behaviour of TSSL with test specimens (the dissertations by M. Drass [1] and M. San-tarsiero [2]) and has itself successfully used this material in many projects. M. Drass' dissertation at the chair of Prof. J. Schneider (University of Darmstadt) was a particularly precise record of the material behaviour of TSSL [1]. In particular, the behaviour under hydrostatic stress conditions can be described perfectly with the Nelder-Drass material model. Since the load-bearing behaviour of TSSL as a silicone is basically comparable to that of conventional 2-component silicones on the market, Glas Trösch, in cooperation with the Institute of Statics and Design at the University of Darmstadt, investigated whether the material model of TSSL can also be transferred to conventional structural 2-component silicones. Using special test specimens, the necessary parameters for the specific material model of two silicones commonly used on the market were determined in a first step. In addition, the entire mechanical load tests of ETAG 002-1 were carried out with the test specimens in order to show that even under high hydrostatic stress conditions, the durability under repeated loads can be reliably carried under the criteria of ETAG 002-1.

3.1. Load-bearing behaviour of 2 component silicones with constrained deformation

For the investigation of the load-bearing behaviour of silicone with hydrostatic state of stress, special test specimens were used in which almost the entire adhesive cross-section is deformation-restrained under tensile loading, i.e. the adhesive joint is under a strongly developed hydrostatic state of stress.

The analytical volume change on a segment of a circle is shown on the right in Fig. 1. The calculated volume change results from the application of the Nelder-Drass material model. This figure shows the condition of the test specimen under the calculated breaking load, which was determined on the basis of the evaluated test results according to ETAG 002-1. The assessment of the load level under tensile stress in areas with hindered deformation is

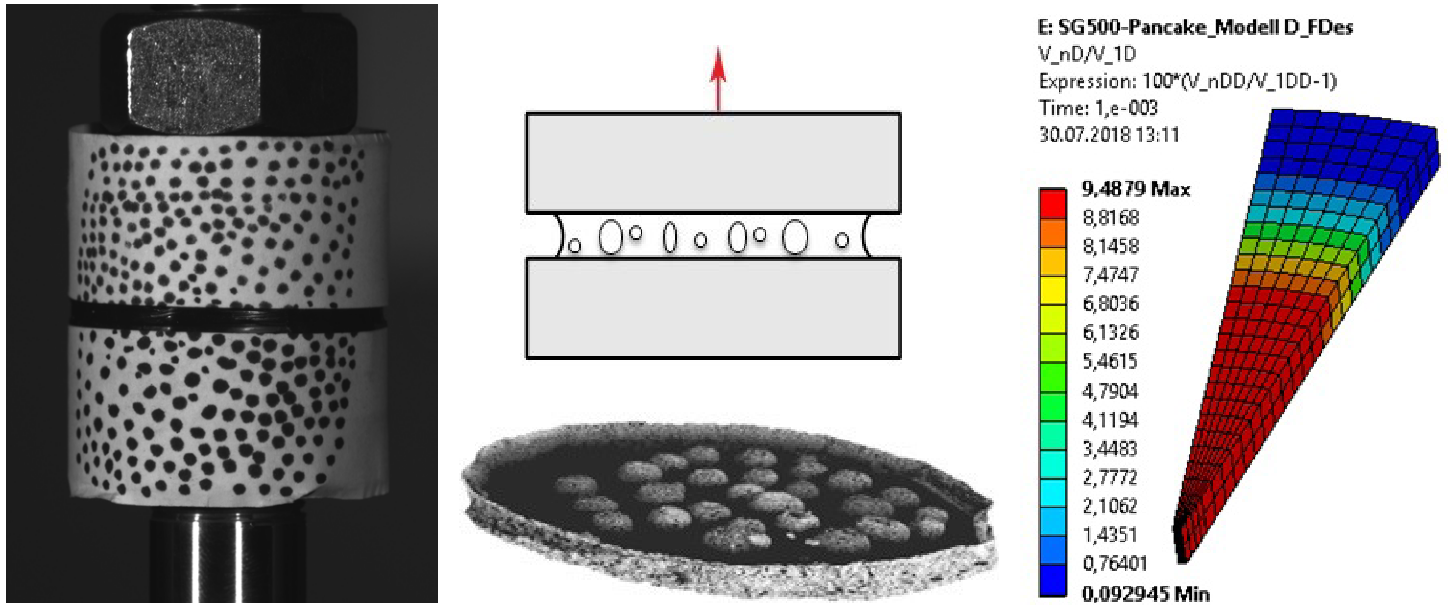

Bild 1 Pancake test specimen with representation of the volume change under hydrostatic stress condition (© M. Drass, Report-Trösch-ISMD-2018; © Euchler, E. et al., Tire Technology International Annual Review)

carried out by determining the volume change that the material undergoes under load.

4. Verification using further bonding geometries

In addition to the pancake test specimens, the calculation results of the material model were also calculated using the usual H-tensile test specimens according to ETAG 002-1. With these test specimens, almost no hydrostatic stress state is formed. Again, there is an excellent agreement between the calculation and the experimental results.

4.1. Structural component test on the SWISSRAILING FLAT balustrade system

In order to verify the general validity of the calculations not only on the basis of laboratory test specimens, the load-bearing behaviour in terms of deformation and strength was precisely documented in a further structural component test. For this purpose, the SWISSRAILING FLAT balustrade system was installed in a test device and loaded at various levels. This balustrade is a bottom constrained laminated glass pane. The constraint support is created with a 180 mm high bonding of the glass panel to an aluminium profile.

The glass pane covers the bonding and the substructure behind it. Figure 2 shows possible installation situations to illustrate the application of the glass balustrade. The silicone bonding has a height of 180 mm and a thickness of 8 mm, which provides effective clamping of the balustrade glass. The silicone is particularly stressed by the bending moment due to the balustrade line and wind loads. Due to the geometric conditions, hydrostatic

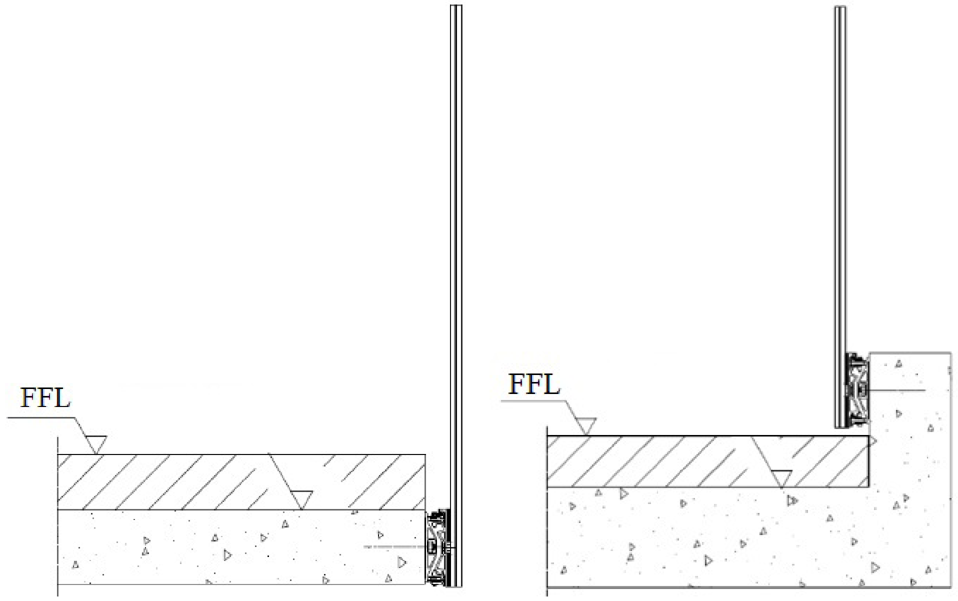

Bild 2 Glass balustrade fixed at the bottom by means of silicone bonding, illustration of possible mounting variants on a concrete structure (© Kassnel-Henneberg, Glas Trösch AG Isolier- und Sicherheitsglas)

stress states occur in the adhesive joint under bending stress, which can be calculated using the Nelder-Drass material model. The test results and the calculations are shown below. In order to be able to carry out the test of the original component effectively and safely, a horizontal arrangement was chosen (see Figure 3), i.e. the balustrade glazing with clamping at the lower edge of the glass was rotated 90 ° into the horizontal. The pane hangs on the bonding and with a lever arm of 1.0 m the desired line load can be applied by using steel weights.

The mirror in Fig. 4 below the bonding is used to safely observe the adhesion surface of the silicone to the glass. The aim was to detect the formation of bubbles in the silicone as a result of the hydrostatic stress state. The width of the glazing was chosen to be quite narrow (0.5 m) in order to limit the loads to be applied. Deviating from the original balustrade system, the glass type had to be changed from TVG to fully tempered glass to prevent glass breakage during the test. The adjustable aluminium construction also had to be strengthened at some points in order to be able to safely carry the enormously high loads during the test. The reason for this lies in the significantly higher safety coefficients for the silicone proof compared to the proofs for aluminium and glass and the resulting high test loads, for which neither the glass nor the aluminium construction of the SWISSRAILING

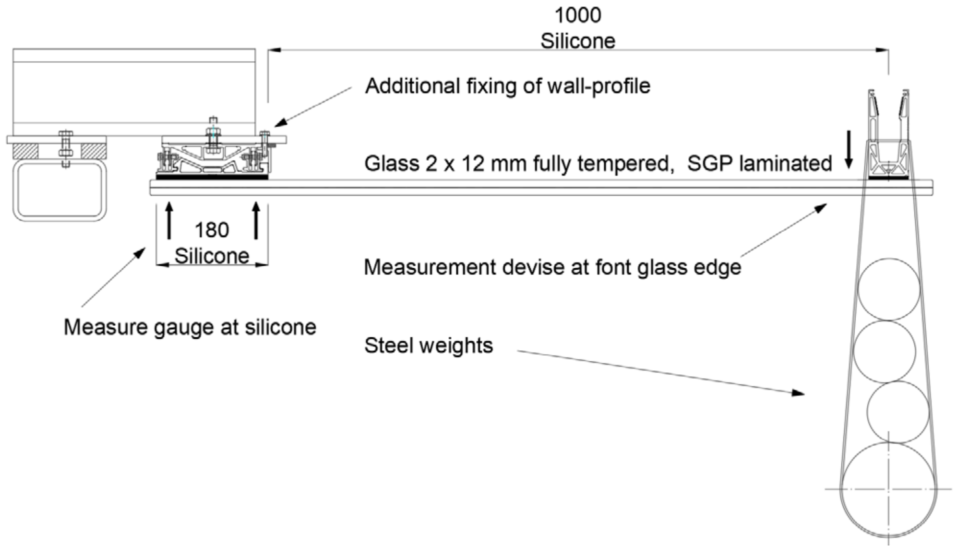

Bild 3 Arrangement for testing the original SWISSRAILING FLAT component (© Kassnel-Henneberg, Glas Trösch AG Insulating and Safety Glass)

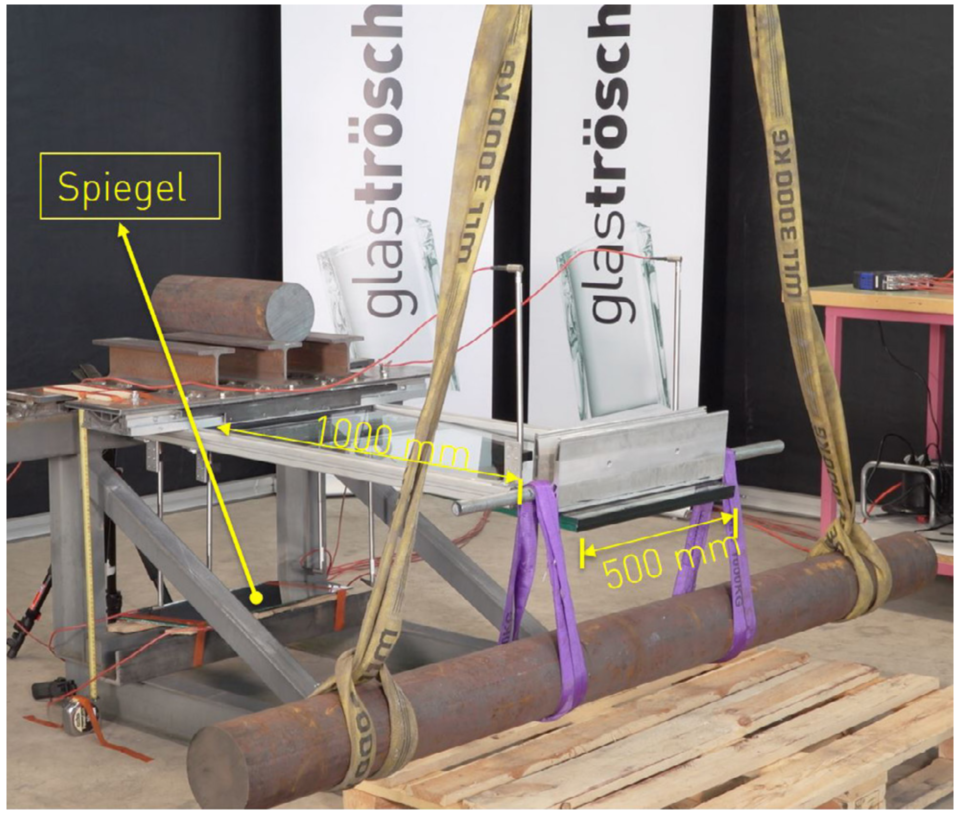

Bild 4 Test device with 6.0 KN/m line load (300 kg), load duration 1 h (© Kassnel-Henneberg, Glas Trösch AG Isolier- und Sicherheitsglas)

FLAT balustrade glazing is designed. In a first loading step, a line load of 6 KN/m was applied to the front edge of the glass (300 kg per 0.5 m glass width). The dead weight of the glass pane is not included. The load on the silicone joint should be as similar as possible to the load on the laboratory test specimens. Influences due to increased loading by dynamic effects (abrupt lowering of the load by the crane) should not take place. In the same way, an attempt was made to adapt the loading speed (duration of load application) to the loading of the laboratory test specimens as closely as possible. In this way, creep influences were to be excluded as much as possible.

It can be seen from the deformation curve in Fig. 5 that an increase in deformation takes place over time, which is not surprising since the load level is already approx. 75 % of the breaking load in the first step. The initial deformation of the front glass edge in the test is 29 mm. The calculation shows a deformation of 30 mm (see Fig. 6). The agreement is therefore very good if the additional influences from interlayer stiffness and also glass thickness tolerances are taken into account. As shown in Figure 5, after the first loading cycle the line load on the front edge of the glass was removed, the load from the dead weight of the glass remained. The deformations almost return to the initial value in a time period of 1.5 h. The load step with 7.44 kN/m was chosen in order to approach the calculated breaking load level. As the system behaved as predicted under load, it was decided to reduce the load step in time and to increase it to the final maximum load of 8.0 kN/m. It was not planned to destroy the adhesive joint during the test. Rather, it was in-tended to demonstrate the "durability" of silicone bonding, even if the type of loading does not correspond to the previous regulations of ETAG 002-1 and other standard specifications due to the present strong hydrostatic stress condition. Figure 7 illustrates in summary which load levels the silicone bonding experiences in the component test under the different load levels.

The designations F_{DES}, F_{Pcak} are the tensile forces of the pancake test specimens. The volume changes determined by calculation are indicated on the right-hand side. The correlation of the line load in the component test is done via the volume change. It can be seen that the load of 8.0 kN/m is already above the breaking load level defined according to ETAG 002-1. The result is also consistent with the observations made during the test. As shown clearly in Figure 5, the increase in deformations over time at the last loading step was very large and failure of the material was only a matter of time. This was also the reason for stopping the test in step 3 after 10 minutes of loading. The test specimen was not intended to be destroyed, but only to be loaded to the limit. After the loading test, the test set-up was arranged vertically and the glass was pendulum-impacted with two pendulum impact tests with a drop height of 900 mm. The silicone joint is thus able to absorb all the further design-relevant loads of a glass balustrade without restriction, despite repeated loading over a longer period of exposure in the range of the breaking strength after unloading.

The test performance on the original component illustrates that the applicability of the laboratory results and the calculation model based on them is given and has general validity. The application of the Nelder-Drass calculation model is thus proven for any geometries and loads. In particular, by carrying out the ETAG test cycles and associated tests on the original component, it was possible to reliably prove that the hydrostatic stress conditions do not have a negative influence on the permanent load-bearing behaviour of

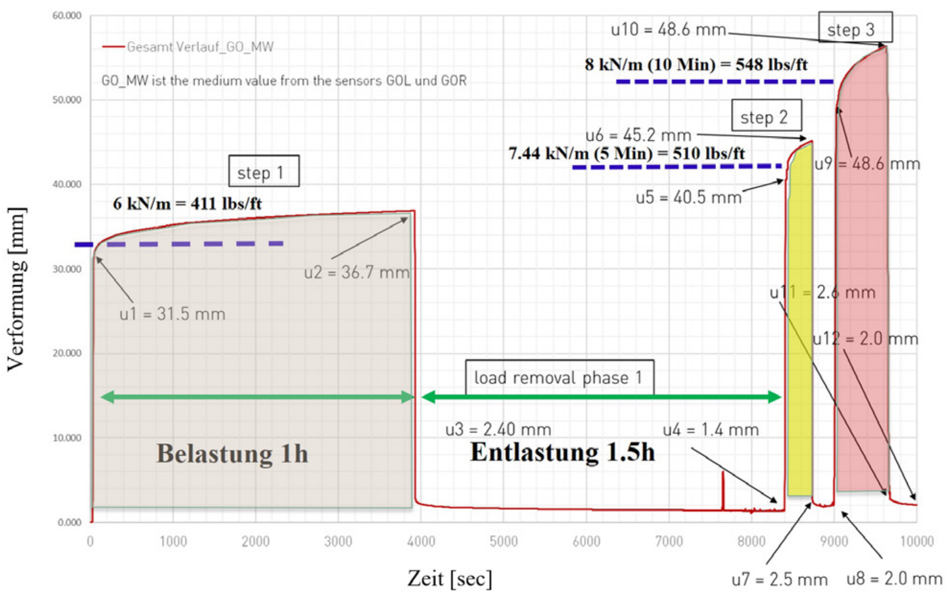

Bild 5 Deformation of the front glass edge as a function of load and time (© Kassnel-Henneberg, A. Hamdan, Glas Trösch AG Insulating and Safety Glass)

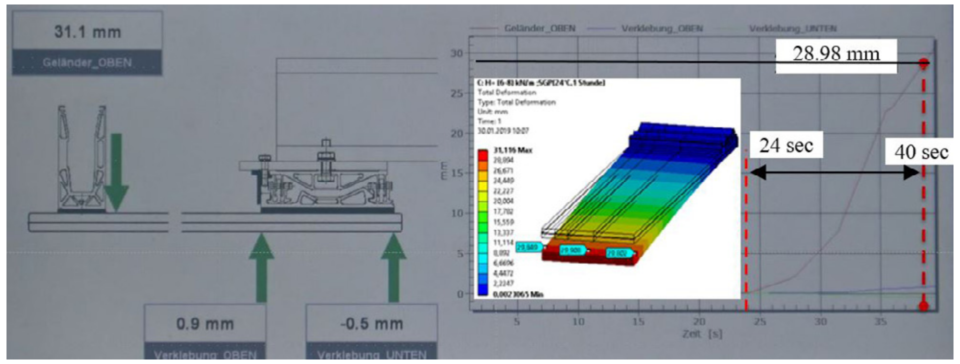

Bild 6 Total deformation at the moment of initial load application of 6 KN/m (© Kass-nel-Henneberg, Glas Trösch AG Insulating and Safety Glass)

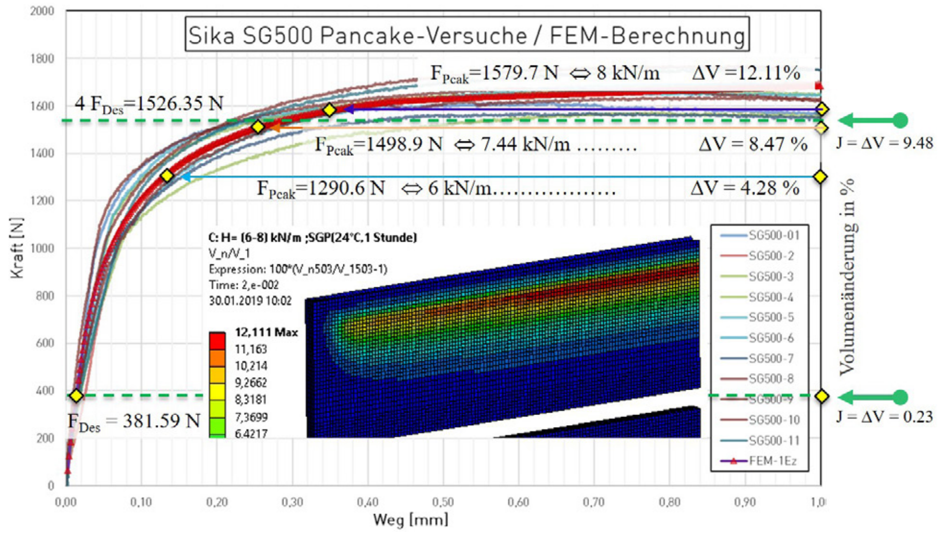

Bild 7 Comparison of the load level between the pancake test and the balustrade test (© Kassnel-Henneberg, A. Hamdan, Glas Trösch AG Insulating and Safety Glass)

silicone. Thus, the basic condition for a general approval of the design procedure by the building authorities was fulfilled in this specific application at the DIBt.

5. Possible applications of any geometries of structural 2-component silicones

The possible applications of the design of structural bonded joints described above are, on the one hand, bonded joints with bond geometries beyond the 1/3-regulation. Irrespective of the geometry, however, it can be usefully applied wherever the silicone is hindered in changing shape under tensile stress and hydrostatic stress states thus occur.

5.1. SWISSRAILING FLAT

The initial product for the application of structural bonding beyond the 1/3 limit according to ETAG 002-1 was the all-glass railing system SWISSRAILING FLAT named above. This product has already been used successfully in Switzerland for years. The dimensioning of the bonding has so far been carried out by means of experimental tests. In the attempt to obtain a general building authority approval for the product in Germany, it was recommended that the verification of the silicone bonding should not only be carried out on a test basis. In order to better understand the construction and thus also the high structural requirements that have to be fulfilled by the bonding, the railing system and its constructive features are further described in more detail.

The essential visual design features of the all glass balustrade system are:

- concealed substructure due to ceramic printing on the glass,
- the glass can project downwards beyond the fixation,
- free upper horizontal glass edge polished after lamination,
- front glass pane hanging freely from the laminated film without additional mechanical fixation.

Constructional attributes:

- perfect adjustability of the glass panes due to the clamping profile technol-ogy
- No constraints and unplanned tensions in the silicone due to improper installation,
- Excellent residual stability for the balustrade line loads of 0.5, 0.8 and 1.0 kN/m verified by testing up to a glass height of 1.5 m above the adhesive joint.

5.2. Punctual bonding

Punctual silicone bonding cannot be carried out with the conventional design methods. The strength of structural silicone is limited compared to other adhesives, but there is no bonding technique that is easier to use and has better durability properties. With the design method described above, considerable loads

Bild 8 All-glass railing SWISSRAILING FLAT in various designs [5] (© Kunz, Kunz Immobilien Langenthal)

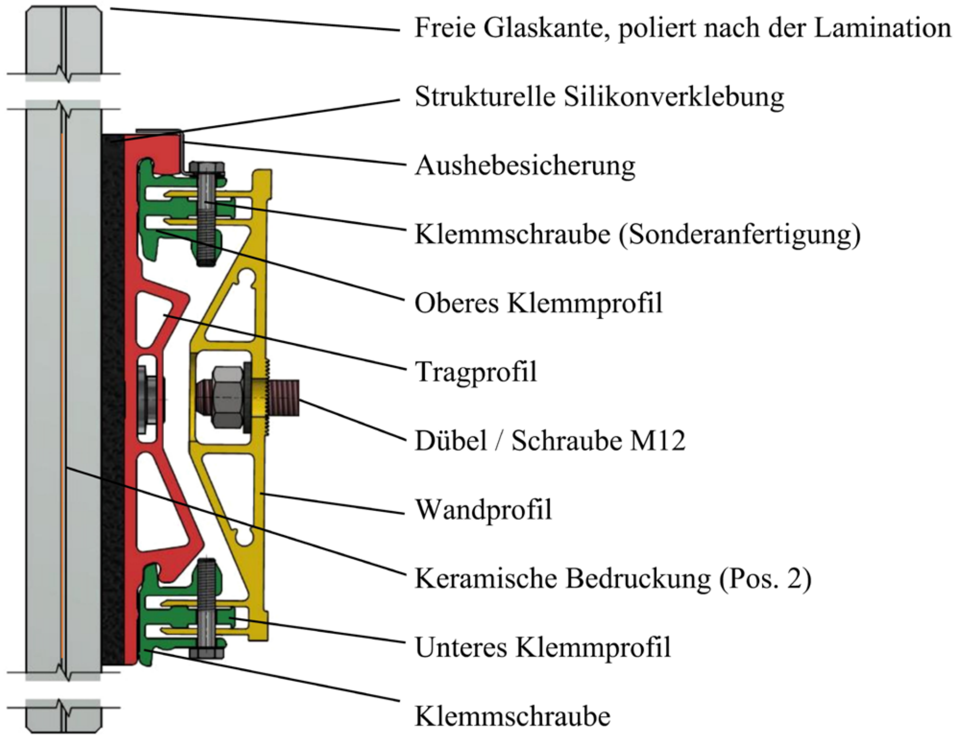

Bild 9 Construction description SWISSRAILING FLAT (© Kassnel-Henneberg, Glas Trösch AG Iso-lier- und Sicherheitsglas)

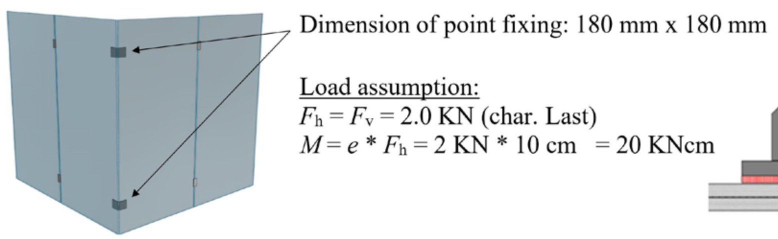

Bild 10 Principle sketch of the corner glazing described and calculation assumptions (© Kassnel-Henneberg, Glas Trösch AG Insulating and Safety Glass)

can be transferred using point bonding, so that it makes sense to use it in façade construction at certain points. As an example, as shown in Fig. 10, a punctual bonding of corner glasses to each other is used, so that an all-glass corner is possible. The components to be bonded can be all glued in the factory.

The glazing with a height of approx. 4.26 m and a width of approx. 2.13 m is fixed at four points by local clamps. With this construction method, the glass in the corner area would require drilling in order to be able to transfer the pressure and suction loads, as the cantilever arms of the point holders are very soft in the direction of the façade and as a result the glass would slip out of the clamp. However, drilling in the area of the clamps causes a very strong increase in tension, so that the glass can no longer be verified. With an adhesive bond, this problem can be overcome so that the glass structure can also be carried out unchanged in the corner area.

As a result of the calculation (see Figure 11), it can be stated that the point bonding can be verified with a utilisation of 83 %, whereby it is not the volume change due to the hydrostatic stress that is decisive, but the edge stresses. The definition of the permissible volume changes and the edge stresses is part of the "Trösch design concept" for silicone, which is approved by the building authorities, and is not explained in detail here. However, the example clearly shows that there is a wide range of applications beyond the 1/3 aspect ratios in the area of punctual silicone bonding, which has not been used so far.

5.3. Verification of the silicone edge seal for curved insulating glass units

In the case of insulating glazing, in exceptional cases there may be an edge seal dimension where the geometric ratios are beyond 1/3 and thus cannot be verified according to ETAG. Here, too, the described material model and design model can be used.

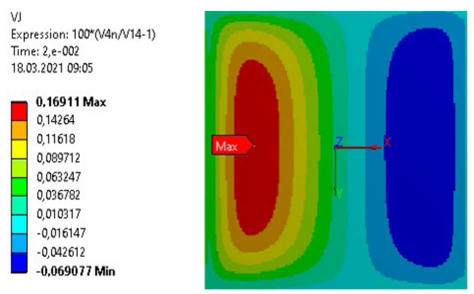

Bild 11 Berechnungsergebnisse in Form von Volumenänderung und Randspannungen (© A. Hamdan, Glas Trösch AG Isolier- und Sicherheitsglas)

6. Literatur

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