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

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

1. Scope

1.1 This practice 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 10 kPa (210 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, laminated, or insulating 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.

1.4 This practice does not apply to any form of wired, patterned, etched, sandblasted, drilled, notched, or grooved glass with surface and edge treatments that alter 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 and Appendix X2 provide additional procedures to determine maximum lateral deflection for glass simply supported on four sides. Appendix X3 presents a procedure to compute approximate probability of breakage for annealed (AN) monolithic glass lites 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 information only. For conversion of quantities in various systems of measurements to SI units, refer to IEEE/ASTM SI-10.

1.8 Appendix X4 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-Treated Flat Glass—Kind HS, Kind FT Coated and Uncoated 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

IEEE/ASTM SI-10 Practice for Use of the International System of Units (SI) (the Modernized Metric System)

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 *aspect ratio (AR), n*—for glass simply supported on four sides, the ratio of the long dimension of the glass to the short dimension of the glass is always equal to or greater than 1.0. For glass simply supported on three sides, the ratio of the length of one of the supported edges perpendicular to the free edge, to the length of the free edge, is equal to or greater than 0.5.

3.2.2 *etched glass, n*—glass surface that has been attacked with hydrofluoric acid or other agent, generally for marking or decoration.

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

[1] This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.51 on Performance of Windows, Doors, Skylights and Curtain Walls.

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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)

	GTF	
Glass Type	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	1.25	1.25	1.25	2.85
FT	2.85	0.43	2.85	1.25	2.85	2.85

3.2.4 *Glass Thickness*:

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

3.2.4.2 *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 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 monolithic thickness designation in Table 4 having the closest minimum thickness that is equal to or less than the value obtained in 3.2.4.2 (*1*).

TABLE 4 Minimum Glass Thicknesses

Nominal Thickness or Designation, mm (in.)	Minimum Thickness, mm (in.)
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)

(3) Exception: The construction of two 6-mm (1⁄4-n.) glass plies plus 0.76-m (0.030-n.) interlayer shall be defined as 12 mm (1⁄2 in.).

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 glass lites that enclose a sealed space 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 X10.

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 *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.

3.2.8.2 *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 X6.1.

3.2.8.4 *non-factored load (NFL), n*—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 *glass weight load, n*—the dead load component of the glass weight.

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

3.2.9 *load share (LS) factor, n*—a multiplying factor derived from the load sharing between the double glazing, of equal or different thicknesses and types (including the layered behavior of LG under long duration loads), in a sealed IG unit.

3.2.9.1 *Discussion*—The LS factor 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 and Appendix X2 present two additional procedures to determine the approximate maximum lateral deflection for a specified load on glass simply supported on four sides.

4.4 An optional procedure for determining the probability of breakage at a given load is presented in Appendix X3.

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 center of glass deflection will not result in loss of edge support.

NOTE 1—This practice does not address aesthetic issues caused by glass deflection.

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, seismic effects, heat flow, edge bite, noise abatement, potential post-breakage consequences, and so forth. 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 a glass type, thickness, and construction for load-resistance evaluation.

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

6.2.1 Determine the NFL from the appropriate chart in Annex A1 (the upper charts of Figs A1.1–A1.12) for the glass thickness and size.

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

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

6.2.4 Determine the approximate maximum lateral (center of glass) deflection from the appropriate chart in Annex A1 (the lower charts of Figs. A1.1–A1.12) 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 and Appendix X2.

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

6.3.1 Determine the NFL from the appropriate chart in Annex A1 (the upper charts of Figs. A1.13–A1.24) for the designated glass thickness and size.

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

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

6.3.4 Determine the approximate maximum lateral (center of unsupported edge) deflection from the appropriate chart in Annex A1 (the lower charts in Figs A1.13–A1.24) for the designated glass thickness, size, and design load.

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

6.4.1 Determine the NFL from the upper chart of Fig. A1.25 for the designated glass thickness and length of unsupported edges.

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

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

6.4.4 Determine the approximate maximum lateral (center of an unsupported edge) deflection from the lower chart of Fig. A1.25 for the designated glass thickness, length of unsupported edge, and design load.

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

6.5.1 Determine the NFL from the upper chart of Fig. A1.26 for the designated glass thickness and length of unsupported edges that are perpendicular to the supported edge.

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

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

6.5.4 Determine the approximate maximum lateral (free edge opposite the supported edge) deflection from the lower chart of Fig. A1.26 for the designated glass thickness, length of unsupported edges, and design load.

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

6.6.1 Determine the NFL from the appropriate chart (the upper charts of Figs A1.27–A1.33) for the designated glass thickness.

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

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

6.6.4 Determine the approximate maximum lateral (center of glass) deflection from the appropriate chart (the lower charts of Figs. A1.27–A1.33) 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 and Appendix X2.

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

6.7.1 Determine the NFL from the appropriate chart (the upper charts of Figs. A1.34–A1.40) for the designated glass thickness and size equal to the LG thickness.

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

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

6.7.4 Determine the approximate maximum lateral (center of unsupported edge) deflection from the appropriate chart (the lower charts of Figs. A1.34–A1.40) for the designated glass thickness, size, and design load.

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

6.8.1 Determine the NFL from the upper chart of Fig. A1.41 for the designated glass thickness and length of unsupported edges.

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

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

6.8.4 Determine the approximate maximum lateral (center of an unsupported edge) deflection from the lower chart of Fig. A1.41 for the designated glass thickness, length of unsupported edge, and design load.

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

6.9.1 Determine the NFL from the upper chart of Fig. A1.42 for the designated glass thickness and length of unsupported edges that are perpendicular to the supported edge.

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

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

6.9.4 Determine the approximate maximum lateral (free edge opposite the supported edge) deflection from the lower chart of Fig. A1.42 for the designated glass thickness, length of unsupported edges, and design load.

6.10 *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*:

6.10.1 Determine the NFL1 for Lite No. 1 and NFL2 for Lite No. 2 from the the upper charts of Figs. A1.1–A1.12 (see Annex A2 for examples).

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

6.10.2 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.

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

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

$$LR1 = NFL1 \times GTF1 \times LS1 \text{ and } LR2 = NFL2 \times GTF2 \times LS2$$

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

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

6.11.1 Determine the NFL for each lite from the upper charts of Figs. A1.1–A1.12 and A1.27–A1.33.

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

6.11.3 Determine LS1 for Lite No. 1 and LS2 for Lite No. 2, from Table 5.

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

$$LR1 = NFL1 \times GTF1 \times LS1 \text{ and } LR2 = NFL2 \times GTF2 \times LS2$$

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

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

6.12.1 Determine the NFL1 for Lite No. 1 and NFL2 for Lite No. 2 from the upper charts of Figs. A1.27–A1.33 (see Annex A2 for examples).

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

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

TABLE 5 Load Share (LS) Factors 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.

Lite No. 1		Lite No. 2																					
Monolithic Glass		Monolithic Glass, Short or Long Duration Load or Laminated Glass, Short Duration Load Only																					
Nominal Thickness		2.5 (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)	
mm	(in.)	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2
2.5	(3/32)	2.00	2.00	2.73	1.58	3.48	1.40	6.39	1.19	10.5	1.11	18.1	1.06	41.5	1.02	73.8	1.01	169.	1.01	344.	1.00	606.	1.00
2.7	(lami)	1.58	2.73	2.00	2.00	2.43	1.70	4.12	1.32	6.50	1.18	10.9	1.10	24.5	1.04	43.2	1.02	98.2	1.01	199.	1.01	351.	1.00
3	(1/8)	1.40	3.48	1.70	2.43	2.00	2.00	3.18	1.46	4.83	1.26	7.91	1.14	17.4	1.06	30.4	1.03	68.8	1.01	140.	1.01	245.	1.00
4	(5/32)	1.19	6.39	1.32	4.12	1.46	3.18	2.00	2.00	2.76	1.57	4.18	1.31	8.53	1.13	14.5	1.07	32.2	1.03	64.7	1.02	113.	1.01
5	(3/16)	1.11	10.5	1.18	6.50	1.26	4.83	1.57	2.76	2.00	2.00	2.80	1.56	5.27	1.23	8.67	1.13	18.7	1.06	37.1	1.03	64.7	1.02
6	(1/4)	1.06	18.1	1.10	10.9	1.14	7.91	1.31	4.18	1.56	2.80	2.00	2.00	3.37	1.42	5.26	1.23	10.8	1.10	21.1	1.05	36.4	1.03
8	(5/16)	1.02	41.5	1.04	24.5	1.06	17.4	1.13	8.53	1.23	5.27	1.42	3.37	2.00	2.00	2.80	1.56	5.14	1.24	9.46	1.12	15.9	1.07
10	(3/8)	1.01	73.8	1.02	43.2	1.03	30.4	1.07	14.5	1.13	8.67	1.23	5.26	1.56	2.80	2.00	2.00	3.31	1.43	5.71	1.21	9.31	1.12
12	(1/2)	1.01	169.	1.01	98.2	1.01	68.8	1.03	32.2	1.06	18.7	1.10	10.8	1.24	5.14	1.43	3.31	2.00	2.00	3.04	1.49	4.60	1.28
16	(5/8)	1.00	344.	1.01	199.	1.01	140.	1.02	64.7	1.03	37.1	1.05	21.1	1.12	9.46	1.21	5.71	1.49	3.04	2.00	2.00	2.76	1.57
19	(3/4)	1.00	606.	1.00	351.	1.00	245.	1.01	113.	1.02	64.7	1.03	36.4	1.07	15.9	1.12	9.31	1.28	4.60	1.57	2.76	2.00	2.00

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

$$LR1 = NFL1 \times GTF1 \times LS1 \text{ and } LR2 = NFL2 \times GTF2 \times LS2$$

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

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

6.13.1 The LR of each lite must first be calculated for that load acting for a short duration as in 6.11, and then for the same load acting for a long duration as given in 6.13.2-6.13.5.

NOTE 3—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.

6.13.2 Determine the values for the NFL1 for Lite No. 1 and NFL2 for Lite No. 2 from the upper charts of Figs. A1.1–A1.12 and A1.27–A1.33 (see Annex A2 for examples).

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

6.13.4 Determine LS1 for Lite No. 1 and LS2 for Lite No. 2 from Table 6 for the relevant lite thickness.

6.13.5 Multiply NFL by GTF and by LS 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:

$$LR1 = NFL1 \times GTF1 \times LS1 \text{ and } LR2 = NFL2 \times GTF2 \times LS2$$

6.13.6 The LR of the IG unit is the lowest of the four calculated LR values LR1 and LR2 for short duration loads from 6.11.4 and LR1 and LR2 for long duration loads from 6.13.5.

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

6.14.1 The LR of each lite must first be calculated for that load acting for a short duration as in 6.12, and then for the same load acting for a long duration as given in 6.14.2-6.14.5.

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

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

Lite No. 1		Lite No. 2													
Monolithic Glass		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.)	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2	LS1	LS2
2.5	(3/32)	3.00	1.50	4.45	1.29	11.8	1.09	20.0	1.05	35.2	1.03	82.1	1.01	147	1.01
2.7	(lami)	2.16	1.86	3.00	1.50	7.24	1.16	12.0	1.09	20.8	1.05	48.0	1.02	85.5	1.01
3	(1/8)	1.81	2.24	2.39	1.72	5.35	1.23	8.68	1.13	14.8	1.07	33.8	1.03	60.0	1.02
4	(5/32)	1.37	3.69	1.64	2.56	3.00	1.50	4.53	1.28	7.34	1.16	16.1	1.07	28.1	1.04
5	(3/16)	1.21	5.75	1.36	3.75	2.13	1.88	3.00	1.50	4.60	1.28	9.54	1.12	16.4	1.07
6	(1/4)	1.12	9.55	1.20	5.96	1.63	2.59	2.11	1.90	3.00	1.50	5.74	1.21	9.54	1.12
8	(5/16)	1.05	21.3	1.09	12.8	1.27	4.76	1.47	3.13	1.84	2.19	3.00	1.50	4.60	1.28
10	(3/8)	1.03	37.4	1.05	22.1	1.15	7.76	1.26	4.83	1.47	3.13	2.11	1.90	3.00	1.50
12	(1/2)	1.01	85.0	1.02	49.7	1.06	16.6	1.11	9.84	1.20	5.92	1.48	3.07	1.87	2.15
16	(5/8)	1.01	172	1.01	100	1.03	32.8	1.06	19.0	1.10	11.0	1.24	5.23	1.43	3.35
19	(3/4)	1.00	304	1.01	176	1.02	57.2	1.03	32.8	1.06	18.7	1.13	8.46	1.24	5.15
22	(7/8)	1.00	440	1.00	256	1.01	82.5	1.02	47.2	1.04	26.7	1.09	11.8	1.17	7.02

6.14.2 Determine NFL1 for Lite No. 1 and NFL2 for Lite No. 2 from the upper charts of Figs A1.1–A1.12 and A1.27–A1.33 (see Annex A2 for examples).

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

6.14.4 Determine LS1 for Lite No. 1 and LS2 for Lite No. 2 from Table 5.

6.14.5 Multiply NFL by GTF and by LS 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:

$$\mathrm{LR1} = \mathrm{NFL1} \times \mathrm{GTF1} \times \mathrm{LS1} \text{ and } \mathrm{LR2} = \mathrm{NFL2} \times \mathrm{GTF2} \times \mathrm{LS2}$$

6.14.6 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 6.14.5.

6.15 *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 4—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.

6.15.1 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-A1.12 (see Annex A2 for examples).

NOTE 5—Lites No. 1 or No. 3 can represent either the outward or inward facing lite of the IG unit.

6.15.2 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.

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

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

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

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

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

	GTF	
Glass Type	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

Where:

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

6.15.4 Multiply NFL by GTF and by 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:

$$LR1 = NFL1 \times GTF1 \times LS1$$

$$LR2 = NFL2 \times GTF2 \times LS2$$

$$LR3 = NFL3 \times GTF3 \times LS3$$

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

6.16 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.

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 LS factors (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–A1.42) 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 **(1, 2)**.[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. A1.42 for both SI and inch-pound units. The NFL charts were developed using a failure prediction model for glass (**3, 4**). 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. A1.42 it was assumed that *m* is equal to 7 and *k* is equal to 2.86 $\times 10^{-53}$ N^{-7} m^{12}(1.365×10^{-29} $in.^{12}$ lb^{-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. A1.42 indicate the maximum lateral deflection of the glass.

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

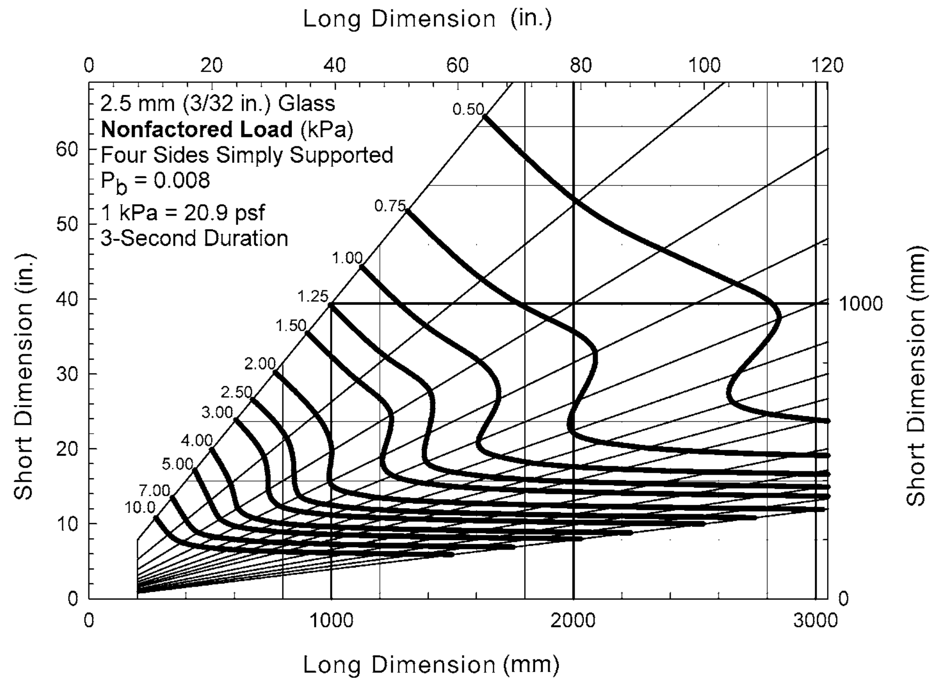
A1.5.1 Select the appropriate chart to be used based upon the nominal glass thickness.

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.

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.



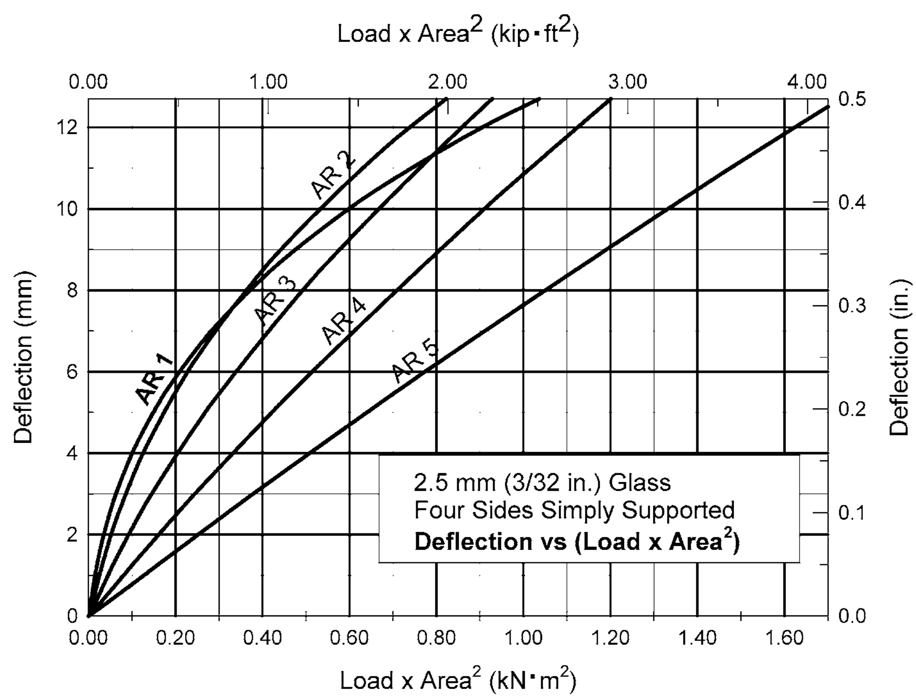
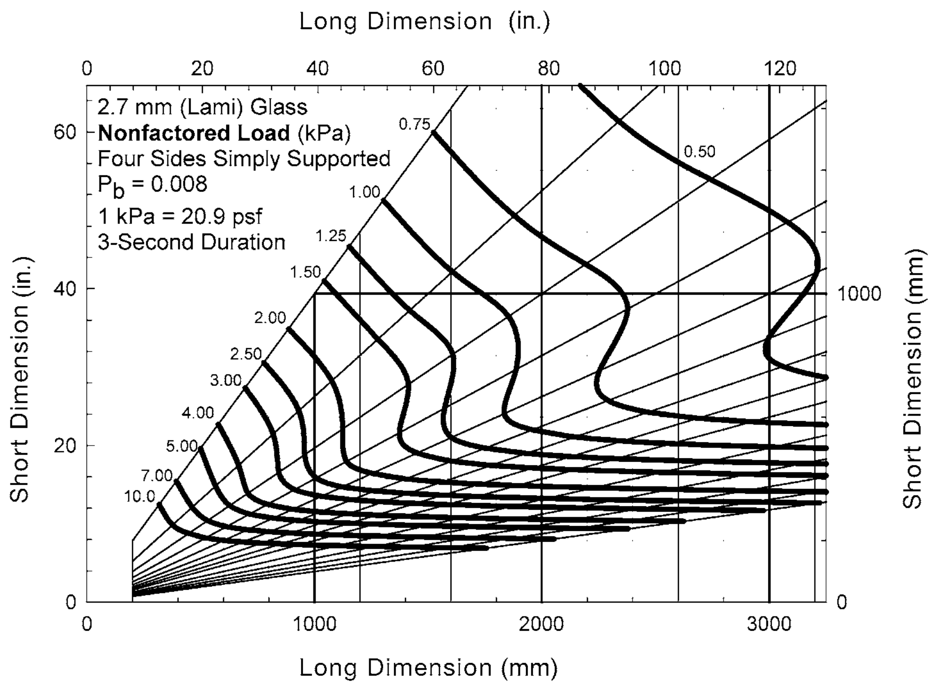


FIG. A1.1 (upper chart) Non-Factored Load Chart for 2.5 mm (3⁄32 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 2.5 mm (3⁄32 in.) Glass with Four Sides Simply Supported



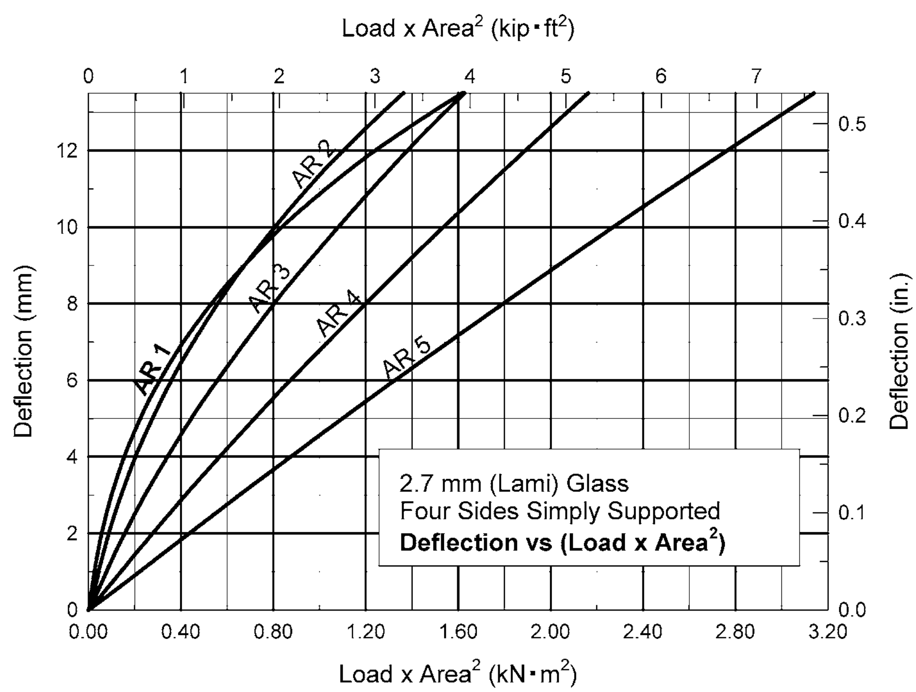


FIG. A1.2 (upper chart) Non-Factored Load Chart for 2.7 mm (Lami) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 2.7 mm (Lami) Glass with Four Sides Simply Supported

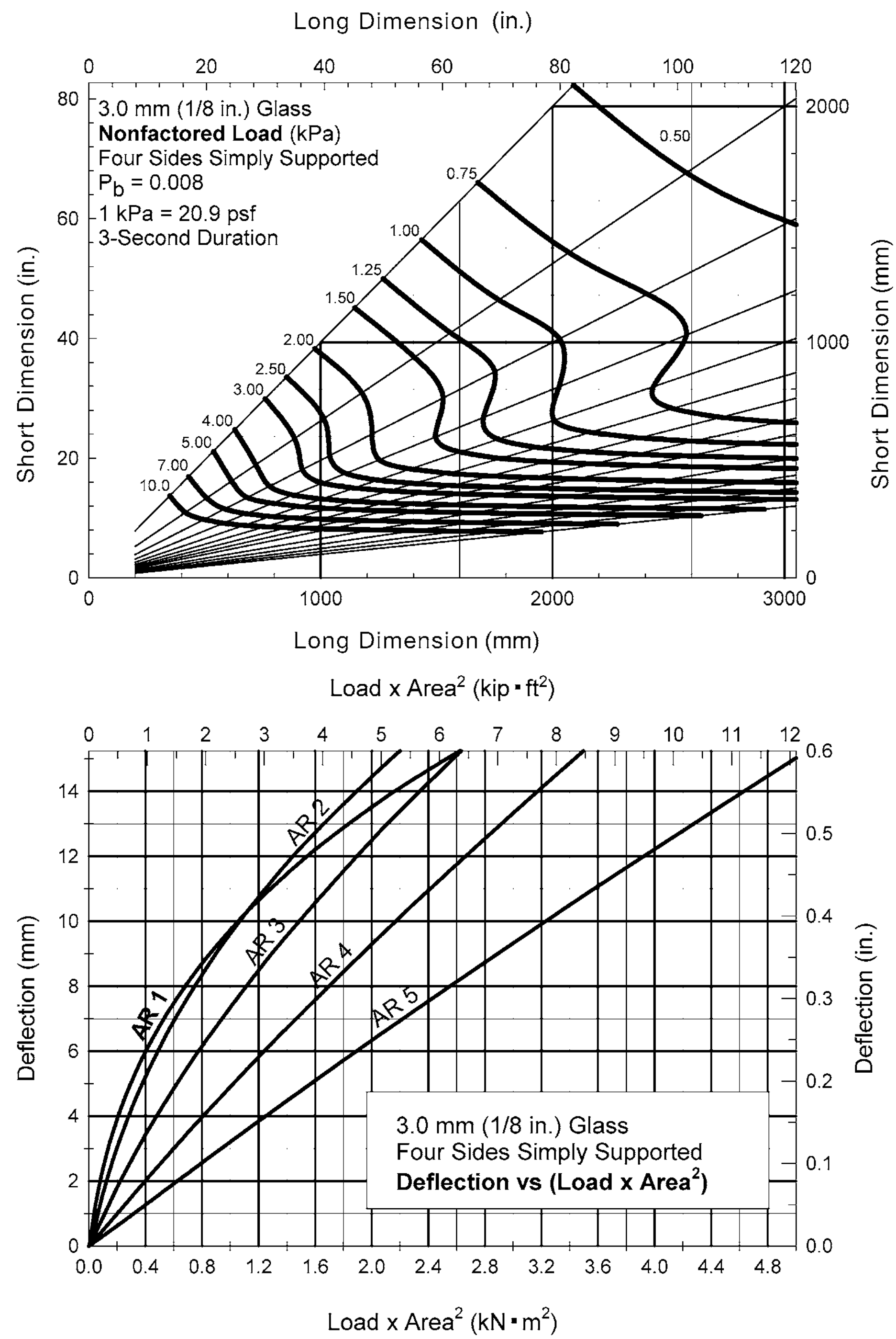
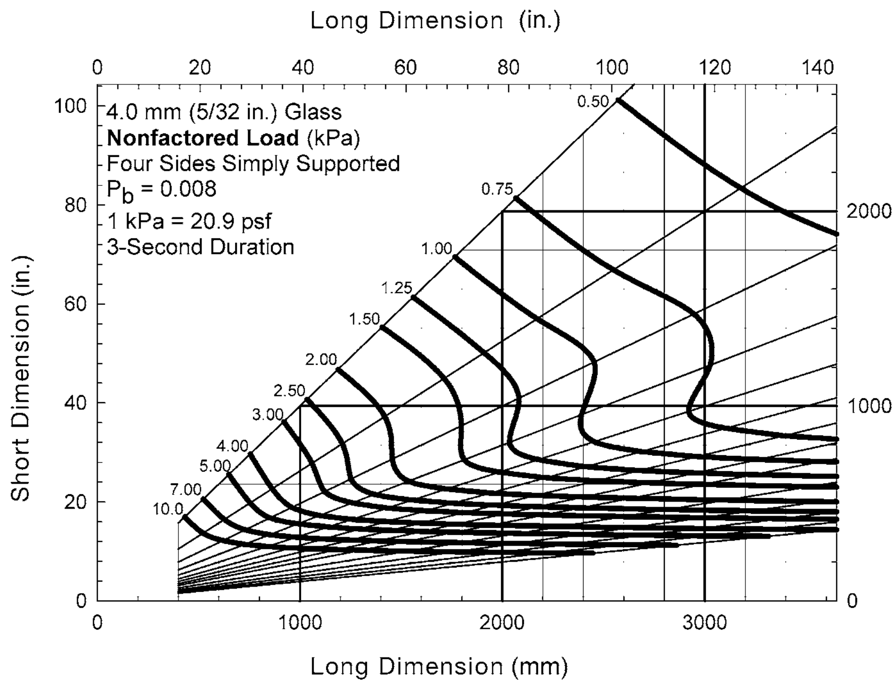


FIG. A1.3 (upper chart) Non-Factored Load Chart for 3.0 mm (⅛ in.) Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 3.0 mm (⅛ in.) Glass with Four Sides Simply Supported



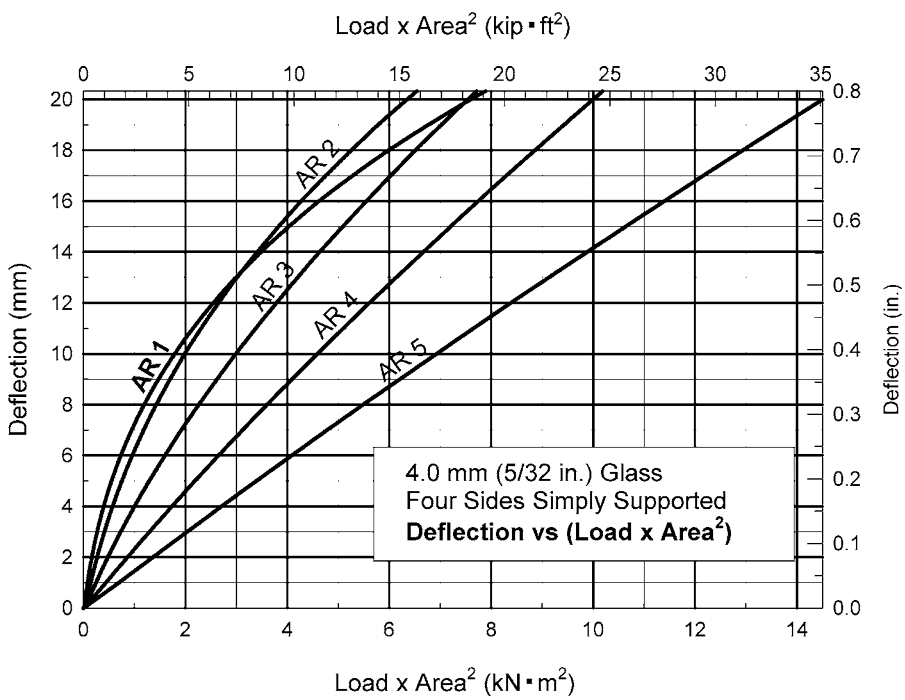
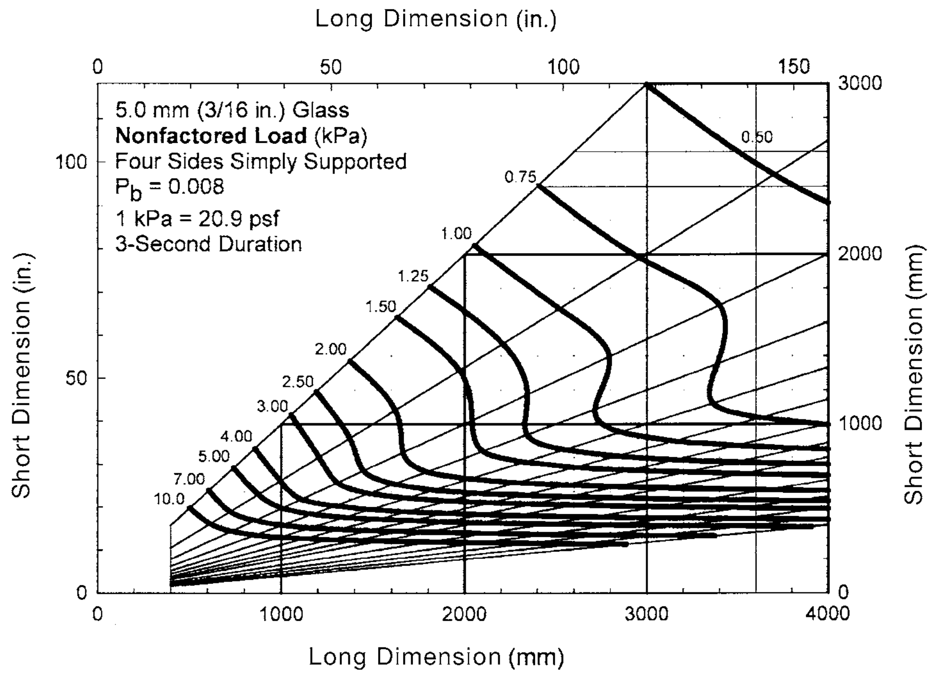


FIG. A1.4 (upper chart) Non-Factored Load Chart for 4.0 mm (5⁄32 in.) Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 4.0 mm (5⁄32 in.) Glass with Four Sides Simply Supported



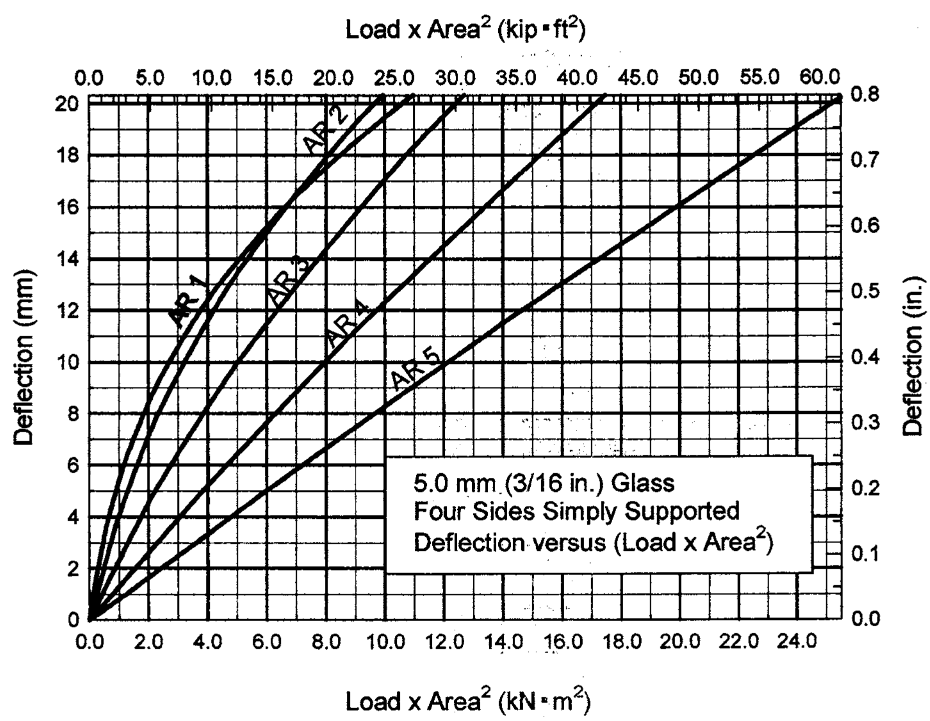
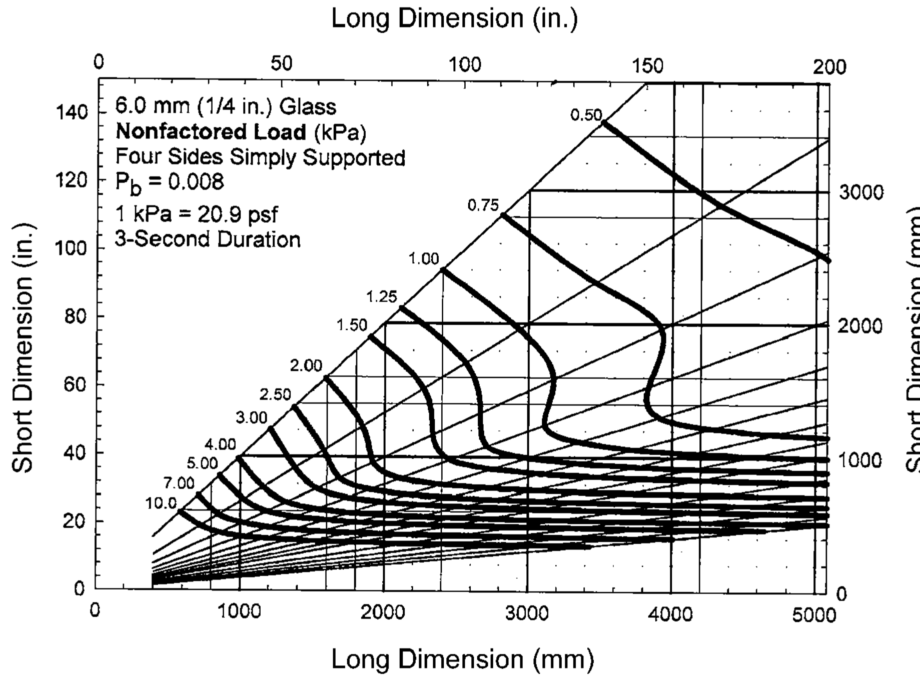


FIG. A1.5 (upper chart) Non-Factored Load Chart for 5.0 mm (3⁄16 in.) Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 5.0 mm (3⁄16 in.) Glass with Four Sides Simply Supported



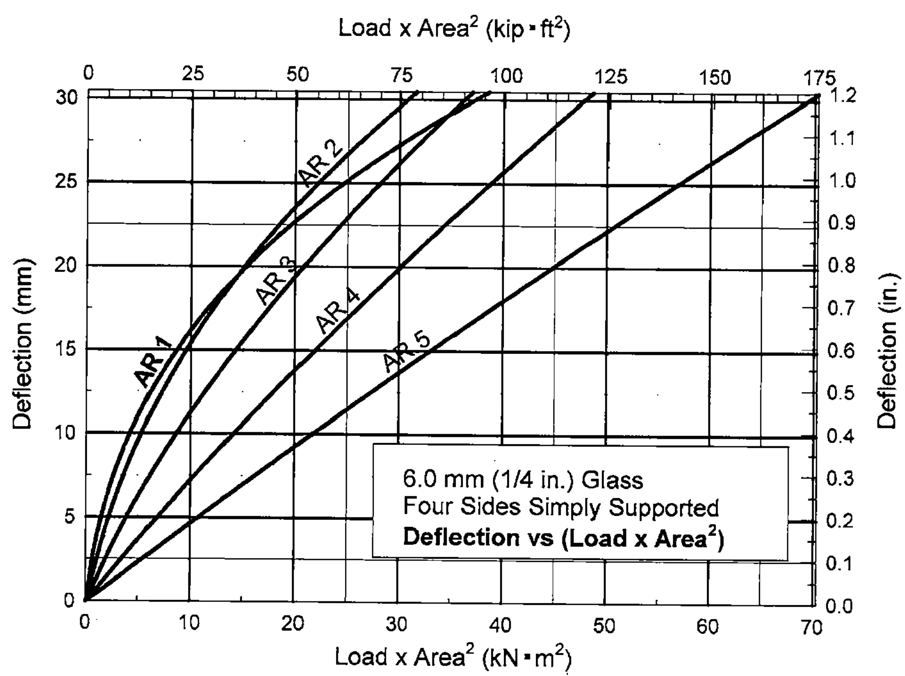
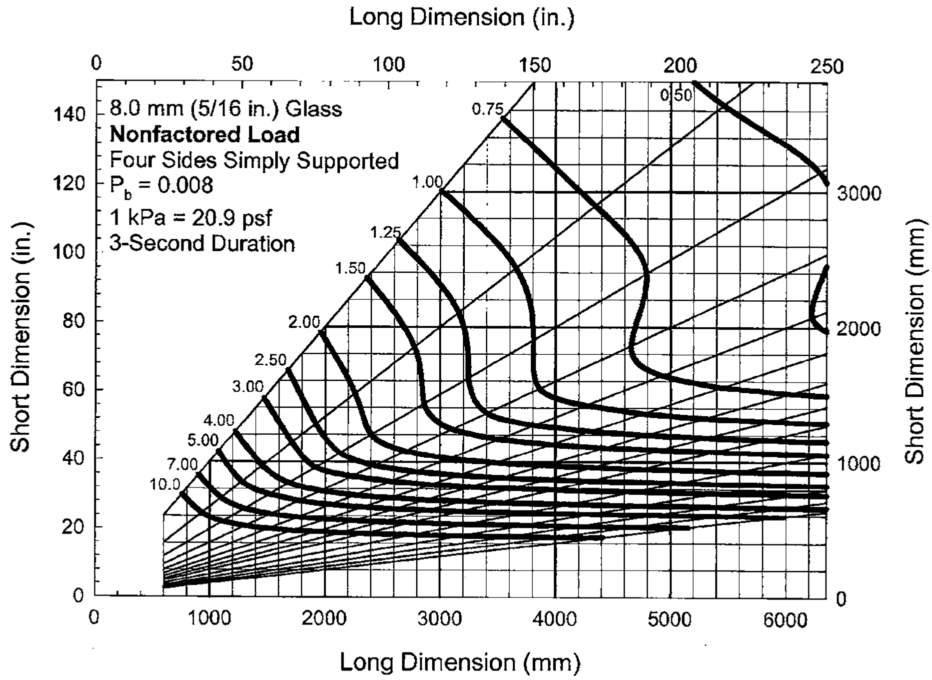


FIG. A1.6 (upper chart) Non-Factored Load Chart for 6.0 mm (¼ in.) Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 6.0 mm (¼ in.) Glass with Four Sides Simply Supported

Expanded charts, 8.0mm and greater.



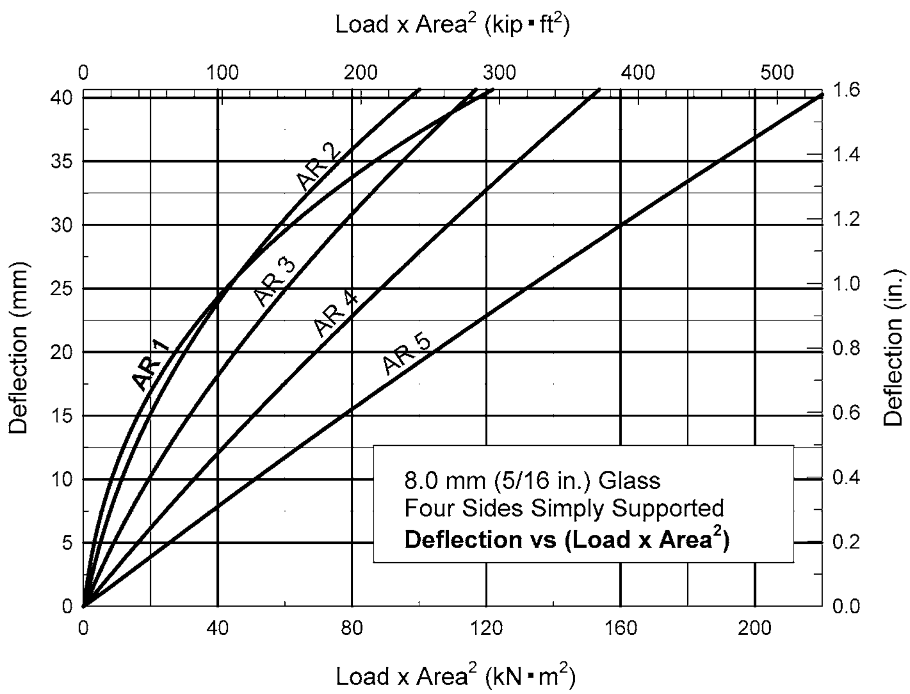
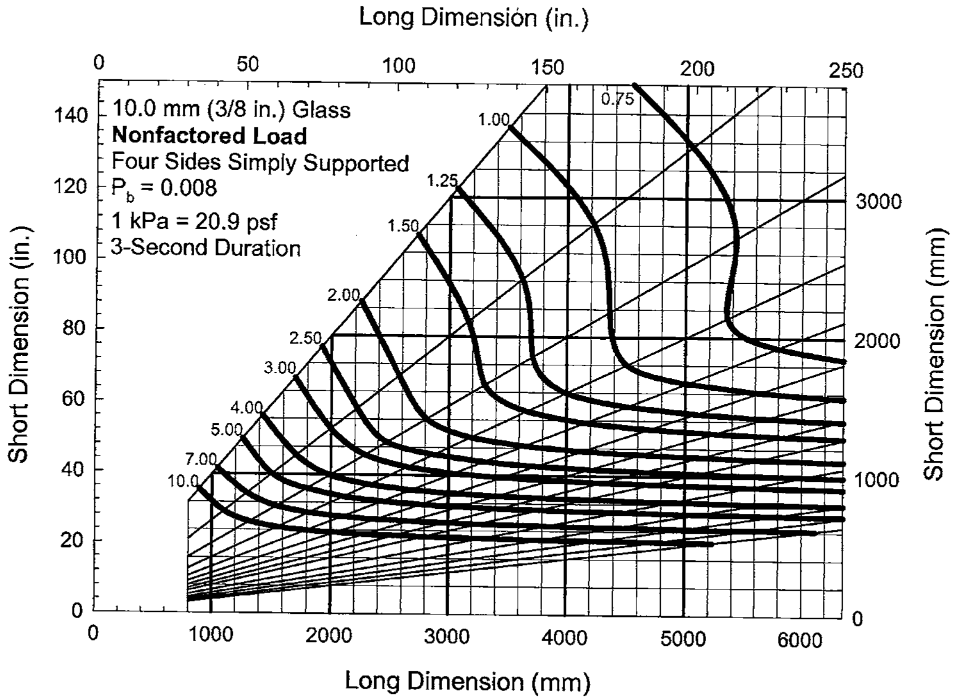


FIG. A1.7 (upper chart) Non-Factored Load Chart for 8.0 mm (5⁄16 in.) Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 8.0 mm (5⁄16 in.) Glass with Four Sides Simply Supported



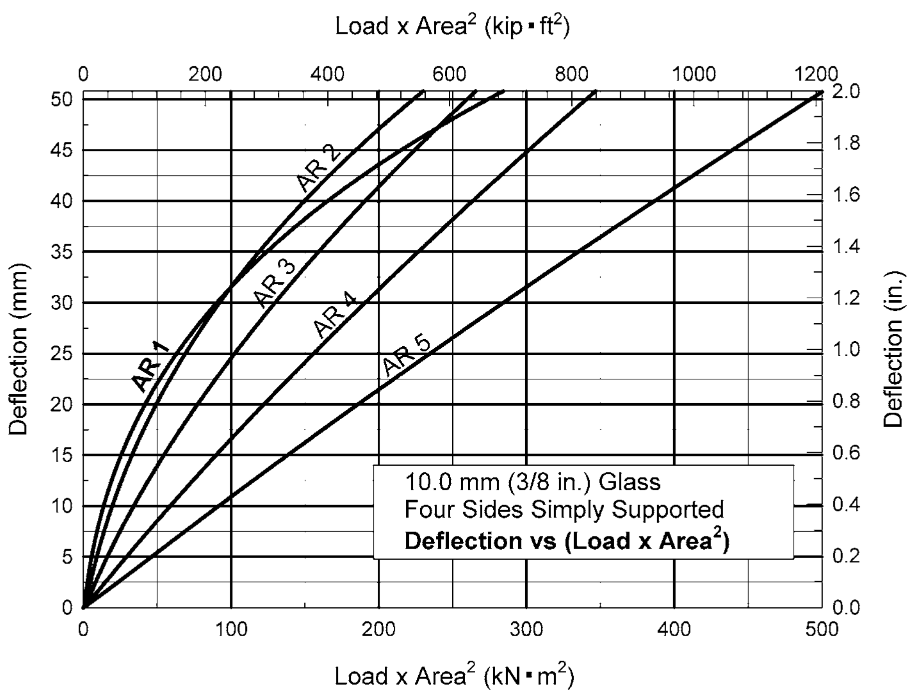
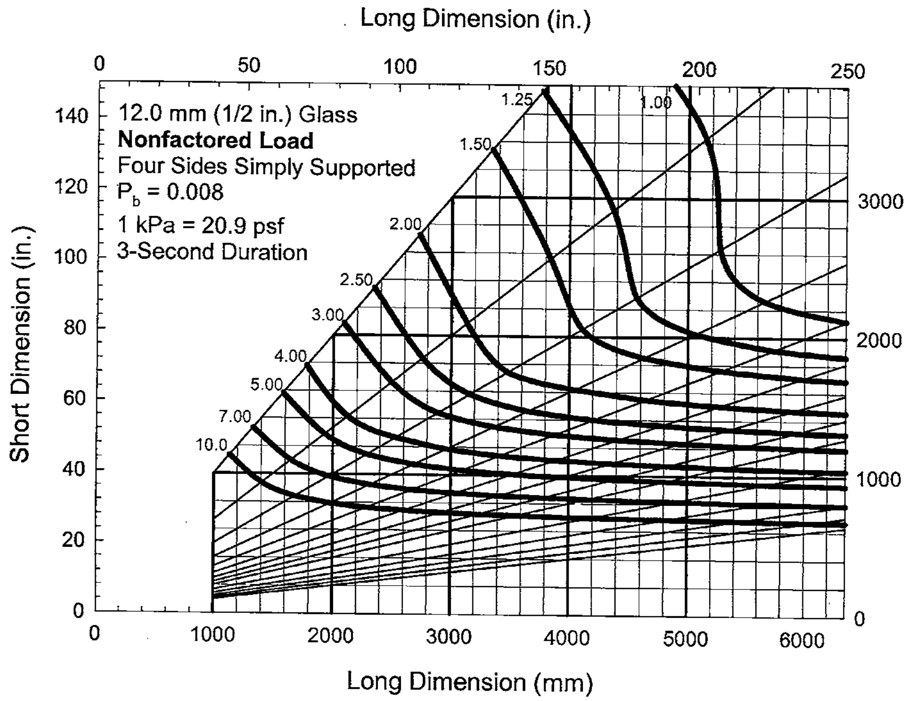


FIG. A1.8 (upper chart) Non-Factored Load Chart for 10.0 mm (3⁄8 in.) Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 10.0 mm (3⁄8 in.) Glass with Four Sides Simply Supported



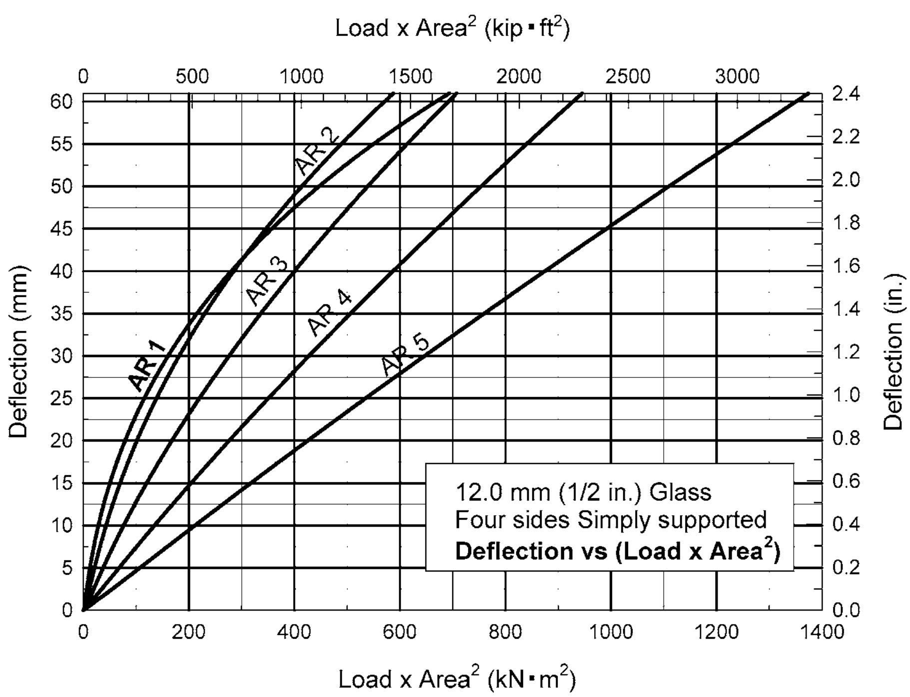
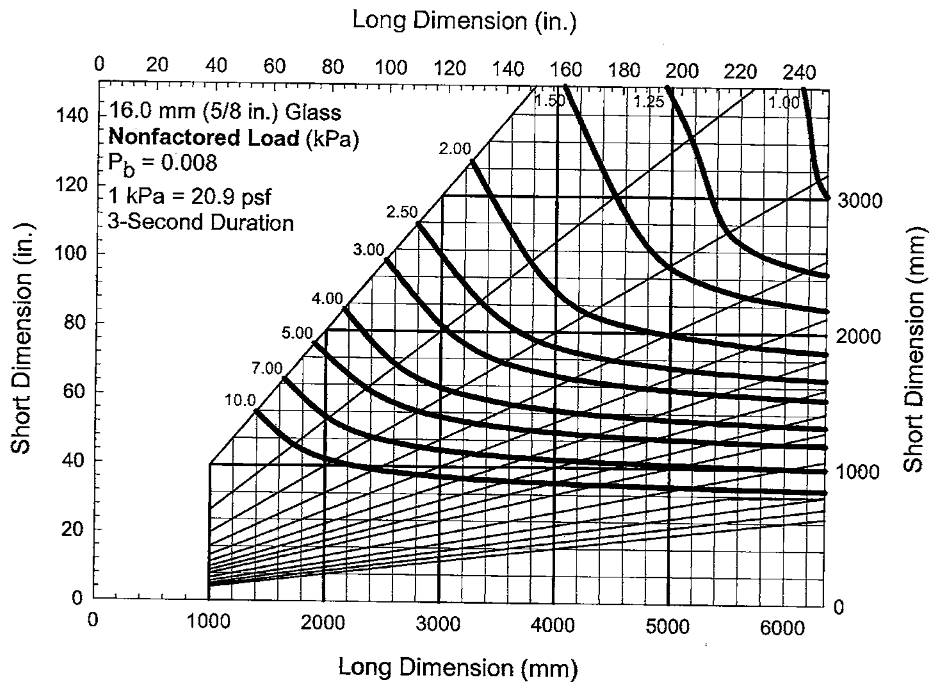


FIG. A1.9 (upper chart) Non-Factored Load Chart for 12.0 mm (½ in.) Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 12.0 mm (½ in.) Glass with Four Sides Simply Supported



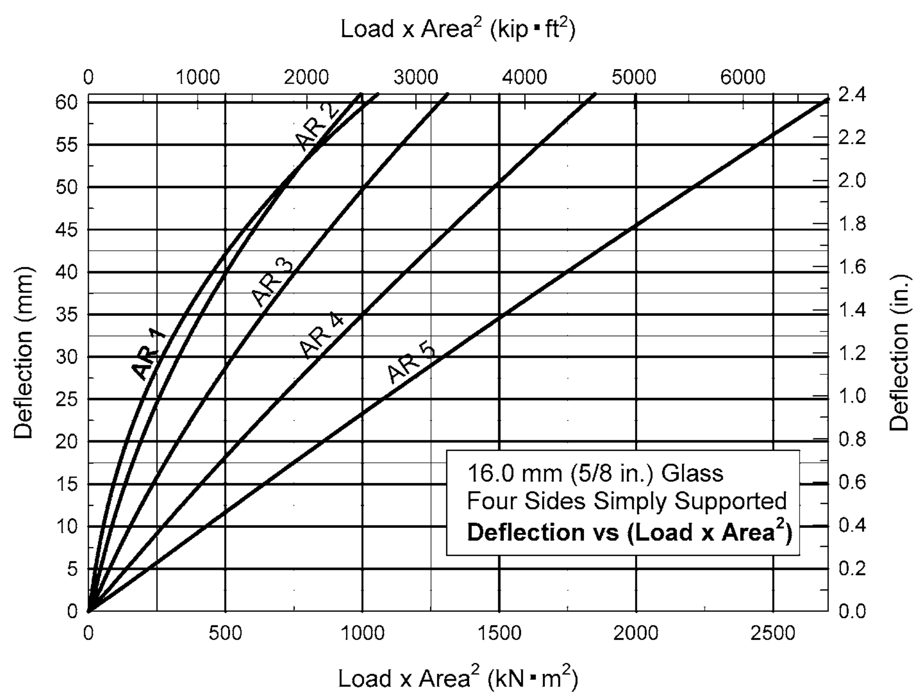
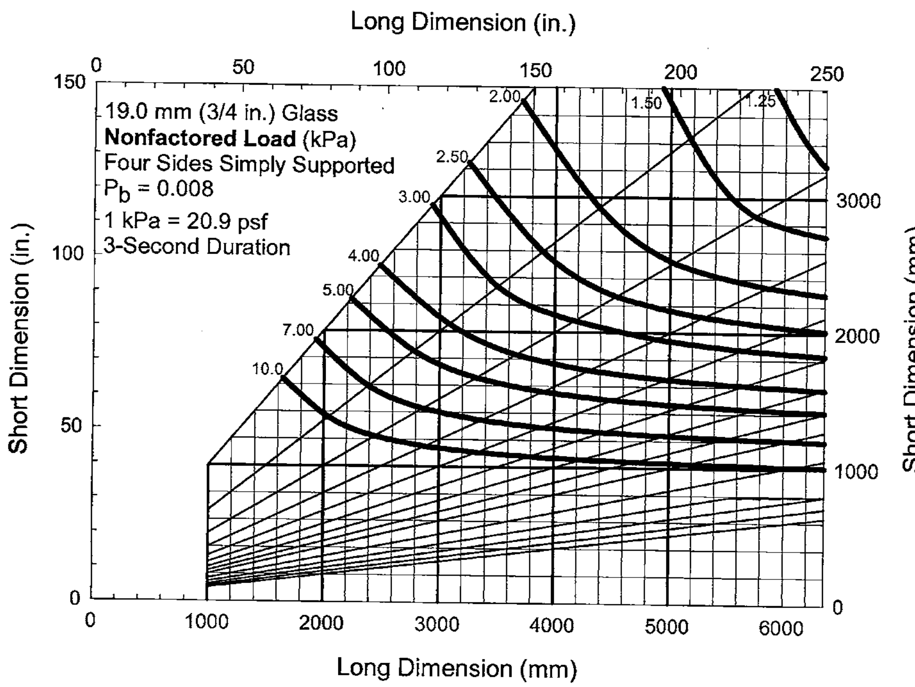


FIG. A1.10 (upper chart) Non-Factored Load Chart for 16.0 mm (5⁄8 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 16.0 mm (5⁄8 in.) Glass with Four Sides Simply Supported



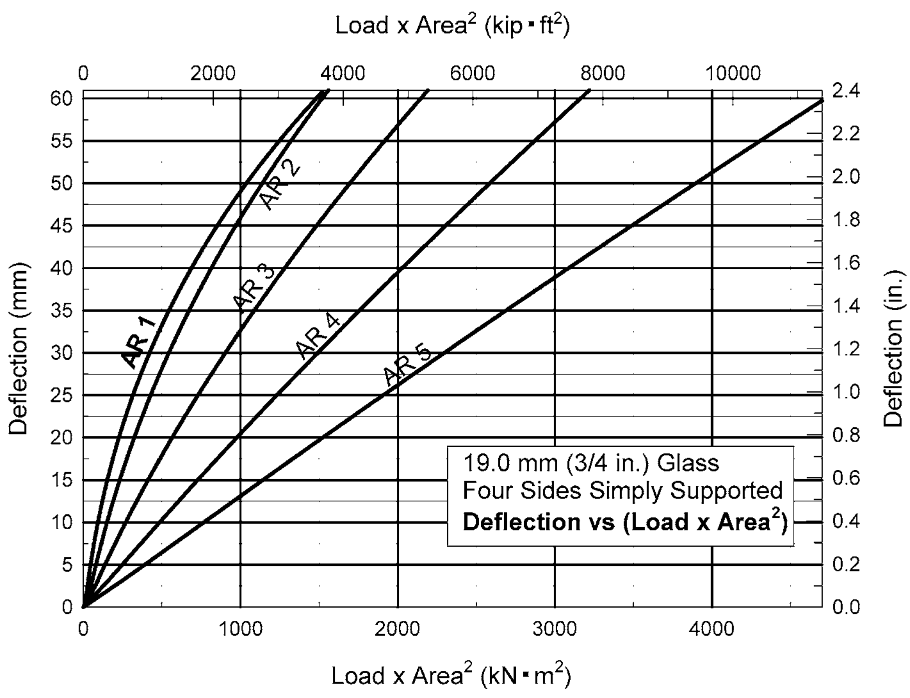


FIG. A1.11 (upper chart) Non-Factored Load Chart for 19.0 mm (¾ in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 19.0 mm (¾ in.) Glass with Four Sides Simply Supported

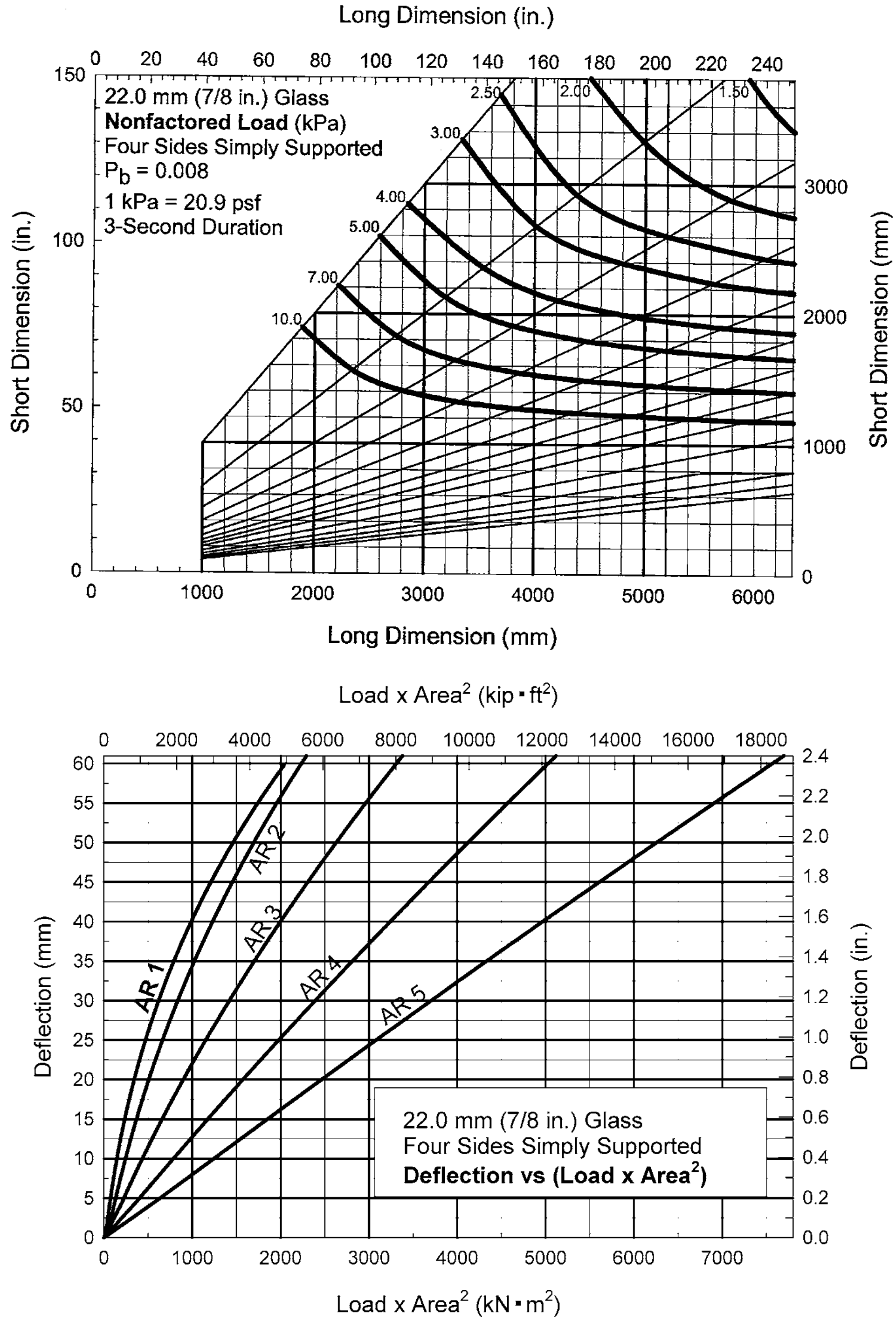
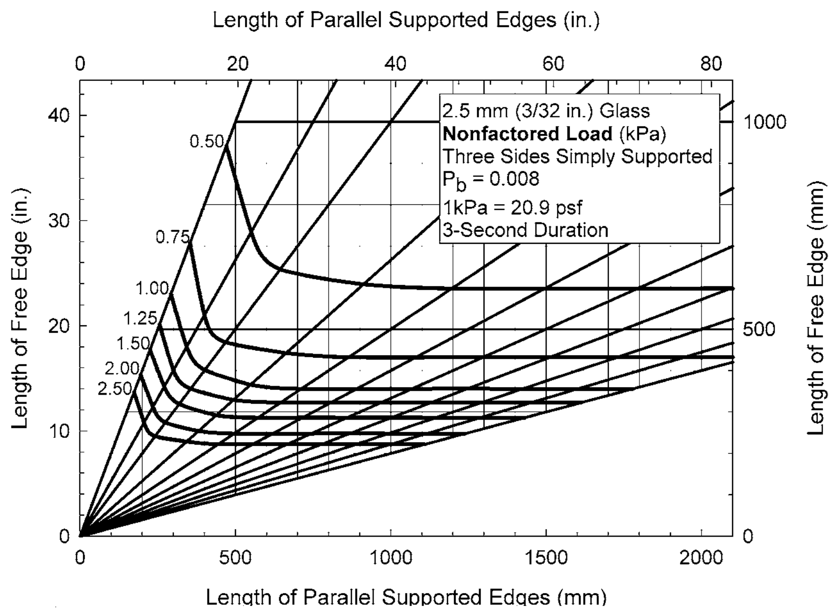


FIG. A1.12 (upper chart) Non-Factored Load Chart for 22.0 mm (7⁄8 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 22.0 mm (7⁄8 in.) Glass with Four Sides Simply Supported



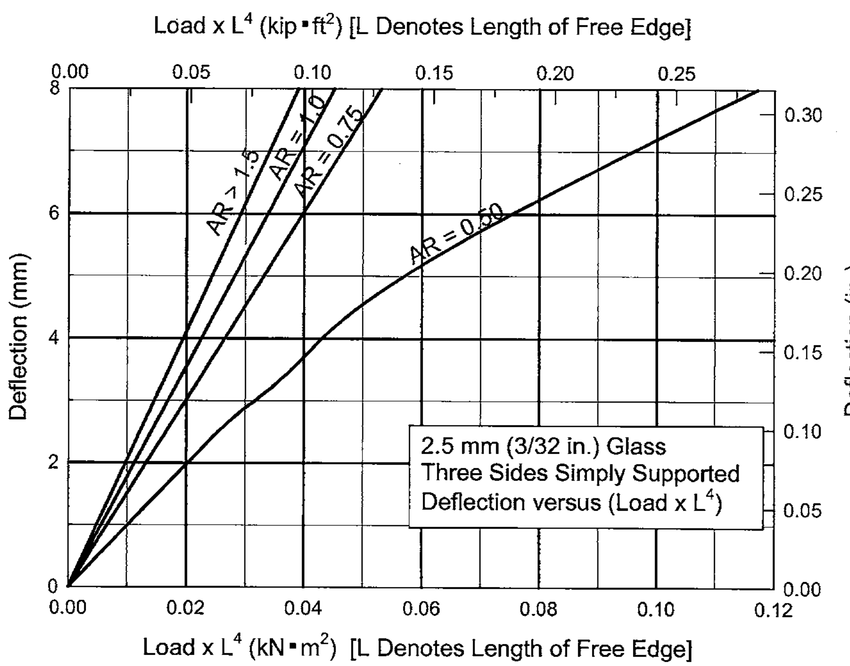
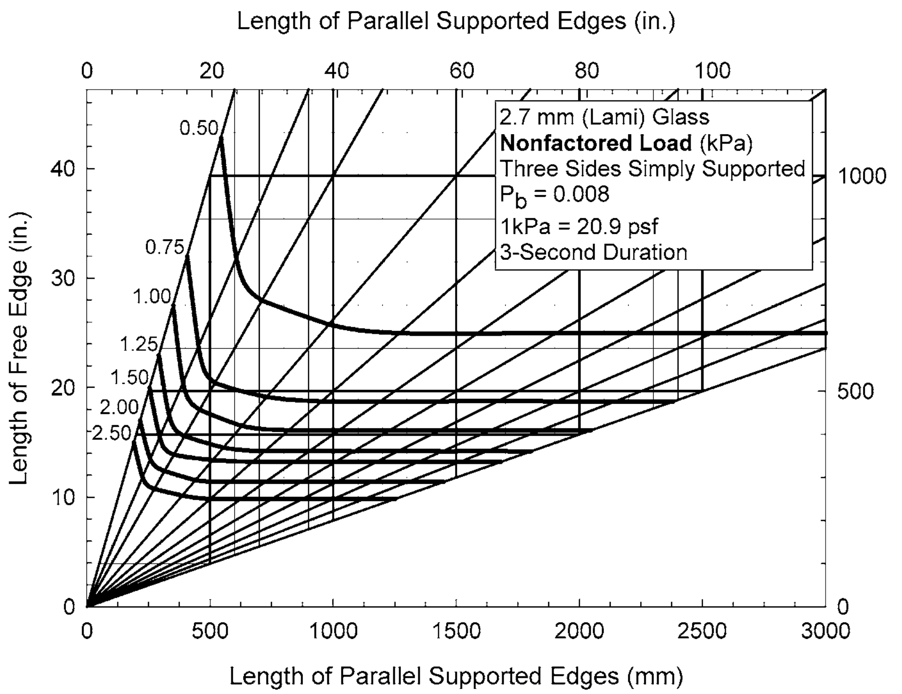


FIG. A1.13 (upper chart) Non-Factored Load Chart for 2.5 mm (3⁄32 in.) Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 2.5 mm (3⁄32 in.) Glass with Three Sides Simply Supported



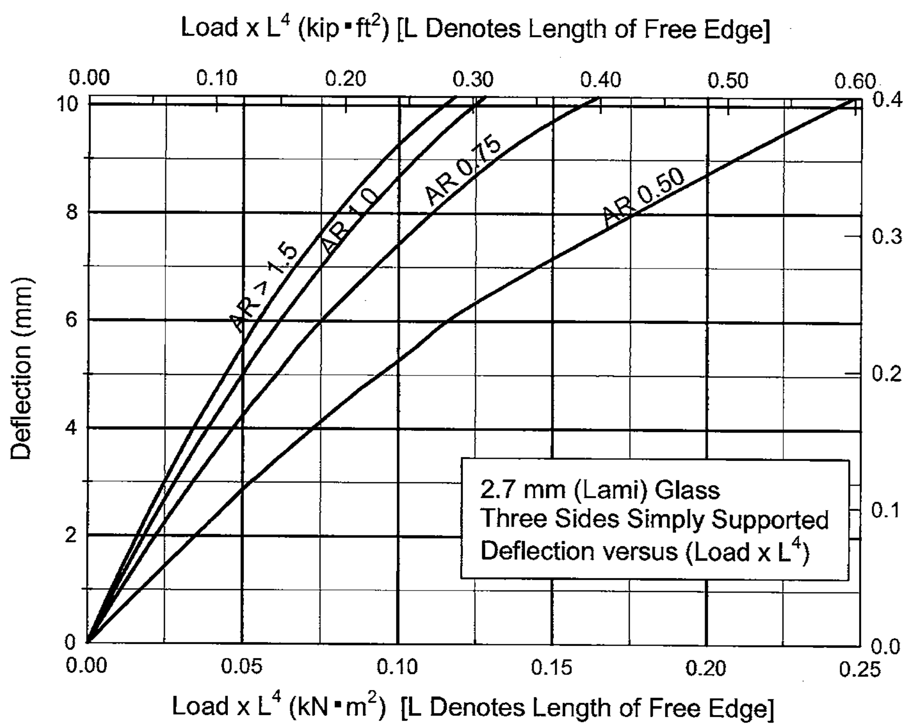
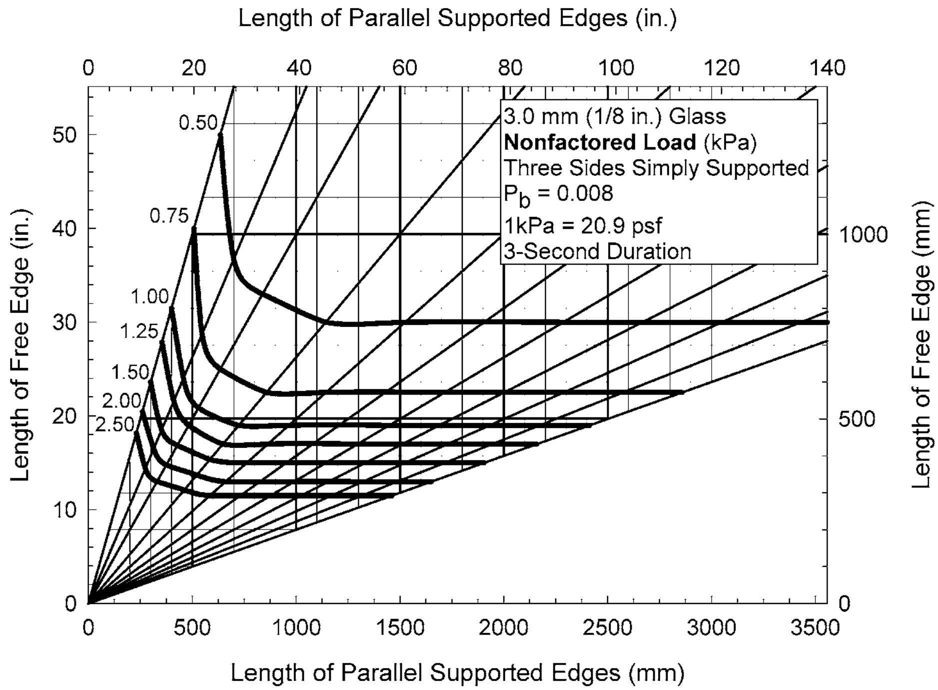


FIG. A1.14 (upper chart) Non-Factored Load Chart for 2.7 mm (Lami) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 2.7 mm (Lami) Glass with Three Sides Simply Supported



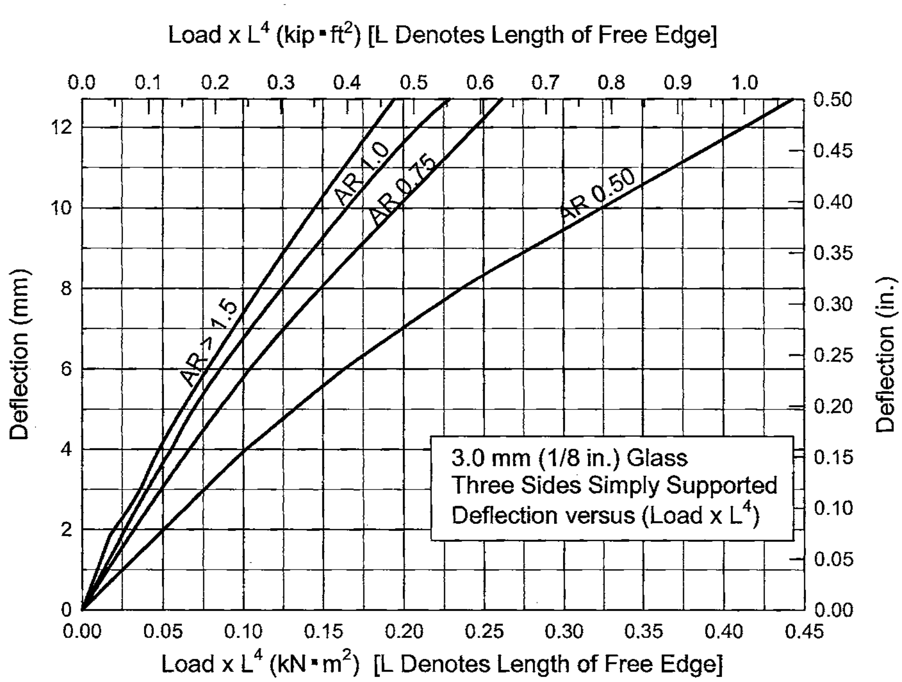
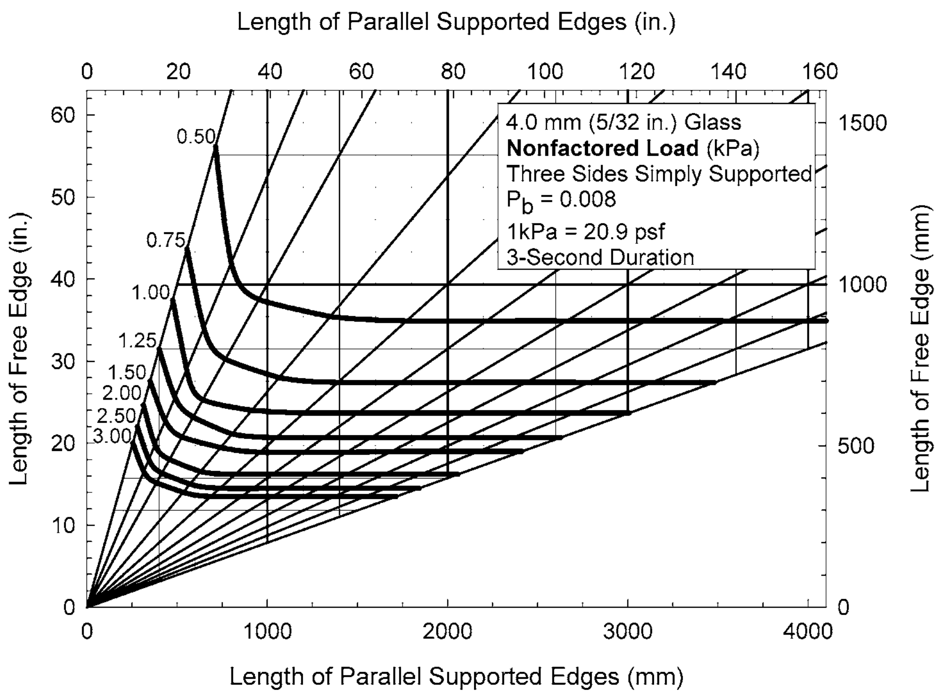


FIG. A1.15 (upper chart) Non-Factored Load Chart for 3.0 mm (⅛ in.) Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 3.0 mm (⅛ in.) Glass with Three Sides Simply Supported



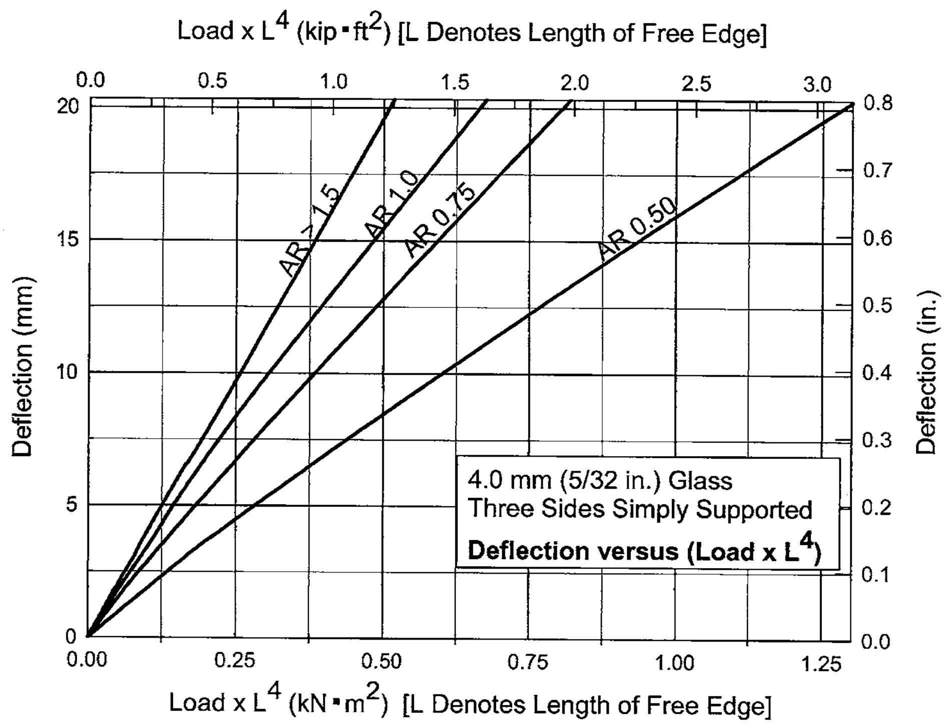
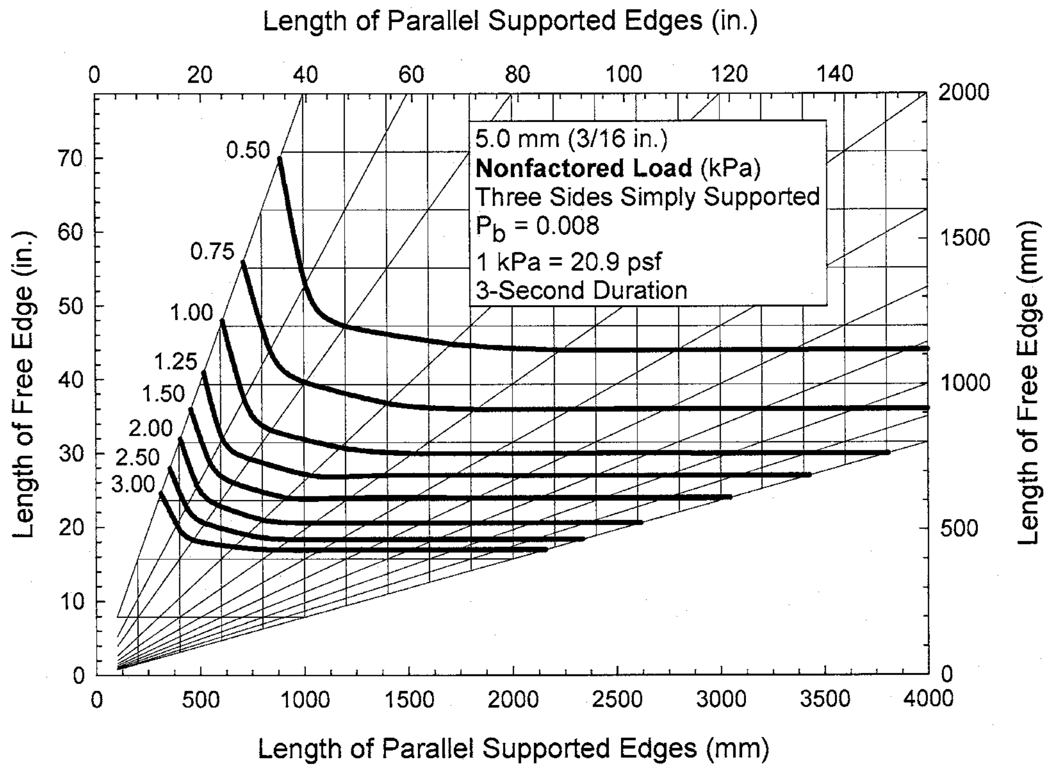


FIG. A1.16 (upper chart) Non-Factored Load Chart for 4.0 mm (5⁄32 in.) Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 4.0 mm (5⁄32 in.) Glass with Three Sides Simply Supported



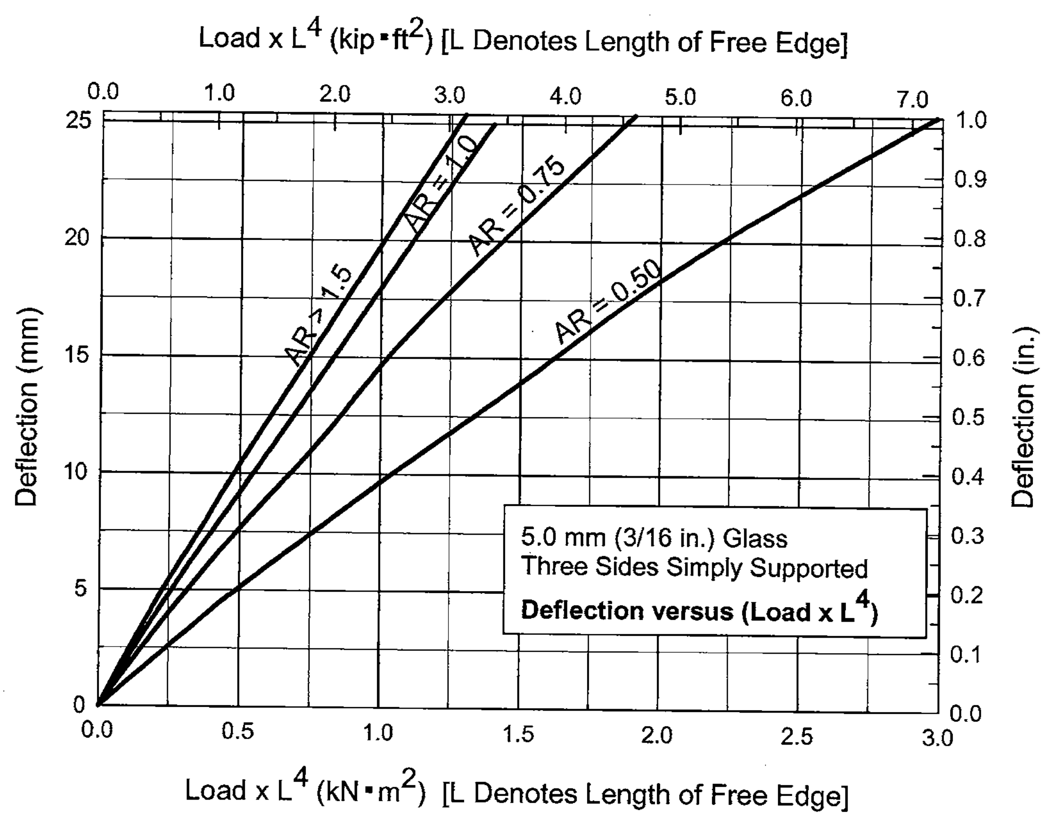
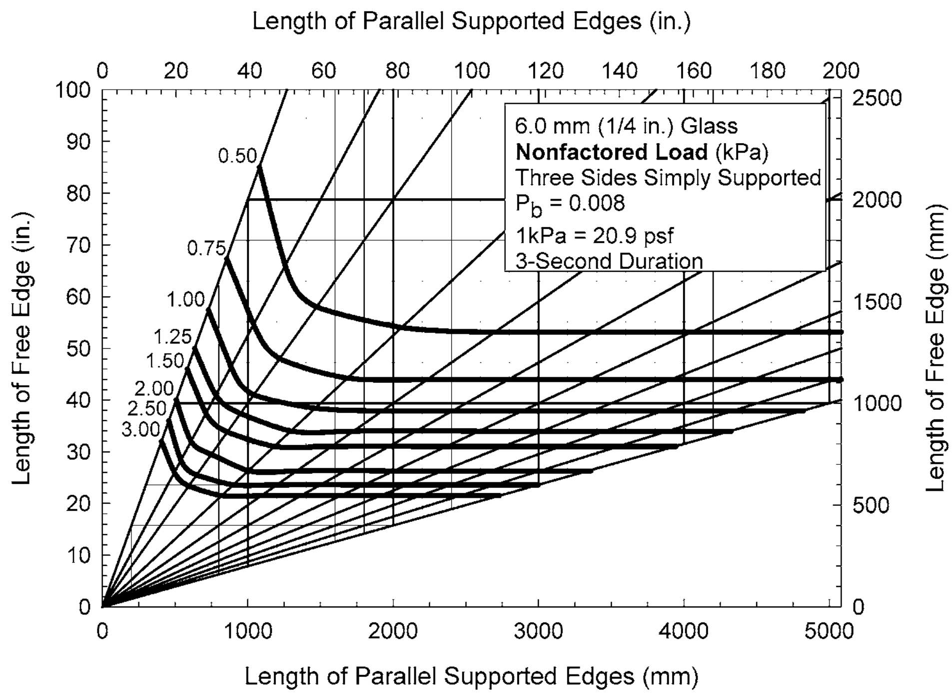


FIG. A1.17 (upper chart) Non-Factored Load Chart for 5.0 mm (3⁄16 in.) Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 5.0 mm (3⁄16 in.) Glass with Three Sides Simply Supported



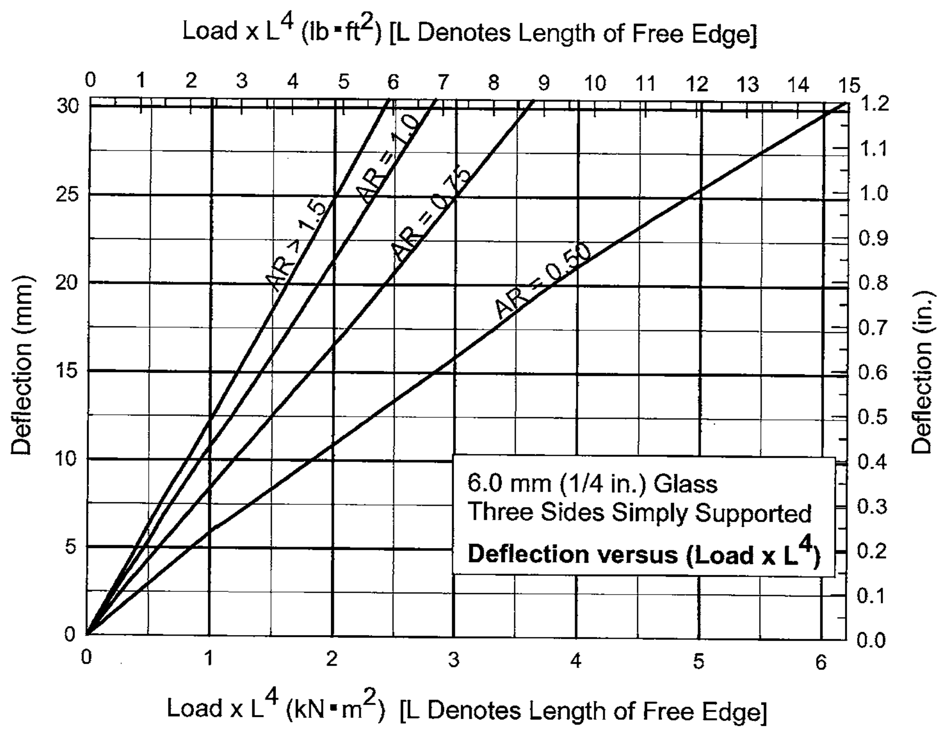
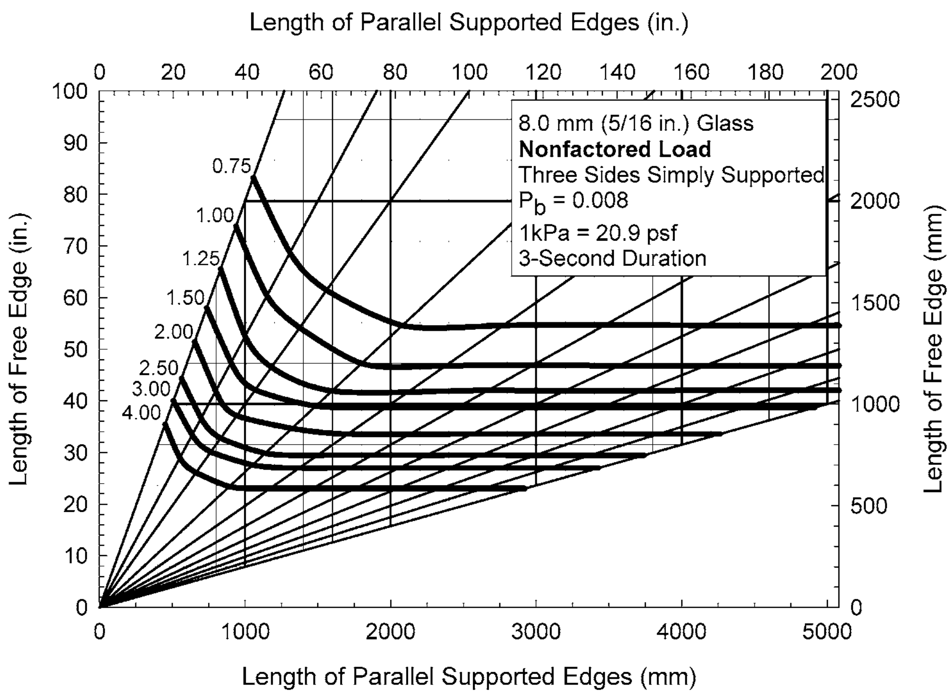


FIG. A1.18 (upper chart) Non-Factored Load Chart for 6.0 mm (¼ in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 6.0 mm (¼ in.) Glass with Three Sides Simply Supported



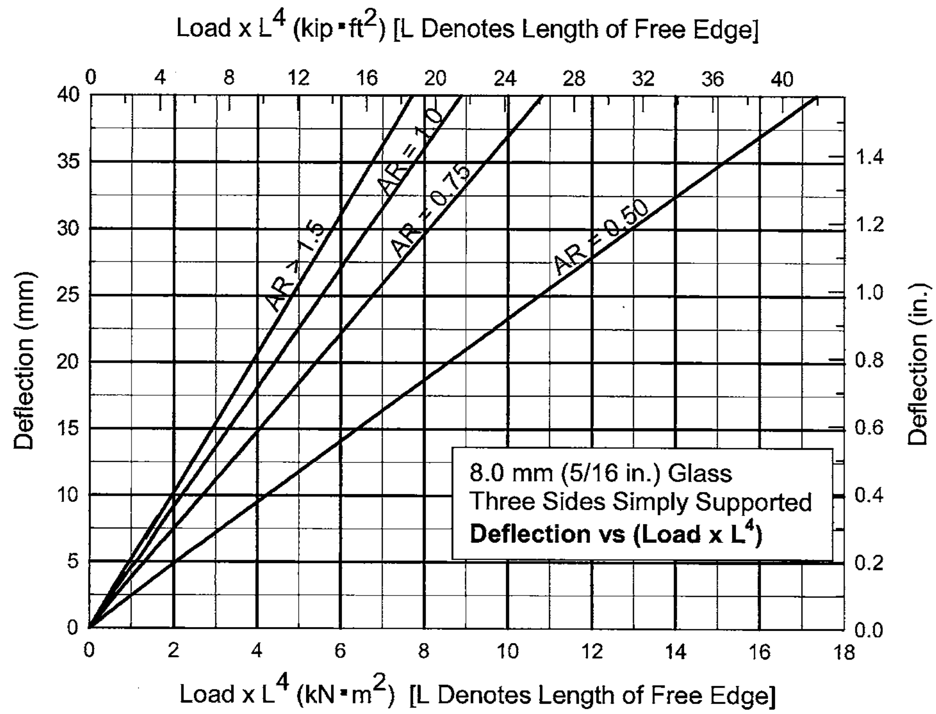
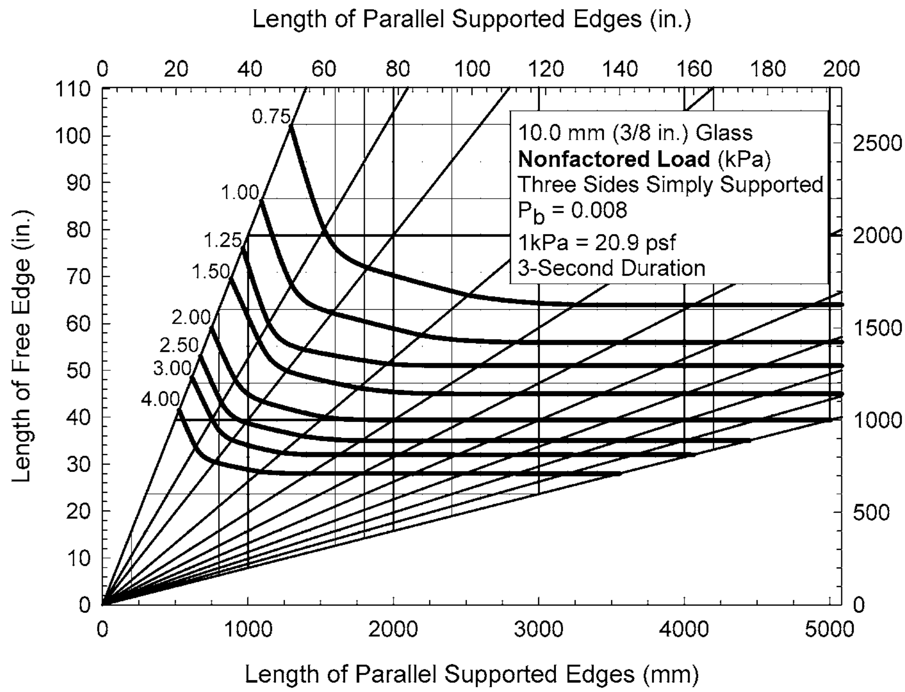


FIG. A1.19 (upper chart) Non-Factored Load Chart for 8.0 mm (5⁄16 in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 8.0 mm (5⁄16 in.) Glass with Three Sides Simply Supported



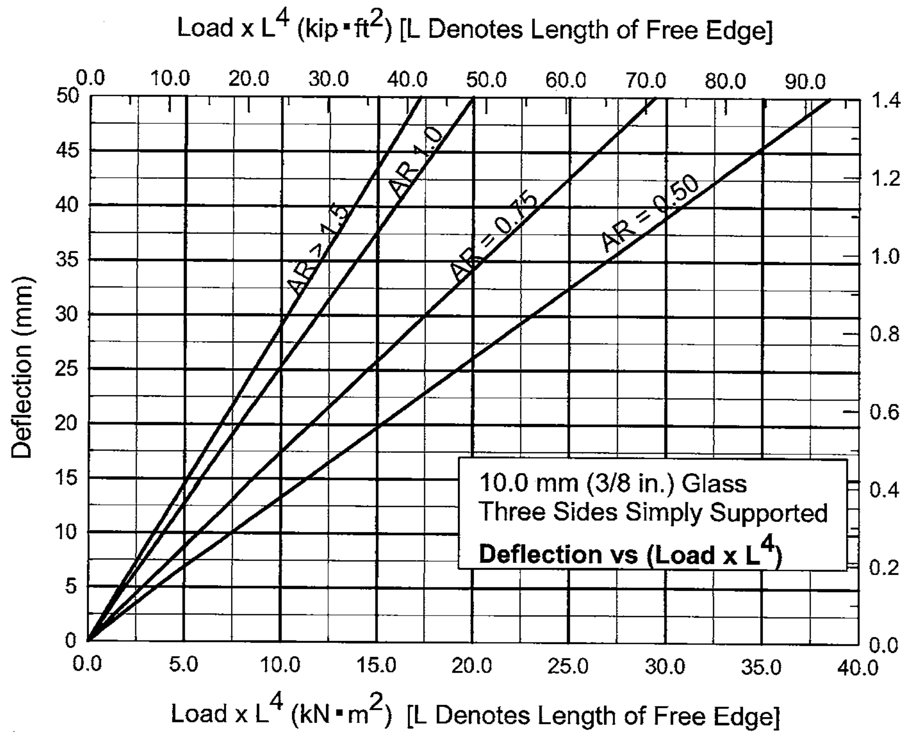
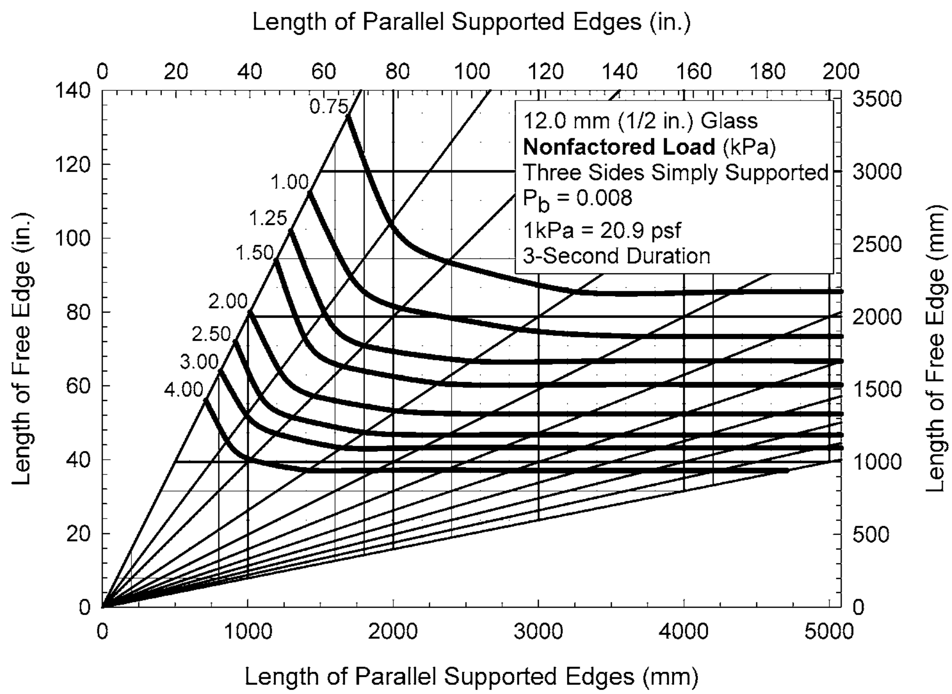


FIG. A1.20 (upper chart) Non-Factored Load Chart for 10.0 mm (3⁄8 in.) Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 10.0 mm (3⁄8 in.) Glass with Three Sides Simply Supported



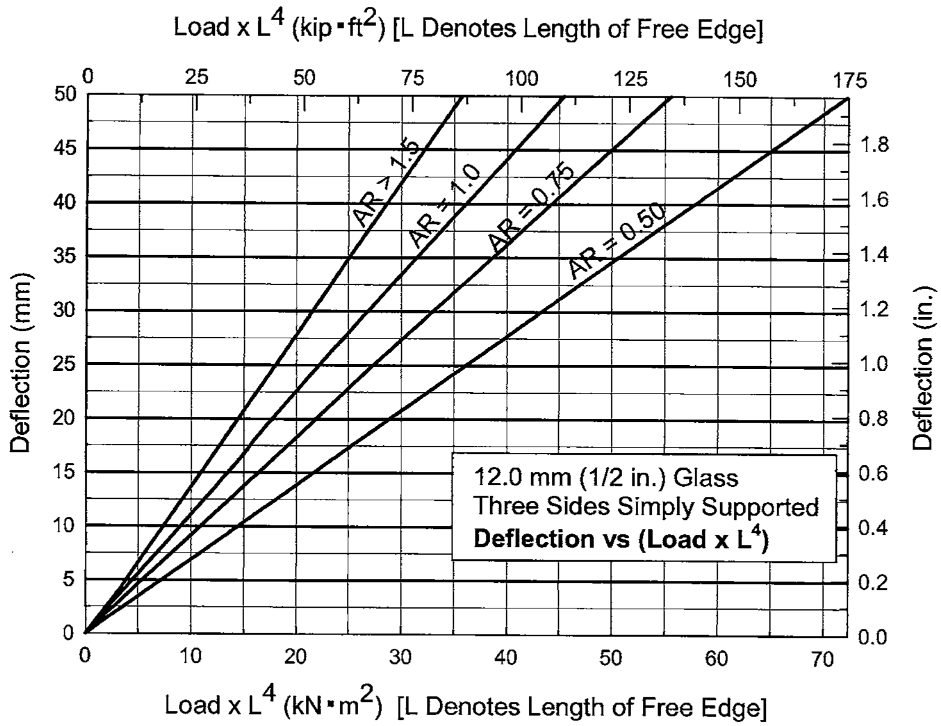


FIG. A1.21 (upper chart) Non-Factored Load Chart for 12.0 mm (½ in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 12.0 mm (½ in.) Glass with Three Sides Simply Supported

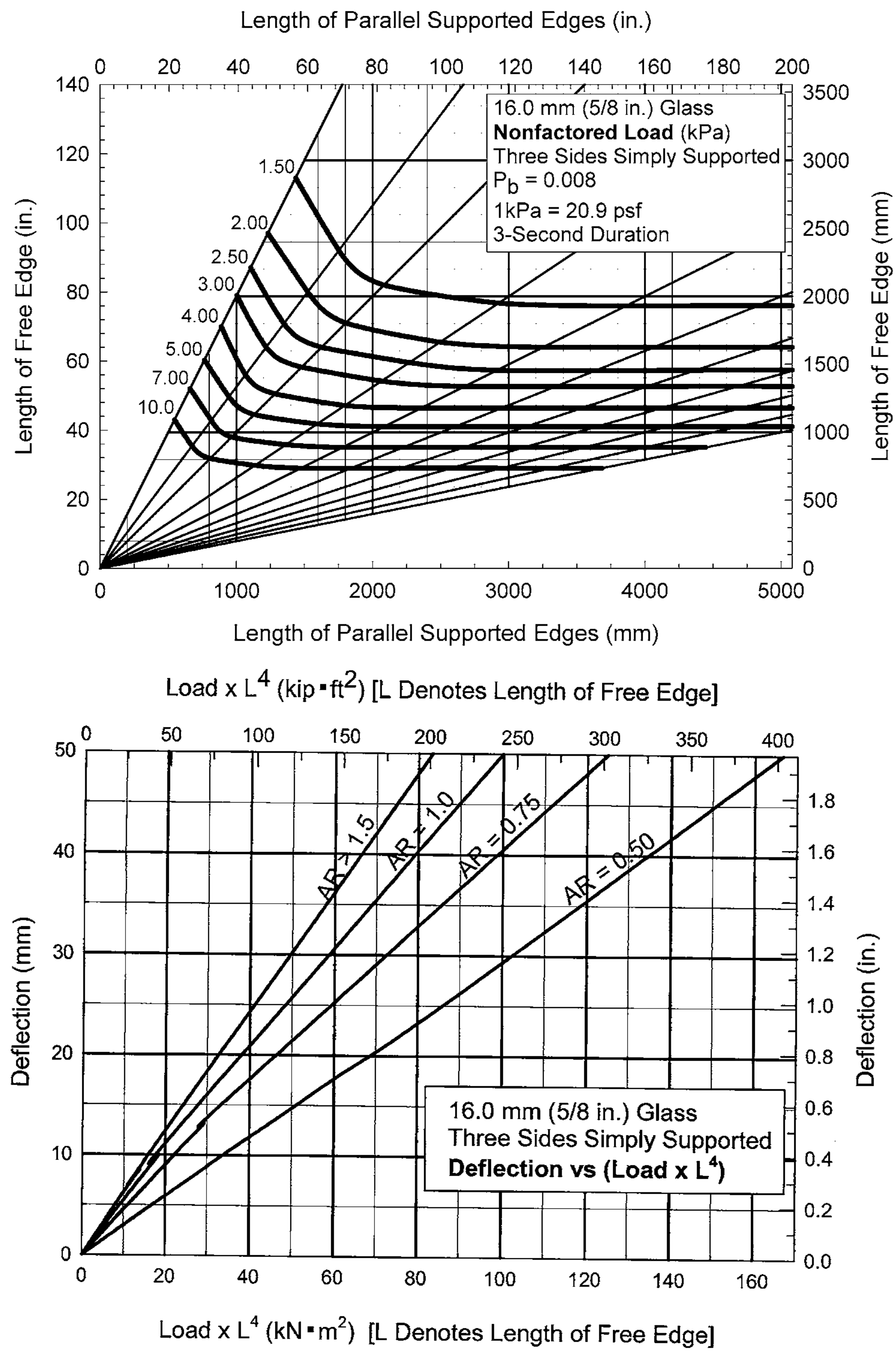


FIG. A1.22 (upper chart) Non-Factored Load Chart for 16.0 mm (⅝ in.) Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 16.0 mm (⅝ in.) Glass with Three Sides Simply Supported

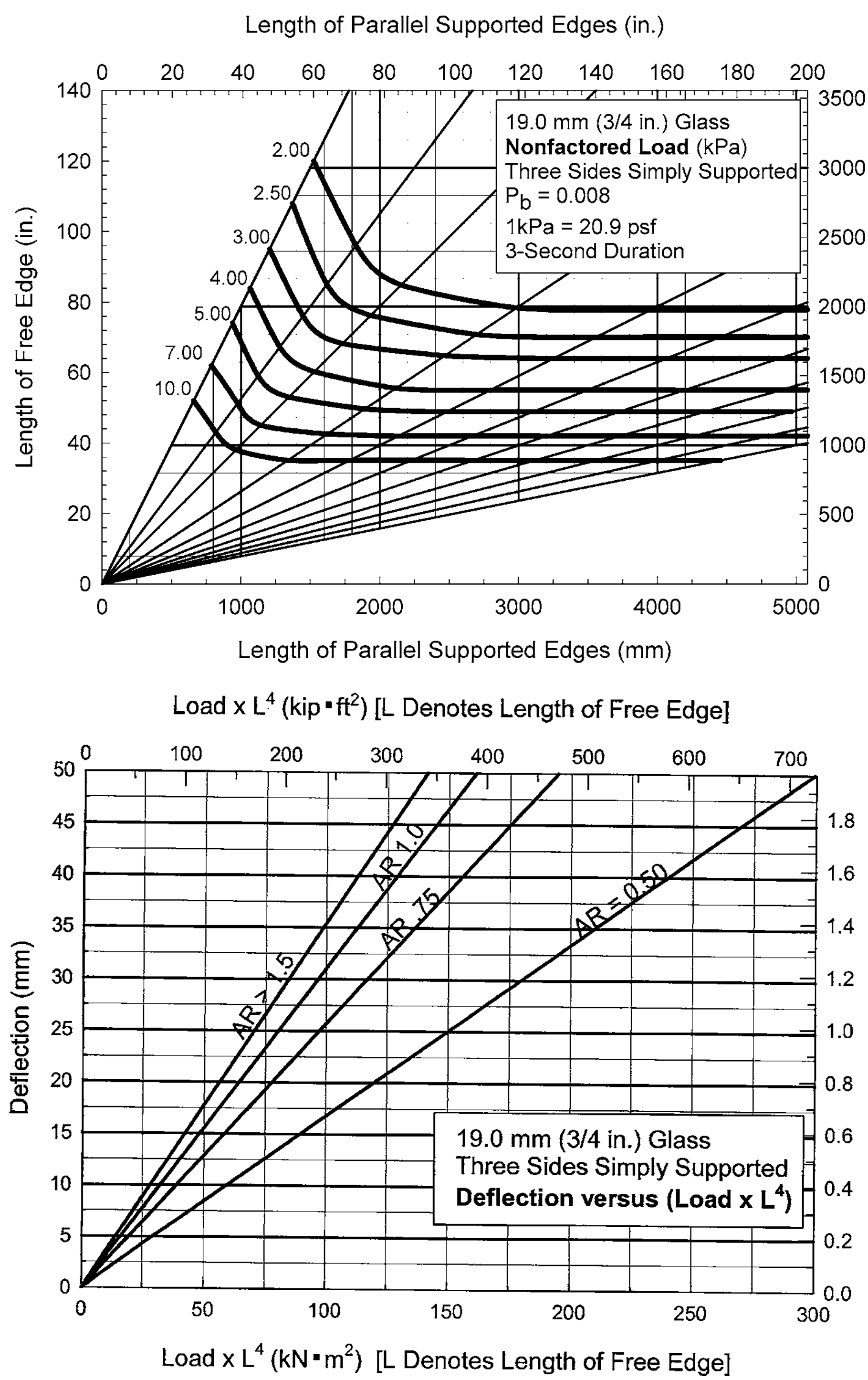
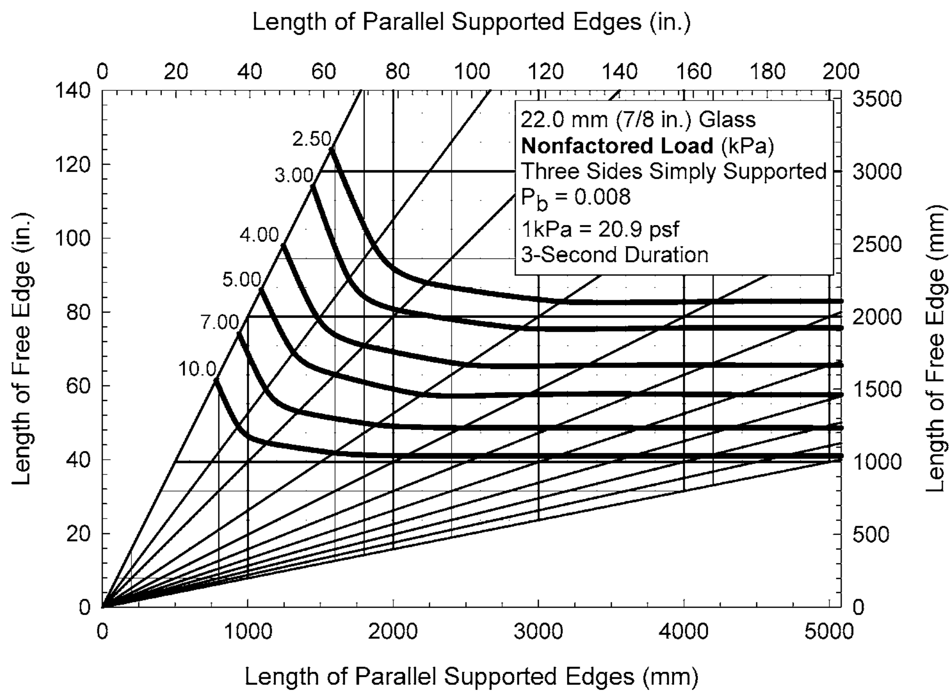


FIG. A1.23 (upper chart) Non-Factored Load Chart for 19.0 mm (¾ in.) Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 19.0 mm (¾ in.) Glass with Three Sides Simply Supported



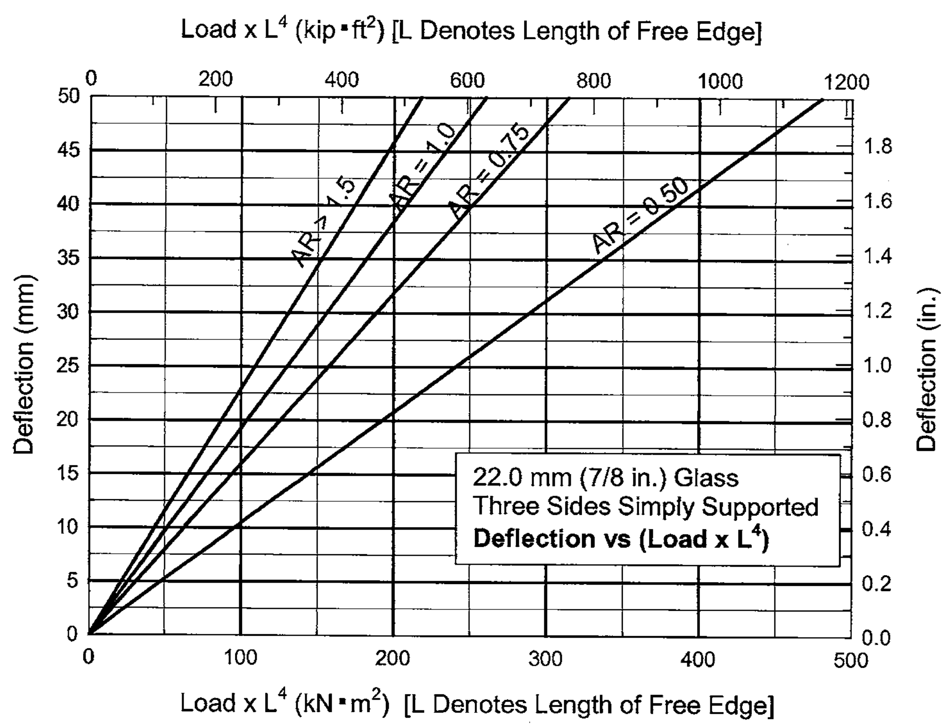
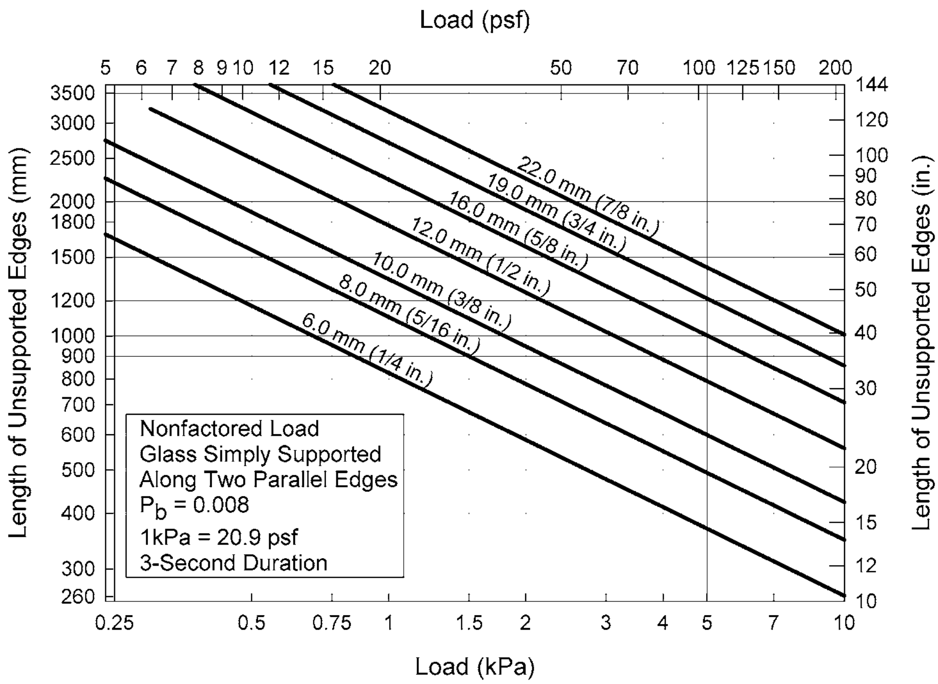


FIG. A1.24 (upper chart) Non-Factored Load Chart for 22.0 mm (⅞ in.) Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 22.0 mm (⅞ in.) Glass with Three Sides Simply Supported



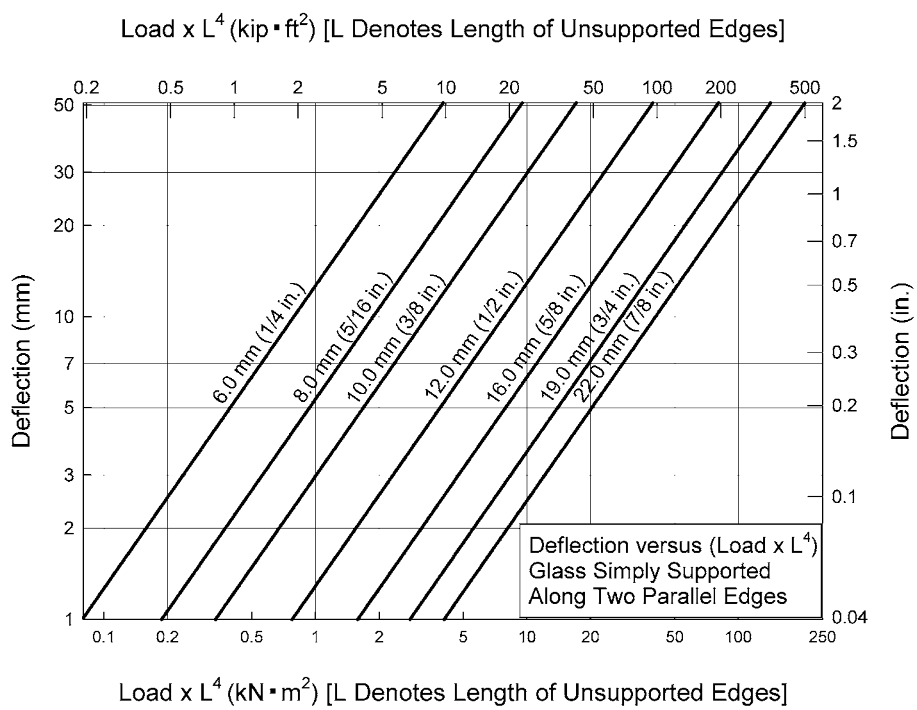
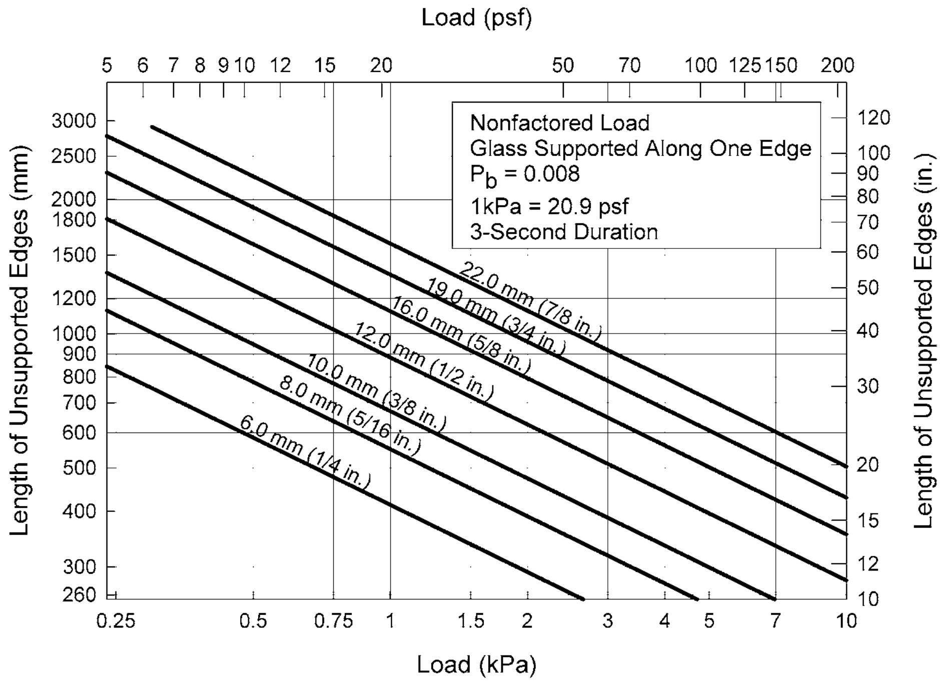


FIG. A1.25 (upper chart) Non-Factored Load Chart for Glass Simply Supported Along Two Parallel Edges
(lower chart) Deflection Chart for Glass Simply Supported Along Two Parallel Edges



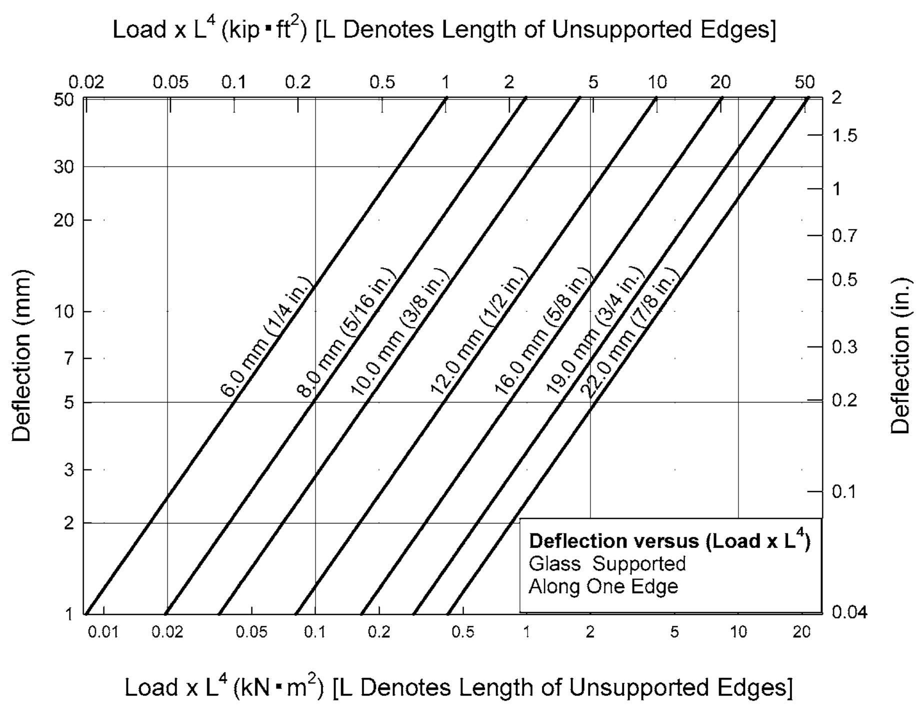
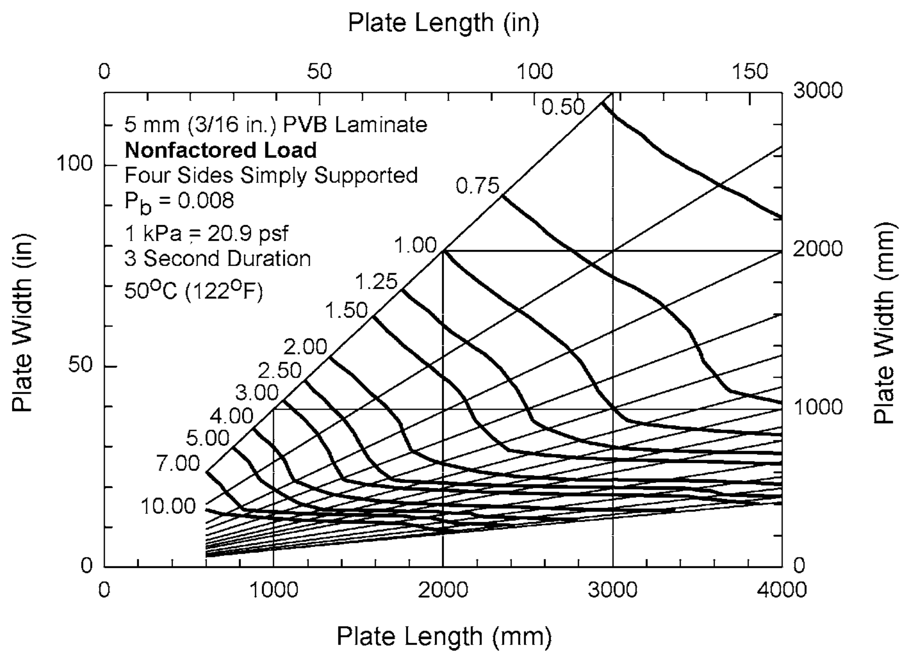


FIG. A1.26 (upper chart) Non-Factored Load Chart for Glass Supported Along One Edge (lower chart) Deflection Chart for Glass Supported Along One Edge



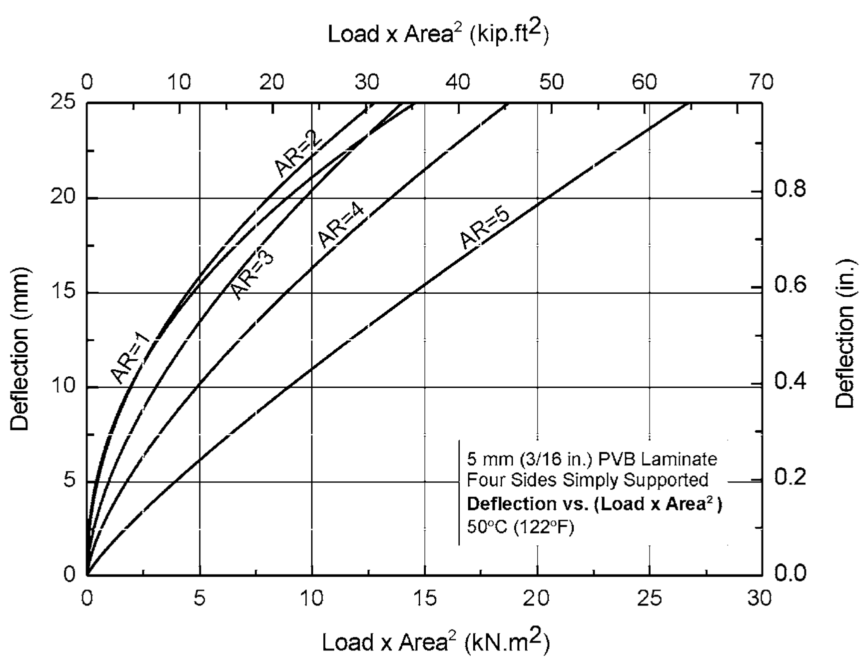
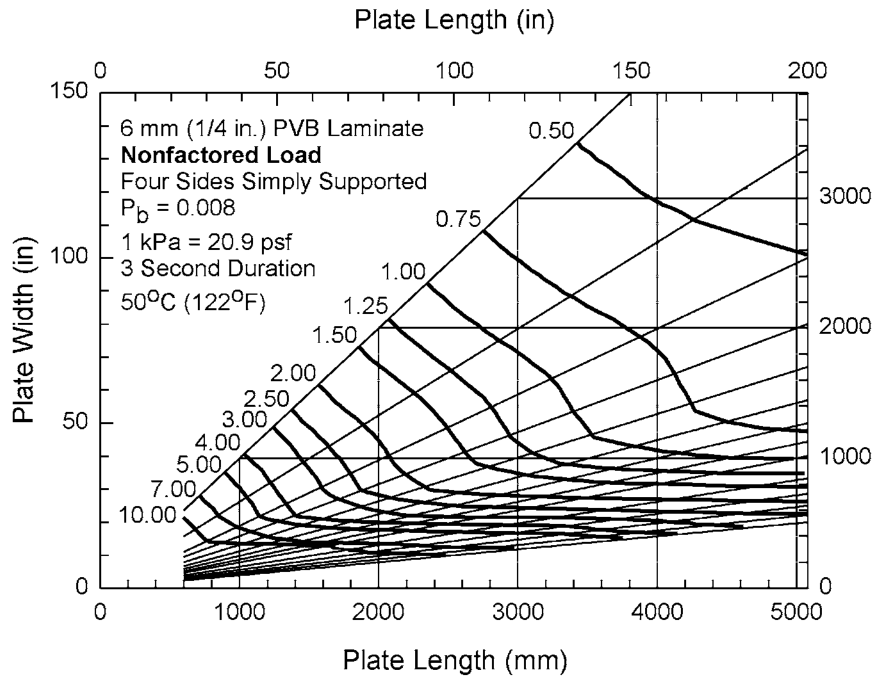


FIG. A1.27 (upper chart) Non-Factored Load Chart for 5.0 mm (3⁄16 in.) Laminated Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 5.0 mm (3⁄16 in.) Laminated Glass with Four Sides Simply Supported



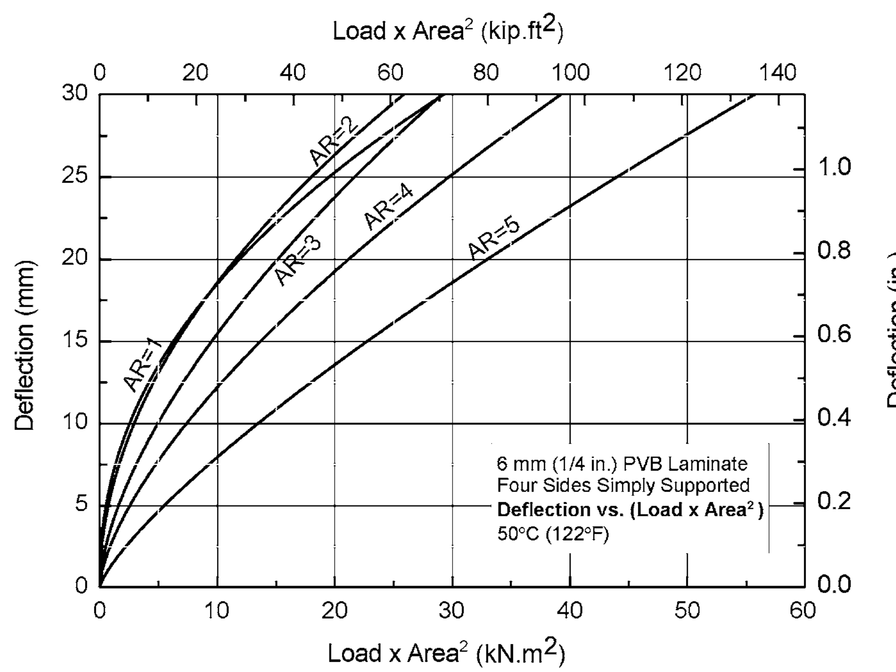
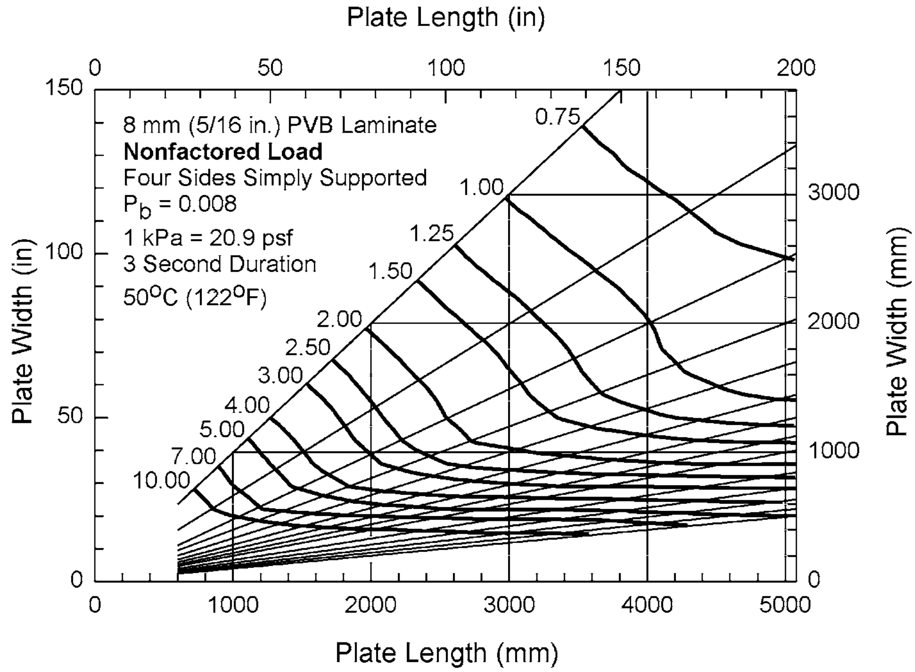


FIG. A1.28 (upper chart) Non-Factored Load Chart for 6.0 mm (¼ in.) Laminated Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 6.0 mm (¼ in.) Laminated Glass with Four Sides Simply Supported



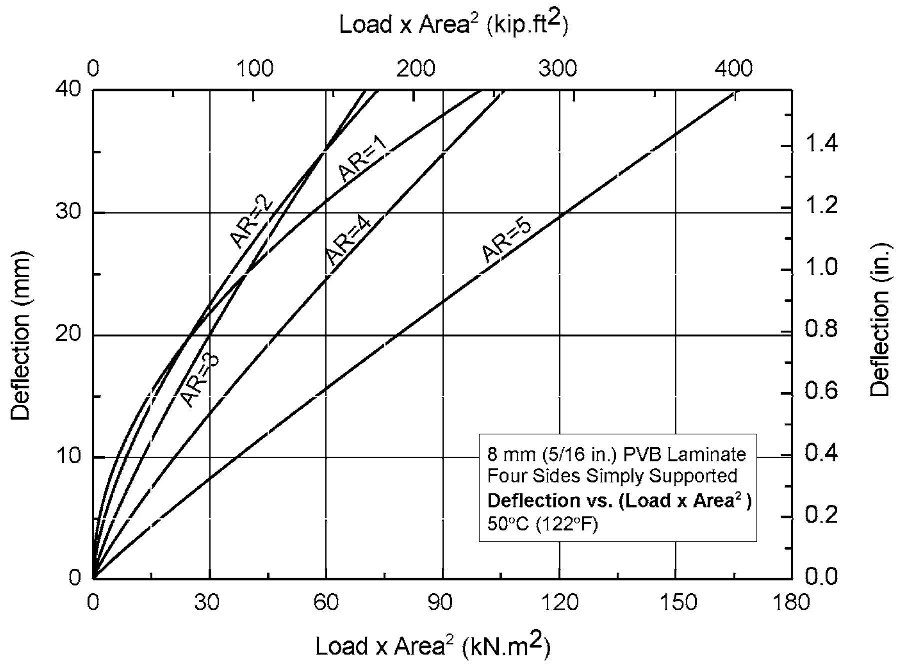


FIG. A1.29 (upper chart) Non-Factored Load Chart for 8.0 mm (5⁄16 in.) Laminated Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 8.0 mm (5⁄16 in.) Laminated Glass with Four Sides Simply Supported

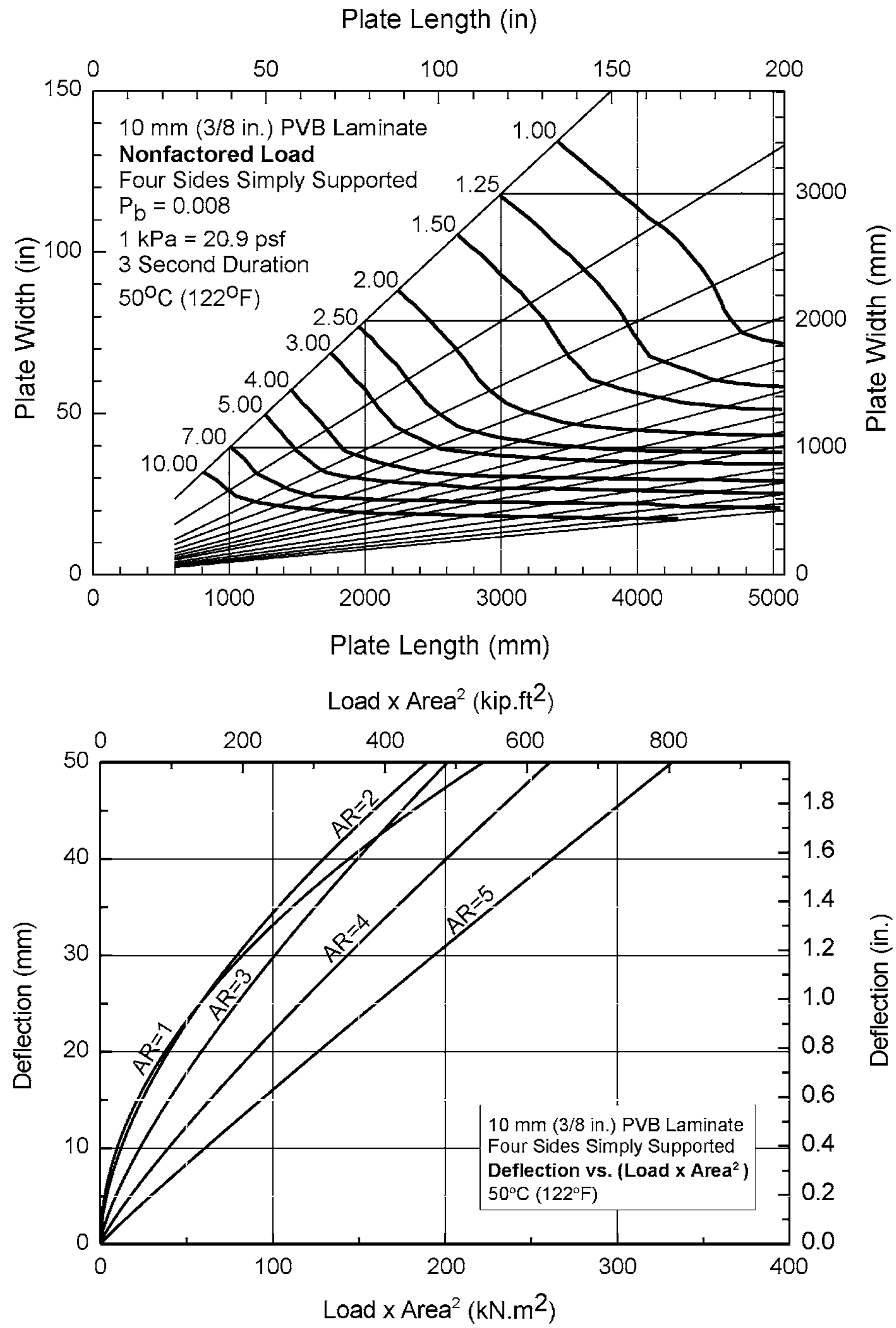
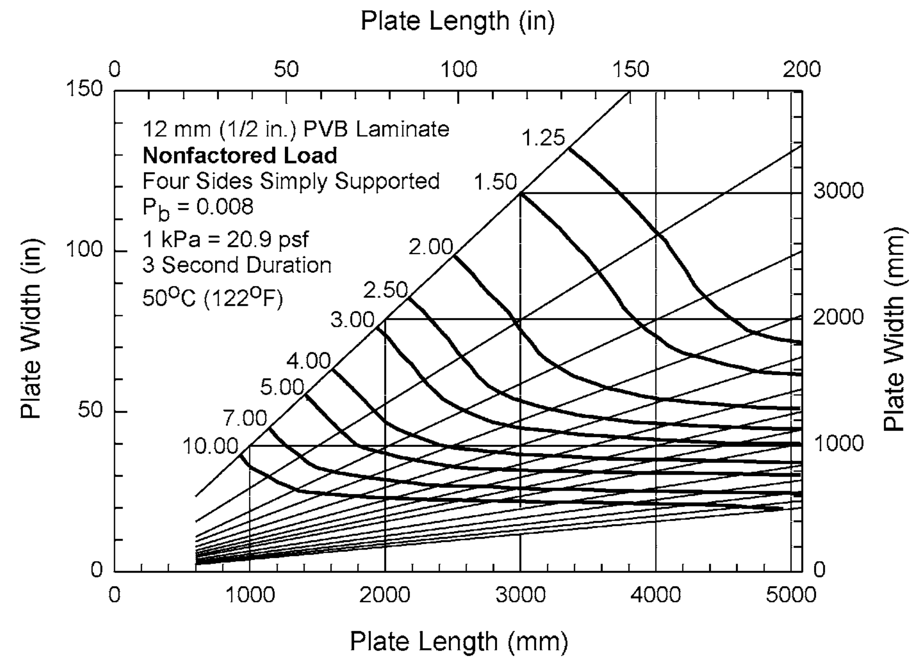


FIG. A1.30 (upper chart) Non-Factored Load Chart for 10.0 mm (3⁄8 in.) Laminated Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 10.0 mm (3⁄8 in.) Laminated Glass with Four Sides Simply Supported



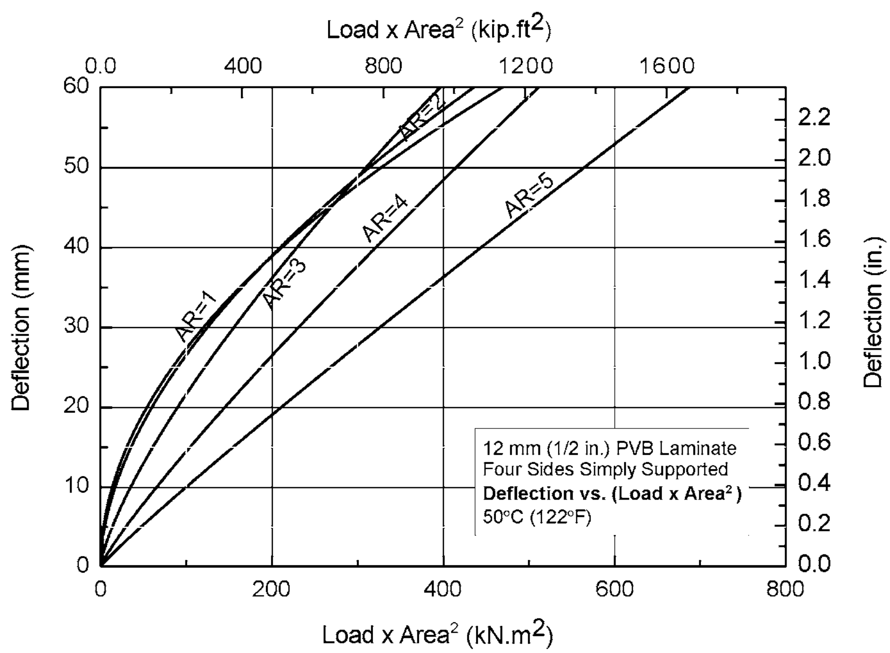


FIG. A1.31 (upper chart) Non-Factored Load Chart for 12.0 mm (½ in.) Laminated Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 12.0 mm (½ in.) Laminated Glass with Four Sides Simply Supported

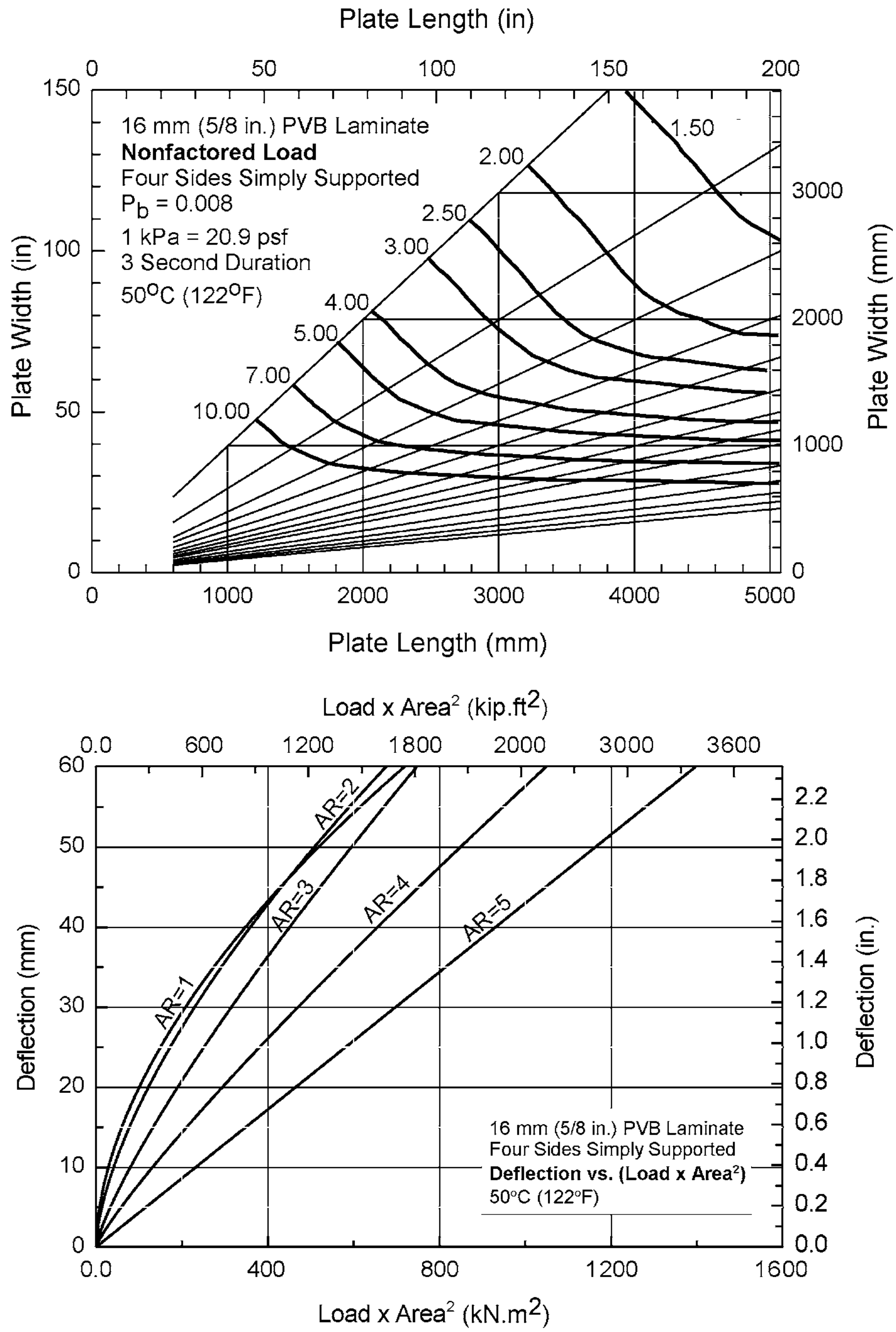
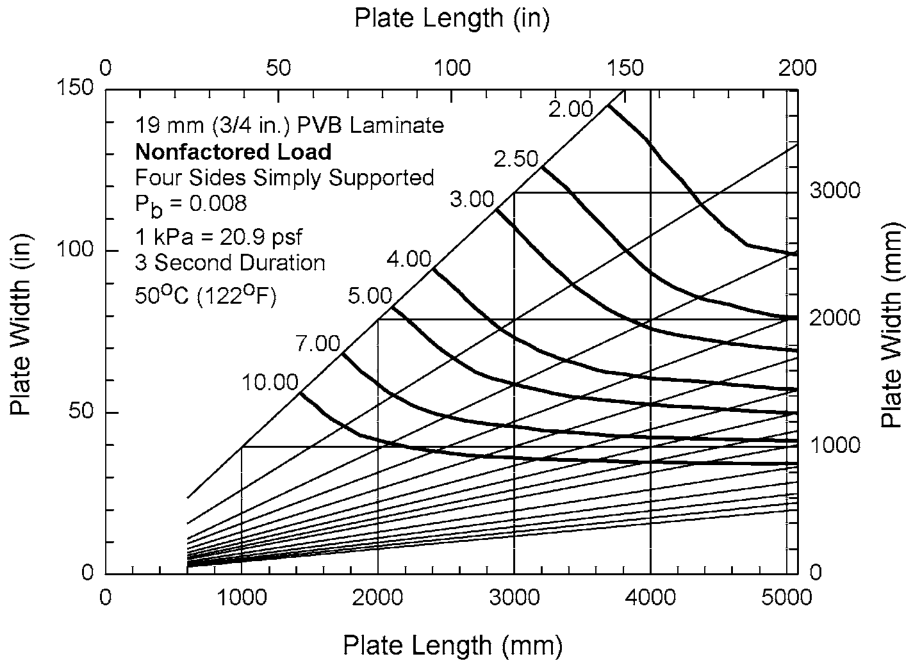


FIG. A1.32 (upper chart) Non-Factored Load Chart for 16.0 mm (⅝ in.) Laminated Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 16.0 mm (⅝ in.) Laminated Glass with Four Sides Simply Supported



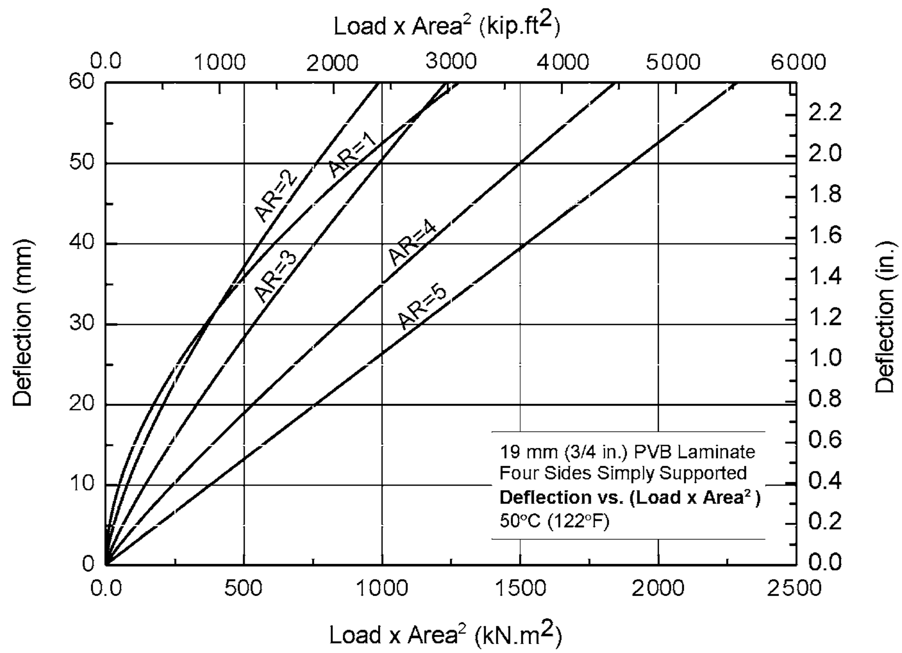
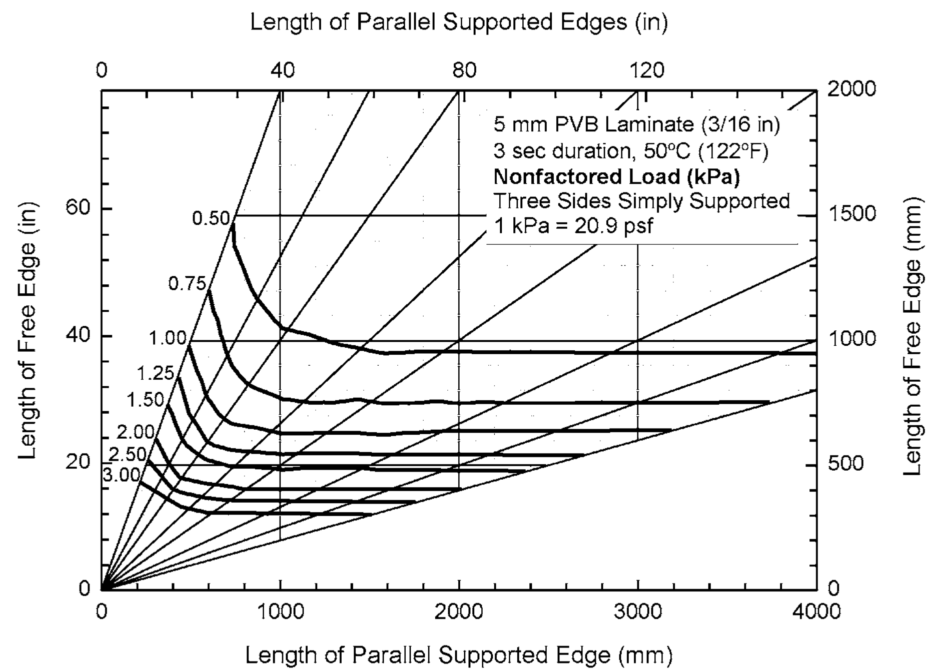


FIG. A1.33 (upper chart) Non-Factored Load Chart for 19.0 mm (¾ in.) Laminated Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 19.0 mm (¾ in.) Laminated Glass with Four Sides Simply Supported



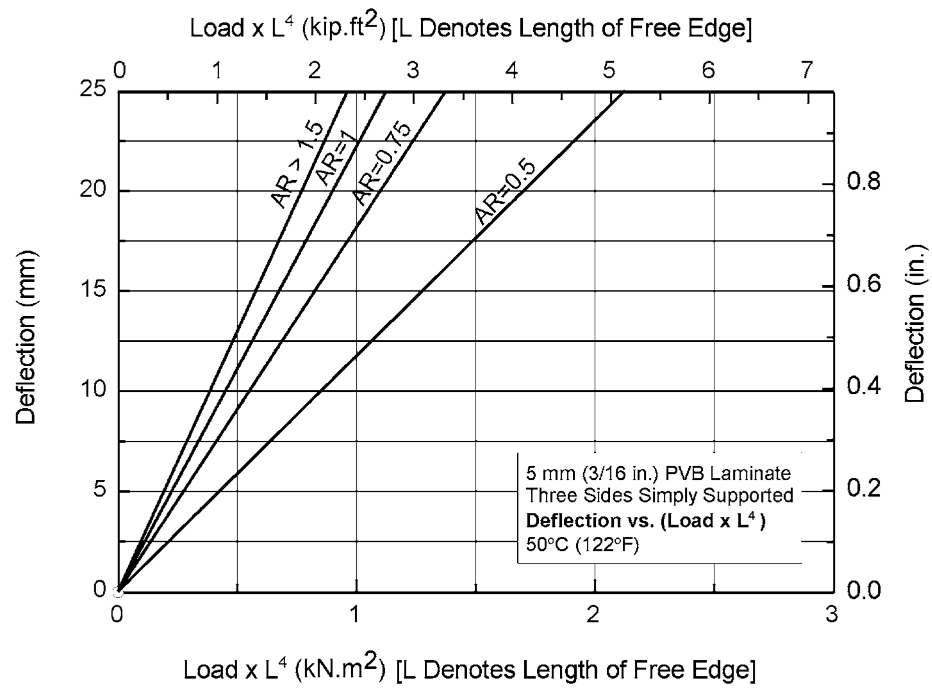


FIG. A1.34 (upper chart) Non-Factored Load Chart for 5.0 mm (3⁄16 in.) Laminated Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 5.0 mm (3⁄16 in.) Laminated Glass with Three Sides Simply Supported

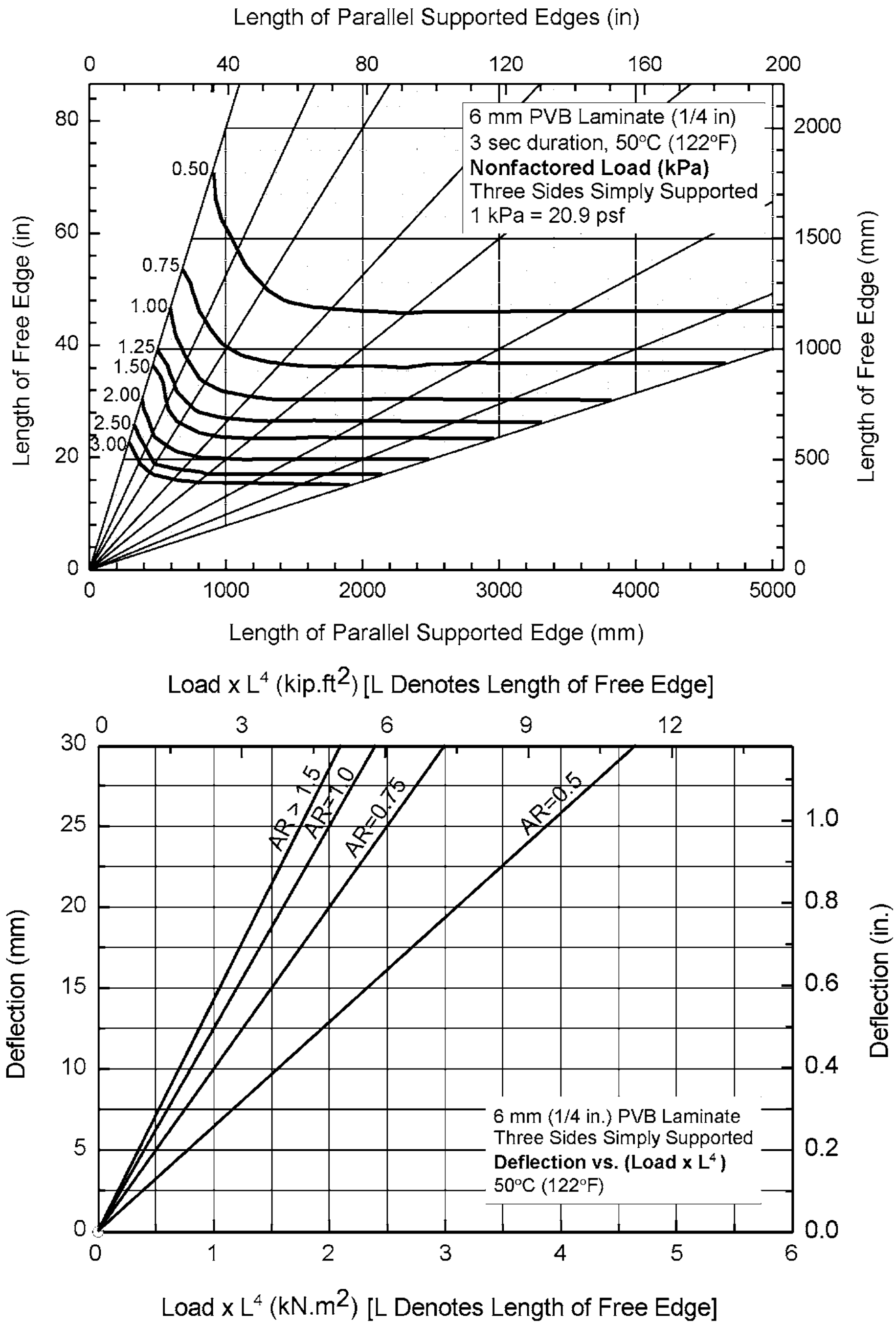
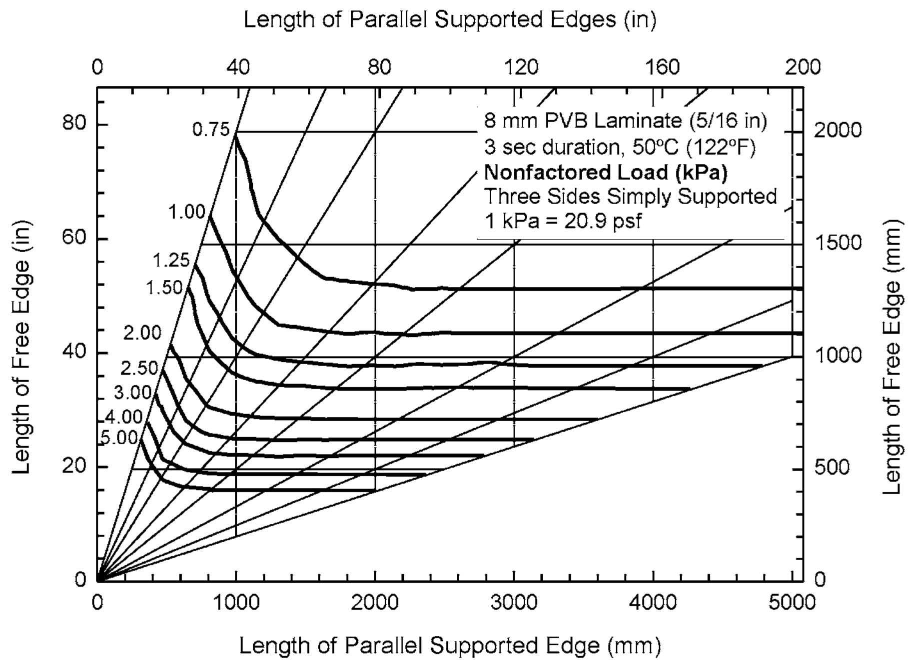


FIG. A1.35 (upper chart) Non-Factored Load Chart for 6.0 mm (¼ in.) Laminated Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 6.0 mm (¼ in.) Laminated Glass with Three Sides Simply Supported



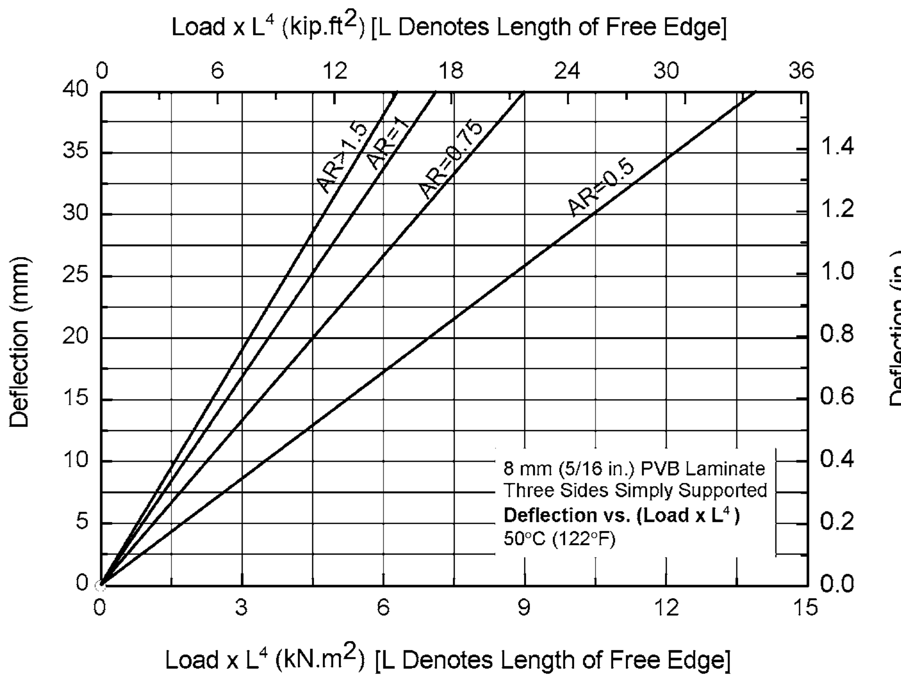
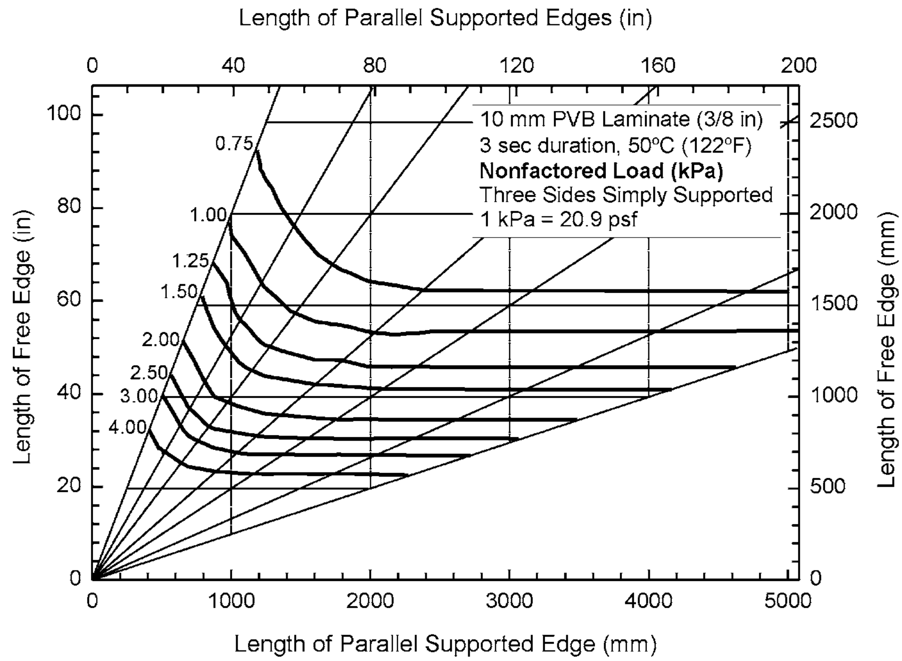


FIG. A1.36 (upper chart) Non-Factored Load Chart for 8.0 mm (5⁄16 in.) Laminated Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 8.0 mm (5⁄16 in.) Laminated Glass with Three Sides Simply Supported



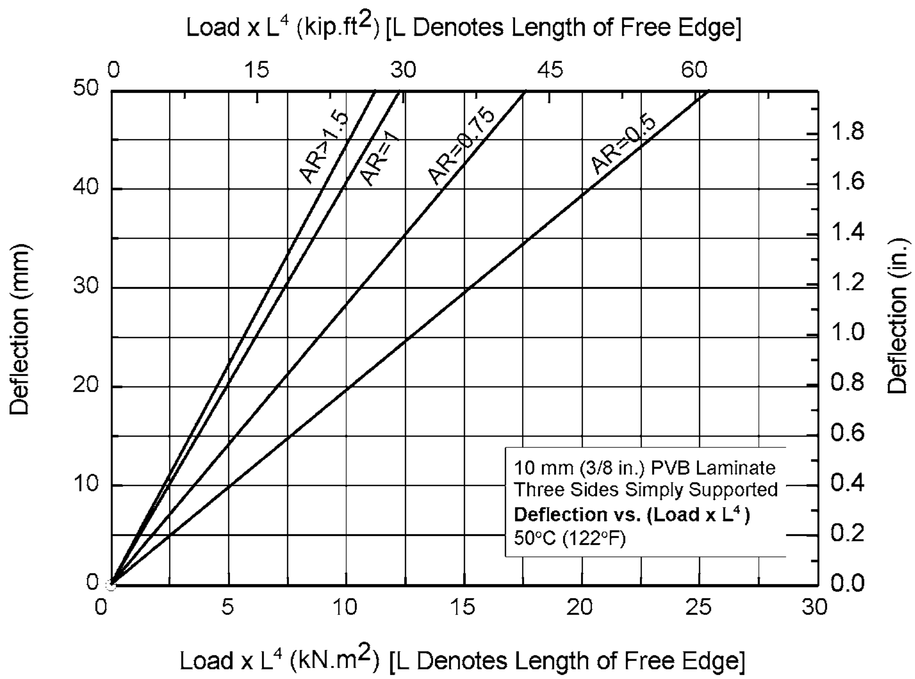
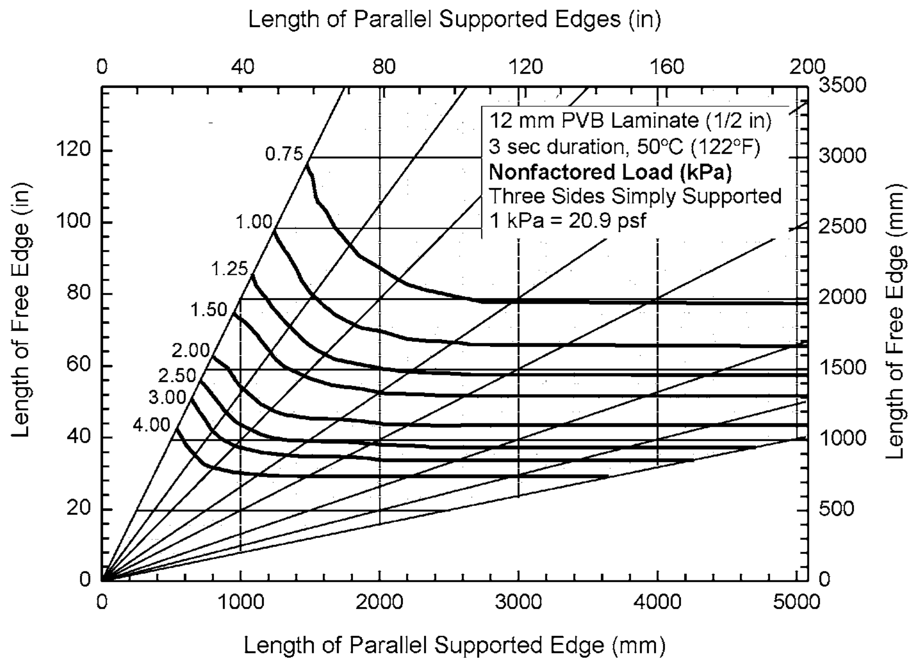


FIG. A1.37 (upper chart) Non-Factored Load Chart for 10.0 mm (3⁄8 in.) Laminated Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 10.0 mm (3⁄8 in.) Laminated Glass with Three Sides Simply Supported



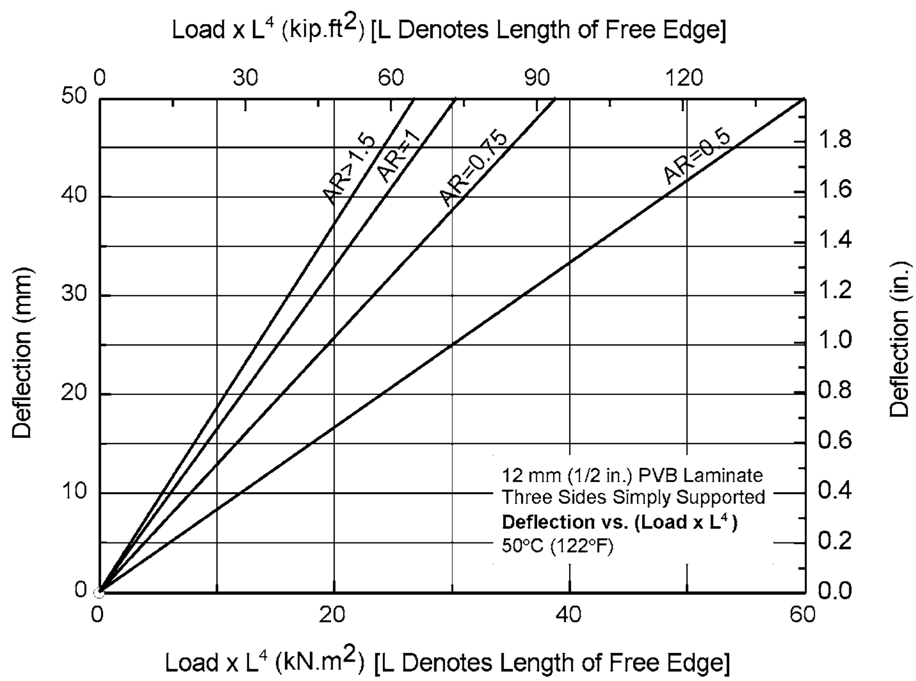
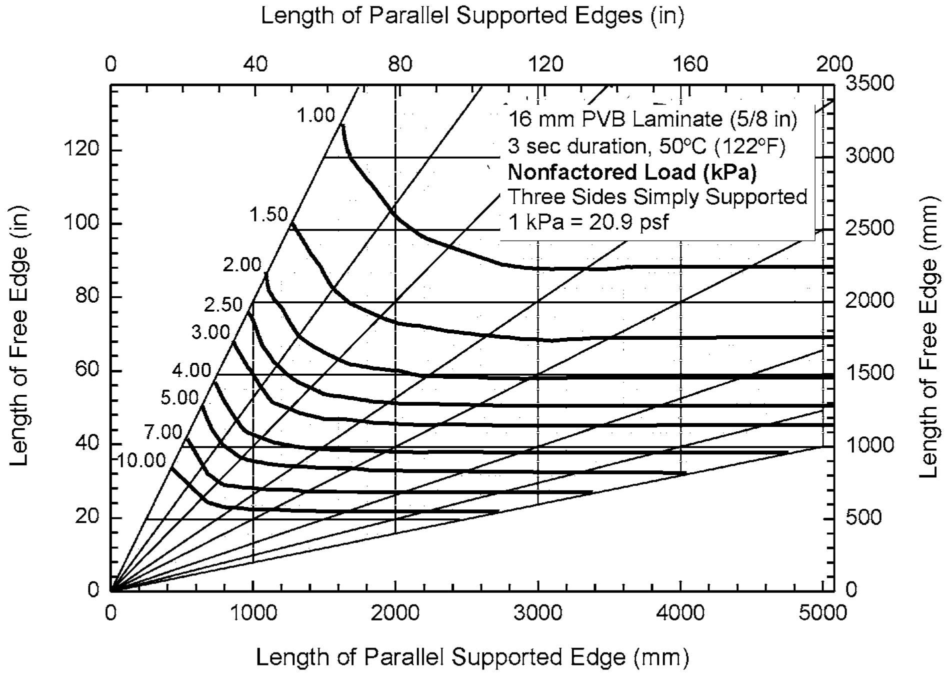


FIG. A1.38 (upper chart) Non-Factored Load Chart for 12.0 mm (½ in.) Laminated Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 12.0 mm (½ in.) Laminated Glass with Three Sides Simply Supported



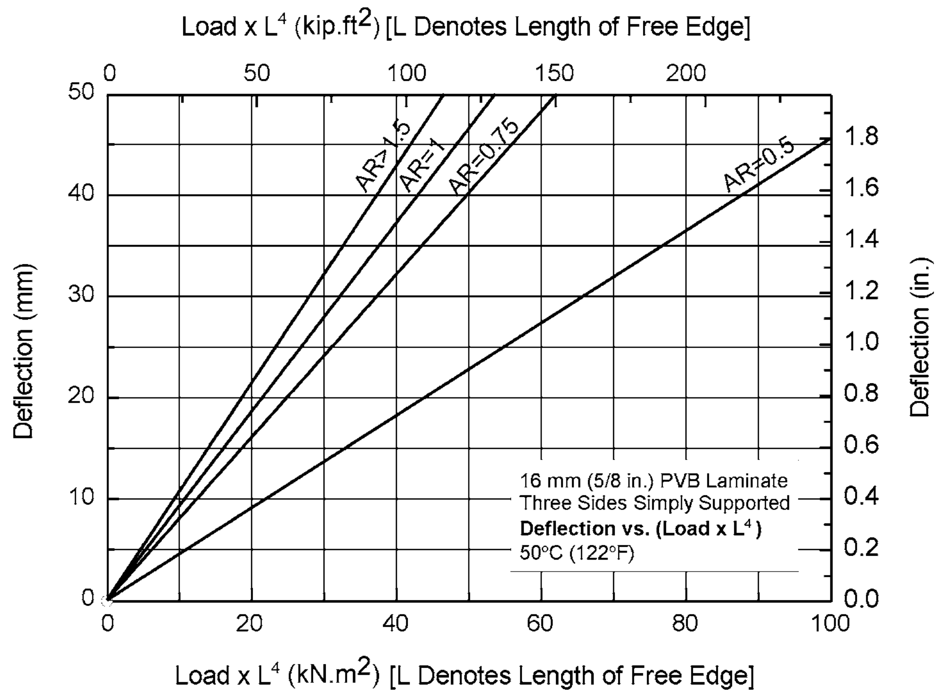


FIG. A1.39 (upper chart) Non-Factored Load Chart for 16.0 mm (⅝ in.) Laminated Glass with Three Sides Simply Supported (lower chart) Deflection Chart for 16.0 mm (⅝ in.) Laminated Glass with Three Sides Simply Supported

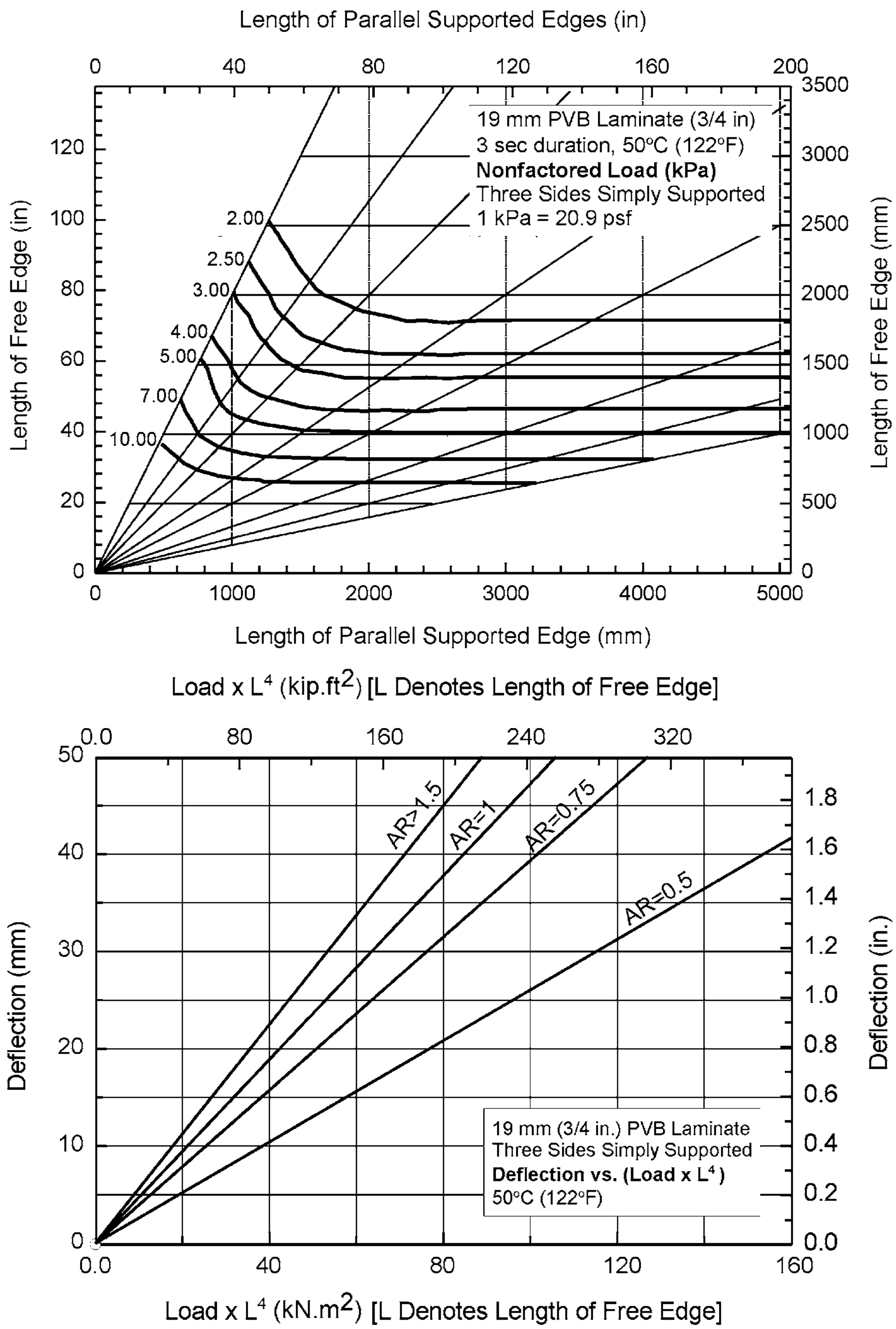


FIG. A1.40 (upper chart) Non-Factored Load Chart for 19.0 mm (¾ in.) Laminated Glass with Three Sides Simply Supported
(lower chart) Deflection Chart for 19.0 mm (¾ in.) Laminated Glass with Three Sides Simply Supported

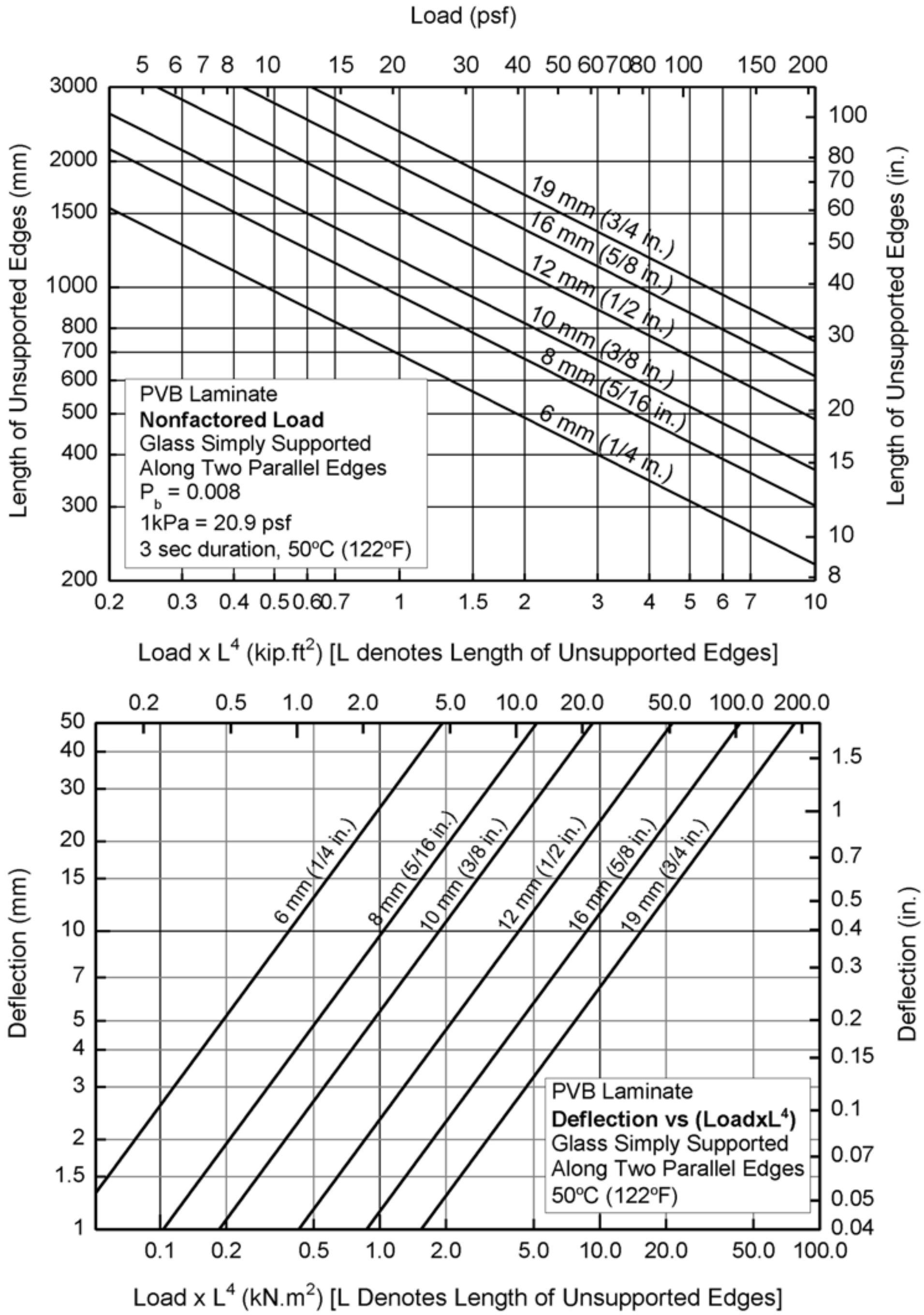


FIG. A1.41 (upper chart) Non-Factored Load Chart for Laminated Glass Simply Supported Along Two Parallel Edges
(lower chart) Deflection Chart for Laminated Glass Simply Supported Along Two Parallel Edges

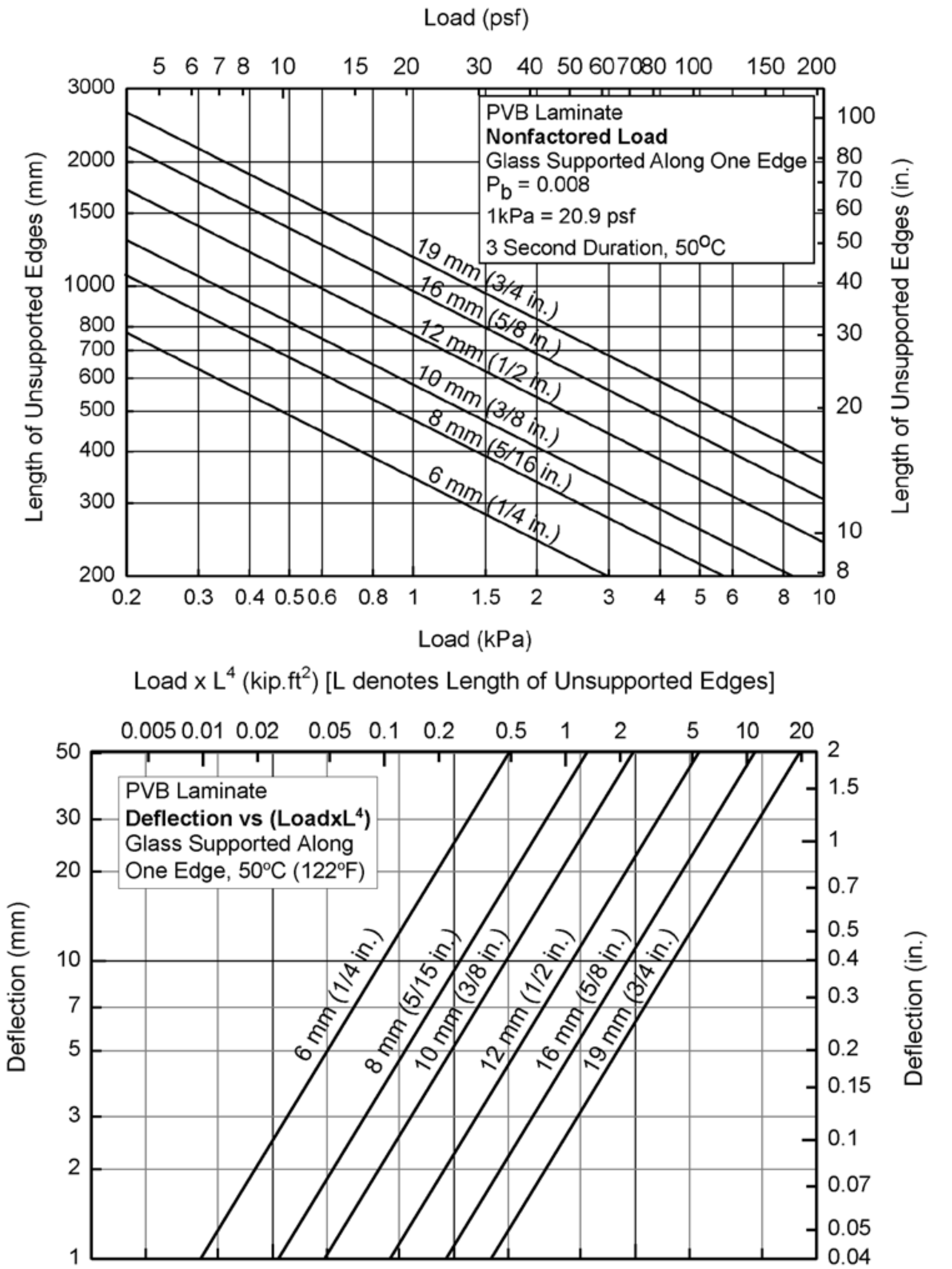


FIG. A1.42 (upper chart) Non-Factored Load Chart for Laminated Glass Supported Along One Edge
(lower chart) Deflection Chart for Laminated Glass Supported Along One Edge

A2. EXAMPLES

A2.1 Examples 1, 2, and 3 illustrate use of the NFL charts and the calculation of the LR. Example 4 illustrates the determination of approximate center of glass deflection.

A2.1.1 *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.

A2.1.2 The appropriate NFL chart is reproduced in Fig. A2.1.

A2.1.3 Enter the horizontal axis of the NFL chart in Fig. A2.1 at 1500 mm and project a vertical line.

A2.1.4 Enter the vertical axis of the NFL chart in Fig. A2.1 at 1200 mm and project a horizontal line.

A2.1.5 Sketch a line of constant AR through the intersection of the lines described in A2.1.3 and A2.1.4 as shown in Fig. A2.1 and interpolate along this line to determine the NFL. The NFL is thus found to be 2.5 kPa.

A2.2 *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.

A2.2.1 The appropriate NFL chart is reproduced in Fig. A2.2.

A2.2.2 Enter the horizontal axis of the NFL chart in Fig. A2.2 at 60 in. and project a vertical line.

A2.2.3 Enter the vertical axis of the NFL chart in Fig. A2.2 at 50 in. and project a horizontal line.

A2.2.4 Sketch a line of constant AR through the intersection of the lines described in A2.1.3 and A2.1.4 as shown in Fig. A2.2 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.

A2.3 *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 mm by 1900 mm. The outboard lite (Lite No. 1) is 6-mm tempered glass; the inboard lite (Lite No. 2) is 8-mm AN 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.

A2.3.1 The NFL for Lite No. 1 (6-mm monolithic tempered) is 1.80 kPa.

A2.3.2 The short duration GTF for Lite No. 1 is 3.80.

A2.3.3 The short duration LS factor for Lite No. 1 is 3.38.

A2.3.4 The LR of the IG based upon the short term LR of Lite No. 1 is:

$$LR = NFL \times GTF \times LS = 1.80 \text{ kPa} \times 3.80 \times 3.38 = 23.1 \text{ kPa} \quad \text{(A2.1)}$$

A2.3.5 The NFL for Lite No. 2 (8-mm AN laminated) is 2.50 kPa.

A2.3.6 The short duration GTF for Lite No. 2 is 1.90.

A2.3.7 The short duration LS factor for Lite No. 2 is 1.42.

A2.3.8 The LR of the IG based upon the short term LR of Lite No. 2:

$$LR = NFL \times GTF \times LS = 2.50 \text{ kPa} \times 1.90 \times 1.42 = 6.75 \text{ kPa} \quad \text{(A2.2)}$$

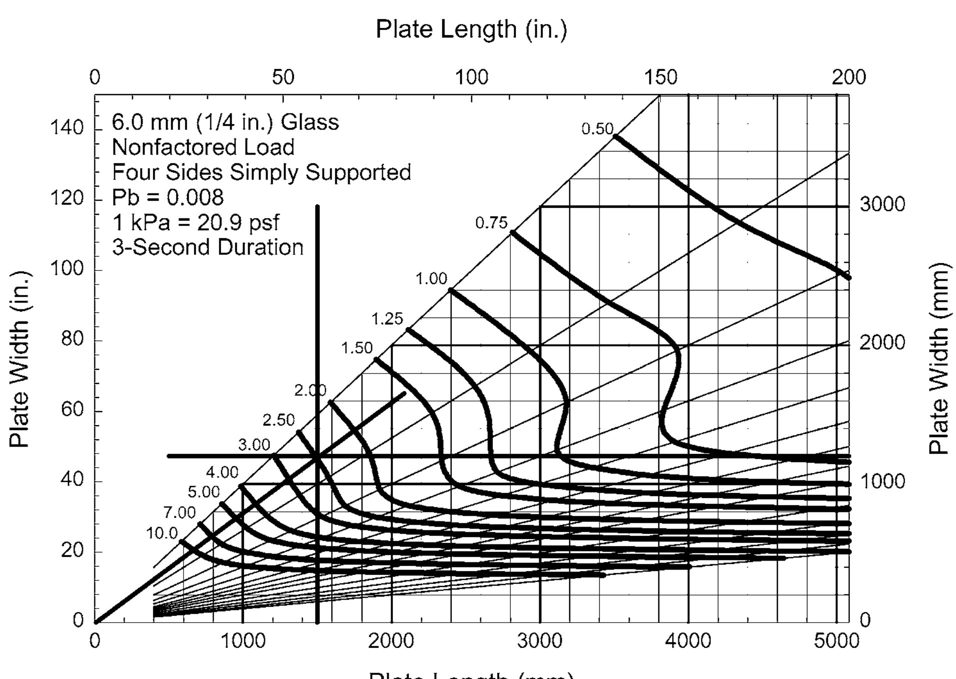


FIG. A2.1 Non-Factored Load Chart for 6.0 mm (¼ in.) Glass

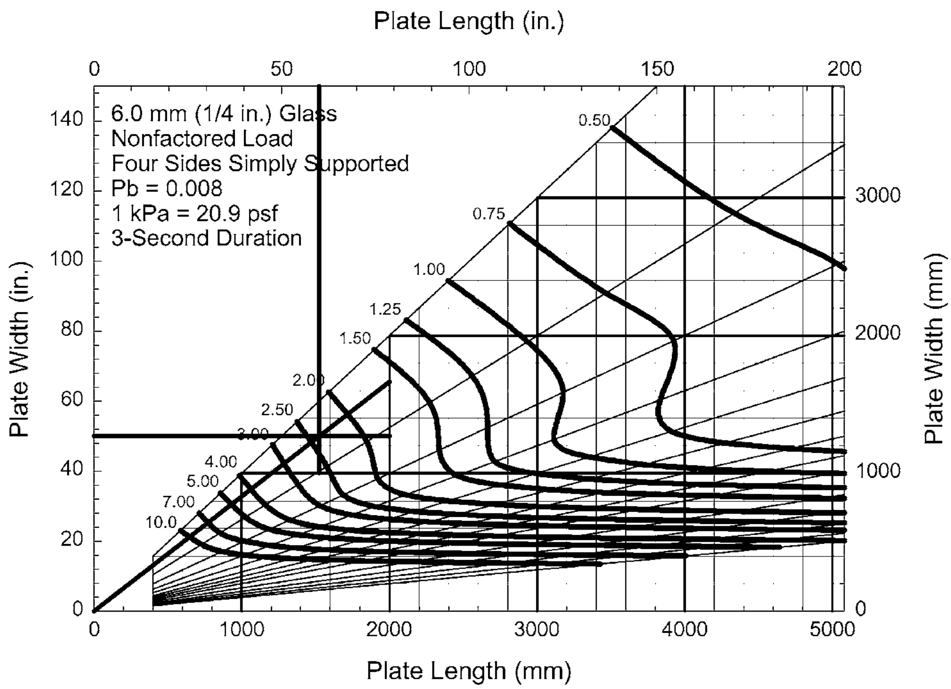


FIG. A2.2 Non-Factored Load Chart for 6.0 mm (¼ in.) Glass

A2.3.9 The long duration GTF for Lite No. 1 is 2.85.

A2.3.10 The long duration LS factor for Lite No. 1 is 1.63.

A2.3.11 The LR of the IG based upon the long term LR of Lite No. 1 is:

$$LR = NFL \times GTF \times LS = 1.80 \text{ kPa} \times 2.85 \times 1.63 = 8.36 \text{ kPa} \quad (A2.3)$$

A2.3.12 The long duration GTF for Lite No. 2 is 1.25.

A2.3.13 The long duration LS for Lite No. 2 is factor 2.59.

A2.3.14 The LR of the IG based upon the short term LR of Lite No. 2 is:

$$LR = NFL \times GTF \times LS = 2.50 \text{ kPa} \times 1.25 \times 2.59 = 8.10 \text{ kPa} \quad (A2.4)$$

A2.3.15 The LR of the IG is 6.75 kPa, the smallest of the values calculated in Eq A2.1-.

NOTE A2.1—The IG has the smallest LR under short duration loading when the laminated AN lite acts in the monolithic mode.

A2.3.16 The load on the horizontal skylight includes the total glass weight (TGW).

$$TGW = GW_1 + GW_2 = 0.15 \text{ kPa} + 0.20 \text{ kPa} = 0.35 \text{ kPa}$$

A2.3.16.1 The TGW of both lites is shared so that Lite No. 1 carries:

$$\left[\frac{LS2}{LS1 + LS2}\right] \times TGW = \left[\frac{1.42}{3.38 + 1.42}\right] \times 0.35 \text{ kPa} = 0.10 \text{ kPa}$$

A2.3.16.2 The TGW of both lites is shared so that Lite No. 2 carries:

$$\left[\frac{LS1}{LS1 + LS2}\right] \times TGW = \left[\frac{3.38}{3.38 + 1.42}\right] \times 0.35 \text{ kPa} = 0.25 \text{ kPa}$$

A2.3.17 The LR of the IG must be reduced by the glass weight. Therefore the LR of the IG is:

$$LR = 6.5 \text{ kPa} - 0.25 \text{ kPa} = 6.50 \text{ kPa} \quad (A2.5)$$

A2.3.18 *Conclusion*—The IG will support the specified long duration load of 6.0 kPa with a probability of breakage less that 8 lites per 1000.

A2.4 *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.

A2.4.1 Calculate the AR of the glass as follows: AR = (1930 mm) / (965 mm) = 2.00.

A2.4.2 Calculate the glass area as follows: Area = (0.965 m) × (1.93 m) = 1.86 m^2.

A2.4.3 Compute (Load × Area^2) as follows: (Load × Area^2) = (1.80 kPa) × (1.86 m^2)^2= 6.24 kN × m^2.

A2.4.4 Project a vertical line upward from 6.24 kN × m^2 along the lower horizontal axis in Fig. A2.3 to the AR2 line.

A2.4.5 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.

A2.5 *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.

A2.5.1 Calculate the AR of the glass as follows: AR = (180 in.)/(60 in.) = 3.00.

A2.5.2 Calculate the glass area as follows: Area = (15 ft) × (5 ft) = 75 ft^2.

A2.5.3 Compute (Load × Area^2) as follows: (Load × Area^2) = (0.020 kip/ft^2) × (75 ft^2)^2= 112 kip × ft^2.

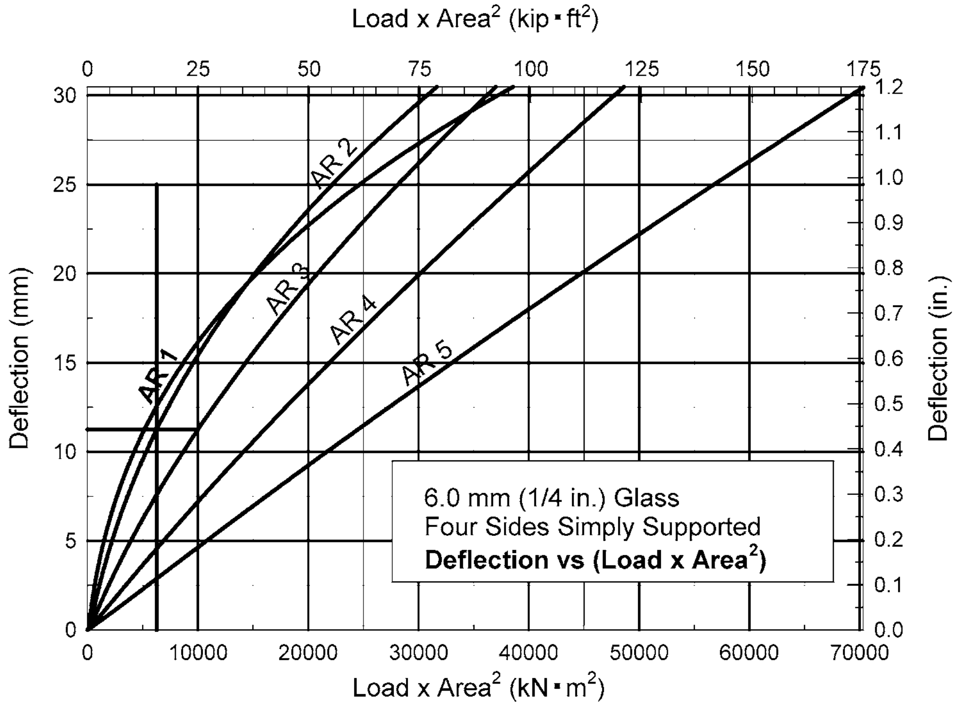


FIG. A2.3 Deflection Chart

A2.5.4 Project a vertical line downward from 112 kip × ft² along the upper horizontal axis in Fig. A2.4 to the AR3 line.

A2.5.5 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.

A2.6 *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 lite, another sealed air space, and a 3-mm AN inner lite will be

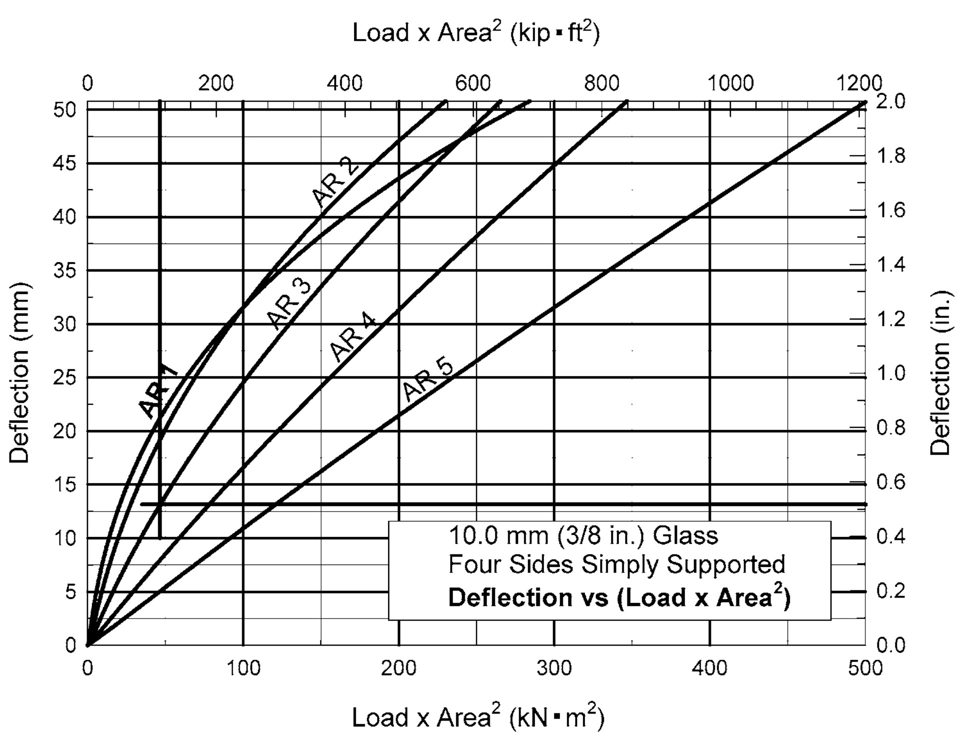


FIG. A2.4 Deflection Chart

subjected to wind load. Will this window glass support a 1.5 kPa short duration load for an 8 in 1000 breakage probability?

A2.6.1 For lites No. 1 and No. 3 the NFL (NFL1 and NFL3) from the 3-mm chart is 1.1 kPa.

A2.6.2 For Lite No. 2 the NFL (NFL2) from the 2.5-mm chart is 0.7 kPa.

A2.6.3 For short duration load the GTF for each of the three AN lites is 0.81.

A2.6.4 The LS factors (LSF1, LSF2, LSF3) for each lite are as follows:

$$LSF1 = (t_1^3 + t_2^3 + t_3^3)/(t_1^3) = (2.92^3 + 2.16^3 + 2.92^3)/(2.92^3) = 2.40$$

$$LSF2 = (t_1^3 + t_2^3 + t_3^3)/(t_2^3) = (2.92^3 + 2.16^3 + 2.92^3)/(2.16^3) = 5.94$$

$$LSF3 = (t_1^3 + t_2^3 + t_3^3)/(t_3^3) = (2.92^3 + 2.16^3 + 2.92^3)/(2.92^3) = 2.40$$

A2.6.5 The LR (LR1, LR2, LR3) of each lite are as follows:

$$LR1 = NFL1 \times GTF1 \times LSF1 = 1.1 \times 0.81 \times 2.40 = 2.13$$

$$LR2 = NFL2 \times GTF2 \times LSF2 = 1.1 \times 0.81 \times 5.94 = 5.29$$

$$LR3 = NFL3 \times GTF3 \times LSF3 = 1.1 \times 0.81 \times 2.40 = 2.13$$

A2.6.6 The LR of the entire triple glazed IG is the lesser of L1, L2, L3. This leaves a short term duration LR for the IG unit of: 2.13 kPa.

A2.6.7 *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.

APPENDIXES

(Nonmandatory Information)

X1. PROCEDURE FOR CALCULATING THE APPROXIMATE CENTER OF GLASS DEFLECTION

X1.1 The first optional procedure presented in Appendix X1 gives the determination of the approximate lateral deflection of a monolithic rectangular glass plate (note the special procedures for laminated and IG) subjected to a uniform lateral load. In development of this procedure, it was assumed that all four edges of the glass are simply supported and free to slip in the plane of the glass. This boundary condition has been shown to be typical of many glass installations (**1**, **3**, **4**).

X1.1.1 This procedure can be used for LG under short-term loads using the LG thickness designation.

X1.1.2 For LG under long-term loads and for symmetrical IG units under long or short-term loads, the approximate lateral deflection is the single lite deflection at half of the design load.

X1.1.3 For IG units under uniform lateral load both lites will deflect by almost equal amounts. The deflection is calculated using the load carried by either lite from Table 5 or Table 6, LS factors. The total load divided by the LS factor for either lite gives the approximate load carried by that lite for deflection calculations.

X1.2 The Vallabhan-Wang nonlinear plate analysis was used to calculate the relationship between the nondimensional load, the nondimensional deflection, and the glass plates AR (**4**). The resulting relationship is depicted in the deflection chart presented in Fig. X1.1. Because the information presented in Fig. X1.1 is nondimensionalized, Fig. X1.1 can be used with either SI or inch-pound units.

X1.2.1 The nondimensional maximum deflection $\hat{w}$ is found by dividing the maximum lateral deflection of the glass, w, by the true glass thickness, t, as follows:

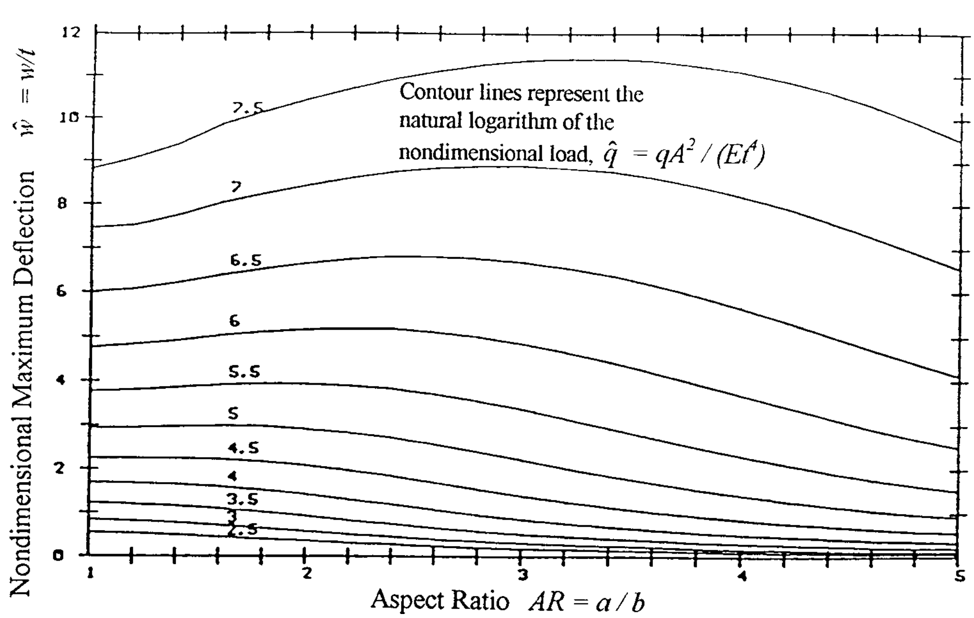


FIG. X1.1 Deflection Chart

$$\hat{w} = w/t \quad (X1.1)$$

The nondimensional maximum deflection is plotted along the vertical axis of the deflection chart. When the actual thickness of the glass is unknown, use the minimum thickness from Table 4 to calculate the deflections.

X1.2.2 The AR of a glass plate is found by dividing the glass length by the glass width as follows:

$$\text{AR} = a/b \quad (X1.2)$$

where:

a = plate length (long dimension), mm (in.), and
b = plate width (short dimension), mm (in.).

X1.2.2.1 The AR is always equal to or greater than 1. The AR is plotted along the horizontal axis of the deflection chart.

X1.2.3 The nondimensional load, q, is calculated using the following equation:

$$q = qA^2 / Et^4 \quad (X1.3)$$

where:

q = applied load, kPa (psi),
t = true glass thickness, mm (in.),
E = Modulus of elasticity of glass, kPa (psi), and
A = area of the rectangular glass plate, mm^2 (in.^{2}).

X1.2.3.1 For practical purposes, the value of E for glass can be taken to be 71.7×10^6 kPa (10.4×10^6 psi). All quantities must be expressed in consistent units.

X1.3 The contour lines plotted on the deflection chart in Fig. X1.1 present the variation of the natural logarithm of the nondimensional loads as a function of the nondimensional deflection and AR.

X1.4 The following procedure can be used to determine the maximum lateral deflection (w) for a particular case.

X1.4.1 Calculate the AR of the glass using Eq X1.2. Locate this point on the horizontal axis of the deflection chart and project a vertical line.

X1.4.2 For monolithic glass and LG under short duration loads, calculate the nondimensional load using Eq X1.3, find its natural logarithm (ln), and interpolate between the contour lines on the deflection chart to locate the corresponding position on the vertical line projected in X1.4.1.

X1.4.2.1 For IG units, calculate the load carried by one lite by dividing the total load by the LS factor. Use this value to calculate the nondimensional load for that lite using Eq X1.3, find its natural logarithm, and interpolate between the contour lines on the deflection chart to locate the corresponding position on the vertical line projected in X1.4.1.

X1.4.3 Project a horizontal line from the point located in X1.4.2. The nondimensional maximum deflection ($\hat{w}$) of the glass is given by the intersection of this horizontal line and the vertical axis of the chart.

X1.4.4 Calculate the maximum deflection (w) of the glass by multiplying the nondimensional deflection ($\hat{w}$) by the true glass thickness.

X1.5 Examples 7 and 8 illustrate this procedure as follows:

X1.5.1 *Example 7: Lateral Deflection Calculation in SI Units*—Determine the maximum lateral deflection (w) associated with 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.

X1.5.1.1 Calculate the AR of the glass as follows:

$$AR = (1500 \text{ mm})/(1200 \text{ mm}) = 1.25 \quad (X1.4)$$

Locate this point on the horizontal axis of the deflection chart presented in Fig. X1.1 and construct a vertical line.

X1.5.1.2 Calculate the natural logarithm of the nondimensional lateral load from Eq X1.3 as follows:

q = 1.80 kPa,
A = (1500 mm) (1200 mm) = 1 800 000 mm^2,
q = (1.80 kPa) (1 800 000 mm^2) ^{2} (71.7×10^6 kPa) (5.6 mm)^4,
q = 82.7, and
$ln(q)$ = (82.7) = 4.42.

Locate the point corresponding to $ln(q)$ = 4.42 on the vertical line drawn in X1.1 by interpolating between the contour lines for $ln(q)$ = 4.0 and 4.5.

X1.5.1.3 Project a horizontal line from the point located in X1.5.1.2. The corresponding nondimensional maximum lateral deflection ($\hat{w}$) is thus seen to be approximately 2.2.

X1.5.1.4 Calculate the maximum lateral deflection of the glass as follows:

$$w = (2.2)\,(5.6 \text{ mm}) = 12.3 \text{ mm} \quad (X1.5)$$

X1.5.2 *Example 8: Lateral Deflection Calculation in Inch-Pound Units*—Determine the maximum lateral deflection associated with a vertical 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.

X1.5.2.1 Calculate the AR of the glass as follows:

$$AR = 60 \text{ in.}/50 \text{ in.} = 1.2 \quad (X1.6)$$

Locate this point on the horizontal axis of the deflection chart presented in Fig. X1.1 and construct a vertical line.

X1.5.2.2 Calculate the natural logarithm of the nondimensional lateral load from Eq X1.3 as follows:

q = (38 lbf/ft^2) (1⁄144 psi/psf) = 0.264 psi,
A = (50 in.) (60 in.) = 3000 in.^{2},
q = (0.264 psi) (3000 in.^{2})^2/[(10.4×10^6 psi) (0.22 in.)^4],
q = 97.5, and
$ln(q)$ = ln(97.5) = 4.58.

Locate the point corresponding to $ln(q)$ = 4.58 on the vertical line drawn in X1.5.2.1 by interpolating between the contour lines for $ln(q)$ = 4.5 and 5.0.

X1.5.2.3 Project a horizontal line from the point located in X1.5.2.2. The corresponding nondimensional maximum lateral deflection is thus seen to be approximately 2.4.

X1.5.2.4 Calculate the maximum lateral deflection of the glass as follows:

$$w = (2.4)\,(0.22 \text{ in.}) = 0.53 \text{ in.} \quad (X1.7)$$

X2. ALTERNATE PROCEDURE FOR CALCULATING THE APPROXIMATE CENTER OF GLASS DEFLECTION

X2.1 Maximum glass deflection as a function of plate geometry and load may be calculated from the following polynomial equations by Dalgliesh (**5**) for a curve fit to the Beason and Morgan (**3**) data from:

$$w = t \times exp(r_0 + r_1 \times x + r_2 \times x^2) \quad \text{(X2.1)}$$

where:

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

$$r_0 = 0.553 - 3.83\,(a/b) + 1.11\,(a/b)^2 - 0.0969\,(a/b)^3 \quad \text{(X2.2)}$$

$$r_1 = -2.29 + 5.83\,(a/b) - 2.17\,(a/b)^2 + 0.2067\,(a/b)^3 \quad \text{(X2.3)}$$

$$r_2 = 1.485 - 1.908\,(a/b) + 0.815\,(a/b)^2 - 0.0822\,(a/b)^3 \quad \text{(X2.4)}$$

$$x = ln\{ln[q(ab)^2 / Et^4]\} \quad \text{(X2.5)}$$

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).

X2.2 Examples 9 and 10 illustrate this procedure as follows:

X2.2.1 *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.

X2.2.2 $a = 1500$
$b = 1200$

From Eq X2.2 $r_0 = -2.689$

X2.2.3 From Eq X2.3 $r_1 = 2.011$

X2.2.4 From Eq X2.4 $r_2 = 0.213$

X2.2.5 $q = 1.80$
$E = 71.7 \times 10^6$
$t = 5.60$

From Eq X2.5 $x = 1.490$

X2.2.6 Therefore from Eq X2.1 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

X2.2.7 *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.

X2.2.8 $a = 60$
$b = 50$

From Eq X2.2 $r_0 = -2.612$

X2.2.9 From Eq X2.3 $r_1 = 1.938$

X2.2.10 From Eq X2.4 $r_2 = 0.227$

X2.2.11 $q = 38$
$E = 10.4 \times 10^6$
$t = 0.220$

From Eq X2.5 $x = 1.527$

X2.2.12 Therefore from Eq X2.1 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.

X3. OPTIONAL PROCEDURE FOR ESTIMATING PROBABILITY OF BREAKAGE FOR ANNEALED (AN) GLASS PLATES UNDER 60-SECOND DURATION LOAD

X3.1 The purpose of the optional procedure presented in Appendix X3 is to provide a method to estimate the probability of breakage, P_b, of rectangular AN glass subjected to a specified design load. This is accomplished using the following approximate relationship:

$$P_b = k(ab)^{1-m}(Et^2)^m e^J \quad \text{(X3.1)}$$

where:

P_b = the probability of breakage,
k and m = surface flaw parameters,
a and b = the rectangular dimensions of the glass,
E = the modulus of elasticity of glass,
t = glass thickness,
e = 2.7182, and
J = the stress distribution factor.

Fig. X3.1 presents values of J as a function of glass AR, AR, and nondimensional lateral load (q). The use of Eq X3.1 is acceptable providing that the calculated probability of breakage is less than 0.05 (50 lites per thousand).

X3.2 The steps involved in this optional procedure to evaluate the probability of breakage for an AN glass plate are listed in X3.2.1-X3.2.5.

X3.2.1 Determine the nondimensional lateral load (q) using Eq X1.3 in Appendix X1. Locate this point on the vertical axis of Fig. X3.1 and extend a horizontal line to the right.

X3.2.2 Determine the AR of the glass using Eq X1.2 in Appendix X1. Locate this point on the horizontal axis on Fig. X3.1 and extend a vertical line upward until it intersects the horizontal line drawn in X3.2.1.

X3.2.3 Use interpolation along the vertical line to estimate the value of J corresponding to the intersection of the two lines.

X3.2.4 Use Eq X3.1 to estimate the probability of breakage of the glass.

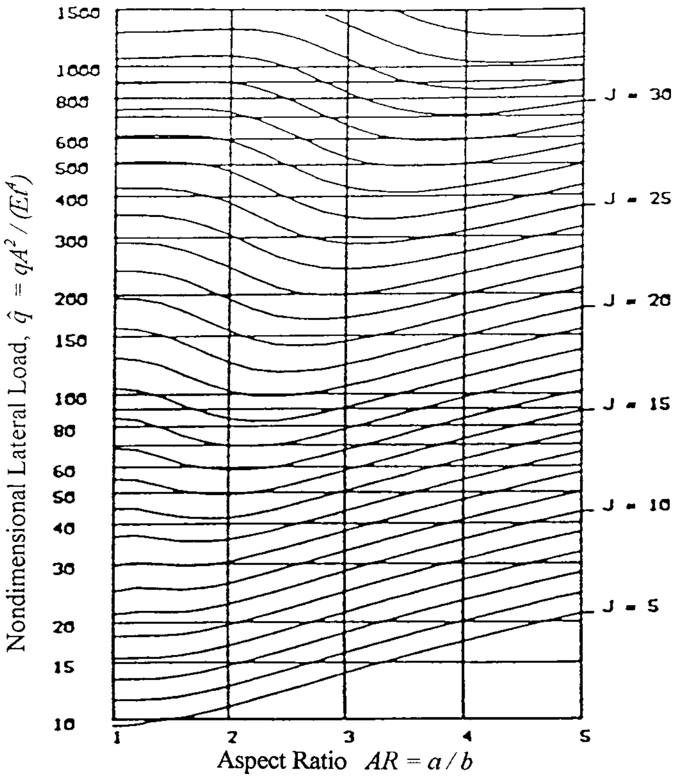


FIG. X3.1 Stress Distribution *J*

X3.2.5 Check to ascertain that the calculated probability of breakage is less than 50 lites per thousand.

X3.3 Use of this method is demonstrated in Examples 11 and 12 as follows:

X3.3.1 *Example 11: Estimating Glass Probability of Breakage Using SI Units*—Determine the probability of breakage associated with a 1200 by 1500 by 6-mm rectangular glass plate exposed to an specified design load of 2.2 kPa. The actual thickness of the glass plate is assumed to be 5.60 mm as determined through direct measurement.

X3.3.1.1 Determine the nondimensional lateral load q as follows:

q = 2.2 kPa,
A = (1200 mm) (1500 mm) = 1 800 000 mm^2,
$\hat{q}$ = [(2.2 kPa) (1 800 000 mm^2)^2]/[(71.7 × 10^6 kPa) (5.6 mm)^4], and
$\hat{q}$ = 101.

Locate this point on the vertical axis of Fig. X3.1 and sketch a horizontal line.

X3.3.1.2 The AR of this plate is 1500/1200 = 1.25, as determined in example X1.5.1. Locate this point on the horizontal axis of Fig. X3.1 and extend a vertical line upward until it intersects the horizontal line of X3.3.1.1.

X3.3.1.3 Interpolate the value of J at the intersection of the two lines in Fig. X3.1. The value of J thus determined is approximately 18.0.

X3.3.1.4 Calculate the probability of breakage as follows:

$$P_b = (2.86 \times 10^{-53}\ m^{12}N^{7})\,(1.2\,m \times 1.5\,m)^{-6} \qquad \text{(X3.2)}$$
$$\times\,[71.7 \times 10^{9}\ Pa \times (0.0056\,m)^2]^7 e^{18.0}$$
$$P_b = 0.016$$

X3.3.1.5 The calculated probability of breakage is less than the 0.050 procedural limit. Therefore, the use of Eq X3.1 is valid. This does not imply that a probability of 0.016 constitutes an acceptable design.

X3.3.2 *Example 12: Estimating Glass Probability of Breakage Using Inch-Pound Units*—Determine the probability of breakage associated with a 50 by 60 by ¼-in. rectangular glass plate exposed to an specified design load of 45 psf. The actual thickness of the glass plate is assumed to be 0.220 in. as determined through direct measurement.

X3.3.2.1 Determine the nondimensional lateral load q as follows:

q = (45 psf) (1⁄144 psi/psf) = 0.312 psi,
A = (50 in.) (60 in.) = 3 000 in.^{2},
$\hat{q}$ = [(0.312 psi) (3 000 in.^{2})^2]/[(10.4 × 10^6 psi) (0.22 in.)^4], and
$\hat{q}$ = 115.

Locate this point on the vertical axis of Fig. X3.1 and sketch a horizontal line.

X3.3.2.2 The AR of this plate is 1.2 as determined in Example 8 (see X1.5.2). Locate this point on the horizontal axis of Fig. X3.1 and extend a vertical line upward until it intersects the horizontal line of X3.3.2.2.

X3.3.2.3 Interpolate the value of J at the intersection of the two lines in Fig. X3.1. The value of J thus determined is approximately 18.5.

X3.3.2.4 Calculate the probability of breakage as follows:

$$P_b = (1.365 \times 10^{-29}\ \text{in.}^{12}\ \text{lb}^{-7})\,(50 \times 60\ \text{in.})^{-6} \qquad \text{(X3.3)}$$
$$\times\,[10.4 \times 10^{6}\ \text{psi}\,(0.22\ \text{in.})^2]^7 e^{18.5} \qquad \text{(X3.3)}$$
$$P_b = 0.017 \qquad \text{(X3.3)}$$

X3.3.2.5 The calculated probability of breakage is less than the 0.050 procedural limit. Therefore, the use of Eq X3.1 is valid. This does not imply that a probability of 0.017 constitutes an acceptable design.

X4. COMMENTARY

X4.1 Determination of Type Factors

X4.1.1 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.

X4.2 Determination of Type Factors for Insulating Glass (IG)

X4.2.1 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.

X4.2.2 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,

$$p = 1.00 \tag{X4.1}$$

X4.2.3 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:

$$p = 0.95 \tag{X4.2}$$

X4.2.4 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:

$$p = 1.05 \tag{X4.3}$$

X4.2.5 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:

$$p = 1.0 \tag{X4.4}$$

X4.2.6 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:

$$asp = 0.95 \tag{X4.5}$$

X5. DETERMINATION OF INSULATING GLASS (IG) LOAD SHARE (LS) FACTORS

X5.1 The LS 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.)

X5.2 For the LS factors in Table 5, the LS factor for Lite No. 1 is:

$$LS1 = (t_1{}^3 + t_2{}^3)/(t_1{}^3) \tag{X5.1}$$

where:

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

Similarly the LS factor for Lite No. 2 is:

$$LS2 = (t_1{}^3 + t_2{}^3)/(t_2{}^3) \tag{X5.2}$$

NOTE X5.1—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 load sharing factors for short duration loads is the sum of the thickness of glass of the 2 plies (in accordance with Table 1).

X5.3 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 LS factor for one ply of the laminated lite of an IG composed of: monolithic glass, air space, laminated, is:

$$LS_{ply} = (t_1{}^3 + 2 \times t_{ply}{}^3)/(t_{ply}{}^3) \tag{X5.3}$$

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

X6. LOAD DURATION FACTORS

X6.1 The purpose of Appendix X6 is to convert a calculated 3-s LR to a load duration listed in Table X6.1. To convert, multiply the LR by the factor in Table X6.1.

TABLE X6.1 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

X7. COMBINING LOADS OF DIFFERENT DURATION

X7.1 The purpose of Appendix X7 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.

X7.2 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:

$$q_3 = \sum_{i=1}^{i=j} q_i \left[\frac{d_i}{3}\right]^{1/n} \tag{X7.1}$$

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.

X8. APPROXIMATE MAXIMUM SURFACE STRESS TO BE USED WITH INDEPENDENT STRESS ANALYSES

X8.1 The purpose of Appendix X8 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).

X8.2 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.

X8.3 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.

X8.4 Maximum allowable surface stress is calculated using the following equation which has its basis in the same glass failure prediction that was used to develop the NFL charts in Section 6.

$$\sigma_{\text{allowable}} = \left(\frac{P_B}{[k\,(d/3)^{7/n} * A]}\right)^{1/7} \tag{X8.1}$$

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.

X8.5 The NFLs that are determined in this manner should be conservative with respect to the values presented in Section 6.

X8.6 Eq X8.1 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.)

X9. APPROXIMATE MAXIMUM EDGE STRESS FOR GLASS

X9.1 The purpose of Appendix X9 is to provide a conservative estimate for the 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 (**6**).

TABLE X9.1 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.

X9.2 This 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. A conservative allowable edge stress value for a 3-s duration can be found in Table X9.1.

X9.3 The 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.

X10. METHOD FOR ESTABLISHING EQUIVALENCY OF NON-POLYVINYL BUTYRAL (PVB) POLYMER INTERLAYERS

X10.1 The purpose of Appendix X10 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.

X10.2 The NFL charts for PVB LG have been derived from a stress analysis that incorporates a viscoelastic model for the plastic interlayer (**7**). 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.

X10.3 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.

X10.3.1 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.

X10.4 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.

X11. METHOD FOR DETERMINING EFFECTIVE THICKNESS OF LAMINATED GLASS FOR ANALYSIS OF LOAD RESISTANCE

X11.1 The purpose of Appendix X11 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 X11 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.

X11.2 The shear transfer coefficient, Γ, which is a measure of the transfer of shear stresses across the interlayer, is given by:

$$\Gamma = \frac{1}{1 + 9.6\dfrac{EI_s h_v}{Gh_s^2 a^2}} \quad \text{(X11.1)}$$

with:

$$I_s = h_1 h_{s;2}^2 + h_2 h_{s;1}^2 \quad \text{(X11.2)}$$

$$h_{s;1} = \frac{h_s h_1}{h_1 + h_2} \quad \text{(X11.3)}$$

$$h_{s;2} = \frac{h_s h_2}{h_1 + h_2} \quad \text{(X11.4)}$$

$$h_s = 0.5\,(h_1 + h_2) + h_v \quad \text{(X11.5)}$$

where:
h_v = interlayer thickness (mm),
h_1 = glass ply 1 minimum thickness (mm) (see Table 4),
h_2 = glass ply 2 minimum thickness (mm) (see Table 4),
E = glass Young's modulus (= 71.7 GPa),
a = length scale (smallest in-plane dimension of the laminate plate), and
G = interlayer storage shear modulus (see X11.4).

X11.2.1 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.

X11.3 For calculations of laminate deflection, the laminate effective thickness, $h_{ef;w}$, is given by:

$$h_{ef;w} = \sqrt[3]{h_1^3 + h_2^3 + 12\Gamma I_s} \quad \text{(X11.6)}$$

X11.3.1 For calculations of the maximum glass bending stress, the laminate effective thicknesses (one for each glass ply) are given by:

$$h_{1;ef;\sigma} = \sqrt{\frac{h_{ef;w}^3}{h_1 + 2\Gamma I_{s;2}}} \quad \text{(X11.7)}$$

$$h_{2;ef;\sigma} = \sqrt{\frac{h_{ef;w}^3}{h_2 + 2\Gamma I_{s;1}}} \quad \text{(X11.8)}$$

X11.3.2 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 (**8**).

X11.4 The primary interlayer property that influences the laminate deformation is the storage shear modulus, G. The storage shear modulus is a measure of the plastic interlayer's shear resistance. The greater the shear resistances, the more effectively the two glass plies couple and resist deformation under loading. The effective laminate thickness approaches the equivalent monolith thickness for stiff interlayers (Γ → 1) and approaches the layered limit for compliant interlayers (Γ → 0).

X11.5 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 (**9**) and used by Bennison et al. (**7**), 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.

X11.6 Laminates shall comply with Specification C1172.

X11.7 *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 X11.1 to Eq X11.8 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.).

X11.7.1 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:

$$\sigma_{max} = \frac{6Pa}{h_{1;ef;\sigma}^2} \quad \text{(X11.9)}$$

$$\delta_{max} = \frac{4Pa^3}{Eh_{ef;w}^3} \quad \text{(X11.10)}$$

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

REFERENCES

(1) Beason, W. L., Kohutek, T. L., and Bracci, J. M., "Basis for ASTM E1300 Glass Thickness Selection Procedure," Civil Engineering Department, Texas A & M University, 1996.

(2) Duser, A.V., Jagota, A., and Bennison, S.J., "Analysis of Glass/Polyvinyl Butyral Laminates Subjected to Uniform Pressure," *Journal of Engineering Mechanics*, ASCE, Vol 125, No. 4, 1999, pp. 435–441.

(3) Beason, W. L., and Morgan, J. R., "Glass Failure Prediction Model," *Journal of Structural Engineering*, Vol 111, No. 9, 1985, pp. 2058–2059.

(4) Vallabhan, C. V. G., "Interactive Analysis of Nonlinear Glass Plates," *Journal of Structural Engineering*, ASCE, Vol 102, No. 2, February 1983, pp. 489–502.

(5) Dalgliesh, A., *CGSB 12.20 Structural Design of Glass for Buildings*, NRC National Research Council of Canada.

(6) Walker, G. R., and Muir, L. M., "An Investigation of the Bending Strength of Glass Louvre Blades," *Proceedings of the 9th Australian Conference on the Mechanics of Structures and Materials*, Sydney, Australia, August, 1984.

(7) Bennison, S. J., Jagota, A., and Smith, C. A., "Fracture of Glass/Polyvinyl Butyral (Butacite)Laminates in Biaxial Flexure," *Journal of the American Ceramic Society*, Vol 82, No. 7, 1999, pp. 1761–1770.

(8) Wölfel, E., "Elastic Composite: An Approximation Solution and its Application Possibilities" *Stahlbau*, Vol 6, 1987, pp. 173–180.

(9) Ferry, J. D., *Viscoelastic Properties of Polymers*, 3rd edition, Hoboken, NJ: John Wiley & Sons, 1980.