INTERNATIONAL

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

This standard is issued under the fixed designation E997; 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 proof load test method is a procedure to ~~determine~~ determine, with a 90 % confidence level, if the probability of breakage under design loads for a given population of glass specimens ~~tested is significantly greater than, significantly less than, or not significantly different than the specified probability of breakage when exposed to a specified design load.~~ is less than a selected value. It is not intended to be a design standard for determining the load resistance of glass. Practice E1300 shall be used for this purpose.

1.2 This test method describes apparatus and procedures to select and apply a 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. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered 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:*[2]

E631 Terminology of Building Constructions

E1300 Practice for Determining Load Resistance of Glass in Buildings

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of general terms related to building construction used in this test method refer to Terminology E631.

3.2 *Definitions of Terms Specific to This Standard:*

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

3.2.2 ~~*equivalent*~~ *design load, n*—the specified uniform ~~design load converted to specified duration (see~~ load and load duration.~~4.2).~~

3.2.3 *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).

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

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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 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.

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

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

3.2.7 *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.~~

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

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

3.2.10 *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 ~~specified duration~~ proof load. Load-time records shall be kept for each glass specimen. Each glass specimen break shall be recorded.

4.2 After testing the required number of glass specimens, it is ~~determined~~ determined, with a 90 % confidence level, if the probability of breakage ~~is significantly less than, significantly greater than, or not significantly different than the specified~~ under design loads for the given population of glass specimens is less than a specified allowable 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 design load (wind, snow, etc.) that can ~~be transformed into a specific duration~~ reasonably be applied to the test specimens or transformed into an 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 shall be taken to protect observers in the event of glass ~~breakage should be observed.~~ breakage. 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.

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

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~~ testing. All glass specimens with edge or surface irregularities not representative of the glass whose strength is to be evaluated 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.~~ verified prior to testing. If calibration is required, the manufacturer's recommendations or good engineering practices ~~should~~shall 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 design load 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 Initial 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:

$$q_p = aq_d \quad (1)$$

where:

q_p = proof load,
a = proof load factor, and
~~q_d = equivalent design load.~~
q_d = 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~~Table 1 through Table 4, given the ~~equivalent~~ design load allowable probability of breakage and the appropriate coefficient of variation, ν. The proof load factor, *a*, ~~corresponding to the minimum sample size or the~~ is selected with due regard to the maximum capacity of the ~~loading apparatus,~~ test apparatus. The tables indicate the initial sample size, n, of glass specimens to be tested. If the sample size entry in Table 1 through Table 4 is blank an alternate proof load factor shall be selected.

TABLE 1 Required Zero Break Sample Size (ν = 0.10)

		Proof Load Factor, *a*	
		1.2	1.3
~~Equivalent Design Load Probability of Breakage~~ Design Load Probability of Breakage	~~0.010~~	~~11~~	
		0.010	10
	~~0.009~~	~~12~~	
	0.009	11	
	0.008	12	
	0.007	13	
	~~0.006~~	~~15~~	
	0.006	14	
	~~0.005~~	~~17~~	
	0.005	16	
	0.004	19	
	~~0.003~~	~~24~~	
	0.003	23	
	~~0.002~~	~~31~~	~~10~~
	0.002	31	
	~~0.001~~	~~53[A]~~	~~15~~
	0.001	_	14

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

TABLE 2 Required Zero Break Sample Size (ν = 0.15)

		Proof Load Factor, *a*			
		~~1.3~~1.3	1.4	1.5	1.6
~~Equivalent Design Load Probability of Breakage~~ Design Load Probability of Breakage	~~0.010~~	~~15~~			
		0.010	14		
	0.009	16			
	~~0.008~~	~~18~~	~~10~~		
	0.008	17			
	~~0.007~~	~~20~~	~~11~~		
	0.007	19	10		
	~~0.006~~	~~22~~	~~12~~		
	0.006	22	11		
	~~0.005~~	~~26~~	~~13~~		
	0.005	25	13		
	0.004	31	15		
	~~0.003~~	~~40~~	~~19~~	~~11~~	
	0.003	39	19	10	
	~~0.002~~	~~55[A]~~	~~26~~	~~14~~	
	0.002	_	26	13	
	~~0.001~~	~~106[A]~~	~~47~~	~~24~~	~~13~~
	0.001		47	23	13

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

~~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, *v*, 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~~Table 1 through Table 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~~ as quickly as possible, but no longer than 15 s. Maintain the proof load for ~~a specified period,~~ the same duration as the specified design load, 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.~~ frame. Select a new glass specimen, and repeat procedures in ~~12.2 – 12.5~~12.2 through 12.5. If the glass specimen does break, record the break and, if desired, determine from Table 5 through Table 8~~and continue.~~ (using the design load probability of failure, the appropriate coefficient of variation, and the selected proof load factor) the "one break" sample size, N_1. This sample size represents the total number of tests to be conducted with only one associated specimen break such that there is a 90 % confidence level that the actual probability of breakage at the design load is less than the allowable probability of breakage. If elected by the specifying authority or other appropriate party, testing may then continue in accordance with procedures in 12.2 through 12.5.

12.7 If, during the course of testing N_1 samples, a second break occurs, record the break and, if desired, determine from Table 9 through Table 12 (using the design load probability of failure, the appropriate coefficient of variation, and the selected proof load factor) the "two break" sample size, N_2. This sample size represents the total number of tests to be conducted with only two associated specimen breaks such that there is a 90 % confidence level that the actual probability of breakage at the design load is less than the allowable probability of breakage. If elected by the specifying authority or other appropriate party, testing may then continue in accordance with procedures in 12.2 through 12.5.

12.8 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.

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~~

TABLE 3 Required Zero Break 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
Design Load Probability of Breakage	0.010	14							
	0.009	15	10						
	0.008	17	11						
	0.007	19	12						
	0.006	22	14						
	0.005	26	17	11					
	0.004	32	21	14	10				
	0.003	43	28	18	13				
	0.002		42	27	19	13	10		
	0.001				38	26	19	14	10

~~A Testing is not recommended because of excess expense.~~

TABLE 4 Required Zero Break 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
Design Load Probability of Breakage	0.010	33	24	18	14	10											
	0.009	37	27	20	15	12											
	0.008	43	31	23	17	13	10										
	0.007	49	36	27	20	15	12										
	0.006		43	32	24	18	14	11									
	0.005			40	30	23	18	14	11								
	0.004				39	30	23	18	15	12							
	0.003					43	34	26	21	17	14	11					
	0.002							45	36	29	23	19	16	13	11		
	0.001												44	37	31	26	22

TABLE 5 Required One Break Sample Size (ν = 0.10)

		Proof Load Factor, *a*	
		1.2	1.3
Design Load Probability of Breakage	0.010	17	
	0.009	18	
	0.008	20	
	0.007	21	
	0.006	24	
	0.005	27	
	0.004	32	
	0.003	39	
	0.002	52	
	0.001	_	24

12.9 ~~Select~~ Rationale used to develop Table 5 through Table 12 is presented in Appendix X1~~a new glass specimen and repeat procedures~~. Guidance for testing a sample of glass specimens with more than two breaks is not given in ~~12.2 – 12.5~~this test method, but may be determined using the principles described in Appendix X1.

13. Interpretation of Results

13.1 If no specimen breaks during the ~~test, the~~ testing of the initial sample size, n, given in Table 1 through Table 4, there is a 90 % confidence level that the actual probability of breakage at the ~~equivalent~~ design load is ~~judged to be significantly~~ less than the ~~specified~~allowable probability of breakage.

TABLE 6 Required One Break Sample Size (ν = 0.15)

		Proof Load Factor, *a*			
		1.3	1.4	1.5	1.6
Design Load Probability of Breakage	0.010	24			
	0.009	26			
	0.008	29			
	0.007	32	17		
	0.006	37	18		
	0.005	43	21		
	0.004	51	25		
	0.003	66	32	17	
	0.002	–	44	23	
	0.001		79	39	22

~~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.~~

13.2 If one ~~to four glass~~ specimen breaks ~~occur, the~~ during the testing of sample size, N_1, given in Table 5 through Table 8, there is a 90 % confidence level that the actual probability of breakage at the ~~equivalent~~ design load is ~~judged to not be significantly different~~ less than the ~~specified~~allowable probability of breakage.

13.3 If two specimens break during the testing of sample size, N_2, given in Table 9 through Table 12, there is a 90 % confidence level that the actual probability of breakage at the design load is less than the allowable 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 start/stop load times and 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.

14.1.7 Interpretation of the test results.

15. Precision and Bias

15.1 Conclusions reached regarding the probability of breakage of the glass specimens tested are based upon statistical ~~inference.~~ inference and assumptions regarding the coefficients of variation of the glass. 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.

16. Keywords

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