INTERNATIONAL

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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 covers 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.

NOTE 1—Ceramic enamel is known to affect glass load resistance. Consult the manufacturer for guidance.

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 6.3).

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

1.8 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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.

[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.

TABLE 1 Glass Type Factors (GTF) for a Single Lite of Monolithic or Laminated Glass (LG)

Glass Type	GTF	
	Short Duration Load (3 s)	Long Duration Load (30 days)
AN	1.0	0.43
HS	2.0	1.3
FT	4.0	3.0

TABLE 2 Glass Type Factors (GTF) for Double Glazed Insulating Glass (IG), Short Duration Load

Lite No. 1 Monolithic Glass or Laminated Glass Type	Lite No. 2 Monolithic Glass or Laminated Glass Type					
	AN		HS		FT	
	GTF1	GTF2	GTF1	GTF2	GTF1	GTF2
AN	0.9	0.9	1.0	1.9	1.0	3.8
HS	1.9	1.0	1.8	1.8	1.9	3.8
FT	3.8	1.0	3.8	1.9	3.6	3.6

TABLE 3 Glass Type Factors (GTF) for Double Glazed Insulating Glass (IG), Long Duration Load (30 day)

Lite No. 1 Monolithic Glass or Laminated Glass Type	Lite No. 2 Monolithic Glass or Laminated Glass Type					
	AN		HS		FT	
	GTF1	GTF2	GTF1	GTF2	GTF1	GTF2
AN	0.39	0.39	0.43	1.25	0.43	2.85
HS	1.25	0.43	1.17	1.17	1.25	2.85
FT	2.85	0.43	2.85	1.25	2.71	2.71

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 length of one of the supported edges perpendicular to the free edge, to the length of the free edge, is equal to or greater than 0.5.

3.2.3 *glass breakage, n*—the fracture of any lite or ply in monolithic, laminated, or insulating glass.

3.2.4 *Glass Thickness:*

3.2.4.1 *thickness designation for laminated glass (LG), n*—a term used to specify a LG construction based on the combined thicknesses of component plies.

(1) Add the minimum thicknesses of the individual glass plies and the nominal interlayer thickness. If the sum of all interlayer thicknesses is greater than 1.52 mm (0.060 in.) use 1.52 mm (0.060 in.) in the calculation.

(2) Select the nominal thickness or designation in Table 4 having the closest minimum thickness that is equal to or less than the value obtained in 3.2.4.1 (*1*).

(3) Exceptions—The construction of two 6 mm (1/4 in.) glass plies plus 0.38 mm (0.015 in.) or 0.76 mm (0.030 in.) interlayer shall be defined as 12 mm (1/2 in.). The construction of two 2.5 mm (3/32 in.) glass plies plus 1.52 mm (0.060 in.) interlayer shall be defined as 5 mm (3/16 in.). The construction of two 4 mm (5/32 in.) glass plies plus any thickness interlayer shall be defined as 8 mm (5/16 in.).

TABLE 4 Nominal and Minimum Glass Thicknesses

Nominal Thickness or Designation, mm (in.)	Minimum Thickness, mm (in.)
2.0 (picture)	1.80 (0.071)
2.5 (3/32)	2.16 (0.085)
2.7 (lami)	2.59 (0.102)
3.0 (1/8)	2.92 (0.115)
4.0 (5/32)	3.78 (0.149)
5.0 (3/16)	4.57 (0.180)
6.0 (1/4)	5.56 (0.219)
8.0 (5/16)	7.42 (0.292)
10.0 (3/8)	9.02 (0.355)
12.0 (1/2)	11.91 (0.469)
16.0 (5/8)	15.09 (0.595)
19.0 (3/4)	18.26 (0.719)
22.0 (7/8)	21.44 (0.844)
25.0 (1)	24.61 (0.969)

3.2.4.2 *thickness designation for monolithic glass, n*—a term that defines a designated thickness for monolithic glass as specified in Table 4 and Specification C1036.

3.2.5 *Glass Types:*

3.2.5.1 *annealed (AN) glass, n*—a flat, monolithic, glass lite of uniform thickness where the residual surface stresses are nearly zero as defined in Specification C1036.

3.2.5.2 *fully tempered (FT) glass, n*—a flat, monolithic, glass lite of uniform thickness that has been subjected to a special heat treatment process where the residual surface compression is not less than 69 MPa (10 000 psi) or the edge compression not less than 67 MPa (9700 psi) as defined in Specification C1048.

3.2.5.3 *heat strengthened (HS) glass, n*—a flat, monolithic, glass lite of uniform thickness that has been subjected to a special heat treatment process where the residual surface compression is not less than 24 MPa (3500 psi) or greater than 52 MPa (7500 psi) as defined in Specification C1048.

3.2.5.4 *insulating glass (IG) unit, n*—any combination of two or three glass lites that enclose one or two sealed spaces respectively, filled with air or other gas.

3.2.5.5 *laminated glass (LG), n*—a flat lite of uniform thickness consisting of two or more monolithic glass plies bonded together with an interlayer material as defined in Specification C1172.

(1) Discussion—Many different interlayer materials are used in LG. The information in this practice applies only to polyvinyl butyral (PVB) interlayer or those interlayers that demonstrate equivalency according to Appendix X8.

3.2.6 *glass type factor (GTF), n*—a multiplying factor for adjusting the LR of different glass types, that is, AN, HS, or FT in monolithic glass, LG, or IG constructions.

3.2.7 *lateral, adj*—perpendicular to the glass surface.

3.2.8 *load, n*—a uniformly distributed lateral pressure.

3.2.8.1 *glass weight load, n*—the dead load component of the glass weight.

3.2.8.2 *load resistance (LR), n*—the uniform lateral load that a glass construction can sustain based upon a given probability of breakage and load duration.

(1) Discussion—Multiplying the non-factored load (NFL) from figures in Annex A1 by the relevant GTF and load share

(LS) factors gives the LR associated with a probability of breakage less than or equal to 0.008.

3.2.8.3 *long duration load, n*—any load lasting approximately 30 days.

(1) Discussion—For loads having durations other than 3 s or 30 days, refer to Table X4.1.

3.2.8.4 *non-factored load (NFL)*—three-second duration uniform load associated with a probability of breakage less than or equal to 0.008 for monolithic AN glass as determined from the figures in Annex A1.

3.2.8.5 *short duration load, n*—any load lasting 3 s or less.

3.2.8.6 *specified design load, n*—the magnitude in kPa (psf), type (for example, wind or snow) and duration of the load given by the specifying authority.

3.2.9 *load share factor (LSF), n*—the portion of applied load going to a particular lite in consideration in a sealed IG unit, whether the lite be monolithic glass or LG (including the layered behavior of LG under long duration loads).

3.2.9.1 *Discussion*—The LSF is used along with the GTF and the NFL value from the NFL charts to give the LR of the IG unit, based on the resistance to breakage of one specific lite only.

3.2.10 *patterned glass, n*—rolled flat glass having a pattern on one or both surfaces.

3.2.11 *probability of breakage (P_b), n*—the statistical likelihood that a given lite or ply would break at the first occurrence of a specified load and duration, typically expressed in decimal format when larger than 0.001 and scientific notation when less than 0.001.

3.2.12 *sandblasted glass, n*—flat glass with a surface that has been sprayed by sand or other media at high velocities to produce a translucent effect.

3.2.13 *specifying authority, n*—the design professional responsible for interpreting applicable regulations of authorities having jurisdiction and considering appropriate site specific factors to determine the appropriate values used to calculate the specified design load, and furnishing other information required to perform this practice.

3.2.14 *wired glass, n*—flat glass with a layer of wire strands or mesh completely embedded in the glass.

4. Material Properties

4.1 *Glass (Soda-lime-silica):*

4.1.1 Modulus of Elasticity = 71.7 GPa (10.4×10^6 psi).

4.1.2 Poisson's Ratio = 0.22.

4.1.3 Density = 2500 kg/m^3(157 lb/ft^3).

4.1.4 Surface Parameters m = 7; k = 2.86×10^{-53} N^{-7} m^{12} (1.365×10^{-29} $in.^{12}$ lb^{-7} in.).

4.1.4.1 These values are based on a load duration of 60 s.

4.1.5 Static Fatigue Constant n = 16 (for all glass types).

4.2 *Interlayers:*

4.2.1 Refer to manufacturer for material properties for relevant load duration and temperature. (Refer to Appendix X8 for material properties used to generate the charts Figs. A1.29-A1.44.)

5. Summary of Practice

5.1 The specifying authority shall provide the design load, the rectangular glass dimensions, the type of glass required, and a statement, or details, showing that the glass edge support system meets the stiffness requirement in 6.2.4.

5.2 The procedure specified in this practice shall be used to determine the uniform lateral LR of glass in buildings. If the LR is less than the specified load, then other glass types and thicknesses may be evaluated to find a suitable assembly having LR equal to or exceeding the specified design load.

5.3 The charts presented in this practice shall be used to determine the approximate maximum lateral glass deflection. Appendix X1 presents additional procedures to determine the approximate maximum lateral deflection for a specified load on glass simply supported on four sides.

6. Significance and Use

6.1 This practice is used to determine the LR of specified glass types and constructions exposed to uniform lateral loads.

6.2 Use of this practice assumes:

6.2.1 The glass is free of edge damage and is properly glazed.

6.2.2 The glass has not been subjected to abuse.

6.2.3 The surface condition of the glass is typical of glass that has been in service for several years, and is weaker than freshly manufactured glass due to minor abrasions on exposed surfaces.

6.2.4 The glass edge support system is sufficiently stiff to limit the lateral deflections of the supported glass edges to no more than 1⁄175 of their lengths. The specified design load shall be used for this calculation.

6.2.5 The deflection of glass or support system, or both, shall not result in loss of glass edge support. The glass bite reduction or pullout shall be considered using the method referenced in (**1**).[3]

NOTE 2—Glass deflections are to be reviewed. This practice does not address aesthetic issues caused by glass deflection.

NOTE 3—This practice does not consider the effects of deflection on insulating glass unit seal performance.

NOTE 4—The designer/engineer must determine what constitutes sufficient glass edge support based on Annex A1, Non-Factored Load Charts.

6.3 Many other factors shall be considered in glass type and thickness selection. These factors include but are not limited to: thermal stresses, spontaneous breakage of tempered glass, the effects of windborne debris, excessive deflections, behavior of glass fragments after breakage, blast, seismic effects, building movement, heat flow, edge bite, noise abatement, and potential post-breakage consequences. In addition, considerations set forth in building codes along with criteria presented in safety-glazing standards and site-specific concerns may control the ultimate glass type and thickness selection.

6.4 For situations not specifically addressed in this standard, the design professional shall use engineering analysis and judgment to determine the LR of glass in buildings.

[3] The boldface numbers in parentheses refer to a list of references at the end of this standard.

7. Procedure

7.1 Select the procedure to determine the load resistance.

7.2 *Basic Procedure:*

7.2.1 *For Monolithic Single Glazing Simply Supported Continuously Along Four Sides:*

7.2.1.1 Determine the NFL from the appropriate chart in Annex A1 (the upper charts of Figs. A1.1-A1.14) for the glass thickness and size.

7.2.1.2 Determine the GTF for the appropriate glass type and load duration (short and long) from Table 1.

7.2.1.3 Multiply NFL by GTF to get the LR of the lite.

7.2.1.4 Determine the appropriate maximum lateral (center of glass) deflection from the approximate chart in Annex A1 (the lower charts of Figs. A1.1-A1.14) for the designation glass thickness, size, and design load. If the maximum lateral deflection falls outside the charges in Annex A1, then use the procedures outlined in Appendix X1.

7.2.2 *For Monolithic Single Glazing Simply Supported Continuously Along Three Sides:*

7.2.2.1 Determine the NFL from the appropriate chart in Annex A1 (the upper charts of Figs. A1.15-A1.26) for the designated glass thickness and size.

7.2.2.2 Determine the GTF for the appropriate glass type and load duration (short or long) from Table 1.

7.2.2.3 Multiply NFL by GTF to get the LR of the lite.

7.2.2.4 Determine the approximate maximum lateral (center of unsupported edge) deflection from the appropriate chart in Annex A1 (the lower charts in Figs. A1.15-A1.26) for the designated glass thickness, size, and design load.

7.2.3 *For Monolithic Single Glazing Simply Supported Continuously Along Two Opposite Sides:*

7.2.3.1 Determine the NFL from the upper chart of Fig. A1.27 for the designated glass thickness and length of unsupported edges.

7.2.3.2 Determine the GTF for the appropriate glass type and load duration (short or long) from Table 1.

7.2.3.3 Multiply NFL by GTF to get the LR of the lite.

7.2.3.4 Determine the approximate maximum lateral (center of an unsupported edge) deflection from the lower chart of Fig. A1.27 for the designated glass thickness, length of unsupported edge, and design load.

7.2.4 *For Monolithic Single Glazing Continuously Supported Along One Edge (Cantilever):*

7.2.4.1 Determine the NFL from the upper chart of Fig. A1.28 for the designated glass thickness and length of unsupported edges that are perpendicular to the supported edge.

7.2.4.2 Determine the GTF for the appropriate glass type and load duration (short or long) from Table 1.

7.2.4.3 Multiply NFL by GTF to get the LR of the lite.

7.2.4.4 Determine the approximate maximum lateral (free edge opposite the supported edge) deflection from the lower chart of Fig. A1.28 for the designated glass thickness, length of unsupported edges, and design load.

7.2.5 *For Single-Glazed Laminated Glass (LG) Constructed With a PVB Interlayer Simply Supported Continuously Along Four Sides Where In-Service Laminated Glass (LG) Temperatures At The Design Load Do Not Exceed 50 °C (122 °F):*

7.2.5.1 Determine the NFL from the appropriate chart (the upper charts of Figs. A1.29-A1.35) for the designated glass thickness.

7.2.5.2 Determine the GTF for the appropriate glass type, load duration (short or long) from Table 1.

7.2.5.3 Multiply NFL by GTF to get the LR of the laminated lite.

7.2.5.4 Determine the approximate maximum lateral (center of glass) deflection from the appropriate chart (the lower charts of Figs. A1.29-A1.35) for the designated glass thickness, size, and design load. If the maximum lateral deflection falls outside the charts in Annex A1, then use the procedures outlined in Appendix X1.

7.2.6 *For Laminated Single Glazing Simply Supported Continuously Along Three Sides Where In-Service Laminated Glass (LG) Temperatures At The Design Load Do Not Exceed 50 °C (122 °F):*

7.2.6.1 Determine the NFL from the appropriate chart (the upper charts of Figs. A1.36-A1.42) for the designated glass thickness and size equal to the LG thickness.

7.2.6.2 Determine the GTF for the appropriate glass type and load duration (short or long) from Table 1.

7.2.6.3 Multiply NFL by GTF to get the LR of the laminated lite.

7.2.6.4 Determine the approximate maximum lateral (center of unsupported edge) deflection from the appropriate chart (the lower charts of Figs. A1.36-A1.42) for the designated glass thickness, size, and design load.

7.2.7 *For Laminated Single Glazing Simply Supported Continuously Along Two Opposite Sides Where In-Service Laminated Glass (LG) Temperatures At The Design Load Do Not Exceed 50 °C (122 °F):*

7.2.7.1 Determine the NFL from the upper chart of Fig. A1.43 for the designated glass thickness and length of unsupported edges.

7.2.7.2 Determine the GTF for the appropriate glass type and load duration (short or long) from Table 1.

7.2.7.3 Multiply NFL by GTF to get the LR of the laminated lite.

7.2.7.4 Determine the approximate maximum lateral (center of an unsupported edge) deflection from the lower chart of Fig. A1.43 for the designated glass thickness, length of unsupported edge, and design load.

7.2.8 *For Laminated Single Glazing Continuously Supported Along One Edge (Cantilever) Where In-Service Laminated Glass (LG) Temperatures At The Design Load Do Not Exceed 50 °C (122 °F):*

7.2.8.1 Determine the NFL from the upper chart of Fig. A1.44 for the designated glass thickness and length of unsupported edges that are perpendicular to the supported edge.

7.2.8.2 Determine the GTF for the appropriate glass type and load duration (short or long) from Table 1.

7.2.8.3 Multiply NFL by GTF to get the LR of the laminated lite.

7.2.8.4 Determine the approximate maximum lateral (free edge opposite the supported edge) deflection from the lower chart of Fig. A1.44 for the designated glass thickness, length of unsupported edges, and design load.

7.2.9 *For Double Glazed Insulating Glass (IG) with Monolithic Glass Lites of Equal (Symmetric) or Different (Asymmetric) Glass Type and Thickness Simply Supported Continuously Along Four Sides:*

7.2.9.1 Determine the NFL1 for Lite No. 1 and NFL2 for Lite No. 2 from the upper charts of Figs. A1.1-A1.14 (see Annex A3 for examples).

NOTE 5—Lites No. 1 or No. 2 can represent either the outward or inward facing lite of the IG unit.

7.2.9.2 Determine the GTF1 for Lite No. 1 and GTF2 for Lite No. 2 from Table 2 or Table 3, for the relevant glass type and load duration.

7.2.9.3 Determine the LSF1 for Lite No. 1 and LSF2 for Lite No. 2 from Table 5, for the relevant lite thickness.

7.2.9.4 Multiply NFL by GTF and divide by the LSF for each lite to determine LR1 for Lite No. 1 and LR2 for Lite No. 2 of the IG unit as follows:

$$LR1 = NFL1 \times GTF1 \div LSF1 \text{ and } LR2 = NFL2 \times GTF2 \div LSF2 \quad (1)$$

7.2.9.5 The LR of the IG unit is the lower of the two values, LR1 and LR2.

7.2.10 *For Double Glazed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides:*

7.2.10.1 Determine the NFL for each lite from the upper charts of Figs. A1.1-A1.14 and Figs. A1.29-A1.35.

7.2.10.2 Determine the GTF1 for Lite No. 1 and GTF2 for Lite No. 2 from Table 2.

7.2.10.3 Determine LSF1 for Lite No. 1 and LSF2 for Lite No. 2, from Table 5.

7.2.10.4 Multiply NFL by GTF and divide by the LSF for each lite to determine LR1 for Lite No. 1 and LR2 for Lite No. 2 of the IG unit as follows:

$$LR1 = NFL1 \times GTF1 \div LSF1 \text{ and } LR2 = NFL2 \times GTF2 \div LSF2 \quad (2)$$

7.2.10.5 The LR of the IG unit is the lower of the two calculated LR values.

7.2.11 *For Double Glazed Insulating Glass with Laminated Glass (LG) over Laminated Glass (LG) Under Short Duration Load Simply Supported Continuously Along Four Sides:*

7.2.11.1 Determine the NFL1 for Lite No. 1 and NFL2 for Lite No. 2 from the upper charts of Figs. A1.29-A1.35 (see Annex A3 for examples).

7.2.11.2 For each lite, determine GTF1 for Lite No. 1 and GTF2 for Lite No. 2 from Table 2.

7.2.11.3 For each lite, determine the LSF1 for Lite No. 1 and LSF2 for Lite No. 2 from Table 5.

7.2.11.4 Multiply NFL by GTF and divide by the LSF for each lite to determine LR1 for Lite No. 1 and LR2 for Lite No. 2 of the IG unit as follows:

$$LR1 = NFL1 \times GTF1 \div LSF1 \text{ and } LR2 = NFL2 \times GTF2 \div LSF2 \quad (3)$$

7.2.11.5 The LR of the IG unit is the lower of the two calculated LR values.

7.2.12 *For Double Glazed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite, Under Long Duration Load Simply Supported Continuously Along Four Sides:*

7.2.12.1 The LR of each lite must first be calculated for that load acting for a short duration as in 7.2.10, and then for the same load acting for a long duration as given in 7.2.12.2 – 7.2.12.5.

NOTE 6—There are some combinations of IG with LG where its monolithic-like behavior under a short duration load gives the IG a lesser LR than under the layered behavior of long duration loads.

7.2.12.2 Determine the NFL for each lite from the upper charts of Figs. A1.1-A1.14 and Figs. A1.29-A1.35 (see Annex A3 for examples).

7.2.12.3 Determine GTF1 for Lite No. 1 and GTF2 for Lite No. 2 from Table 3 for the relevant glass type.

7.2.12.4 Determine LSF1 for Lite No. 1 and LSF2 for Lite No. 2 from Table 6 for the relevant lite thickness.

7.2.12.5 Multiply NFL by GTF and divide by the LSF for each lite to determine LR1 for Lite No. 1 and LR2 for Lite No. 2 of the IG unit, based on the long duration LR of each lite, as follows:

$$LR1 = NFL1 \times GTF1 \div LSF1 \text{ and } LR2 = NFL2 \times GTF2 \div LSF2 \quad (4)$$

7.2.12.6 The LR of the IG unit is the lowest of the four calculated LR values LR1 and LR2 for short duration loads from 7.2.10.4 and LR1 and LR2 for long duration loads from 7.2.12.5.

7.2.13 *For Double Glazed Insulating Glass with Laminated Glass (LG) over Laminated Glass (LG) Under Long Duration Load:*

7.2.13.1 The LR of each lite must first be calculated for that load acting for a short duration as in 7.2.11, and then for the same load acting for a long duration as given in 7.2.13.2 – 7.2.13.5.

7.2.13.2 Determine NFL1 for Lite No. 1 and NFL2 for Lite No. 2 from the upper charts of Figs. A1.29-A1.35 (see Annex A3 for examples).

7.2.13.3 Determine the GTF1 for Lite No. 1 and GTF2 for Lite No. 2 from Table 3.

7.2.13.4 Determine LSF1 for Lite No. 1 and LSF2 for Lite No. 2 from Table 5.

7.2.13.5 Multiply NFL by GTF and divide by the LSF for each lite to determine the LRs (LR1 and LR2 for Lites No. 1 and No. 2) of the IG unit, based on the long duration LR of each lite, as follows:

$$LR1 = NFL1 \times GTF1 \div LSF1 \text{ and } LR2 = NFL2 \times GTF2 \div LSF2 \quad (5)$$

7.2.13.6 The LR of the IG unit is the lowest of the four calculated LR values LR1 and LR2 for short duration loads from 6.12.4 and LR1 and LR2 for long duration loads from 7.2.13.5.

7.2.14 *For Triple Glazed Insulating Glass (IG) with Three Lites of Monolithic Glass of Equal (Symmetric) or Different (Asymmetric) Thickness with Two Separately Sealed Air Spaces and Equal Glass Type, Simply Supported Continuously Along Four Sides:*

NOTE 7—The user is recommended to limit the combined width of both air spaces in the IG unit to less than or equal to 25 mm (1 in.). A larger combined dimension may result in excessive sealant stress and glass stresses due to temperature and altitude conditions.

TABLE 5 Load Share Factors (LSF) for Double Glazed Insulating Glass (IG) Units

NOTE 1—Lite No. 1 Monolithic glass, Lite No. 2 Monolithic glass, short or long duration load, or Lite No. 1 Monolithic glass, Lite No. 2 Laminated glass, short duration load only, or Lite No. 1 Laminated Glass, Lite No. 2 Laminated Glass, short or long duration load.

NOTE 2—Values are approximated. Use Vallabhan and Chou (2) for alternate method. See Appendix X3 for basis of these values.

Lite No. 1		Lite No. 2																											
Monolithic Glass		Monolithic Glass, Short or Long Duration Load or Laminated Glass, Short Duration Load Only																											
Nominal Thickness		2.0 (picture)		2.5 (3⁄32)		2.7 (lami)		3 (1⁄8)		4 (5⁄32)		5 (3⁄16)		6 (1⁄4)		8 (5⁄16)		10 (3⁄8)		12 (1⁄2)		16 (5⁄8)		19 (3⁄4)		22 (7⁄8)		25 (1)	
mm	(in.)	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2
2.0	(picture)	0.500	0.500	0.367	0.633	0.251	0.749	0.190	0.810	0.097	0.903	0.058	0.942	0.033	0.967	0.014	0.986	0.008	0.992	0.003	0.997	0.002	0.998	0.001	0.999	0.0006	0.9994	0.0004	0.9996
2.5	(3⁄32)	0.633	0.367	0.500	0.500	0.367	0.633	0.288	0.712	0.157	0.843	0.096	0.904	0.055	0.945	0.024	0.976	0.014	0.986	0.006	0.994	0.003	0.997	0.002	0.998	0.001	0.999	0.0007	0.9993
2.7	(lami)	0.749	0.251	0.633	0.367	0.500	0.500	0.411	0.589	0.243	0.757	0.154	0.846	0.092	0.908	0.041	0.959	0.023	0.977	0.010	0.990	0.005	0.995	0.003	0.997	0.002	0.998	0.001	0.999
3	(1⁄8)	0.810	0.190	0.712	0.288	0.589	0.411	0.500	0.500	0.316	0.684	0.207	0.793	0.127	0.873	0.057	0.943	0.033	0.967	0.015	0.985	0.007	0.993	0.004	0.996	0.003	0.997	0.002	0.998
4	(5⁄32)	0.903	0.097	0.843	0.157	0.757	0.243	0.684	0.316	0.500	0.500	0.361	0.639	0.239	0.761	0.117	0.883	0.069	0.931	0.031	0.969	0.015	0.985	0.009	0.991	0.005	0.995	0.004	0.996
5	(3⁄16)	0.942	0.058	0.904	0.096	0.846	0.154	0.793	0.207	0.639	0.631	0.500	0.500	0.357	0.643	0.189	0.811	0.115	0.885	0.053	0.947	0.027	0.973	0.015	0.985	0.010	0.990	0.006	0.994
6	(1⁄4)	0.967	0.033	0.945	0.055	0.908	0.092	0.873	0.127	0.761	0.239	0.643	0.357	0.500	0.500	0.296	0.704	0.190	0.810	0.092	0.908	0.048	0.952	0.027	0.973	0.017	0.983	0.011	0.989
8	(5⁄16)	0.986	0.014	0.976	0.024	0.959	0.041	0.943	0.057	0.883	0.117	0.811	0.189	0.704	0.296	0.500	0.500	0.358	0.642	0.195	0.805	0.106	0.894	0.063	0.937	0.040	0.960	0.027	0.973
10	(3⁄8)	0.992	0.008	0.986	0.014	0.977	0.023	0.967	0.033	0.931	0.069	0.885	0.115	0.810	0.190	0.642	0.358	0.500	0.500	0.303	0.697	0.176	0.824	0.108	0.892	0.069	0.931	0.047	0.953
12	(1⁄2)	0.997	0.003	0.994	0.006	0.990	0.010	0.985	0.015	0.969	0.031	0.947	0.053	0.908	0.092	0.805	0.195	0.697	0.303	0.500	0.500	0.330	0.670	0.217	0.783	0.146	0.854	0.102	0.898
16	(5⁄8)	0.998	0.002	0.997	0.003	0.995	0.005	0.993	0.007	0.985	0.015	0.973	0.027	0.952	0.048	0.894	0.106	0.824	0.176	0.670	0.330	0.500	0.500	0.361	0.639	0.259	0.741	0.187	0.813
19	(3⁄4)	0.999	0.001	0.998	0.002	0.997	0.003	0.996	0.004	0.991	0.009	0.985	0.015	0.973	0.027	0.937	0.063	0.892	0.108	0.783	0.217	0.639	0.361	0.500	0.500	0.382	0.618	0.290	0.710
22	(7⁄8)	0.9994	0.0006	0.999	0.001	0.998	0.002	0.997	0.003	0.995	0.005	0.990	0.010	0.983	0.017	0.960	0.040	0.931	0.069	0.854	0.146	0.741	0.259	0.618	0.382	0.500	0.500	0.398	0.602
25	(1)	0.9996	0.0004	0.999	0.0007	0.999	0.001	0.998	0.002	0.996	0.004	0.994	0.006	0.989	0.011	0.973	0.027	0.953	0.047	0.898	0.102	0.813	0.187	0.710	0.290	0.602	0.398	0.500	0.500

TABLE 6 Load Share Factors (LSF) for Double Glazed Insulating Glass (IG) Units

NOTE 1—Lite No. 1 Monolithic glass, Lite No. 2 Laminated glass, long duration load only.

NOTE 2—Values are approximated. Use Vallabhan and Chou (2) for alternate method.

Lite No. 1 Monolithic Glass		Lite No. 2 Laminated Glass													
Nominal Thickness		5 (3⁄16)		6 (1⁄4)		8 (5⁄16)		10 (3⁄8)		12 (1⁄2)		16 (5⁄8)		19 (3⁄4)	
mm	(in.)	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2	LSF1	LSF2
2.0	(picture)	0.224	0.776	0.144	0.856	0.051	0.949	0.030	0.970	0.017	0.983	0.007	0.993	0.004	0.996
2.5	(3⁄32)	0.333	0.667	0.225	0.775	0.085	0.915	0.050	0.950	0.028	0.972	0.012	0.988	0.007	0.993
2.7	(lami)	0.463	0.537	0.333	0.667	0.139	0.861	0.083	0.917	0.048	0.952	0.021	0.979	0.012	0.988
3	(1⁄8)	0.553	0.447	0.417	0.583	0.187	0.813	0.115	0.885	0.068	0.932	0.030	0.970	0.017	0.983
4	(5⁄32)	0.728	0.272	0.609	0.391	0.333	0.667	0.221	0.779	0.136	0.864	0.062	0.938	0.035	0.965
5	(3⁄16)	0.826	0.174	0.733	0.267	0.469	0.531	0.333	0.667	0.217	0.783	0.105	0.895	0.061	0.939
6	(1⁄4)	0.895	0.105	0.832	0.168	0.614	0.386	0.474	0.526	0.333	0.667	0.174	0.826	0.105	0.895
8	(5⁄16)	0.953	0.047	0.922	0.078	0.791	0.209	0.682	0.318	0.543	0.457	0.333	0.667	0.218	0.782
10	(3⁄8)	0.973	0.027	0.955	0.045	0.872	0.128	0.794	0.206	0.681	0.319	0.473	0.527	0.333	0.667
12	(1⁄2)	0.988	0.012	0.980	0.020	0.940	0.060	0.898	0.102	0.831	0.169	0.674	0.326	0.535	0.465
16	(5⁄8)	0.994	0.006	0.990	0.010	0.970	0.030	0.947	0.053	0.909	0.091	0.808	0.192	0.701	0.299
19	(3⁄4)	0.997	0.003	0.994	0.006	0.983	0.017	0.970	0.030	0.947	0.053	0.882	0.118	0.806	0.194
22	(7⁄8)	0.998	0.002	0.996	0.004	0.989	0.011	0.981	0.019	0.966	0.034	0.923	0.077	0.870	0.130
25	(1)	0.999	0.001	0.998	0.002	0.993	0.007	0.987	0.013	0.977	0.023	0.948	0.052	0.910	0.090

7.2.14.1 Determine the NFL1 for Lite No. 1, NFL2 for Lite No. 2, and NFL3 for Lite No. 3 from the upper charts of Figs. A1.1-A1.14 (see Annex A3 for examples).

NOTE 8—Lites No. 1 or No. 3 can represent either the outward or inward facing lite of the IG unit.

7.2.14.2 Determine GTF1 for Lite No. 1, GTF2 for Lite No. 2, and GTF3 for Lite No. 3 from Table 7 for the relevant glass type and load duration.

7.2.14.3 Determine LSF1 for Lite No. 1, LSF2 for Lite No. 2, and LSF3 for Lite No. 3 by using the following equations:

$$LSF1 = (t_1^3)/(t_1^3 + t_2^3 + t_3^3) \quad (6)$$

$$LSF2 = (t_2^3)/(t_1^3 + t_2^3 + t_3^3) \quad (7)$$

$$LSF3 = (t_3^3)/(t_1^3 + t_2^3 + t_3^3) \quad (8)$$

where:

t_1, t_2, and t_3 = the respective minimum glass thicknesses for each lite taken from Table 4.

7.2.14.4 Multiply NFL by GTF and divide by the LSF for each lite to determine LR1 for Lite No. 1, LR2 for Lite No. 2 and LR3 for Lite No. 3 of the insulating glass unit as follows:

$$LR1 = NFL1 \times GTF1 \div LSF1 \quad (9)$$

$$LR2 = NFL2 \times GTF2 \div LSF2 \quad (10)$$

$$LR3 = NFL3 \times GTF3 \div LSF3 \quad (11)$$

7.2.14.5 The load resistance of the triple glazed IG unit is the lower of the three values: LR1, LR2, and LR3.

TABLE 7 Glass Type Factor (GTF) for Triple Glazed Insulating Glass (IG)

Glass Type	GTF	
	Short Duration Load (3 s)	Long Duration Load (30 days)
AN	0.81	0.34
HS	1.62	1.03
FT	3.24	2.58

7.2.15 If the LR thus determined is less than the specified design load and duration, the selected glass types and thicknesses are not acceptable. If the LR is greater than or equal to the specified design load, then the glass types and thicknesses are acceptable for a probability of breakage less than or equal to 0.008.

7.3 *Analytical Procedure:*

7.3.1 *For Monolithic Single Glazing Simply Supported Continuously Along Four Sides:*

7.3.1.1 Determine the in-plane surface tensile stresses according to A2.1 using the minimum thickness corresponding to the desired nominal thickness listed in Table 4 for the specified design load applied to the lite.

7.3.1.2 Determine the probability of breakage according to A2.2.

7.3.1.3 If the probability of breakage is less than or equal to 0.008, then the load resistance is greater than or equal to specified design load.

7.3.1.4 Determine the maximum lateral (center of glass) deflection according to A2.1 using the minimum thickness corresponding to the desired nominal thickness listed in Table 4 for the specified design load applied to the lite.

7.3.2 *For Laminated Single Glazing Simply Supported Continuously Along Four Sides:*

7.3.2.1 Determine the effective thickness for stress for each glass ply, *h1;ef;σ h2;ef;σ* comprising the LG and the effective thickness deflection, $h_{ef;w}$ for LG according to Appendix X9 using published shear moduli for the LG interlayer material for the temperature / load duration combination corresponding to the design load duration designation as follows:

(1) Long duration load, 20 °C at 30 days.

(2) Short duration load, 50 °C at 3 s.

NOTE 9—The effective thickness procedure provides one effective thickness to analyze the LG lite for deflection and an effective thickness for each ply to analyze each ply for stress.

7.3.2.2 Determine the in-plane surface tensile stresses according to A2.1 using the effective thickness for stress for each glass ply, $h1;ef;\sigma$ $h2;ef;\sigma$ comprising the LG for the specified design load applied to the LG.

7.3.2.3 Determine the probability of breakage according to A2.2 for each glass ply comprising the LG.

7.3.2.4 If each of the plies comprising the LG lite have a probability of breakage of less than or equal to 0.008, then the load resistance is greater than or equal to specified design load.

7.3.2.5 Determine the maximum lateral (center of glass) deflection according to A2.1 using the effective thickness for deflection, $h_{ef;w}$, for the specified design load applied to the LG lite.

7.3.3 *For Double Glazed Insulating Glass Units Simply Supported Continuously Along Four Sides:*

7.3.3.1 Determine the proportion of the specified design load carried by each lite in the IG using a method that maintains the ideal gas law equilibrium for the air space between IG assembly and loaded conditions. The method should accurately account for the displaced volumes of the lites comprising the IG when loaded.

(1) Use the minimum thickness corresponding to the specified nominal thickness designation listed in Table 4 for MO glass.

(2) Use the effective thickness for deflection, $h_{ef;w}$, for the LG according to Appendix X9 using published shear moduli for the LG interlayer material for the temperature / load duration combination corresponding to the design load duration designation as follows:

(a) Long duration load, 20 °C at 30 days.

(b) Short duration load, 50 °C at 3 s.

7.3.3.2 Determine the in-plane surface tensile stresses for each lite comprising the IG according to 7.3.1.1 for MO lites and 7.3.2.1 for LG lites using the respective apportioned specified design load according to 7.3.3.1.

7.3.3.3 Multiply the apportioned specified design load by 1.11 (1/0.9) if atmospheric pressure and temperature changes are neglected in 7.3.3.1.

7.3.3.4 Determine the probability of breakage according to A2.2 for each MO lite and each LG glass ply comprising the IG.

7.3.3.5 If the probability of breakage is less than or equal to 0.008 for each MO lite and each LG ply comprising the IG, then the load resistance is greater than or equal to specified design load.

7.3.3.6 Determine the maximum lateral (center of glass) deflection for each lite comprising the IG according to 7.3.1.4 for MO lites and 7.3.2.5 for LG lites using the respective apportioned specified design load according to 7.3.3.1.

7.3.3.7 Repeat Steps 7.3.3.1 – 7.3.3.6 with the specified design load applied in the opposite direction (reverse the loading direction).

8. Report

8.1 Report the following information:

8.1.1 Date of calculation,

8.1.2 The specified design load and duration, the short dimension of the glass, the long dimension of the glass, the glass type(s) and thickness(es), the GTF(s), the LSFs (for IG), the factored LR and the approximate lateral deflection, the glass edge support conditions, and

8.1.3 A statement that the procedure followed was in accordance with this practice or a full description of any deviations.

9. Precision and Bias

9.1 The NFL charts (the upper charts of Figs. A1.1-A1.44) are based upon a theoretical glass breakage model that relates the strength of glass to the surface condition. Complete discussions of the formulation of the model are presented elsewhere (**3, 4**).[3]

9.1.1 A conservative estimate of the surface condition for glass design was used in generation of the charts. This surface condition estimate is based upon the best available glass strength data and engineering judgment. It is possible that the information presented in the NFL charts may change as further data becomes available.

10. Keywords

10.1 annealed glass; deflection; flat glass; fully tempered glass; glass; heat-strengthened glass; insulating glass; laminated glass; load resistance; monolithic glass; probability of breakage; snow load; soda lime silicate; strength; wind load

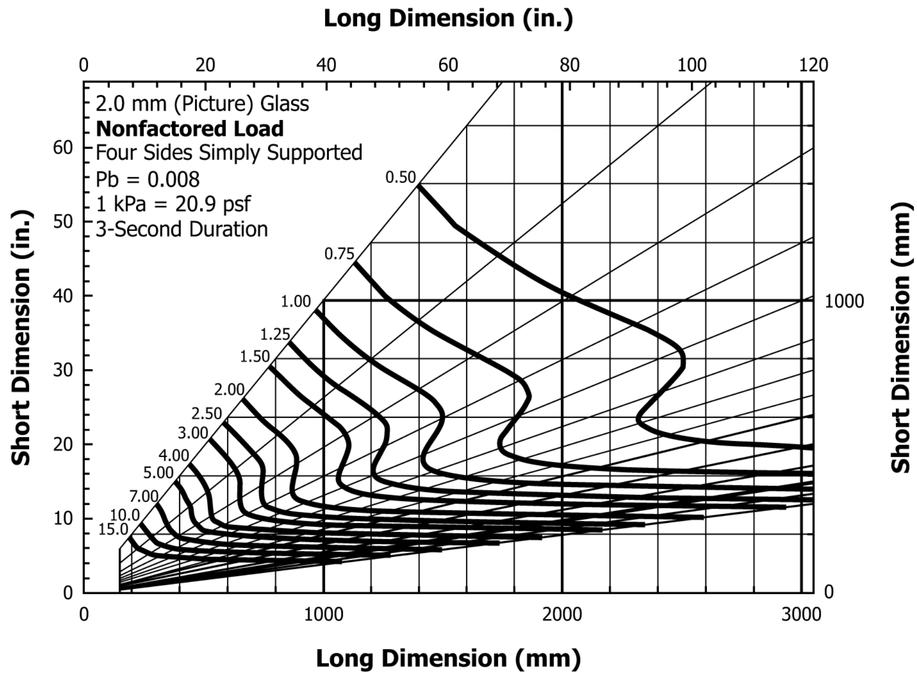
ANNEXES

(Mandatory Information)

A1. NON-FACTORED LOAD (NFL) CHARTS

A1.1 NFL charts are presented in the upper charts of Fig. A1.1 through Fig. A1.44 for both SI and inch-pound units. The NFL charts were developed using a failure prediction model for glass (**5,6**). The model allows the probability of breakage of any lite or ply to be specified in terms of two surface flaw parameters, *m* and *k*.

A1.2 The values of the surface flaw parameters associated with a particular glass sample vary with the treatment and condition of the glass surface. In development of the NFL charts presented in upper charts of Fig. A1.1 through Fig. A1.44 it was assumed that m is equal to 7 and k is equal to 2.86 $\times 10^{-53}$ N^{-7} m^{12} (1.365 $\times 10^{-29}$ $in.^{12}$ lbf^{-7}). These flaw



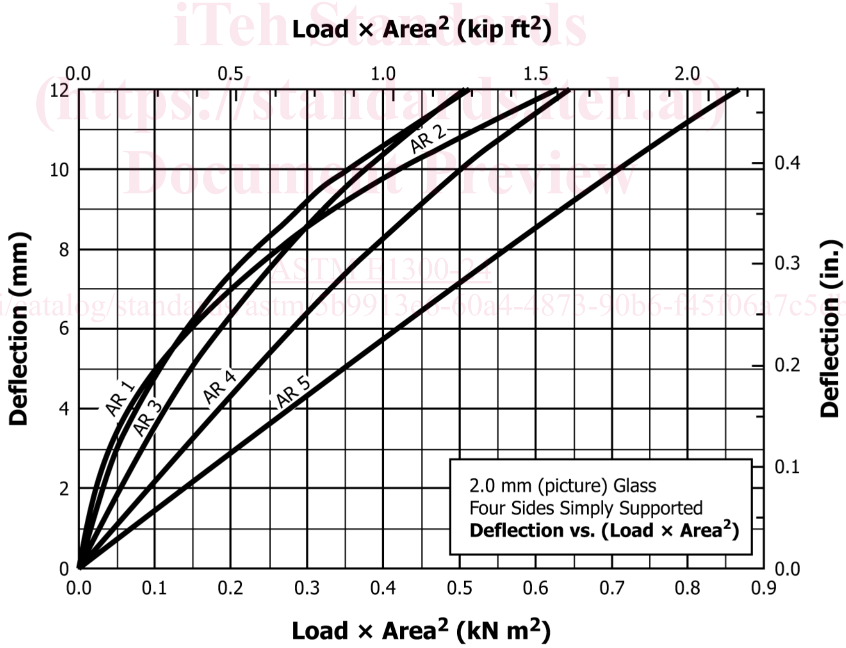


FIG. A1.1 (upper chart) Non-Factored Load Chart for 2.0 mm (Picture) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 2.0 mm (Picture) Glass with Four Sides Simply Supported

parameters represent the surface strength of weathered window glass that has undergone in-service conditions for approximately 20 years. The selection of the surface flaw parameters was based upon the best available data and engineering judgment. If the charts are used to predict the strength of freshly manufactured glass, the results may be conservative. This method does not apply to glass that has been subjected to severe surface degradation or abuse such as weld splatter or sand blasting.

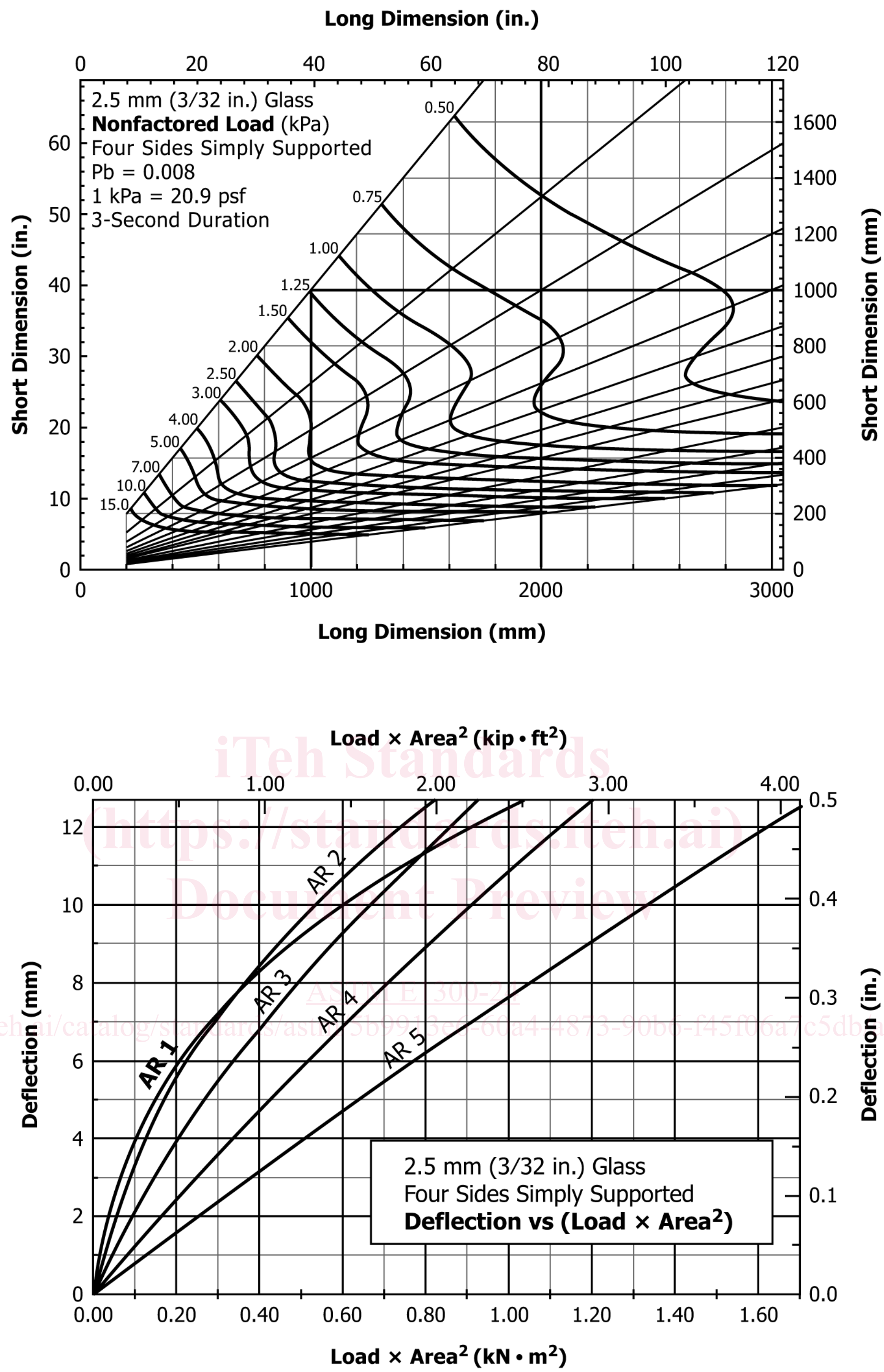


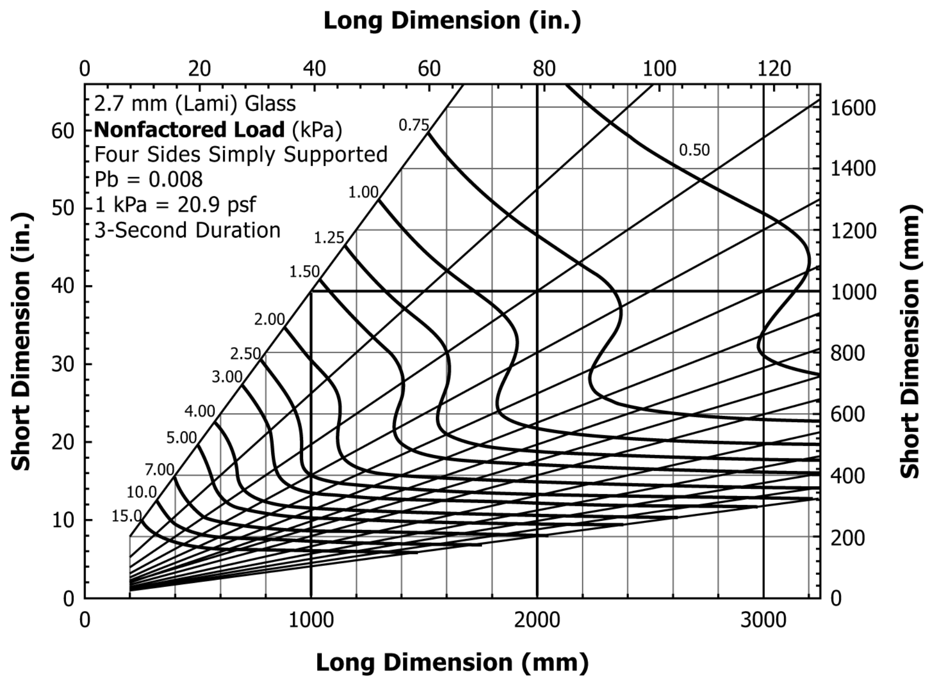
FIG. A1.2 (upper chart) Non-Factored Load Chart for 2.5 mm (3⁄32 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 2.5 mm 3⁄32 in.) Glass with Four Sides Simply Supported

A1.3 The data presented in the NFL charts are based on the minimum glass thicknesses allowed by Specification C1036. These minimum glass thicknesses are presented in Table 4. Glass may be manufactured thicker than those minimums. Not accounting for this fact in the NFL charts makes the charts conservative from a design standpoint.

A1.4 The maximum center of glass lateral deflection of a lite is often a major consideration in the selection of glass. No recommendations are made in this practice regarding acceptable lateral deflections. The lower charts of Fig. A1.1 through Fig. A1.44 indicate the maximum lateral deflection of the glass.

A1.5 The following steps are used to determine the NFL for a particular situation:

A1.5.1 Select the appropriate chart to be used based upon the nominal glass thickness.



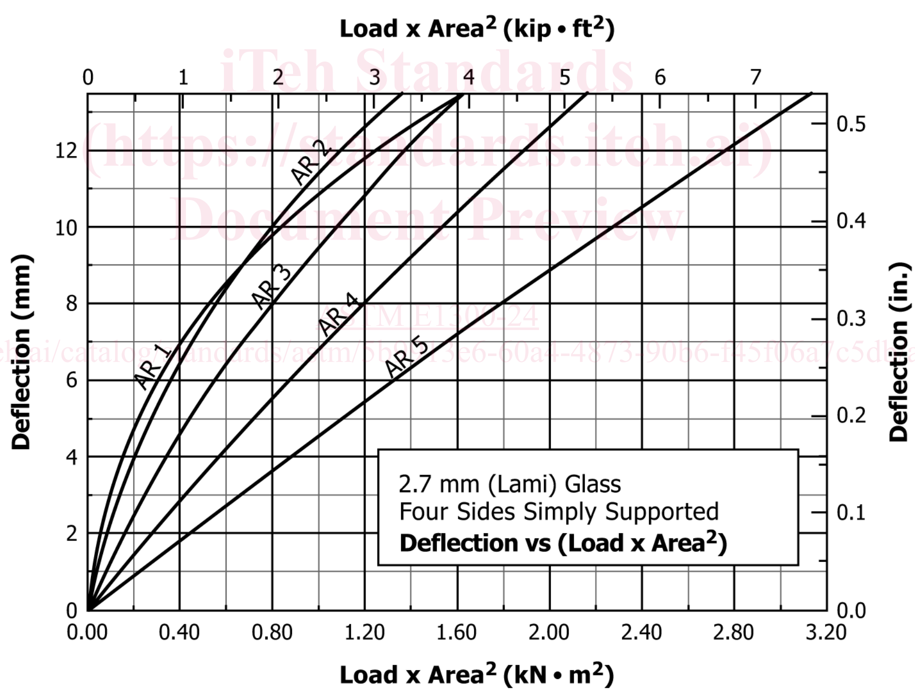


FIG. A1.3 (upper chart) Non-Factored Load Chart for 2.7 mm (Lami) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 2.7 mm (Lami) Glass with Four Sides Simply Supported

A1.5.2 Enter the horizontal axis of the chart at the point corresponding to the long dimension of the glass and project a vertical line.

A1.5.3 Enter the vertical axis of the chart at the point corresponding to the short dimension of the glass and project a horizontal line until it intersects the vertical line of A1.5.2.

A1.5.4 Draw a line of constant AR from the point of zero length and width through the intersection point in A1.5.3.

A1.5.5 Determine the NFL by interpolating between the load contours along the diagonal line of constant AR drawn in A1.5.4.

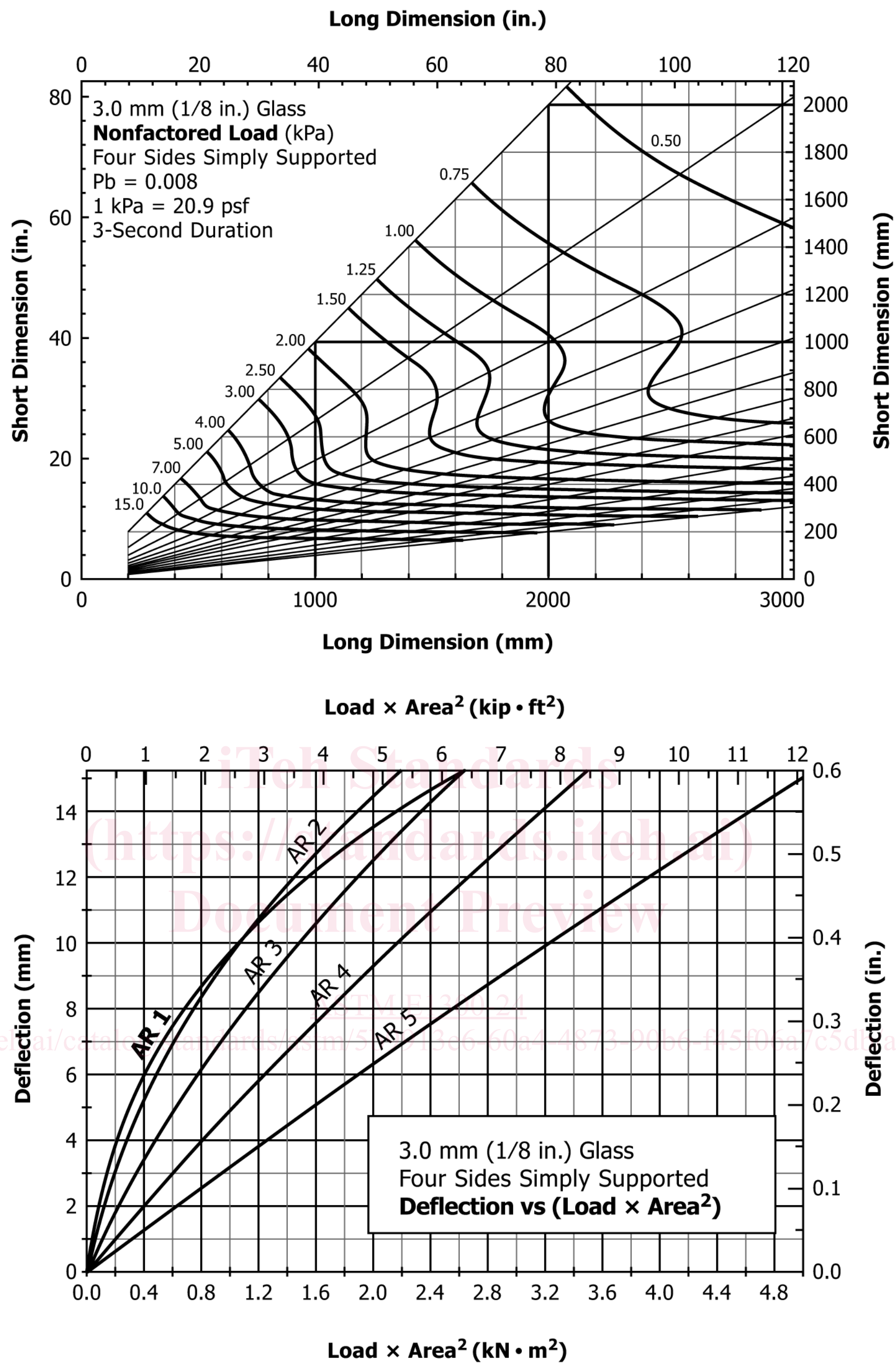
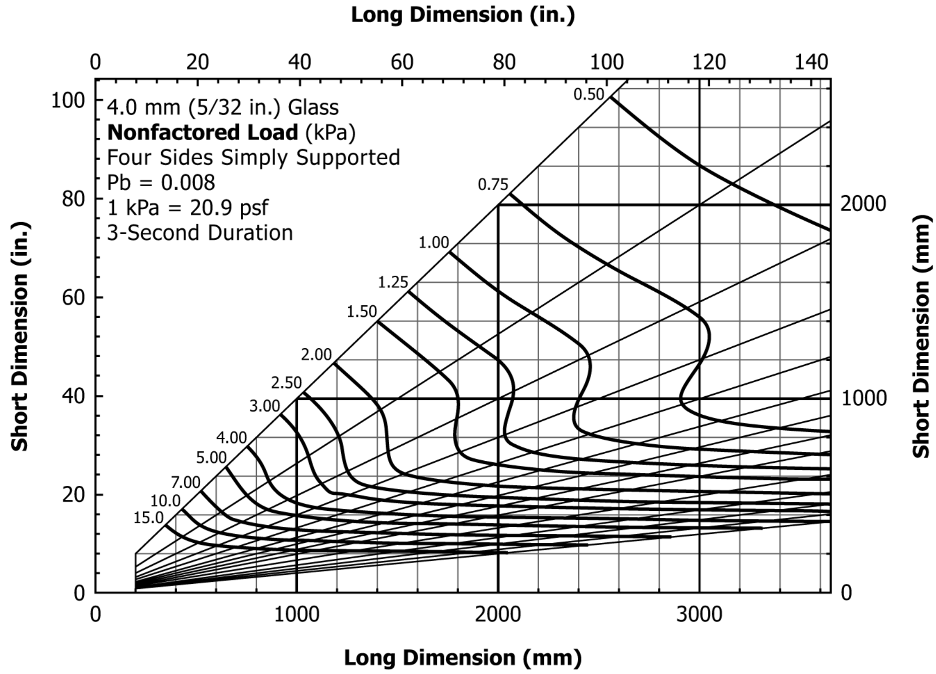


FIG. A1.4 (upper chart) Non-Factored Load Chart for 3.0 mm (⅛ in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 3.0 mm (⅛ in.) Glass with Four Sides Simply Supported



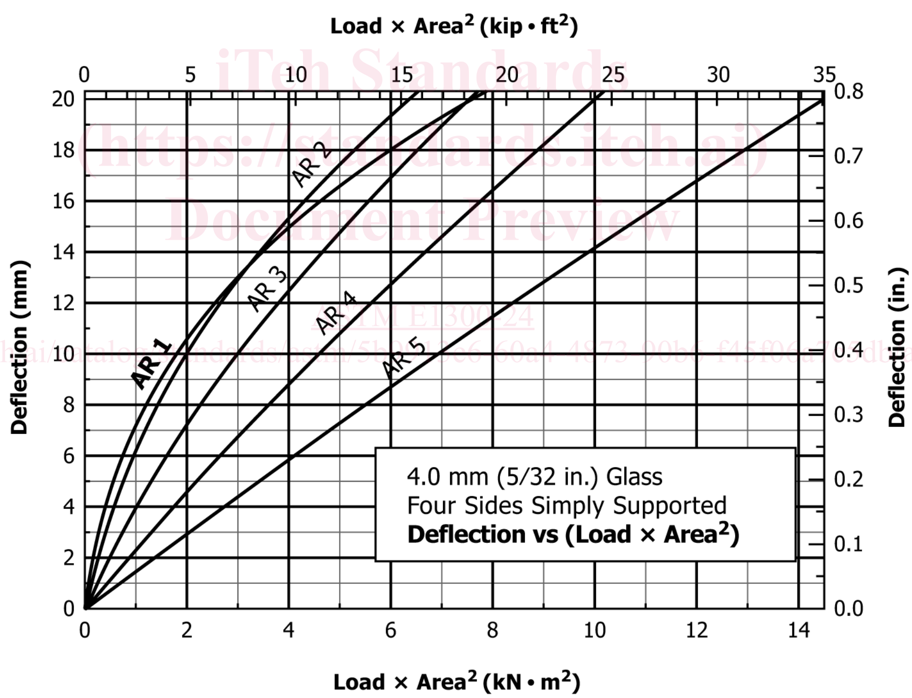
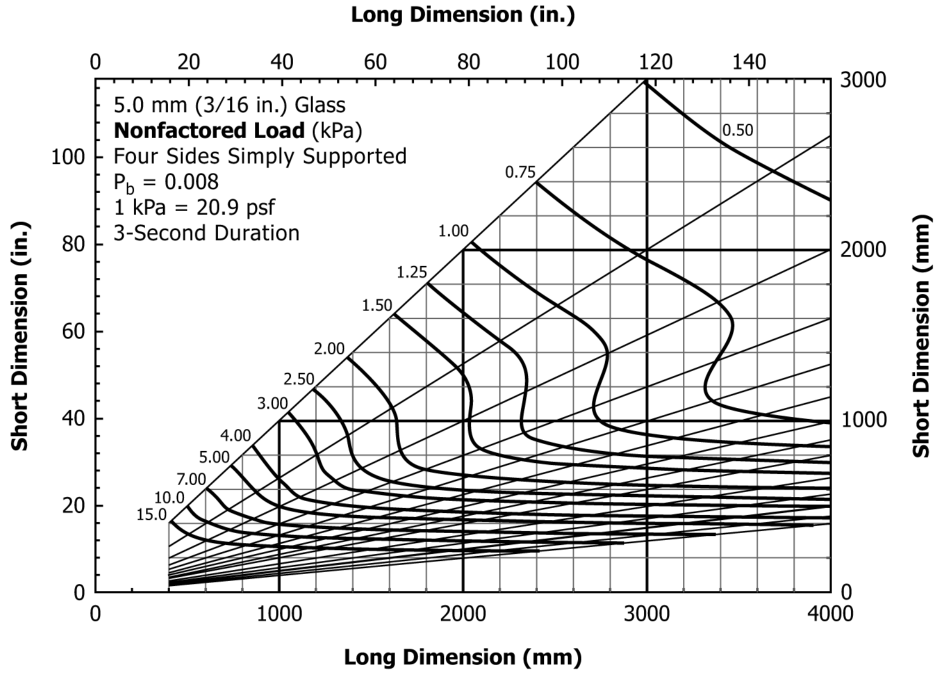


FIG. A1.5 (upper chart) Non-Factored Load Chart for 4.0 mm (5⁄32 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 4.0 mm (5⁄32 in.) Glass with Four Sides Simply Supported



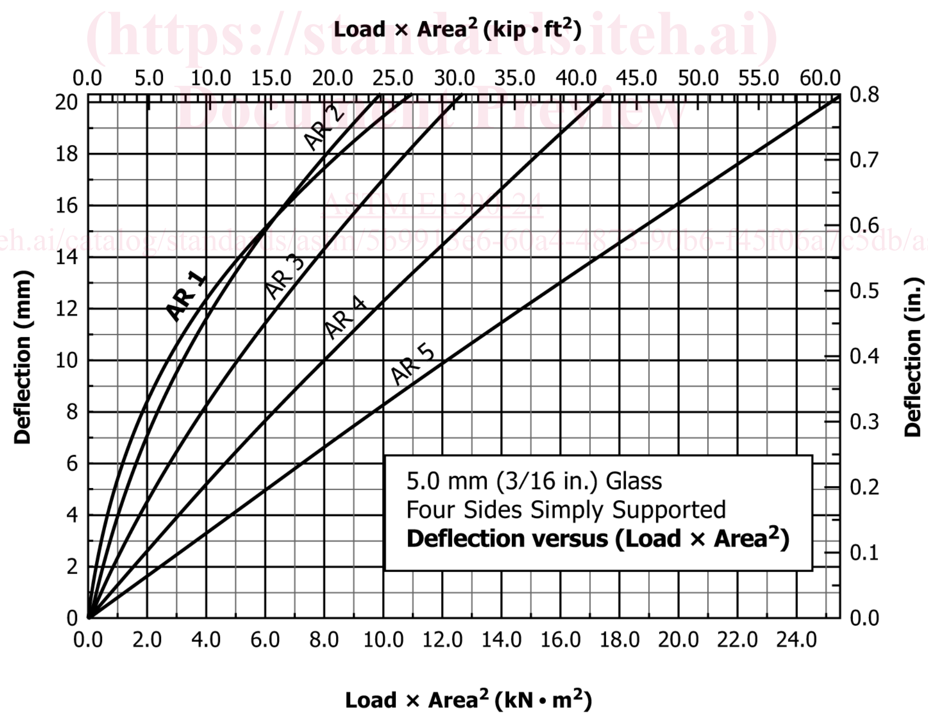


FIG. A1.6 (upper chart) Non-Factored Load Chart for 5.0 mm (3⁄16 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 5.0 mm (3⁄16 in.) Glass with Four Sides Simply Supported