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Serviceability: The Missing Standard in Glass Railing Design

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Abstract

All-glass railings have become indispensable in modern architecture. They combine aesthetics and safety but place high demands on design and fastening. While pendulum impact tests and static calculations demonstrate basic safety, serviceability is often overlooked. A railing must return to its original position after loads such as wind or impact. In practice, however, certain systems do not fully return to their initial position. Wedges, rubber components or movable bearings shift, leaving railings permanently inclined - often misinterpreted as poor installation although it is a system-inherent weakness. The Swiss glass construction standard SIA 2057 differs significantly from comparable standards in other countries. It explicitly emphasizes serviceability, durability and the avoidance of local stress peaks. A critical aspect is the bottom glass edge restraint: in many systems it is not designed as true line support, leading to stress concentrations and an increased risk of glass breakage. In practice, this means that damage usually results from insufficient system design rather than faulty installation. Ensuring long-term safety requires not only uniform regulation but also practical test procedures, such as simulating horizontal loads on the handrail. The contribution presents damage cases, compares international standards and highlights solutions. Its aim is to strengthen awareness of serviceability as a decisive quality criterion and to underline the need for clear rules and validated testing methods.

Keywords

All-glass railings, Serviceability, SIA 2057, Testing procedures, Norms comparison

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Fig. 1: Lack of Serviceability.

1. Introduction

All-glass balustrades have become indispensable in modern architecture. They meet high aesthetic requirements and perform a safety-relevant function as fall-protection elements. In contrast to conventional railing systems, the glass itself assumes the primary load-bearing function. Conventional verification procedures predominantly focus on the ultimate limit state of load-bearing capacity. Structural calculations as well as impact or pendulum tests serve to verify fracture safety and residual load-bearing capacity after glass breakage. This ensures structural safety under defined load cases. The behavior after unloading – i.e., whether the system returns to its geometric design position – is rarely defined as an independent requirement with measurable limit values in existing regulations. This is precisely where a practical problem arises: wedges may migrate, elastic supports may settle, profiles may permanently spread, and glass elements may remain in an inclined position under certain boundary conditions. Such phenomena are frequently assessed as installation errors but are often system-related. The starting point of this study is therefore the discrepancy between normatively covered load-bearing capacity and actual long-term performance. The objective is to analyze serviceability as an independent quality criterion, to identify normative differences in system understanding, to describe typical mechanisms of serviceability loss, and to derive from this an additional testing procedure for evaluating restoring capability. Typical manifestations of insufficient serviceability are illustrated in Fig. 1.

2. Structural Behaviour of All-Glass Balustrades

2.1. Normative Modelling Approaches

The assessment of all-glass balustrades depends significantly on the underlying structural model. A central difference exists between DIN 18008-4 (Germany) and SIA 2057 (Switzerland). DIN 18008-4 generally considers the free-standing glass section above the clamping zone as the governing load-bearing element; the restraint is often modeled as an idealized boundary condition. The specific detailing of the installation situation – local load introduction, discrete support, prestressing mechanisms – is not always represented computationally with the same level of detail. SIA 2057, by contrast, requires that for bottom-clamped glass balustrades the calculation model represent the entire glass pane including the clamping zone (SIA 2057, 5.5.1.3) and that local stress concentrations resulting from the constructive restraint configuration be captured (SIA 2057, 5.5.1.4). SIA therefore demands an explicit representation of real clamping and support conditions, which is essential for stress peaks, durability, and serviceability (see Fig. 2)

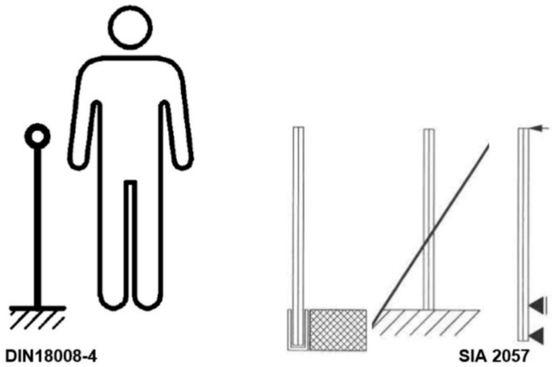

Fig. 2: Structural system DIN 18008 vs. SIA 2057.

2.2. Support Conditions and Local Stress Concentrations

Irrespective of the applicable standard, the avoidance of unintended local stress concentrations is a fundamental requirement. DIN 18008-1 requires support "avoiding unintended local stress concentrations" (DIN 18008-1, 10.1.1) and demands that design-relevant restraint forces resulting from temperature effects or installation be constructively excluded or otherwise considered (DIN 18008-1, 10.1.3). SIA 2057 similarly requires sufficiently accurate consideration of restraint stresses, particularly those resulting from temperature or substructure deformations (SIA 2057, 4.2.1.4; 6.1.2). In addition, requirements concern contact mechanics: TRLV and ÖN B 3716-1 require that no contact between glass and rigid materials (e.g., metal) may occur under load and temperature effects (TRLV 3.1.4; ÖN B 3716-1, 6.2). In practice, many clamping systems are discrete: rotating wedges, sliding wedges, split wedges or clamping jaws generate locally concentrated pressure zones. These often do not appear in idealized models but may be decisive – both for local edge stresses and for restoring behaviour.

2.3. Influence of the Substructure and Indirect Actions

All-glass balustrades are part of an overall load-bearing system. DIN 18008-1 requires that influences of the supporting structure (imperfections, deformations) be considered in verification (DIN 18008-1, 7.1.5). Indirect actions such as restrained deformations due to temperature changes, moisture or settlement must be treated as a separate category of action in accordance with DIN 1055-100 (DIN 1055-100, 3.1.2.3). Since these actions act directly in the clamping zone, an idealized restraint assumption without considering real profile deformation and restraints carries the risk of underestimating local stresses. The installation situation is therefore an integral part of both the structural and serviceability model.

2.4. Line Support versus Discrete Clamping and Moisture Effects

SIA 2057 evaluates recessed, bonded or clamped supports as point supports; combinations of local supports with line supports are likewise considered point-supported (SIA 2057, 6.3.1.1). It also refers to increased fracture risk due to local stress concentrations in the case of non-linear support (SIA 2057, 5.5.5.2). In practice, systems are often formally described as line-supported although point loads are introduced. Fig. 3 illustrates such a case, where local bonding points using adhesive anchors (e.g. Hilti HIT) lead to discrete load introduction instead of continuous line support. Mechanically, this results in a grid-like load introduction with increased contact pressures – a potential starting point for edge stresses, wedge migration and permanent positional changes. Moisture management is also critical. ÖN B 3716-1 requires that edges of laminated glass (VSG) must not be permanently exposed to moisture and that drying of exposed edges must not be impeded (ÖN B 3716-1, 6.2). Consequently, complete embedding of exposed laminated edges in moisture-conducting profiles may not be constructively permissible depending on detailing. TRAV additionally requires materials to be permanently resistant to frost, temperature fluctuations, UV radiation and contact materials (TRAV 2.4).

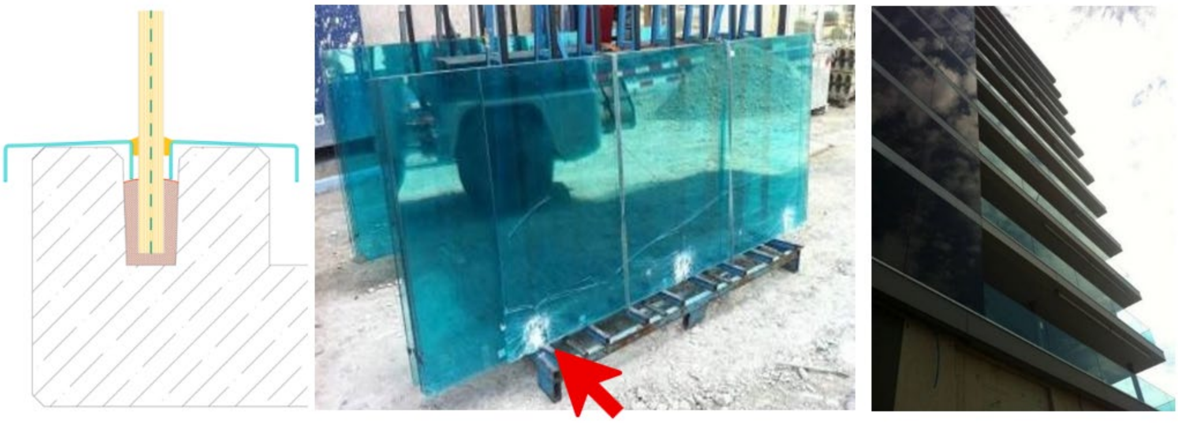

Fig. 3: Nominal line support versus discrete load introduction through local adhesive bonding points.

2.5. Impact Behaviour and Complete System Modelling

SIA 2057 permits analytical impact verification only if the structural behaviour of the glazing, including the retaining construction and connection to the substructure, is represented with sufficient accuracy in the model (SIA 2057, 4.3.5.3); a fully dynamic transient simulation is recommended (SIA 2057, 4.3.5.4). For evaluating local contact conditions and restoring capability, a simplified beam model of the cantilevering glass section alone is therefore insufficient; the decisive factor is the entire system consisting of profile, contact zone, restraints and substructure.

3. Serviceability as an Independent Limit State

3.1. Distinction between Load-Bearing Capacity and Serviceability

In structural glass engineering, verification is often focused on load-bearing capacity. Serviceability, by contrast, concerns functional performance and geometric behaviour during operation. EN 1990 distinguishes between reversible and irreversible serviceability limit states (EN 1990, 3.4). DIN 1055-100 emphasizes that serviceability concerns functionality, comfort and visual appearance (DIN 1055-100, 10.1). For all-glass balustrades this means: load-bearing capacity addresses fracture safety, whereas serviceability describes positional stability and functional performance during operation.

3.2. Serviceability States, Performance and Quality Criterion

In many all-glass balustrades with wedge- or elastomer-based clamping systems, irreversible states occur without fracture. Typical phenomena are permanent deviation from vertical alignment, cumulative slip and irreversible profile spreading. The focus thus shifts from maximum stress toward the restoring capability of the overall system. SIA 2057 assigns serviceability to quality requirements and ranks it equally with structural safety, residual load-bearing capacity and durability (SIA 2057, 2.7.1). Loss of positional stability leads to loss of confidence, altered load introduction, increased restraint stresses in the clamping zone and may contribute to progressive damage under further load cycles.

3.3. Positional Stability and Restoring Behaviour

In all-glass balustrades, serviceability can essentially be reduced to positional stability and restoring capability. Neither is automatically ensured by load-bearing verification; both depend on contact pressure, profile deformability, friction and contact conditions, ageing behaviour of polymer components and ingress of moisture and particles. Serviceability is therefore largely a system-related issue.

4. The Installation Fixation Load Case (IFL)

4.1. Definition and Structural Relevance

Calculations are typically performed for self-weight, wind load, imposed load or impact; the installation condition is rarely treated as a separate load case. In practice, all-glass balustrades are fixed using wedges, clamping jaws or elastomeric inserts. This results in prestressing forces in the clamping zone already in the installation state. These are structurally intended but not precisely reproducible and are usually not part of the structural verification. DIN 18008-1 requires restraint forces due to installation to be constructively excluded or considered (DIN 18008-1, 10.1.3). SIA 2057 requires comparable treatment for constructively unavoidable restraints (SIA 2057, 6.1.2). Installation-induced prestresses must therefore be classified as relevant actions.

4.2. Mechanical Characteristics of the IFL

The Installation Fixation Load Case (hereinafter IFL) describes the stress state in the glass resulting from constructive fixation during installation. Typical characteristics are locally concentrated contact pressures, eccentric load introduction due to uneven wedge penetration depths, pre-deformation of the profile flanges and prestressing in the glass edge region. The actual clamping force introduced depends on tolerances, temperature, friction coefficients and installation force and cannot be precisely quantified under practical installation conditions. The question remains how, in practice, the perpendicular pressure acting on the glass can be determined solely by wedge advancement. Practical installation experience indicates that immediately after installation a manual stability check is commonly performed. During this procedure installers typically apply a horizontal force at handrail level corresponding approximately to a line load of about 0.3 kN/m. This action may therefore be considered a realistic estimate of the order of magnitude of the Installation Fixation Load Case (IFL). Nevertheless, this condition forms the starting point for all subsequent actions.

4.3. Superposition and Influence on Serviceability

According to DIN 1055-100, imposed or restrained deformations must be treated as indirect actions (DIN 1055-100, 3.1.2.3). The IFL is structurally a forced deformation. If not considered, edge stresses may be underestimated – particularly in combination with temperature restraints, substructure deformation and service load. The IFL affects not only load-bearing capacity but directly serviceability: uneven wedge forces and elastomer settlement lead to asymmetric friction conditions, reduced restoring reserve and initial inclination. Under repeated service loads, redistributions may occur: wedges migrate, elastomers settle, profile flanges deform permanently. Depending on profile material and system concept, plastic profile deformation, screw relaxation or viscoelastic settlement may act as mechanisms. In installation practice, clamping effectiveness is often tested by horizontal leaning/pushing at handrail height. This preloading is mechanically part of the installation condition and may influence the initial position.

4.4. Consequences for Verification Concepts

A realistic verification concept should consider the IFL as a defined initial condition: the stress state prior to service loads is not zero, and restoring capability depends essentially on the stability of the prestressing system. The IFL is therefore a structurally relevant system state.

5. Time-Dependent Influences on Serviceability

5.1. Ageing of Polymeric Interlayers and Hysteresis

Many systems use elastomeric or polymer interlayers such as EPDM or silicone elastomers, plastic wedges or similar inserts. These materials are subject to creep, relaxation, compression set, UV/ozone ageing and temperature-dependent stiffness changes. Moisture and freeze–thaw effects can further influence elastomer behaviour and positional stability, see Fig. 4. SIA 2057 therefore requires durability and resistance to relevant environmental influences (SIA 2057, 2.6.2), as does TRAV (TRAV 2.4).

Fig. 4: Moisture and freeze–thaw effects affecting elastomers and positional stability.

The ageing behaviour of such components is difficult to quantify in general terms. Typical compression set values for elastomeric materials may range between approximately 10–30 % under long-term loading and elevated temperature conditions, depending on material composition and environmental exposure. While high-quality elastomers such as EPDM or silicone usually provide well-documented long-term properties, some systems also use materials such as PVC, TPE or double-sided adhesive films with less transparent durability data. In addition, identical components are often used for different glass thicknesses, which raises fundamental engineering questions and calls for systematic experimental verification of their long-term mechanical behaviour.

5.2. Particle Ingress and Mechanical Blockage

Under service load, temporary profile opening may occur, creating entry paths for fine dust, sand, quartz grains or organic particles. SIA 2057 requires avoidance of permanent moisture exposure and provision for maintenance and cleaning (SIA 2057, 2.6.1; 2.6.4). Particles in the contact zone between glass and profile may act as mechanical blockage, as shown in Fig. 5. Upon unloading, they prevent complete return movement (grain blockage). This term refers to mechanical interposition of foreign particles reducing the closing path of the profile flanges after unloading. The consequence is permanent deviation from vertical alignment, top-edge misalignment and cumulative slip – without exceeding normative loads.

Fig. 5: Sand, gravel and particles in the clamping insert area.

5.3. Climatic Actions and Environmental Exposure

Outdoor all-glass balustrades are exposed to temperature changes, freeze–thaw cycles, UV radiation, driving rain and moisture. EN 1990 requires environmental influences affecting durability to be considered through material selection and constructive detailing (EN 1990, 4.1.7). Temperature differences between glass and profile produce relative length changes. If restrained by high-friction or constraining contact conditions, additional restraint stresses arise. Moisture promotes particle ingress and agglomeration or binding. Installation prestress creates an initial condition; under repeated service loads profiles may temporarily open, allowing particle ingress while elastomer components gradually lose restoring capability. The resulting condition is a potentially irreversible loss of serviceability with potentially still existing load-bearing capacity.

6. Observed Damage Mechanisms, System Assessment

6.1. Typical Observations in Practice

In operation, recurring phenomena are observed, often without fracture: permanent deviation from vertical alignment, progressive slip and locally bent profile flanges, and glass fracture in the clamping zone without apparent external overload. Such phenomena often occur only after years and are typically the result of cumulative effects.

6.2. Mechanical Interpretation

Mechanically, these observations can be attributed to local stress peaks due to discrete load introduction, unconsidered installation prestress, profile spreading, grain blockage, loss of restoring force and restraints. SIA 2057 refers to increased fracture risk for non-linear support (SIA 2057, 5.5.5.2). Fractures in the clamping zone often show crack initiation near local compression zones, indicating constructively induced contact and stress problems.

6.3. Serviceability Loss Without Glass Fracture

Permanent positional change frequently occurs without glass fracture. After load cycles, the glass may no longer remain in its vertical position, profile flanges may remain partially spread, wedges may have migrated. This corresponds to an irreversible serviceability limit state (EN 1990, 3.4): load-bearing capacity may still exist, but function and geometric design position do not.

6.4. System-Related Weakness Versus Installation Error

An installation error exists if manufacturer specifications were not followed, impermissible materials were used or installation forces are clearly outside typical ranges. A systemic weakness exists if uniform contact pressure is not ensured, restoring capability is not constructively secured, serviceability is lost despite standard-compliant installation or time-dependent effects cannot be controlled. Since standards require durability and resistance (SIA 2057, 2.6.2; TRAV 2.4) and restraints must be considered (DIN 18008-1, 10.1.3; SIA 2057, 6.1.2), causes must be assessed as systemic rather than purely workmanship-related where constructive requirements cannot be fulfilled.

6.5. Consequences for Assessment Practice

Assessment must not be limited to load-bearing verification. It must be examined whether the real clamping situation was modelled in conformity with the structural model, whether installation prestress/restraints were considered, whether restoring capability is constructively ensured and whether long-term influences are systematically evaluated.

7. Limits of Existing Test Procedures

7.1. Focus on Load-Bearing Capacity

Normative tests (static line load, impact/pendulum test, residual load-bearing capacity) predominantly assess the immediate response of newly installed systems. Failure or fracture behaviour is evaluated, but not the behaviour after unloading or under repeated loading.

7.2. Lack of Evaluation of Installation Condition and Time-Dependent Effects

The IFL factually exists but is not assessed as a defined initial condition. Neither long-term stability of installation prestress nor migration of contact pressures under load cycles nor reproducible return to the initial position are investigated. The normative requirement to consider restraints is thus only indirectly covered. Real use is cyclic (leaning, changing wind, occasional impacts); polymer-based components change over time. Short-term testing in the new condition does not answer whether restoration occurs after many load cycles, whether particle ingress causes permanent positional change or whether settlement/loss of restoring force impairs function.

7.3. Impact Verification Without Evaluation of Restoring Capability

SIA 2057 requires complete system modelling for analytical impact verification (SIA 2057, 4.3.5.3). Even if impact verification is passed, it remains open whether the system returns to its design position. A system may "pass" impact testing yet remain functionally inclined.

7.4. Lack of Systematic Evaluation of Positional Stability

Typically evaluated are maximum deflection, fracture behaviour and residual load-bearing capacity. Not systematically evaluated are permanent deviation from vertical alignment, permanent profile spreading, cumulative slip or restoring times. These parameters directly affect function and visual appearance (DIN 1055-100, 10.1).

8. Proposal for an Extended Testing Procedure for Serviceability

8.1. Objective

The objective is an additional testing procedure for evaluating long-term serviceability of systems whose fixation relies essentially on local clamping, frictional engagement or elastomeric interlayers. The assessment determines whether the system returns to its design position after repeated service loading under realistic environmental conditions without readjustment and without permanent positional change (see Fig. 6)

Fig. 6: Simplified test setup with narrower glass and correspondingly reduced weight for evaluating serviceability.

8.2. General Test Concept – Specimen and Boundary Conditions

The concept is based on four guiding assumptions: (1) IFL as initial condition, (2) cyclic service load, (3) profile opening promotes particle ingress, (4) ageing/settlement alters restoring behaviour. The testing procedure shall be structured sequentially and modularly. The test specimen shall use a standard production profile and clamping system, without any special execution. Glass dimensions shall correspond to the maximum permissible system height, with a representative clamping length (e.g. ≥ 1.2 m). Installation shall be carried out in accordance with manufacturer specifications. No additional securing/bonding unless part of the system. Relevant positions shall be marked and measured instrumentally.

8.3. Reference Measurement

Recording of the initial condition: deviation from vertical alignment (mm/m), top-edge position (mm), reference dimension of profile flange spacing, wedge positions.

8.4. Cyclic Service Load Test

The test begins with a defined initial load (IFT) of approx. 0.3 kN/m as horizontal line load at the upper glass edge. This represents a practice-relevant preloading. Subsequently, cyclic horizontal line loads with suitable frequency shall be applied. Load amplitude and number of cycles shall be derived from a representative wind load collective, particularly considering expected wind gusts over a defined period, for example five years.

8.5. Simulation of Particle Ingress

Defined particle ingress (standardized test dust or quartz sand of defined grain size; classification to be specified) into the clamping zone during or after cycling, followed by continuation of cycles. The objective is the reproducible testing of grain blockage and loss of restoring capability.

8.6. Climatic Preconditioning

Temperature cycling, moisture exposure or combined sequences to simulate ageing and restraint effects. Reference to durability requirements (SIA 2057, 2.6.2; EN 1990, 4.1.7).

8.7. Performance and Evaluation Parameters

Key performance Indicators (KPIs): permanent deviation from vertical alignment $\Delta\theta$ (mm/m), permanent top-edge offset Δu (mm), permanent profile spreading Δb_{pl}, cumulative slip (mm), restoring time t_{90}. Serviceability is fulfilled if after all modules no progressive displacement is detectable, no impermissible permanent positional changes remain and no readjustment is required. Acceptance limits must be defined project-specifically or normatively; the procedure proposes measurable parameters and sequences.

8.8. Integration with Normative Load-Bearing Verification

The testing procedure does not replace load-bearing verification but complements it. Meaningful sequence: (1) IFL including preloading, (2) service cycling, (3) normative main load (e.g. 0.5 kN/m residential, 1.0 kN/m public; in Switzerland often 0.8 kN/m). This verifies whether load-bearing capacity is achieved under realistic installation and preloading conditions.

9. Conclusions

For all-glass balustrades, a relevant gap may exist between normatively covered load-bearing verification and real long-term performance. Load-bearing capacity alone is insufficient to describe long-term system performance. In systems with discrete, friction-based clamping and polymer interlayers, restoring capability becomes an independent system property influencing long-term performance. Normatively, essential requirements are established: avoidance of local stress concentrations, avoidance of rigid contact, consideration of restraints and substructure deformations as well as requirements regarding durability and moisture management. Decisive is the consistent transfer of these requirements to the clamping zone and the real system model. The difference in system understanding – idealized restraint versus explicit modelling of the entire system including the clamping zone – is central in this respect. The Installation Fixation Load Case creates an initial condition of prestress, contact pressure and profile pre-deformation. This is superimposed with cyclic use, ageing of viscoelastic components, particle ingress and climatically induced restraints. From this interaction an irreversible serviceability limit state may result, typically expressed by permanent inclination, cumulative slip or profile deformation - often without fracture, but with functional and visual consequences and potentially increasing local edge stresses over time. Existing test procedures verify load-bearing capacity in the new condition but insufficiently represent serviceability loss under cyclic loading and time-dependent influencing factors. An additional testing procedure is required that defines the installation condition as initial state, represents cyclic service loads, makes particle ingress testable and optionally includes climatic preconditioning. Evaluation must consider not only maximum deformation under load but restoring capability and positional stability after unloading using measurable parameters ($\Delta\theta$, Δu, Δb_pl, slip, t90). Five fields of action result: (1) consistent representation of the real clamping zone in the structural model, (2) explicit consideration of installation-induced restraints/prestresses, (3) constructive assurance of uniform, permanently stable contact pressure without rigid contacts, (4) definition of restoring capability as an independent performance characteristic, and (5) implementation of supplementary test methods representing real operating conditions. Serviceability is thus an integral component of the structural quality of fall-protection glazing, and systematic evaluation of restoring capability enhances durability and reduces damage cases.

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