Glass in building - Determination of the strength of glass panes - Part 3: General method of calculation and determination of strength of glass by testing
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Annex ZN (informative): Proposal for a model of a National Annex (informative)
Foreword

This draft European Standard has been prepared by the Technical Committee CEN TC 129 ‘Glass in Building’, the secretariat of which is held by IBN.

CEN/TC 129/WG 8 ‘Mechanical Strength’ prepared the draft ‘Glass in building - Determination of the strength of glass panes - Part 3: General method of calculation and determination of strength of glass by testing’.

CEN/TC 129 has decided to submit Part 3 of this draft European Standard to the CEN enquiry.
Introduction

European Standard prEN 13474 gives the principles of determining the strength of glass for resistance to loads.

Part 1 of this European Standard gives simple methods for determining by calculation the resistance to load of glass used in fenestration.
Part 2 of this European Standard gives simple methods for determining by calculation the resistance to load of glass used in common non-structural applications other than fenestration.
Part 3 of this European Standard gives the general method of calculation of the strength and load resistance of glass and determination of the load resistance of glass by testing.

The principles of determining the strength of glass to resist loads are based on the structural Eurocode EN 1990: Basis of structural design. The actions are determined in accordance with the structural Eurocode series EN 1991: Basis of structural design - Actions on structures, including the National annexes.

In the design processes, the safety aspect is part of national competency. For that reason this European Standard foresees that, to conform the rules applied by the Eurocodes, the material partial factor $\gamma_M$ is subject to nationally to determine parameters:

- a first value for the ultimate limit state (ULS);
- a second value for the serviceability limit state.

Those values can be found in an informative (National) annex to this European Standard.

When a Member State does not use its prerogative and no values for the material partial factor has been determined, the recommended values given in this European Standard should be used.
1 **Scope**

This European Standard gives the principles of determining the strength of glass to resist loads. It gives:

- the general method of calculation, and
- determination of load resistance by testing for any application.

For simple calculation of the load resistance of glass products for fenestration or for common applications other than fenestration, refer to prEN 13474-1 and prEN 13474-2.

This European Standard does not determine suitability for purpose. Resistance to applied loads is only one part of the design process, which may also need to take into account:

- environmental factors (e.g. sound insulation, thermal properties),
- safety characteristics (e.g. fire performance, breakage characteristics in relation to human safety, security)

2 **Normative references**

This European Standard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated by amendment or revision. For undated references, the latest edition of the publication referred to applies.

EN 572 Glass in Building - Basic soda lime silicate glass products
EN 572-1 Glass in Building - Basic soda lime silicate glass products - Part 1: Definitions and general physical and mechanical properties
EN 1036 Glass in building - Mirrors from silver coated float glass for internal use
EN 1096 Glass in building - Coated glass
EN 1296 Glass in building - Insulating glass units
EN 1748-1 Glass in Building - Basic borosilicate glass products
EN 1748-1-1 Glass in Building - Basic borosilicate glass products - Part 1: Definitions and general physical and mechanical properties
EN 1748-2 Glass in Building - Basic glass ceramics products
EN 1748-2-1 Glass in Building - Basic glass ceramics products - Part 1: Definitions and general physical and mechanical properties
EN 1863 Glass in building - Heat strengthened soda lime silicate glass
EN 1863-1 Glass in building - Heat strengthened soda lime silicate glass - Part 1: Definition and description
EN 1990 Eurocode – Basis of structural design
EN 1991 Actions on structures
EN 1991-1-4 Wind actions
EN 1997 Geotechnical design
EN 1998 Design of structures for earthquake
EN 12150 Glass in building - Thermally toughened soda lime silicate safety glass
3 Definitions

3.1 annealed glass

Glass which has been treated during manufacture to minimise the residual stress in the glass, allowing it to be cut by scoring and snapping. Examples are float glass, drawn sheet glass, patterned glass and wired glass.

3.2 effective thickness (of laminated glass)

A thickness calculated for laminated glass which, when used in place of the glass thickness in an engineering formula, will result in a reasonably accurate determination of the deflection of and / or stress in the laminated glass.

3.3 prestressed glass

Glass which has been subjected to a strengthening treatment, by heat or chemicals, which induces a compressive surface stress into the whole surface of the glass, balanced by a tensile
stress within the body of the glass. Examples are thermally toughened safety glass, heat strengthened glass and chemically strengthened glass.

### 3.4 structures and infill panels

#### 3.4.1 main Structure

The beams, the columns, the floor forming the main structure of the building (see figure 1).

Note. These are structural for so far that they carry themselves and secondary structures, and, in case of failure, endanger the fundamental stability of the building. The main structural elements must have a safety and a reliability appropriate to their design use and larger factor of safety than the one applicable to the secondary structure or to the non structural infill elements. These main structures are the reference structure and constitute the point of reference for the coefficients determined hereafter.

#### 3.4.2 secondary structure (e.g. glass fins)

Windows assembly frames, which are secondary structures insofar as their stability is their own.

Note. A failure of these secondary structures only affects the infill panels or the non-structural elements carried by this secondary structure and in no case has any effects on the main structure of the building. The secondary structures can be replaced independently of the main structures.

#### 3.4.3 infill panels

Elements placed in structures in order to close a building and which do not contribute in any manner to the stability of the main structure.

Note.

#### 3.4.4 classes of consequence

Classes which allow for the fact that the failure of the secondary structures or the infill panels does not have the same economic and/or human consequences of that of the failure of the main structures.

Note. A reduced factor of safety is thus acceptable on the actions. The coefficient of class of consequence, \( k_{FI} \), expresses the reduction of safety applicable to the secondary structures and infill panels compared to that applicable for the main structures according to the EN 1990 appendix B. This coefficient is integrated in the partial coefficients relating to the actions, \( \gamma_Q \) and \( \gamma_G \), except in the case where the action has a favourable effect in a combination of actions. The coefficient of class of consequence does not apply to the partial coefficients relating to materials.
3.5 unfactored load

an action as obtained from EN 1991 (e.g. wind load, snow load), including all the factors relevant for determining the action, but before applying the partial factors for actions $\gamma_0$, $\gamma_0$ and/or $\gamma$

4 Symbols and abbreviations

$A$ Surface area of the pane ($= a \times b$)
$a$ Shorter dimension of the pane
$a^*$ Characteristic length of an insulating glass unit
$b$ Longer dimension of the pane
$C_d$ Limiting design value of the relevant serviceability criterion
$c_H$ Coefficient for the effect of altitude change on isochore pressure (=0,12 kPa/m)
$c_{\text{prob}^2}$ Probability factor applied to the wind pressure for different return periods
$c_T$ Coefficient for the effect of cavity temperature change on isochore pressure (=0,34 kPa/K)
$E$ Young’s modulus
$E_d$ Effect of the action(s)
$E_{\text{SLS},d}$ Serviceability limit state design value of the effect of the action(s)
$E_{\text{ULS},d}$ Ultimate limit state design value of the effect of the action(s)
$E_{\text{ULS},G}$ Ultimate limit state design value of the effect of a permanent action
$E_{\text{ULS},i}$ Ultimate limit state design value of the effect of a non-dominant action
$E_{\text{ULS},1}$ Ultimate limit state design value of the effect of the dominant action
$E\{F_{\text{SLS},d}\}$ Calculation of the effect of the serviceability limit state design value

$E\{F_{\text{ULS},d}\}$ Calculation of the effect of the ultimate limit state design value

$F_{d}$ Design value of the action
$F_{d,1}$ Design value of the action on pane 1 of an insulating glass unit
$F_{d,2}$ Design value of the action on pane 2 of an insulating glass unit
$F_{\text{SLS},d}$ Serviceability limit state design value of a single action or of a combination of actions.

$F_{\text{ULS},d}$ Ultimate limit state design value of a single action or of a combination of actions.

$f_{b,k}$ Characteristic value of the bending strength of prestressed glass
$f_{g,d}$ Allowable maximum stress for the surface of glass panes
$f_{g,k}$ Characteristic value of the bending strength of annealed glass

$G$ Value of self weight load
$H$ Altitude
$H_P$ Altitude of production of insulating glass unit
$h$ Nominal thickness of the pane
$h_1$ Nominal thickness of pane 1 of an insulating glass unit or ply 1 of a laminated glass
$h_2$ Nominal thickness of pane 2 of an insulating glass unit or ply 2 of a laminated glass
$h_3$ Nominal thickness of pane 3 of an insulating glass unit or ply 3 of a laminated glass

$h_{\text{ef},w}$ Effective thickness of a laminated glass for calculating out-of-plane bending deflection
Effective thickness of a laminated glass for calculating out-of-plane bending stress of ply $j$

Nominal thickness of pane $i$ of an insulating glass unit or ply $i$ of a laminated glass

Nominal thickness of pane $j$ of an insulating glass unit or ply $j$ of a laminated glass

the distance of the mid-plane of the glass ply 1 from the mid-plane of the laminated glass, ignoring the thickness of the interlayers

the distance of the mid-plane of the glass ply 2 from the mid-plane of the laminated glass, ignoring the thickness of the interlayers

the distance of the mid-plane of the glass ply 3 from the mid-plane of the laminated glass, ignoring the thickness of the interlayers

the distance of the mid-plane of the glass ply $j$ from the mid-plane of the laminated glass, ignoring the thickness of the interlayers

Coefficient used in the calculation of large deflection stresses

Coefficient used in the calculation of large deflection deflections

Coefficient used in the calculation of large deflection volume changes

Coefficient of class of consequence expressing the reduction of safety applicable to the secondary structures and infill panels compared to that applicable for the main structures

Factor for the load duration

Factor for the load duration of the dominant action in a load combination

Factor for the load duration when there are combined loads

Factor for the load duration of a permanent in a load combination

Factor for the load duration of a non-dominant action in a load combination

Factor for the glass surface profile

Factor for strengthening of prestressed glass

Air pressure

Isochore pressure for an insulating glass unit

Isochore pressure due to the effect of change in cavity temperature and air pressure

Isochore pressure due to the effect of change in altitude

Air pressure at the time of production of insulating glass unit

Non-dimensional uniformly distributed load

Value of the single action or dominant action

Values of the actions which are not dominant

Design value of the resistance to the actions

Nominal cavity width of a double glazed insulating glass unit

Insulating glass unit cavity temperature

Temperature of production of insulating glass unit

Load duration (in hours)

Volume change in an insulating glass unit cavity due to the deflection of one of the panes

Allowable deflection

Maximum deflection calculated for the design load

Coefficient used in the approximate calculation of $k_4$

Coefficient used in the approximate calculation of $k_1$

Coefficient used in the approximate calculation of $k_1$

Coefficient used in the approximate calculation of $k_1$
\( \delta_1 \) Stiffness partition for pane 1 of an insulating glass unit
\( \delta_2 \) Stiffness partition for pane 2 of an insulating glass unit
\( \gamma_G \) Partial factor for permanent actions, also accounting for model uncertainties and dimensional variations
\( \gamma_M \) Material partial factor
\( \gamma_{MA} \) Material partial factor for annealed glass
\( \gamma_{Mv} \) Material partial factor for surface prestress
\( \gamma_Q \) Partial factor for variable actions, also accounting for model uncertainties and dimensional variations
\( \varphi \) Insulating glass unit factor
\( \lambda \) Aspect ratio of the pane ( = \( a/b \) )
\( \mu \) Poisson number
\( \rho \) Glass density
\( \sigma_{\text{max}} \) Maximum stress calculated for the design load
\( \sigma \) Coefficient for the shear transfer of an interlayer in laminated glass
\( \psi \) Combination factors for the actions
\( \psi_{0,i} \) Combination factors for the actions which are not dominant
\( \psi_{1} \) Partial factor for a frequent value of a variable action
\( \psi_2 \) Combination factor for a quasi-permanent value of a variable action
\( \psi_{2,i} \) Combination factor for a quasi-permanent value of a variable action

Note. This value is determined - in so far as it can be fixed on statistical bases - so that either the total time, within the reference period, during which it is exceeded is only a small given part of the reference period, or the frequency of it being exceeded is limited to a given value. It may be expressed as a determined part of the characteristic value by using a factor \( \psi_1 \leq 1 \)

Note. This value is determined so that the total period of time for which it will be exceeded is a large fraction of the reference period. It may be expressed as a determined part of the characteristic value by using a factor \( \psi_2 \leq 1 \)

Note. This value is determined so that the total period of time for which it will be exceeded is a large fraction of the reference period. It may be expressed as a determined part of the characteristic value by using a factor \( \psi_{2,i} \leq 1 \)

5 Requirements

5.1 Basis of determination of glass strength

The process shall conform to EN 1990: Eurocode – Basis of structural design.

The determination of actions shall be in accordance with the relevant parts of EN 1991: Actions on structures. Where relevant or required, the following shall also be taken into account:

- EN 1997: Geotechnical design, and
5.2 General requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Ultimate limit state</th>
<th>Serviceability limit state</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E_{ULS,d} \leq R_d$ (1.a)</td>
<td>$E_{SLS,d} \leq C_d$ (1.b)</td>
</tr>
</tbody>
</table>

where the effect of the actions is:

\[ E_{ULS,d} = E\left(F_{ULS,d}\right) \] (2.a) \[ E_{SLS,d} = E\left(F_{SLS,d}\right) \] (2.b)

in which:

$F_{ULS,d}$ is the Ultimate Limit State design value of a single action or of a combination of actions.

$F_{SLS,d}$ is the Serviceability Limit State design value of a single action or of a combination of actions.

and where:

$E_{ULS,d}$ is the design value of the effect of the action(s), expressed as calculated stress, caused by the action(s).

$R_d$ is the design value of the corresponding resistance, expressed as maximum ultimate limit state allowable stress $f_{g;d}$, taking into account the material partial factor for the ultimate limit state $\gamma_M$ (see 5.3).

$E_{SLS,d}$ is the design value of the effect of the action(s), expressed as calculated stress or deflection, caused by the action(s).

$C_d$ is the limiting design value of the relevant serviceability criterion, expressed as maximum serviceability limit state allowable stress $f_{g;d}$ or limit on deflection, $w_d$, taking into account the material partial factor for the serviceability limit state $\gamma_M$ (see 5.3).

5.3 Material partial factor

The recommended values of the material partial factor are given in table 2.

<table>
<thead>
<tr>
<th>Material</th>
<th>Ultimate limit state</th>
<th>Serviceability limit state</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annealed glass(1)</td>
<td>$\gamma_{M,A} = 1,8$</td>
<td>$\gamma_{M,A} = 1,0$</td>
</tr>
<tr>
<td>Surface prestress</td>
<td>$\gamma_{M,V} = 1,2$</td>
<td>$\gamma_{M,V} = 1,0$</td>
</tr>
</tbody>
</table>

Note (1). The material partial factor for annealed glass is also applied to a component of the strength of prestressed glass - see equation (7).

For specific National values, see Annex ZN.

5.4 Process of determining the load resistance of glass

For any calculation or test, the mechanical and physical properties of glass shall be determined in accordance with clause 6.

The design value of the actions shall be determined in accordance with clause 7.
The allowable stresses for the glass, for the ultimate limit state and for the serviceability limit state (if required), shall be determined in accordance with clause 8.

Where a design deformation limit applies for the serviceability limit state, such a value shall be determined in accordance with EN 1990. Where no other standard specifies a design deformation limit, this shall be determined in accordance with 9.1.4.

For calculations, the principles and conditions shall be in accordance with clause 9.

Determination of load resistance by testing, or assisted by testing, shall be in accordance with annex A.

6 Mechanical and physical properties of glass

6.1 Values

The values of the mechanical and physical properties needed for calculation, such as Young's modulus $E$, the Poisson number $\mu$, and the density of glass $\rho$, are obtained from the following product standards:

EN 572-1, EN 1748-1-1, EN 1748-2-1, EN 1863-1, EN 12150-1, EN 12337-1, EN ISO 12543-1, EN 13024-1, EN 14178-1, EN 14179-1, EN 14321-1.

6.2 Approximate values

When (e.g. for assembling different glass materials) no distinction between the various differences in mechanical and physical properties can be taken into account, or when it is not necessary, the following values may be used:

- glass density $\rho = 2500 \text{ kg/m}^3$;
- Young’s modulus $E = 70000 \text{ MPa}$;
- Poisson number $\mu = 0.22$;

These values are applicable approximations for glasses with:

- a density between 2250 and 2750 kg/m$^3$;
- a Young’s modulus between 63000 MPa and 77000 MPa
- a Poisson number between 0.20 and 0.25

These ranges cover the following glass materials (the list not exhaustive):

- Basic soda lime silicate glass products conforming to EN 572 and processed glass products made from these basic glass products such as heat strengthened glass conforming to EN 1863, chemically strengthened glass conforming to EN 12337, thermally toughened soda lime silicate safety glass conforming to EN 12150 and heat soaked thermally toughened soda lime silicate safety glass conforming to EN 14179.
Basic borosilicate glass conforming to EN 1748-1, and processed glass products made of this basic glass such as thermally toughened borosilicate safety glass conforming to EN 13024.

Basic glass ceramics conforming to EN 1748-2, and processed glass products made of this basic glass.

Basis alkaline earth silicate glass conforming to EN 14178-1, and processed glass products made of this basic glass such as thermally toughened alkaline earth silicate safety glass in accordance with EN 14321.

Coated glass conforming to EN 1096 made using one of the above types of glass

Mirror glass conforming to EN 1036 made using one of the above types of glass

Assembled glass made of one or more of the glass types listed above such as laminated glass and laminated safety glass conforming to EN 14449 and EN 12543.

Assembled glass made of one or more of the glass types listed above such as insulating glass units conforming to EN 1279.

7 Actions

7.1 Assumptions related to the actions and combinations of actions

With regard to actions and combinations of actions in the service limit state, the frequent combination applies. (see EN 1990 clauses 6.5.3 and 4.1.3)

With regard to the combination of the actions in an ultimate limit state, the fundamental combination applies. (See EN 1990 clauses 6.5.3 and 4.1.3)

7.2 Combinations of actions

The values of the actions shall be determined in accordance with the appropriate parts of EN 1991.

The design value of the action (design load) shall be:

for ultimate limit state \[ F_d = \gamma_G (G + \sum \gamma_Q Q_{k,i}) \] (3.a)

for serviceability limit state \[ F_d = (G + \sum \gamma_1 Q_{k,1} + \sum \gamma_2 Q_{k,i}) \] (3.b)

where:

- \( F_d \) is the design value of the combination of actions;
- \( G \) is the value of permanent actions (e.g. self-weight load, permanent equipment);
- \( Q_{k,1} \) is the characteristic value of the leading variable action (e.g. imposed load on floor, wind, snow);
- \( Q_{k,i} \) is the characteristic value of the accompanying variable action (e.g. wind, snow);
- \( \gamma_{0,i} \) are factors for combination value of accompanying variable actions;
- \( \gamma_1 \) is the factor for frequent value of a variable action;
- \( \gamma_2 \) is the factor for quasi-permanent value of a variable action;
- \( \gamma_G \) is the partial factor for permanent actions, also accounting for model uncertainties and dimensional variations.
\( \gamma_0 \): is the partial factor for variable actions, also accounting for model uncertainties and dimensional variations.

The recommended values of the partial load factors, \( \gamma \), are given in table 3.

**Table 3: Partial load factors**

<table>
<thead>
<tr>
<th>Type of element to be calculated</th>
<th>( \gamma_0 )</th>
<th>( \gamma_0^{(3)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>favourable</td>
<td>unfavourable</td>
</tr>
<tr>
<td>Main structure(^{(1)})</td>
<td>see Eurocodes</td>
<td>see Eurocodes</td>
</tr>
<tr>
<td>Secondary structure(^{(1)})</td>
<td>1,3</td>
<td>1,0</td>
</tr>
<tr>
<td>Infill panel(^{(2)})</td>
<td>1,1</td>
<td>1,0</td>
</tr>
</tbody>
</table>

Notes.

(1) Structural construction covered by Eurocodes
(2) Non structural element not covered by Eurocodes
(3) The lower value is used when the permanent action has a favourable effect in combination with other actions. The higher value is used when the permanent action is considered acting alone or has a unfavourable effect in combination with other loads.

For specific National values, see Annex YN.

The recommended values of the partial factors, \( \psi \), are given in table 4.

**Table 4: \( \psi \) factors**

<table>
<thead>
<tr>
<th></th>
<th>Main structure(^{(1)})</th>
<th>Secondary structure(^{(1)})</th>
<th>Infill panel(^{(2)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>( \psi_0 )</td>
<td>see Eurocodes</td>
<td>0,6</td>
</tr>
<tr>
<td>( \psi_1 )</td>
<td>see Eurocodes</td>
<td>0,9</td>
<td>0,9</td>
</tr>
<tr>
<td>( \psi_2 )</td>
<td>see Eurocodes</td>
<td>0,2</td>
<td>0,2</td>
</tr>
<tr>
<td>Snow</td>
<td>( \psi_0 )</td>
<td>see Eurocodes</td>
<td>0,6</td>
</tr>
<tr>
<td>( \psi_1 )</td>
<td>see Eurocodes</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>( \psi_2 )</td>
<td>see Eurocodes</td>
<td>0,2</td>
<td>0,2</td>
</tr>
<tr>
<td>Other</td>
<td>( \psi_0 )</td>
<td>See Eurocodes or national annexes</td>
<td></td>
</tr>
<tr>
<td>( \psi_1 )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \psi_2 )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes.

(1) Structural construction covered by Eurocodes
(2) Non structural element not covered by Eurocodes

For specific National values, see Annex YN.
7.3 Wind action

The wind actions calculated using EN 1991-1-4 are characteristic values (See EN 1990, 4.1.2). They are determined from the basic values of wind velocity or the velocity pressure. In accordance with EN 1990 4.1.2 (7)P, the basic values are characteristic values which are exceeded with an annual probability of 0.02, which is equivalent to a mean return period of 50 years.

NOTE: All coefficients or models used to derive wind actions from basic values are chosen so that the probability of the calculated wind actions does not exceed the probability of these basic values.

A probability factor, $c_{\text{prob}^2}$, can be applied to the design wind pressure allowing for a different wind return period. Values are given in table 5.

Table 5: $c_{\text{prob}}$ values

<table>
<thead>
<tr>
<th>Years</th>
<th>$c_{\text{prob}^2}$</th>
<th>Years</th>
<th>$c_{\text{prob}^2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.241222</td>
<td>30</td>
<td>0.935845</td>
</tr>
<tr>
<td>5</td>
<td>0.702303</td>
<td>40</td>
<td>0.972028</td>
</tr>
<tr>
<td>10</td>
<td>0.795309</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>0.847782</td>
<td>60</td>
<td>1.022806</td>
</tr>
<tr>
<td>20</td>
<td>0.884522</td>
<td>65</td>
<td>1.032807</td>
</tr>
<tr>
<td>25</td>
<td>0.912822</td>
<td>70</td>
<td>1.042061</td>
</tr>
</tbody>
</table>

8 Strength and stress

8.1 Allowable stress for annealed glass

8.1.1 Formulae

The allowable stress for annealed glass material, whichever composition, is

$$f_{g,d} = \frac{k_{\text{mod}}k_{sp}f_{g,k}}{\gamma_{M,A}}$$

(4)

where $f_{g,k}$ is the characteristic value of the bending strength ($f_{g,k} = 45 \text{ N/mm}^2$),

$\gamma_{M,A}$ is the material partial factor for annealed glass (see 5.3 and Annex ZN).

$k_{sp}$ is the factor for the glass surface profile (see 8.1.2).

$k_{\text{mod}}$ is the factor for the load duration (see 8.1.3).

NOTE 1. CEN report CR rrr explains the origin of the value of $f_{g,k}$. 
8.1.2 Glass surface profile factor

The factor for the glass surface profile is given in table 6.

**Table 6: Factor for the glass surface profile**

<table>
<thead>
<tr>
<th>Glass material (whichever glass composition)</th>
<th>Factor for the glass surface profile $k_{sp}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Float glass</td>
<td>1,0</td>
</tr>
<tr>
<td>Drawn sheet glass</td>
<td>1,0</td>
</tr>
<tr>
<td>Enamelled float or drawn sheet glass$^{(1)}$</td>
<td>(1,0)</td>
</tr>
<tr>
<td>Patterned glass</td>
<td>0,75</td>
</tr>
<tr>
<td>Enamelled patterned glass$^{(1)}$</td>
<td>(0,75)</td>
</tr>
<tr>
<td>Polished wired glass</td>
<td>0,75</td>
</tr>
<tr>
<td>Patterned wired glass</td>
<td>0,6</td>
</tr>
</tbody>
</table>

Note 1. These glass types are not generally available as annealed glass, but the values of $k_{sp}$ are also required in the formulae for prestressed glass (see 8.2).

8.1.3 Factor for duration of load

The factor for the load duration of annealed glass is

$$ k_{mod} = 0,663t^{-\frac{1}{16}} $$

(5)

where $t$ is the load duration in hours.

For normal building loads, the factor $k_{mod}$ has a maximum value of $k_{mod} = 1$ and a minimum value of $k_{mod} = 0,25$.

Note. For exceptional loads of very short duration, e.g. explosions, values of $k_{mod}$ greater than 1 may be used. The formula in equation (5) may be considered valid for durations down to 20 msec.

Typical values of $k_{mod}$ are given in table 7.
Table 7: Factors for load duration

<table>
<thead>
<tr>
<th>Action</th>
<th>Load duration</th>
<th>( k_{\text{mod}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>personnel loads</td>
<td>short, single(^{(1)})</td>
<td>0,85</td>
</tr>
<tr>
<td>wind</td>
<td>short, multiple(^{(2)})</td>
<td>0,74</td>
</tr>
<tr>
<td>snow</td>
<td>intermediate(^{(3)})</td>
<td>0,44</td>
</tr>
<tr>
<td>daily temperature variation</td>
<td>intermediate</td>
<td>0,57</td>
</tr>
<tr>
<td>11 hours extreme peak duration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>barometric pressure variation</td>
<td>intermediate</td>
<td>0,50</td>
</tr>
<tr>
<td>yearly temperature variation</td>
<td>intermediate</td>
<td>0,39</td>
</tr>
<tr>
<td>6 month extreme mean value duration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dead load, self weight</td>
<td>permanent</td>
<td>0,29</td>
</tr>
</tbody>
</table>

Notes:
1. The value of \( k_{\text{mod}} = 0,85 \) is based on a personnel load of 1 minute duration. Other values may be considered depending on the type of personnel load being evaluated and also the building use.
2. The value of \( k_{\text{mod}} = 0,74 \) is based on a cumulative equivalent duration of 5 minutes, considered representative of the effect of a storm which may last several hours. Higher values of \( k_{\text{mod}} \) may be considered for wind.
3. \( k_{\text{mod}} = 0,44 \) can be considered representative for snow loads lasting between 1 week \((k_{\text{mod}} = 0,48)\) and 3 months \((k_{\text{mod}} = 0,41)\). Other values of \( k_{\text{mod}} \) may be appropriate depending on local climate.

Where loads with different durations need to be treated in combination, the appropriate factor for load duration for the combined loads, \( k_{\text{mod};c} \), is determined from the following equation.

\[
k_{\text{mod};c} = \frac{E_{\text{ULS},G} + E_{\text{ULS},1} + \sum E_{\text{ULS},j}}{k_{\text{mod},G} + k_{\text{mod},1} + \sum k_{\text{mod},j}}
\]  \hspace{1cm} (6)

Note. If the effect of the loads, \( E_{\text{ULS}} \), are acting in opposite senses, only those acting in the same sense as the effect of the dominant load, \( E_{\text{ULS},1} \), should be used in equation (6) to determine \( k_{\text{mod};c} \).

8.2 Allowable stress of prestressed glass

8.2.1 Formula

The allowable stress of prestressed glass material, whichever composition is

\[
f_{g,i} = \frac{k_{\text{mod}} k_{sp} f_{g,k}}{\gamma_{M,A}} + \frac{k_{i}(f_{b,k} - f_{g,k})}{\gamma_{M,y}}
\]  \hspace{1cm} (7)

where \( f_{g,k} \), \( \gamma_{M,A} \), \( k_{\text{mod}} \) and \( k_{sp} \) are described in 8.1.
\( \gamma_{M,y} \) is the material partial factor for surface prestress (see 5.3 and Annex ZN).
\( f_{b,k} \) is the characteristic value of the bending strength of prestressed glass (see 8.2.2).
8.2.2 Characteristic bending strength

The values of characteristic bending strength for prestressed glass are given in table 9.

**Table 9: Values of characteristic strength and strengthening factors for prestressed glass**

| Glass material per product (whichever composition) | Values for characteristic bending strength $f_{b,k}$ for prestressed glass processed from: |  
| --- | --- | --- |
| | thermally toughened safety glass, and heat soaked thermally toughened safety glass | heat strengthened glass | chemically strengthened glass |
| float glass or drawn sheet glass | 120 N/mm$^2$ | 70 N/mm$^2$ | 150 N/mm$^2$ |
| patterned glass | 90 N/mm$^2$ | 55 N/mm$^2$ | 150 N/mm$^2$ |
| enamelled float or drawn sheet glass | 75 N/mm$^2$ | 45 N/mm$^2$ |  |
| enamelled patterned glass | 75 N/mm$^2$ | 45 N/mm$^2$ |  |

8.2.3 Strengthening factor

The presence of tong marks in vertically toughened glass reduces the effectiveness of the prestressing locally compared with horizontally toughened glass which has no tong marks. The strengthening factor for method of manufacture is given in table 10.
Table 10: Strengthening factor

<table>
<thead>
<tr>
<th>Manufacturing process</th>
<th>Strengthening factor, $k_v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal toughening (or other process without the use of tongs or other devices to hold the glass)</td>
<td>1.0</td>
</tr>
<tr>
<td>Vertical toughening (or other process using tongs or other devices to hold the glass)</td>
<td>0.6</td>
</tr>
</tbody>
</table>

9 Calculation principles and conditions

9.1 General method of calculation

9.1.1 Design load

The characteristic value of the design load, $F_d$, shall be determined in accordance with clause 7.

*Note: If glass is used in an application where there is no specific design load from standards or regulations, consideration should be given to using a glass thickness sufficient to resist an unfactored short duration uniformly distributed load of 500 N/m².*

9.1.2 Stress and deflection calculation

The design load shall be used for calculating the tensile or tensile bending stress in the glass and the deflection of the glass.

The method used for the determination shall be an engineering formula or method appropriate to the load distribution, the shape of the glass and the support conditions. For common applications of glass, Part 1 and Part 2 of this European Standard give simple methods.

In general, the maximum stress and the maximum deflection, $w_{max}$, shall be calculated according to linear theory. Where the deflection induced by the actions exceeds half the glass thickness, linear theory of plate bending may excessively overestimate the stresses and maximum deflection. In this case the stress distribution and maximum deflection can be calculated according to non-linear plate theory. Annex B gives formulae for non-linear calculations for four-edge supported rectangular panes.

*Note: For fenestration, Part 1 of this European Standard gives an approximate method using glass factors to compensate for the use of linear plate bending theory in fenestration, where the effect of actions is generally non-linear. The derivation of this is given in Annex C.*

For laminated glass, the stress in each ply shall be calculated. For insulating glass units, the stress in each pane shall be calculated. A method for determining the loads applied to each pane of an insulating glass unit is given in Annex D.
9.1.3 Allowable stress

The allowable stress, \( f_{g;d} \), shall be determined according to clause 8. The value of the load duration factor used to calculate the allowable stress shall be appropriate to the anticipated duration of the single load (or the dominant load where there are combined loads).

9.1.4 Allowable deflection

There is no specific requirement of glass to limit the deflection of the glass under load. Other standards or regulations may require deflection limits for particular applications.

If required, the allowable deflection, \( w_d \), shall be in accordance with the appropriate standard or regulation.

Consideration should be given to ensuring the glass is not excessively flexible when subjected to applied loads, as this can cause alarm to building users. In the absence of any specific requirement, deflections shall be limited to Span/65 or 50 mm, whichever is the lower value.

9.1.5 Comparisons of stress and deflection

The maximum stress calculated for the design load shall not exceed the allowable stress:

\[
\sigma_{\text{max}} \leq f_{g;d} \tag{8}
\]

If there is a requirement for limitation of the glass deflection, the maximum deflection calculated for the most onerous load condition shall not exceed the allowable deflection:

\[
w_{\text{max}} \leq w_d \tag{9}
\]

If there are combinations of loads to be considered, it may be necessary to perform the procedures in 9.1.1 to 9.1.5 more than once, taking alternative loads as the dominant load, in order to determine the most onerous condition. The most onerous condition is either:

- the highest value of the effective stress, in relation to the allowable stress based on the duration of the dominant load; or
- the largest value of maximum deflection.

Note: The most onerous condition may differ for stress and deflection.

9.2 Calculation method for laminated glass and laminated safety glass

9.2.1 Calculation method

In cases where shear stress is developed in laminated glass parallel with the interlayer, the interlayer can be considered as having some shear resistance. This can be taken into account in evaluating resistance to bending of the laminated glass using a suitable engineering formula in combination with the shear resistance of the interlayer.

The following approach, using the concept of ‘effective thickness’ can be used.
The effective thickness for calculating bending deflection is:

$$h_{ef:w} = \sqrt[3]{\left(1 - \sigma \right) \sum_i h_i^3 + \sigma \left(\sum_i h_i\right)^3}$$  \hspace{1cm} (10)$$

and the effective thickness for calculating the stress of glass ply number $j$ is:

$$h_{ef:st;j} = \frac{\left(h_{ef:w}\right)^3}{\sqrt{h_j + 2 \sigma h_{m;j}}}$$  \hspace{1cm} (11)$$

where $\sigma$ is a coefficient between 0 and 1 representing no shear transfer (0) and full shear transfer (1), $h_i, h_j$ are the thicknesses of the glass plies (see figure 2), and $h_{m;j}$ is the distance of the mid-plane of the glass ply $j$ from the mid-plane of the laminated glass, ignoring the thickness of the interlayers (see figure 2).

The effective thicknesses for calculating stresses and deflection in laminated glass comprising two plies of the same thickness using a value of $\sigma = 0.25$ are given in table 11.
Table 11. Effective thicknesses of laminated glass with two plies of the same thickness and \( \tau = 0.25 \)

<table>
<thead>
<tr>
<th>Glass thickness mm</th>
<th>Short duration loads (( \tau = 0.25 ))</th>
<th>Long duration loads (( \tau = 0.05 ))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( h_{ef;w} ) mm</td>
<td>( h_{ef;\tau_\ell} ) mm</td>
</tr>
<tr>
<td>3 + 3</td>
<td>4.55</td>
<td>5.02</td>
</tr>
<tr>
<td>4 + 4</td>
<td>6.07</td>
<td>6.69</td>
</tr>
<tr>
<td>5 + 5</td>
<td>7.59</td>
<td>8.37</td>
</tr>
<tr>
<td>6 + 6</td>
<td>9.11</td>
<td>10.04</td>
</tr>
<tr>
<td>8 + 8</td>
<td>12.15</td>
<td>13.39</td>
</tr>
<tr>
<td>10 + 10</td>
<td>15.18</td>
<td>16.73</td>
</tr>
</tbody>
</table>

9.2.2 Determination of \( \tau \)

The value of \( \tau \) to be used for a specific interlayer and a particular load case depends on the interlayer stiffness family to which the interlayer belongs for that particular load case.

The interlayer stiffness families and the equivalent values of \( \tau \) are given in table 12.

Table 12. Value of \( \tau \) associated with interlayer stiffness family

<table>
<thead>
<tr>
<th>Interlayer stiffness family</th>
<th>Value of ( \tau )</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.7</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>0.25</td>
</tr>
<tr>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Each interlayer has its interlayer stiffness family assigned for a number of different load cases according to the test method and evaluation from prEN vwxzy. The load cases are given in table 13.

Table 13. Load cases

<table>
<thead>
<tr>
<th>Load case</th>
<th>Load duration</th>
<th>Temperature range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind load</td>
<td>3 seconds</td>
<td>0 °C &lt; ( T ) &lt; 20 °C</td>
</tr>
<tr>
<td>Personnel loads - normal duty</td>
<td>30 seconds</td>
<td>0 °C &lt; ( T ) &lt; 30 °C</td>
</tr>
<tr>
<td>Personnel loads - crowds</td>
<td>5 minutes</td>
<td>0 °C &lt; ( T ) &lt; 30 °C</td>
</tr>
<tr>
<td>Snow load - external canopies</td>
<td>3 weeks</td>
<td>-20 °C &lt; ( T ) &lt; 0 °C</td>
</tr>
<tr>
<td>Snow load - roofs</td>
<td>3 weeks</td>
<td>-20 °C &lt; ( T ) &lt; 20 °C</td>
</tr>
<tr>
<td>Permanent</td>
<td>50 years</td>
<td>-20 °C &lt; ( T ) &lt; 40 °C</td>
</tr>
</tbody>
</table>

9.3 Calculation method for insulating glass units

The calculation method for insulating glass units conforming to EN 1279 shall take into account the consequences arising from the presence of the hermetically sealed and fixed
quantity of gas within the cavity or cavities of the insulating glass unit. This shall take into account:

- the presence of the fixed quantity of gas causing actions which are applied to only one pane to develop effects in all the panes in the insulating glass unit (a phenomenon also known as load sharing);
- changes in ambient barometric pressure conditions relative to the barometric pressure at the time of sealing the insulating glass unit causing actions (internal actions) which develop effects in all the panes;
- changes in the temperature of the gas in the cavity causing actions (internal actions) which develop effects in all the panes.

A method is given in Annex D for determining the proportions of the loads applied to the individual panes of a double glazed insulating glass unit.

If insulating glass units conform to EN 1279-5, then the stresses generated in the seal when the units are subjected to normally expected loads in service - e.g. wind, snow, self-weight, personnel, or climatic, but excluding exceptional loads such as explosion pressures - will not cause premature failure of the hermetic seal, provided the deflection of the glass is not excessive.
Annex A (normative)

Principles of determining the load resistance of glass by testing

A.1 General

Testing of glass as a construction element or part thereof shall preferably be performed on full scale models. Where models different from full scale are used, appropriate techniques shall be used to:

- verify that calculated and measured values for the model used do not differ significantly;
- evaluate the expected deformations and stresses for the considered construction element with a reliable degree of accuracy and confidence.

For the ultimate limit state the following requirement applies.

\[ E_d \leq R_d \]  \hspace{1cm} (A.1)

where  \( E_d \) is the effect of the action(s), expressed:
- as measured stress;
- or as an evaluated stress on the basis of the measured stress when no 1 to 1 scale model has been used;
caused by the action(s), which shall be determined in accordance with clause 7 of this European Standard.

\( R_d \) is the design value of the corresponding resistance, expressed;
- as the maximum allowable stress, \( f_{g;\text{d}} \), determined in accordance with this European Standard.

For the serviceability limit state the following requirement applies

\[ E_d \leq C_d \]  \hspace{1cm} (A.2)

where  \( E_d \) is the effect of the action(s), expressed:
- as measured stress;
- or as an evaluated stress on the basis of the measured stress when no 1 to 1 scale model has been used;
- or as deformation;
caused by the action(s), which shall be determined in accordance with clause 7 of this European Standard.

\( C_d \) is the limiting design value, expressed:
- as the maximum allowable stress, \( f_{g;\text{d}} \), determined in accordance with this European Standard;
- or as the maximum allowable deformation in accordance with this European Standard.
A.2 Factors affecting load resistance

Glass is a homogeneous isotropic material having almost perfect linear-elastic behaviour over its tensile strength range.

Glass has a very high compressive strength and theoretically a very high tensile strength, but the surface of the glass has many irregularities which act as weaknesses when glass is subjected to tensile stress. These irregularities are caused by attack from moisture and by contact with hard materials (e.g. grit) and are continually modified by moisture which is always present in the air.

Tensile strengths of around 10 000 N/mm$^2$ can be predicted from the molecular structure, but bulk glass normally fails at stresses considerably below 100 N/mm$^2$.

The presence of the irregularities and their modification by moisture contributes to the properties of glass which need consideration when performing tests of strength.

Because of the very high compressive strength, glass always fails under tensile stress. Since glass in buildings is very rarely used in direct tension, the most important property for load resistance is the tensile bending strength.

The major influences on the bending strength and load resistance of glass are the following factors:

a) rate and duration of loading;

b) area of surface stressed in tension;

c) the surface condition.

The bending strength and load resistance of laminated glass is also influenced by the following factors affecting the interlayer properties:

d) rate and duration of loading giving rise to creep of the interlayer;

e) temperature affecting the stiffness of the interlayer.

The influence exerted by factors a) to e) on bending strength and load resistance should be taken into account in the testing method and/or subsequent analysis.

A.3 Effect of rate and duration of loading

Since glass is linearly elastic, altering the rate or duration of load does not affect stresses or deflections if all the other components are also linearly elastic. However the duration of the load has a significant effect on the ultimate strength. In particular, if the design load is long duration, it is not sensible to test to ultimate failure in a short duration test. Better is to measure the induced stress (e.g. by the use of strain gauges) and compare it with the allowable long duration stress.
For laminated glass there is no simple way to measure the stresses in a short duration test to obtain an estimate of long duration stresses, since the greater shear transfer over short duration can develop significantly different stresses in the glass plies. The test and the analysis model need to take this into account.

A.4 Effect of stressed surface area

There is an area effect on glass strength depending on the specimen size. On average, smaller sizes will break at higher stresses than larger sizes. This can be overcome by using test specimens of sizes representative of the application. It affects only the breakage stress, not the stress generated by a specific load.

The interlaminar shear transfer in laminated glass is size dependent. Larger pane sizes have greater shear transfer than smaller pane sizes. The test specimen sizes should be representative of the application.

A.5 Surface condition

The variation in microscopic flaws in glass surfaces means that the load resistance obtained in a test to ultimate failure of nominally identical glass specimens can vary by a factor of 4. Caution should be used in assessing factors of safety related to ultimate strength tests unless a large number have been performed (more than 10 to obtain a reliable mean strength and more than 20 in order to obtain a reliable characteristic strength).

A.6 Temperature

Variations of temperature within the range normally obtained in buildings have negligible effect on the reaction of glass to load and stress. Temperature can have a major effect on the properties of laminated glass interlayers. Where possible tests on laminated glass should be conducted at a temperature representative of service.
Annex B (informative)

Calculation formulae for stress and deflection for large deflections of rectangular panes supported on all edges.

Of the dimensions $a$ and $b$ of the pane, $a$ shall be taken as the shorter dimension. The aspect ratio is given by $\lambda = a/b$ and the area is given by $A = ab$

For practical determination of the stress, the deflection and the change in volume (for the cavity of insulating glass units), formulae are given as follows:

Maximum tensile bending stress

$$\sigma_{\text{max}} = k_1 \frac{A}{h^2} F_d$$ \hspace{1cm} (B1)

Deflection

$$w_{\text{max}} = k_4 \frac{A^2}{h^3} F_d \frac{F_d}{E}$$ \hspace{1cm} (B2)

Volume

$$V = k_5 \frac{A^3}{h^3} \frac{F_d}{E}$$ \hspace{1cm} (B3)

The values of the coefficients are given in tables B.1 to B.3.
In case of four-edge supported panes, the dimensionless coefficients \( k_1 \) and \( k_4 \), depend on the aspect ratio, \( \lambda \), and the non-dimensional load.

Non-dimensional load

\[
p^* = \left( \frac{A}{4h^2} \right)^2 \frac{F_d}{E}
\]

The coefficients in tables B.1 to B.3 are valid for a Poisson number in the range 0.20 to 0.24. They can be interpolated linearly. For small deflections (linear theory) the values for \( p^* = 0 \) apply.

**Table B.1: Coefficient \( k_1 \) for calculation of the maximum stress**

<table>
<thead>
<tr>
<th>( \lambda = a/b )</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.268</td>
<td>0.261</td>
<td>0.244</td>
<td>0.223</td>
<td>0.190</td>
<td>0.152</td>
<td>0.135</td>
<td>0.130</td>
<td>0.129</td>
<td>0.128</td>
<td>0.128</td>
</tr>
<tr>
<td>0.9</td>
<td>0.287</td>
<td>0.278</td>
<td>0.258</td>
<td>0.234</td>
<td>0.197</td>
<td>0.155</td>
<td>0.137</td>
<td>0.131</td>
<td>0.130</td>
<td>0.129</td>
<td>0.129</td>
</tr>
<tr>
<td>0.8</td>
<td>0.304</td>
<td>0.295</td>
<td>0.273</td>
<td>0.247</td>
<td>0.205</td>
<td>0.159</td>
<td>0.138</td>
<td>0.131</td>
<td>0.130</td>
<td>0.130</td>
<td>0.130</td>
</tr>
<tr>
<td>0.7</td>
<td>0.314</td>
<td>0.306</td>
<td>0.285</td>
<td>0.261</td>
<td>0.218</td>
<td>0.165</td>
<td>0.140</td>
<td>0.130</td>
<td>0.129</td>
<td>0.129</td>
<td>0.129</td>
</tr>
<tr>
<td>0.6</td>
<td>0.314</td>
<td>0.309</td>
<td>0.294</td>
<td>0.274</td>
<td>0.235</td>
<td>0.176</td>
<td>0.143</td>
<td>0.129</td>
<td>0.127</td>
<td>0.126</td>
<td>0.126</td>
</tr>
<tr>
<td>0.5</td>
<td>0.300</td>
<td>0.298</td>
<td>0.290</td>
<td>0.279</td>
<td>0.253</td>
<td>0.197</td>
<td>0.151</td>
<td>0.128</td>
<td>0.124</td>
<td>0.123</td>
<td>0.122</td>
</tr>
<tr>
<td>0.4</td>
<td>0.268</td>
<td>0.268</td>
<td>0.266</td>
<td>0.262</td>
<td>0.252</td>
<td>0.221</td>
<td>0.171</td>
<td>0.129</td>
<td>0.119</td>
<td>0.116</td>
<td>0.116</td>
</tr>
<tr>
<td>0.3</td>
<td>0.217</td>
<td>0.217</td>
<td>0.217</td>
<td>0.216</td>
<td>0.215</td>
<td>0.208</td>
<td>0.189</td>
<td>0.141</td>
<td>0.116</td>
<td>0.107</td>
<td>0.105</td>
</tr>
<tr>
<td>0.2</td>
<td>0.149</td>
<td>0.149</td>
<td>0.149</td>
<td>0.149</td>
<td>0.149</td>
<td>0.149</td>
<td>0.148</td>
<td>0.140</td>
<td>0.123</td>
<td>0.100</td>
<td>0.091</td>
</tr>
<tr>
<td>0.1</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.074</td>
<td>0.073</td>
</tr>
</tbody>
</table>

For the purposes of calculation:

\[
k_1 = \frac{1}{\left[ \frac{1}{z_2^2} + \left( \frac{p^*}{z_3 + (z_4 p^*)^2} \right)^{0.5} \right]}
\]

where

\[
\begin{align*}
z_2 &= 24\lambda \left[ 0.0447 + 0.0803 \left( 1 - \exp\left( -1.17 \left( \frac{1}{\lambda} - 1 \right)^{0.73} \right) \right) \right] \\
z_3 &= 4.5 \left( \frac{1}{\lambda} - 1 \right)^2 + 4.5 \\
z_4 &= 0.585 - 0.05 \left( \frac{1}{\lambda} - 1 \right)
\end{align*}
\]
Table B.2: Coefficient $k_4$ for calculation of the maximum deflection

<table>
<thead>
<tr>
<th>$\lambda=a/b$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0461</td>
<td>0.0414</td>
<td>0.0354</td>
<td>0.0310</td>
<td>0.0255</td>
<td>0.0189</td>
<td>0.0137</td>
<td>0.0088</td>
<td>0.0062</td>
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<td>0.0036</td>
</tr>
<tr>
<td>0.9</td>
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<td>0.0409</td>
<td>0.0351</td>
<td>0.0309</td>
<td>0.0254</td>
<td>0.0188</td>
<td>0.0136</td>
<td>0.0088</td>
<td>0.0062</td>
<td>0.0044</td>
<td>0.0036</td>
</tr>
<tr>
<td>0.8</td>
<td>0.0437</td>
<td>0.0399</td>
<td>0.0346</td>
<td>0.0305</td>
<td>0.0253</td>
<td>0.0188</td>
<td>0.0136</td>
<td>0.0087</td>
<td>0.0062</td>
<td>0.0044</td>
<td>0.0036</td>
</tr>
<tr>
<td>0.7</td>
<td>0.0404</td>
<td>0.0377</td>
<td>0.0333</td>
<td>0.0297</td>
<td>0.0248</td>
<td>0.0186</td>
<td>0.0136</td>
<td>0.0087</td>
<td>0.0062</td>
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<td>0.0036</td>
</tr>
<tr>
<td>0.6</td>
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<td>0.0339</td>
<td>0.0309</td>
<td>0.0281</td>
<td>0.0240</td>
<td>0.0183</td>
<td>0.0134</td>
<td>0.0087</td>
<td>0.0062</td>
<td>0.0044</td>
<td>0.0036</td>
</tr>
<tr>
<td>0.5</td>
<td>0.0287</td>
<td>0.0281</td>
<td>0.0267</td>
<td>0.0251</td>
<td>0.0222</td>
<td>0.0176</td>
<td>0.0132</td>
<td>0.0086</td>
<td>0.0062</td>
<td>0.0044</td>
<td>0.0036</td>
</tr>
<tr>
<td>0.4</td>
<td>0.0208</td>
<td>0.0207</td>
<td>0.0204</td>
<td>0.0199</td>
<td>0.0187</td>
<td>0.0159</td>
<td>0.0125</td>
<td>0.0085</td>
<td>0.0061</td>
<td>0.0044</td>
<td>0.0036</td>
</tr>
<tr>
<td>0.3</td>
<td>0.0128</td>
<td>0.0128</td>
<td>0.0127</td>
<td>0.0127</td>
<td>0.0125</td>
<td>0.0119</td>
<td>0.0105</td>
<td>0.0079</td>
<td>0.0059</td>
<td>0.0043</td>
<td>0.0035</td>
</tr>
<tr>
<td>0.2</td>
<td>0.0059</td>
<td>0.0059</td>
<td>0.0059</td>
<td>0.0059</td>
<td>0.0059</td>
<td>0.0059</td>
<td>0.0058</td>
<td>0.0055</td>
<td>0.0048</td>
<td>0.0038</td>
<td>0.0033</td>
</tr>
<tr>
<td>0.1</td>
<td>0.0015</td>
<td>0.0015</td>
<td>0.0015</td>
<td>0.0015</td>
<td>0.0015</td>
<td>0.0015</td>
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<td>0.0015</td>
<td>0.0015</td>
<td>0.0015</td>
<td>0.0015</td>
</tr>
</tbody>
</table>

For the purposes of calculation:

$$k_4 = \frac{\left(\frac{1}{z_1^4} + 4p^*^2\right)^{0.5} - \frac{1}{z_1^2}}{2}$$

$$\frac{1}{16p^*}$$

where $$z_1 = 192 \left(1 - \mu^2\right) \lambda^2 \left[0.00406 + 0.00896 \left(1 - \exp\left(-1.123 \left(\frac{1}{\lambda} - 1\right)^{0.07}\right)\right)\right]$$

Note: For $p^* = 0$, $k_4 = \frac{z_1}{16}$

Table B.3: Coefficient $k_5$ for calculation of the volume change

<table>
<thead>
<tr>
<th>$\lambda=a/b$</th>
<th>1.0</th>
<th>0.9</th>
<th>0.8</th>
<th>0.7</th>
<th>0.6</th>
<th>0.5</th>
<th>0.4</th>
<th>0.3</th>
<th>0.2</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_5$</td>
<td>0.0190</td>
<td>0.0136</td>
<td>0.0181</td>
<td>0.0160</td>
<td>0.0150</td>
<td>0.0124</td>
<td>0.0094</td>
<td>0.0061</td>
<td>0.0031</td>
<td>0.0006</td>
</tr>
<tr>
<td>$k_5$</td>
<td>0.0190</td>
<td>0.0230</td>
<td>0.0283</td>
<td>0.0345</td>
<td>0.0417</td>
<td>0.0496</td>
<td>0.0588</td>
<td>0.0678</td>
<td>0.0775</td>
<td>0.0860</td>
</tr>
</tbody>
</table>

For the purposes of calculation:

$$k_5 = \frac{z_1}{16} \left[0.4198 + 0.22 \exp\left(-6.8(z)^{1.33}\right)\right]$$

$$k_5 = \frac{z_1}{16 \cdot \lambda^7} \left[0.4198 + 0.22 \exp\left(-6.8(z)^{1.33}\right)\right]$$

where $z_1$ is given in table B.2
Annex C (Informative)

Procedure for obtaining the simplified method used in prEN 13474-1 from the four edge supported non-linear method given in prEN 13474-3

Proposed to insert the contents of document CEN/TC129/WG8 - N186 (to be revised) here
Annex D (Informative)

Calculation process for insulating glass units

D.1 General

In case of double glazing, with panes of thickness $h_1$ and $h_2$, the distribution (partition) of external uniformly distributed loads (e.g. wind, snow, self weight) is essentially determined by the distribution (partition) of the stiffness of the panes, that is:

Stiffness partition for pane 1 with thickness $h_1$: \[
\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}
\] (D1)

Stiffness partition for pane 2 with thickness $h_2$: \[
\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1
\] (D2)

Additionally, the distribution (partition) of external loads as well as the effect of internal loads is determined by the insulating unit factor $\varphi$ :

\[
\varphi = \frac{1}{1 + (a/a^*)^4}
\] (D3)

The length $a$ gives the actual dimension of the unit (e.g. in case of a rectangular unit the length of the short edge) while $a^*$ is the characteristic length of the unit, depending on the thickness of the glass panes and the gas space, $s$, and the shape of the unit.

\[
a^* = 28.9 \left( \frac{sh_1^3 h_2^3}{h_1^3 + h_2^3} \right)^{0.25}
\] (D4)

The coefficient of volume, $k_s$, depends on the shape of the unit (see table B.3 in Annex B)

D.2 Distribution (partition) of external loads (load sharing)

By means of the internal pressure the external loads (e.g. wind on pane 1) are distributed to both panes.

Table D.1: Load partition for external loads

<table>
<thead>
<tr>
<th>Load</th>
<th>Partition of load carried by pane 1</th>
<th>Partition of load carried by pane 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>External load $F_d$ acting on pane 1</td>
<td>$F_{d,1} = (\delta_1 + \varphi\delta_2)F_d$</td>
<td>$F_{d,2} = (1 - \varphi)\delta_2 F_d$</td>
</tr>
<tr>
<td>External load $F_d$ acting on pane 2</td>
<td>$F_{d,1} = (1 - \varphi)\delta_1 F_d$</td>
<td>$F_{d,2} = (\varphi\delta_1 + \delta_2)F_d$</td>
</tr>
</tbody>
</table>

D.3 Effect of internal loads

D.3.1 Internal loads applied to the panes
The internal loads given by the isochore pressure are reduced by the flexibility of the panes described by the insulating glass unit factor, $\varphi$.

### Table D.2: Internal loads

<table>
<thead>
<tr>
<th>Isochore pressure $p_0$</th>
<th>Load carried by pane 1</th>
<th>Load carried by pane 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-\varphi p_0$</td>
<td>$\varphi p_0$</td>
<td></td>
</tr>
</tbody>
</table>

#### D.3.2 Isochore pressure

The isochore pressure generated by a difference of altitude is:

$$p_{H,0} = c_H \cdot (H - H_p)$$  \hspace{1cm} (D5)

where $c_H = 0,012$ kPa/m

Isochore pressure generated by a difference of temperature and/or air pressure is:

$$p_{C,0} = c_T \cdot (T - T_p) - (p - p_p)$$  \hspace{1cm} (D6)

where $c_T = 0,34$ kPa/K

The isochore pressure is:

$$p_0 = p_{H,0} + p_{C,0}$$  \hspace{1cm} (D7)
Annex YN (informative)

Proposal for a model of a National Annex (informative)

The values of the partial load factors for glass to be used on the territory of [Member State] are:

Table YN1. $\gamma$ partial factors

<table>
<thead>
<tr>
<th>Type of element to be calculated</th>
<th>$\gamma_0$</th>
<th>$\gamma_0^{(3)}$</th>
<th>favourable</th>
<th>unfavourable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main structure$^{(1)}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary structure$^{(1)}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infill panel$^{(2)}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes.
(1) Structural construction covered by Eurocodes
(2) Non structural element not covered by Eurocodes
(3) The lower value is used when the permanent action has a favourable effect in combination with other actions. The higher value is used when the permanent action is considered acting alone or has a unfavourable effect in combination with other loads.

Table YN2. $\psi$ partial factors

<table>
<thead>
<tr>
<th></th>
<th>Main structure$^{(1)}$</th>
<th>Secondary structure$^{(1)}$</th>
<th>Infill panel$^{(2)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind $\psi_0$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\psi_1$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\psi_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snow $\psi_0$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\psi_1$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\psi_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other $\psi_0$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\psi_1$</td>
<td></td>
<td></td>
<td>See Eurocodes or national annexes</td>
</tr>
<tr>
<td>$\psi_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes.
(1) Structural construction covered by Eurocodes
(2) Non structural element not covered by Eurocodes

When not filled in, the recommended values in this European Standard should be used (see 7.2).

Probability factor for wind return period: \( \xi_{\text{prob}} = 1.0 \).
Annex ZN (informative)

Proposal for a model of a National Annex (informative)

Nationally determined material partial factors by [Member State]

The values of the material partial factor for glass to be used on the territory of [Member State] are:

<table>
<thead>
<tr>
<th></th>
<th>Ultimate limit state</th>
<th>Serviceability limit state</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annealed glass⁴)</td>
<td>$\gamma_{M,A} = \ldots$</td>
<td>$\gamma_{M,A} = \ldots$</td>
</tr>
<tr>
<td>Surface prestress</td>
<td>$\gamma_{M,V} = \ldots$</td>
<td>$\gamma_{M,V} = \ldots$</td>
</tr>
</tbody>
</table>

Note (1). The material partial factor for annealed glass is also applied to a component of the strength of prestressed glass - see equation (7).

When not filled in, the recommended values in this European Standard should be used (see 5.3).