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Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials¹

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1. Scope

1.1 This test method covers the performance of exterior windows, curtain walls, doors, and impact protective systems 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 impact protection systems 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.

NOTE 1—Exception: Exterior garage doors and rolling doors are governed by ANSI/DASMA 115 and are beyond the scope of this test method.

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.

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 Performance of Windows, Doors, Skylights and Curtain Walls.

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2. Referenced Documents

2.1 ASTM Standards:²

E330 Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference

E631 Terminology of Building Constructions

E997 Test Method for Evaluating Glass Breakage Probability Under the Influence of Uniform Static Loads by Proof Load Testing

E1233 Test Method for Structural Performance of Exterior Windows, Doors, Skylights, and Curtain Walls by Cyclic Air Pressure Differential

E1996 Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes

2.2 ASCE/SEI Standard:³

ASCE/SEI 7 American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures

2.3 American Lumber Standard:⁴

Document PS20-94 American Softwood Lumber Standard

2.4 ANSI/DASMA Standard:⁵

ANSI/DASMA 115 Standard Method for Testing Sectional Garage Doors and Rolling Doors: Determination of Structural Performance Under Missile Impact and Cyclic Wind Pressure

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 Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, <http://www.asce.org>.

⁴ Available from American Lumber Standard Committee, Inc. (ALSC), P.O. Box 210, Germantown, MD 20875-0210, <http://www.alsc.org>.

⁵ Available from Door & Access Systems Manufacturers Association International (DASMA), 1300 Sumner Avenue, Cleveland, OH 44115-2851, <http://www.dasma.com>.

3. Terminology

3.1 *Definitions*: General terms used in this test method are defined in Terminology E631.

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/ft²). 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 ASCE/SEI 7).

3.2.5.1 *Discussion*—Use design pressure based on allowable stress design.

3.2.5.2 *Discussion*—The basic wind speed maps in the 2010 edition of ASCE/SEI 7 provide ultimate strength design level wind speeds. For design under service load conditions, either the ultimate design wind speeds in ASCE/SEI 7-10 need to be converted to nominal design wind speeds, or the resulting design pressures need to be converted to service load levels.

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

3.2.7 *impact protective system*—construction applied, attached, or locked over an exterior glazed opening system to protect that system from windborne debris during high wind events.

3.2.7.1 *Discussion*—Impact protective system include types that are fixed, operable, or removable.

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

3.2.9 *positive (negative) cyclic test load*—the specified difference in static air pressure, creating an inward (outward) loading, for which the specimen is to be tested under repeated conditions, expressed in Pa (lb/ft²).

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 impact protective systems is typically based on positive and negative design pressure(s). Design pressures based on wind speeds with a mean recurrence interval (usually 25 to 100 years) that relates to desired levels of structural reliability and are appropriate for the type and importance of the building (1).⁶ The adequacy of the structural design is substantiated by other test methods such as Test Methods E330 and E1233 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 impact protective systems 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 impact protective systems 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 ASCE/SEI 7), which is one of several design parameters, can

⁶ The boldface numbers in parentheses refer to the list of references at the end of this standard.

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 ASCE/SEI 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 ASCE/SEI 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.

5.4.1 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 ASCE/SEI 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 E330 and E1233, 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 $\pm 2\%$ 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) \pm 5 %, with an 8-mm ($5/16$ -in.) nominal diameter, and an impact speed between 0.40 and 0.85 of the basic wind speed (3-s gust in accordance with ASCE/SEI 7).

6.2.7.2 *Large Missile*—A No. 2 or better Southern Yellow Pine or Douglas Fir 2 \times 4 in. lumber having an American Lumber Standard Committee accredited agency mark having a mass of between 910 g \pm 100 g (2.0 \pm 0.25 lb) and 6800 g \pm 100 g (15.0 \pm 0.25 lb) and having a length between 525 mm \pm 100 mm (21 in. \pm 4 in.) and 4.0 m \pm 100 mm (13.2 ft \pm 4 in.) and an impact speed between 0.10 and 0.55 of the basic wind speed (3-s gust in accordance with ASCE/SEI 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.

NOTE 2—The range of missile speeds in 6.2.7.1 and 6.2.7.2 covers ultimate design wind speed at the lower end of the range and nominal design wind speed at the upper end.

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 impact protective system 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 \pm 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 \pm 1 %.

9.2 Electronic pressure transducers shall be calibrated at six 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 (see Specification E1996):

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