Designation: E 997 – 01

An American National Standard

Standard Test Method for Structural Performance of Glass in Exterior Windows, Curtain Walls, and Doors Under the Influence of Uniform Static Loads by Destructive Methods[1]

This standard is issued under the fixed designation E 997; 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 test method is a procedure to determine if the probability of breakage of glass specimens tested is significantly greater than, signficantly less than, or not significantly different than the specified probability of breakage when exposed to a specified 60–s duration equivalent design load. It is not intended to be a design standard for determining the load resistance of glass. Practice E 1300 shall be used for this purpose.

1.2 This test method describes apparatus and procedures to select and apply a 60-s duration proof load to glass specimens, to determine the number of glass specimens to be tested, and to evaluate statistically the probability of breakage. This test method may be conducted using the standard test frame specified herein or a test frame of the user's design.

1.3 Proper use of this test method requires a knowledge of the principles of pressure measurement and an understanding of recommended glazing practices.

1.4 The values stated in inch-pound units are to be regarded as standard.

1.5 *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.* Specific precautionary statements are given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

E 1300 Practice for Determining the Load Resistance of Glass in Buildings[2]

3. Terminology

3.1 *Definitions:*

3.2 *coefficient of variation*, *n*—ratio of the standard deviation of the breakage load to the mean breakage load.

3.3 *equivalent design load*, *n*—the specified uniform design load converted to a 60–s duration (see 4.2).

3.4 *glass specimen*, *n*—the glass to be tested, for example, a single pane, an insulating glass unit, laminated glass, etc. (does not include test frame).

3.5 *glass specimen breakage*, *n*—the fracture or cracking of any glass component of a glass specimen.

3.6 *negative load*, *n*—an outward-acting load that results in the indoor side of a glass specimen being the high-pressure side.

3.7 *positive load*, *n*—an inward-acting load that results in the outdoor side of a glass specimen being the high-pressure side.

3.8 *probability of breakage*, *n*—the probability that a glass specimen will break when tested at a given load. General industry practice is to express the probability of breakage as lites per 1000 lites.

3.9 *proof load*, *n*—a magnitude of uniform load at which glass specimens shall be tested.

3.10 *proof load factor, a*, *n*—the constant which, when multiplied by the equivalent design load, determines the proof load.

3.11 *specifying authority*, *n*—professional(s) responsible for determining and furnishing information required to perform the test.

4. Summary of Test Method

4.1 This test method consists of individually glazing glass specimens in a test frame that is mounted into or against one face of a test chamber and supplying air to, or exhausting air from, the test chamber so that each glass specimen is exposed to a 60-s duration proof load. Load-time records shall be kept for each glass specimen. Each glass specimen break shall be recorded.

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

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[2] *Annual Book of ASTM Standards*, Vol 04.11

4.2 After testing the required number of glass specimens, it is determined if the probability of breakage is significantly less than, significantly greater than, or not significantly different than the specified probability of breakage.

5. Significance and Use

5.1 Glass specimens to be tested shall be mounted in a standard test frame with four sides supported, or in a test frame designed to represent specific glazing conditions.

5.1.1 A standard test frame shall be used when it is desired to evaluate the probability of breakage of glass specimens with edge support conditions held constant.

5.1.2 A test frame designed to represent a specific glazing condition shall be used when it is desired to evaluate the probability of breakage of glass specimens in the specified glazing system.

5.2 Loads on glass in windows, curtain walls, and doors may vary greatly in magnitude, direction, and duration. Any load (wind, snow, etc.) that can be transformed into a 60-s duration equivalent uniform design load can be considered. Load transformation techniques are addressed in the literature **(1, 2, 3).**[3]

5.3 The strength of glass varies with many different factors including surface condition, load duration, geometry, relative humidity, and temperature **(4).** A thorough understanding of those strength variations is required to interpret results of this test method.

6. Apparatus

6.1 The description of apparatus is general in nature. Any equipment capable of performing the test procedure within the allowable tolerances is permitted.

6.2 *Major Components*:

6.2.1 *Test Frame*, in which glass specimens are mounted for testing. The test frame shall provide either standardized support conditions or specified support conditions. Specifications of standardized support conditions are presented in Annex A1.

6.2.2 *Test Chamber*, sealed, with an opening in which or against which the test frame is installed. At least one static pressure tap shall be provided to measure the test chamber pressure and shall be so located that the reading is minimally affected by the velocity of the air supply to or from the test chamber or any air movement. The air supply opening into the test chamber shall be arranged so that the air does not impinge directly on the glass specimen with any significant velocity. A means of access into the test chamber may be provided to facilitate adjustments and observations after the specimen has been installed.

6.2.3 *Air System*, a controllable blower, compressed air supply, exhaust system, reversible blower, or other device designed to apply the proof load to the glass specimen with required control.

6.2.4 *Pressure Measuring Apparatus*, to record continuous test chamber pressures within an accuracy of ±2%.

6.2.5 *Temperature Measuring Apparatus*, to measure the ambient temperature within an accuracy of ±1°F (0.6°C).

6.2.6 *Relative Humidity Apparatus*, to measure the relative humidity within an accuracy of ±2 %.

7. Safety Precautions

7.1 Proper precautions to protect observers in the event of glass breakage should be observed. At the pressures used in this test method, considerable energy and hazard are involved. In cases of breakage, the hazard to personnel is less with an exhaust system, as the specimen will tend to blow into rather than out of the test chamber. Personnel should not be permitted in such chambers during tests.

8. Sampling and Glass Specimens

8.1 Surface condition, cutting, fabrication, and packaging of the glass specimens shall be representative of the glass whose strength is to be evaluated.

8.2 All glass specimens shall be visually inspected for edge or surface irregularities prior to testing, and all questionable glass specimens shall not be tested.

8.3 Glass specimens shall be handled carefully at all times because the strength of glass is influenced by its surface and edge conditions.

9. Calibration

9.1 Pressure-measuring systems should be routinely checked. If calibration is required, the manufacturer's recommendations or good engineering practices should be followed.

10. Required Information

10.1 The specifying authority shall provide the magnitude of the equivalent design load (positive or negative), the orientation of the glass specimen to the test chamber, the allowable probability of breakage for the glass specimens, and the coefficient of variation of the breakage loads typical of the glass specimens tested.

10.2 The specifying authority shall state whether the glass specimens shall be glazed in a standard test frame (see Annex A1) or in a test frame designed to simulate a specific glazing system. If the test frame is to simulate a specific glazing system, complete glazing details and support conditions shall be provided by the specifying authority.

11. Selection of Proof Load and Sample Size

11.1 The glass specimens shall be tested with a proof load that is larger than the equivalent design load. The proof load is found by multiplying the design load by the proof load factor, a, as follows:

$$q_p = aq_d \tag{1}$$

where:

q_p = proof load,
a = proof load factor, and
q_d = equivalent design load.

11.1.1 If the glass specimens are to be tested in a standard test frame, the proof load factor, a, is found in Tables 1-4, given the equivalent design load probability of breakage and the appropriate coefficient of variation, ν. The proof load factor, a,

[3] The boldface numbers in parentheses refer to the references listed at the end of this method.

TABLE 1 Required Sample Size (ν = 0.10)

		Proof Load Factor, *a*	
		1.2	1.3
Equivalent Design Load Probability of Breakage	0.010	11	
	0.009	12	
	0.008	12	
	0.007	13	
	0.006	15	
	0.005	17	
	0.004	19	
	0.003	24	
	0.002	31	10
	0.001	53[A]	15

[A]Testing is not recommended because of excess expense.

TABLE 2 Required Sample Size (ν = 0.15)

		Proof Load Factor, *a*			
		1.3	1.4	1.5	1.6
Equivalent Design Load Probability of Breakage	0.010	15			
	0.009	16			
	0.008	18	10		
	0.007	20	11		
	0.006	22	12		
	0.005	26	13		
	0.004	31	15		
	0.003	40	19	11	
	0.002	55[A]	26	14	
	0.001	106[A]	47	24	13

[A]Testing is not recommended because of excess expense.

corresponding to the minimum sample size or the maximum capacity of the loading apparatus, shall be selected.

11.1.2 If the glass specimens are to be tested in a test frame that is representative of a specific glazing system, the maximum allowable proof load that can be resisted by the test frame shall be determined using engineering principles. The proof load factor, *a*, is then determined by dividing the maximum allowable proof load by the equivalent design load. Tables 1-4 are then entered with the calculated value of *a*, the specified coefficient of variation, ν, and the equivalent design load probability of breakage to determine the number of glass specimens to be tested. If the corresponding entry in Table 1 is blank, then the proof load factor should be reduced to a value based upon a minimum sample size.

11.2 Rationale to develop Tables 1-4 is presented in Appendix X1.

12. Procedure

12.1 Measure and record the ambient temperature and the relative humidity.

12.2 Install glass specimens in the test frame in accordance with recommendations presented in Annex A1 for standard support conditions or as specified for a specific glazing system.

12.3 Apply one half of the proof load to the glass specimen and hold for 10 s. Reduce the test pressure to zero and vent the test chamber for a period from 3 to 5 min before the pressure-measuring apparatus is adjusted to zero.

12.4 If air leakage around the glass specimen is excessive, tape may be used to cover any cracks and joints through which leakage is occurring. However, tape shall not be used when there is a possibility that it will significantly restrict differential movement between the glass specimen and the test frame.

12.5 Apply the proof load to the glass specimen in a period from 40 to 60 s, maintain the proof load for a period of 60 s, and then vent the test chamber. Continuous load-time records shall be kept for the duration of the loading.

12.6 If the glass specimen does not break, remove it from the test frame, and discard it. Select a new glass specimen, and repeat procedures in 12.2-12.5. If the glass specimen does break, record the break and continue.

12.7 Inspect the test frame for permanent deformation or other failures of principal members. If failure of the standard test frame occurs, it shall be appropriately stiffened and strengthened and the test restarted. If failure occurs in a user specified test frame, the proof load shall be reduced or the test frame appropriately stiffened or strengthened and the test restarted.

12.8 Select a new glass specimen and repeat procedures in 12.2-12.5.

13. Interpretation of Results

13.1 If no specimen breaks during the test, the probability of breakage at the equivalent design load is judged to be significantly less than the specified probability of breakage.

13.2 If more than four glass specimens break, the probability of breakage at the equivalent design load is judged to be significantly greater than the specified probability of breakage.

13.3 If one to four glass specimen breaks occur, the probability of breakage at the equivalent design load is judged to not be significantly different than the specified probability of breakage.

14. Report

14.1 The report shall include the following information:

14.1.1 The date of the test, the date of the report, the ambient temperature, and the relative humidity.

14.1.2 Identification of the glass specimens (manufacturer, source of supply, dimensions both nominal and measured, manufacturer's designation, materials, and other pertinent information).

14.1.3 Detailed drawings of the glass specimens, test frame, and test chamber indicating orientation of the glass specimen to the test chamber. A complete description of pressure-measuring apparatus, and a statement that the test was conducted using a standard test frame or a test frame of the user's design.

14.1.4 Records of pressure differences exerted across each glass specimen during the test with each specimen being properly identified.

14.1.5 Identification or description of any applicable specification.

14.1.6 A statement that the tests were conducted in accordance with this test method, or a full description of any deviations.

15. Precision and Bias

15.1 Conclusions reached regarding the probability of breakage of the glass specimens tested are based upon statistical inference. As a result, there exists a small probability that the conclusion reached is incorrect. A full discussion of assumptions made in development of the decision criteria is presented in Appendix X1.

TABLE 3 Required Sample Size (ν = 0.20)

		Proof Load Factor, *a*							
		1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2
Equivalent Design Load Probability of Breakage	0.010	15	10						
	0.009	16	11						
	0.008	18	12						
	0.007	20	13						
	0.006	23	15	10					
	0.005	27	18	12					
	0.004	33	21	15	10				
	0.003	45	29	19	13	10			
	0.002	66[A]	41	27	19	13	10		
	0.001	142[A]	88[A]	57[A]	39	27	19	14	11

[A]Testing is not recommended because of excess expense.

TABLE 4 Required Sample Size (ν = 0.25)

		Proof Load Factor, *a*															
		1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
Equivalent Design Load Probability of Breakage	0.010	33	23	18	13	10											
	0.009	37	26	20	15	11											
	0.008	42	30	22	17	13	10										
	0.007	48	34	26	20	15	12										
	0.006	58[A]	42	31	23	18	14	11									
	0.005	72[A]	53[A]	39	30	22	17	14	11								
	0.004	93[A]	69[A]	50[A]	38	29	23	18	14	11							
	0.003	134[A]	100[A]	74[A]	55[A]	43	33	26	21	16	13	11					
	0.002	220[A]	165[A]	125[A]	96[A]	72[A]	56[A]	44	35	28	23	19	15	13	10		
	0.001	534[A]	418[A]	323[A]	252[A]	197[A]	157[A]	125[A]	98[A]	79[A]	64[A]	53[A]	44	36	30	25	21

[A]Testing is not recommended because of excess expense. Equivalent Design Load Probability of Breakage

16. Keywords

16.1 curtain walls; destructive testing; doors; exterior windows; glass performance; performance testing; structural performance; uniform static loads

ANNEX

(Mandatory Information)

A1. STANDARD GLASS TEST FRAME

A1.1 Introduction

A1.1.1 The standard test frame shall be designed to support a rectangular glass specimen in a vertical plane and expose it to a positive (inward-acting) load. The test frame consists of two primary systems, a structural support system and a glazing system. The structural support system shall be designed to resist applied loads with limited deflections and provide an interface between the test chamber and the glazing system. The glazing system shall be designed to limit lateral displacements of the glass specimen edges while minimizing rotational and in-plane restraints of the glass specimen edges. This annex presents pertinent details relating to the design and construction of a standard test frame.

A1.2 Structural Support System

A1.2.1 The structural support system consists of four main structural members arranged as shown in Fig. A1.1. The inside rectangular dimensions, *a* and *b*, of the support system shall be found by subtracting 1 in. from the corresponding dimensions of the glass specimens. These dimensions shall be maintained within a tolerance $\pm 1/16$ in. (1.6 mm).

A1.2.2 The structural members shall be selected from available American Standard channels with flange widths greater than or equal to 1¾ in. (44 mm). The structural members shall be designed to withstand the appropriate proof load without permanent deformations. In addition, the structural members shall be designed to meet the following deflection criteria:

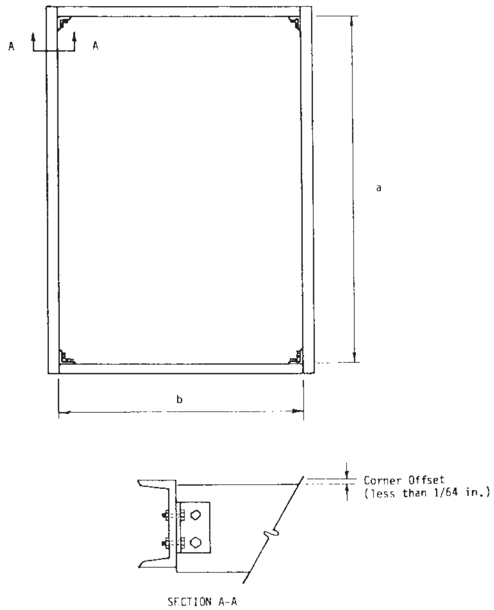

FIG. A1.1 Structural Support System

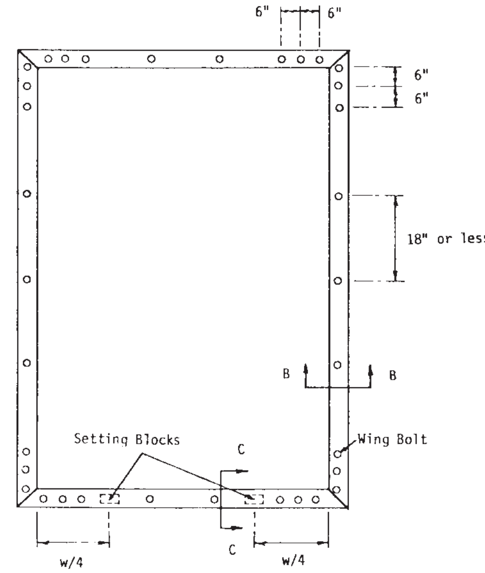

FIG. A1.2 Standard Glazing System

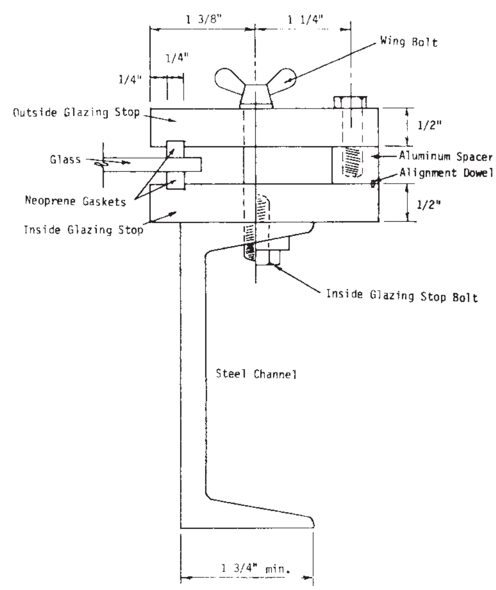

FIG. A1.3 Section *B-B* of Standard Glazing System

A1.2.2.1 The maximum lateral deflection (referenced to glass specimen) of the structural members shall not exceed *L*/750 where *L* is the length of the shorter side of the glass specimen,

A1.2.2.2 The maximum rotation of the structural members shall not exceed 1°, and

A1.2.2.3 The maximum in-plane deflection (referenced to the glass specimen) of the structural members shall not exceed *L*/2000.

A1.2.3 The corner connections of the support system shall be designed using angle braces and bolts to minimize racking or twisting during testing.

A1.2.4 In addition to the above criteria, the following fabrication tolerances shall be met:

A1.2.4.1 The maximum out-of-plane offset at the corners shall not exceed 1⁄64 in. (0.4 mm) (see Fig. A1.1),

A1.2.4.2 The maximum planar variation of the outside edges of the structural members shall not exceed 1⁄16 in. (1.6 mm),

A1.2.4.3 The maximum difference in the measured diagonals of the interior rectangular opening shall not exceed 1⁄8 in. (3.2 mm), and

A1.2.4.4 The depth of the structural members shall be sufficient to allow unimpaired lateral displacements of the glass specimens during the test.

A1.2.5 Holes shall be provided as required in the flanges of the structural members for fasteners.

A1.3 Glazing System

A1.3.1 The glazing system, which attaches to the vertical structural support system, consists of the following major components (see Fig. A1.2, Fig. A1.3, and Fig. A1.4):

A1.3.1.1 Inside and outside glazing stops,

A1.3.1.2 Aluminum spacers,

A1.3.1.3 Inside and outside neoprene gaskets,

A1.3.1.4 Structural fasteners, and

A1.3.1.5 Neoprene setting blocks.

A1.3.2 The glass specimen rests on two neoprene setting blocks (85 ± 5 Shore A durometer) as shown in Fig. A1.4. The glass specimen is laterally supported around its perimeter with neoprene gaskets (65 ± 5 Shore A durometer). The glass specimen shall be centered within the glazing system to a tolerance of ±1⁄16 in. (1.6 mm). A minimal clamping force (4 to 10 lbf/in.) (700 to 1750 N/m) is applied to the edge of the glass specimen by loosely tightening the wing bolts that are spaced around the specimen perimeter.

A1.3.3 The glazing stops shall be fabricated using 1⁄2 by 3-in. (13 by 76-mm) aluminum bar stock (6061 T 6511) in sections no shorter than 24 in. (610 mm) or the smaller rectangular glass specimen dimension. A 1⁄8 by 3⁄8-in. (3.2 by 9.5-mm) rectangular slot shall be machined in the glazing stops as shown in Fig. A1.3. At each corner the glazing stops shall be mitered and fitted as shown in Fig. A1.2.

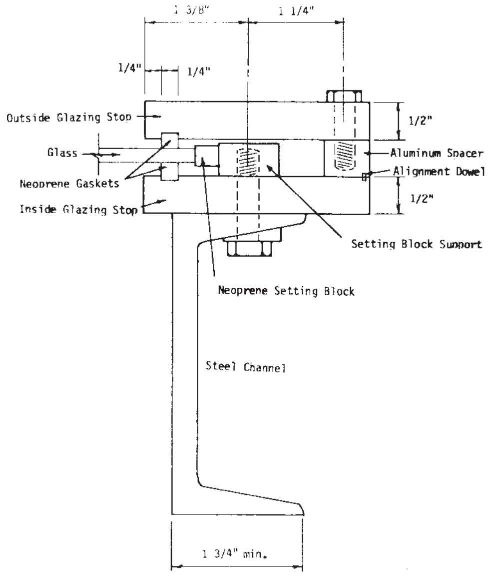

FIG. A1.4 Section *C-C* of Standard Glazing System

A1.3.4 The inside glazing stop shall be fastened to the top flange of the structural support members using ¼-in. (6.4-mm) diameter bolts. These bolts pass through a clear hole in the channel flange into a threaded hole in the inside glazing stop. These bolts shall not extend above the surface of the inside glazing stop. These bolts shall be spaced no further than 24 in. (610 mm) apart with no fewer than two bolts per glazing stop section.

A1.3.5 The outside glazing stop shall be secured to the support system using ⅜-in. (9.5-mm) diameter wing bolts. These bolts pass through the outside glazing stop through the inside glazing stop and into a threaded hole in the support channels. In the corner areas there shall be three wing bolts spaced at 6-in. (152-mm) intervals as shown in Fig. A1.2. Between these corner bolts, the bolts shall be spaced no further than 18 in. (457 mm) apart with a minimum of two bolts per glazing stop section.

A1.3.6 The rectangular aluminum spacers shall be fabricated using ¾-in. (19-mm) wide aluminum bar stock. The depth of the spacers shall be equal to the thickness of the glass plus ⅜ in. (9.5 mm). This dimension shall be maintained within a tolerance of ±1/32 in. (0.8 mm). The lengths of the spacers shall correspond to the lengths of matching outside glazing stop sections. In corner areas the spacers shall extend no further than 1 in. (25.4 mm) past the corner of the installed glass specimen. The spacers shall be fastened to the outside glazing stops using ¼-in. (6.4-mm) diameter bolts. These bolts pass through the outside glazing stop into a threaded hole in the spacer. These bolts shall be spaced no further than 24 in. (610 mm) apart with no fewer than 2 bolts per glazing stop section.

A1.3.7 Two neoprene (85 ± 5 Shore A durometer) setting blocks shall be centered at the quarter points of the glass specimen as shown in Fig. A1.2. Appropriate supports, fastened through the inside glazing stop to the support channels, shall be provided. The required length of a setting block (in in. (in mm)) is found by multiplying the glass specimen area (square feet (square metres)) by 0.10. However, in no case shall the setting block length be less than 4 in. (102 mm). The width of the setting block shall be 1/16 in. (1.6 mm) greater than the specimen thickness so that continuous support across the thickness of the specimen is provided.

A1.3.8 The neoprene gaskets shall be fabricated using 5/16-in. (7.9 mm) thick neoprene (65 ± 5 Shore A durometer) to fit snugly into the glazing stop slots. These gaskets shall be placed so that continuous support of the glass specimen perimeter is achieved. The gaskets may be held in place using an appropriate glue or cement. However, the neoprene surface in contact with the glass specimen shall be kept free of all foreign materials.

A1.3.9 Silicone sealant or other appropriate material may be used to seal joints against leakage. However, under no circumstances is a sealant to contact the glass specimen.

APPENDIX

(Nonmandatory Information)

X1. STATISTICAL BASIS FOR TEST METHOD

X1.1 The purpose of this test method is to determine whether the true probability of breakage of a set of glass specimens exposed to a design load is significantly less than, greater than or not significantly different from the design probability of breakage. The most direct approach to accomplish this purpose is to expose a sample of representative glass specimens to the design load recording all breaks, and then to analyze the resulting data to determine if the probability of breakage is less than or equal to the design probability of breakage. However, because the design probability of breakage associated with most glass specimens is small (typically less than 0.008), a prohibitively large number of specimens would have to be tested to reach a statistically defensible conclusion.

X1.2 The approach adopted in development of this test method is to increase the probability of breakage of the glass specimens to be tested by exposing the specimens to a proof load whose magnitude is greater than the design load. By thus increasing the specimen probability of breakage, the number of specimens that must be tested to reach a statistically, defensible conclusion is reduced to an acceptable level.

X1.3 The number of glass specimens that must be tested depends upon the magnitude of the design probability of breakage, the ratio of the proof load to the design load, and the coefficient of variation of the glass specimen breakage loads. Information to determine the required number of specimens to be tested and the allowable number of specimen breaks is presented in Sections 11 and 12. Fundamental concepts of probability and statistics along with critical assumptions used to generate this information is presented in this appendix.

X1.4 The first assumption made in development of this test method is that the glass specimen breakage loads are normally distributed. The normal distribution is the best understood and most widely used continuous probability distribution function available. Further, the normal distribution has historically been used to represent glass specimen breakage loads.

X1.5 The standard normal probability density function, *f(z)*, is as follows:

$$f(z) = \frac{1}{\sqrt{2\pi}} \exp\left[-\frac{z^2}{2}\right] \quad (X1.1)$$

$$z = \frac{q - \mu}{\sigma} \quad (X1.2)$$

where:
q = breakage load,
μ = mean breakage load, and
σ = breakage load standard deviation.

The standard normal cumulative probability function, *F(z)*, is found by integrating the density function, Eq X1.1 from negative infinity to a particular value of the standard variate, z_0, as follows:

$$F(z_0) = \int_{-\infty}^{z_0} \exp\left[-\frac{z^2}{2}\right] dz \quad (X1.3)$$

Eq X1.3 cannot be integrated directly, hence, values of the standard normal cumulative probability function must be found using numerical methods **(5).** Values of *F(z)* are available in numerous texts and handbooks **(5, 6).**

X1.6 The ratio of the standard deviation of a distribution to the mean of the distribution (sometimes expressed as a percent) is called the coefficient of variation, ν, of the distribution. The relationship between the mean, standard deviation, and coefficient of variation is as follows:

$$\sigma = \nu\mu \quad (X1.4)$$

The coefficient of variation is particularly useful when addressing glass strength because its magnitude tends to be constant for a particular glass type (annealed, tempered, laminated, etc.). Typical values of the coefficient of variation of different types of glass are presented in Table X1.1.

TABLE X1.1 Typical Coefficients of Variation, ν, for Flat Glass

Glass Type	Typical Coefficient of Variation, ν^A
Annealed	0.20–0.25
Heat strengthened	0.15
Tempered	0.10

[A] Glass manufacturers should be contacted for more specific information. These values may vary significantly.

X1.7 If Eq X1.4 is substituted into Eq X1.2, the following relationship results:

$$z = \frac{q - \mu}{\nu\mu} \quad (X1.5)$$

Eq X1.5 can be rearranged, resulting in the following relationship:

$$q = \mu(\nu z + 1) \quad (X1.6)$$

Eq X1.5 and Eq X1.6 can be used in conjunction with tabulated values of the standard normal cumulative distribution to calculate the probability of breakage of a glass specimen exposed to a proof load given a design load and its associated probability of breakage. For example, consider a sample of annealed glass with a coefficient of variation of 0.25 and a design probability of breakage of 0.008. The value of the standard normal variate, *z*, corresponding to a probability of breakage of 0.008 is −2.41. Eq X1.6 can be used to express the magnitude of the design load, *qd*, in terms of the mean breakage load, μ, as follows:

$$q_d = \mu[(0.25)(-2.41) + (1.0)] = 0.40\mu \quad (X1.7)$$

If a proof load factor, *a*, of 2.0 is considered the proof load magnitude, q_p, will be 0.80μ. Eq X1.5 can then be used to determine the corresponding value of the standard normal variate as follows:

$$z = \frac{0.80\mu - \mu}{0.25\mu} = -0.80 \quad (X1.8)$$

Then the probability of a specimen break at the proof load, *p*, can be found to be 0.21 using tabulated values of the standard normal cumulative distribution.

X1.8 The basic test plan is to select a sample of several glass specimens and to independently expose each specimen to the proof load, noting each break. There are two possible outcomes for each specimen. Either the specimen breaks or does not break. Further, if the glass specimens are reasonably similar, the probability that a particular specimen breaks when exposed to the proof load can be assumed to be constant. It is further assumed that the outcome for one specimen does not affect the outcome for another specimen. With these assumptions, the process can be modeled using the binomial distribution.

X1.9 If the probability of an event occurring in one trial is given by *p*, then the probability, *Pr*, of it occurring *r* times in *n* independent trials is the binomial distribution as follows:

$$Pr = \frac{n!}{r!(n-r)!} p^r (1-p)^{n-r} \quad (X1.9)$$

If *n* is large and *p* is small, the binomial distribution can be approximated using the Poisson distribution as follows:

$$Pr = \frac{e^{-(np)}(np)^r}{r!} \quad (X1.10)$$

Eq X1.10 is sufficiently accurate to calculate probabilities of specimen breakage required in this test, provided that *n* is greater than or equal to 10, and *p* is less than or equal to 0.25.

X1.10 Based upon the number of glass specimens tested and the number of glass specimens that break, it is concluded whether the true probability of breakage of a set of glass specimens exposed to a design load is significantly less than, significantly greater than, or not significantly different than the specified design probability of breakage. Because the strengths of similar glass specimens vary significantly, the conclusions reached through the use of this procedure may be correct or incorrect. Therefore, the procedure has been adjusted to minimize the errors associated with the conclusions.

X1.11 If the procedure is conducted and no glass breaks occur, it is concluded that the actual probability of breakage is less than the specified probability of breakage. This test procedure has been designed to minimize the probability that this conclusion is arrived at; when, in fact, the actual probability of breakage is not less than the specified probability of breakage. The probability of this error is inversely proportional to the number of specimens tested (*n*). The probability of this error occurring when (*n*) specimens are tested is calculated using equation Eq X1.10 as follows:

$$P_0 = e^{-np} \qquad \text{(X1.11)}$$

where *p* is the proof load probability of breakage. The maximum allowable probability of this error occurring is set to 0.10. If this value is substituted into equation Eq X1.11 the following expression results:

$$0.10 = e^{-np} \qquad \text{(X1.12)}$$

If the natural logs of both sides of Eq X1.12 are taken and the resulting relationship rearranged, the relationship between the proof load probability and the sample size is as follows:

$$n = \frac{2.303}{p} \qquad \text{(X1.13)}$$

Eq X1.13 is used to determine the required sample size given the probability of proof load breaks.

X1.12 The other incorrect outcome results when it is concluded that the actual probability of breakage is greater than the specified probability of breakage when in fact it is not. The probability of this error is controlled by the allowable number (*r*) of specimen breaks per test. The probability associated with this error is estimated using the following relationship:

$$\textit{Probable Error} = 1 - \Sigma_0 \qquad \text{(X1.14)}$$

where all the variables have been defined. The relationship between the number of allowable breaks (*r*) and the probability of this type of error is presented in Table X1.2 as determined with Eq X1.14. In this test procedure, it is concluded that the actual probability of breakage is greater than the specified probability of breakage if five (5) or more specimens fail. Thus, the probability of this type of error is set to about 3 % as shown in Table X1.2.

X1.13 Consider again the previous example of annealed glass specimens with a coefficient of variation of 0.25, a design probability of breakage of 0.008, a proof load factor of 2, and the previously calculated proof load probability of breakage, *p*, of 0.21. The required sample size is calculated using Eq X1.13 as follows:

TABLE X1.2 Relationship Between the Number of Breaks and the Probability of Error Discussed in X1.12

Number of Breaks, *r*	Probability of X1.12 Error[A]
0	0.900
1	0.670
2	0.405
3	0.201
4	0.084
5	0.030
6	0.009

[A] Values are calculated using Eq X1.14.

$$n = \frac{2.303}{0.21} = 10.97 \simeq 11 \qquad \text{(X1.15)}$$

Therefore, eleven glass specimens are to be tested. If no breaks occur, it will be concluded that the actual probability of breakage is less than the specified probability of breakage. If five or more breaks occur, it will be concluded that the actual probability of breakage is greater than the specified probability of breakage. If one to four breaks occur, it is concluded that there is no significant difference between the actual and specified probabilities of breakage.

X1.14 To simplify use of this test method, Section 11 was prepared with Table 1 so that the user can conveniently apply the method. Two examples of the use of Section 10 are presented below to aid the user.

X1.14.1 *Example 1*:

X1.14.1.1 The destructive test procedure shall be conducted to determine if the probability of breakage of a set of annealed glass specimens ($\nu = 0.20$) is equal to or less than 8⁄1000 at a design load of 30 lbf/ft^2. The standard test frame shall be used.

X1.14.1.2 To determine the proper sample size, Table 3 is entered with an equivalent design probability of breakage of 0.008 and a proof load factor is selected based upon the minimum sample size of 12. The proof load factor thus selected is 1.6. Therefore, 12 glass specimens are independently subjected to a proof load of 48 lbf/ft^2.

X1.14.1.3 In this example, it was found that 5 glass specimens broke. Therefore, it is concluded that the probability of breakage of glass specimens subjected to the design load is greater than 0.008.

X1.14.2 *Example 2*:

X1.14.2.1 The destructive test procedure shall be conducted to determine if the probability of breakage of a set of annealed glass specimens ($\nu = 0.20$) is equal to or less than 0.001 when exposed to a design load of 40 lbf/ft^2. The specimens shall be tested in a test frame representative of a particular glazing system.

X1.14.2.2 First the representative test frame is analyzed using engineering principles, and it is determined that the test frame can safely withstand a proof load of 80 lbf/ft^2.

X1.14.2.3 The value of the proof load factor, *a*, is then computed to be 2.0. Then Table 3 is entered with a proof load factor, *a*, of 2.0 and an equivalent design probability of breakage of 0.001, and it is determined that 19 specimens should be exposed to a proof load of 80 lbf/ft^2.

X1.14.2.4 In this example it was found that 4 glass specimens broke. Therefore, it is concluded that the actual probability of the glass specimens subjected to the design load is less than 0.001.

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