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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[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

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)

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.).

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 breakage probability less than or equal to 8 lites per 1000.

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 8 lites per 1000 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 fraction of glass lites or plies that would break at the first occurrence of a specified load and duration, typically expressed in lites per 1000.

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. Summary of Practice

4.1 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 5.2.4.

4.2 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.

4.3 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.

5. Significance and Use

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

5.2 Use of this practice assumes:

5.2.1 The glass is free of edge damage and is properly glazed,

5.2.2 The glass has not been subjected to abuse,

5.2.3 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,

5.2.4 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.

5.2.5 The deflection of glass or support system, or both, shall not result in loss of glass edge support.

NOTE 1—Glass deflections are to be reviewed. This practice does not address aesthetic issues caused by glass deflection.

NOTE 2—This practice does not consider the effects of deflection on insulating glass unit seal performance.

5.3 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.

5.4 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.

6. Procedure

6.1 Select the procedure to determine the load resistance.

6.2 *Basic Procedure:*

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

6.2.1.1 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.

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

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

6.2.1.4 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.

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

6.2.2.1 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.

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

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

6.2.2.4 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.

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

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

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

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

6.2.3.4 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.

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

6.2.4.1 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.

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

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

6.2.4.4 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.

6.2.5 *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):*

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

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

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

6.2.5.4 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.

6.2.6 *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):*

6.2.6.1 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.

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

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

6.2.6.4 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.

6.2.7 *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):*

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

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

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

6.2.7.4 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.

6.2.8 *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):*

6.2.8.1 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.

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

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

6.2.8.4 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.

6.2.9 *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:*

6.2.9.1 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 3—Lites No. 1 or No. 2 can represent either the outward or inward facing lite of the IG unit.

6.2.9.2 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.

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

6.2.9.4 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:

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

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

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

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

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 (1) 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

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

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

6.2.10.4 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:

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

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

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

6.2.11.1 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).

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

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

6.2.11.4 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:

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

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

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

6.2.12.1 The LR of each lite must first be calculated for that load acting for a short duration as in 6.2.10, and then for the same load acting for a long duration as given in 6.2.12.2 – 6.2.12.5.

NOTE 4—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.

6.2.12.2 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).

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

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

6.2.12.5 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:

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

6.2.12.6 The LR of the IG unit is the lowest of the four calculated LR values LR1 and LR2 for short duration loads from 6.2.10.4 and LR1 and LR2 for long duration loads from 6.2.12.5.

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

6.2.13.1 The LR of each lite must first be calculated for that load acting for a short duration as in 6.2.11, and then for the same load acting for a long duration as given in 6.2.13.2 – 6.2.13.5.

6.2.13.2 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).

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

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

6.2.13.5 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:

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

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 (1) 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

6.2.13.6 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 6.2.13.5.

6.2.14 *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 5—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.

6.2.14.1 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 6—Lites No. 1 or No. 3 can represent either the outward or inward facing lite of the IG unit.

6.2.14.2 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.

6.2.14.3 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.

6.2.14.4 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:

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

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

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

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

6.2.15 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 breakage probability of less than, or equal to, 8 in 1000.

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

6.3 *Analytical Procedure:*

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

6.3.1.1 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.

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

6.3.1.3 If the probability of breakage, $P_b \leq 0.008$, then the load resistance is greater than or equal to specified design load.

6.3.1.4 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.

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

6.3.2.1 Determine the effective thickness for stress for each glass ply, *h1;ef;σ h2;ef;σ* comprising the LG and the effective thickness deflection, *hef;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 7—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.

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

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

6.3.2.4 If each of the plies comprising the LG lite have a probability of breakage, $P_b \leq 0.008$, then the load resistance is greater than or equal to specified design load.

6.3.2.5 Determine the maximum lateral (center of glass) deflection according to A2.1 using the effective thickness for deflection, *hef;w*, for the specified design load applied to the LG lite.

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

6.3.3.1 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, *hef;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.

6.3.3.2 Determine the in-plane surface tensile stresses for each lite comprising the IG according to 6.3.1.1 for MO lites and 6.3.2.1 for LG lites using the respective apportioned specified design load according to 6.3.3.1.

6.3.3.3 Multiply the apportioned specified design load by 1.11 (1/0.9) if atmospheric pressure and temperature changes are neglected in 6.3.3.1.

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

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

6.3.3.6 Determine the maximum lateral (center of glass) deflection for each lite comprising the IG according to 6.3.1.4 for MO lites and 6.3.2.5 for LG lites using the respective apportioned specified design load according to 6.3.3.1.

6.3.3.7 Repeat Steps 6.3.3.1 – 6.3.3.6 with the specified design load applied in the opposite direction (reverse the loading direction).

7. Report

7.1 Report the following information:

7.1.1 Date of calculation,

7.1.2 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

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

8. Precision and Bias

8.1 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 (**2, 3**).[3]

8.1.1 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.

9. Keywords

9.1 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

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

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 (**4, 5**). 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 × 10^{-53} N^{-7} m^{12} (1.365 × 10^{-29} in.^{12} lbf^{-7}). These flaw 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.

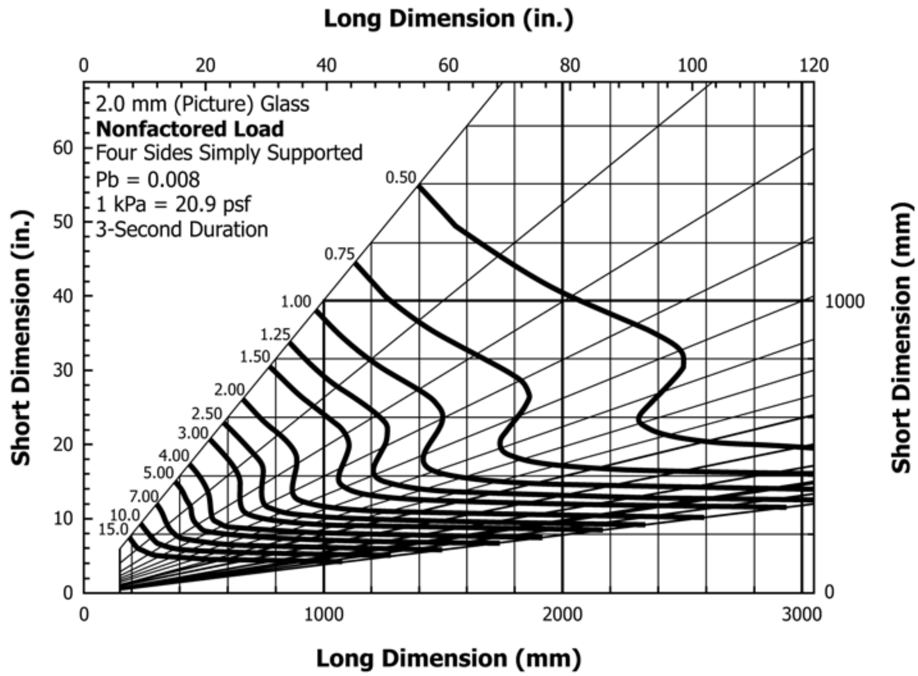
A1.3 The data presented in the NFL charts are based on the minimum glass thicknesses allowed by Specification C1036. These minimum glass thicknesses are presented in Table 4. Glass may be manufactured thicker than those minimums. Not accounting for this fact in the NFL charts makes the charts conservative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

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.



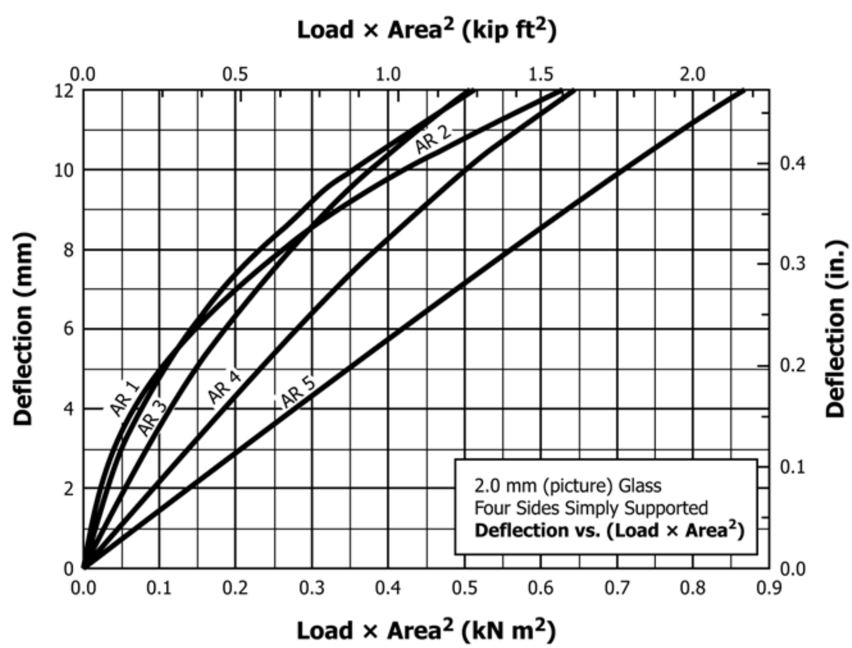
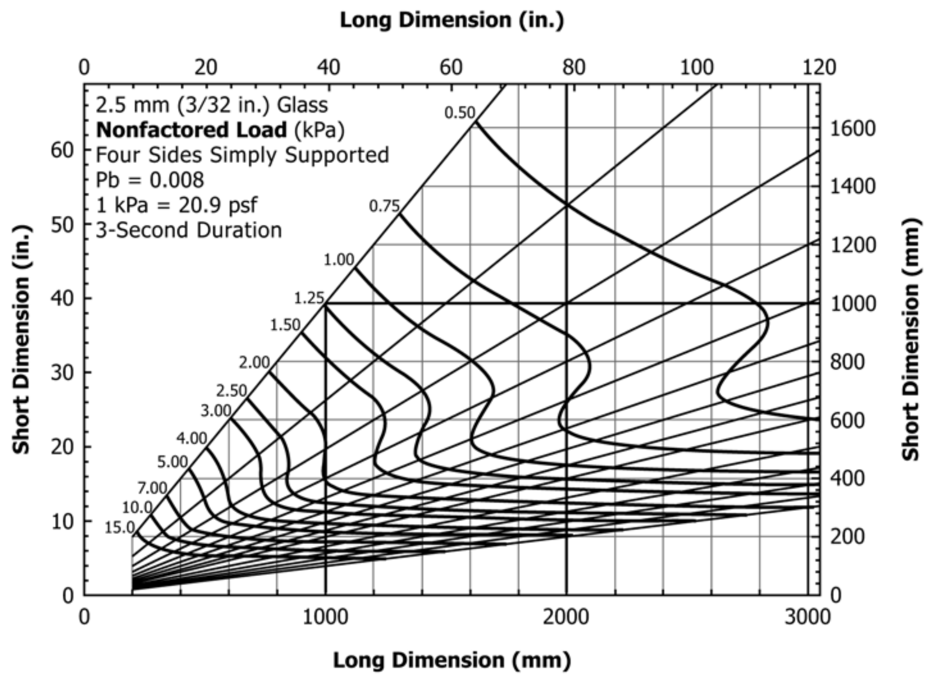


FIG. A1.1 (upper chart) Non-Factored Load Chart for 2.0 mm (Picture) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 2.0 mm (Picture) Glass with Four Sides Simply Supported

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.



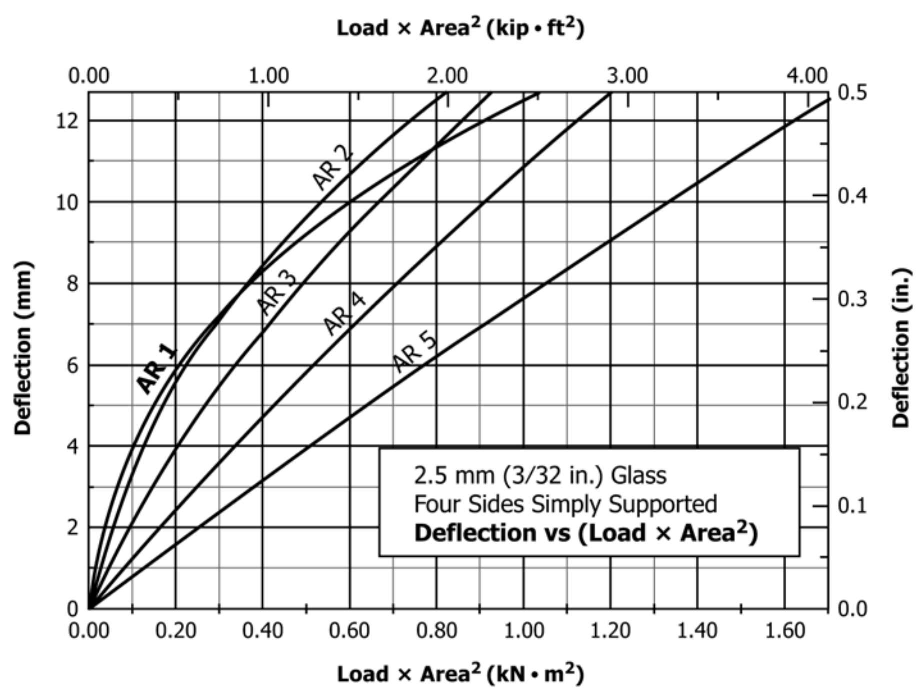


FIG. A1.2 (upper chart) Non-Factored Load Chart for 2.5 mm (3⁄32 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 2.5 mm 3⁄32 in.) Glass with Four Sides Simply Supported

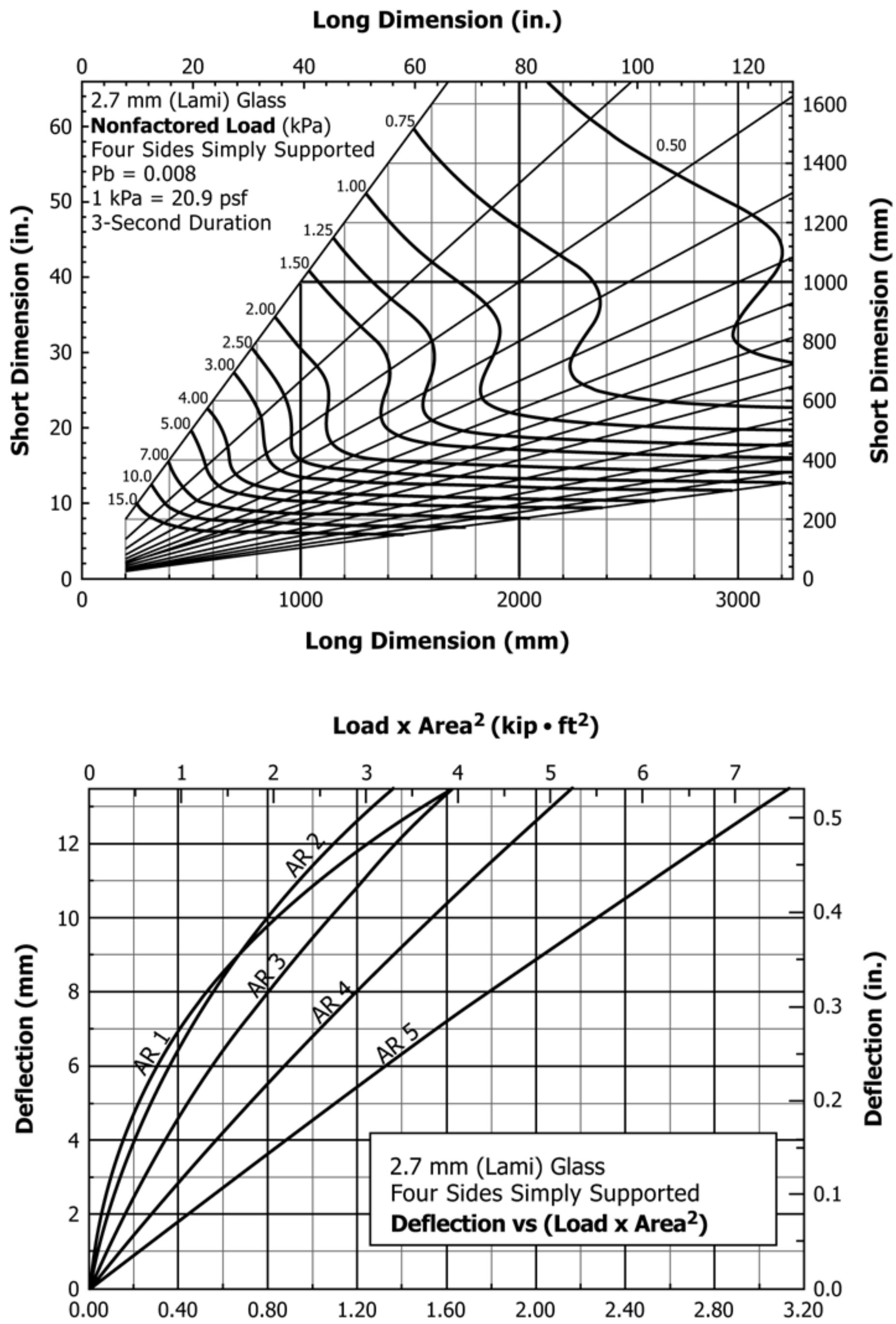


FIG. A1.3 (upper chart) Non-Factored Load Chart for 2.7 mm (Lami) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 2.7 mm (Lami) Glass with Four Sides Simply Supported

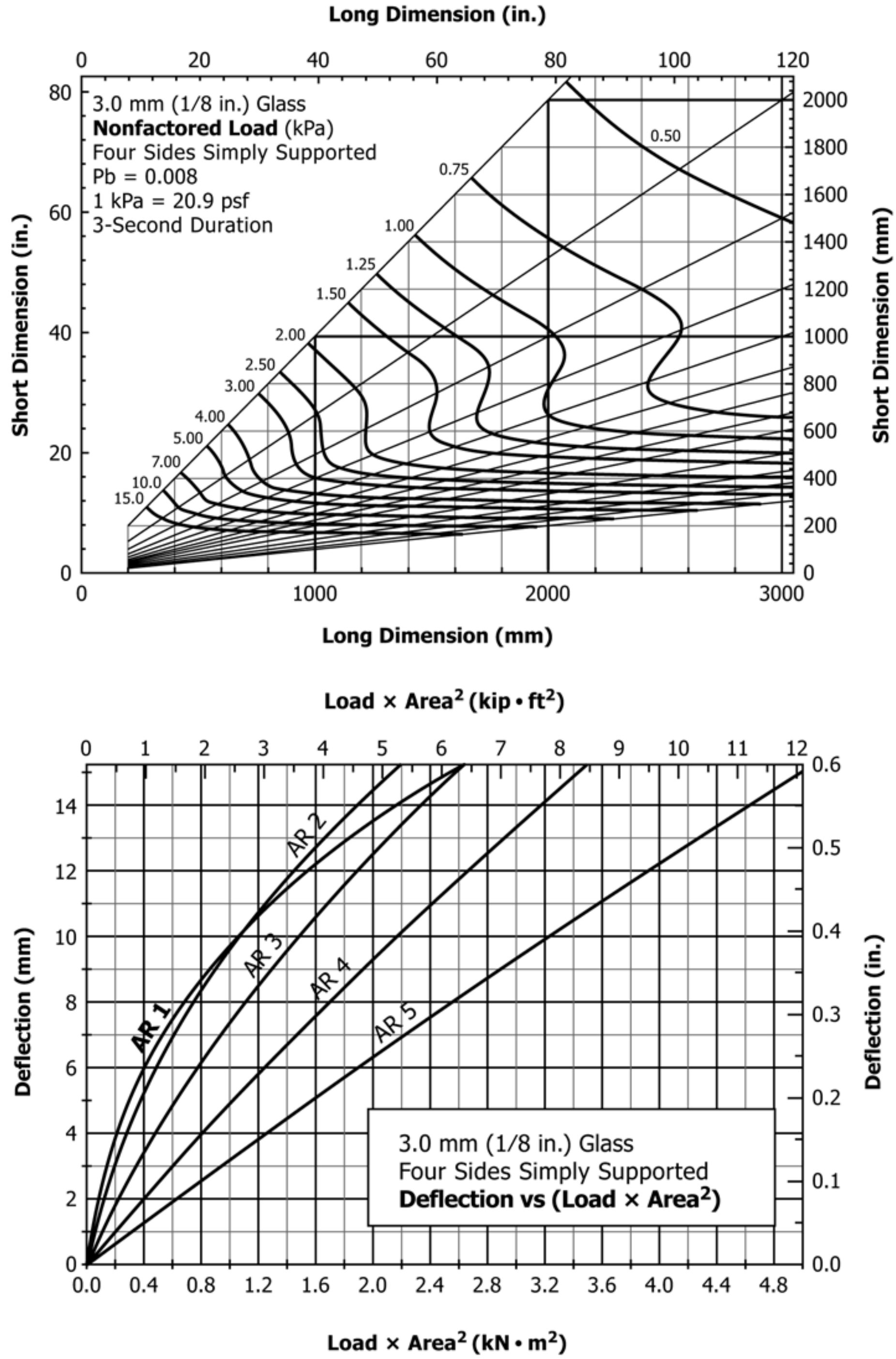
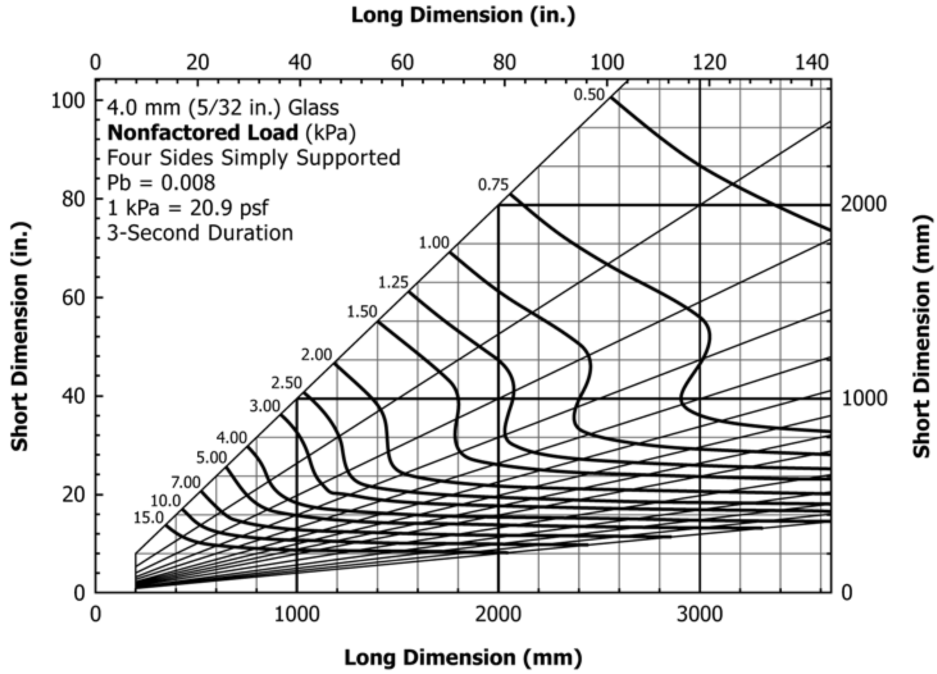


FIG. A1.4 (upper chart) Non-Factored Load Chart for 3.0 mm (⅛ in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 3.0 mm (⅛ in.) Glass with Four Sides Simply Supported



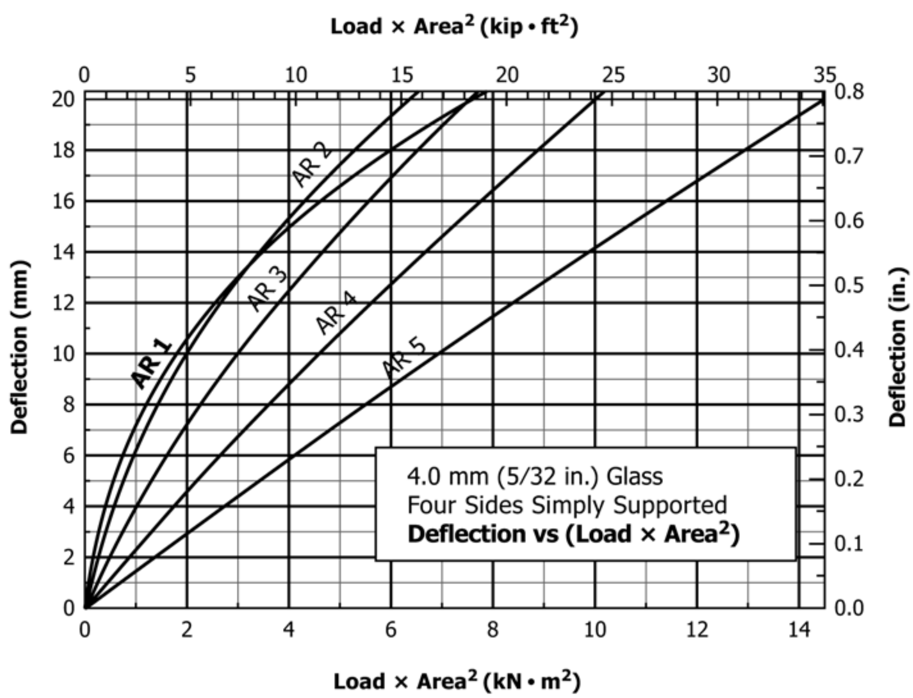
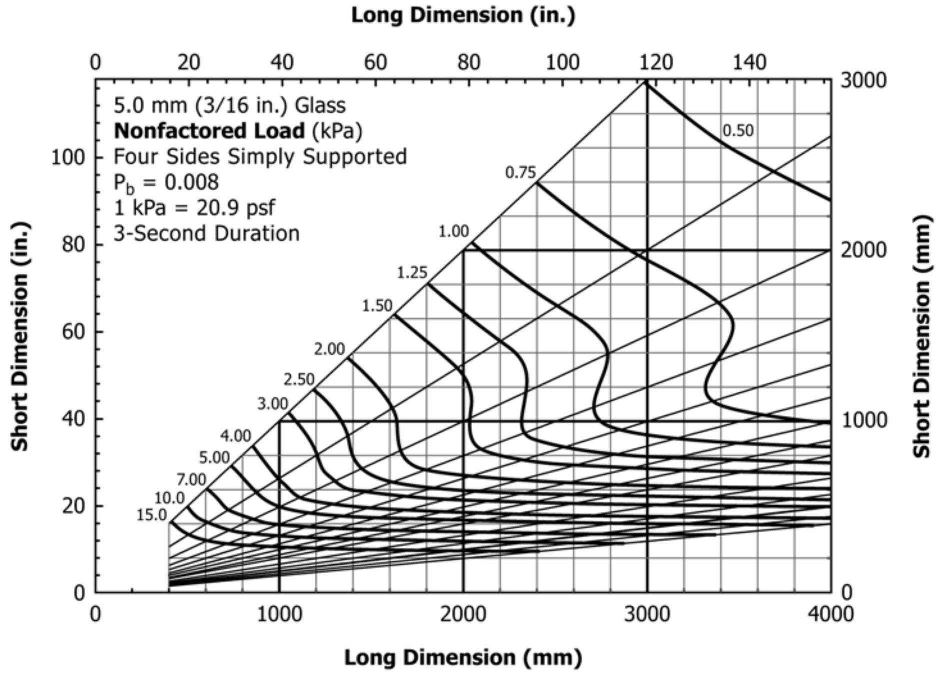


FIG. A1.5 (upper chart) Non-Factored Load Chart for 4.0 mm (5⁄32 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 4.0 mm (5⁄32 in.) Glass with Four Sides Simply Supported



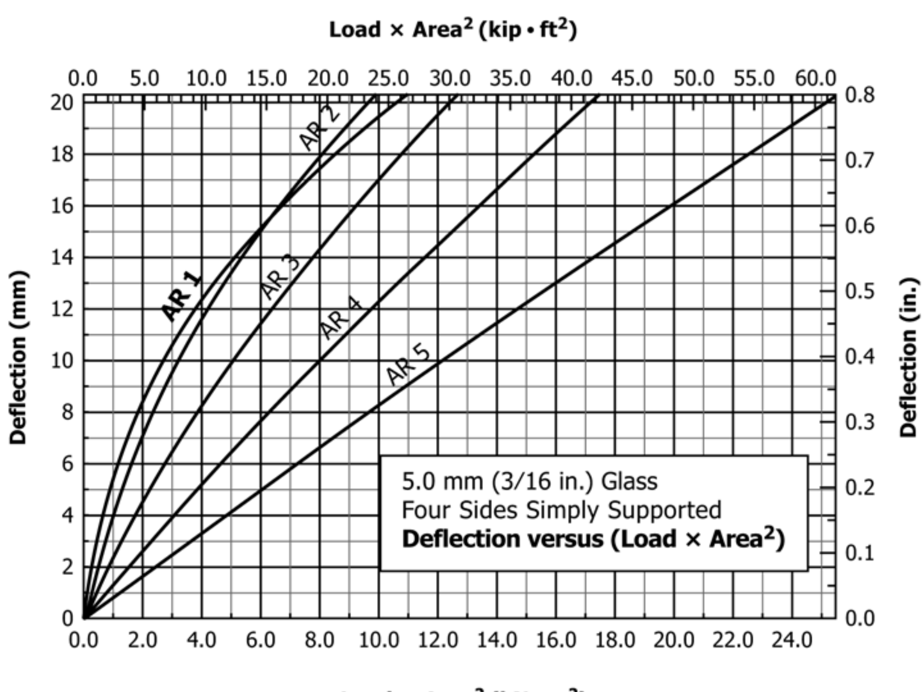
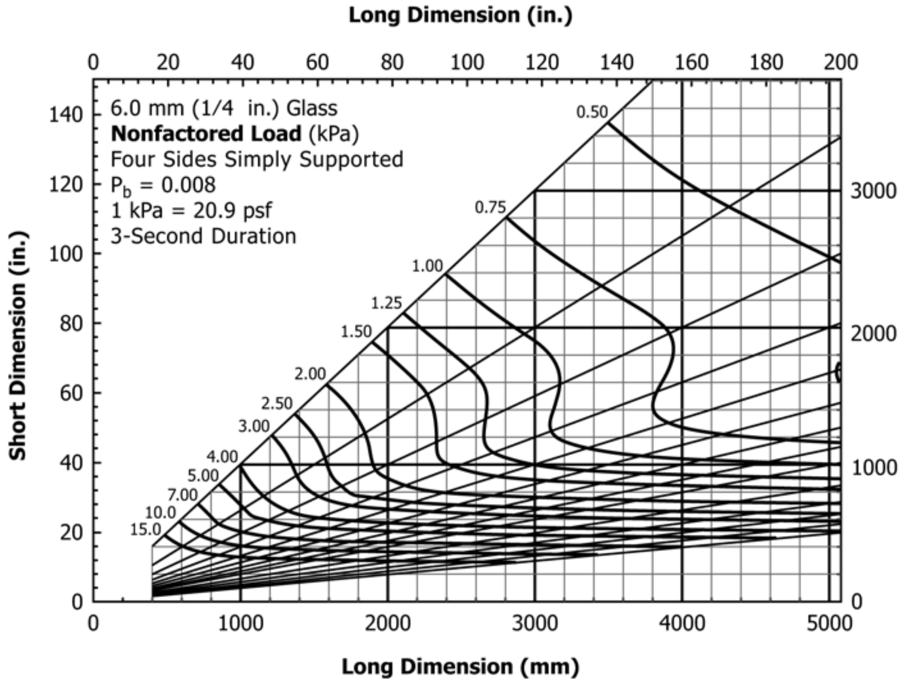


FIG. A1.6 (upper chart) Non-Factored Load Chart for 5.0 mm (3⁄16 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 5.0 mm (3⁄16 in.) Glass with Four Sides Simply Supported



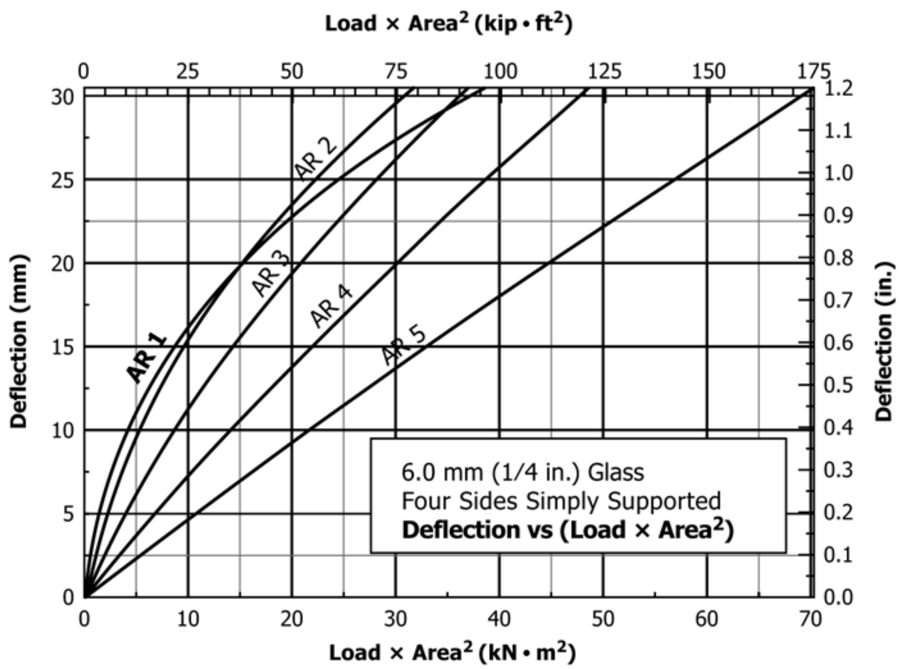
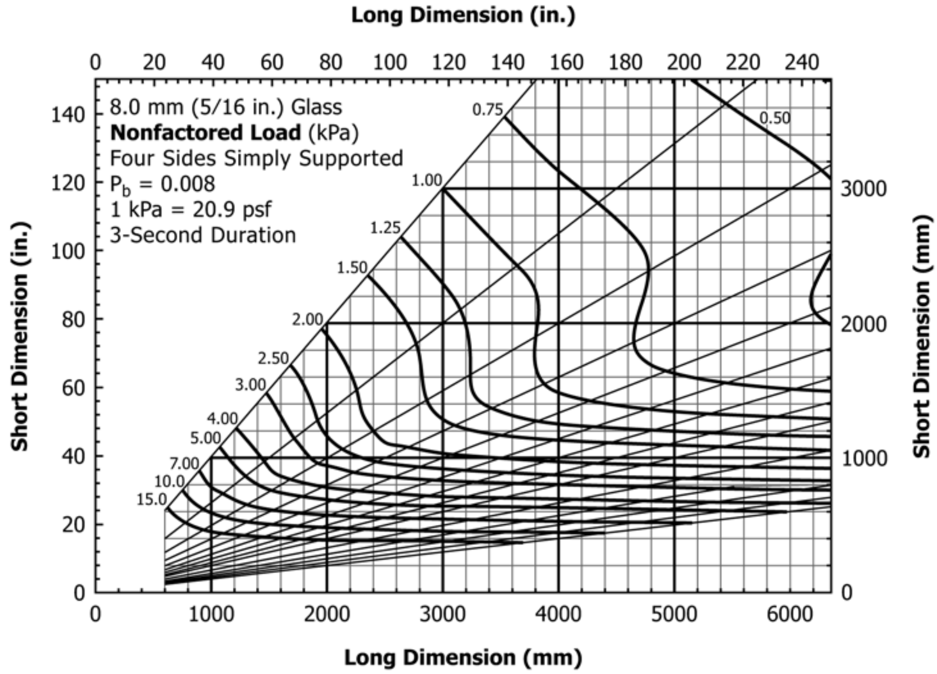


FIG. A1.7 (upper chart) Non-Factored Load Chart for 6.0 mm (¼ in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 6.0 mm (¼ in.) Glass with Four Sides Simply Supported



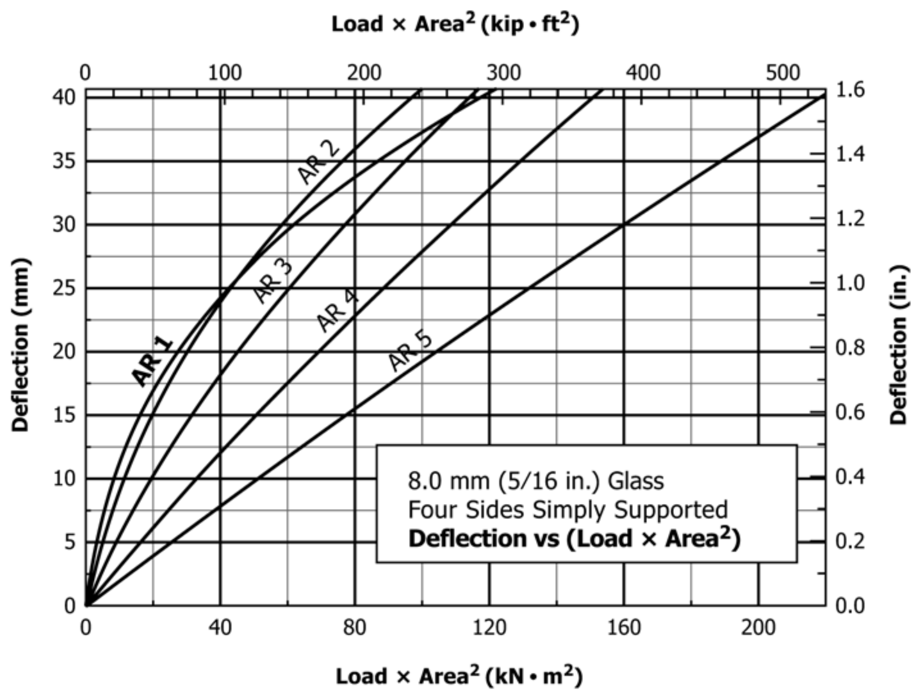
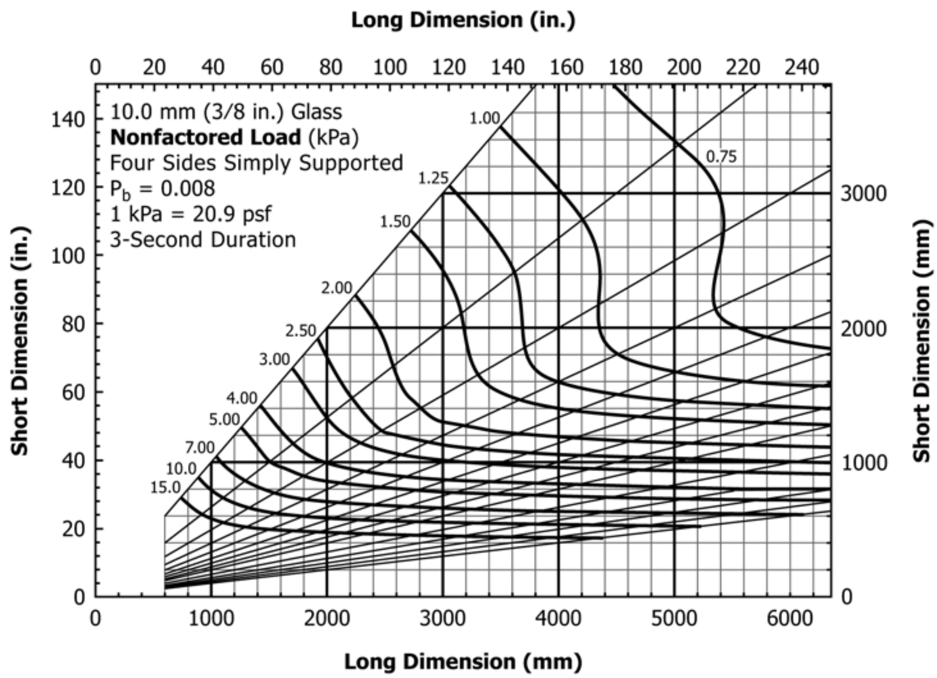


FIG. A1.8 (upper chart) Non-Factored Load Chart for 8.0 mm (5⁄16 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 8.0 mm (5⁄16 in.) Glass with Four Sides Simply Supported



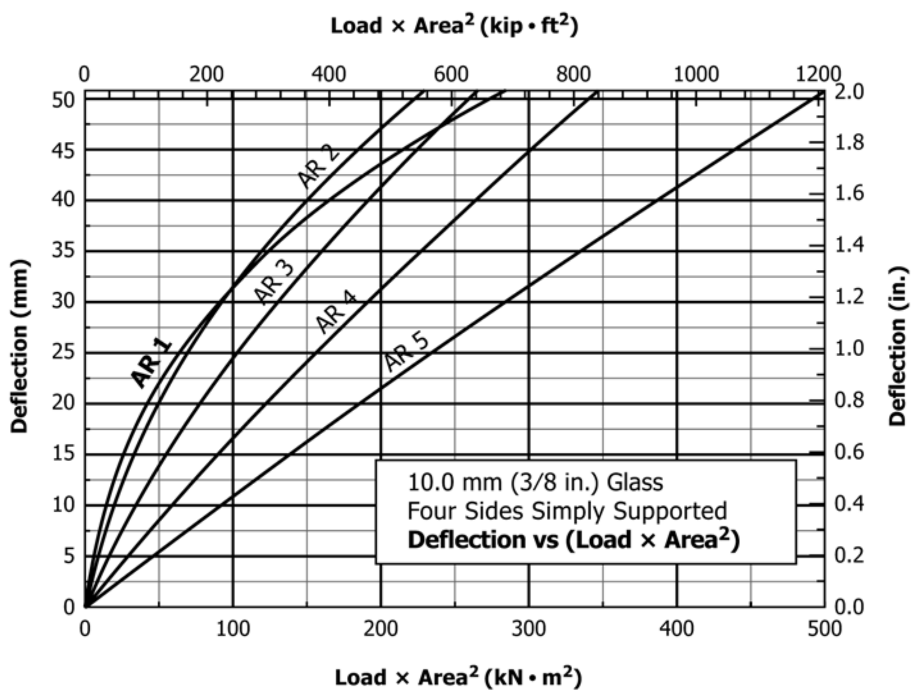
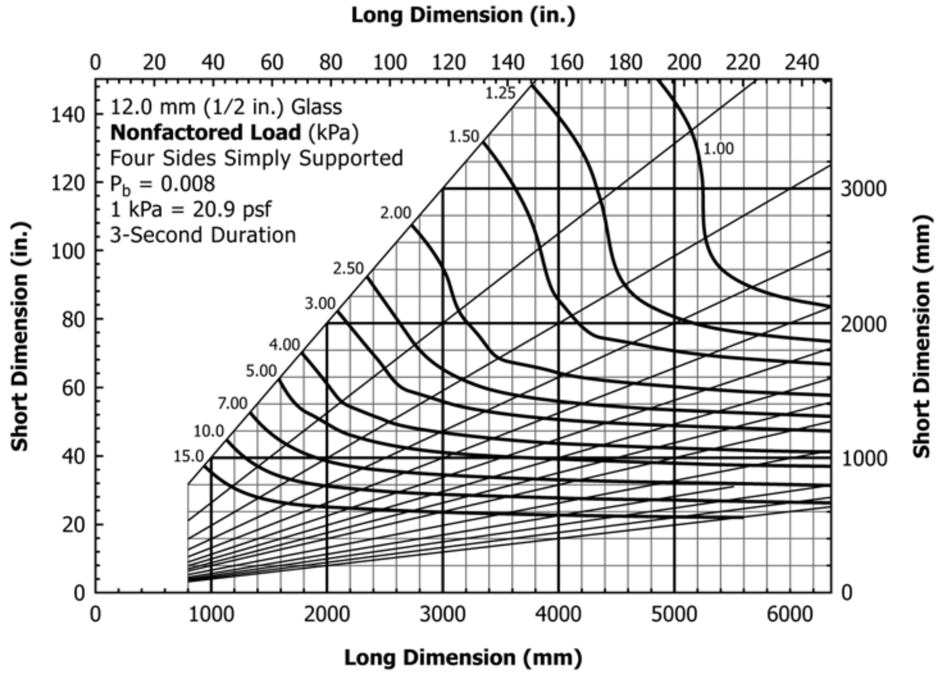


FIG. A1.9 (upper chart) Non-Factored Load Chart for 10.0 mm (3⁄8 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 10.0 mm (3⁄8 in.) Glass with Four Sides Simply Supported



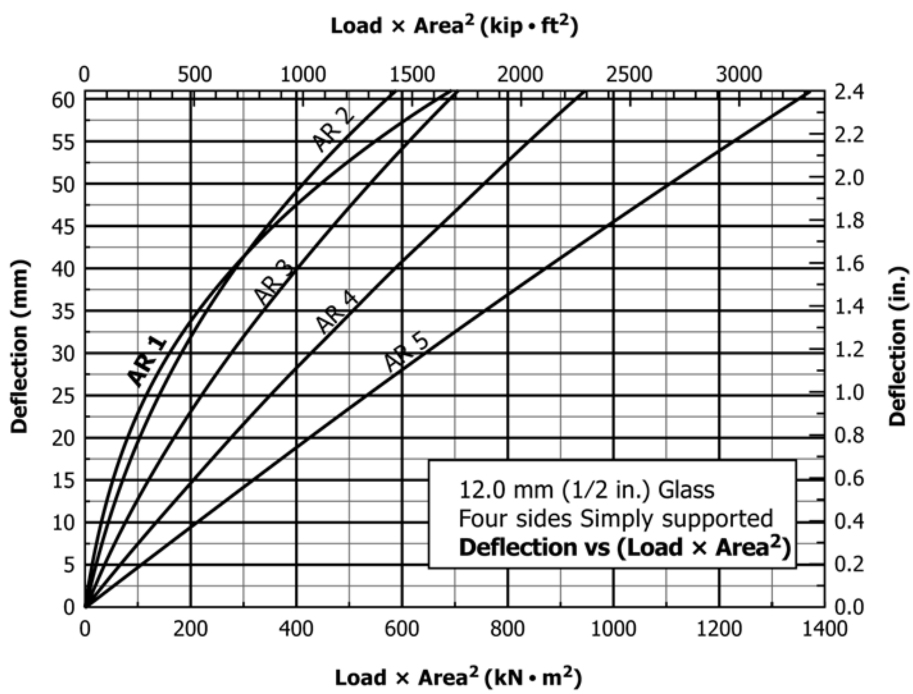
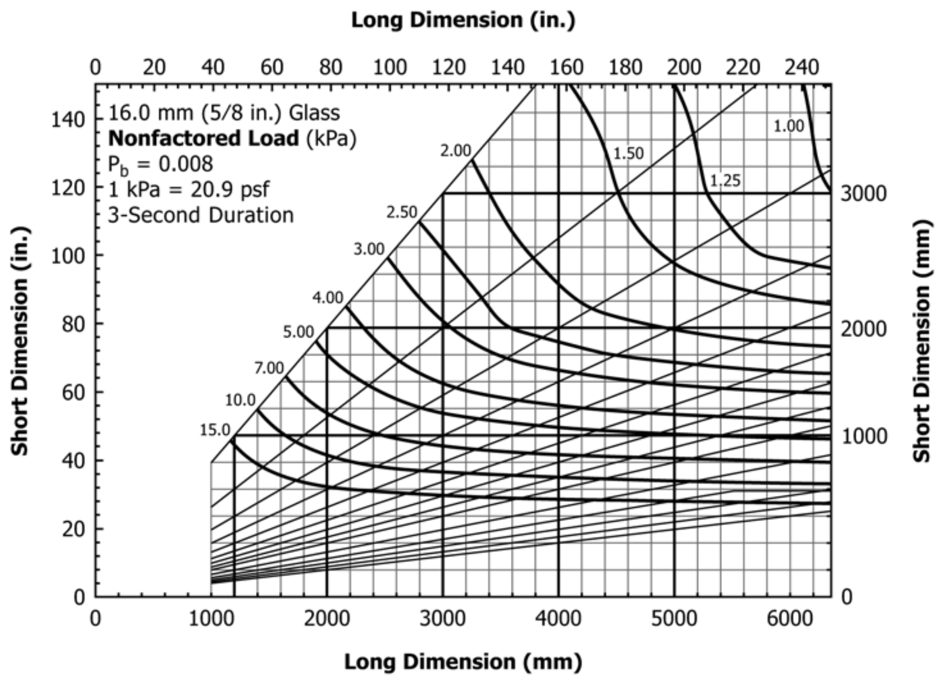


FIG. A1.10 (upper chart) Non-Factored Load Chart for 12.0 mm (½ in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 12.0 mm (½ in.) Glass with Four Sides Simply Supported



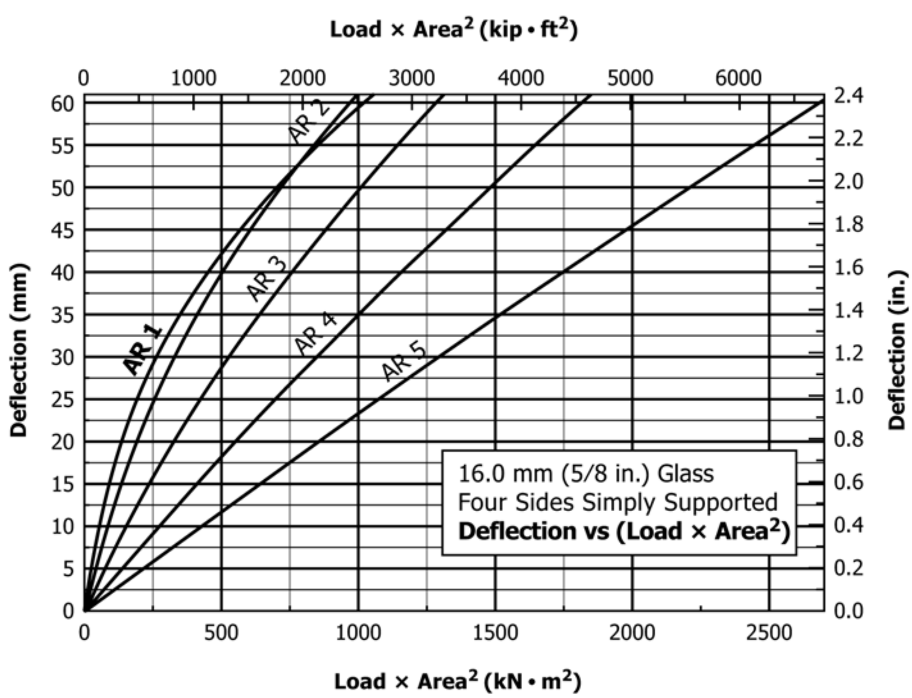
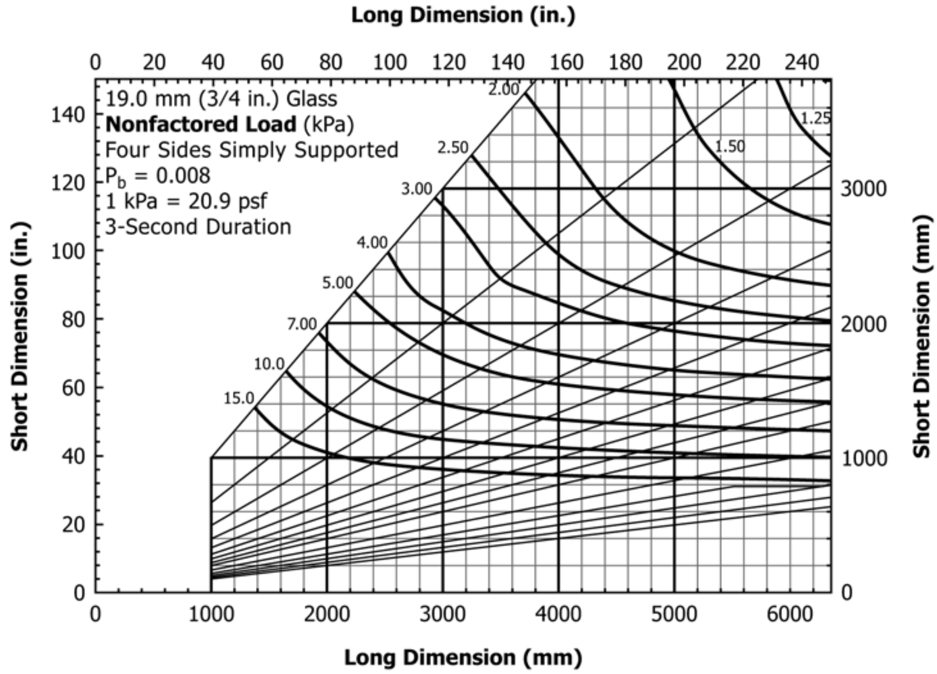


FIG. A1.11 (upper chart) Non-Factored Load Chart for 16.0 mm (⅝ in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 16.0 mm (⅝ in.) Glass with Four Sides Simply Supported



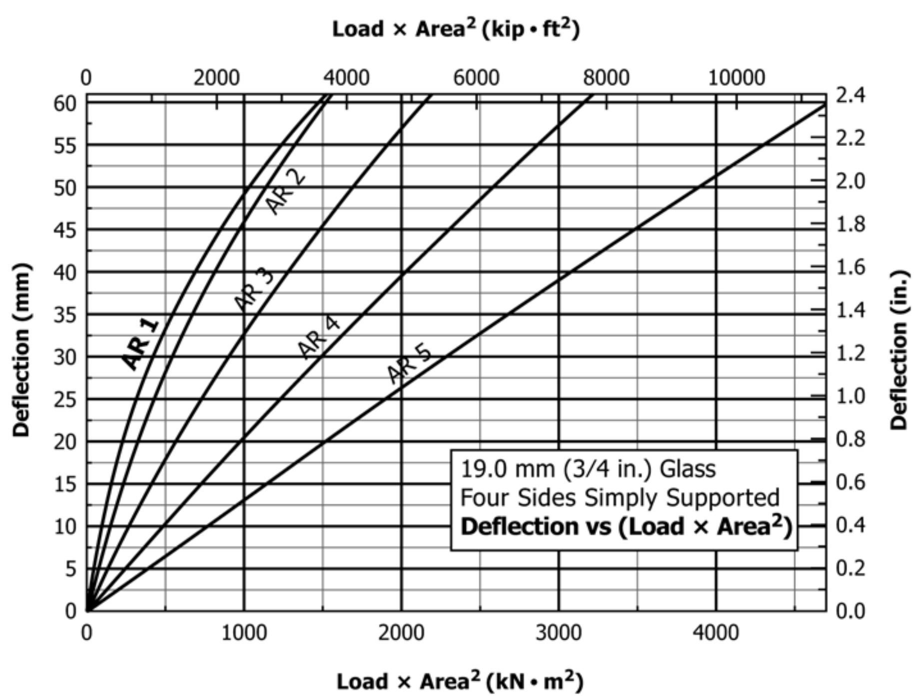
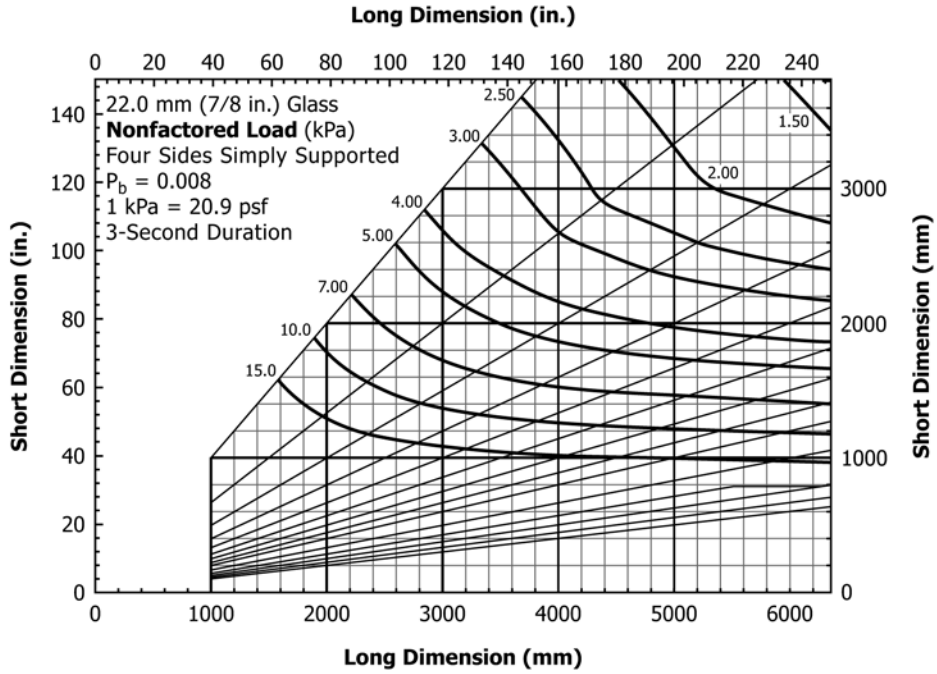


FIG. A1.12 (upper chart) Non-Factored Load Chart for 19.0 mm (¾ in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 19.0 mm (¾ in.) Glass with Four Sides Simply Supported



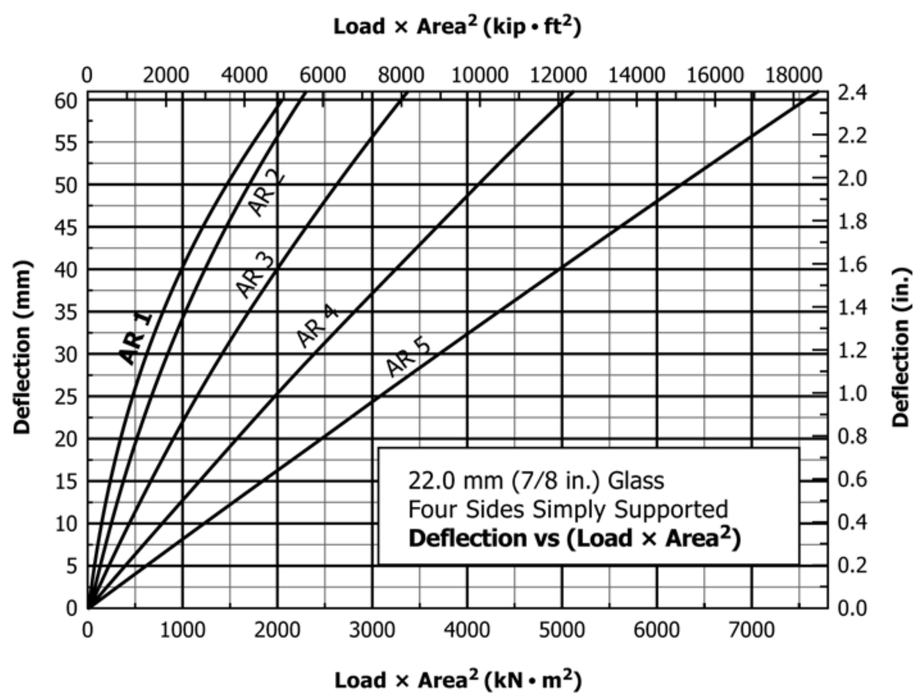
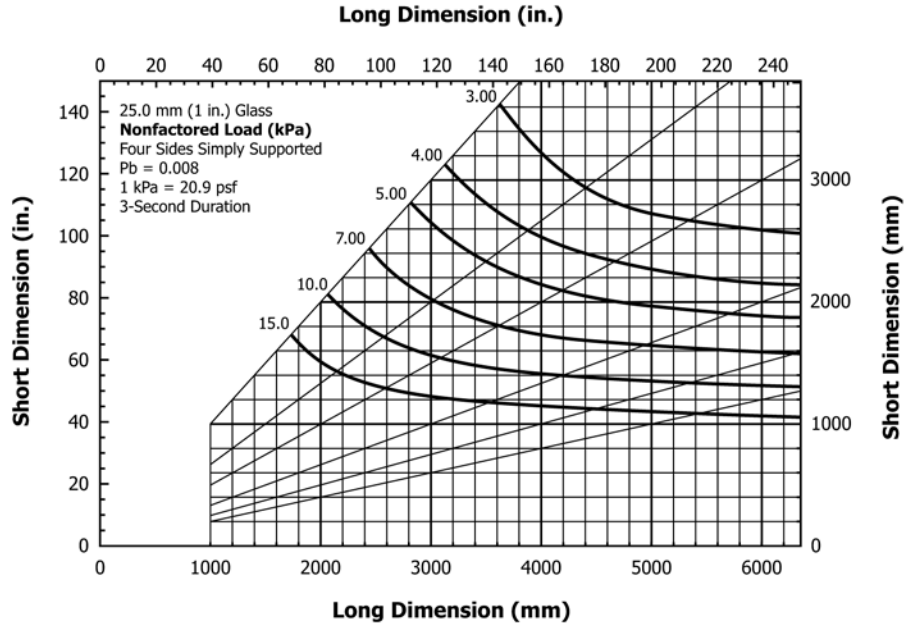


FIG. A1.13 (upper chart) Non-Factored Load Chart for 22.0 mm (⅞ in.) Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 22.0 mm (⅞ in.) Glass with Four Sides Simply Supported



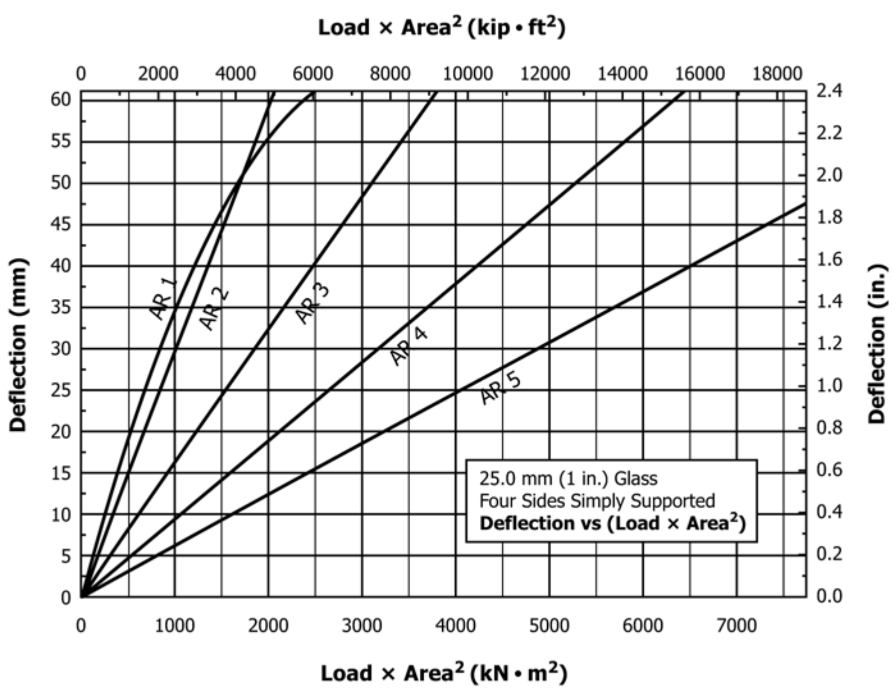
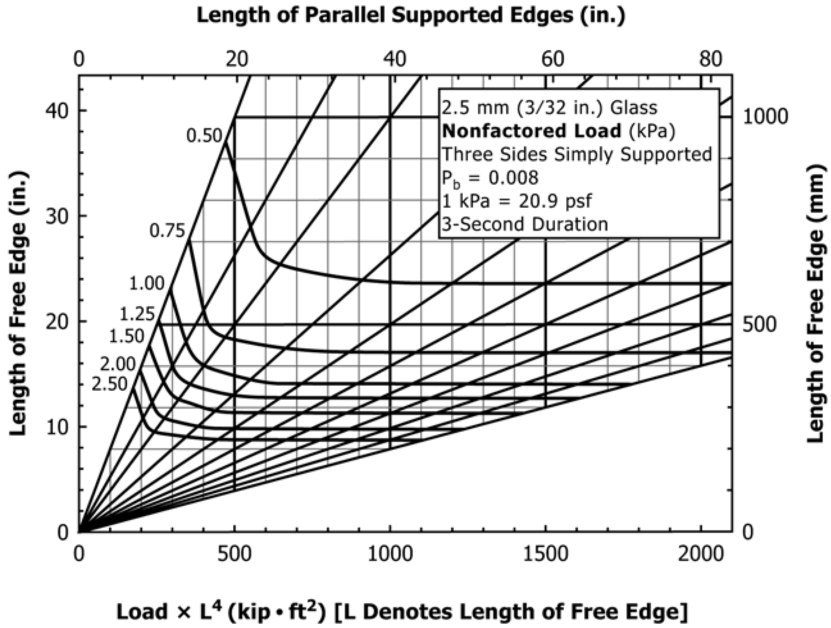


FIG. A1.14 (upper chart) Non-Factored Load Chart for 25.0 mm (1 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 25.0 mm (1 in.) Glass with Four Sides Simply Supported



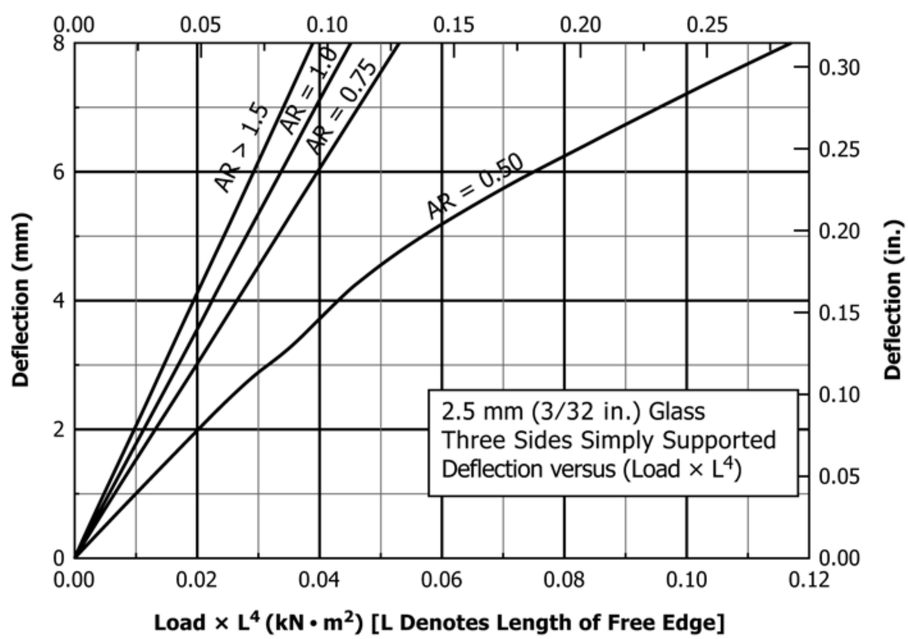
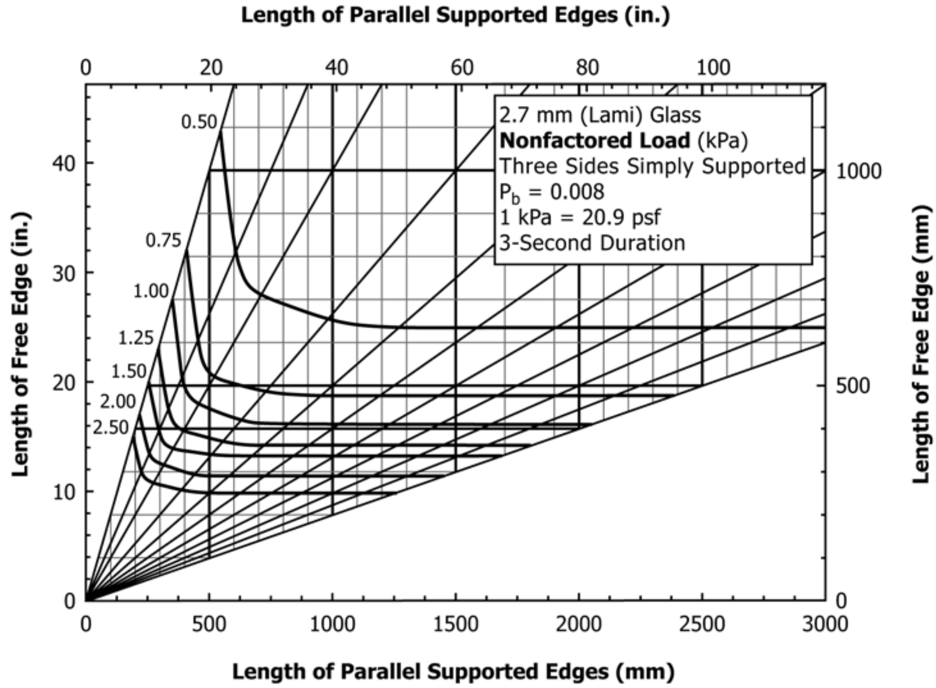


FIG. A1.15 (upper chart) Non-Factored Load Chart for 2.5 mm (3⁄32 in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 2.5 mm (3⁄32 in.) Glass with Three Sides Simply Supported



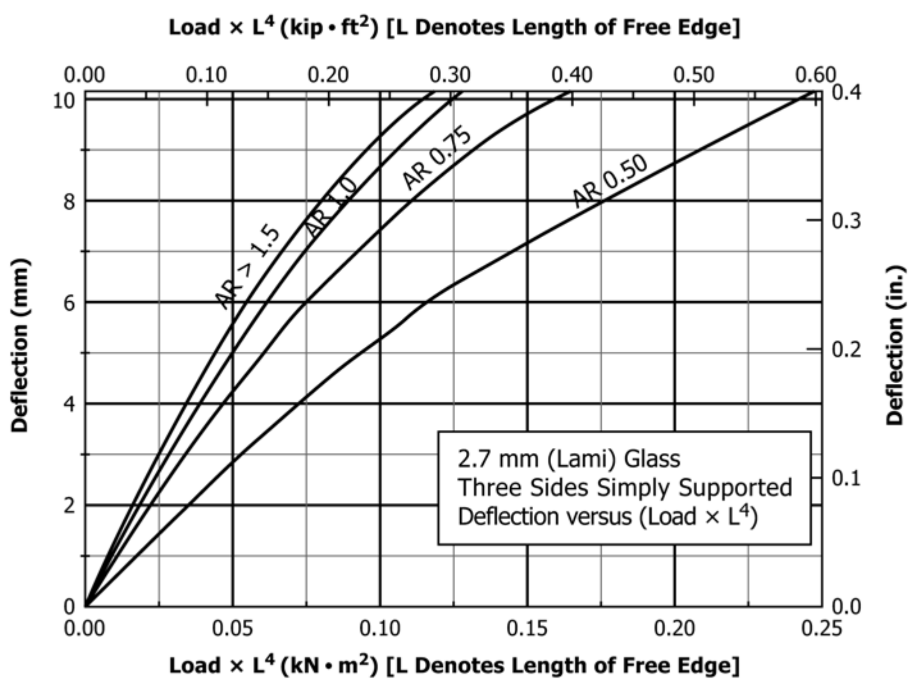
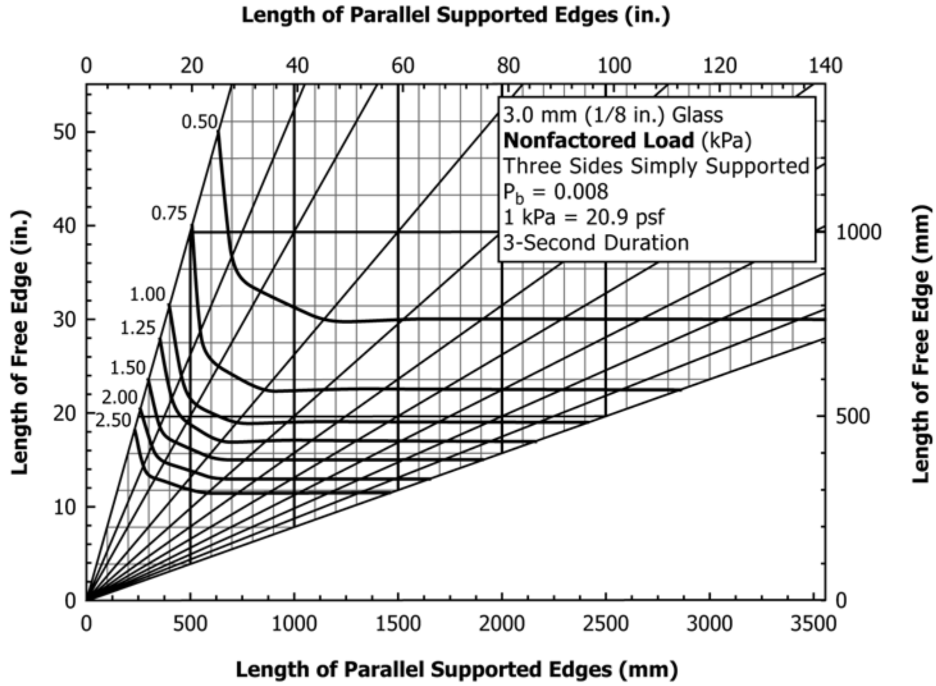


FIG. A1.16 (upper chart) Non-Factored Load Chart for 2.7 mm (Lami) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 2.7 mm (Lami) Glass with Three Sides Simply Supported



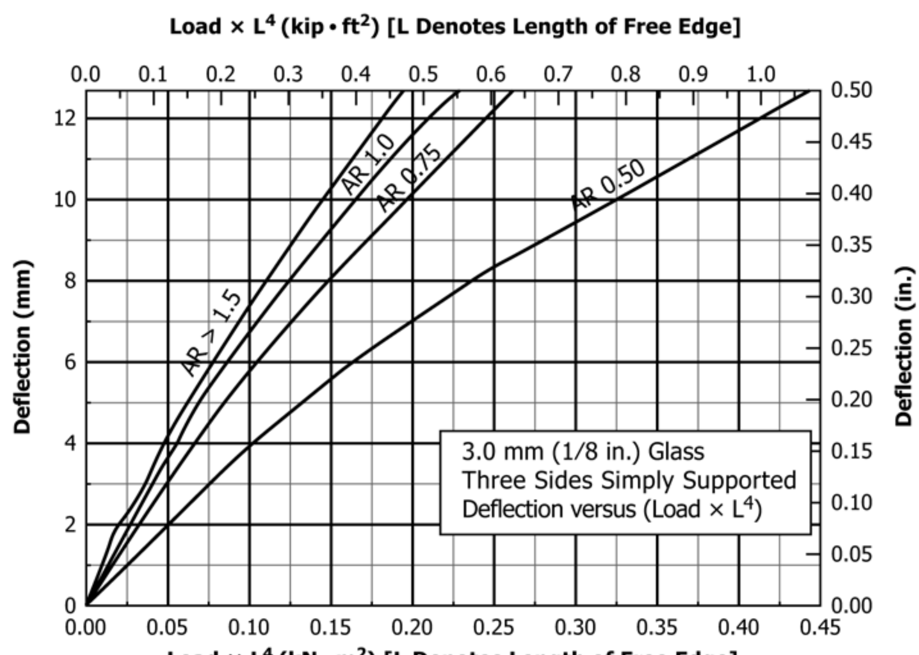
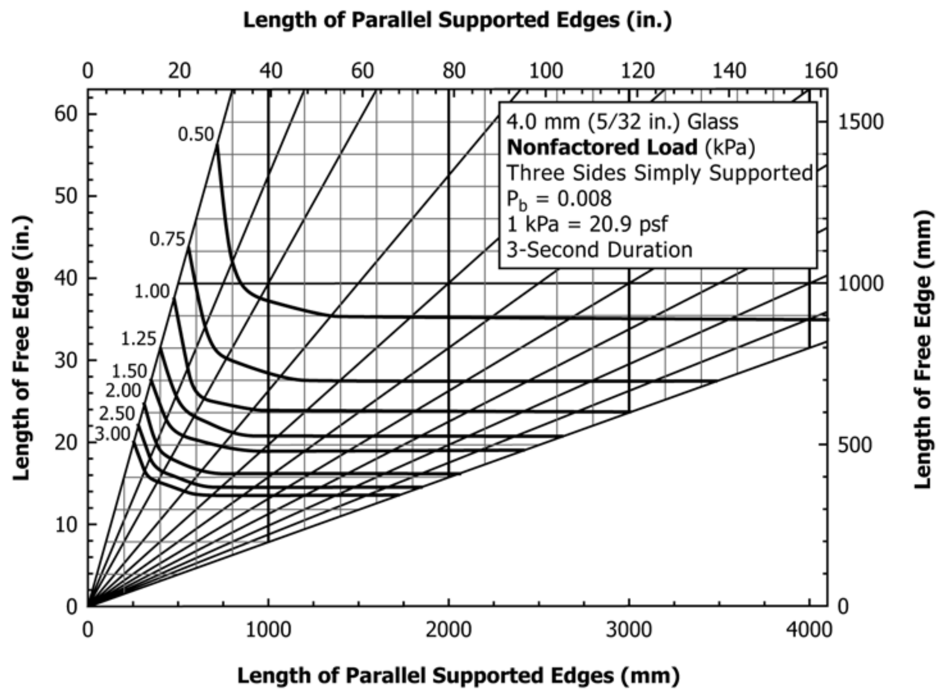


FIG. A1.17 (upper chart) Non-Factored Load Chart for 3.0 mm (⅛ in.) Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 3.0 mm (⅛ in.) Glass with Three Sides Simply Supported



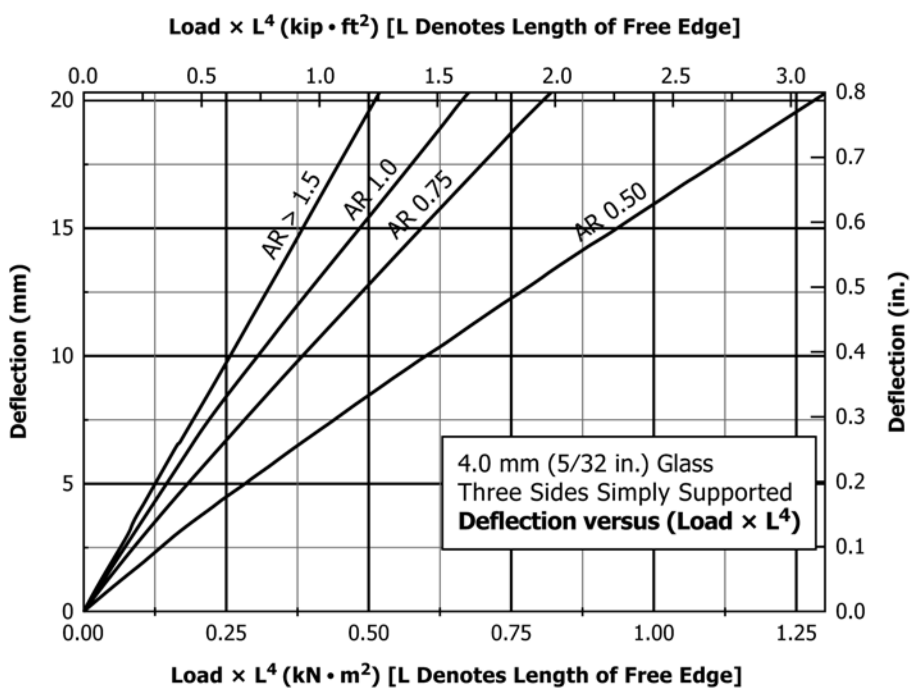
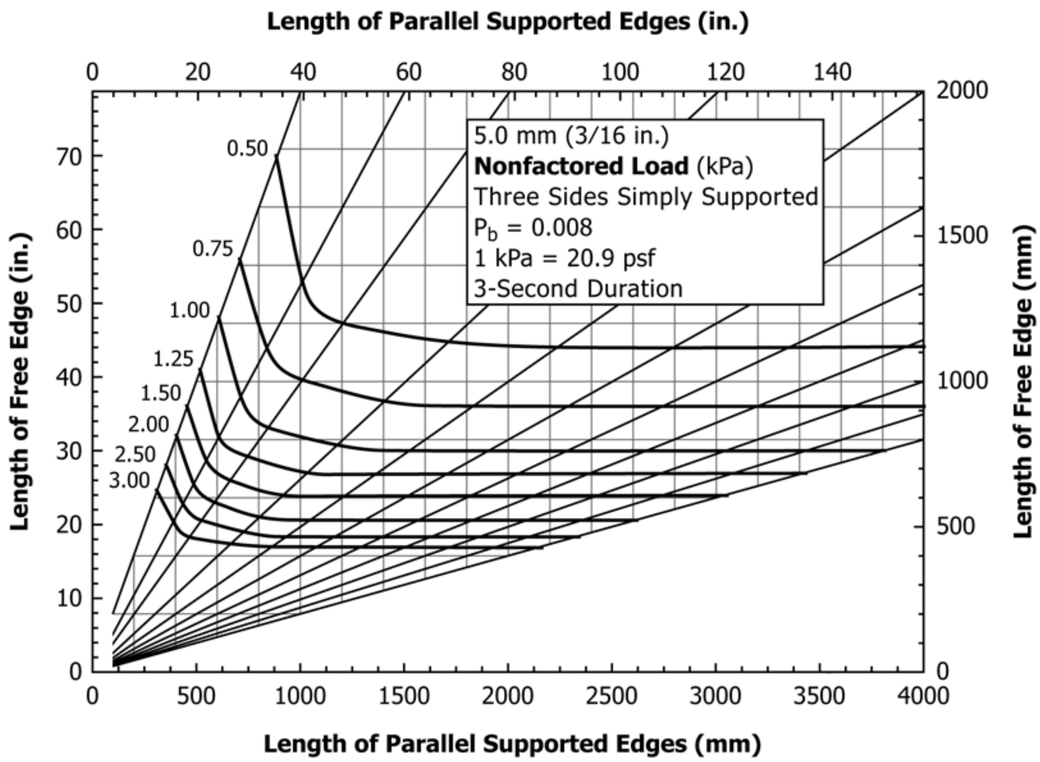


FIG. A1.18 (upper chart) Non-Factored Load Chart for 4.0 mm (5⁄32 in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 4.0 mm (5⁄32 in.) Glass with Three Sides Simply Supported



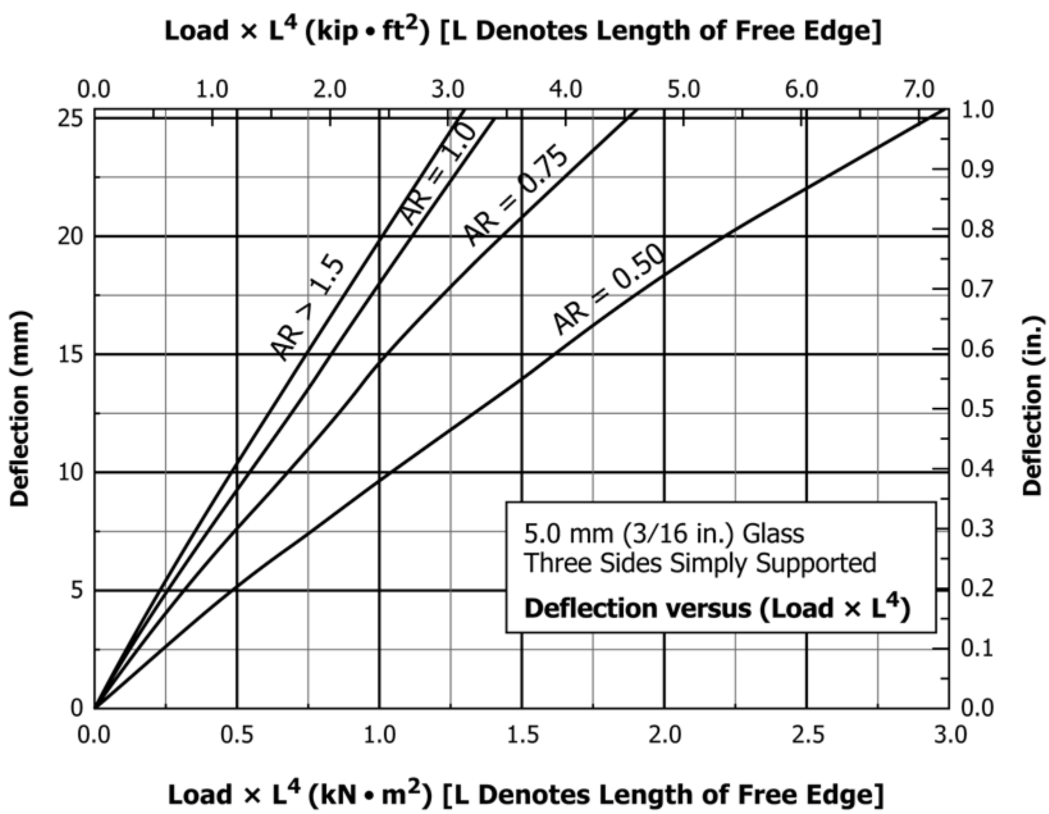
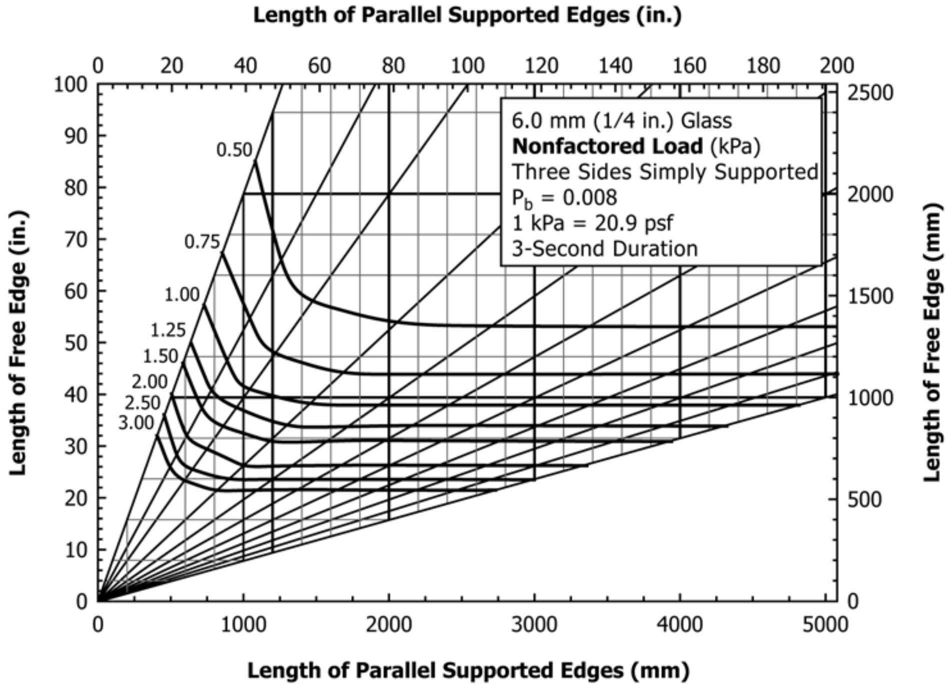


FIG. A1.19 (upper chart) Non-Factored Load Chart for 5.0 mm (3⁄16 in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 5.0 mm (3⁄16 in.) Glass with Three Sides Simply Supported



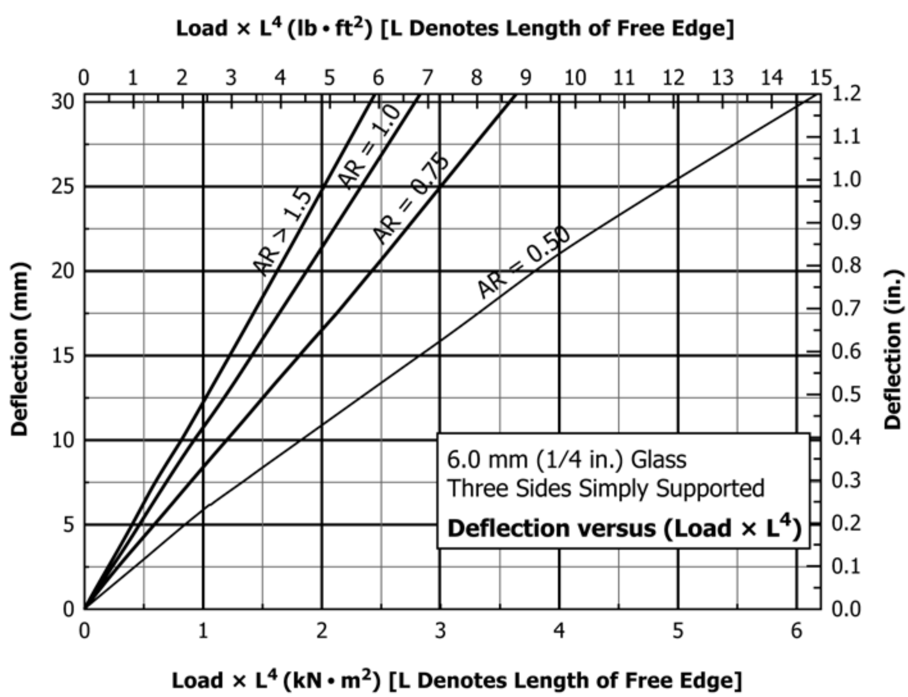
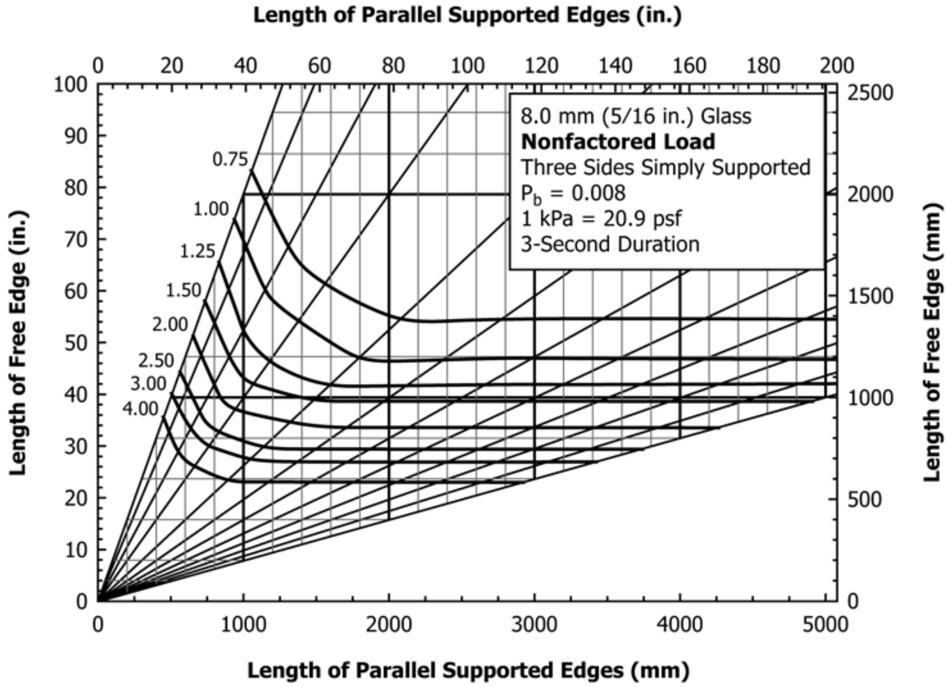


FIG. A1.20 (upper chart) Non-Factored Load Chart for 6.0 mm (¼ in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 6.0 mm (¼ in.) Glass with Three Sides Simply Supported



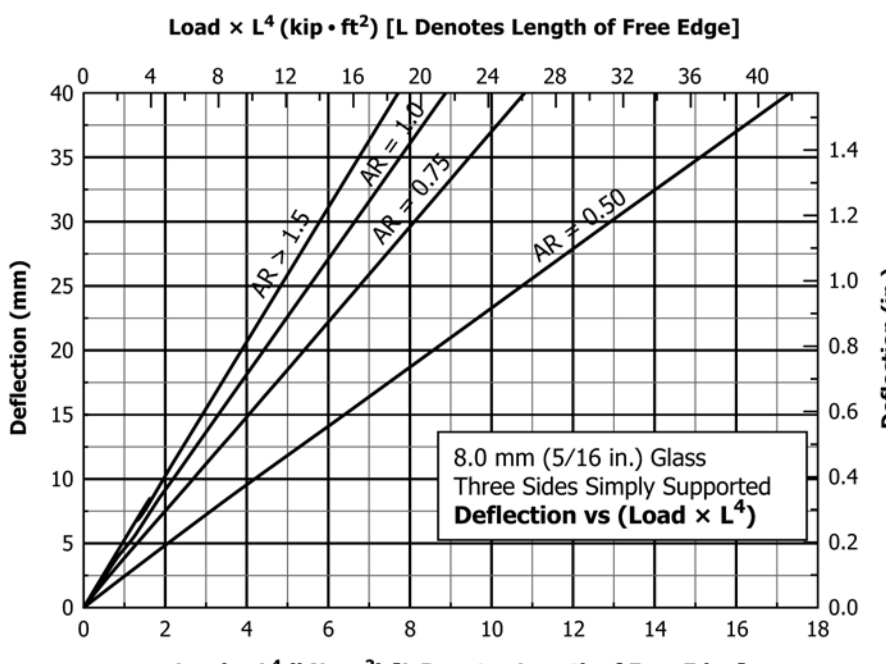


FIG. A1.21 (upper chart) Non-Factored Load Chart for 8.0 mm (5⁄16 in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 8.0 mm (5⁄16 in.) Glass with Three Sides Simply Supported

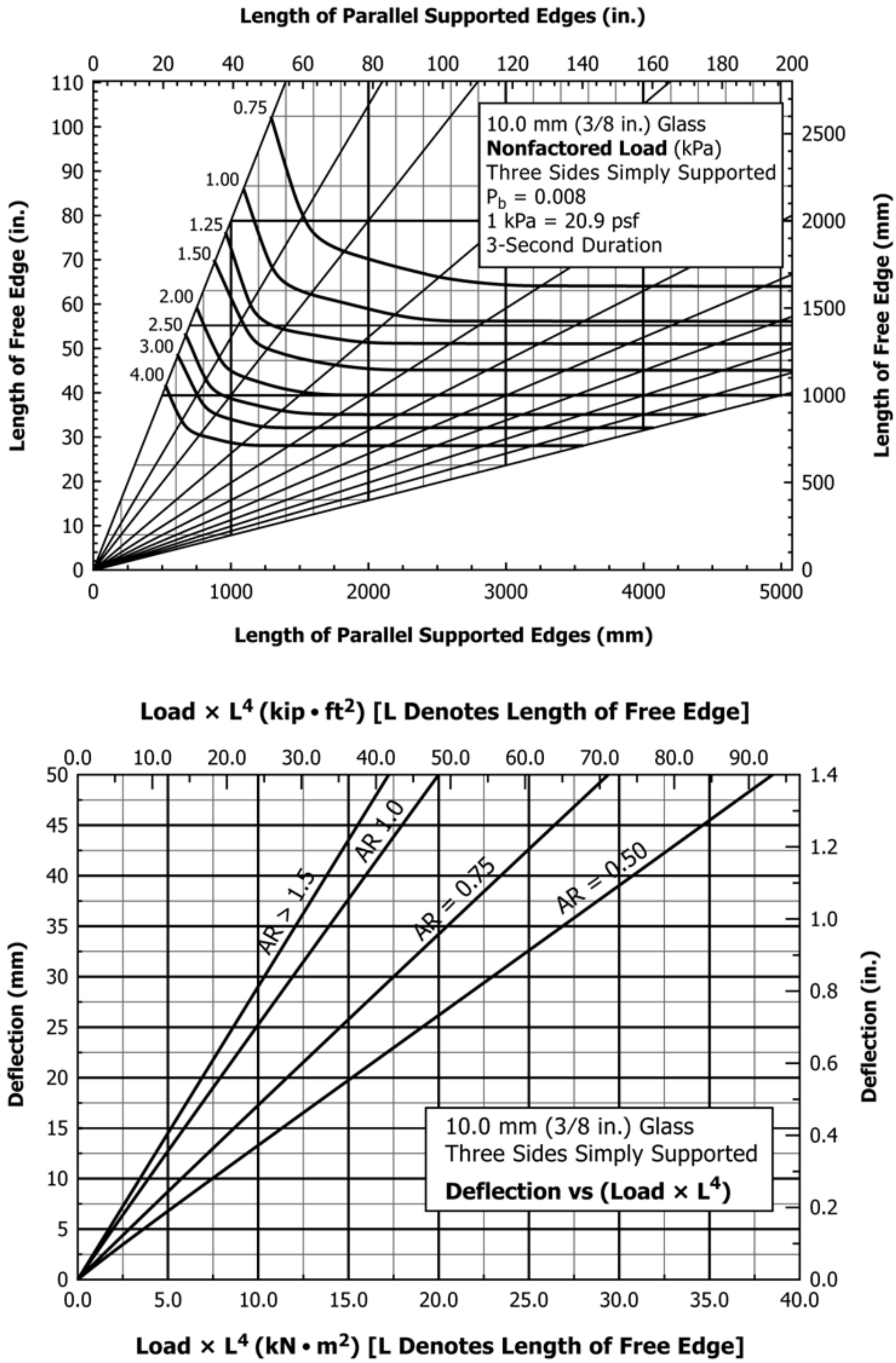
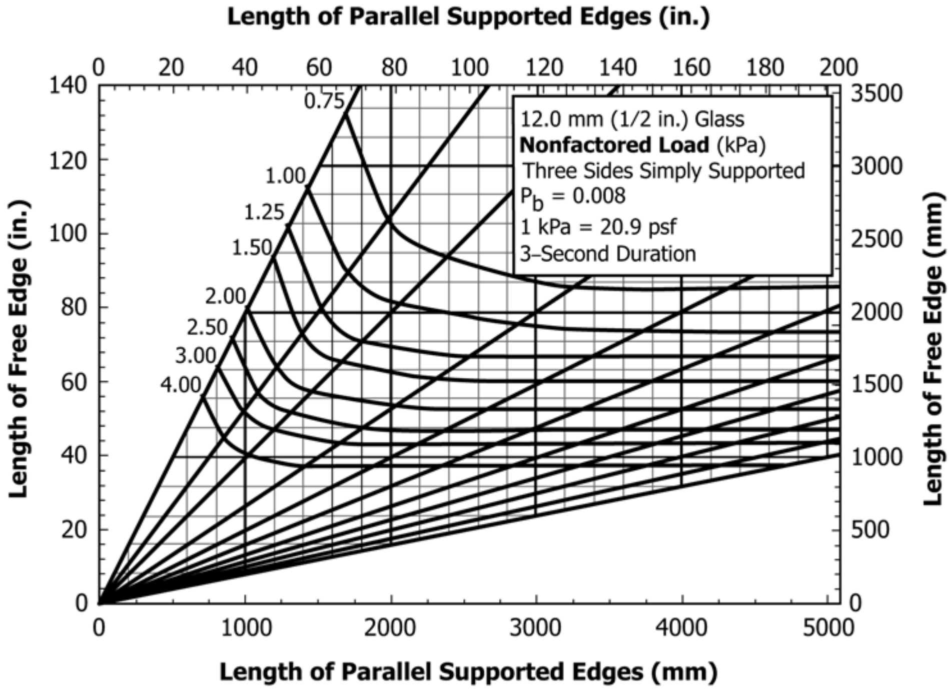


FIG. A1.22 (upper chart) Non-Factored Load Chart for 10.0 mm (⅜ in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 10.0 mm (⅜ in.) Glass with Three Sides Simply Supported



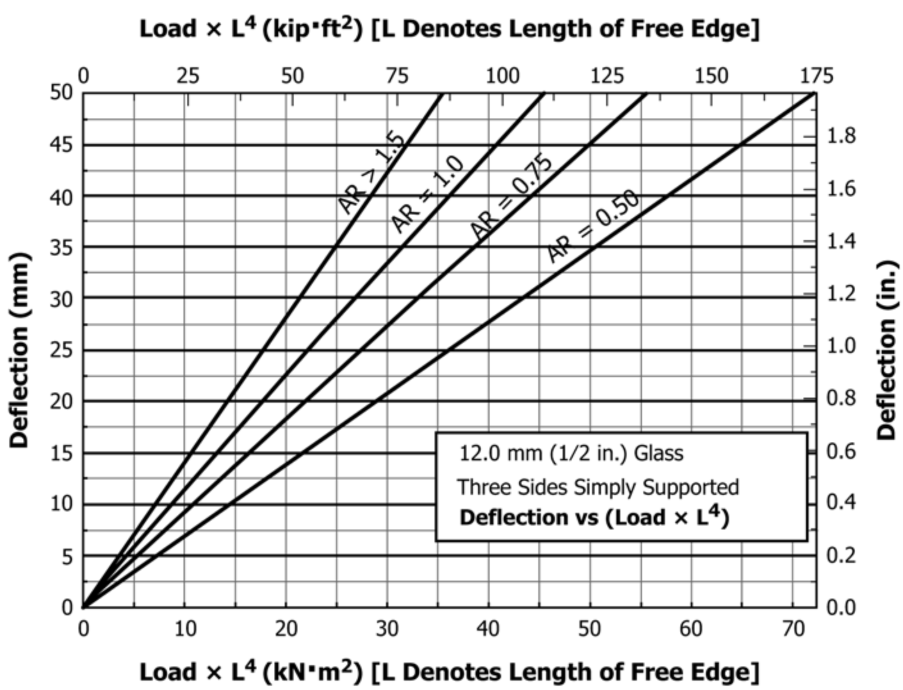
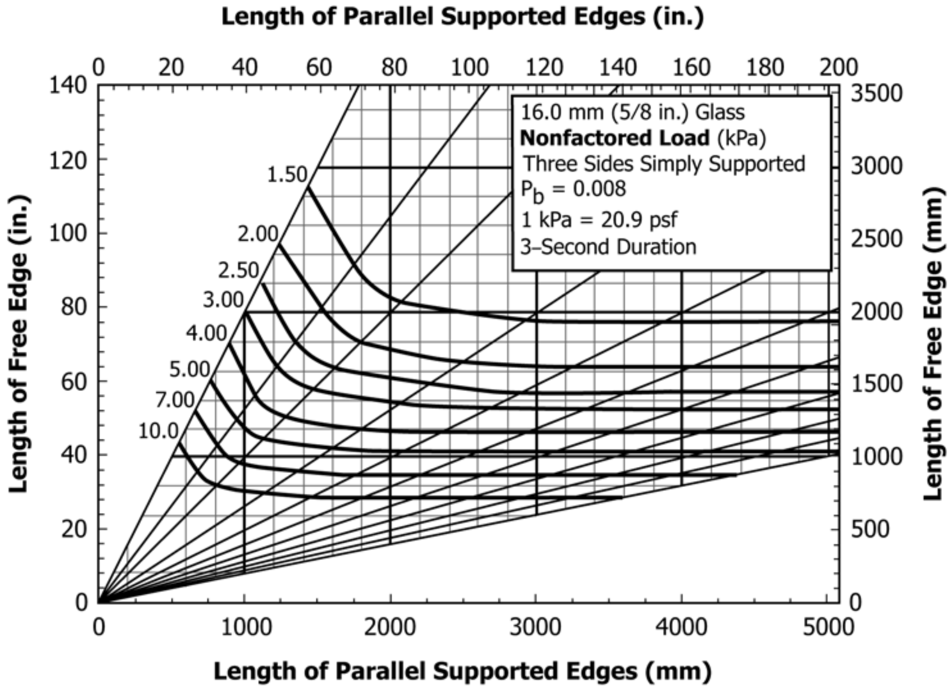


FIG. A1.23 (upper chart) Non-Factored Load Chart for 12.0 mm (½ in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 12.0 mm (½ in.) Glass with Three Sides Simply Supported



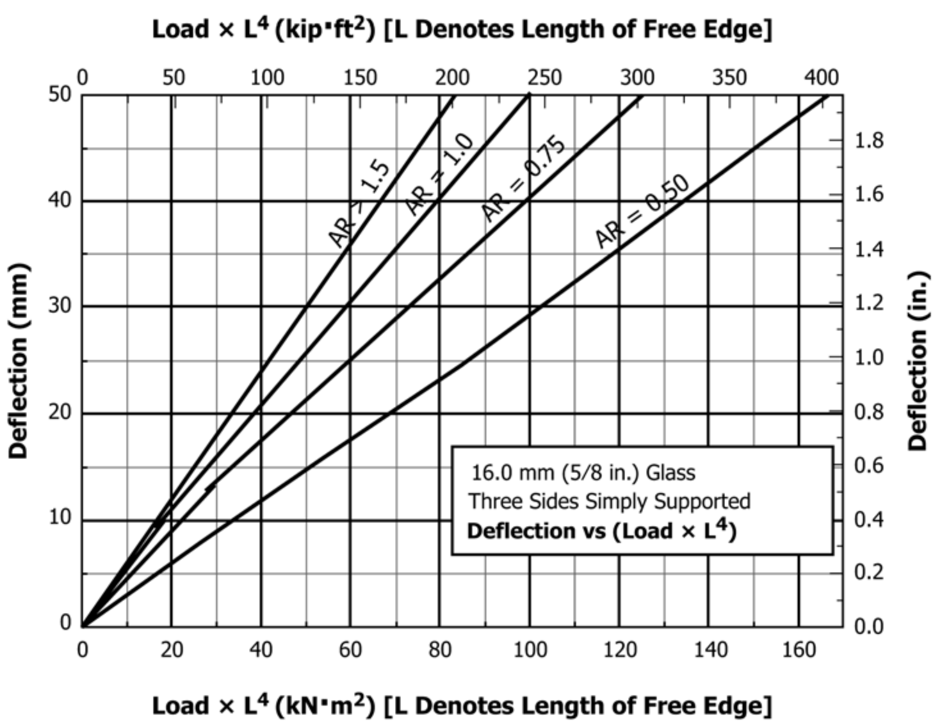
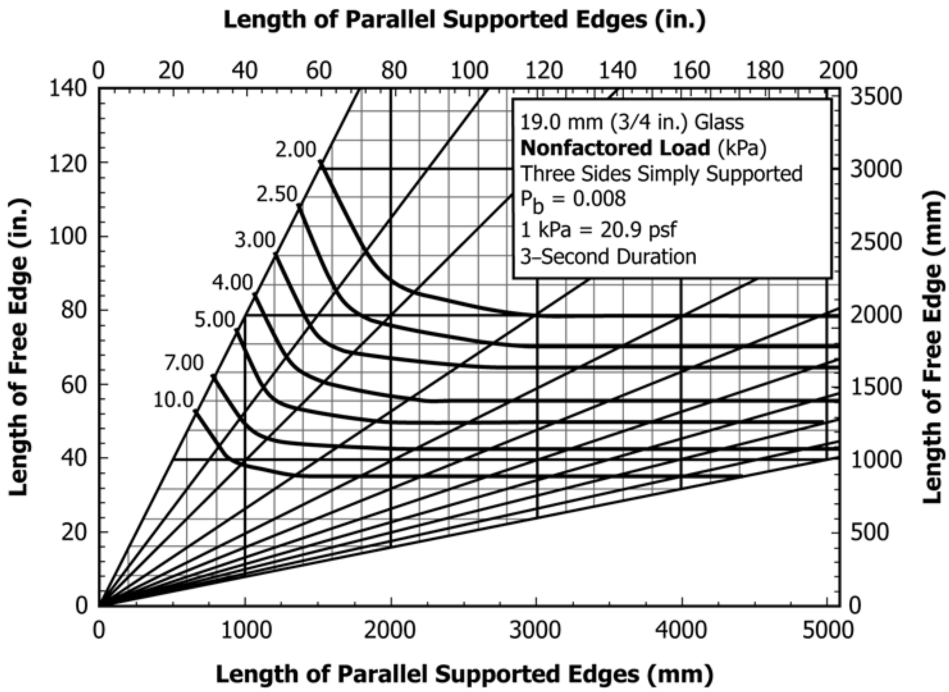


FIG. A1.24 (upper chart) Non-Factored Load Chart for 16.0 mm (⅝ in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 16.0 mm (⅝ in.) Glass with Three Sides Simply Supported



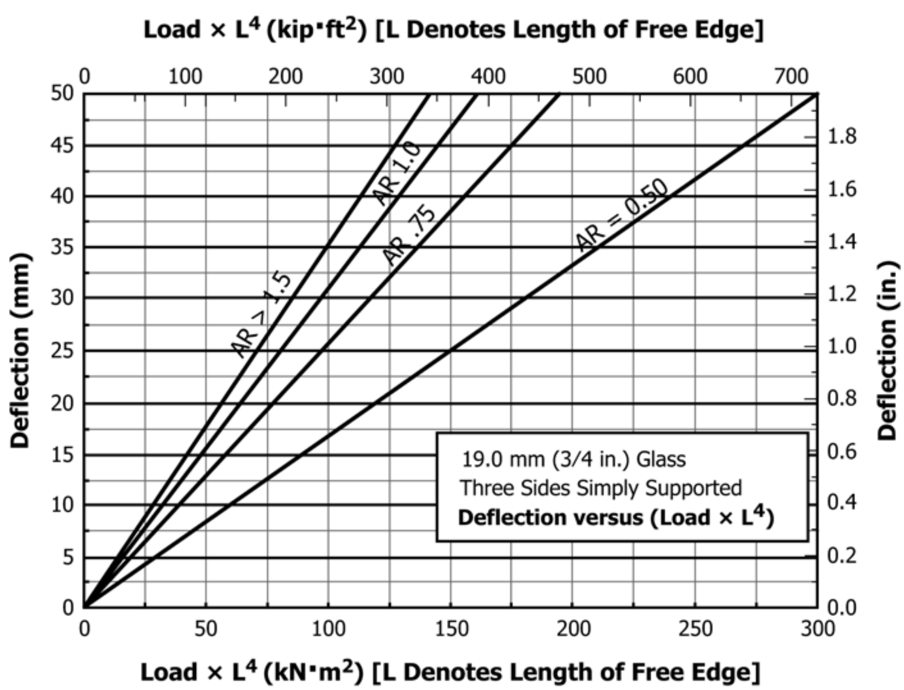
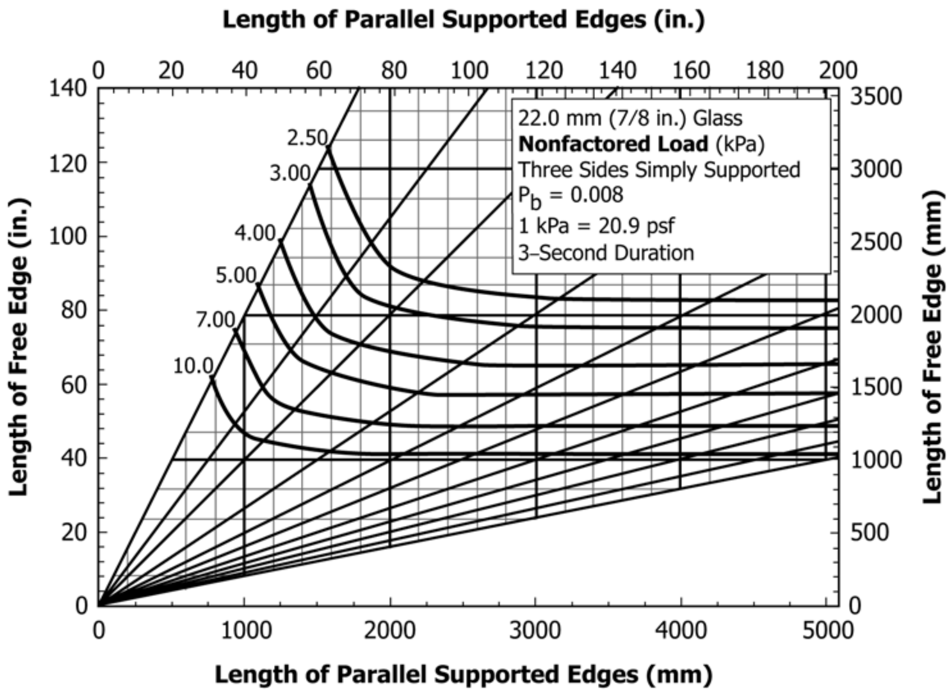


FIG. A1.25 (upper chart) Non-Factored Load Chart for 19.0 mm (3⁄4 in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 19.0 mm (3⁄4 in.) Glass with Three Sides Simply Supported



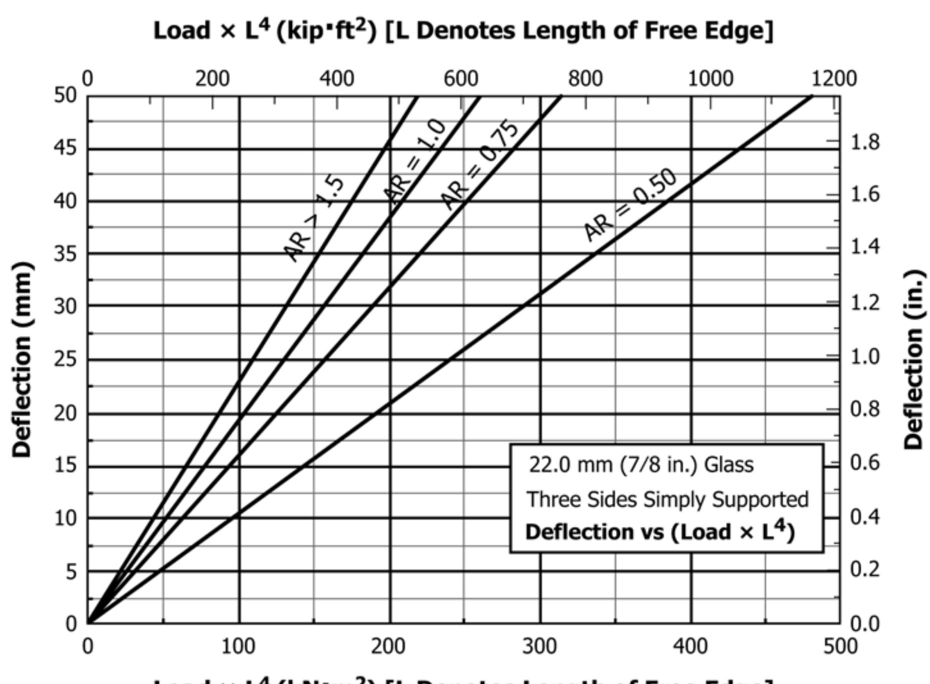
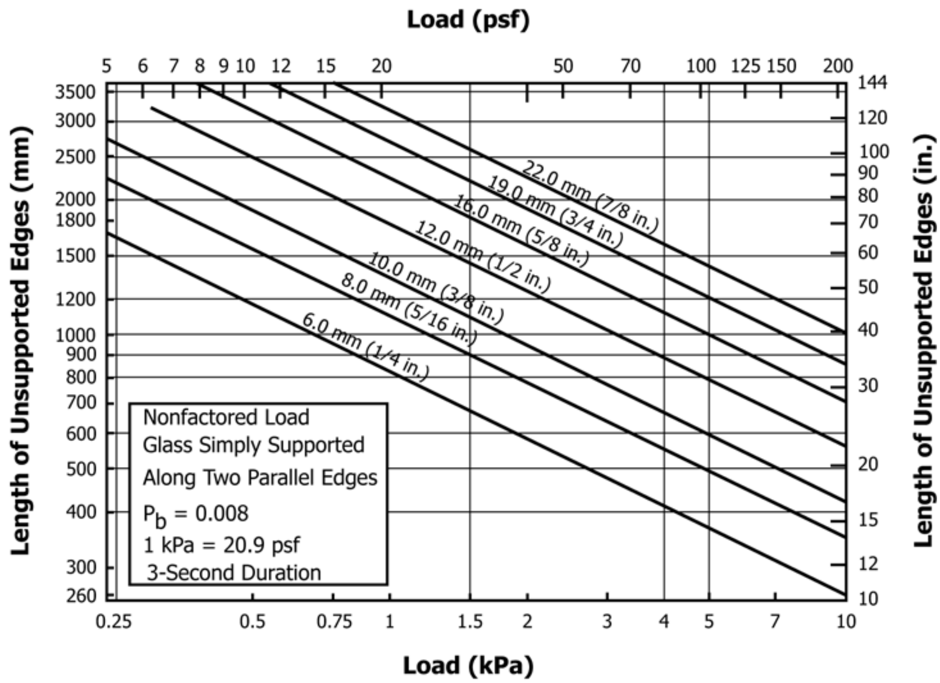


FIG. A1.26 (upper chart) Non-Factored Load Chart for 22.0 mm (7⁄8 in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 22.0 mm (7⁄8 in.) Glass with Three Sides Simply Supported



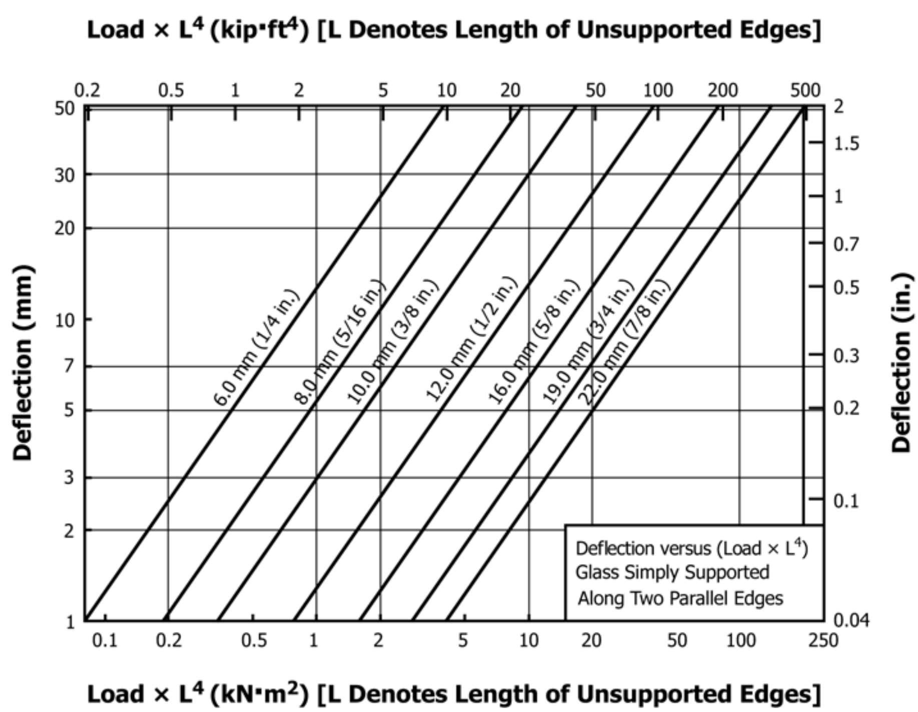
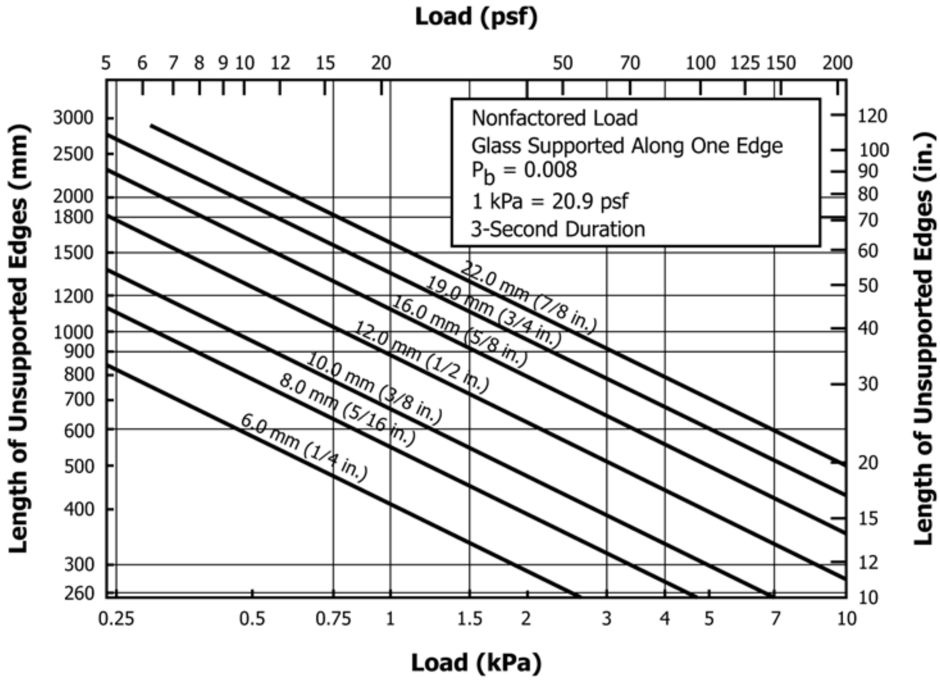


FIG. A1.27 (upper chart) Non-Factored Load Chart for Glass Simply Supported Along Two Parallel Edges (lower chart) Deflection Chart for Glass Simply Supported Along Two Parallel Edges



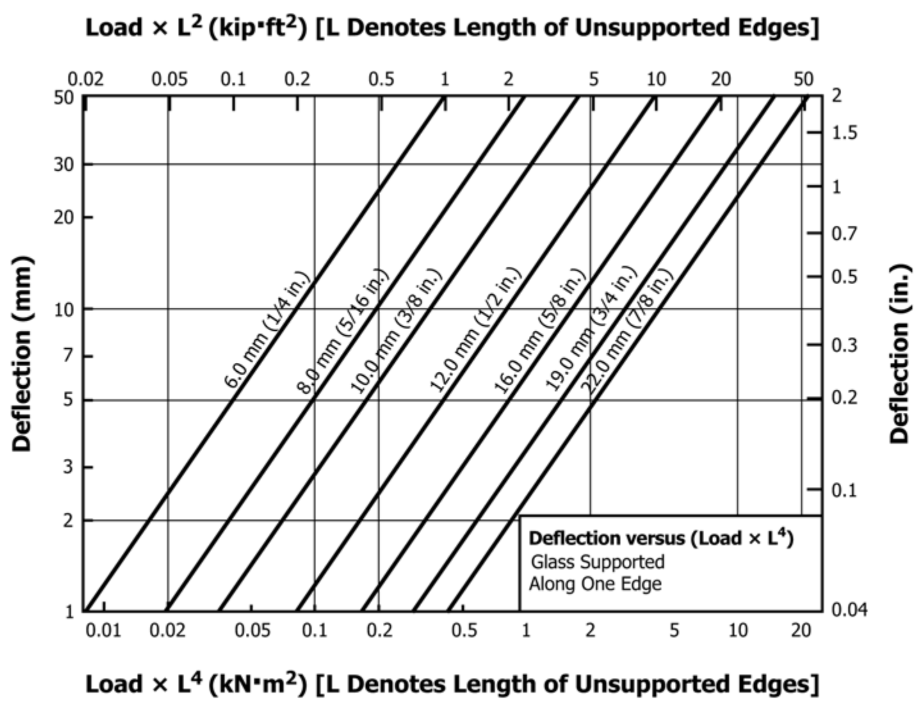
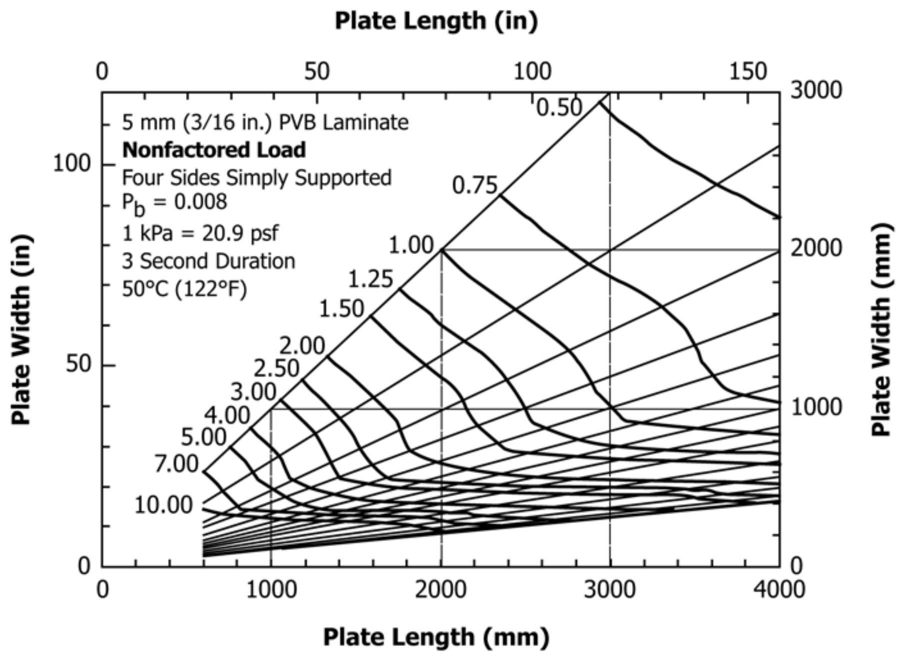


FIG. A1.28 (upper chart) Non-Factored Load Chart for Glass Supported Along One Edge (lower chart) Deflection Chart for Glass Supported Along One Edge



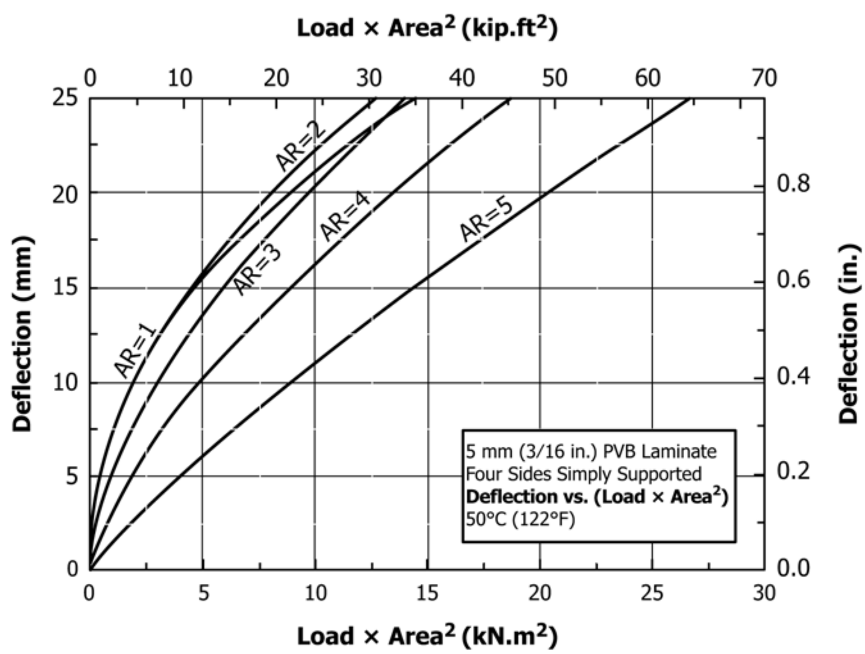


FIG. A1.29 (upper chart) Non-Factored Load Chart for 5.0 mm (3⁄16 in.) Laminated Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 5.0 mm (3⁄16 in.) Laminated Glass with Four Sides Simply Supported

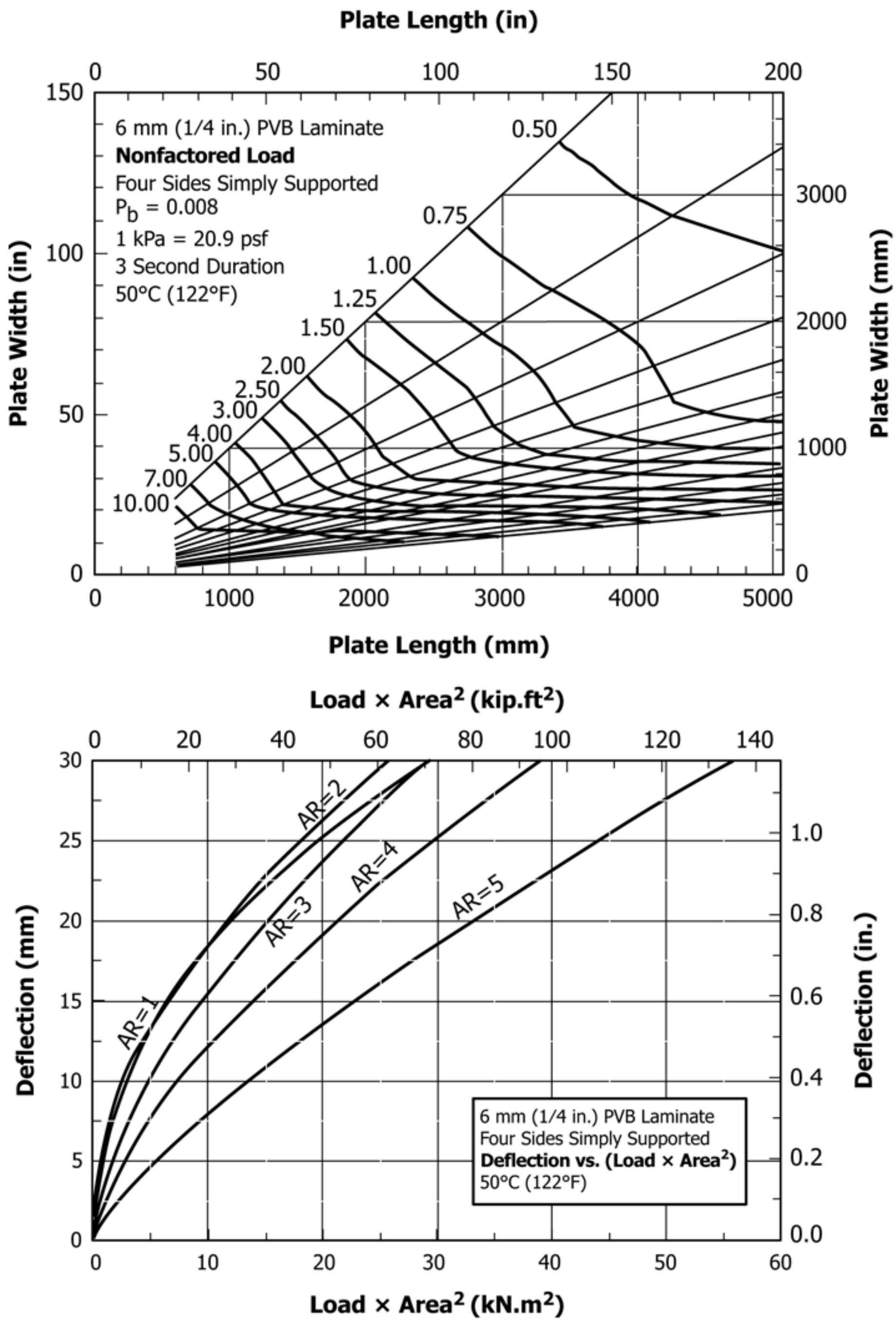
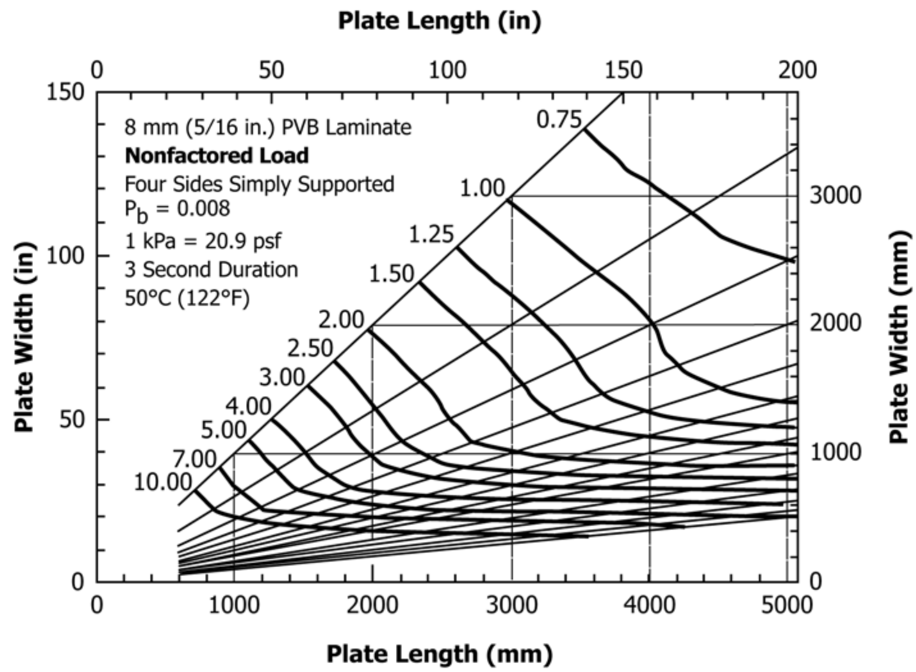


FIG. A1.30 (upper chart) Non-Factored Load Chart for 6.0 mm (¼ in.) Laminated Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 6.0 mm (¼ in.) Laminated Glass with Four Sides Simply Supported



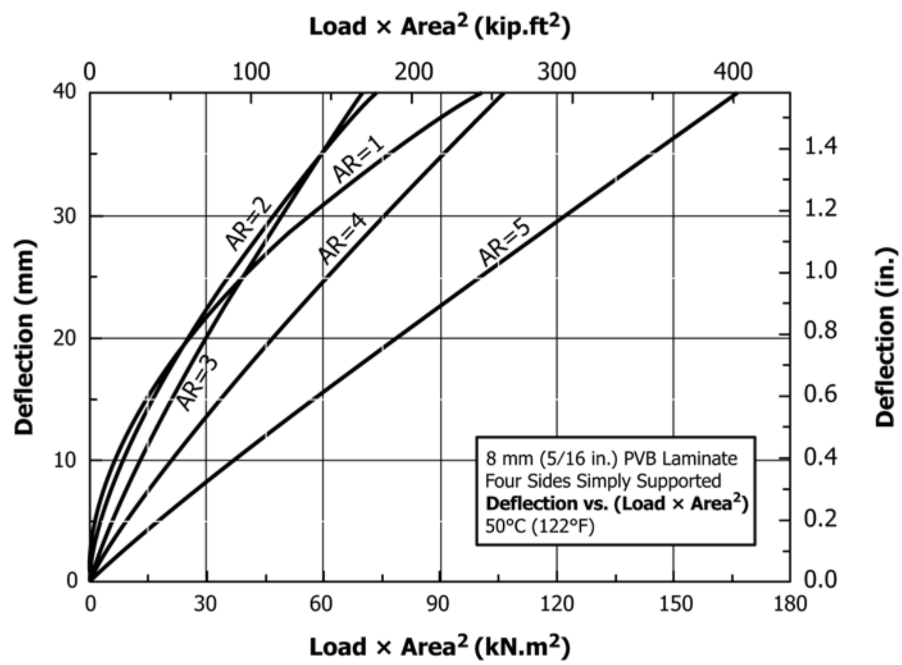
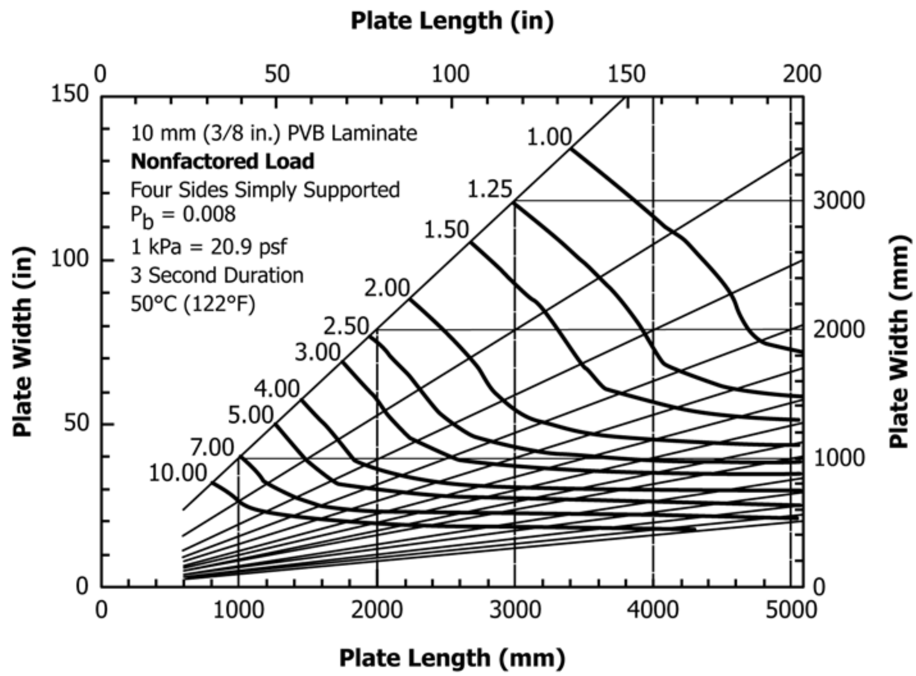


FIG. A1.31 (upper chart) Non-Factored Load Chart for 8.0 mm (5⁄16 in.) Laminated Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 8.0 mm (5⁄16 in.) Laminated Glass with Four Sides Simply Supported



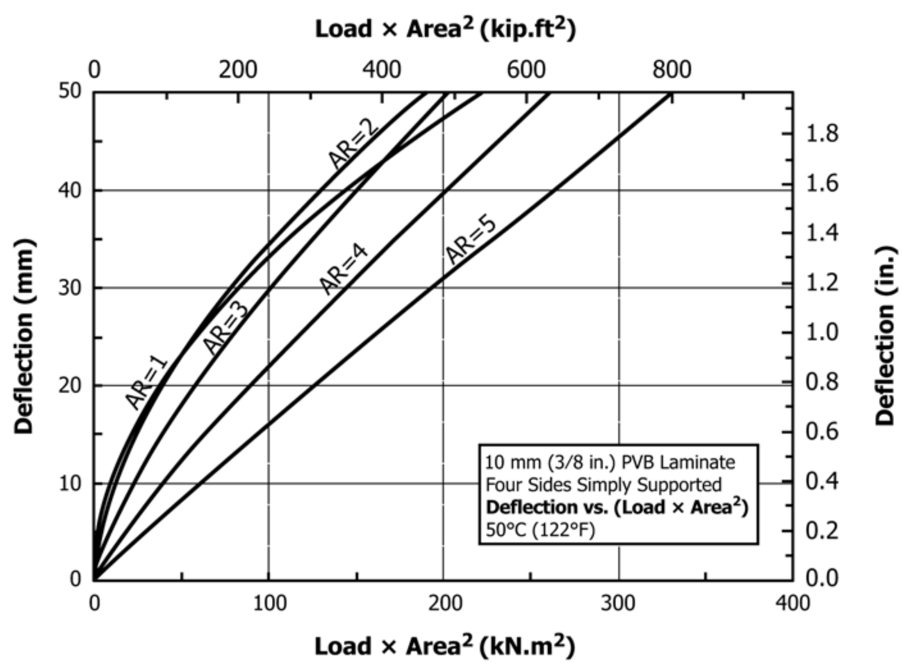
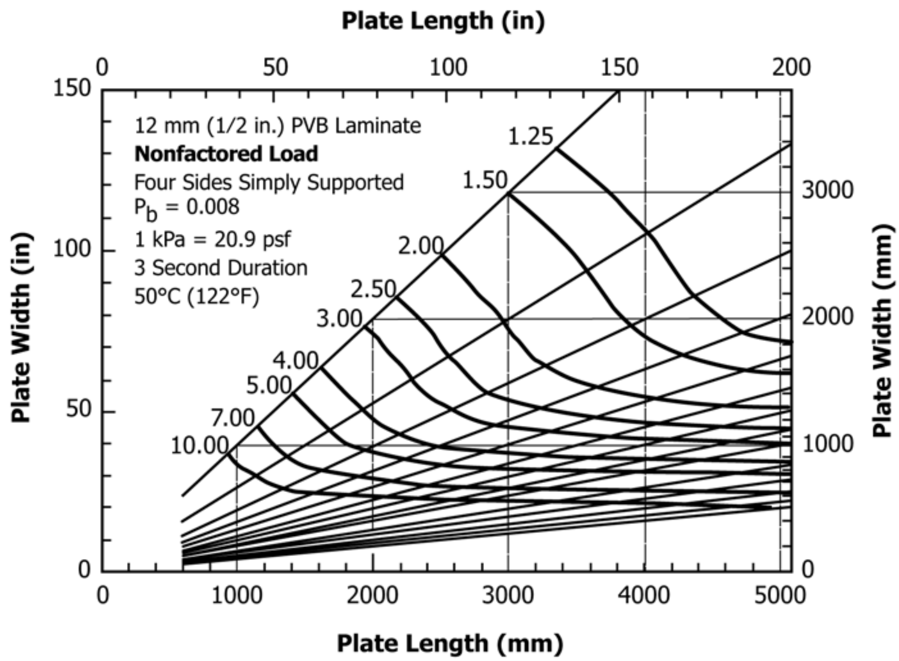


FIG. A1.32 (upper chart) Non-Factored Load Chart for 10.0 mm (3⁄8 in.) Laminated Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 10.0 mm (3⁄8 in.) Laminated Glass with Four Sides Simply Supported



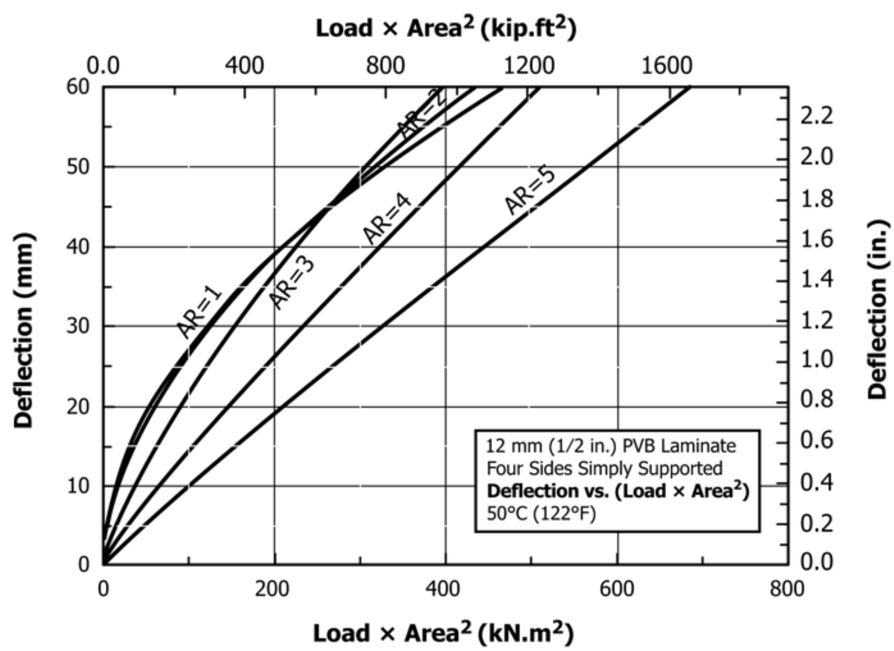
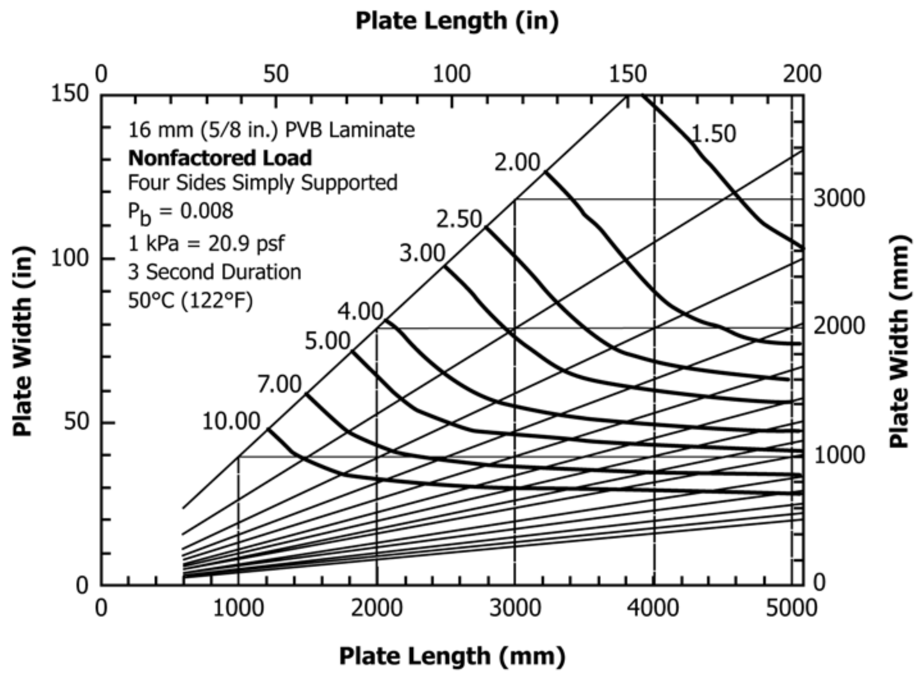


FIG. A1.33 (upper chart) Non-Factored Load Chart for 12.0 mm (½ in.) Laminated Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 12.0 mm (½ in.) Laminated Glass with Four Sides Simply Supported



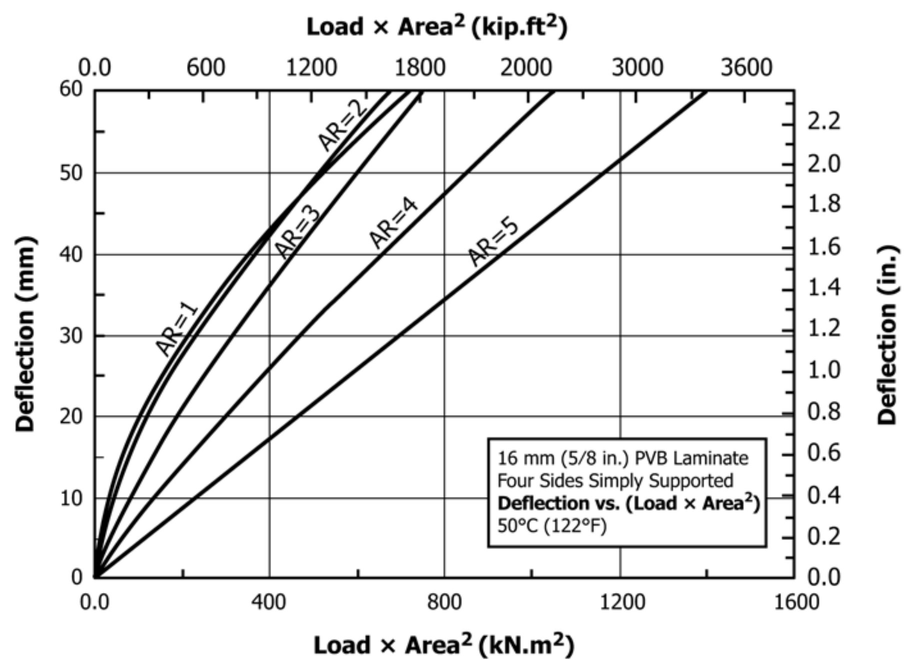
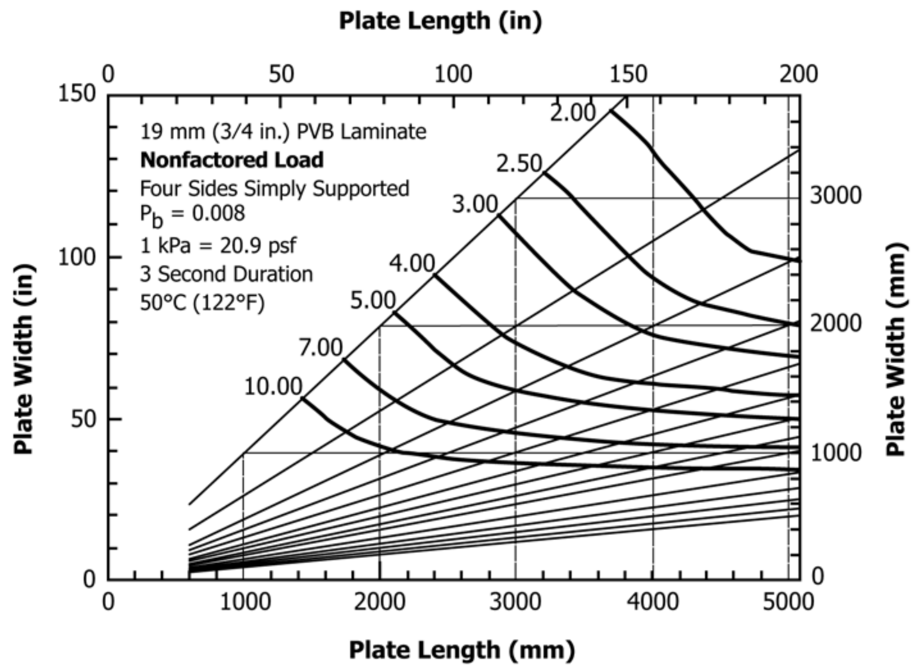


FIG. A1.34 (upper chart) Non-Factored Load Chart for 16.0 mm (⅝ in.) Laminated Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 16.0 mm (⅝ in.) Laminated Glass with Four Sides Simply Supported



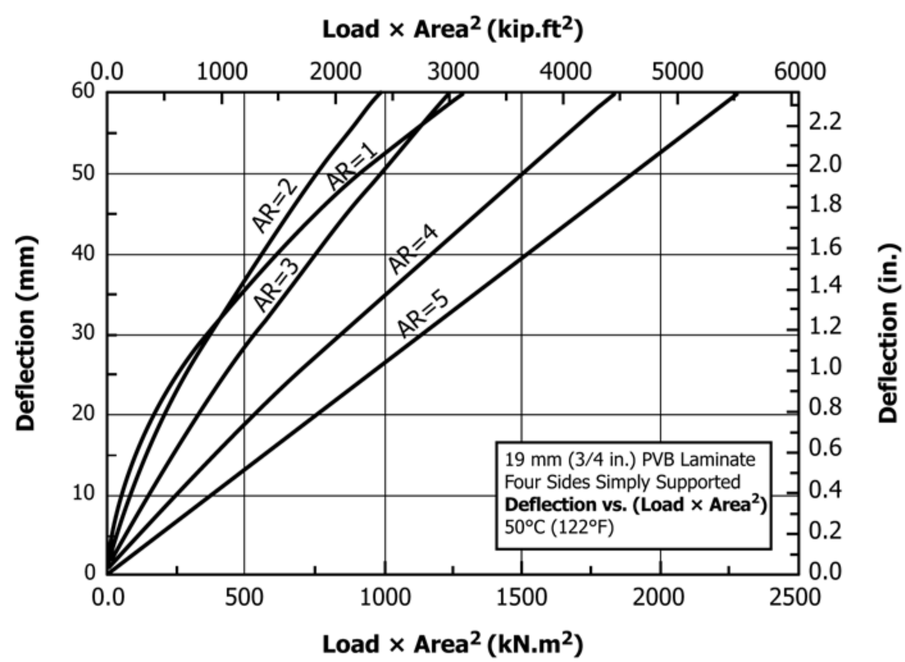
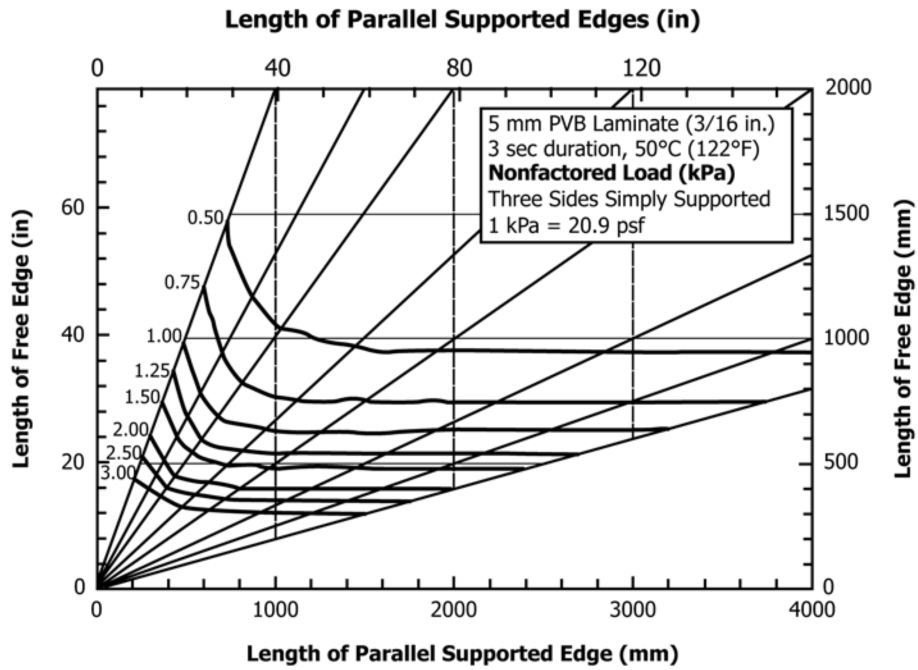


FIG. A1.35 (upper chart) Non-Factored Load Chart for 19.0 mm (¾ in.) Laminated Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 19.0 mm (¾ in.) Laminated Glass with Four Sides Simply Supported



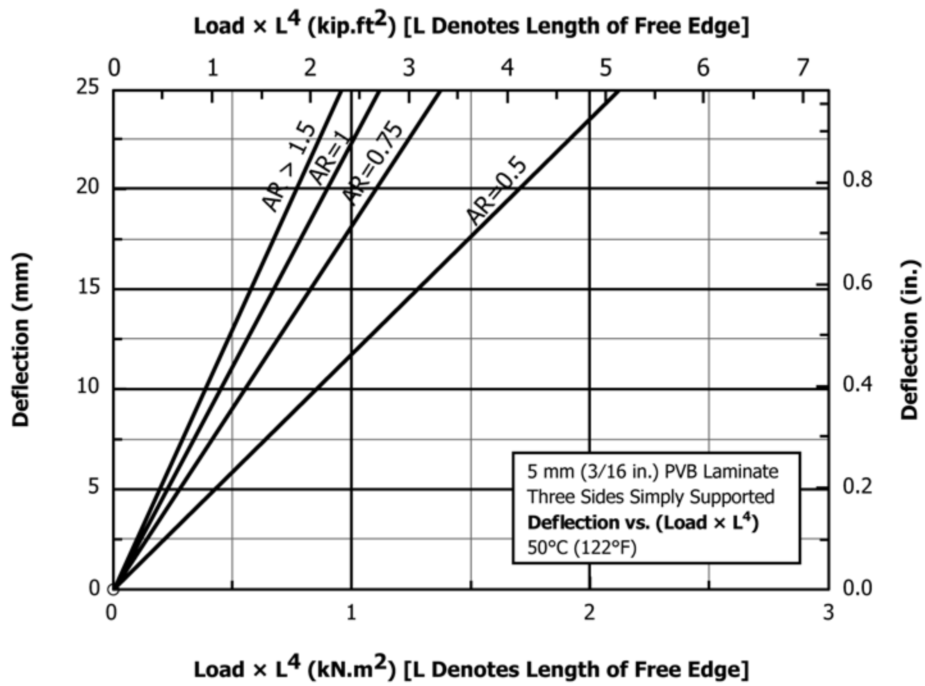
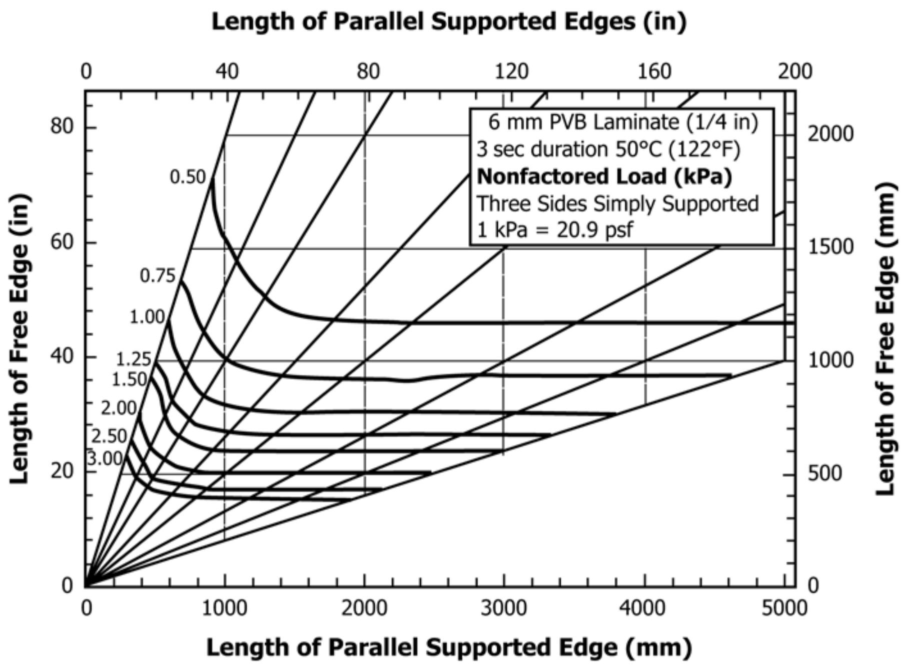


FIG. A1.36 (upper chart) Non-Factored Load Chart for 5.0 mm (3⁄16 in.) Laminated Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 5.0 mm (3⁄16 in.) Laminated Glass with Three Sides Simply Supported



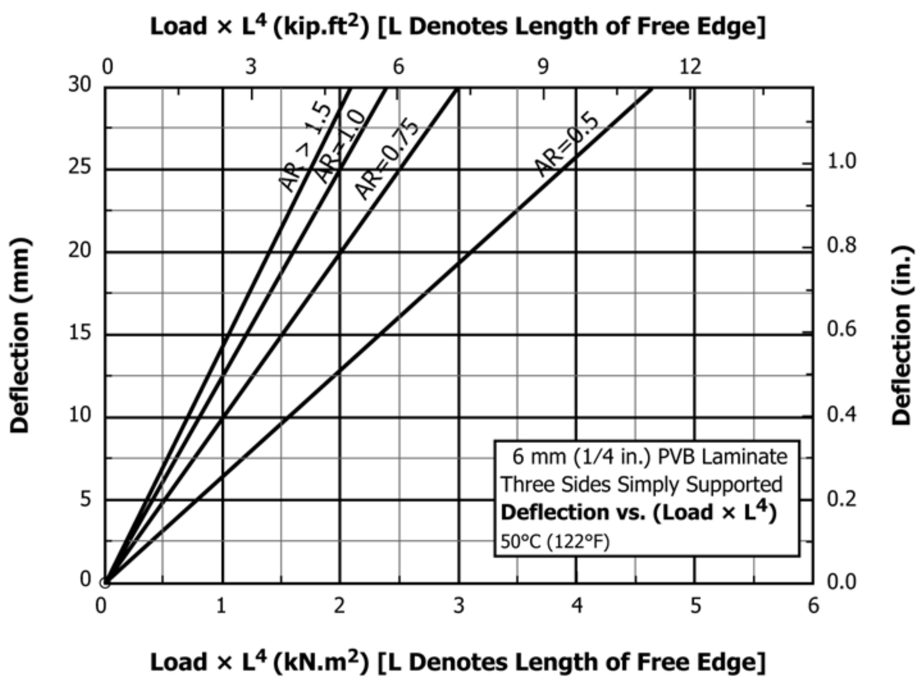
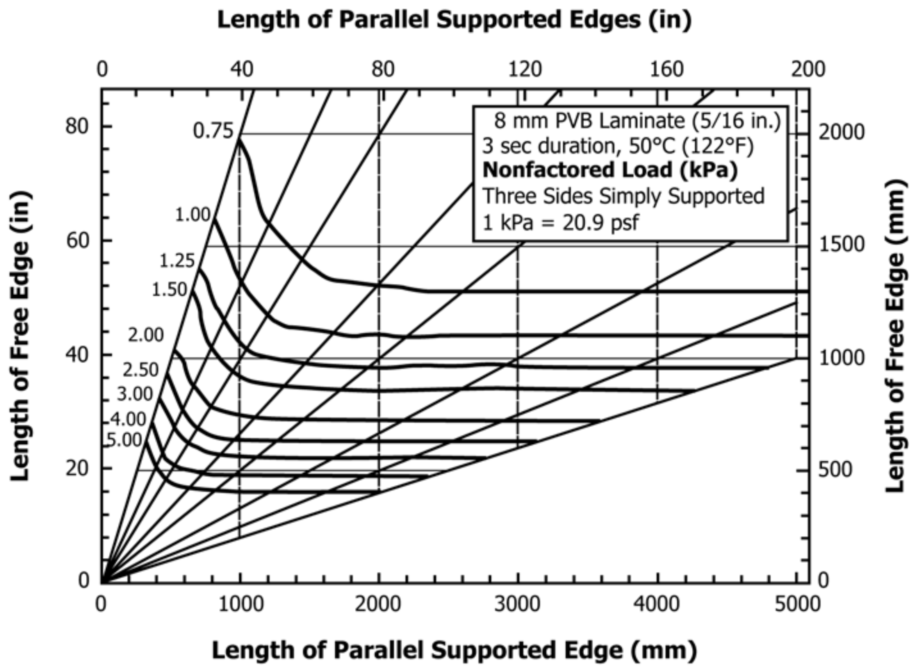


FIG. A1.37 (upper chart) Non-Factored Load Chart for 6.0 mm (¼ in.) Laminated Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 6.0 mm (¼ in.) Laminated Glass with Three Sides Simply Supported



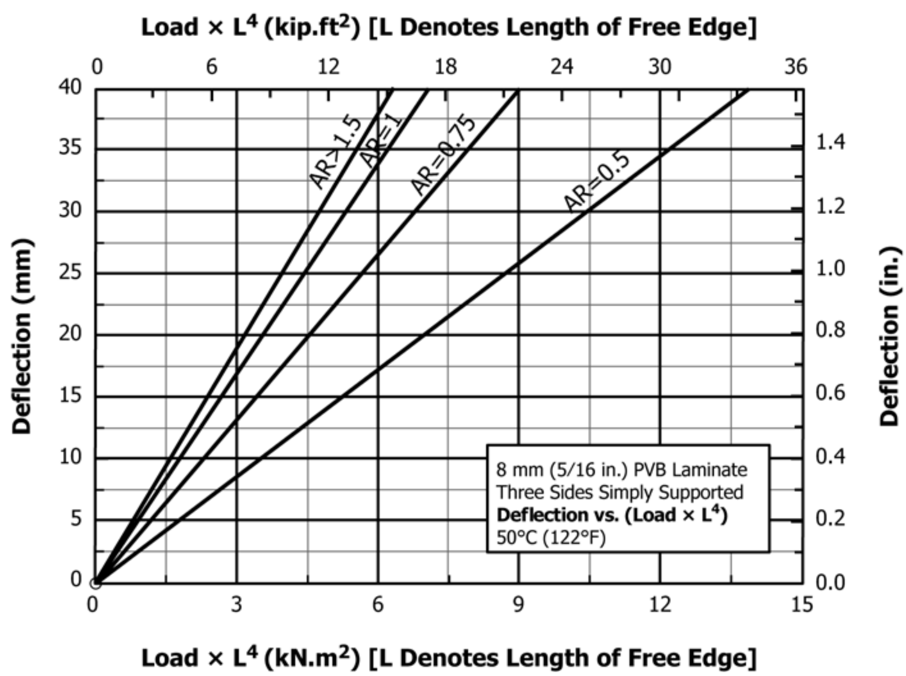


FIG. A1.38 (upper chart) Non-Factored Load Chart for 8.0 mm (5⁄16 in.) Laminated Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 8.0 mm (5⁄16 in.) Laminated Glass with Three Sides Simply Supported

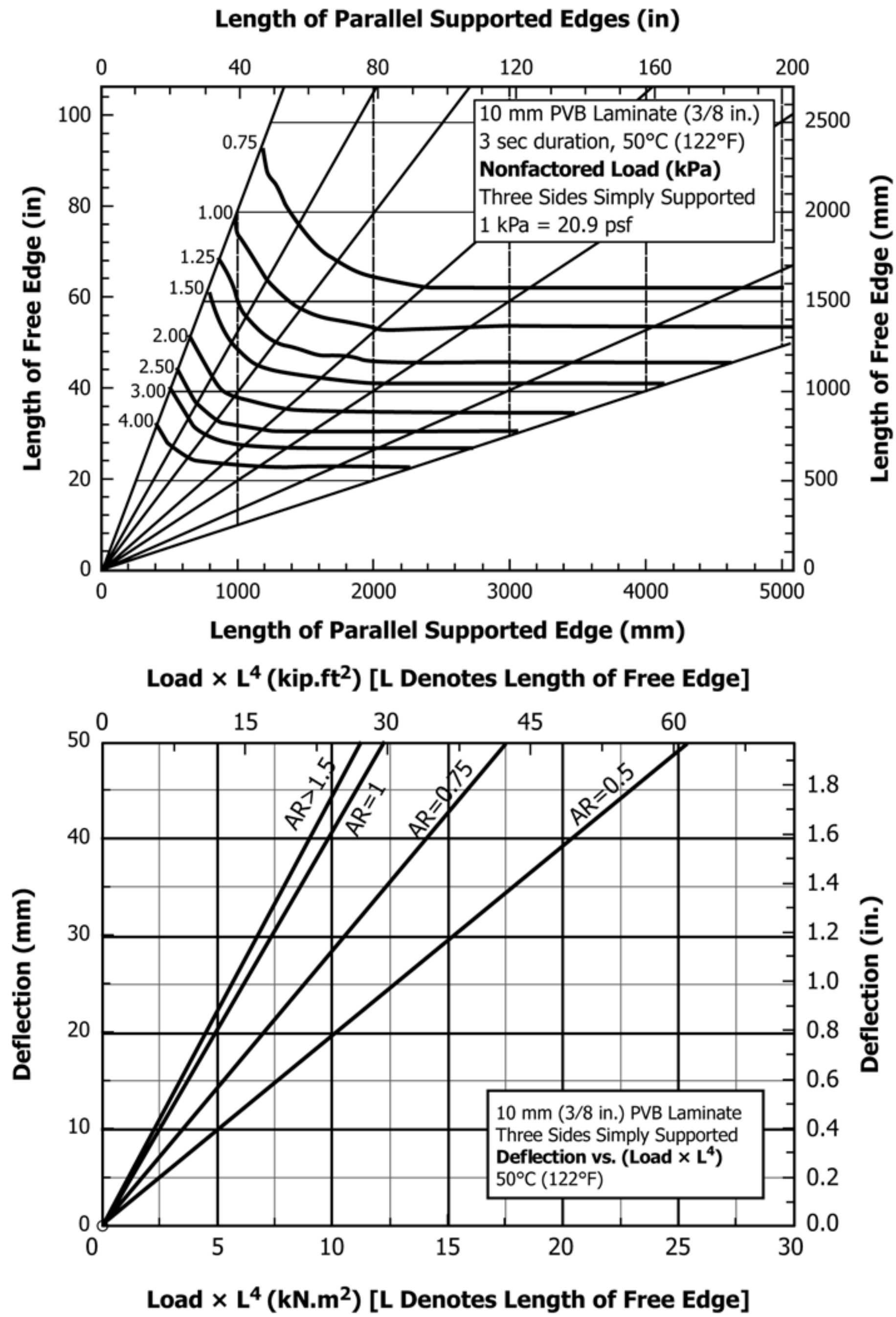
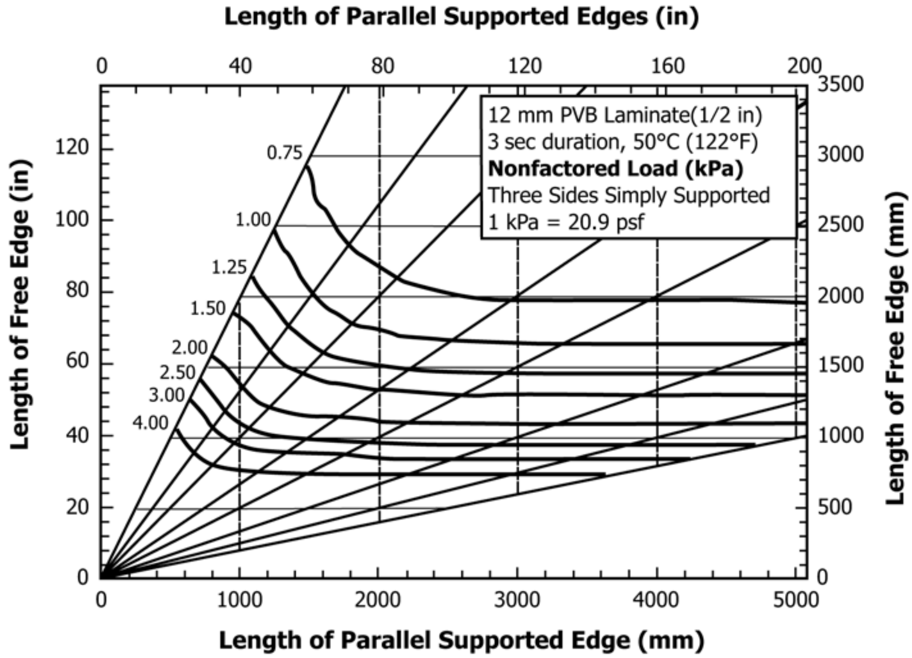


FIG. A1.39 (upper chart) Non-Factored Load Chart for 10.0 mm (3/8 in.) Laminated Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 10.0 mm (3/8 in.) Laminated Glass with Three Sides Simply Supported



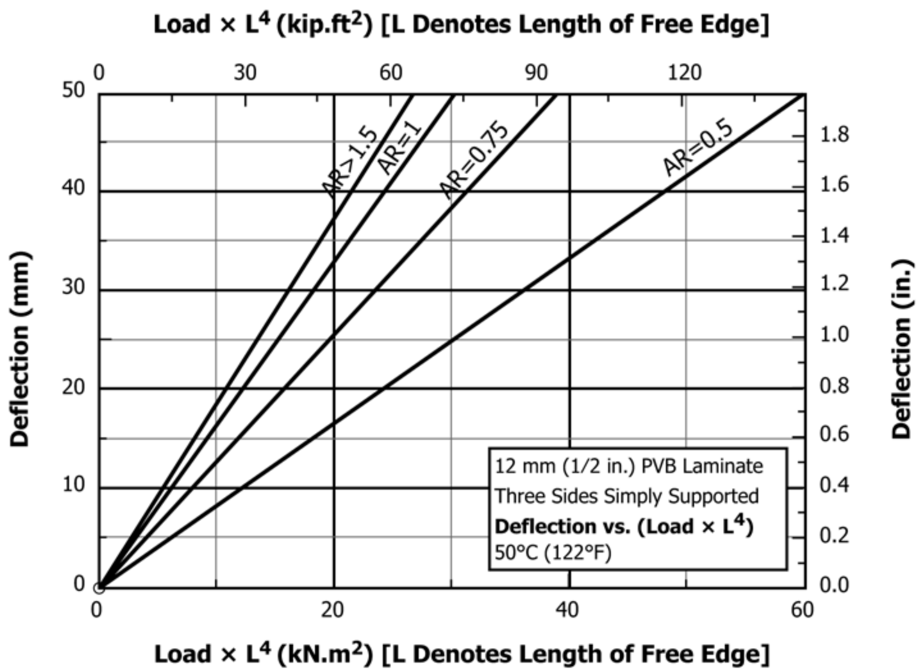
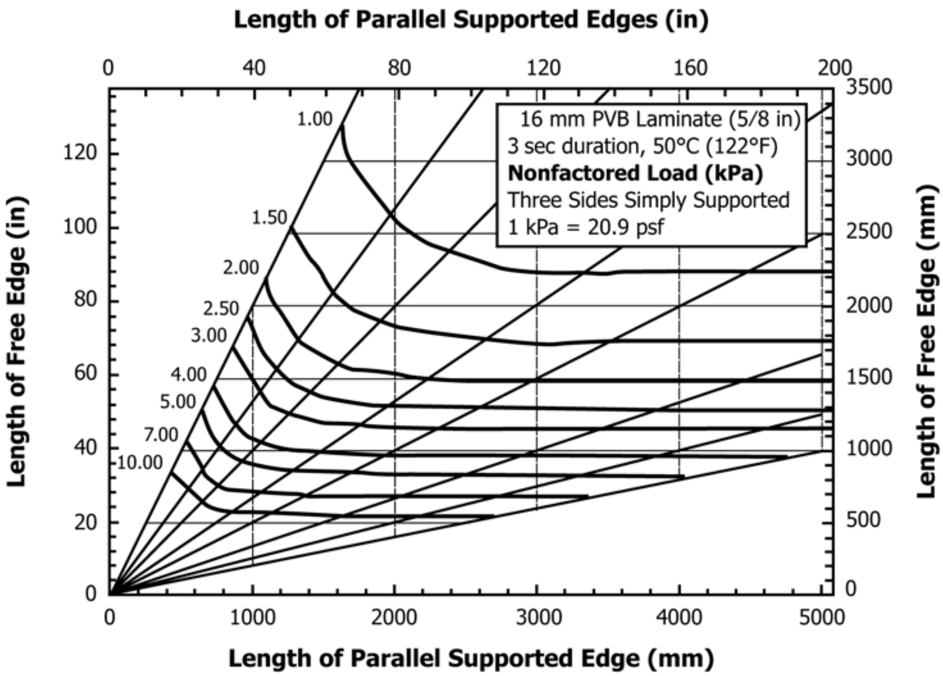


FIG. A1.40 (upper chart) Non-Factored Load Chart for 12.0 mm (½ in.) Laminated Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 12.0 mm (½ in.) Laminated Glass with Three Sides Simply Supported



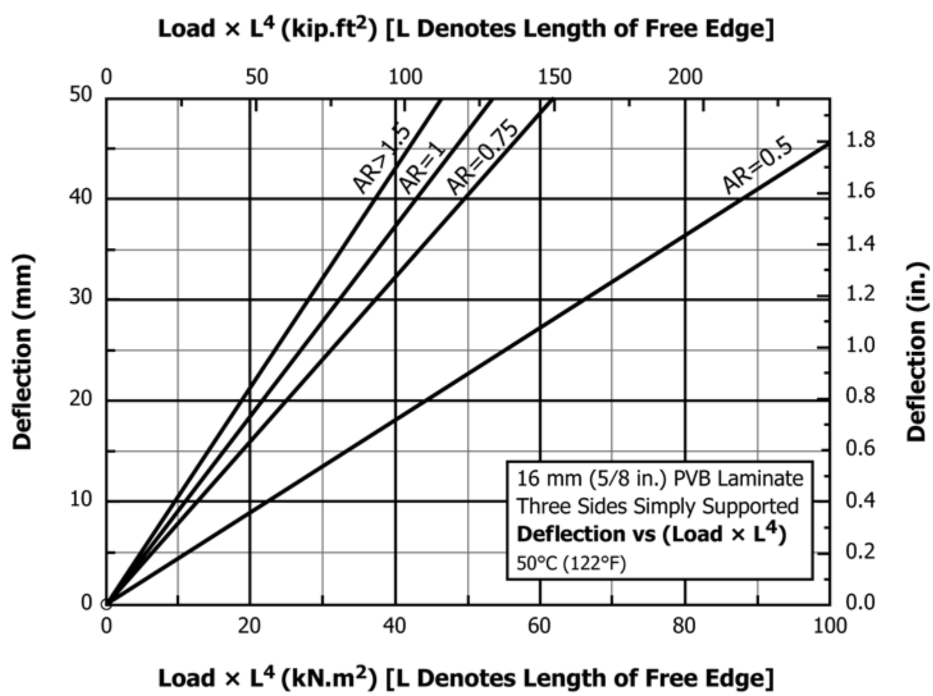
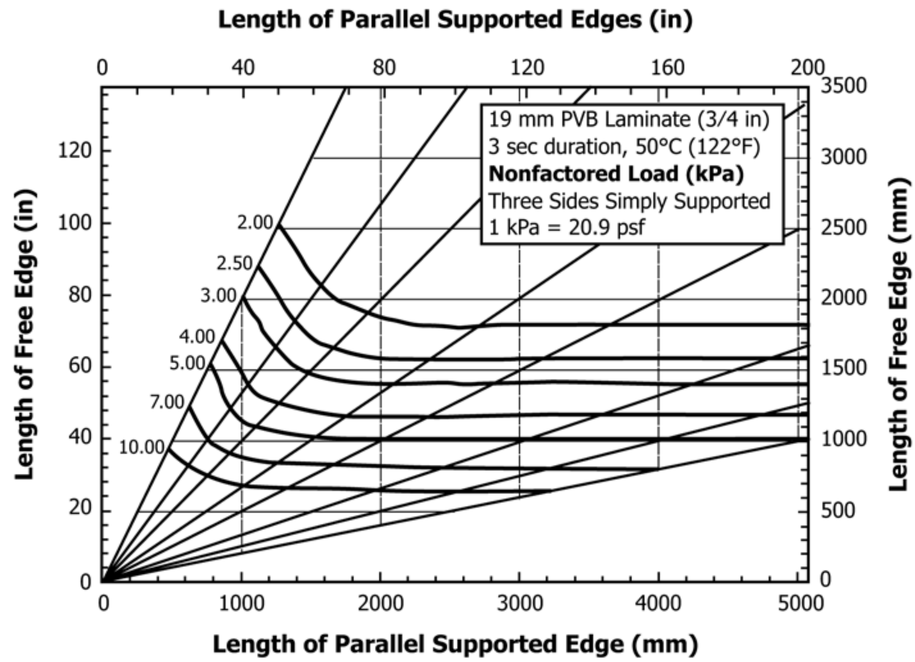


FIG. A1.41 (upper chart) Non-Factored Load Chart for 16.0 mm (⅝ in.) Laminated Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 16.0 mm (⅝ in.) Laminated Glass with Three Sides Simply Supported



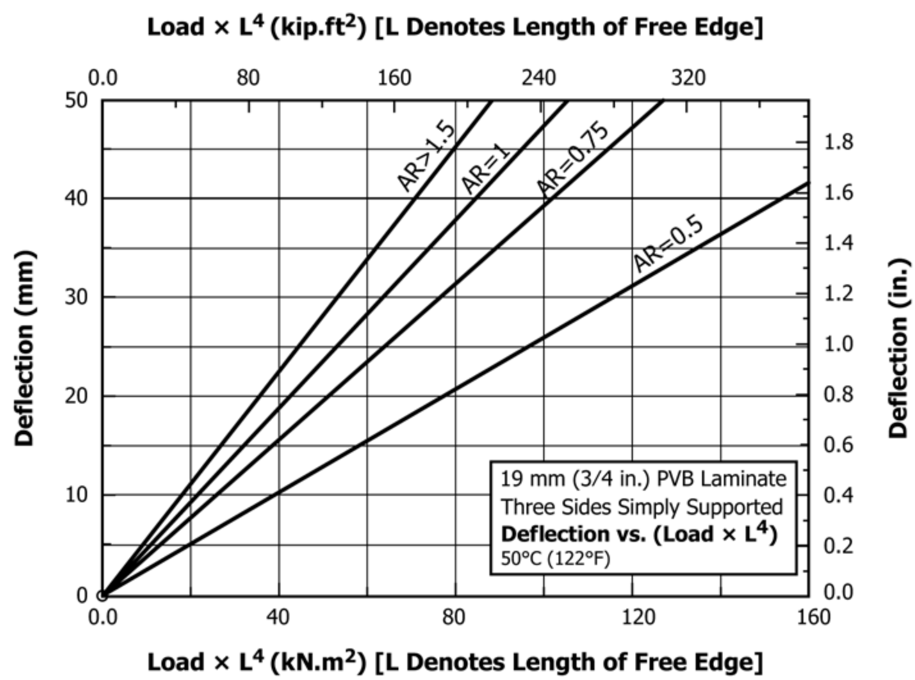
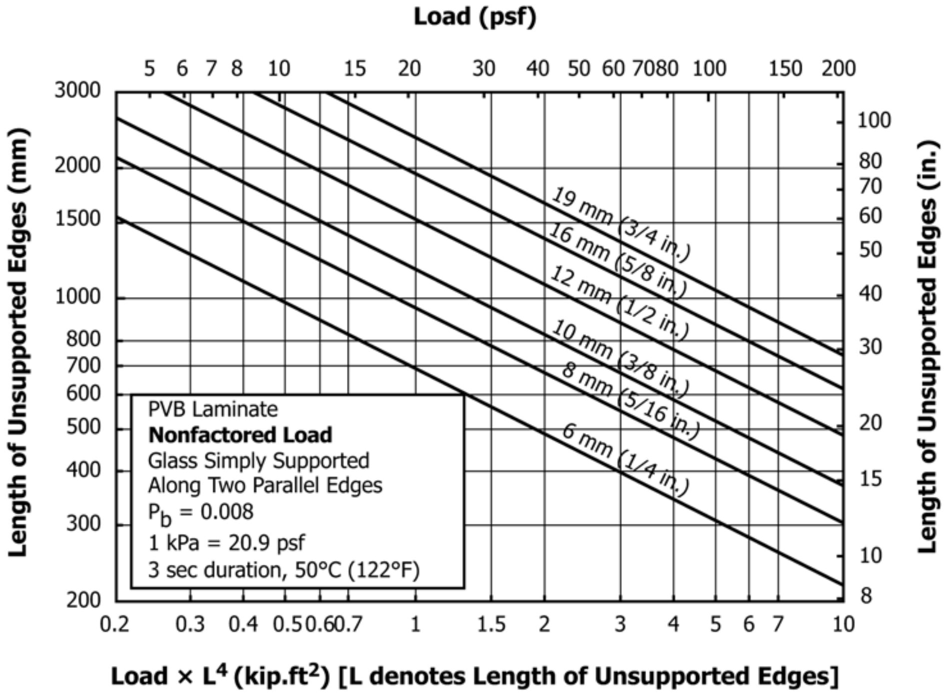


FIG. A1.42 (upper chart) Non-Factored Load Chart for 19.0 mm (¾ in.) Laminated Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 19.0 mm (¾ in.) Laminated Glass with Three Sides Simply Supported



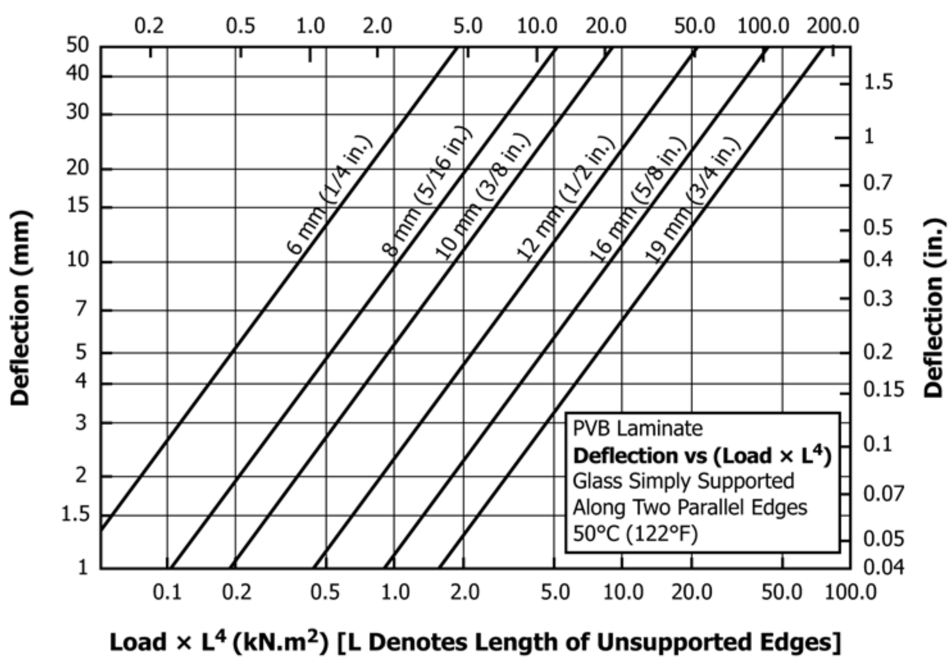
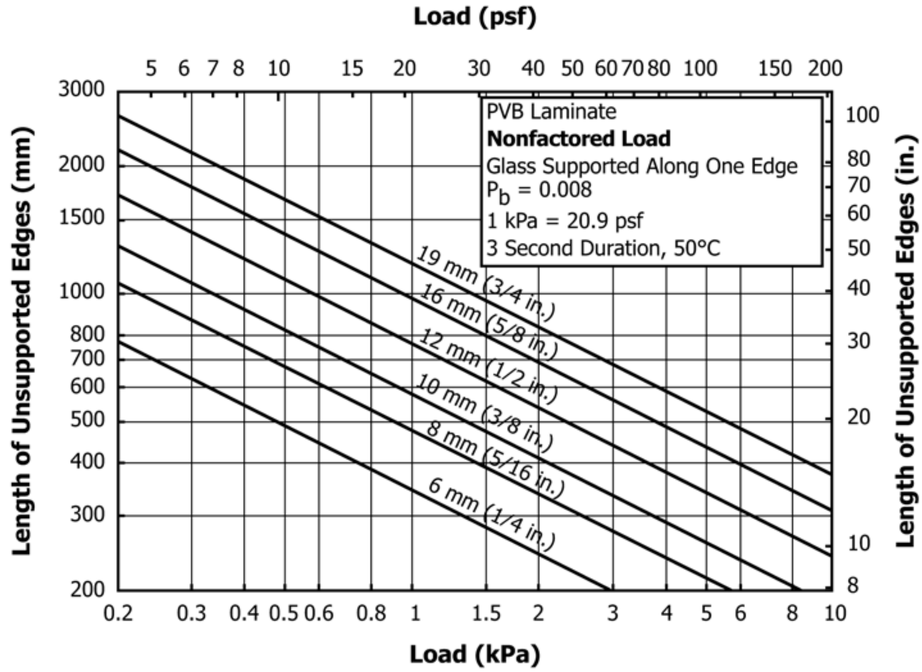


FIG. A1.43 (upper chart) Non-Factored Load Chart for Laminated Glass Simply Supported Along Two Parallel Edges (lower chart) Deflection Chart for Laminated Glass Simply Supported Along Two Parallel Edges



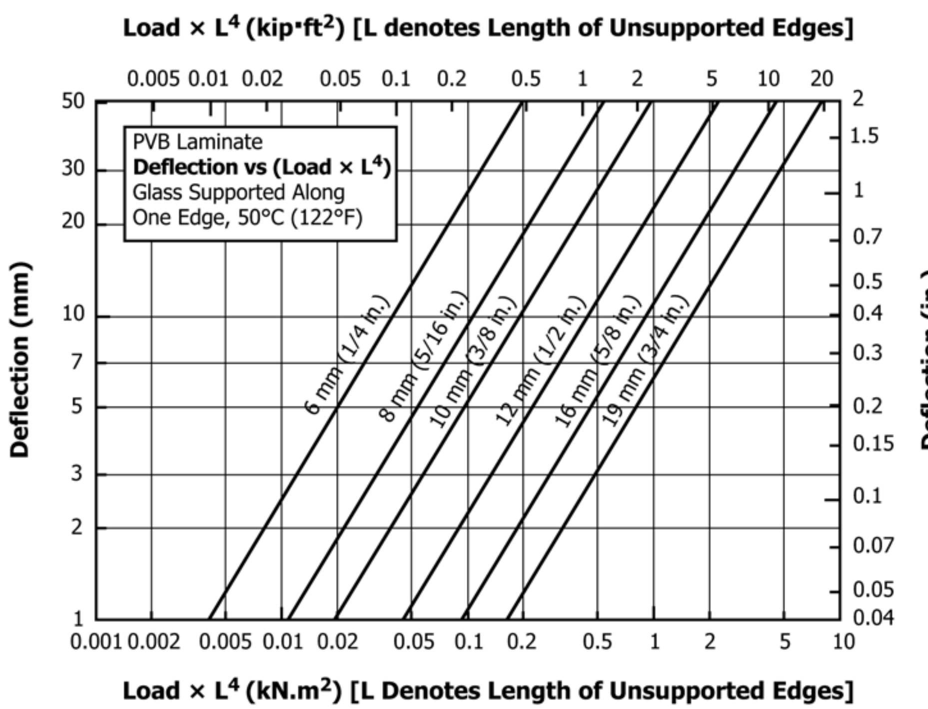


FIG. A1.44 (upper chart) Non-Factored Load Chart for Laminated Glass Supported Along One Edge (lower chart) Deflection Chart for Laminated Glass Supported Along One Edge

A2. PROCEDURE TO DETERMINE PROBABILITY OF BREAKAGE OF MONOLITHIC GLASS

A2.1 The stress analysis method used to determine the in-plane surface tensile stresses must incorporate the non-linear 2-way bending and membrane action of plates. Only the stresses in the plane of the lite surface are used in the probability of breakage calculation. The stress analysis method must be verified to produce acceptable values for surface stresses by ensuring the NFL chart values correspond to specified design load results in a 0.008 probability of breakage for a given geometry when calculated using A2.2.

A2.2 The probability of breakage denoted as P_b, based on a two parameter Weibull distribution, is given by:

$$P_b = 1 - e^{-B} \quad (A2.1)$$

with:

$$B = k \cdot \sum_{i=1}^{N} \left(\left(c_i \cdot \left(\frac{t_d}{60s} \right)^{\frac{1}{n}} \cdot (\sigma_{\max_i} - \text{RCSS}) \right)^{m} \cdot A_i \right) \quad (A2.2)$$

$$c_i = -0.005 \cdot r_i^6 + 0.022 \cdot r_i^5 + 0.055 \cdot r_i^4 + 0.039 \cdot r_i^3 + 0.031 \cdot r_i^2 + 0.06 \cdot r_i + 0.8 \quad (A2.3)$$

$$r_i = \frac{(\sigma_{\min_i} - \text{RCSS})}{(\sigma_{\max_i} - \text{RCSS})} \quad (A2.4)$$

where:

k = $(2.86 \times 10^{-53}$ N^{-7} m$^{12})$ or $(1.365 \times 10^{-29}$ in.^{12} lbf$^{-7})$,
m = 7,
N = number of stress values,
t_d = duration of loading,
n = 16,
σ_{max_i} = i^{th} maximum principal stress,
σ_{min_i} = i^{th} minimum principal stress,
$RCSS$ = residual compressive surface stress; 0 MPa (0 psi) for AN glass, 24.0 MPa (3500 psi) for HS glass, 69.0 MPa (10 000 psi) for FT glass, and
A_i = i^{th} tributary area corresponding to the principal stresses, m^2 (in.^{2}).

A3. EXAMPLES

A3.1 Examples 1, 2, and 3 illustrate use of the NFL charts and the calculation of the LR. Examples 4 and 5 illustrate the determination of the approximate center of glass deflection. Example 6 illustrates the calculation of LR for a triple insulating glass unit.

A3.1.1 *Example 1: Use of Non-Factored Load (NFL) Charts in SI Units*—Determine the NFL associated with a 1200 by 1500 mm, 6 mm thick monolithic AN glass plate.

A3.1.2 The appropriate NFL chart is reproduced in Fig. A3.1.

A3.1.3 Enter the horizontal axis of the NFL chart in Fig. A3.1 at 1500 mm and project a vertical line.

A3.1.4 Enter the vertical axis of the NFL chart in Fig. A3.1 at 1200 mm and project a horizontal line.

A3.1.5 Sketch a line of constant AR through the intersection of the lines described in A3.1.3 and A3.1.4 as shown in Fig. A3.1 and interpolate along this line to determine the NFL. The NFL is thus found to be 2.5 kPa.

A3.2 *Example 2: Use of Non-Factored Load (NFL) Charts in Inch-Pound Units*—Determine the NFL associated with a 50 by 60 by ¼-in. monolithic AN glass plate.

A3.2.1 The appropriate NFL chart is reproduced in Fig. A3.2.

A3.2.2 Enter the horizontal axis of the NFL chart in Fig. A3.2 at 60 in. and project a vertical line.

A3.2.3 Enter the vertical axis of the NFL chart in Fig. A3.2 at 50 in. and project a horizontal line.

A3.2.4 Sketch a line of constant AR through the intersection of the lines described in A3.1.3 and A3.1.4 as shown in Fig. A3.2 and interpolate along this line to determine the NFL. The NFL is thus found to be 2.4 kPa. Convert kPa to inch-pound units by multiplying 2.4 by 20.9 = 50.2 psf.

A3.3 *Example 3: Determination of the Load Resistance (LR) of Asymmetrical Double Glazed Insulating Glass (IG) Unit in SI Units*—A horizontal skylight consists of an IG unit with rectangular dimensions of 1520 by 1900 mm. The outboard lite (Lite No. 1) is 6-mm tempered glass; the inboard lite (Lite No. 2) is 8-mm HS LG; the airspace thickness is 12 mm. Determine if the skylight will support a 6.0 kPa long duration load with a probability of breakage less than or equal to 8 lites 1000.

A3.3.1 The NFL for Lite No. 1 (6-mm monolithic tempered) is 1.80 kPa.

A3.3.2 The short duration GTF for Lite No. 1 is 3.80.

A3.3.3 The short duration LSF for Lite No. 1 is 0.296.

A3.3.4 The LR of the IG based upon the short term LR of Lite No. 1 is:

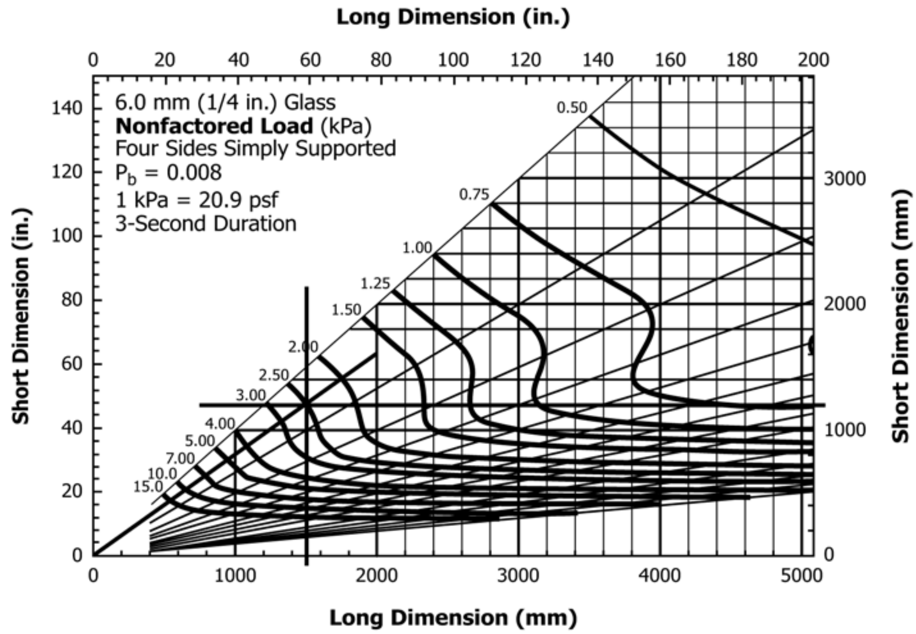


FIG. A3.1 Non-Factored Load Chart for 6.0 mm (¼ in.) Glass

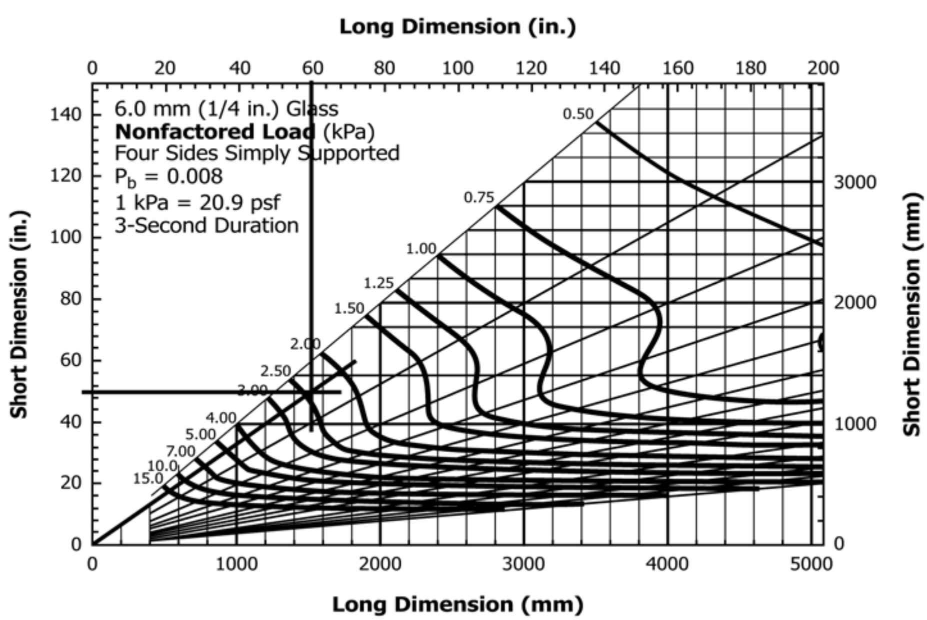


FIG. A3.2 Non-Factored Load Chart for 6.0 mm (¼ in.) Glass

$$LR = NFL \times GTF \div LSF = 1.80\ kPa \times 3.80 \div 0.296 = 23.1\ kPa \quad (A3.1)$$

A3.3.5 The NFL for Lite No. 2 (8-mm HS laminated) is 2.50 kPa.

A3.3.6 The short duration GTF for Lite No. 2 is 1.90.

A3.3.7 The short duration LSF for Lite No. 2 is 0.704.

A3.3.8 The LR of the IG based upon the short term LR of Lite No. 2:

$$LR = NFL \times GTF \div LSF = 2.50\ kPa \times 1.90 \div 0.704 = 6.75\ kPa \quad (A3.2)$$

A3.3.9 The long duration GTF for Lite No. 1 is 2.85.

A3.3.10 The long duration LSF for Lite No. 1 is 0.614.

A3.3.11 The LR of the IG based upon the long term LR of Lite No. 1 is:

$$LR = NFL \times GTF \div LSF = 1.80\ kPa \times 2.85 \div 0.614 = 8.36\ kPa \quad (A3.3)$$

A3.3.12 The long duration GTF for Lite No. 2 is 1.25.

A3.3.13 The long duration LSF for Lite No. 2 is 0.386.

A3.3.14 The LR of the IG based upon the long term LR of Lite No. 2 is:

$$LR = NFL \times GTF \div LSF = 2.50\ kPa \times 1.25 \div 0.386 = 8.10\ kPa \quad (A3.4)$$

A3.3.15 The LR of the IG is 6.75 kPa, the smallest of the values calculated in Eq A3.1-A3.4.

NOTE A3.1—The IG has the smallest LR under short duration loading when the laminated HS lite acts in the monolithic mode.

A3.3.16 The load on the horizontal skylight includes the total glass weight (TGW).

NOTE A3.2—The specific weight (unit weight) of glass, denoted as γ_G, is taken as 2.45×10^{-2} kPa/mm.

NOTE A3.3—The specific weight (unit weight) of PVB, denoted as γ_{pvb} is taken as 1.05×10^{-2} kPa/mm.

$$TGW = \gamma_G \times (t_1 + t_{2ply1} + t_{2ply2}) + \gamma_{pvb} \times (t_{2pvb}) \quad (A3.5)$$

$$TGW = 2.45 \times 10^{-2} \frac{kPa}{mm} \times (5.56 \text{ mm} + 3.78 \text{ mm} + 3.78 \text{ mm})$$
$$+ 1.05 \times 10^{-2} \frac{kPa}{mm} \times (1.52 \text{ mm}) = 0.34 \text{ kPa} \quad (A3.6)$$

A3.3.17 The LR of the IG must be reduced by the glass weight. Therefore the LR of the IG is:

$$LR = 6.75 \text{ kPa} - 0.34 \text{ kPa} = 6.41 \text{ kPa} \quad (A3.7)$$

A3.3.18 *Conclusion*—The IG will support the specified long duration load of 6.0 kPa with a probability of breakage less than 8 lites per 1000.

A3.4 *Example 4: Approximate Center of Glass Deflection Determination in SI Units*—Determine the approximate center of glass deflection associated with a vertical 965 by 1930 by 6-mm rectangular glass plate subjected to a uniform lateral load of 1.8 kPa.

A3.4.1 Calculate the AR of the glass as follows:

$$AR = (1930 \text{ mm})/(965 \text{ mm}) = 2.00 \quad (A3.8)$$

A3.4.2 Calculate the glass area as follows:

$$Area = (0.965 \text{ m}) \times (1.93 \text{ m}) = 1.86 \text{ m}^2 \quad (A3.9)$$

A3.4.3 Compute (Load × Area^2) as follows:

$$(\text{Load} \times \text{Area}^2) = (1.80 \text{ kPa}) \times (1.86 \text{ m}^2)^2 = 6.24 \text{ kN} \times \text{m}^2 \quad (A3.10)$$

A3.4.4 Project a vertical line upward from 6.24 kN × m^2 along the lower horizontal axis in Fig. A3.3 to the AR2 line.

A3.4.5 Project a horizontal line from the intersection point of the vertical line and the AR2 line to the left vertical axis and read the approximate center of glass deflection as 11 mm.

A3.5 *Example 5: Approximate Center of Glass Deflection Determination in Inch-Pound Units*—Determine the approximate center of glass deflection associated with a vertical 60 by 180 by ⅜ in. rectangular glass plate subjected to a uniform lateral load of 20 psf.

A3.5.1 Calculate the AR of the glass as follows:

$$AR = (180 \text{ in.})/(60 \text{ in.}) = 3.00 \quad (A3.11)$$

A3.5.2 Calculate the glass area as follows:

$$Area = (15 \text{ ft}) \times (5 \text{ ft}) = 75 \text{ ft}^2 \quad (A3.12)$$

A3.5.3 Compute (Load × Area^2) as follows:

$$(\text{Load} \times \text{Area}^2) = (0.020 \text{ kip/ ft}^2) \times (75 \text{ ft}^2)^2 = 112 \text{ kip} \times \text{ft}^2 \quad (A3.13)$$

A3.5.4 Project a vertical line downward from 112 kip × ft^2 along the upper horizontal axis in Fig. A3.4 to the AR3 line.

A3.5.5 Project a horizontal line from the intersection point of the vertical line and the AR3 line to the right vertical axis and read the approximate center of glass deflection as 0.52 in.

A3.6 *Example 6: Determination of the Load Resistance (LR) of an Asymmetrical Triple Glazed Insulating Glass (IG) Unit in SI Units*—A vertical window with glass size 1000 by 1500 mm of AN 3-mm lite, a sealed air space, a 2.5-mm AN

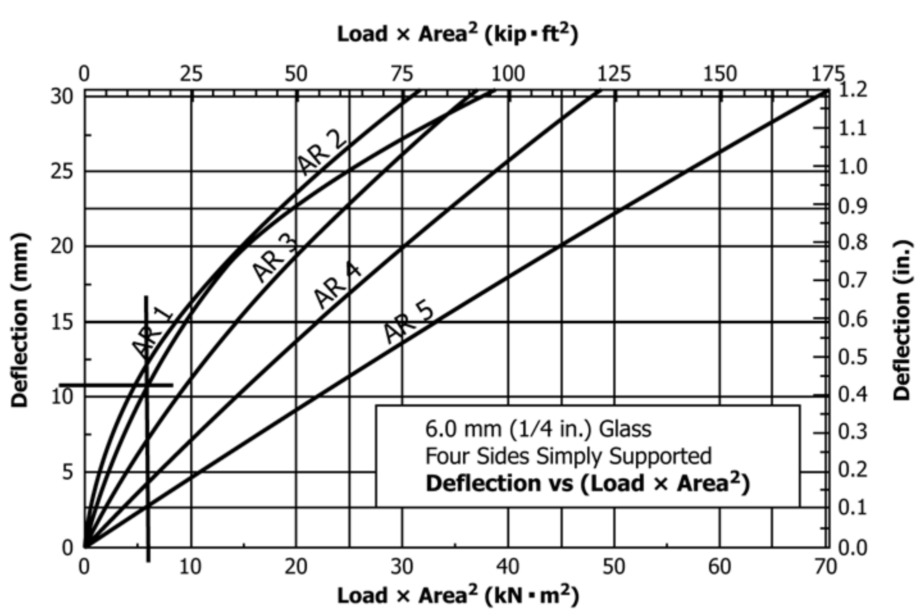


FIG. A3.3 Deflection Chart

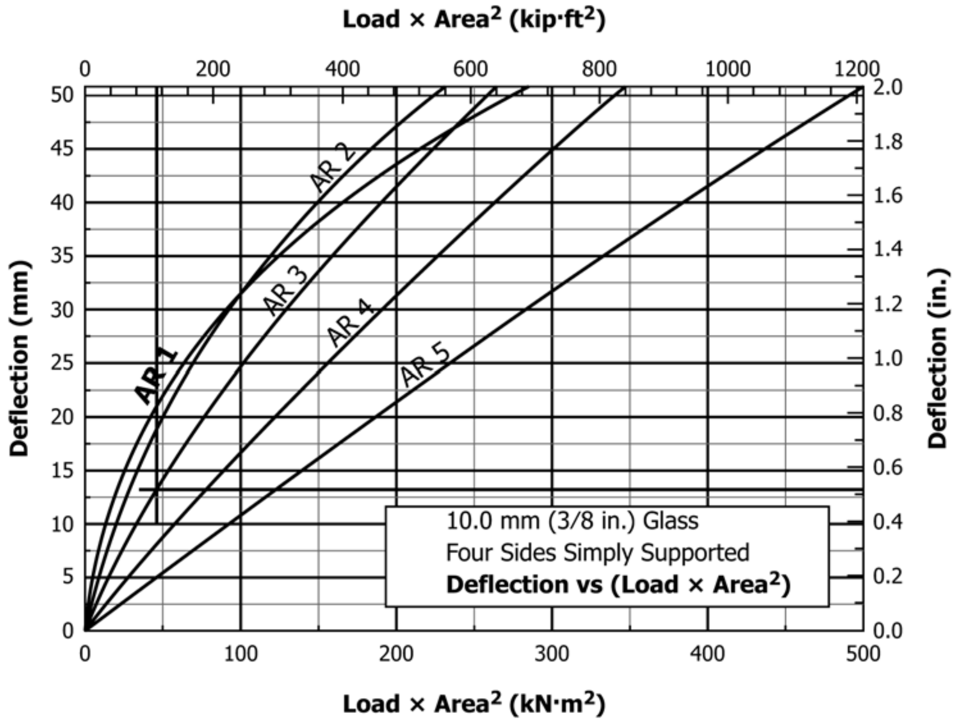


FIG. A3.4 Deflection Chart

lite, another sealed air space, and a 3-mm AN inner lite will be subjected to wind load. Will this window glass support a 1.5 kPa short duration load for an 8 in 1000 breakage probability?

A3.6.1 For lites No. 1 and No. 3 the NFL (NFL1 and NFL3) from the 3-mm chart is 1.34 kPa.

A3.6.2 For Lite No. 2 the NFL (NFL2) from the 2.5-mm chart is 0.88 kPa.

A3.6.3 For short duration load the GTF for each of the three AN lites is 0.81.

A3.6.4 The LSF (LSF1, LSF2, LSF3) for each lite are as follows:

$$LSF1 = (t_1^3)/(t_1^3 + t_2^3 + t_3^3) = (2.92^3)/(2.92^3 + 2.16^3 + 2.92^3) = 0.416 \quad (A3.14)$$

$$LSF2 = (t_2^3)/(t_1^3 + t_2^3 + t_3^3) = (2.16^3)/(2.92^3 + 2.16^3 + 2.92^3) = 0.168 \quad (A3.15)$$

$$LSF3 = (t_3^3)/(t_1^3 + t_2^3 + t_3^3) = (2.92^3)/(2.92^3 + 2.16^3 + 2.92^3) = 0.416 \quad (A3.16)$$

A3.6.5 The LR (LR1, LR2, LR3) of each lite are as follows:

$$LR1 = NFL1 \times GTF1 \div LSF1 = 1.34 \text{ kPa} \times 0.81 \div 0.416 = 2.61 \text{ kPa} \quad (A3.17)$$

$$LR2 = NFL2 \times GTF2 \div LSF2 = 0.88 \text{ kPa} \times 0.81 \div 0.168 = 4.24 \text{ kPa} \quad (A3.18)$$

$$LR3 = NFL3 \times GTF3 \div LSF3 = 1.34 \text{ kPa} \times 0.81 \div 0.416 = 2.61 \text{ kPa} \quad (A3.19)$$

A3.6.6 The LR of the entire triple glazed IG is the lesser of LR1, LR2, LR3. This leaves a short term duration LR for the IG unit of: 2.61 kPa.

A3.6.7 *Conclusion*—This design will support the specified short term duration load of 1.5 kPa for a breakage probability of less than 8 in 1000.

A3.7 *Example 7: Determination of the Probability of Breakage of a Double Glazed Insulating Glass (IG) Unit in US Units*—A vertical window consists of an IG unit with rectangular dimensions of 50 by 30 in. The outboard lite (Lite No. 1) is LG comprised of two 3⁄32 in. plies with a 0.030 in. PVB interlayer; the inboard lite (Lite No. 2) is 1⁄8 in. AN glass, and the airspace thickness is 3⁄8 in. Determine if the probability of breakage of window is less than 8 lites 1000 for a 3-s 70 psf load applied to Lite No. 1.

A3.7.1 For Lite No. 1, the effective thicknesses are as follows:

t_{1Def} = 0.149 in.
$t_{1Str,p1}$ = 0.165 in.
$t_{1Str,p2}$ = 0.165 in.

A3.7.2 For Lite No. 21, the thickness is 0.115 in.

A3.7.3 The load carried by Lite No. 1 and Lite No. 2 using the iterative method advance by Vallabhan and Chou (1) are as follows:

DL1 = 46.1 psf
DL2 = 23.9 psf

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:

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

where:

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

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

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

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

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

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,

$$p = 1.00 \tag{X2.1}$$

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:

$$p = 0.95 \tag{X2.2}$$

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:

$$p = 1.05 \tag{X2.3}$$

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:

$$p = 1.0 \tag{X2.4}$$

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:

$$asp = 0.95 \tag{X2.5}$$

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:

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

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:

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

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:

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

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:

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

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.

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

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:

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

with:

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

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

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

$$h_s = 0.5\left(h_1 + h_2\right) + h_v \quad \text{(X9.5)}$$

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:

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

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

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

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

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 ($\Gamma \rightarrow 1$) and approaches the layered limit for compliant interlayers ($\Gamma \rightarrow 0$).

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 30ºC (86ºF). 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:

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

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

gives:

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

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