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An American National Standard

Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Storm Shutters Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials[1]

This standard is issued under the fixed designation E 1886; 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 determines the performance of exterior windows, curtain walls, doors, and storm shutters impacted by missile(s) and subsequently subjected to cyclic static pressure differentials. A missile propulsion device, an air pressure system, and a test chamber are used to model some conditions which may be representative of windborne debris and pressures in a windstorm environment. This test method is applicable to the design of entire fenestration or shutter assemblies and their installation. The performance determined by this test method relates to the ability of elements of the building envelope to remain unbreached during a windstorm.

1.2 The specifying authority shall define the representative conditions (see 10.1).

1.3 The values stated in SI units are to be regarded as the standard. Values given in parentheses are for information only. Certain values contained in reference documents cited herein may be stated in inch-pound units and must be converted by the user.

1.4 *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 hazard statements are given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

E 330 Test Method for Structural Performance of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference[2]

E 631 Terminology of Building Constructions[2]

E 997 Test Method for Structural Performance of Glass in Exterior Windows, Curtain Walls, and Doors Under the Influence of Uniform Static Loads by Destructive Methods[2]

E 1233 Test Method for Structural Performance of Exterior Windows, Curtain Walls, and Doors by Cyclic Static Air Pressure Differential[2]

2.2 *ANSI/ASCE Standard:*

ANSI/ASCE 7, American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures[3]

2.3 *American Lumber Standard:*

Document PS20-94—American Softwood Lumber Standard[4]

3. Terminology

3.1 *Definitions:* General terms used in this test method are defined in Terminology E 631.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *2 × 4 in. lumber*—a dressed piece of surface dry, softwood lumber as defined in Document PS20-94.

3.2.2 *air pressure cycle*—beginning at a specified air pressure differential, the application of positive (negative) pressure to achieve another specified air pressure differential and returning to the initial specified air pressure differential.

3.2.3 *air pressure differential*—the specified differential in static air pressure across the specimen, creating an inward (outward) load, expressed in Pa (lb/ft^2). The maximum air pressure differential (P) is specified or is equal to the design pressure.

3.2.4 *basic wind speed*—the wind speed as determined by the specifying authority.

3.2.5 *design pressure*—the uniform static air pressure difference, inward or outward, for which the test specimen would be designed under service load conditions using conventional structural engineering specifications and concepts. This pressure is determined by either analytical or wind tunnel procedures (such as are specified in ANSI/ASCE 7).

3.2.6 *fenestration assembly*—the construction intended to be installed to fill a wall or roof opening.

3.2.7 *missile*—the object which is propelled toward a test specimen.

3.2.8 *positive (negative) cyclic test load*—the specified difference in static air pressure, creating an inward (outward)

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

[3] Available from the American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191-4400.

[4] Available from the American Lumber Standard Committee, Inc., P.O. Box 210, Germantown, MD 20875.

loading, for which the specimen is to be tested under repeated conditions, expressed in Pa (lb/ft^2).

3.2.9 *shutter assembly*—the construction intended to be installed in front of fenestration assemblies to provide protection.

3.2.10 *specifying authority*—the entity responsible for determining and furnishing information required to perform this test method.

3.2.11 *test loading program*—the entire sequence of air pressure cycles to be applied to the test specimen.

3.2.12 *test specimen*—the entire assembled unit submitted for test.

3.2.13 *windborne debris*—objects carried by the wind in windstorms.

3.2.14 *windstorm*—a weather event, such as a hurricane, with high sustained winds and turbulent gusts capable of generating windborne debris.

4. Summary of Test Method

4.1 This test method consists of mounting the test specimen, impacting the test specimen with a missile(s), and then applying cyclic static pressure differentials across the test specimen in accordance with a specified test loading program, observing and measuring the condition of the test specimen, and reporting the results.

5. Significance and Use

5.1 Structural design of exterior windows, curtain walls, doors, and storm shutters is typically based on positive and negative design pressure(s). Design pressures based on wind speeds with a mean recurrence interval (usually 25–100 years) that relates to desired levels of structural reliability and are appropriate for the type and importance of the building **(1)**.[5] The adequacy of the structural design is substantiated by other test methods such as Test Methods E 330 and E 1233 which discuss proof loads as added factors of safety. However, these test methods do not account for other factors such as impact from windborne debris followed by fluctuating pressures associated with a severe windstorm environment. As demonstrated by windstorm damage investigations, windborne debris is present in hurricanes and has caused a significant amount of damage to building envelopes **(2-7)**. The actual in-service performance of fenestration assemblies and storm shutters in areas prone to severe windstorms is dependent on many factors. Windstorm damage investigations have shown that the effects of windborne debris, followed by the effects of repeated or cyclic wind loading, were a major factor in building damage **(2-7)**.

5.1.1 Many factors affect the actual loading on building surfaces during a severe windstorm, including varying wind direction, duration of the wind event, height above ground, building shape, terrain, surrounding structures, and other factors **(1)**. The resistance of fenestration or shutter assemblies to wind loading after impact depends upon product design, installation, load magnitude, duration, and repetition.

5.1.2 Windows, doors, and curtain walls are building envelope components often subject to damage in windstorms. The damage caused by windborne debris during windstorms goes beyond failure of building envelope components such as windows, doors, and curtain walls. Breaching of the envelope exposes a building's contents to the damaging effects of continued wind and rain **(1, 4-7)**. A potentially more serious result is internal pressurization. When the windward wall of a building is breached, the internal pressure in the building increases, resulting in increased outward acting pressure on the other walls and the roof. The internal pressure coefficient (see ANSI/ASCE 7), which is one of several design parameters, can increase by a factor as high as four. This can increase the net outward acting pressure by a factor as high as two.

5.1.3 The commentary to ANSI/ASCE 7-93 discusses internal pressure coefficients and the increased value to be used in designing envelopes with "openings" as follows:

> "Openings" in Table 9 (*Internal Pressure Coefficients for Buildings*) means permanent or other openings that are likely to be breached during high winds. For example, if window glass is likely to be broken by missiles during a windstorm, this is considered to be an opening. However, if doors and windows and their supports are designed to resist specified loads and the glass is protected by a screen or barrier, they need not be considered openings. (109)

Thus, there are two options in designing buildings for windstorms with windborne debris: buildings designed with "openings" (partially enclosed buildings) to withstand the higher pressures noted in the commentary to ANSI/ASCE 7-93 and, alternatively, building envelope components designed so they are not likely to be breached in a windstorm when impacted by windborne debris. The latter approach reduces the likelihood of exposing the building contents to the weather.

5.2 In this test method, a test specimen is first subjected to specified missile impact(s) followed by the application of a specified number of cycles of positive and negative static pressure differential **(8)**. The assembly must satisfy the pass/fail criteria established by the specifying authority, which may allow damage such as deformation, deflection, or glass breakage.

5.3 The windborne debris generated during a severe windstorm varies greatly, depending upon windspeed, height above the ground, terrain, surrounding structures, and other sources of debris **(4)**. Typical debris in hurricanes consists of missiles including, but not limited to, roof gravel, roof tiles, signage, portions of damaged structures, framing lumber, roofing materials, and sheet metal **(4,7,9)**. Median impact velocities for missiles affecting residential structures considered in Ref **(7)** ranged from 9 m/s (30 fps) to 30 m/s (100 fps). The missiles and their associated velocity ranges used in this test method are selected to reasonably represent typical debris produced by windstorms.

5.4 To determine design wind loads, averaged wind speeds are translated into air pressure differences. Superimposed on the averaged winds are gusts whose aggregation, for short periods of time (ranging from fractions of seconds to a few seconds) may move at considerably higher speeds than the averaged winds. Wind pressures related to building design, wind intensity versus duration, frequency of occurrence, and other factors are considered.

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

5.4.1 Wind speeds are typically selected for particular geographic locations and probabilities of occurrence from wind speed maps such as those prepared by the National Weather Service, from appropriate wind load documents such as ANSI/ASCE 7 or from building codes enforced in a particular geographic region.

5.4.2 Equivalent static pressure differences are calculated using the selected wind speeds **(1)**.

5.5 Cyclic pressure effects on fenestration assemblies after impact by windborne debris are significant **(6-8, 10-12)**. It is appropriate to test the strength of the assembly for a time duration representative of sustained winds and gusts in a windstorm. Gust wind loads are of relatively short duration. Other test methods, such as Test Methods E 330 and E 1233, do not model gust loadings. They are not to be specified for the purpose of testing the adequacy of the assembly to remain unbreached in a windstorm environment following impact by windborne debris.

5.6 Further information on the subjects covered in Section 5 is available in Refs **(1-12)**.

6. Apparatus

6.1 Use any equipment capable of performing the test procedure within the allowable tolerances.

6.2 *Major Components*:

6.2.1 *Mounting Frame*—The fixture which supports the test specimen in a vertical position during testing. The maximum deflection of the longest member of the mounting frame either during impact or the maximum specified static air pressure differential shall not exceed $L/360$, where L denotes the longest unsupported length of a member of the mounting frame. Deflection measurements shall be made normal to the plane of the specimen at the point of maximum deflection. The mounting frame shall be either integral with the test chamber or capable of being installed into the test chamber prior to or following missile impact(s). The mounting frame must be anchored so it does not move when the specimen is impacted.

6.2.2 *Air Pressure Cycling Test Chamber*—An enclosure or box with an opening against which the test specimen is installed. It must be capable of withstanding the specified cyclic static pressure differential. Pressure taps shall be provided to facilitate measurement of the cyclic static pressure differential. They shall be located such that the measurements are unaffected by air supplied to or evacuated from the test chamber or by any other air movements.

6.2.3 *Air Pressure System*—A controllable blower, a compressed air supply/vacuum system, or other suitable system capable of providing the required maximum air pressure differential (inward and outward acting) across the test specimen. Specified pressure differentials across the test specimen shall be imposed and controlled through any system that subjects the test specimen to the prescribed test loading program. Examples of suitable control systems include manually operated valves, electrically operated valves, or computer controlled servo-valves.

6.2.4 *Air Pressure Measuring Apparatus*—Pressure differentials across the test specimen shall be measured by an air pressure measuring apparatus with an accuracy of ±2 % of its maximum rated capacity, or ±100 Pa (2 psf), whichever is less, and with a response time less than 50 ms. Examples of acceptable apparatus are: mechanical pressure gages and electronic pressure transducers.

6.2.5 *Missile Propulsion Device(s)*—Any device capable of propelling the missile at a specified speed, orientation, and impact location. The missile shall not be accelerating upon impact due to the force of gravity along a line normal to the specimen. Examples of commonly used missile propulsion devices are found in Appendix X1.

6.2.6 *Speed Measuring System*—A system capable of measuring missile speeds within the tolerances defined in 11.2.1. Typical speed measuring systems are described in Appendix X2.

6.2.7 *Missile*—Missiles shall be one or more of the following:

6.2.7.1 *Small Missile*—A solid steel ball having a mass of 2 g (0.004 lb) ± 5 %, with an 8-mm (5⁄16-in.) nominal diameter, and an impact speed between 0.40 and 0.75 of the basic wind speed (3-s gust in accordance with ANSI/ASCE 7).

6.2.7.2 *Large Missile*—A No. 2 or better Southern Yellow Pine or Douglas Fir 2 × 4 in. lumber having an American Lumber Standard Committee accredited agency mark having a mass of between 2050 g ± 100 g (4.5 ± 0.25 lb) and 6800 g ± 100 g (15.0 ± 0.25 lb) and having a length between 1.2 m ± 100 mm (4 ft ± 4 in.) and 4.0 m ± 100 mm (13.2 ft ± 4 in.) and an impact speed between 0.10 and 0.55 of the basic wind speed (3-s gust in accordance with ANSI/ASCE 7). The missile shall have no defects, including knots, splits, checks, shakes, or wane within 30 cm (12 in.) of the impact end. The impact end shall be trimmed square in accordance with the rules certified by the American Lumber Standard Committee. If required for propulsion, a circular sabot having a mass of no more than 200 g (0.5 lb) may be applied to the trailing edge of the large missile. The mass and length of the large missile includes the mass and length of the sabot.

6.2.7.3 *Other Missile*—Any other representative missile with mass, size, shape, and impact speed as a function of basic wind speed determined by engineering analysis such as Ref **(9)**.

7. Hazards

7.1 This test method involves potentially hazardous situations. Proper precautions shall be taken to protect all personnel.

7.2 All observers shall be isolated from the path of the missile during the missile impact portion of the test.

7.3 Keep observers at a safe distance from the test specimen during the entire procedure.

8. Test Specimens

8.1 The test specimen shall consist of the entire fenestration or shutter assembly and contain all devices used to resist wind and windborne debris. Test specimens for large fenestration and curtain wall assemblies shall be one panel unless otherwise specified.

8.2 All parts of the test specimen shall be full size, as specified for actual use, using the identical materials, details, and methods of construction.

9. Calibration

9.1 The speed measuring system shall be calibrated to an accuracy of ±2 % of the elapsed time required to measure the speed of the specified missile. Calibration shall be performed at the manufacturers specified interval, but in any event, not more than six months prior to the test date. The speed measuring system shall be calibrated by at least one of the following methods:

9.1.1 Photographically, using a stroboscope and a still camera,

9.1.2 Photographically, using a high speed motion picture or video camera with a frame rate exceeding 500 frames per second and capable of producing a clear image and a device that allows single frame viewing,

9.1.3 Using gravity to accelerate a free-falling object having negligible air drag through the timing system and comparing measured and theoretical elapsed times, or

9.1.4 Using any independently calibrated speed measuring system with an accuracy of ±1 %.

9.2 Electronic pressure transducers shall be calibrated at 6 month intervals using a NIST traceable calibrating system or a manometer readable to 2.5 Pa.

9.3 Calibration of manometers is normally not required provided the instruments are used at a temperature near their design temperature.

10. Required Information

10.1 The specifying authority shall supply the following information and requirements:

10.1.1 Number of test specimens,

10.1.1.1 Conditioning temperature of specimens,

10.1.2 Pass/fail criteria,

10.1.3 Basic wind speed,

10.1.4 Missile,

10.1.4.1 Description of the missile, including dimensions, mass, and tolerances,

10.1.4.2 Missile speed at impact, or the equation relating missile speed to basic wind speed,

10.1.4.3 Missile orientation at impact,

10.1.4.4 Number of impacts, and

10.1.4.5 Location of impacts on the test specimens and tolerances.

10.1.5 Test loading program, and

10.1.5.1 The maximum air pressure differential and its relationship to the design pressure,

10.1.5.2 The positive and negative cyclic test loads,

10.1.5.3 The number of cycles of cyclic test load sequence to be applied, and

10.1.5.4 The minimum and maximum duration for each cycle.

10.1.6 Whether or not certification of the calibration is required.

11. Test Procedure

11.1 *Preparation*—Remove from the test specimen any sealing or construction material that is not intended to be used when the unit is installed in or on a building. Support and secure the test specimen into the mounting frame in a vertical position using the same number and type of anchors normally used for product installation as defined by the manufacturer or as required for a specific project. If this is impractical, install the test specimen with the same number of equivalent fasteners located in the same manner as the intended installation. This test shall not be used to evaluate anchorage of curtain wall and heavy commercial assemblies. In those cases, the specimen shall be securely anchored to facilitate testing. The test specimen shall not be removed from the mounting frame at any time during the test sequence.

11.1.1 Unless otherwise specified, separate and condition the specimens for at least 4 h within a temperature range of 15°C to 35°C (59°F to 95°F).

11.1.2 *Missile Impact*—Secure the specimen and mounting frame such that the missile will impact the exterior side of the specimen as installed.

11.1.3 Locate the end of the propulsion device from which the missile will exit at a minimum distance from the specimen equal to 1.5 times the length of the missile. This distance shall be no less than 1.80 m.

11.1.4 Set up appropriate signal/warning devices to prevent test or other personnel, or both, from coming between the propulsion device and the test specimen during testing.

11.1.5 Weigh each missile within 15 min prior to impact.

11.1.6 Load the missile into propulsion device.

11.1.7 Reset the speed measuring system.

11.1.8 Align the missile propulsion device such that the specified missile will impact the test specimen at the specified location.

11.2 Propel the missile at the specified impact speed and location.

11.2.1 The measured missile speed will be within the following respective tolerances at any point after the missile acceleration caused by the propulsion device equals zero:

±2 % specified speed when speed ≤23 m/s
±1 % specified speed when speed >23 m/s

11.2.2 For missiles having a longitudinal axis, on impact the longitudinal axis of the missile shall be within ±5° of a line normal to the specimen at the specified impact point.

NOTE 1—From a horizontal datum, measure the vertical height to the center of the exit end of the propulsion device (if it is horizontal), h_B, and the vertical height to the center of the missile impact point on the specimen, h_I. To ensure the missile rotates less than 5° prior to impact:

$$5° \leq \tan^{-1}\left|\frac{h_B - h_I}{d}\right| \tag{1}$$

where d denotes horizontal distance from the exit end of the propulsion device to the specimen.

11.3 If required, repeat steps 11.1.4-11.2 at all additional impact locations specified for the specimen.

11.4 *Air Pressure Cycling*—If the mounting frame is not integral within the test chamber, attach the mounting frame to the test chamber such that the exterior side of the test specimen faces outward from the chamber.

11.4.1 If at any time during testing the specified maximum pressure differential cannot be achieved in either direction due to excessive air leakage, cover all cracks and joints through which leakage occurs with tape or film in such manner as to stop the leakage. Tape shall not be used when there is a probability that it will restrict significantly differential movement between adjoining segments of the specimen, in which case cover both sides of the test specimen with a single