Title

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Guidelines for Determining the Load Resistance of Thin-Glass Triple-Pane Insulating Glass Unit Configurations

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Guidelines for Determining the Load Resistance of Thin-Glass Triple-Pane Insulating Glass Unit Configurations

Prepared for the
California Energy Commission

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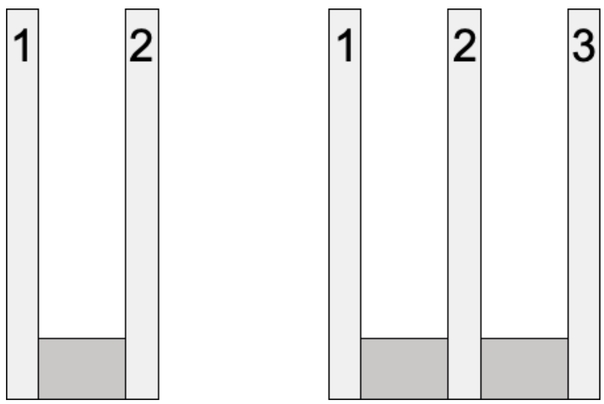
1. SCOPE

This guideline is intended to provide information relevant to the specification of triple-pane insulating glass (IG) units where the thickness of lite number 2 (center lite) is less than or equal to the thickness of lite numbers 1 and 3, as shown in Figure 1. Procedures and charts are presented to determine the load resistance (LR) of common soda-lime glass thicknesses from 0.7 mm (3/128 in.) to 1.8 mm (9/128 in.) exposed to a uniform lateral load of short or long duration, for a 0.008 probability of breakage. Deflection under load, horizontal self-weight deflection, and natural frequency procedures and charts are also included to aide in the selection of glass thickness to meet manufacturing and/or loading criteria determined by the user.

Figure 1. Lite numbering for a) double-pane and b) triple-pane IG units



This guideline is intended to supplement ASTM E1300-16, Standard Practice for Determining Load Resistance of Glass in Buildings[1]. The guideline is limited to vertical glass with four sides simply supported. It is intended to provide information to aid in the selection of triple-pane glazing configurations. It does not address all sizing or safety concerns, and the user assumes all risks from its use. Users should refer to ASTM E1300 where possible and that standard takes priority when in conflict with this document.

2. SUMMARY OF USE

The procedures, tables, and figures presented in this guideline can be used to determine the thickness of glass required to meet the desired performance criteria for a given scenario based on load resistance (LR), deflection in vertical orientation, deflection in horizontal orientation, and natural frequency. The appendices include the following reference table and figures:

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[1] ASTM Standard E1300, 2016, "Standard Practice for Determining Load Resistance of Glass in Buildings," ASTM International, West Conshohocken, PA, 2021, DOI: 10.1520/E1300-16

Appendix A: Load Share Factors for Triple Glazed Insulating Glass (IG) Units

Appendix B: Non-Factored Load (NFL) Charts
Appendix C: Horizontal Deflection Charts
Appendix D: Natural Frequency Charts
Appendix E: IG Unit Weight Chart

ASTM C1036[2] provides standard specifications for flat glass. The minimum thickness for standard nominal glass sizes from 1.0 mm (micro-slide) to 25 mm (1 in.) are included in the standard. These minimum thicknesses are utilized in ASTM E1300 for the calculation of nonfactored load (NFL), deflection, and glass type factor (GTF) calculations. These thicknesses are reproduced in Table 1 up to 10 mm (3/8 in.). The authors were unable to identify minimum dimension tolerance standards for glass less than 1.0 mm (micro- slide), so thicknesses less than 1.0 mm (micro-slide) presented in Table 1 are based off flat glass manufacturer reported internal standards. Typical thickness is utilized for the natural frequency and IGU weight charts. This data is based on the minimum reported typical thicknesses at each glass thickness from multiple flat glass suppliers.

Table 1. Nominal, Minimum and Typical Glass Thicknesses

Nominal Thickness mm (in.)	Minimum Thickness mm (in.)	Typical Thickness mm (in.)
0.7 (3/128)*	0.5 (0.020)*	0.71 (0.028)*
0.9 (5/128)*	0.7 (0.028)*	0.92 (0.036)*
1.0 (micro-slide)	0.79 (0.031)	1.02 (0.039)
1.2 (3/64)*	1.0 (0.039)*	1.22 (0.048)*
1.5 (photo)	1.27 (0.05)	1.53 (0.060)
1.8 (9/128)*	1.6 (0.063)*	1.78 (0.070)*
2.0 (picture)	1.80 (0.071)	1.98 (0.078)
2.5 (single)	2.16 (0.085)	2.24 (0.088)
2.7 (lami)	2.59 (0.102)	2.64 (0.104)
3.0 (double)	2.92 (0.115)	2.97 (0.117)
4.0 (5/32)	3.78 (0.149)	3.86 (0.152)
5.0 (3/16)	4.57 (0.180)	4.65 (0.183)
6.0 (1/4)	5.56 (0.219)	5.64 (0.222)
8.0 (5/16)	7.42 (0.292)	7.92 (0.300)
10.0 (3/8)	9.02 (0.355)	9.22 (0.363)

*non-standard glass thicknesses

[2] ASTM Standard C1036, 2021, "Standard Specification for Flat Glass," ASTM International, West Conshohocken, PA, 2021, DOI: 10.1520/C1036-21

The glass type factor (GTF) is a factor to adjust load resistance based on glass type; Annealed (AN), heat strengthened (HS), and fully tempered (FT). The GTF from of Table 7 in ASTM E1300-16 for triple-pane IG units shall be used for all related calculations in this guide. The table is reproduced here for clarity.

Table 2. 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

IG unit manufacturers often limit the maximum area and length of an IG unit based on glass thickness. These maximums are independent of loading requirements and are most often internal guidelines for safe handling within their factory. The table below shows typical requirements for annealed glass from a broad selection of US and international manufacturers. This table is provided for guidance on sizing the external lites (1 and 3) of a triple pane IG unit.

Table 3. IG Unit Sizing Limits for Load Bearing Glass Lites

Nominal Thickness external lites	Maximum Area	Maximum Length
mm (in.)	m^2 (ft^2)	mm (in.)
2.5 (single)	0.93 (10)	1780 (70)
3.0 (double)	1.39 (15)	2030 (80)
4.0 (5/32)	1.86 (20)	2290 (90)
5.0 (3/16)	3.25 (35)	2540 (100)
6.0 (1/4)	4.65 (50)	3050 (120)

3. PROCEDURES/EXAMPLES

Five examples are provided to illustrate potential uses of this guide.

Example 1: Determine the short duration Load Resistance (LR) of a four sided simply supported 800 by 1200 mm triple-pane annealed IG unit with thickness of lite1 = 3.0 mm (double), lite2 = 1.0 mm (micro-slide) and lite2 = 3.0 mm (double):

1. Determine the LSF1 for lite 1, LSF2 for lite 2, and LSF3 for lite 3 from Appendix A.

   LSF1 = 0.495

   LSF2 = 0.010

   LSF3 = 0.495

   When LSF2 is ≤0.05, the lite can be assumed non-structural in the assembly and the nonfactored load (NFL2) and load resistance (LR2) can be disregarded for the remainder of the load calculation.

2. Determine the NFL1 for lite 1, NFL2 for lite 2, and NFL3 for lite 3 from the upper charts of Figures in Appendix B. For glass thicknesses greater than 1.8 mm (9/128 in.) the figures provided in ASTM E1300 Appendix 1 should be utilized.

   NFL1 = 1.95 kPa (from ASTM E1300-16 Fig. A1.4 upper chart)

   NFL2 = not calculated since lite is non-structural, per step 1

   NFL3 = 1.95 kPa (from ASTM E1300-16 Fig. A1.4 upper chart)

3. Determine the GTF1 for lite 1, GTF2 for lite 2, and GTF3 for lite 3 from Table 2.

   GTF1 = 0.81

   GTF2 = 0.81

   GTF3 = 0.81

4. Multiply NFL by GTF and divide by LSF to determine the LR for each lite.

   LR1 = NFL1 x GTF1 ÷ LSF1 = 1.95 kPa x 0.81 ÷ 0.495 = 3.19 kPa

   LR2 = not calculated since lite is non-structural, per step 1

   LR3 = NFL3 x GTF3 ÷ LSF3 = 1.95 kPa x 0.81 ÷ 0.495 = 3.19 kPa

5. The LR of the IG unit is the minimum of LR1, LR2 and LR3

   LR = 3.19 kPa

Example 2: Determine the short duration Load Resistance (LR) of a four sided simply supported 600 by 800 mm triple-pane annealed IG unit with thickness of lite1 = 2.5 mm (single), lite2 = 1.8 mm (9/128) and lite2 = 2.5 mm (single):

1. Determine the LSF1 for lite 1, LSF2 for lite 2, and LSF3 for lite 3 from Appendix A.

   LSF1 = 0.416

   LSF2 = 0.169

   LSF3 = 0.416

LSF2 is ≥0.05, so is structural and cannot be disregarded for the remainder of the load calculation.

2. Determine the NFL1 for lite 1, NFL2 for lite 2, and NFL3 for lite 3 from the upper charts of Figures in Appendix B. For glass thicknesses greater than 1.8 mm (9/128 in.) the figures provided in ASTM E1300 Appendix 1 should be utilized.
   NFL1 = 2.25 kPa (from ASTM E1300-16 Fig. A1.2 upper chart)
   NFL2 = 1.50 kPa
   NFL3 = 2.25 kPa (from ASTM E1300-16 Fig. A1.2 upper chart)

3. Determine the GTF1 for lite 1, GTF2 for lite 2, and GTF3 for lite 3 from Table 2.
   GTF1 = 0.81
   GTF2 = 0.81
   GTF3 = 0.81

4. Multiply NFL by GTF and divide by LSF to determine the LR for each lite.
   LR1 = NFL1 x GTF1 ÷ LSF1 = 2.25 kPa x 0.81 ÷ 0.416 = 4.38 kPa
   LR2 = NFL2 x GTF2 ÷ LSF2 = 1.50 kPa x 0.81 ÷ 0.169 = 7.19 kPa
   LR3 = NFL3 x GTF3 ÷ LSF3 = 2.25 kPa x 0.81 ÷ 0.416 = 4.38 kPa

5. The LR of the IG unit is the minimum of LR1, LR2 and LR3
   LR = 4.38 kPa

Example 3: Determine the minimum glass thickness for each annealed lite of an 800 x 1000 mm triple-pane IG unit for a short duration LR ≥2.0 kPa, overall thickness (OA) of 25 mm, and horizontal deflection of any lite ≤ 30% of between glass gap width. Assume equal air space thickness.

1. Determine the GTF1 for lite 1, GTF2 for lite 2, and GTF3 for lite 3
   GTF1 = 0.81
   GTF2 = 0.81
   GTF3 = 0.81

2. Assume lite 2 is non-structural.
   LSF1 = 0.50
   LSF2 = 0
   LSF3 = 0.50

When LSF2 is ≤0.05, the lite can be assumed non-structural in the assembly and the nonfactored load (NFL2) and load resistance (LR2) can be disregarded for the remainder of the load calculation.

3. Multiply LR by LSF and divide by GTF to determine the NFL required for each lite

   NFL1 = LR x LSF1 ÷ GTF1 = 2.0 kPa x 0.50 ÷ 0.81 =1.23 kPa

   NFL2 = not calculated since lite is non-structural, per step 2

   NFL3 = LR x LSF3 ÷ GTF3 = 2.0 kPa x 0.50 ÷ 0.81 =1.23 kPa

4. Determine the glass thickness required to meet the calculated NFL1 for lite 1 and NFL3 for lite 3 from the upper charts in Appendix B. For glass thicknesses greater than 1.8 mm (9/128 in.) the figures provided in ASTM E1300 Appendix 1 should be utilized.

   From Figure B.6 upper chart for 1.8 mm (9/128 in.) glass:

   NFL1 ≈0.90 kPa, which is less than 1.23 kPa from step 3.

   NFL3 ≈0.90 kPa, which is less than 1.23 kPa from step 3.

   From ASTM E1300-16 Figure A1.2 upper chart for 2.5 mm (single) glass:

   NFL1 ≈1.5 kPa, which is greater than 1.23 kPa from step 3

   NFL3 ≈1.5 kPa, which is greater than 1.23 kPa from step 3

   Therefore:

   Lite 1 thickness = 2.5 mm (single)

   Lite 3 thickness = 2.5 mm (single)

5. *Determine the horizontal deflection (HD) for glass thicknesses less than or equal to the thickness of lite 1 and lite 3.*

   AR = Long Dimension / Short Dimension = 1000 mm / 800 mm = 1.25

   *Area = Long Dimension x Short Dimension = 1000 mm*800 mm/(1000000 mm^2/m^2) = 0.8 m^2*

   From Figures C.1 through C.8 for horizontal deflection (HD)

   0.7 mm (3/128 in.): HD_0.7 = 4.9 mm

   0.9 mm (5/128 in.): HD_0.9 = 4.5 mm

   1.0 mm (micro-slide): HD_1.0 = 4.2 mm

   1.2 mm (3/64 in.): HD_1.2 = 3.6 mm

   1.5 mm (photo): HD_1.5 = 3.0 mm

   1.8 mm (9/128 in.): HD_1.8 = 2.5 mm

   2.0 mm (picture): HD_2.0 = 2.1 mm

   2.5 mm (single): HD_2.5 = 1.7 mm

6. *Determine the size of each gas gap (GG) by subtracting the typical thickness (T) of each lite in the IG unit from the overall thickness (OA) and divide by 2 for the two gas gaps in a triple pane. Calculate for each glass thicknesses (T2) less than or equal to the thickness of lite 1 and lite 3.*

0.7 mm: GG_0.7 = (OA–T1–T2–T3)/2 = (25 mm –2.24 mm –0.71 mm –2.24 mm) / 2 = 9.91 mm
0.9 mm: GG_0.9 = (OA–T1–T2–T3)/2 = (25 mm –2.24 mm –0.92 mm –2.24 mm) / 2 = 9.80 mm
1.0 mm: GG_1.0 = (OA–T1–T2–T3)/2 = (25 mm –2.24 mm –1.02 mm –2.24 mm) / 2 = 9.75 mm
1.2 mm: GG_1.2 = (OA–T1–T2–T3)/2 = (25 mm –2.24 mm –1.22 mm –2.24 mm) / 2 = 9.65 mm
1.5 mm: GG_1.5 = (OA–T1–T2–T3)/2 = (25 mm –2.24 mm –1.53 mm –2.24 mm) / 2 = 9.50 mm
1.8 mm: GG_1.8 = (OA–T1–T2–T3)/2 = (25 mm –2.24 mm –1.78 mm –2.24 mm) / 2 = 9.37 mm
2.0 mm: GG_2.0 = (OA–T1–T2–T3)/2 = (25 mm –2.24 mm –1.98 mm –2.24 mm) / 2 = 9.27 mm
2.5 mm: GG_2.5 = (OA–T1–T2–T3)/2 = (25 mm –2.24 mm –2.24 mm –2.24 mm) / 2 = 9.14 mm

7. *Divide the horizontal deflection from step 5 by the glass gap width from step 6 for each of the potential lite 2 glass thicknesses.*

   0.7 mm: HD_0.7 / GG_0.7 x 100 = 4.9 mm / 9.91 mm x 100 = 49%
   0.9 mm: HD_0.9 / GG_0.9 x 100 = 4.5 mm / 9.80 mm x 100 = 46%
   1.0 mm: HD_1.0 / GG_1.0 x 100 = 4.2 mm / 9.75 mm x 100 = 43%
   1.2 mm: HD_1.2 / GG_1.2 x 100 = 3.6 mm / 9.65 mm x 100 = 37%
   1.5 mm: HD_1.5 / GG_1.5 x 100 = 3.0 mm / 9.50 mm x 100 = 32%
   1.8 mm: HD_1.8 / GG_1.8 x 100 = 2.5 mm / 9.37 mm x 100 = 27%
   2.0 mm: HD_2.0 / GG_2.0 x 100 = 2.1 mm / 9.27 mm x 100 = 23%
   2.5 mm: HD_2.5 / GG_2.5 x 100 = 1.7 mm / 9.14 mm x 100 = 19%

8. *The lite 2 minimum glass thickness is the thinnest glass with a horizontal deflection of ≤30% of between glass gap width.*

   From step 7, HD_1.8 = 27%, so Lite 2 thickness (T2) = 1.8 mm (9/128 in.)

9. *With the lite 2 thickness defined, iterate Steps 2 through 8 until the glass thicknesses remain unchanged.*

   From Appendix A, with T1 = 2.5 mm (single), T2 = 1.8 mm (9/128 in.), and T3 = 2.5 mm (single):
   LSF1 = 0.416
   LSF2 = 0.169

LSF3 = 0.416

LSF2 is ≥0.05, so is structural and cannot be disregarded for the remainder of the load calculation.

Multiply LR by LSF and divide by GTF to determine the NFL required for each lite

NFL1 = LR x LSF1 ÷ GTF1 = 2.0 kPa x 0.416 ÷ 0.81 =1.03 kPa
NFL2 = LR x LSF2 ÷ GTF2 = 2.0 kPa x 0.169 ÷ 0.81 = 0.42 kPa
NFL3 = LR x LSF3 ÷ GTF3 = 2.0 kPa x 0.416 ÷ 0.81 =1.03 kPa

From Figure B.5 upper chart for 1.8 mm (9/128 in.) glass:

NFL1 ≈0.90 kPa, which is less than 1.03 kPa from previous step
NFL3 ≈0.90 kPa, which is less than 1.03 kPa from previous step

From ASTM E1300-16 Figure A1.3 upper chart for 2.5 mm (single) glass:

NFL1 ≈1.5 kPa, which is greater than 1.03 kPa from previous step
NFL3 ≈1.5 kPa, which is greater than 1.03 kPa from previous step

Therefore, glass thickness of 2.5 mm is required to meet load and thickness remains unchanged so iteration is complete. The minimum glass thicknesses required are:

Lite 1 thickness = 2.5 mm (single)
Lite 2 thickness = 1.8 mm (9/128 in.)
Lite 3 thickness = 2.5 mm (single)

Example 4: Determine the weight of the IG unit in Example 3.

Long Dimension = 1000 mm Short
Dimension = 800 mm
AR = Long Dimension / Short Dimension = 1000 mm / 800 mm = 1.25

1. From Appendix E for AR = 1.25 and Short Dimension = 800 mm, the IG unit weight per unit thickness is 2 kg/mm

2. Total glass thickness is the sum of typical glass thickness for each glass layer

From Table 1 the typical thickness for each lite are:

Lite 1 thickness = t_{lite1} *= 2.5 mm (single) [Nominal] = 2.24 mm*
Lite 2 thickness = t_{lite2} *= 1.8 mm (9/128 in.) [Nominal] = 1.78 mm*
Lite 3 thickness = t_{lite3} *= 2.5 mm (single) [Nominal] = 2.24 mm*

$t_{total} = t_{lite1} + t_{lite2} + t_{lite3}$ = 2.24 mm + 1.78 mm + 2.24 mm = 6.26 mm

3. Calculate the total IG unit weight by multiplying the weight per unit thickness from step 1 by the total thickness from step 2.

   IG weight = 2 kg/mm x 6.26 mm = 12.52 kg

Example 5: Determine the minimum glass thickness for each lite of a 1200 mm x 1600 mm triple-pane IG unit for a natural frequency ≥5 Hz for lite 1 and lite 3, and ≥ 3 Hz for lite 2.

1. *Determine IG unit properties required to use tables in Appendix D.*
   Long Dimension = 1600 mm
   Short Dimension = 1200 mm
   AR = Long Dimension / Short Dimension = 1600 mm / 1200 mm = 1.33

2. Determine the Natural Frequency for glass layers from Appendix D with AR = 1.33 and Short Dimension = 1200 mm
   0.7 mm (3/128 in.): NF_0.7 = 1.9
   0.9 mm (5/128 in.): NF_0.9 = 2.5
   1.0 mm (micro-slide): NF_1.0 = 2.7
   1.2 mm (3/64 in.): NF_1.2 = 3.3
   1.5 mm (photo): NF_1.5 = 4.0
   1.8 mm (9/128 in.): NF_1.8 = 5.0
   2.0 mm (picture): NF_2.0 = 5.5

3. Determine the minimum glass thicknesses that meet defined frequency limits.
   Lite 1 thickness = 1.8 mm (9/128 in.)
   Lite 2 thickness = 1.2 mm (3/64 in.)
   Lite 3 thickness = 1.8 mm (9/128 in.)

4. APPENDIX A. LOAD SHARE FACTORS FOR TRIPLE GLAZED INSULATING GLASS (IG) UNITS

Lite No. 2 Monolithic Glass	Lite No. 1 and 3 Monolithic Glass														
Nominal Thickness	0.7 (3/128)	0.9 (5/128)	1.0 (micro-slide)	1.2 (3/64)	1.5 (photo)	1.8 (9/128)	2 (picture)	2.5 (single)	2.7 (lami)	3 (double)	4 (5/32)	5 (3/16)	6 (1/4)	8 (5/16)	10 (3/8)
mm (in.)	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3	LSF1 LSF2 LSF3
0.7 (3/128)	.333 .333 .333	.423 .154 .423	.444 .113 .444	.471 .059 .471	.485 .030 .485	.492 .015 .492	.495 .011 .495	.497 .006 .497	.498 .004 .498	.499 .003 .499	.499 .001 .499	.500 .001 .500	.500 .000 .500	.500 .000 .500	.500 .000 .500
0.9 (5/128)		.333 .333 .333	.371 .258 .371	.427 .146 .427	.461 .077 .461	.480 .040 .480	.486 .029 .486	.492 .017 .492	.495 .010 .495	.497 .007 .497	.498 .003 .498	.499 .002 .499	.500 .001 .500	.500 .000 .500	.500 .000 .500
1.0 (micro-slide)			.333 .333 .333	.401 .198 .401	.446 .107 .446	.472 .057 .472	.480 .041 .480	.488 .024 .488	.493 .014 .493	.495 .010 .495	.498 .005 .498	.499 .003 .499	.499 .001 .499	.500 .001 .500	.500 .000 .500
1.2 (3/64)				.333 .333 .333	.402 .196 .402	.446 .109 .446	.461 .079 .461	.476 .047 .476	.486 .028 .486	.490 .020 .490	.495 .009 .495	.497 .005 .497	.499 .003 .499	.499 .001 .499	.500 .001 .500
1.5 (photo)					.333 .333 .333	.400 .200 .400	.425 .149 .425	.454 .092 .454	.472 .056 .472	.480 .040 .480	.491 .019 .491	.495 .011 .495	.497 .006 .497	.499 .003 .499	.499 .001 .499
1.8 (9/128)						.333 .333 .333	.370 .260 .370	.416 .169 .416	.447 .105 .447	.462 .076 .462	.482 .037 .482	.489 .021 .489	.494 .012 .494	.498 .005 .498	.499 .003 .499
2 (picture)							.333 .333 .333	.388 .224 .388	.428 .144 .428	.448 .105 .448	.474 .051 .474	.485 .030 .485	.492 .017 .492	.496 .007 .496	.498 .004 .498
2.5 (single)								.333 .333 .333	.388 .225 .388	.416 .168 .416	.457 .085 .457	.475 .050 .475	.486 .028 .486	.494 .012 .494	.497 .007 .497
2.7 (lami)									.333 .333 .333	.371 .259 .371	.431 .139 .431	.458 .083 .458	.476 .048 .476	.490 .021 .490	.494 .012 .494
3 (double)										.333 .333 .333	.406 .187 .406	.442 .115 .442	.466 .068 .466	.485 .030 .485	.492 .017 .492
4 (5/32)											.333 .333 .333	.390 .221 .390	.432 .136 .432	.469 .062 .469	.482 .035 .482
5 (3/16)												.333 .333 .333	.391 .217 .391	.448 .105 .448	.469 .061 .469
6 (1/4)													.333 .333 .333	.413 .174 .413	.448 .105 .448
8 (5/16)														.333 .333 .333	.391 .218 .391
10 (3/8)															.333 .333 .333

5. APPENDIX B: NON-FACTORED LOAD (NFL) CHARTS

The NFL charts presented here are created using the same methodology as those provided in ASTM E1300 – 16 Standard Practice for Determining Load Resistance of Glass in Buildings. The glass thicknesses of 0.7 mm (3/128 in.), 0.9 mm (5/128 in.), 1.0 mm (micro-slide), 1.2 mm (3/64 in.), 1.5 mm (photo), and 1.8 mm (9/128 in.) provided here are not included in the current edition of ASTM E1300 – 16. The NFL charts were developed using the procedure presented in Annex 2 of ASTM E1300 – 16.

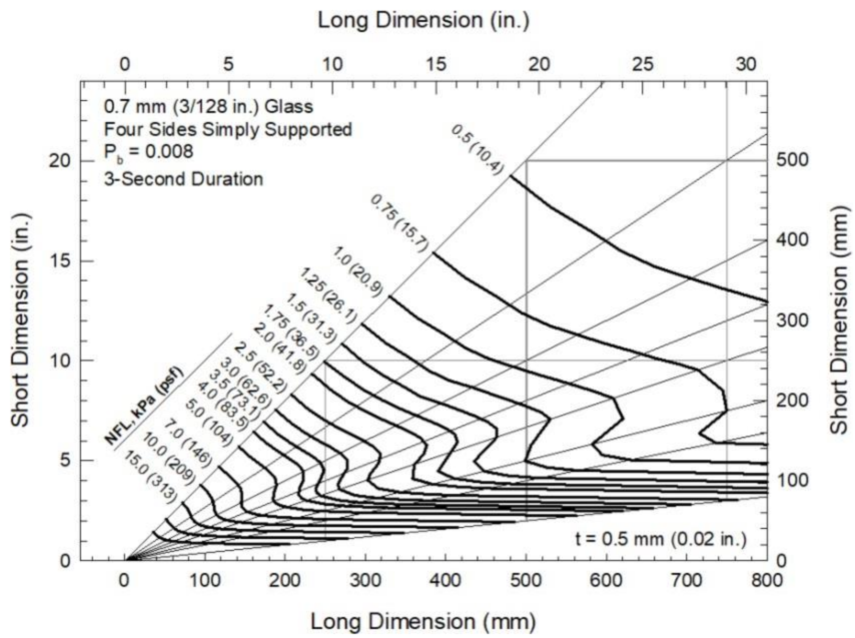
The data presented in the NFL charts are based on the minimum glass thicknesses allowed by ASTM C1036. These minimum glass thicknesses are presented in Table 1. Glass may be manufactured thicker than those minimums. Not accounting for this fact in the NFL charts makes the charts conservative from a design standpoint. The authors were unable to identify minimum dimension tolerance standards for glass thicknesses of 0.7 mm (3/128 in.), 0.9 mm (5/128 in.), 1.2 mm (3/64 in.) or 1.8 mm (9/128 in.), so thicknesses for these products in Table 1 are based off flat glass manufacturer reported internal standards.

The maximum center of glass lateral deflection of a lite is often a major consideration in the selection of glass. No recommendations are made regarding acceptable lateral deflections. The lower charts of Fig. B.1 through Fig. B.6 indicate the maximum lateral deflection of the glass.

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

1. Select the appropriate chart to be used based upon the nominal glass thickness.
2. Enter the horizontal axis of the chart at the point corresponding to the long dimension of the glass and project a vertical line.
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 step 2.
4. Draw a line of constant aspect ratio (AR) from the point of zero length and width through the intersection point in step 3.
5. Determine the NFL by interpolating between the load contours along the diagonal line of constant AR drawn in step 4.

Figure B.1: (upper chart) Non-Factored Load Chart for 0.7 mm (3/128 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 0.7 mm (3/128 in.) Glass with Four Sides Simply Supported



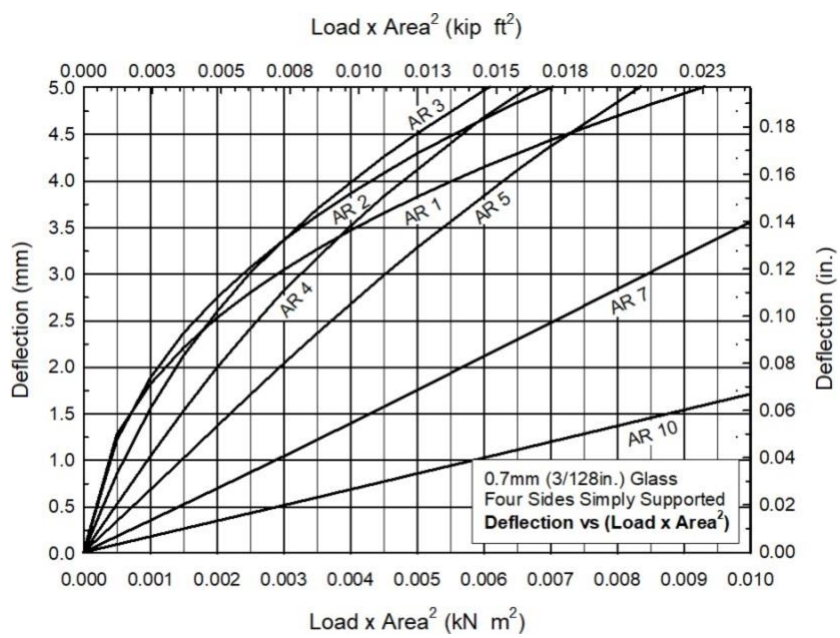
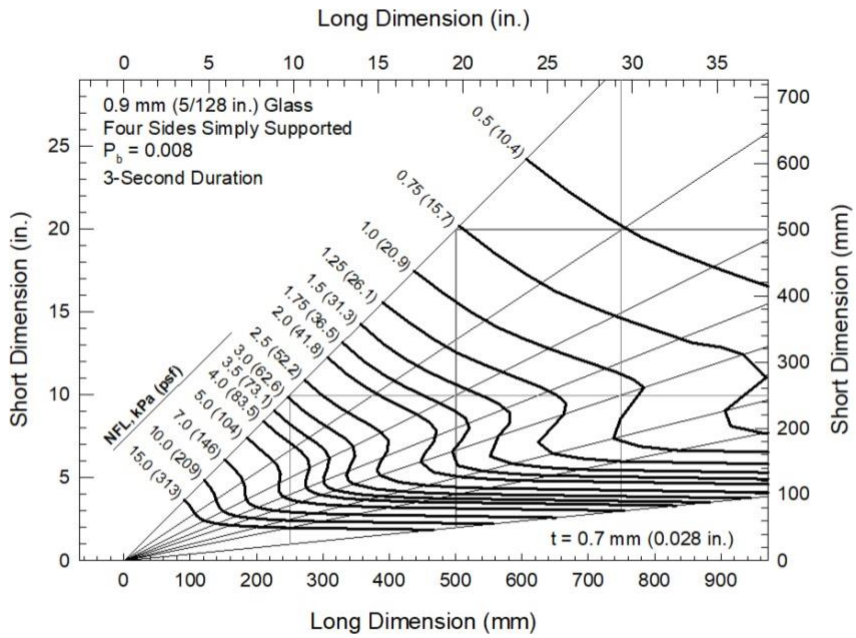


Figure B.2: (upper chart) Non-Factored Load Chart for 0.9 mm (5/128 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 0.9 mm (5/128 in.) Glass with Four Sides Simply Supported



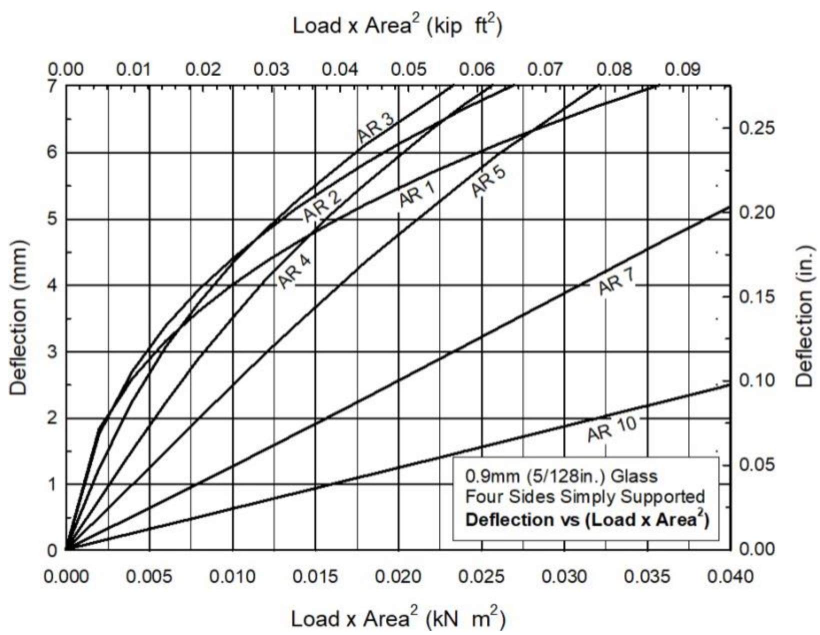
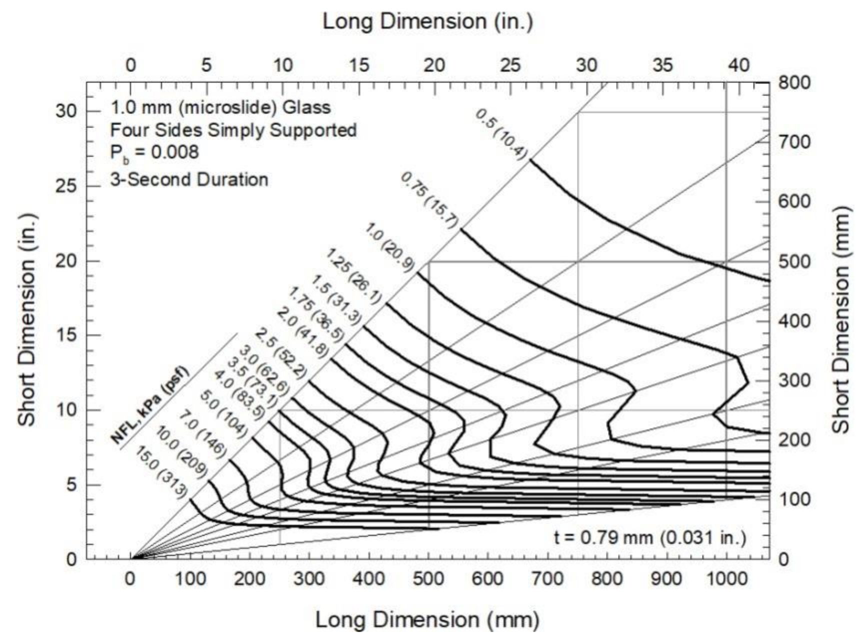


Figure B.3: (upper chart) Non-Factored Load Chart for 1.0 mm (micro-slide) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 1.0 mm (micro-slide) Glass with Four Sides Simply Supported



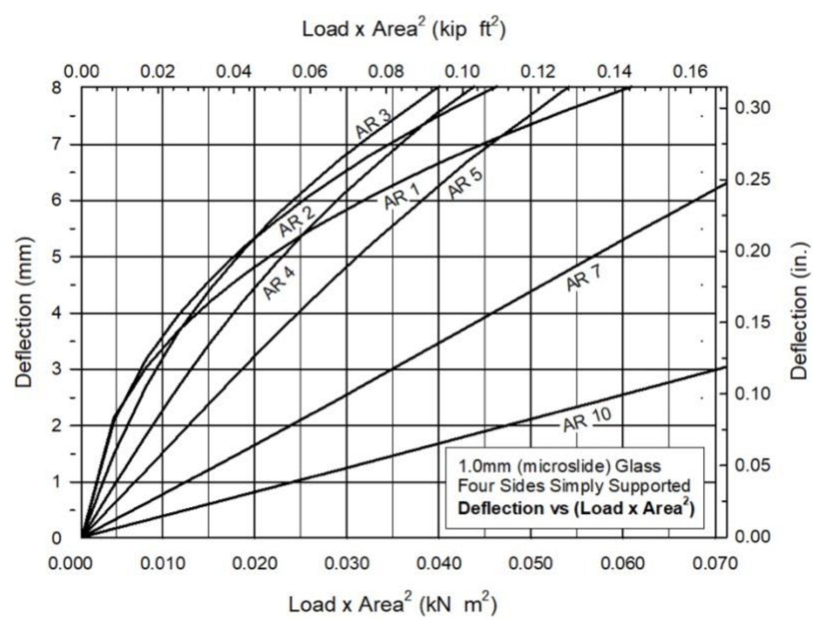
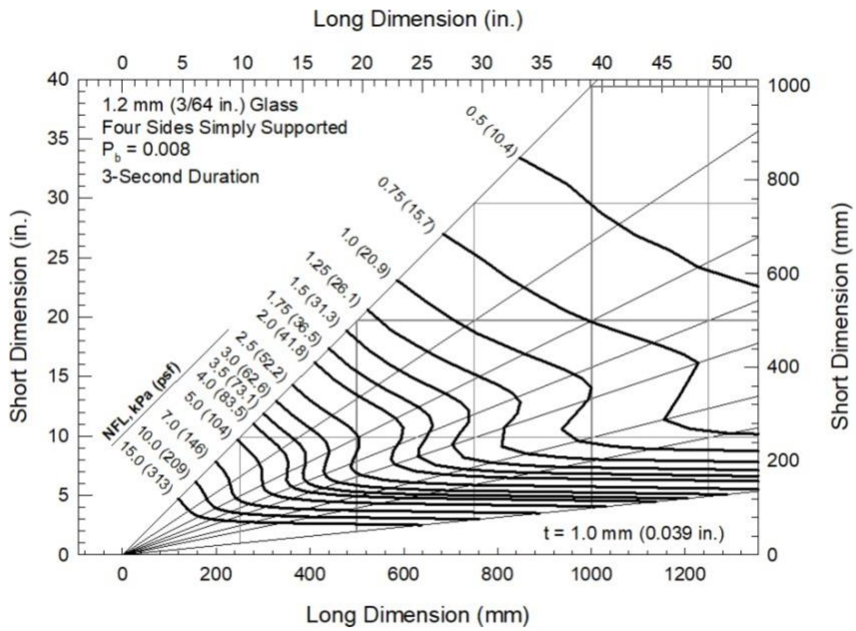


Figure B.4: (upper chart) Non-Factored Load Chart for 1.2 mm (3/64 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 1.2 mm (3/64 in.) Glass with Four Sides Simply Supported



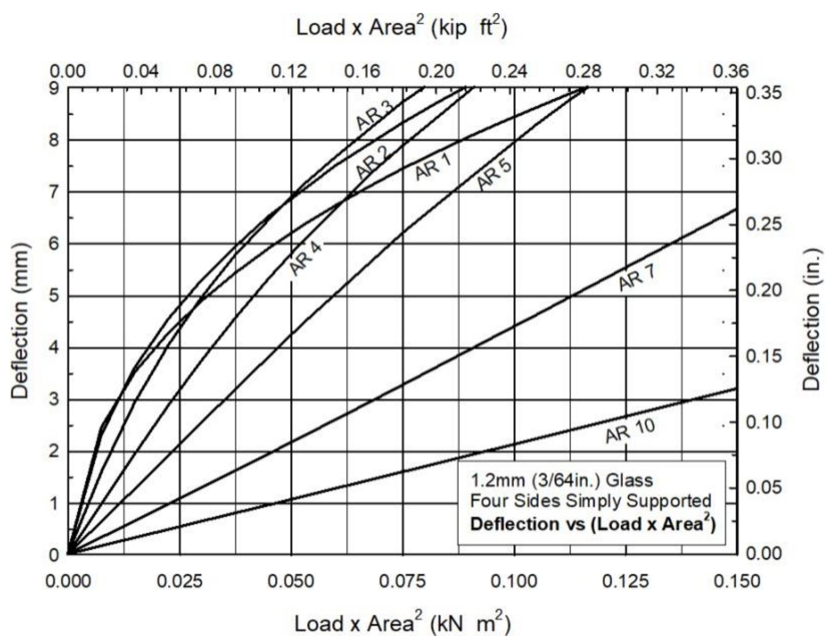
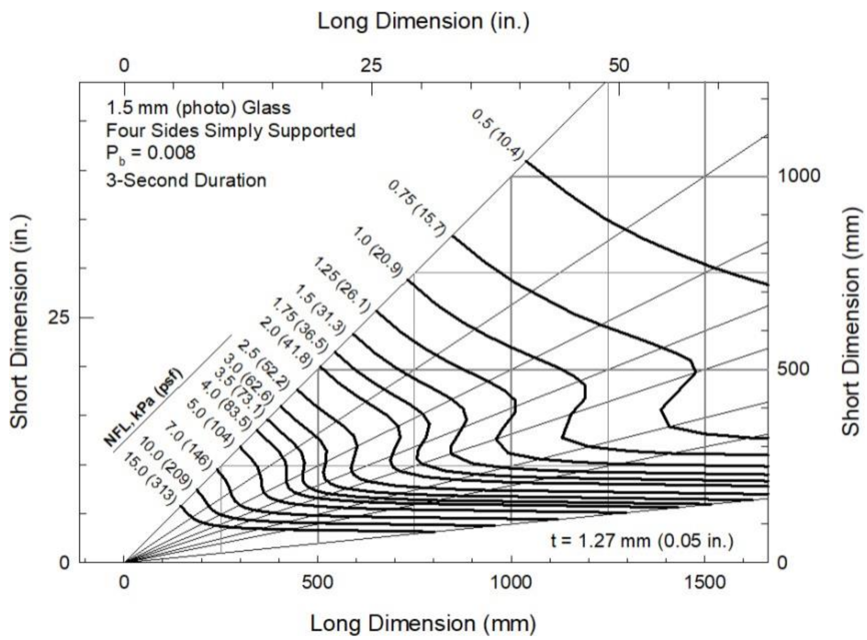


Figure B.5: (upper chart) Non-Factored Load Chart for 1.5 mm (photo) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 1.5 mm (photo) Glass with Four Sides Simply Supported



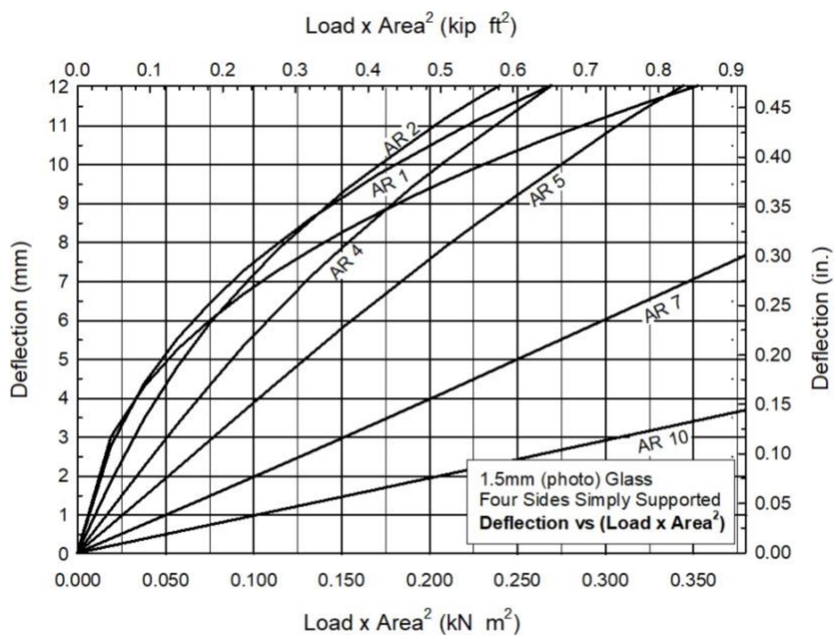
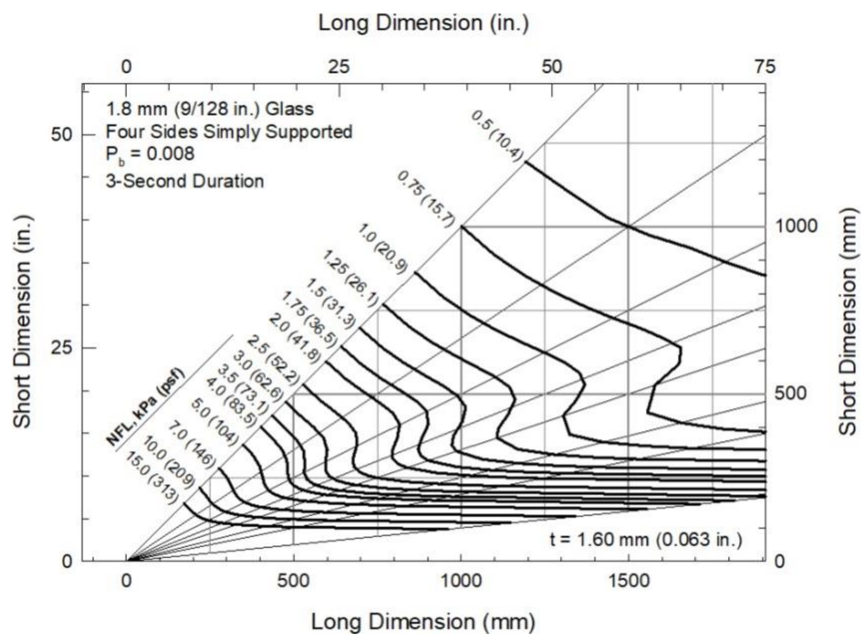
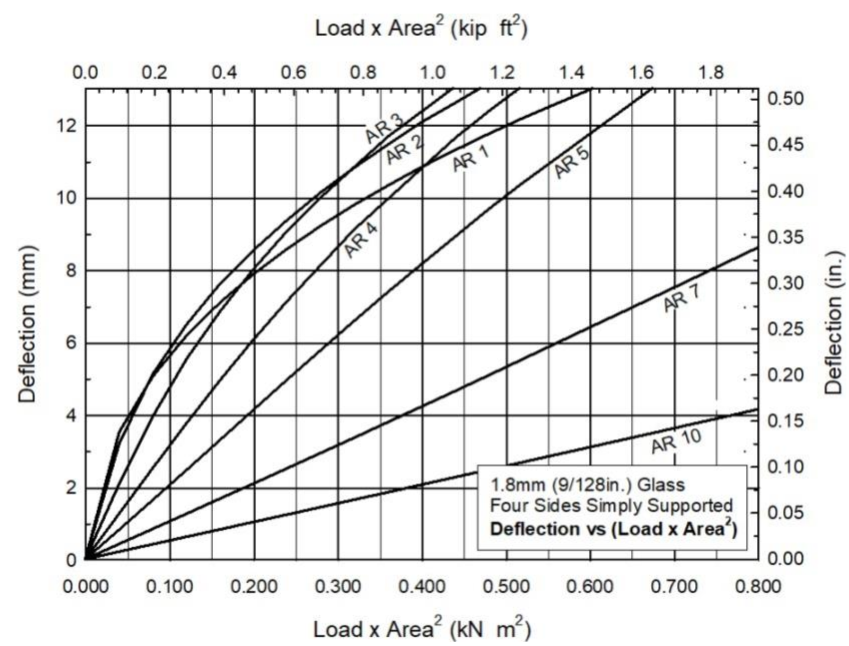


Figure B.6: (upper chart) Non-Factored Load Chart for 1.8 mm (9/128 in.) Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 1.8 mm (9/128 in.) Glass with Four Sides Simply Supported





6. APPENDIX C: HORIZONTAL DEFLECTION CHARTS

The horizontal deflection charts presented here show the predicted deflection due to self-weight of four sides simply supported glass tilted horizontally. Glass thicknesses of 0.7 mm (3/128 in.), 0.9 mm (5/128 in.), 1.0 mm (micro-slide), 1.2 mm (3/64 in.), 1.5 mm (photo), 1.8 mm (9/128 in.), 2.0 mm (picture), 2.5 mm (3/32 in.), 2.7 mm (lami), 3.0 mm (1/8 in.), 4.0 mm (5/32 in.), 5.0 mm (3/16 in.), 6.0 mm (1/4 in.), 8.0 mm (5/16 in.), and 10.0 mm (3/8 in.) are provided. The horizontal deflection charts were developed using a finite element model for glass by Yew[3].

The data presented in the horizontal deflection charts are based on the minimum glass thicknesses allowed by ASTM C1036. These minimum glass thicknesses are presented in Table 1. Glass may be manufactured thicker than those minimums. Not accounting for this fact in the horizontal deflection charts makes the charts conservative from a design standpoint. The authors were unable to identify minimum dimension tolerance standards for glass thicknesses of 0.7 mm (3/128 in.), 0.9 mm (5/128 in.), 1.2 mm (3/64 in.) or 1.8 mm (9/128 in.), so thicknesses for these products in Table 1 are based off flat glass manufacturer reported internal standards. No recommendations are made regarding acceptable horizontal deflections.

The following steps are used to determine the horizontal deflection for a particular situation:

1. Select the appropriate chart to be used based upon the nominal glass thickness.
2. Calculate the glass AR as follows: AR = (long dimension) / (short dimension)
3. Calculate the glass Area as follows: Area = (long dimension) x (short dimension)
4. Enter the horizontal axis of the chart at the point corresponding to the area of the glass and project a vertical line to the glass AR.
5. Project a horizontal line from the intersection point of the vertical line and the AR line to the left vertical axis and read the approximate horizontal deflection.

[3] Yew, G. Z., Norville, H. S., and Morse, S. M. (2019). “Nonlinear finite-element analysis of laminated glass using the four-node reissner-mindlin formulation and assumed transverse shear strain fields.” Journal of Engineering Mechanics, 145(7), 04019042.

Figure C.1: Horizontal Deflection Chart for 0.7 mm (3/128 in.) Glass with Four Sides Simply Supported

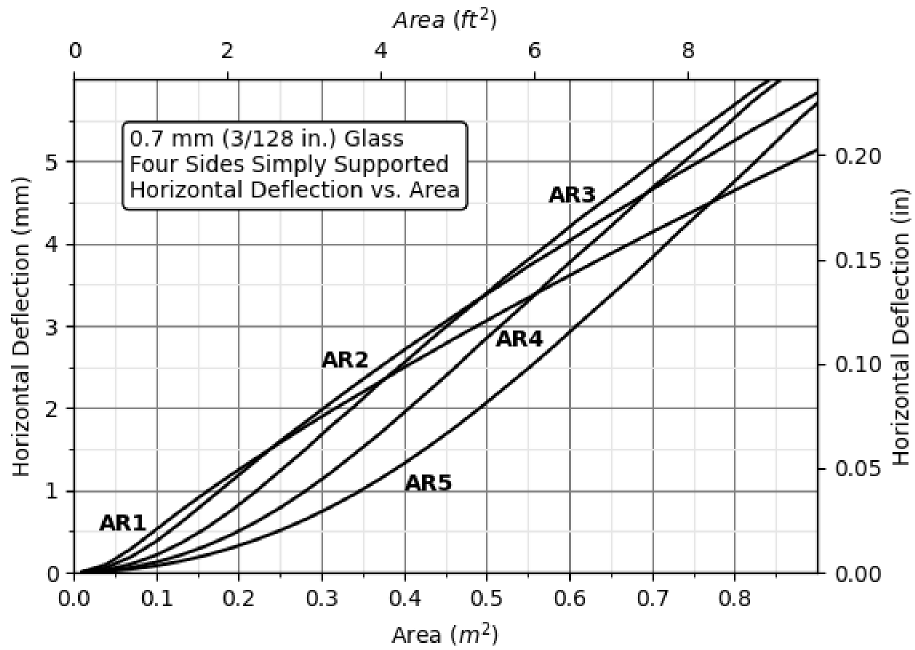


Figure C.2: Horizontal Deflection Chart for 0.9 mm (5/128 in.) Glass with Four Sides Simply Supported

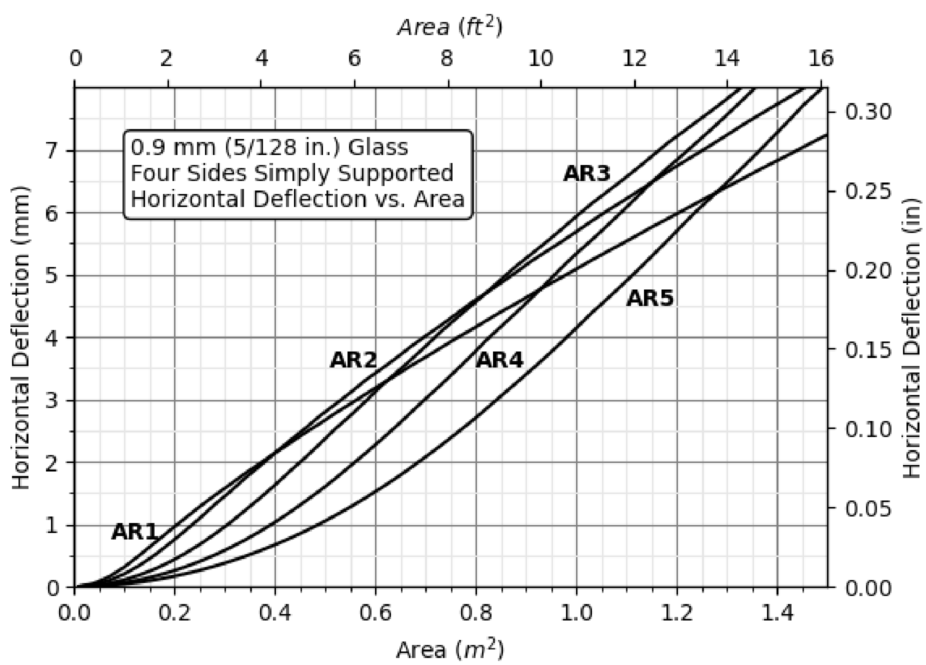


Figure C.3: Horizontal Deflection Chart for 1.0 mm (micro-slide) Glass with Four Sides Simply Supported

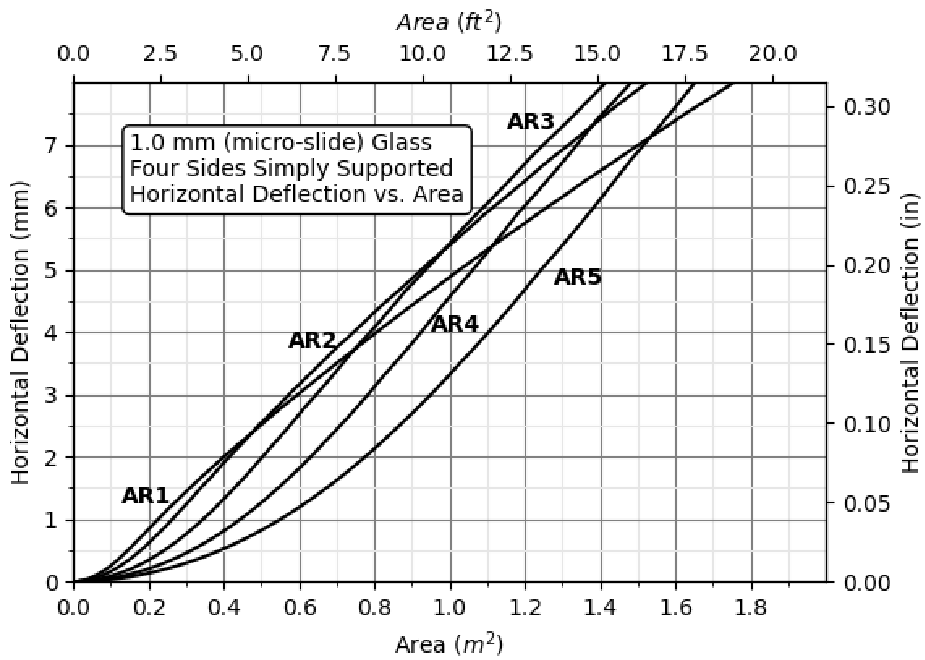


Figure C.4: Horizontal Deflection Chart for 1.2 mm (3/64 in.) Glass with Four Sides Simply Supported

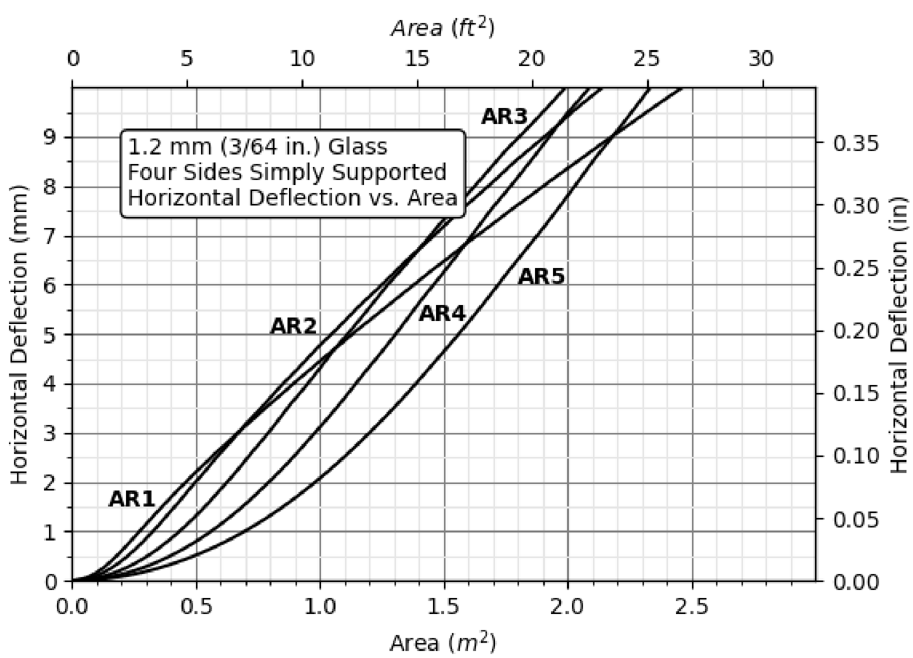


Figure C.5: Horizontal Deflection Chart for 1.5 mm (photo) Glass with Four Sides Simply Supported

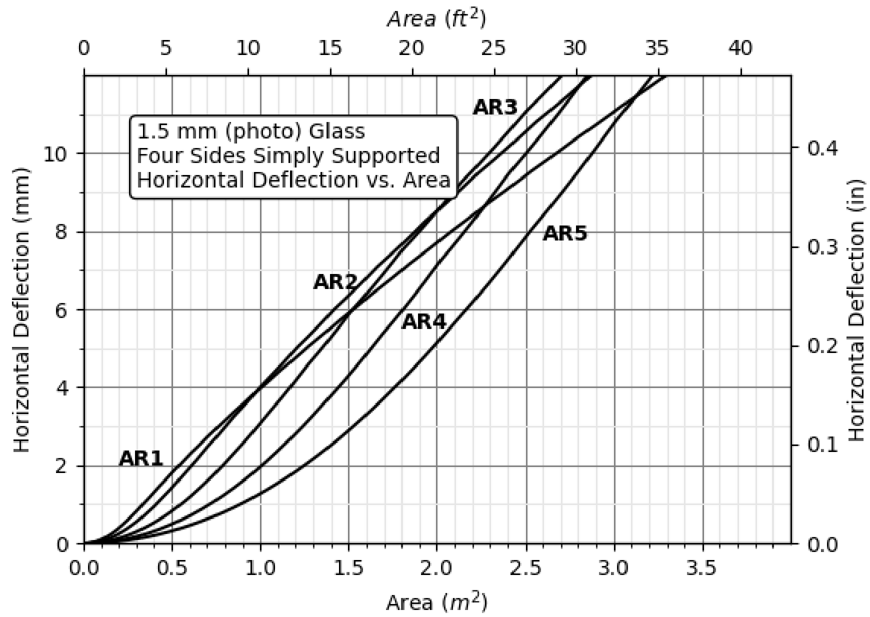


Figure C.6: Horizontal Deflection Chart for 1.8 mm (9/128 in.) Glass with Four Sides Simply Supported

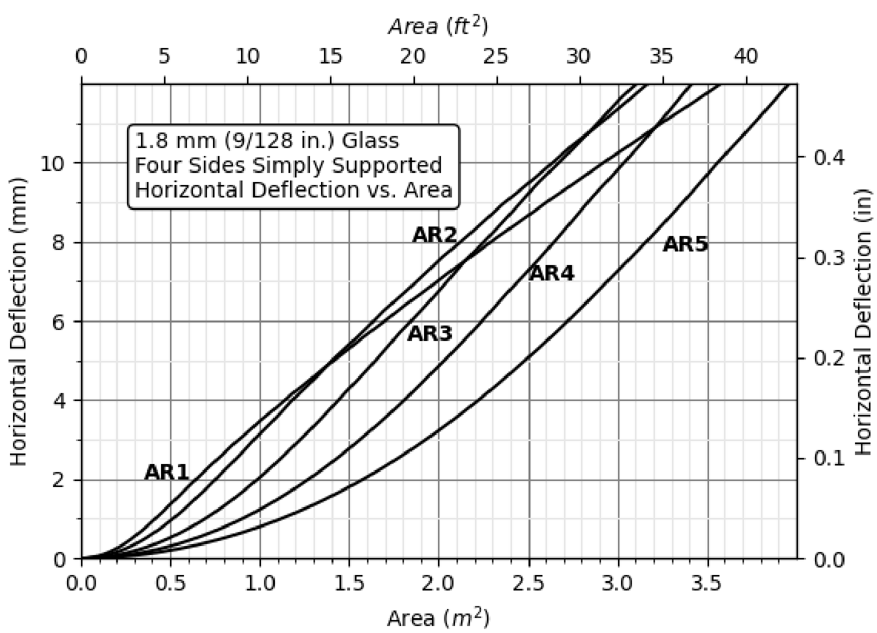


Figure C.7: Horizontal Deflection Chart for 2.0 mm (Picture) Glass with Four Sides Simply Supported

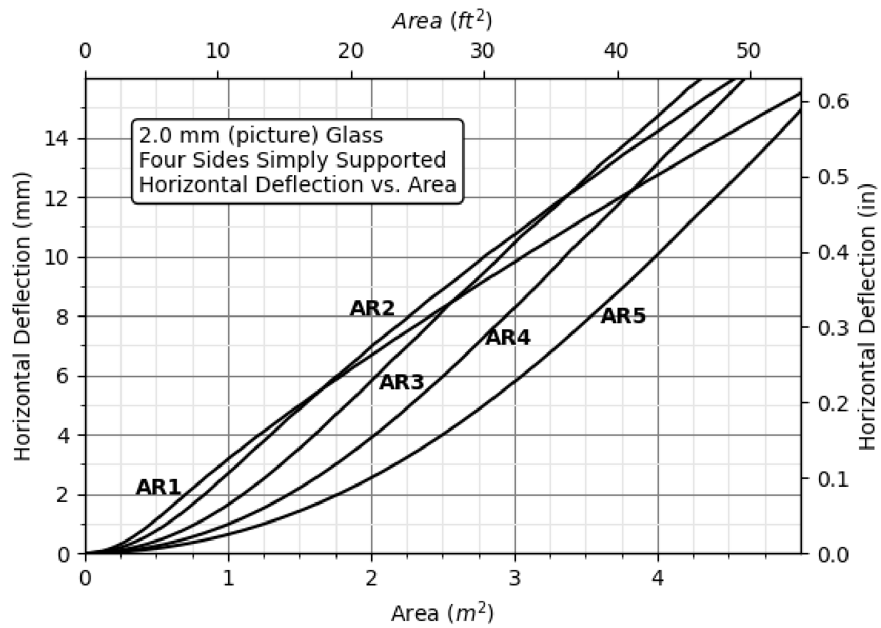


Figure C.8: Horizontal Deflection Chart for 2.5 mm (single) Glass with Four Sides Simply Supported

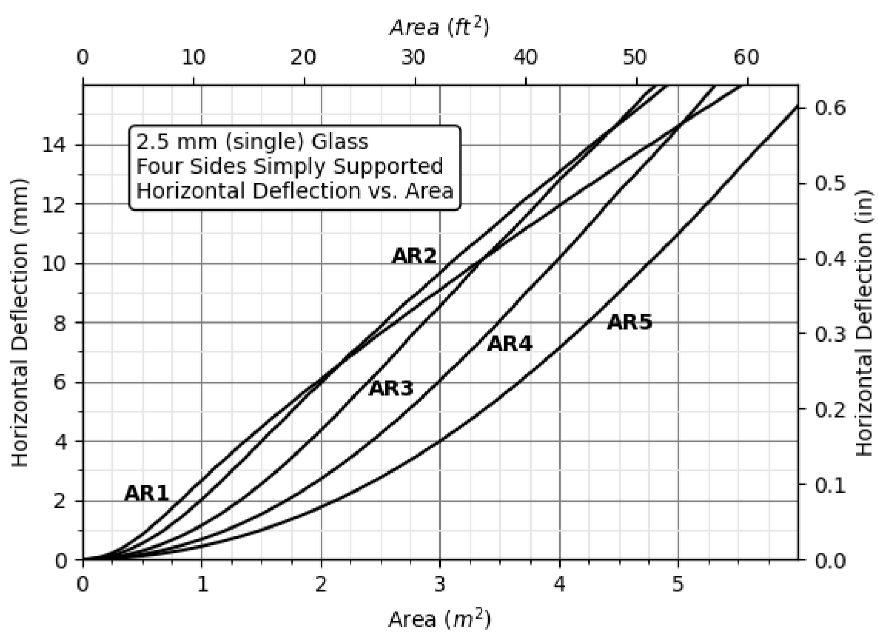


Figure C.9: Horizontal Deflection Chart for 2.7 mm (lami) Glass with Four Sides Simply Supported

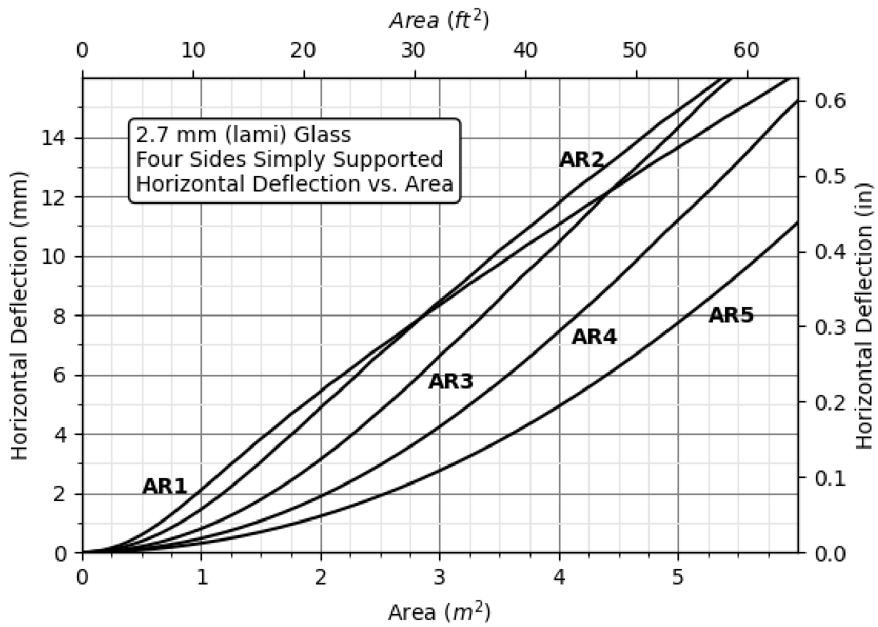


Figure C.10: Horizontal Deflection Chart for 3.0 mm (double) Glass with Four Sides Simply Supported

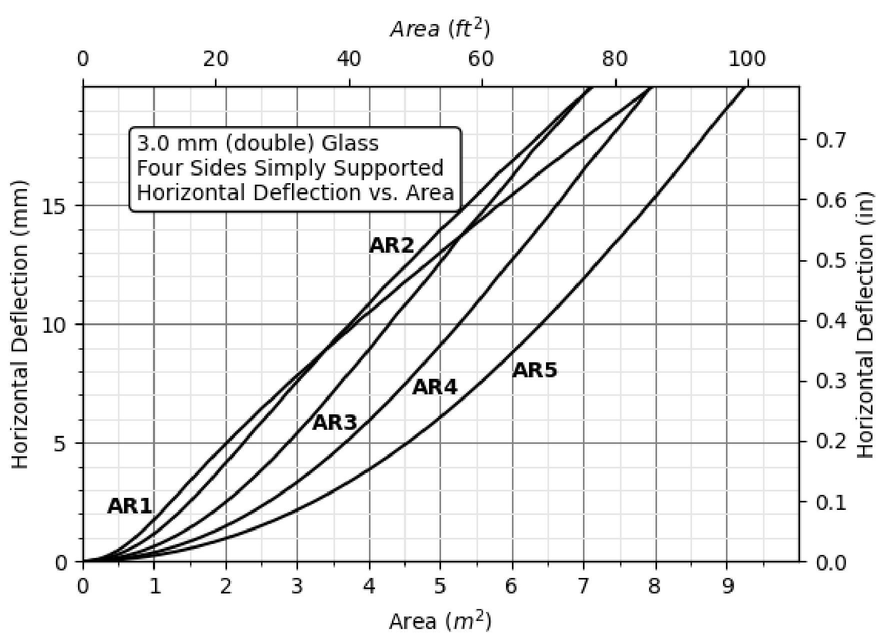


Figure C.11: Horizontal Deflection Chart for 4.0 mm (5/32 in.) Glass with Four Sides Simply Supported

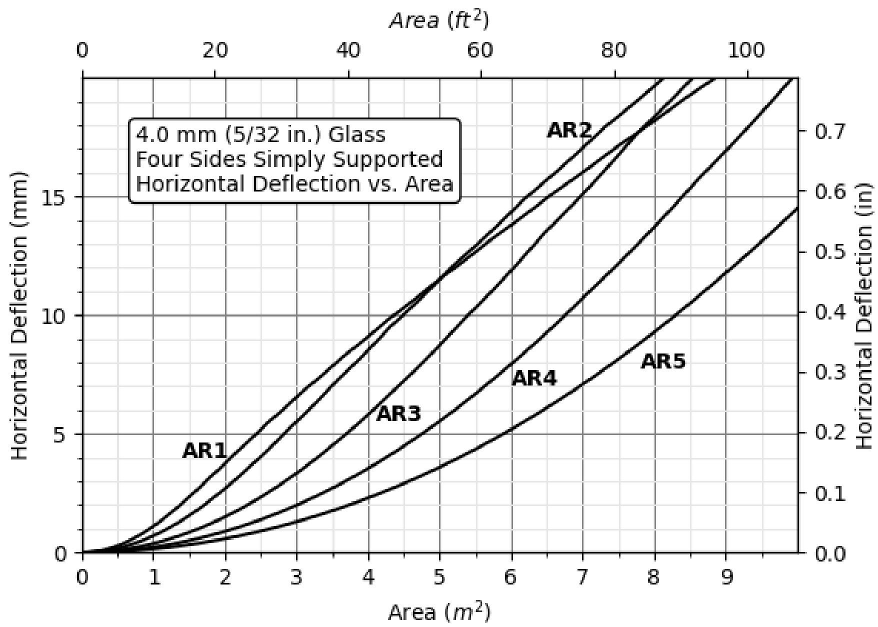


Figure C.12: Horizontal Deflection Chart for 5.0 mm (3/16 in.) Glass with Four Sides Simply Supported

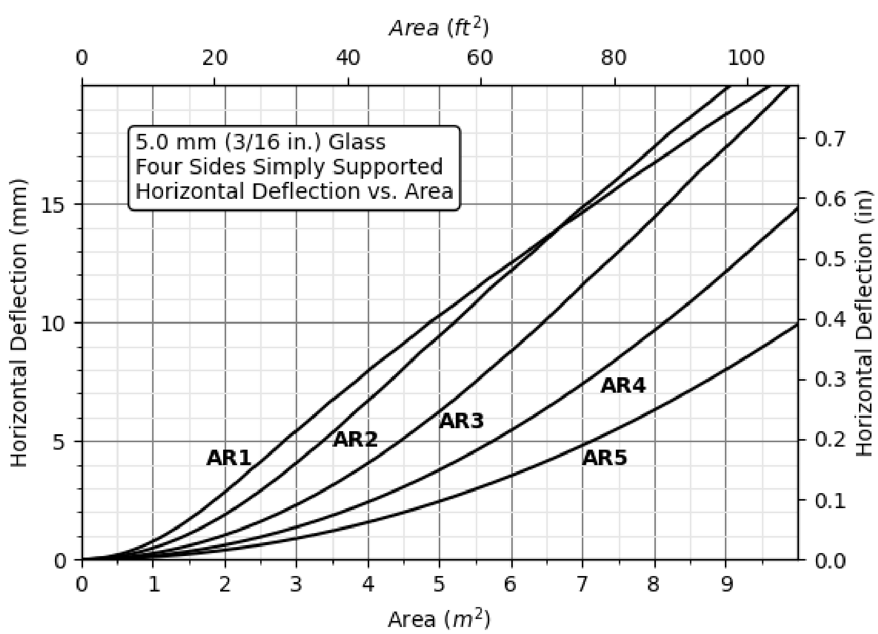


Figure C.13: Horizontal Deflection Chart for 6.0 mm (1/4 in.) Glass with Four Sides Simply Supported

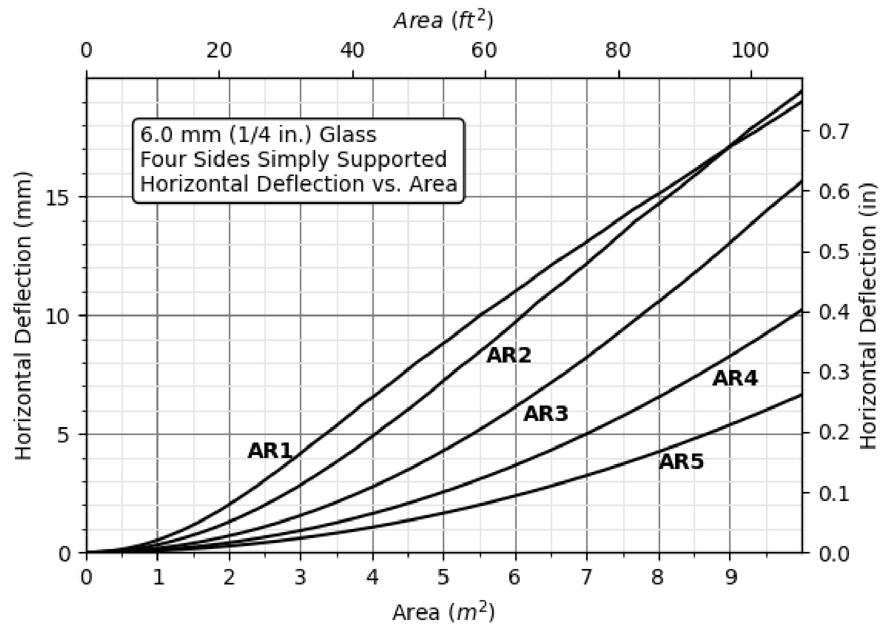


Figure C.14: Horizontal Deflection Chart for 8.0 mm (5/16 in.) Glass with Four Sides Simply Supported

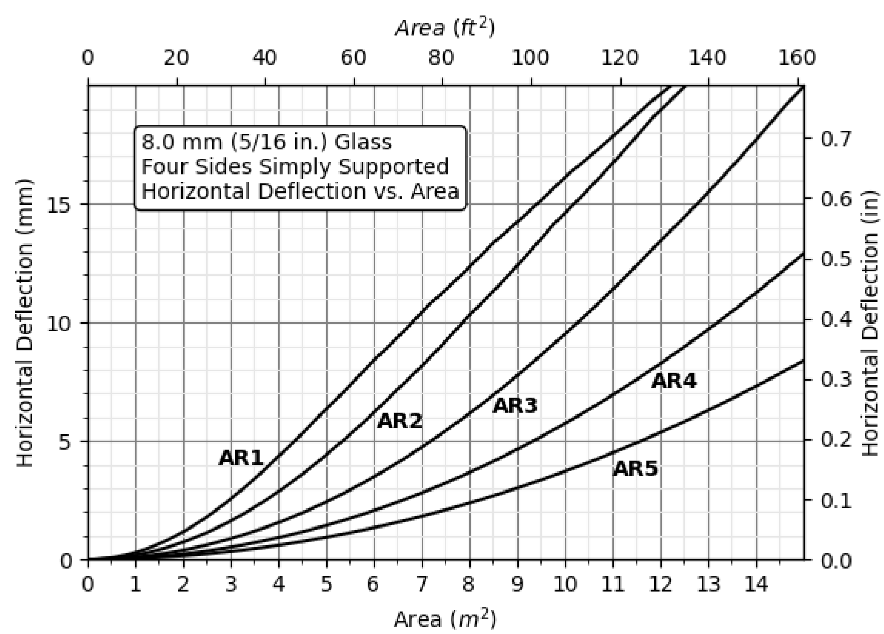
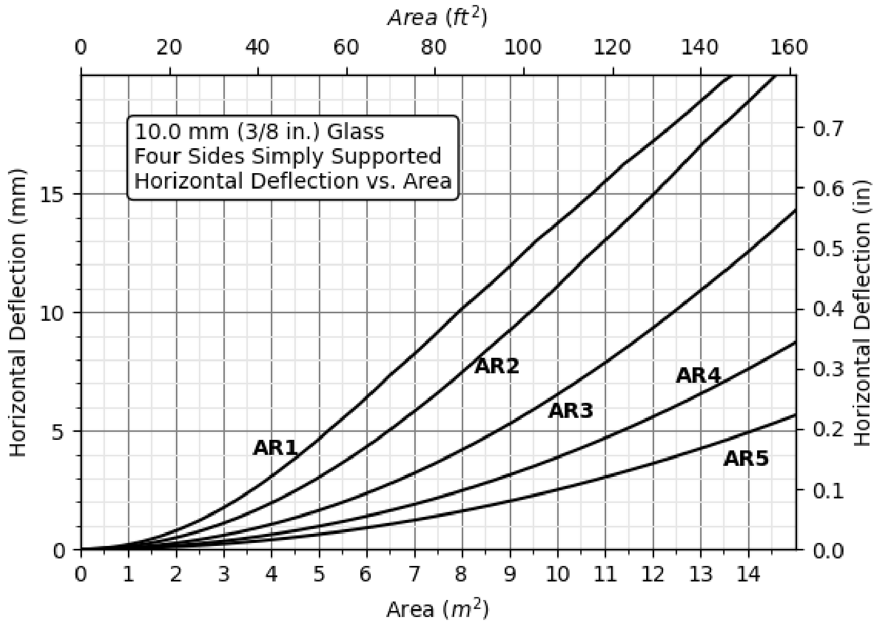


Figure C.15: Horizontal Deflection Chart for 10.0 mm (3/8 in.) Glass with Four Sides Simply Supported



7. APPENDIX D: NATURAL FREQUENCY CHARTS

The natural frequency charts presented here show the predicted natural frequency of four sides simply supported glass. Glass thicknesses of 0.7 mm (3/128 in.), 0.9 mm (5/128 in.), 1.0 mm (micro-slide), 1.2 mm (3/64 in.), 1.5 mm (photo), 1.8 mm (9/128 in.), 2.0 mm (picture), 2.5 mm (3/32 in.), 2.7 mm (lami), 3.0 mm (1/8 in.), 4.0 mm (5/32 in.), 5.0 mm (3/16 in.), 6.0 mm (1/4 in.), 8.0 mm (5/16 in.), and 10.0 mm (3/8 in.) are provided. The natural frequency charts were developed using formulations developed by Biggs[4] and Leissa[5]. For 4-side support as shown below. The data presented in the natural frequency charts are based on the typical glass thicknesses from Table1. Glass may be manufactured thinner or thicker than the typical values. No recommendations are made regarding acceptable natural frequencies.

$$\omega = [(D/mh)]^{1/2}\ [(\pi/a)^2+(\pi/b)^2)]\ \text{(radians/sec)}$$

$$f = \omega/2\pi\ \text{(Hz)}$$

Where ω = angular frequency in radians/sec; f = natural frequency in cycles/sec (Hz); a = long dimension (in.); b = short dimension (in.); h = thickness (in.); m = unit mass for glass (lb- sec^2/in^4.); E = modulus of elasticity for glass in psi; and υ = Poisson's Ratio for glass; and $D = Eh^3/12(1- \upsilon^2)$.

The following steps are used to determine the natural frequency for a particular situation:

1. Select the appropriate chart to be used based upon the nominal glass thickness.
2. Calculate the glass AR as follows: AR = (long dimension) / (short dimension)
3. Enter the horizontal axis of the chart at the point corresponding to the AR of the glass and project a vertical line.
4. Project a horizontal line from the short dimension to intersect the vertical line from step 3.
5. Determine the natural frequency by interpolating between the natural frequency contours at the point of intersection from step 4.

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[4] Biggs, J. M., Introduction to Structural Dynamics, McGraw-Hill, New York, 1964

[5] Leissa, A.W., "Vibration of Plates", Office of Technology Utilization, NASA, Washington, D.C., 1969.

Figure D.1: Natural Frequency Chart for 0.7 mm (3/128 in.) Glass with Four Sides Simply Supported

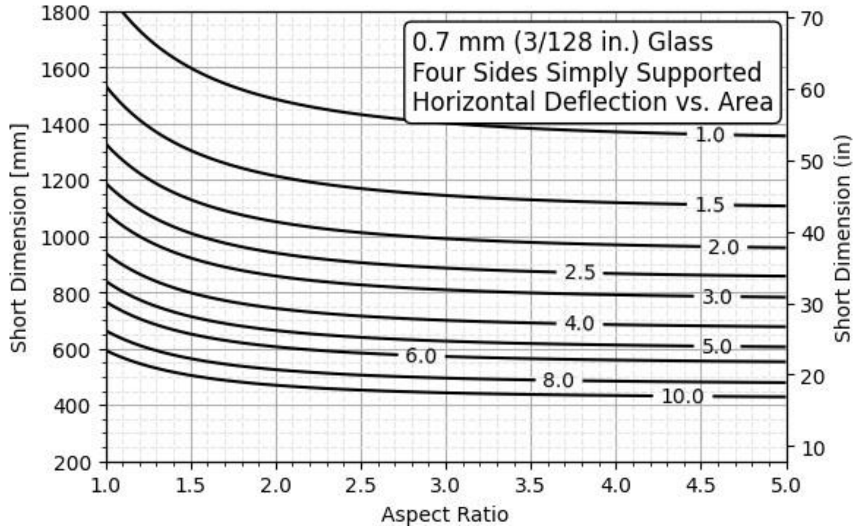


Figure D.2: Natural Frequency Chart for 0.9 mm (5/128 in.) Glass with Four Sides Simply Supported

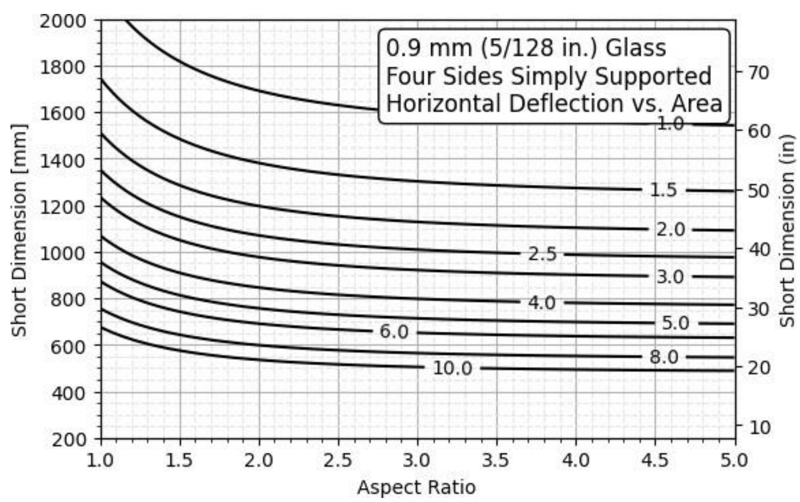


Figure D.3: Natural Frequency Chart for 1.0 mm (micro-slide) Glass with Four Sides Simply Supported

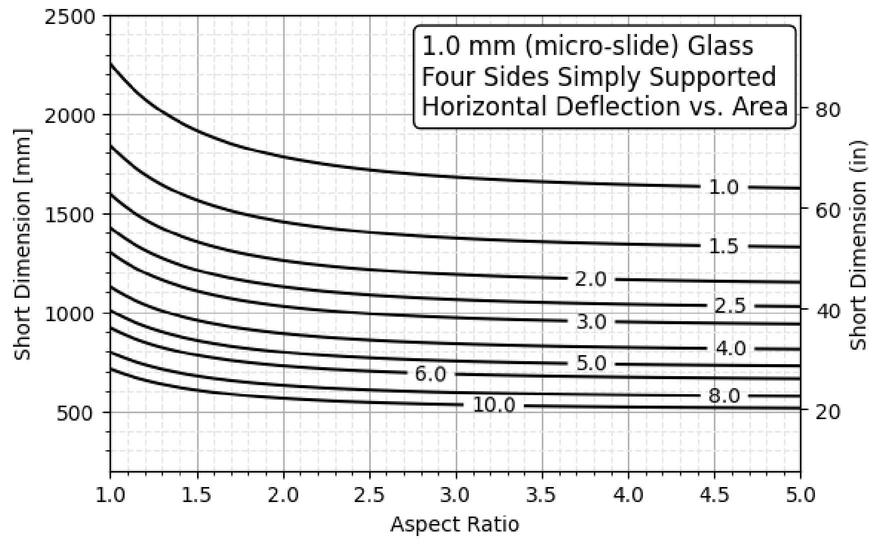


Figure D.4: Natural Frequency Chart for 1.2 mm (3/64 in.) Glass with Four Sides Simply Supported

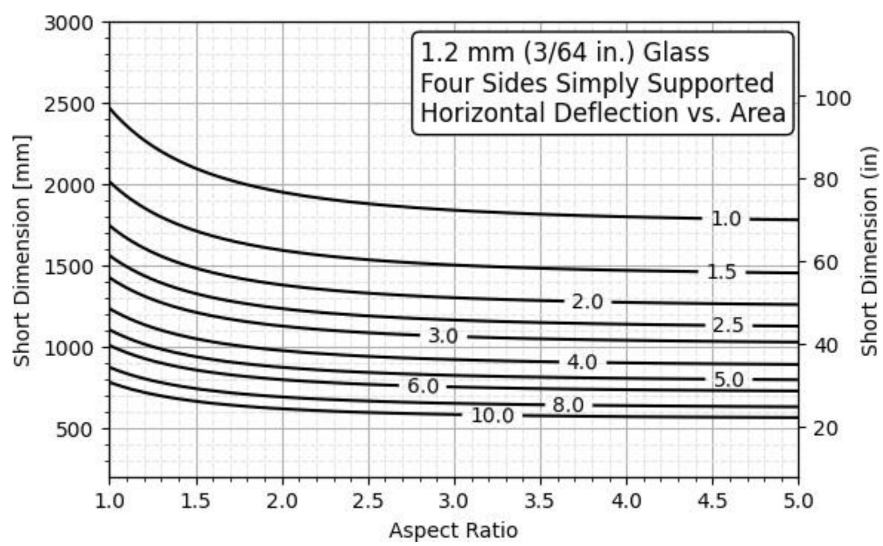


Figure D.5: Natural Frequency Chart for 1.5 mm (photo) Glass with Four Sides Simply Supported

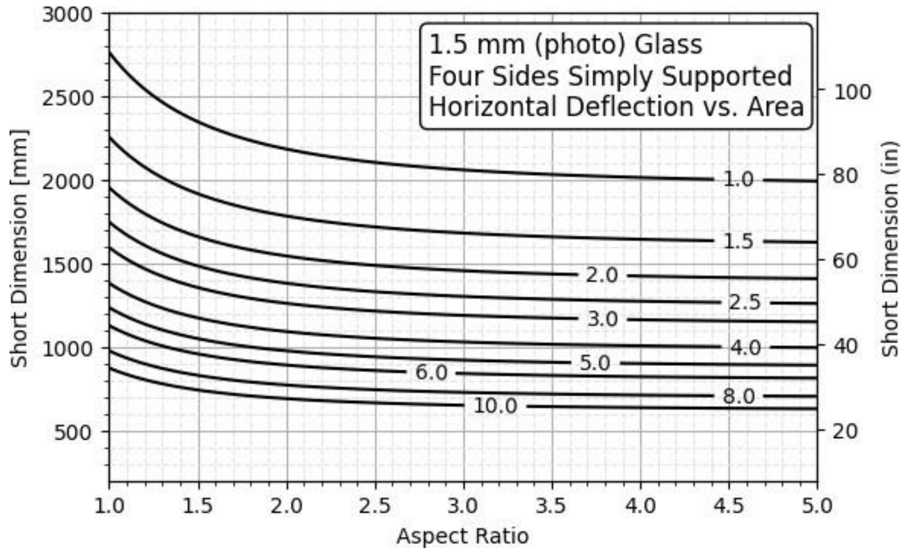


Figure D.6: Natural Frequency Chart for 1.8 mm (9/128 in.) Glass with Four Sides Simply Supported

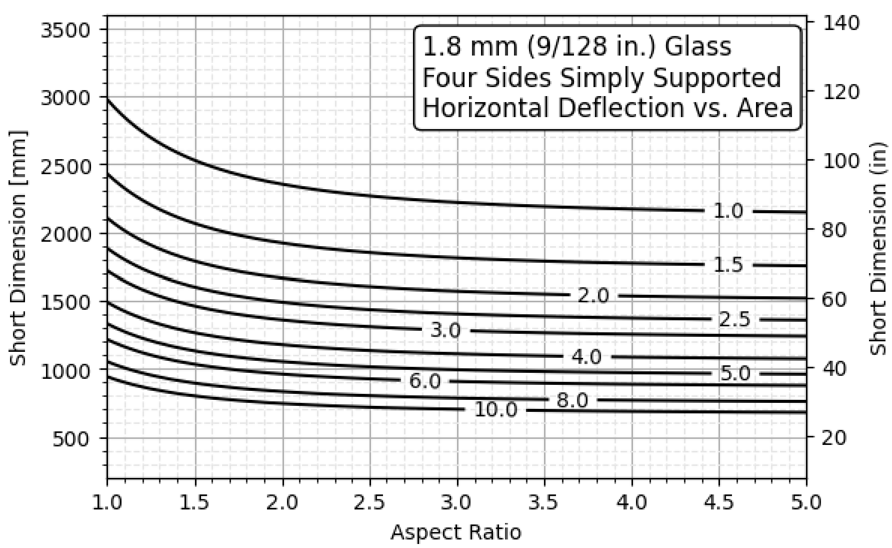


Figure D.7: Natural Frequency Chart for 2.0 mm (picture) Glass with Four Sides Simply Supported

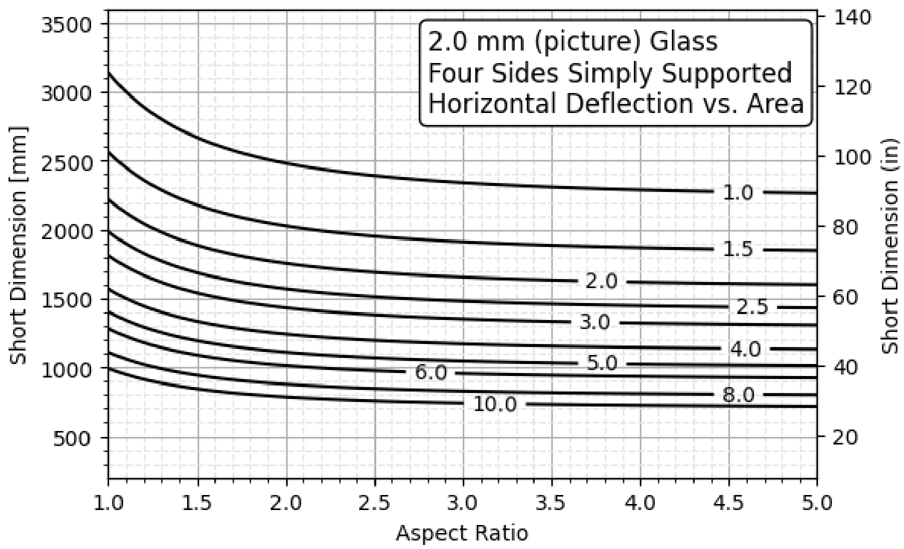


Figure D.8: Natural Frequency Chart for 2.5 mm (single) Glass with Four Sides Simply Supported

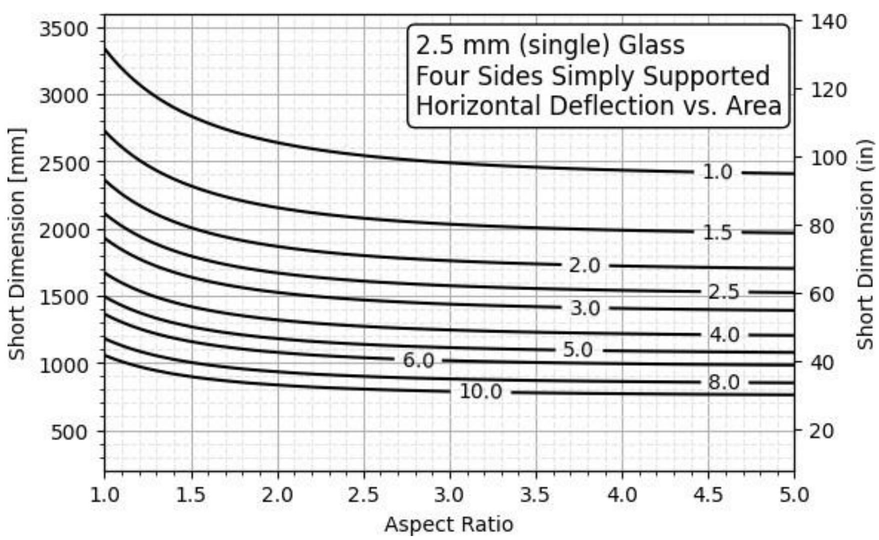


Figure D.9: Natural Frequency Chart for 2.7 mm (lami) Glass with Four Sides Simply Supported

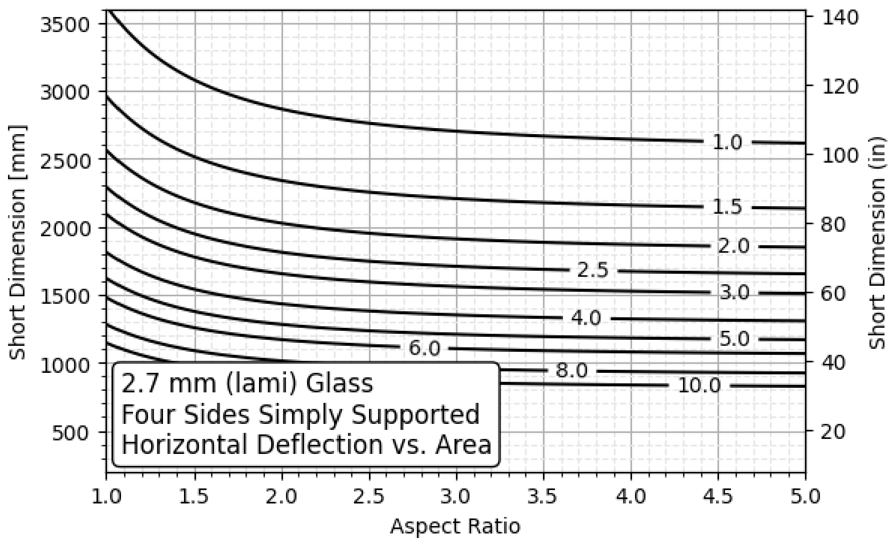


Figure D.10: Natural Frequency Chart for 3.0 mm (double) Glass with Four Sides Simply Supported

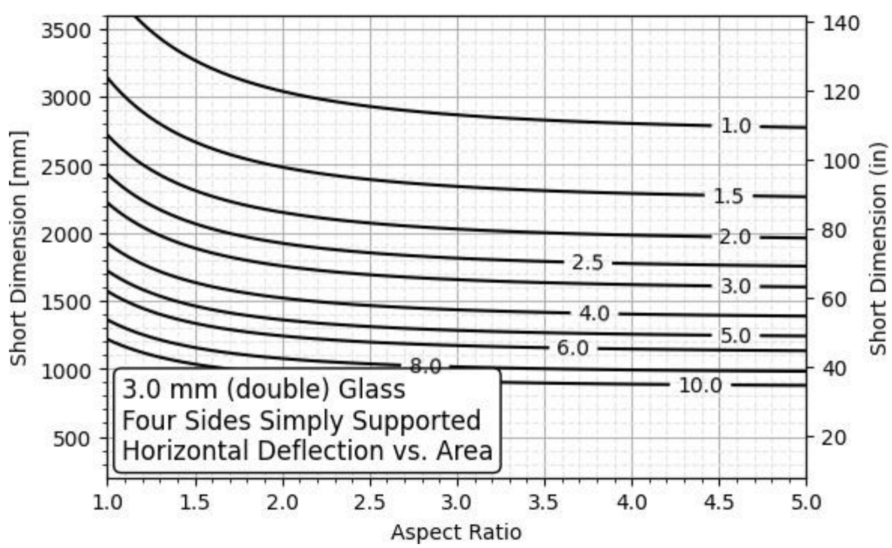


Figure D.11: Natural Frequency Chart for 4.0 mm (5/32 in.) Glass with Four Sides Simply Supported

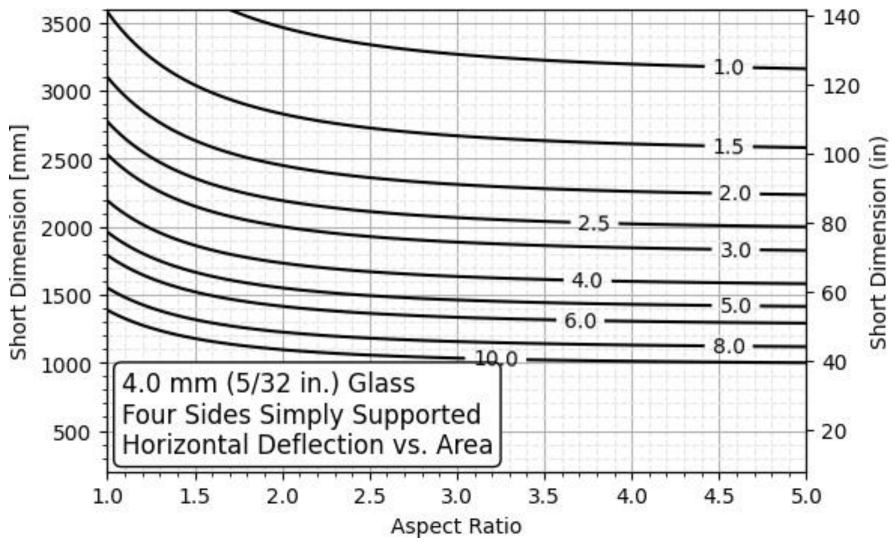


Figure D.12: Natural Frequency Chart for 5.0 mm (3/16 in.) Glass with Four Sides Simply Supported

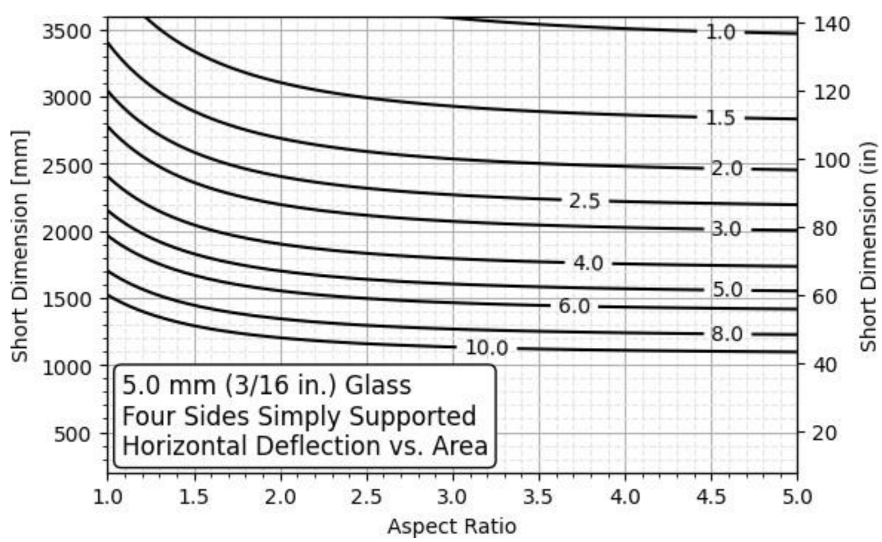


Figure D.13: Natural Frequency Chart for 6.0 mm (1/4 in.) Glass with Four Sides Simply Supported

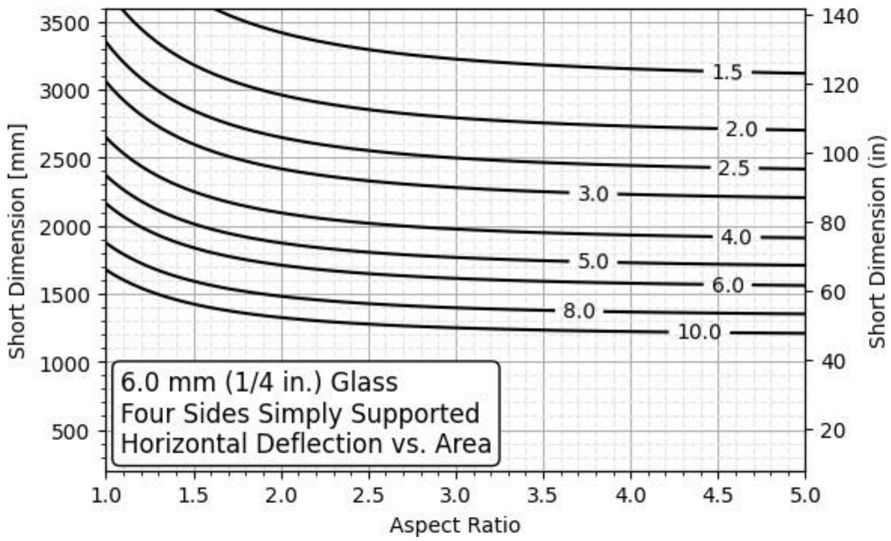


Figure D.14: Natural Frequency Chart for 8.0 mm (5/16 in.) Glass with Four Sides Simply Supported

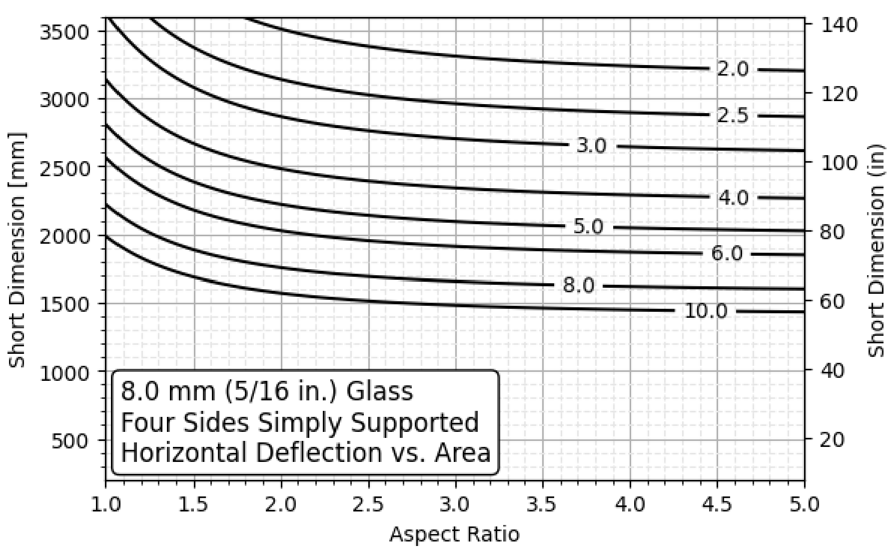
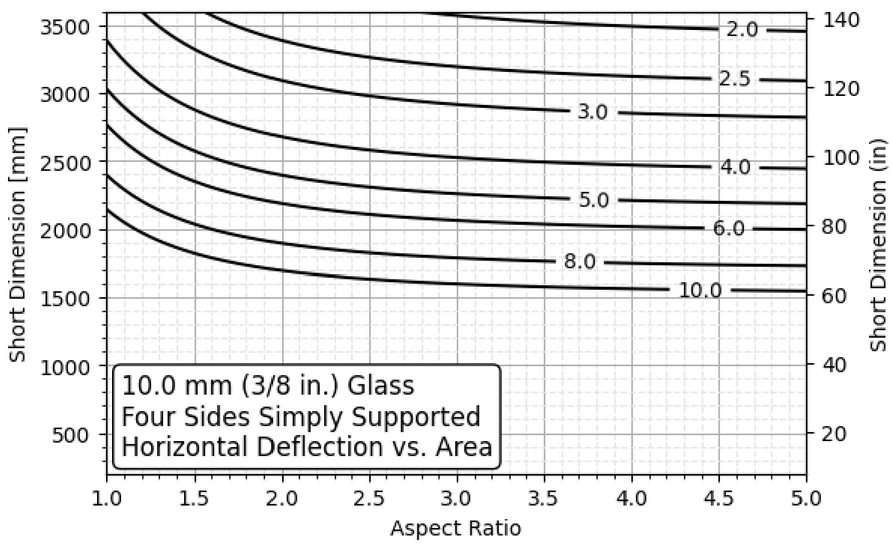


Figure D.15: Natural Frequency Chart for 10.0 mm (3/8 in.) Glass with Four Sides Simply Supported



8. APPENDIX E: IGU WEIGHT CHART

The weight chart presented here shows the calculated weight of the glass in an IGU based on the total thickness of glass in the IG unit. Total glass thickness is the sum of thickness for each glass layer. The weight of all non-glass components in IG units is not included in the chart since this weight varies significantly with the system used. The weight of spacer and sealant components are typically a small fraction of the total IG unit weight and can be ignored in most cases.

The following steps are used to determine IG unit weight for a particular situation:

1. Calculate the glass AR as follows: AR = (long dimension) / (short dimension)
2. Enter the horizontal axis of the chart at the point corresponding to the AR of the glass and project a vertical line.
3. Project a horizontal line from the short dimension to intersect vertical line from step 2.
4. Determine the IGU weight per unit thickness by interpolating between the IGU weight contours at the point of intersection from step 3.
5. Calculate the total glass thickness based on the average glass thickness from Table 1 as follows: $t_{total} = t_{lite1} + t_{lite2} + t_{lite3}$
6. Calculate the total IG unit weight by multiplying the weight per unit thickness from step 4 by the total thickness from step 5.