Designation: E1300 − 16

Standard Practice for
Determining Load Resistance of Glass in Buildings[1]

This standard is issued under the fixed designation E1300; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes procedures to determine the load resistance (LR) of specified glass types, including combinations of glass types used in a sealed insulating glass (IG) unit, exposed to a uniform lateral load of short or long duration, for a specified probability of breakage.

1.2 This practice applies to vertical and sloped glazing in buildings for which the specified design loads consist of wind load, snow load and self-weight with a total combined magnitude less than or equal to 15 kPa (315 psf). This practice shall not apply to other applications including, but not limited to, balustrades, glass floor panels, aquariums, structural glass members, and glass shelves.

1.3 This practice applies only to monolithic and laminated glass constructions of rectangular shape with continuous lateral support along one, two, three, or four edges. This practice assumes that (*1*) the supported glass edges for two, three, and four-sided support conditions are simply supported and free to slip in plane; (*2*) glass supported on two sides acts as a simply supported beam; and (*3*) glass supported on one side acts as a cantilever. For insulating glass units, this practice only applies to insulating glass units with four-sided edge support.

1.4 This practice does not apply to any form of wired, patterned, sandblasted, drilled, notched, or grooved glass. This practice does not apply to glass with surface or edge treatments that reduce the glass strength.

1.5 This practice addresses only the determination of the resistance of glass to uniform lateral loads. The final thickness and type of glass selected also depends upon a variety of other factors (see 5.3).

1.6 Charts in this practice provide a means to determine approximate maximum lateral glass deflection. Appendix X1 provides additional procedures to determine maximum lateral deflection for glass simply supported on four sides.

1.7 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for mathematical conversions to inch-pound units that are provided for information only and are not considered standard.

1.8 Appendix X2 lists the key variables used in calculating the mandatory type factors in Tables 1-3 and comments on their conservative values.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
C1036 Specification for Flat Glass
C1048 Specification for Heat-Strengthened and Fully Tempered Flat Glass
C1172 Specification for Laminated Architectural Flat Glass
D4065 Practice for Plastics: Dynamic Mechanical Properties: Determination and Report of Procedures
E631 Terminology of Building Constructions

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminology E631 for additional terms used in this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *acid etched glass, n*—glass surface that has been treated primarily with hydrofluoric acid and potentially in combination with other agents. Acid etched glass strength shall be considered as equivalent to float glass in this practice provided the glass thickness conforms to Specification C1036.

3.2.2 *aspect ratio (AR), n*—for glass simply supported on four sides, the ratio of the long dimension of the glass to the short dimension of the glass is always equal to or greater than 1.0. For glass simply supported on three sides, the ratio of the

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[1] This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.52 on Glass Use in Buildings.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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A3.7.4 The probability of breakages for Lite No. 1 and Lite No. 2 for the load carried by each are as follows:

$Pb_{1,p1}$ = 3.57e-3
$Pb_{1,p2}$ = 3.57e-3
Pb_2 = 8.35e-4

A3.7.5 *Conclusion*—The IG will support the specified short duration load of 70 psf with a probability of breakage of 3.57e-3.

APPENDIXES

(Nonmandatory Information)

X1. ALTERNATE PROCEDURE FOR CALCULATING THE APPROXIMATE CENTER OF GLASS DEFLECTION

X1.1 Maximum glass deflection as a function of plate geometry and load may be calculated from the following polynomial equations by Dalgliesh **(6)** for a curve fit to the Beason and Morgan **(4)** data from:

$$w = t \times exp\left(r_0 + r_1 \times x + r_2 \times x^2\right) \qquad (X1.1)$$

where:

w = center of glass deflection (mm) or (in.), and
t = plate thickness (mm) or (in.).

$$r_0 = 0.553 - 3.83\,(a/b) + 1.11\,(a/b)^2 - 0.0969\,(a/b)^3 \qquad (X1.2)$$

$$r_1 = -2.29 + 5.83\,(a/b) - 2.17\,(a/b)^2 + 0.2067\,(a/b)^3 \qquad (X1.3)$$

$$r_2 = 1.485 - 1.908\,(a/b) + 0.815\,(a/b)^2 - 0.0822\,(a/b)^3 \qquad (X1.4)$$

$$x = ln\{ln[q(ab)^2/Et^4]\} \qquad (X1.5)$$

where:

q = uniform lateral load (kPa) or (psi),
a = long dimension (mm) or (in.),
b = short dimension (mm) or (in.), and
E = modulus of elasticity of glass (71.7×10^6 kPa) or (10.4×10^6 psi).

X1.1.1 The polynomial equations give an approximate fit to center deflections of thin lites under enough pressure to cause non-linear behavior. Such deflections, which will exceed the lite thickness, should be rounded to the nearest mm (0.04 in.). Caution is advised for pressures less than ⅓ design capacity of the lite. For aspect ratios greater than 5, use 5.

X1.2 Examples 9 and 10 illustrate this procedure as follows:

X1.2.1 *Example 9: Lateral Deflection Calculation in SI Units Using Method X2*—Determine the maximum lateral deflection (w) of a vertical 1200 by 1500 by 6-mm rectangular glass plate subjected to a uniform lateral load of 1.80 kPa. The actual thickness of the glass is 5.60 mm as determined through direct measurement.

X1.2.2 $a = 1500$
$b = 1200$
From Eq X1.2 $r_0 = -2.689$

X1.2.3 From Eq X1.3 $r_1 = 2.011$

X1.2.4 From Eq X1.4 $r_2 = 0.213$

X1.2.5 $q = 1.80$
$E = 71.7 \times 10^6$
$t = 5.60$
From Eq X1.5 $x = 1.490$

X1.2.6 Therefore from Eq X1.1 the maximum center of glass deflection is:
$w = 5.6\ exp(-2.689 + 2.111 \times 1.490 + 0.213 \times 1.490^2)$
$w = 12.2$ mm

X1.2.7 *Example 10: Lateral Deflection Calculation in Inch-Pound Units Using Method X 2*—Determine the maximum lateral deflection (w) associated with a 50 by 60 by ¼-in. rectangular glass plate subjected to a uniform lateral load of 38 psf. The actual thickness of the glass is 0.220 in. as determined through direct measurement.

X1.2.8 $a = 60$
$b = 50$
From Eq X1.2 $r_0 = -2.612$

X1.2.9 From Eq X1.3 $r_1 = 1.938$

X1.2.10 From Eq X1.4 $r_2 = 0.227$

X1.2.11 $q = 38$
$E = 10.4 \times 10^6$
$t = 0.220$
From Eq X1.5 $x = 1.527$

X1.2.12 Therefore from Eq X1.1 the maximum center of glass deflection is:
$w = 0.220\ exp(-2.612 + 1.938 \times 1.527 + 0.227 \times 1.527^2)$
$w = 0.53$ in.

X2. COMMENTARY

X2.1 Determination of Type Factors

X2.1.1 The GTF presented in Tables 1-3 are intended to portray conservative representations of the behaviors of the various types of glass. Rigorous engineering analysis that accounts for the geometrically nonlinear performance of glass lites, glass surface condition, residual surface compression, surface area under stress, geometry, support conditions, load type and duration, and other relevant parameters can result in other type factors.

X2.2 Determination of Type Factors for Insulating Glass (IG)

X2.2.1 The IG type factors presented in Tables 2 and 3 have been calculated by multiplying the single lite GTF, for short or long duration load, from Table 1 or Table 2, by a probability (*p*) factor and a sealed air space pressure (*asp*) factor.

X2.2.2 The factor *p* allows for the number of glass surfaces from which a fracture can originate. As the area of glass under a given stress increases there is an increased risk of breakage occurring. For a single monolithic lite with two surfaces equally at risk,

$$p = 1.00 \qquad (X2.1)$$

X2.2.3 For a symmetrical IG with two monolithic lites of equal thickness and both AN, both HS, or both FT, the two outer surfaces (No. 1 and No. 4) are the most probable source of the fracture origin, but there is also a finite probability or a fracture originating on the protected surfaces, No. 2 and No. 3, so the factor is adjusted to:

$$p = 0.95 \qquad (X2.2)$$

X2.2.4 For an IG with one lite of AN glass and the other lite of heat treated (HS or FT) monolithic or heat treated LG, the air space surface of the AN glass is protected and therefore less likely than the exposed surface to be the location of the fracture origin. Therefore the AN lite probability factor becomes:

$$p = 1.05 \qquad (X2.3)$$

X2.2.5 There is insufficient data available on the probability of the fracture origin occurring on any one particular surface of an asymmetric IG when one lite is monolithic HS or FT and the other lite is monolithic FT or HS, or when the other lite is laminated AN, laminated HS or laminated FT, and so for these cases:

$$p = 1.0 \qquad (X2.4)$$

X2.2.6 A sealed air space pressure (*asp*) factor is included in the IG type factor because the lites of an IG unit are seldom parallel. This is due to sealed air space pressure differences caused by changes in: barometric pressure, temperature, and altitude from the time the unit was sealed. The factor for all IG units is:

$$asp = 0.95 \qquad (X2.5)$$

X3. DETERMINATION OF INSULATING GLASS (IG) LOAD SHARE FACTORS (LSF)

X3.1 The load sharing between the lites of a sealed IG unit is assumed to be proportional to the stiffness of the lites, that is, the glass thickness raised to the power of 3. (Where membrane stresses predominate, the exponent is less than 3 but this regime is outside the range of typical architectural glass design.) Values are approximate. Use Vallabhan and Chou **(1)** for alternate method.

X3.2 For the LSFs in Table 5, the LSF for Lite No. 1 is:

$$\mathrm{LSF1} = (t_1^3)/(t_1^3 + t_2^3) \qquad (X3.1)$$

where:

t_1 = minimum thickness of Lite No. 1, and
t_2 = minimum thickness of Lite No. 2.

Similarly the LSF for Lite No. 2 is:

$$\mathrm{LSF2} = (t_2^3)/(t_1^3 + t_2^3) \qquad (X3.2)$$

NOTE X3.1—The orientation of the IG unit is not relevant. Either Lite No. 1 or No. 2 can face the exterior.

Under short duration loads LG is assumed to behave in a monolithic-like manner. The glass thickness used for calculating LSFs for short duration loads is the sum of the thickness of glass of the 2 plies (in accordance with Table 1).

X3.3 Under long duration loads LG is assumed to behave in a layered manner. The load sharing is then based on the individual ply thicknesses of the LG. The LSF for one ply of the laminated lite of an IG composed of: monolithic glass, air space, laminated, is:

$$\mathrm{LSF_{ply}} = (t_{ply}^3)/(t_1^3 + 2 \times t_{ply}^3) \qquad (X3.3)$$

where t_{ply} is the minimum thickness of one glass ply of the laminate.

X4. LOAD DURATION FACTORS

X4.1 The purpose of Appendix X4 is to convert a calculated 3-s LR to a load duration listed in Table X4.1. To convert, multiply the LR by the factor in Table X4.1.

TABLE X4.1 Load Duration Factors

NOTE 1—Calculated to 8/1000 lites probability of breakage (see 3.2.11).

Duration	Factor
3 s	1.00
10 s	0.93
60 s	0.83
10 min	0.72
60 min	0.64
12 h	0.55
24 h	0.53
1 week	0.47
1 month (30 days)	0.43
1 year	0.36
beyond 1 year	0.31

X5. COMBINING LOADS OF DIFFERENT DURATION

X5.1 The purpose of Appendix X5 is to present an approximate technique to determine a design load which represents the combined effects of *j* loads of different duration. All loads are considered normal to the glass surface.

X5.2 Identify each load q_i, and its associated duration, d_i, given in seconds for *j* loads. Use the following equation to calculate the equivalent 3-s duration design load:

$$q_3 = \sum_{i=1}^{i=j} q_i \left[\frac{d_i}{3}\right]^{1/n} \qquad \text{(X5.1)}$$

where:

q_3 = the magnitude of the 3-s duration uniform load,
q_I = the magnitude of the load having duration d_i, and
n = 16 for AN glass.

X6. APPROXIMATE MAXIMUM SURFACE STRESS TO BE USED WITH INDEPENDENT STRESS ANALYSES

X6.1 The purpose of Appendix X6 is to provide a conservative technique for estimating the maximum allowable surface stress associated with glass lites continuously supported along all edges of the lite. The maximum allowable stress (*allowable*) is a function of area (*A*), load duration in seconds (*d*), and probability of breakage (P_b).

X6.2 This maximum allowable surface stress can be used for the design of special glass shapes and loads not covered elsewhere in this practice. This includes trapezoids, circular, triangular, and other odd shapes. A conservative allowable surface stress value for a 3-s duration load is 23.3 MPa (3 380 psi) for AN glass, 46.6 MPa (6 750 psi) for heat-strengthened glass, and 93.1 MPa (13 500 psi) for FT glass.

X6.3 The maximum surface stress in the glass lite should be calculated using rigorous engineering analysis, which takes into account large deflections, when required. This maximum calculated stress must be less than the maximum allowable stress.

X6.4 Maximum allowable surface stress is calculated using the following equation which has its basis in the same glass failure prediction that was used to develop the NFL charts in Section 6.

$$\sigma_{\text{allowable}} = \left(\frac{P_b}{[k\,(d/3)^{7/n} * A]}\right)^{1/7} \qquad \text{(X6.1)}$$

where:

$\sigma_{allowable}$ = maximum allowable surface stress,
P_b = probability of breakage,
k = a surface flaw parameter,
d = the duration of the loading,
A = the glass surface area, and
n = 16 for AN glass.

X6.5 The NFLs that are determined in this manner should be conservative with respect to the values presented in Section 6.

X6.6 Eq X6.1 is applicable where the probability of breakage (P_b) is less than 0.05. (Note that Section 6 references a P_b less than or equal to 0.008.)

X7. APPROXIMATE MAXIMUM EDGE STRESS FOR GLASS

X7.1 The purpose of Appendix X7 is to provide an estimate for the approximate maximum allowable edge stress (*allowable*) for glass lites associated with a maximum probability of breakage (P_b) less than or equal to 0.008 for a 3-s load duration **(7)**.

TABLE X7.1 Allowable Edge Stress

	Clean Cut Edges, MPa (psi)	Seamed Edges, MPa (psi)	Polished Edges, MPa (psi)
Annealed	16.6 (2400)	18.3 (2650)	20.0 (2900)
Heat-strengthened	N/A[A]	36.5 (5300)	36.5 (5300)
Tempered	N/A	73.0 (10 600)	73.0 (10 600)

[A] N/A–Not Applicable.

X7.2 This approximate maximum allowable edge stress can be used for the design of glass shapes and support conditions where edge stress is significant. This includes applications where the glass is not supported on one or more edges. An approximate allowable edge stress value for a 3-s duration can be found in Table X7.1.

X7.3 The approximate maximum edge stress in the glass lite should be calculated using rigorous engineering analysis, which takes into account large deflections, when required. This maximum calculated stress must be less than the maximum allowable stress.

X8. METHOD FOR ESTABLISHING EQUIVALENCY OF NON-POLYVINYL BUTYRAL (PVB) POLYMER INTERLAYERS

X8.1 The purpose of Appendix X8 is to provide a criterion for specifying when the non-factored LR charts for PVB LG may be used for LG made with plastic interlayers other than PVB.

X8.2 The NFL charts for PVB LG have been derived from a stress analysis that incorporates a viscoelastic model for the plastic interlayer **(8)**. The viscoelastic model accurately describes the evolution of polymer shear modulus at 50°C (122°F) under load duration of 3 s. The PVB interlayer can be characterized with an effective Young's modulus of 1.5 MPa (218 psi) for these conditions. This Young's modulus value is a lower bound of the known values for the commercially available PVB interlayers at 50°C (122°F) after 3-s load duration.

X8.3 For LG made with non-PVB plastic interlayers, the non-factored LR charts for PVB LG may be used if the plastic interlayer has a Young's modulus greater than or equal to 1.5 MPa (218 psi), at 50°C (122°F) under an equivalent 3-s load. The Young's modulus value should be determined following Practice D4065. The forced constant amplitude, fixed frequency tension oscillation test specified in Table 1 of Practice D4065 should be used and the storage Young's modulus measured at 50°C (122°F) under a 0.3 Hz sinusoidal loading condition.

X8.3.1 If the shear modulus of the non-PVB polymer interlayer is greater than or equal to 0.4 MPa (the shear modulus of PVB at 50°C (122°F)), then the non-PVB interlayer is considered equivalent to PVB and the NFL charts for PVB laminates can be used to determine the LR of the non-PVB interlayer glass laminate.

X8.4 This specification can only be applied to interlayer that are monolithic, or become monolithic with processing and have a thickness greater than 0.38 mm (0.015 in.). Interlayers comprised of differing polymers in multiple layers are not covered in this procedure.

X9. METHOD FOR DETERMINING EFFECTIVE THICKNESS OF LAMINATED GLASS FOR ANALYSIS OF STRESSES AND DEFLECTION

X9.1 The purpose of Appendix X9 is to provide engineering formula for calculating the effective thickness of laminated glass. Two different effective laminate thickness values are determined for a specific case: (*1*) an effective thickness, $h_{ef;w}$, for use in calculations of laminate deflection, and (*2*) an effective laminate thickness, $h_{1,e,\sigma}$ for use is calculations of laminate glass stress. These effective thickness values can be used with standard engineering formulae or finite element methods for calculating both deflection and glass stress of laminates subjected to load. The method applies to 2-ply laminates fabricated from both equal and unequal thickness glass plies. The intent of Appendix X9 is to provide a method that allows the user to perform engineering analysis of laminated glass for cases not covered by the non-factored load charts.

X9.2 The shear transfer coefficient, Γ, which is a measure of the transfer of shear stresses across the interlayer, is given by:

$$\Gamma = \frac{1}{1 + 9.6\dfrac{EI_s h_v}{Gh_s^2 a^2}} \qquad \text{(X9.1)}$$

with:

$$I_s = h_1 h_{s;2}^2 + h_2 h_{s;1}^2 \qquad \text{(X9.2)}$$

$$h_{s;1} = \frac{h_s h_1}{h_1 + h_2} \qquad \text{(X9.3)}$$

$$h_{s;2} = \frac{h_s h_2}{h_1 + h_2} \qquad (X9.4)$$

$$h_s = 0.5\,(h_1 + h_2) + h_v \qquad (X9.5)$$

where:

h_v = interlayer thickness,
h_1 = glass ply 1 minimum thickness (see Table 4),
h_2 = glass ply 2 minimum thickness (see Table 4),
E = glass Young's modulus of elasticity,
a = smallest in-plane dimension of bending of the laminate plate, and
G = interlayer complex shear modulus (see X9.4).

X9.2.1 Note that for interlayers comprised of a stack of different polymers, the interlayer thickness h_v, is considered to be the total stack thickness. The shear transfer coefficient, Γ, varies from 0 to 1.

X9.3 For calculations of laminate deflection, the laminate effective thickness, $h_{ef;w}$, is given by:

$$h_{ef;w} = \sqrt[3]{h_1^3 + h_2^3 + 12\Gamma I_s} \qquad (X9.6)$$

X9.3.1 For calculations of the maximum glass bending stress, the laminate effective thicknesses (one for each glass ply) are given by:

$$h_{1;ef;\sigma} = \sqrt{\frac{h_{ef;w}^3}{h_1 + 2\Gamma h_{s;2}}} \qquad (X9.7)$$

$$h_{2;ef;\sigma} = \sqrt{\frac{h_{ef;w}^3}{h_2 + 2\Gamma h_{s;1}}} \qquad (X9.8)$$

X9.3.2 The calculation normally needs only to be performed for the thickest ply, unless there are different types of glass in the laminate that have different allowable stresses **(9)**.

X9.4 The primary interlayer property that influences the laminate deformation is the complex shear modulus, *G*. The complex shear modulus is a measure of the plastic interlayer's shear resistance. The greater the shear resistances, the more effectively the two glass plies couple and resist deformation under loading. The effective laminate thickness approaches the equivalent monolith thickness for stiff interlayers (Γ → 1) and approaches the layered limit for compliant interlayers (Γ → 0).

X9.5 Key to the use of the method is the accurate determination of the interlayer shear modulus. All interlayers are viscoelastic so consideration must be given to load duration and temperature for the intended use. Interlayer samples shall experience full laminating thermal history prior to measurement. The shear modulus value shall be determined following Practice D4065. The forced constant amplitude, fixed frequency tension oscillation test specified in Table 1 and Fig. 5 of Practice D4065 shall be used and the shear modulus extracted for the temperature and load duration of interest. Typical load duration-temperature combinations for design purposes are: (*1*) 3 s/50°C (122°F) for wind loads, and (*2*) 30 days/23°C (73°F) for snow loads. Note that for load durations beyond the physical capabilities of the test apparatus employed for the measurement, use the time-temperature-superposition (TTS) procedure established by Ferry **(10)** and used by Bennison et al. **(8)**, to estimate the shear modulus at the load duration of interest. For interlayers comprised of a stack of different polymers, the shear modulus shall be measured on the individual polymer components of the stack and the shear modulus value for most compliant polymer layer shall be used in determining the shear transfer coefficient, Γ. Contact the interlayer manufacturer for appropriate shear modulus values.

X9.6 Laminates shall comply with Specification C1172.

X9.7 *Example 13*—An engineer wishes to calculate the maximum glass stress and deflection of a laminated glass beam with dimensions 1.0 m × 1.75 m (39.4 in. × 68.9 in.). The beam is fixed along one long edge (cantilever) and is subjected to a line load, *P*, of 0.75 kN/m (51.4 lbf/foot) applied to the opposite parallel edge. The proposed laminate construction is 10 mm glass | 1.52 mm interlayer | 10 mm glass (3/8 in. glass | 0.060 in. interlayer | 3/8 in. glass). From consideration of the application, it is specified that the line load duration is 60 min at a sustained temperature of 30°C (86°F). For these loading duration and temperature considerations the interlayer shear modulus, *G*, is determined to be 0.44 MPa (63.8 psi).

Therefore:

h_v = 1.52 mm (0.060 in.),
h_1 = 9.02 mm (0.355 in.),
h_2 = 9.02 mm (0.355 in.),
E = 71.7 GPa (10 399 ksi),
a = 1.0 m (39.4 in.), and
G = 0.44 MPa (63.8 psi).

Substituting into Eq X9.1 to Eq X9.8 gives:

I_s = 501 mm^3 (0.031 in.^{3}),
$h_{s;1}$ (= $h_{s;2}$) = 5.27 mm (0.208 in.),
h_s = 10.54 mm (0.415 in.), and
Γ = 0.085.

Effective thickness for deflection:

$h_{ef;w}$ = 12.56 mm (0.495 in.).

Effective thickness for stress:

$h_{1;ef;\sigma} = h_{2;ef;\sigma}$ = 14.13 mm (0.556 in.).

X9.7.1 In order to calculate the maximum beam glass stress, σ_{max}, and the maximum beam deflection, δ_{max}, the effective thickness values are substituted into the standard engineering formulae for a cantilevered beam with a line load:

$$\sigma_{max} = \frac{6Pa}{h_{1;ef;\sigma}^2} \qquad (X9.9)$$

$$\delta_{max} = \frac{4Pa^3}{Eh_{ef;w}^3} \qquad (X9.10)$$

gives:

σ_{max} = 22.5 MPa (3263 psi), and
δ_{max} = 21.1 mm (0.831 in.).