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DIN 18008 – Experience after one year of applying the new German glass design standard

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The new German Glass design standard DIN 18008 – parts 1 to 5 – was finally established in the beginning of 2015, being accepted by the authorities already a few months earlier. As the application is obligatory since then, a lot of experience could be gained in the meantime. Every standard has to pass several steps of control and revision before being approved. Nevertheless the actual application brings up new aspects and questions about certain details and the corresponding interpretation and intention of the standard. The following paper will discuss some important aspects of DIN 18008 in order to provide some clarification for the users of DIN 18008 and some input to the working groups of the future European glass standards as well as for the next review of the DIN 18008.

Keywords: German glass standard, application experience, regulation, basic design principles, future design standard development

1. Introduction

1.1. Standard structure and content

The German glass standard DIN 18008 “Glass in Building – Design and construction rules” consists of 6 parts:

- Part 1: “Terms and general bases”
- Part 2: “Linearly supported glazing”
- Part 3: “Point fixed glazing”
- Part 4: “Additional requirements for barrier glazing”
- Part 5: “Additional requirements for walk-on glazing”
- Part 6: “Additional requirements for walk-on and fall-through-protection glazing in case of maintenance procedures” (working-title)

whereof parts 1 and 2 were published in December 2010, parts 3 – 5 in July 2013 and part 6 in February 2016. Parts 1 – 5 became mandatory in 2015, part 6 is not yet officially established by the authorities. The following paper will concentrate on parts 1 to 5.

The general structure of the 6 parts is self-explaining, regarding the subtitles of each part. Part 1 is the basis for all other parts, defining the general safety concept according to the Eurocode safety concept. Part 2 and 3 cover most glass structures as they are either linearly supported, point supported or a combination of these (covered in part 3). Parts 4 to 6 cover additional requirements for certain applications. Only the titles of part 5 and 6 might be confusing as both titles refer to “walk-on glazing”. While part 5 refers to regularly accessible glazing like glass floors or even (pedestrian) bridge decks, part 6 refers to any overhead or horizontal glazing that may be accessed – usually by one person only – for maintenance or servicing.

1.2. Standard context

For a better understanding of some of the problems explained below, it could be helpful to be aware of some specialties in German building and construction regulation. Besides design according to approved design standards there are two more ways to a legal and appropriate structure or building.

- Special building permit (“Zustimmung im Einzelfall”)
- General building approval (“Allgemeine bauaufsichtliche Zulassung”)

The special building permit is limited to structures or structural details that are not according to any approved standard or general building approval. Very similar to the “European Technical Approvals” (ETA) or the “European Technical Assessment” as it will be called in the future, the general building approval tries to fill the gap between special building permits that are only valid for an individual building and building standards that usually take years to be established, reviewed and/or approved. The generals building permits are issued by the “Deutsches Institut für Bautechnik DIBt” and can be requested for building products or construction types – using certain products. Product approvals usually refer to a design standard, to define the design basis for the product. Most of glass related products still refer to the “old” design rules “TRLV”, “TRAV” and “TRPV” as the approval’s validity is up to 5 years. This leads to a certain incompatibility of many approved products and design standard especially as with DIN 18008 the basic safety concept changed from “allowable stresses” in the “TRxV” to design values with partial safety factors for both, actions and resistance.

2. Part 1 – Terms and general bases

As the title reveals, the content of the first part are basic requirements for the application of this standard and definitions of relevant terms.

2.1. Calculation effort and safety level

DIN 18008-1 differentiates between annealed and pre-stressed glass either heat strengthened (HSG) or fully tempered glass (FTG). For annealed glass a time depending stress resistance has to be considered. This led to a significant increase of calculation effort – compared to the former design rules – as usually several loads with different load durations have to be considered (e.g. dead load: permanent, barrier load: “medium duration” (approx. 1 hr.), wind: “short duration” (3 s)). What makes the calculation even more extensive is that for climatic loads of insulating glass units (IGUs) DIN 18008 differentiates between the altitude difference of production and installation as a permanent load and the air pressure variation due to weather conditions as a “medium duration” load. Therefore for certain standard window situations more than 30 load combinations have to be considered. The advantage of this procedure is that the calculation is more adapted to the mechanical properties of the material glass and therefore more appropriate. In other countries (e.g. the Netherlands) the load duration is considered even more precisely leading to more load cases. Additionally the time depending resistance is considered for all glass types but for the pre-stresses glass types only for that part of the action-caused stresses that exceed the pre-stress limit.

About the necessary effort, the comparison of old and new standards has been discussed and also been published a lot. The question is: Is the – possible – breakage of e.g. one layer of an IGU really a matter of safety at this level? The safety factors of DIN 18008 for the calculation for IGUs – as well as in most up-to-date glass design standards – are same as in the Eurocodes for structural members at ultimate limit state (ULS). That means that e.g. for the verification of standard window panes for wind and climatic actions the same safety level is required as e.g. for the main framework of a high rise tower. Of course it must be ensured that the glass would not drop out of the frame, but for many vertical glass members, especially in IGUs or if made of laminated glass, the breakage itself does not necessarily cause any danger – in contrast to the failure of a main framework member.

For those situations, where no danger arises from breakage, the verification by calculation could be limited to the level of serviceability (serviceability level state: SLS). As a consequence, the question of accountability for possible glass breakage must be clarified as it becomes more probable. This is currently discussed in the review process and will be taken into account for the next edition.

2.2. Resistance stresses

The resistance stresses are only described as formulas in DIN 18008, with all parameters defined or explained except the characteristic resistance stresses f_k. The lack of the explicit values is often criticized by users but is caused by the DIN regulations that state that a double regulation must be avoided. As the glass resistance stresses are defined in the basic product standards, they cannot be defined in DIN 18008 again, especially as it directly refers to these product standards. These are

- EN 572-2 i.c.w. “BRL” for annealed float glass with f_k = 45 N/mm²,
- DIN EN 12150-1 for fully tempered glass with f_k = 120 N/mm²,
- DIN EN 12150-1 for enamelled fully tempered glass with f_k = 75 N/mm²,
- DIN EN 1863 for heat strengthened glass with f_k = 70 N/mm² and
- DIN EN 1863 also for enamelled heat strengthened glass with f_k = 45 N/mm².

One way to meet the expectations of both sides might be to add these values as a comment whether in an extra comment document or as a comment/annotation within the standard.

2.3. Shear effect

According to DIN 18008-1 the shear effect of the interlayer must not be taken into account for calculation if the effect is favourable/positive to the results and must be taken into account – as full shear transfer – if the effect is unfavourable/negative to the results. But the load carrying capacity may be increased by 10% for laminated safety glass (LSG) and laminated glass (LG).

On the other hand there are several general approvals for interlayer that allow the consideration of the shear effect for certain situation. Up to now all of these approvals refer to the old technical rules (TRxV) and can therefore not directly be applied with DIN 18008. To the authors' understanding the shear modulus values can be used with DIN 18008 if the additional factor of 1.1 for LSG is not being used. The review of DIN 18008-1 should consider the shear effect and clarify the intention of the LSG-factor.

2.4. Nonlinear behaviour

Although the procedure of calculation structures with nonlinear effects is part of DIN 1055-100 as well as of Eurocode 0, DIN 18008-1 explicitly requests the user to follow this procedure. The background to this regulation is that the common procedure of calculation with partial safety factors on the actions leads to a lower safety level if the action effect increases less than the action. The different procedures and its effects in such a situation are shown in figure 1.

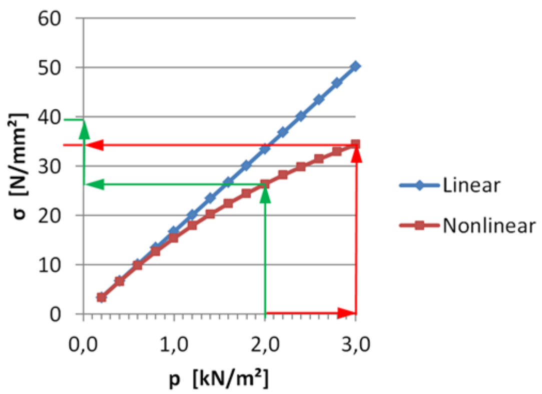

Fig. 1 Comparison of linear and nonlinear behaviour

For a four-side simply (Navier-) supported glass plate figure 1 shows the different results for linear (blue) and non-linear (dark-red) calculation. Due to the membrane effect, the maximum stresses (effect) increases slower than the action (distributed load) according to the non-linear calculation. Therefore DIN 18008-1 demands the user to calculate the effects by dividing the design load by the partial safety factor of the leading load (the result is the characteristic load for this simple example) and multiply the result (effect) with this factor. This procedure is shown in figure 1 with green arrows. If the calculation is done the usual way – the partial safety factor is applied directly to the action – as shown in red arrows in figure 1, the result (maximum stress) is about 15% smaller compared to the "right" procedure.

The "right" procedure is formulated as a "should be"-regulation in DIN 1055-100 and as a "can-be" regulation in Eurocode 0. Only paragraph 8.2.2 in DIN 18008-1 makes it a "has-to-be"-regulation in Germany. The experience shows that the "right" procedure is almost never applied; additionally most glass-calculation-programs don't even offer the possibility to calculate with safety-factors on the effect-side.

Therefore it should be considered to do without this paragraph or limit it to certain situations, although the safety level is slightly smaller with the standard calculation procedure. The situation right now is that almost any glass related calculation can easily be declared as "not according to approved standard" by the checking engineer if a non-linear calculation has been performed the common way.

2.5. References to action standards

Although DIN 18008-1 requests the user in 6.1 to determine the actions according to "corresponding standards" what could be understood as "currently valid", which would be the Eurocode 1 (in combination with Eurocode 0), it refers directly to DIN 1055-100 (which is the old equivalent to Eurocode 0) in 8.3 for the verification at ultimate limit state. As standard concepts should not be mixed, many users consequently determine all actions according to DIN 1055 what brings an important difference: according to DIN 1055 barrier load and wind load do not need to be superposed at all whereas according to the Eurocode it must me superposed with the corresponding combination reduction factors. Especially for glass barriers this makes a big difference resulting in different glass thicknesses. Therefore the next review of part 1 should clarify the intention of referring to DIN 1055 and whether the interaction of wind and horizontal barrier loads has to be taken into account.

3. Part 2 – Linearly supported glazing

Part 2 of DIN 18008 is very close to it's precursor regulation "TRLV" that was in use since 1998 – with some modifications during that period. Therefore most details are very well-tried and only some issues still up to discussion.

3.1. Residual load carrying capacity

For requirements regarding the residual load carrying capacity (RLCC) part 1 refers to the following parts for design specific regulations. Unfortunately part 1 doesn't include any regulations besides general constructional restrictions for "horizontal" glazing. Thus every design aberrant to any of these constructional restrictions makes the design drop out of the design standard necessitating a general or individual building permit.

However the procedure of verification of sufficient RLCC is always the same: A test sample identical to the designed glass element is being loaded with half the design load and the accessible plies are broken with a centre punch trying to create a disadvantageous fracture pattern. If the element can bear this load for 24 hours, the RLCC can be regarded as being sufficient.

If this common "standard" test procedure would be included in part 2 – like several testing procedures are included in parts 3 to 6 – aberrant designs could be verified by a general appraisal certificate "only", issued by an – accredited – testing institute instead of applying for an individual or general approval. This would mean a significant decrease of effort and time especially as the restrictions are quite strict. For example: any "horizontal glazing" with a span of more than 1.2 m (at the short side) must be supported on all four sides. Additionally, if the glass element would be accessible, there would be a testing procedure provided in parts 5 and 6.

3.2. One side supported glazing

Part 2 is restricted to plane glazing with linear supports on at least two opposite sides of the glass element acting in both directions (e.g. wind pressure and suction). This restriction excludes many common structures like wind walls or dividing glass walls. While a glass barrier, clamped on the bottom edge only (called "category B" in DIN 18008-4) can be verified according to part 4 that refers to part 2 for calculation, the same glass barrier can – if following the restriction strictly – not be verified if it acts not as an anti-fall barrier but as a wind wall only. That is because part 4 is not relevant (for anti-fall elements only) and part 2 excludes one-side supported glazing.

A similar situation appears when looking at glass dividing walls that are frequently used to separate balcony areas belonging to different flats. These are usually clamped or fixed at two sides, but not on opposite sides but on adjoining sides. And again these elements cannot be verified due to the "two-opposite-side restriction".

At least for vertical glazing this restriction should be questioned. For horizontal glazing the verification becomes more complicated as the question about RLCC arises. Maybe this could be resolved in combination with a RLCC testing procedure as discussed in 3.1 or by demanding an additional safety fixing keeping the glass in place if the clamping becomes loose.

3.3. Curved Glass

Similar to the restriction covered in 3.2 also curved glass is excluded by the condition of "plane glass" in part 2. It is a cutback compared to the former "TRLV" where curved glass was allowed. Right now there is no – approved – standard for curved glass as a building product, therefore this restriction doesn't much harm as there is a separate approval necessary anyway. Nevertheless the applications with curved glass are becoming more very quickly so it could be a good idea to leave this restriction out after the next review process to provide the possibility to do a verification of curved glass according to DIN 18008 as soon as an approved building product standard for curved glass is established. Especially on the European level this should be considered for the future Eurocode Glass.

4. Part 3 - Point fixed glazing

Part 3 is a further developed "TRPV" with some important extensions as support and reference values for the verification of the user's finite element model, the simplified verification concept, by which a point supported glazing can be calculated without using a finite element model (FEM) and a testing procedure for the point fixings.

As the main part is still quite close to the former "TRPV" the problems and questions came up when using the new elements of part 3.

4.1. Verification of the FEM by comparison – annex B

As the convergence test of the finite element model became obligatory with DIN 18008, many users tried to do the verification using annex B that provides a comparison model with comparison results that should be obtained within a margin of 5 %.

Unfortunately the reference values are for a steel plate instead of a glass plate (due to a different Poissons's ratio), which is correctly stated in the text, but which is often overlooked by the users.

Additionally the given values are the results of experiments and not of calculations. The comparison with other tests, as well as with the results in recent scientific publications and also with the results of some very experienced users showed slightly different values.

In a review it should be considered to adapt the results and additionally some more comparison data or references to it could be provided.

4.2. Testing procedure for point fixings – annex D

Annex D concerns only testing institutes as only approved institutes are allowed to issue a general appraisal certificate based on the testing results. As up to now there are no institutes approved for this testing procedure, so the experience is very little. Nevertheless some institutes started testing according to this regulation and came up with some questions and remarks.

The basic complain is that the testing seems more complicated than the former standard testing procedure: loading until failure. What makes the new concept more extensive is the stepwise increase of load with unloading between the load steps. The main reason behind this is to enable the user to find the serviceability limit load of the fixing for the investigated load direction/type.

Up to now the standard testing procedure was to load the fixing until its failure to determine the ultimate load F_u and calculate the characteristic resistance value as the 5%-percentile of the ultimate values, assuming a 75% confidence level. The condition of the point fixing at any load was not taken into account. Figure 2 shows a point fixing under approx. 2/3 of the ultimate lateral load. This condition is certainly not acceptable for any type of glazing.

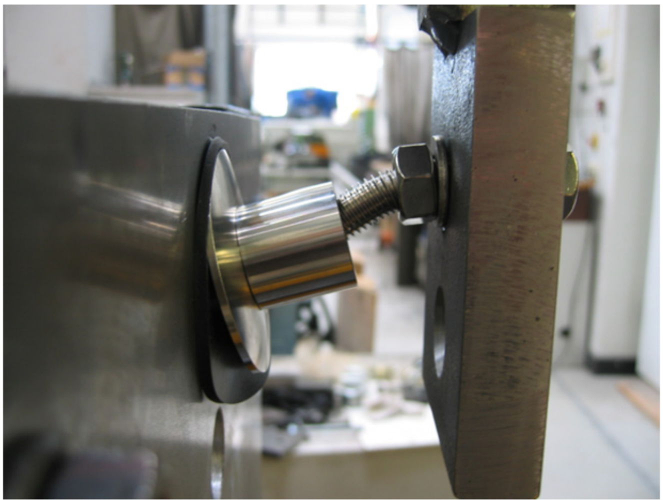

Fig. 2 Comparison of linear and nonlinear behaviour

With DIN 18008 came the new safety concept, providing the basic situations of ultimate limit state ULS and serviceability limit state SLS. Therefore also the testing procedure aims to provide sufficient data to determine both values. As SLS criteria the elastic limit was chosen to avoid permanent deformations at characteristic load level. And to be able to determine the elastic level, it was decided to load the fixing in 10 equal steps in order to detect the lead level where permanent deformations occur.

According to the feedback of the testing institutes even more confusing seemed the formulation of the "target value" F_a. There are two reasons for that value: First: If the user is requested to apply the load in ten equal steps, there must be a value to start with. And this can be done by setting a target value F_a and starting with 10% of the target value.

The second reason for F_a is the prevention of damage to the testing machine, usually a hydraulic or electric cylinder with adapters to fix the specimens to be tested. It's usually not the cylinder itself that might get damaged, but the adapters and connecting brackets that are being deformed, especially if the test samples show large deformations sometimes changing the load transfer mechanism. On the other hand – as explained before – such deformation cannot be accepted in the real structure, thus there is no need to risk damage to the machinery anyway.

The following example shows an easy way to get useful results with the testing procedure in annex D:

In a first pre-test an acceptable maximum deformation at SLS should be defined (F_{start}), providing a first approximation for C_d. The target value F_a can then be estimated to

$$F_a = F_{start} \cdot \gamma_m \cdot \gamma_{m2} \cdot \gamma_f = F_{start} \cdot 1.1 \cdot 1.25 \text{ as worst case.}$$

If then $F_u = 3 \cdot F_a$ and an elastic limit $F_{el} > F_{start}$ can be reached in all tests, the resistance value at SLS van be determined to

$$R_d = F_a / \gamma_m \cdot \gamma_{m2} = F_{start} \cdot \gamma_f$$

thus ensuring that $R_d > \gamma_f \cdot C_d$. By that the R_d will always be high enough to allow a characteristic load up to C_d supposing C_d as the load causing the maximum tolerable deformation at SLS as described above. This – of course – only applies if neither the elastic limit nor a breakage at a load smaller than $3 \cdot F_a$ leads to lower limit values.

If this way or another, a defined testing procedure for point fixings would be very helpful in a future Eurocode too, not necessarily as a “must-have” for all point fixings but as an alternative to a verification by calculation. Many point fixings have a quite complex geometry, and different materials, making the calculation sophisticated. Additionally testing often leads to better – higher – results as the calculation usually works with worst case assumptions.

However, any testing procedure should be laid out to provide both, a resistance value R_d as the load carrying capacity at ULS and a resistance value C_d as the maximum acceptable load at SLS.

Additionally, the load-deformation-diagrams can be used to determine the stiffness for each load direction. These values can be used in the calculation to get better results – especially if temperature loads have to be taken into account.

4.3. RLCC

As for linearly supported glazing the residual load carrying capacity for point fixed glazing is also only verifiable by observing all given restrictions for horizontal glazing. The same testing procedure as described in 3.1 could be included in part 3 to provide a possibility to verify a sufficient RLCC if one or more conditions for horizontal glazing is not met.

4.4. Edge distance of drilling

Part 3 demands an edge distance of at least 80 mm between the edge of the glass pane and the drilling edge. This is due to the lower stress resistance near the edges as the pre-stress in the glass decreases there. For some applications – i.e. sliding doors or glass barriers “category B” – this requirement cannot be fulfilled. Part 1 allows smaller edge distances if the stress limit of annealed glass is considered instead of heat strengthened or fully tempered glass.

If this concept is applied strictly, most standard “category B” glazing according to part 4 – B.3e could not be verified by calculation as the edge distance typically is about 35 mm and the stresses at the bore hole would exceed the maximum stress for float glass. Therefore it would be desirable to improve this regulation according to research results concerning the pre-stress distribution in the edge area. Otherwise a comment on how to deal with the small edge distance in common “category B” glazing would be helpful (in part 4).

5. Part 4: Additional requirements for barrier glazing

Parts 4 is very specific as it is adopted from the former regulation “TRAV”, adopting the general differentiation of three basic classes of barrier glazing. The basic concept is to differentiate different requirements for different risk levels. Risk level to be understood as the risk a person would be exposed if falling against the (glass) barrier and the glass would break. The lowest level is called “category C” and requires an independent handrail, able to carry the static barrier load with or without glass. The highest level is “category A” with glass as the only barrier without any handrail or secondary drop protection. Between those two – consequently – a “category B” is set-up with a handrail connected to and depending on the glass. It is additionally specified as clamped at the bottom edge – the typical all glass balustrade.

With this very specific set-up also the problems arising are quite specific and will therefore only be discussed briefly in this chapter.

5.1. Definition of “category B”

“Category B” is defined as clamped along the bottom edge, the individual glass panes being connected by a continuous handrail either fixed directly on the upper edge or with point fixings. This definition is often understood as a design principle rather than a risk class as the important distinction is only explained in chapter 6 – actions and verification: The handrail must be capable of bearing the barrier load even if the glass is broken or at least partly broken if the edges are protected. As a consequence any so called "category B" glazing without a handrail or consisting of one glass pane only with the handrail not being connected to any independent structure cannot be regarded as "category B" but must be considered as "category A" with its more demanding requirements – i.e. a drop height of 900 mm at the pendulum test.

It might be a good idea to specify this important requirement right at the beginning where the categories are defined.

5.2. Stay safe in position

According to 5.1 an edge guard is not necessary for categories "A" and "C" if LSG is used, the glazing is fixed with point fixings with plates on both sides – and if the glazing stays safe in its position if the glass breaks.

The last requirement is expressed quite vague. As for point fixed glazing annealed glass is not admitted the only distinction to be made is whether it is LSG made of HSG or LSG made of FTG. To the authors' understanding LSG made of FTG cannot be regarded to stay safe in position without further examination as the risk of "unbuttoning" is quite high due to the small fracture pattern of FTG.

It would be very helpful if a future edition of part 4 would specify the requirement of "kept safe in position". It could provide a minimum thickness and stiffness of the interlayer and/or a testing procedure to examine the glazing behavior in case of doubt.

5.3. Edge guard

Part 4 – annex E provides a testing procedure for the verification of the effectiveness of edge guards. This is a great improvement as the term "edge guard" was interpreted very differently in the past. Unfortunately the testing procedure is included and connected to the standard testing procedure for the verification of the barrier glazing (pendulum test). As a result an edge guard cannot be regarded to be effective itself but only for the configuration is had been tested with (except for the two very massive edge guards described in annex F). The reason for this procedure was to consider the possibility of micro cracks caused by the edge guard test that might stay undetected under the edge guard but might cause a loss of resistance for the pendulum test.

It showed that the combined testing is extremely laborious and for many – solid – edge guards in vain as the glass pane is not affected by the edge guard test (steel ball drop) at all. Therefore two alternatives should be considered:

An easy testing procedure would be to execute the steel ball drop on a specified glass sample and examine it afterwards to detect damages to the glass edge. It should be considered that for all pre-stressed glass types certain edge damage is allowed – up to 5 % of the glass thickness. This definition could be applied to evaluate the glass edge condition after the ball drop test, too. A stricter requirement could be to allow no visible damage to the glass surface after the steel ball drop(s).

If the possibility of invisible micro cracks has to be considered, an independent standardized test set-up for the combination of steel ball drop and pendulum test could be established: A standard glass format and type with the edge guard mounted on. Then first the steel ball test would be executed and afterwards the pendulum test. If the set-up passes the pendulum test, the edge guard was effective (enough).

Either way, the combination of steel ball drop and pendulum test for any individual test set-up should be limited for those situations where the edge guard does not pass the above mentioned simplified tests, but still might be effective enough to let the investigated configuration pass the pendulum test.

5.4. Minor subjects

According to C.1.5 the user is allowed to calculate the soft impact on IGUs without considering the interaction through the enclosed gas volume if the inner glass is designed for the full impact load. Furthermore the user is requested to verify the outer pane for 50% of the impact load if the thickness ratio – outside pane thickness to inside pane thickness – is smaller or equal to 1.5. Otherwise the outer pane has to be verified for 100% of the impact load. The given verbalization makes it difficult to understand whether this second requirement applies always or only if the interaction of outer and inner pane through the enclosed gas volume is not considered. To the authors' opinion this requirement applies always as also the testing procedure requires an additional test for the outer pane even if the inner pane did not break during the pendulum test (A.1.11).

In the former TRAV the deviation of approved point fixed glazing was defined according the given parallelogram for "category B" glazing. In DIN 18008-4 an additional figure was included to explain the allowed angles and distances for point fixed glazing. But while the TRAV allowed an angle of 49° as minimum angle between two glass edges (and part 4 still allows 49° degrees for "category B" glazing – corresponding to a inclination of 41° for the stairs in figure B.4) the new figure B.2 limits the minimum angle to 60°, corresponding to a maximal inclination of

30° of the stairs. To the author's knowledge this change was not intended and should be adjusted during the next review.

6. Part 5: Additional requirements for walk-on glazing

Although part 5 is the only officially established part of DIN 18008 – until now – with no direct precursor document, the procedure for both – calculation and testing – is well established. The calculation follows the requirements in part 2 and 3 with the live loads according to the building type. The testing procedure was previously defined by the building authorities.

The only major complain so far was that the table of approved glazing is very limited regarding the maximum size. It is to be expected that this gap will be filled quickly by general appraisal certificates that can be issued for tested configurations now instead of general building approvals that were necessary before.

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