Designation: E 1996 – 03

An American National Standard

Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors and Storm Shutters Impacted by Windborne Debris in Hurricanes[1]

This standard is issued under the fixed designation E 1996; 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 specification covers exterior windows, glazed curtain walls, doors and storm shutters used in buildings located in geographic regions that are prone to hurricanes.

1.2 This specification provides the information required to conduct Test Method E 1886.

1.3 Qualification under this specification provides a basis for judgment of the ability of applicable elements of the building envelope to remain unbreached during a hurricane; thereby minimizing the damaging effects of hurricanes on the building interior and reducing the magnitude of internal pressurization. While this standard was developed for hurricanes, it may be used for other types of similar windstorms capable of generating windborne debris.

1.4 This specification provides a uniform set of guidelines based upon currently available information and research.[2] As new information and research becomes available it will be considered.

1.5 All values are stated in SI units and are to be regarded as standard. Values given in parentheses are for information only. Where certain values contained in reference documents cited and quoted herein are stated in inch-pound units they must be converted by the user.

1.6 The following precautionary statement pertains only to the test method portion, Section 5, of this specification: *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.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 631 Terminology of Building Constructions[3]

E 1886 Test Method for Performance of Exterior Windows, Curtain Walls, Doors and Storm Shutters Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials[3]

2.2 *ASCE Standard:*

ASCE 7, American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures[4]

3. Terminology

3.1 *Definitions*:

3.1.1 General terms used in this specification are defined in Terminology E 631.

3.1.2 Terms common to this specification and Test Method E 1886 are defined in Test Method E 1886, unless defined herein.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *assembly height*—vertical elevation above adjacent ground level at which fenestration or shutter assembly is to be installed, measured to the center of the assembly.

3.2.2 *basic wind speed*—three-second gust speeds as defined in the latest edition of ASCE 7.

3.2.3 *infill*—glazing in a fenestration assembly or curtain wall.

3.2.4 *integral mullion*—a horizontal or vertical member which is bounded at both ends by crossing frame members.

3.2.5 *maximum deflection*—Greatest deformation of an element or component under the application of an applied force.

3.2.6 *maximum dynamic deflection*—greatest deformation of an element or component during the missile impact.

3.2.7 *porous storm shutter assembly*—an assembly whose aggregate open area exceeds ten percent of its projected surface area.

3.2.8 *valley*—a pivoting axis of a shutter assembly designed to rotate adjacent slats or panels outward.

4. Test Specimens

4.1 *Number of Test Specimens*:

4.1.1 Three test specimens shall be submitted for the large missile test.

4.1.2 Three test specimens shall be submitted for the small missile test.

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

Current edition approved April 10, 2003. Published May 2003. Originally approved in 1999. Last previous edition approved in 2002 as E 1996 – 02.

[2] See the Significance and Use Section of Test Method E 1886.

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

[4] Available from American Society of Civil Engineers, .

4.2 Test specimens shall be prepared as specified in Test Method E 1886.

4.3 The size of the test specimen shall be determined by the specifying authority. All components of each test specimen shall be full size.

4.4 Where it is impractical to test the entire assembly such as curtain wall and heavy commercial assemblies, test the largest size of each type of panel as required by the specifying authority to qualify the entire assembly.

4.5 Fenestration assemblies and shutter assemblies intended to be mulled together shall be tested separately or tested by combining three specimens into one mounting frame separated only by the mullions.

5. Test Methods

5.1 Test specimens shall be tested according to Test Method E 1886.

5.2 Determine the missile based upon building classification, wind speed and assembly height according to Section 6.

5.3 *Location of Impact*:

5.3.1 *Large Missile Test*—Impact each shutter assembly specimen and each fenestration assembly infill type once as shown in Fig. 1.

5.3.1.1 Impact one specimen with the center of the missile within a 65–mm (2 ½–in.) radius circle and with the center of the circle located at the center of each type of infill.

5.3.1.2 Impact a different specimen with the center of the missile within a 65–mm (2 ½–in.) radius circle and with the center of the circle located 150 mm (6 in.) from supporting members at a corner.

5.3.1.3 Impact the remaining specimen with the center of the missile within a 65–mm (2 ½–in.) radius circle and with the center of the circle located 150 mm (6 in.) from supporting members at a diagonally opposite corner.

5.3.2 *Additional Impact Locations in Wind Zone 4 (see* Fig. 1*)*:

5.3.2.1 Impact the same specimen specified in 5.3.1.1 a second time with the center of the second missile within a 65–mm (2 ½–in.) radius circle and with the center of the circle located 150 mm (6 in.) from supporting member at a corner.

5.3.2.2 Impact the same specimen specified in 5.3.1.2 a second time with the center of the second missile within a 65–mm (2 ½–in.) radius circle and with the center of the circle located at the center of each type of infill.

5.3.2.3 Impact the same specimen specified in 5.3.1.3 a second time with the center of the second missile within a 65–mm (2 ½–in.) radius circle and with the center of the circle located at the center of each type of infill except as specified in 5.3.3.6.

5.3.2.4 For test specimens with bracing at the specified impact location(s), the impact location(s) shall be relocated to the nearest area with no bracing.

5.3.3 *Special Considerations*:

5.3.3.1 For test specimens containing multiple panels, impact the exterior glazing surface innermost from the exterior plane of the fenestration or shutter assembly.

5.3.3.2 For test specimens containing fixed and operable panels of the same type of infill, impact the operable portion.

5.3.3.3 For operable test specimens, a corner impact location shall be nearest a locking device and the other corner impact location shall be at a corner diagonally opposite.

5.3.3.4 For test specimens with bracing at the specified impact locations(s), the impact location(s) shall be relocated to the nearest area with no bracing.

5.3.3.5 The impacts on accordion shutters shall be at the valleys located closest to the impact locations shown in Fig. 1.

5.3.3.6 In Wind Zone 4, impact the integral mullion mid-span in lieu of the impact specified in 5.3.2.3 if applicable.

5.3.3.7 In Wind Zone 4, impact one vertical mullion with the longest span at mid span in addition to impacts specified in 5.3.

5.3.4 *Small Missile Test*—Impact each shutter assembly specimen and each fenestration assembly infill type three times with ten steel balls each as shown in Fig. 2.

5.3.4.1 Each impact location shall receive distributed impacts simultaneously from ten steel balls. The impact shall be described in the test report.

5.3.4.2 The corner impact locations shall be entirely within a 250–mm (10–in.) radius circle having its center located at 275 mm (11 in.) from the edges.

5.3.4.3 The edge impact locations shall be entirely within a 250–mm (10–in.) radius circle at the centerline between two corners having its center located at 275 mm (11 in.) from the edge.

5.3.4.4 The center impact location shall be entirely within a 250–mm radius (10–in.) circle having its center located at the horizontal and vertical centerline of the infill.

NOTE 1—Impact locations for small missile test may overlap depending on the size of the specimen.

5.4 *Air Pressure Cycling*

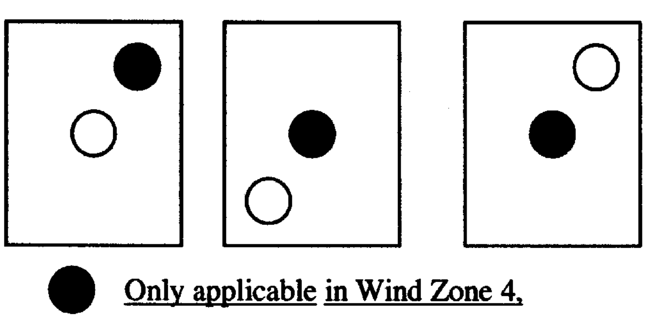

FIG. 1 Impact Location for Large Missile Test (Each Type of Infill)

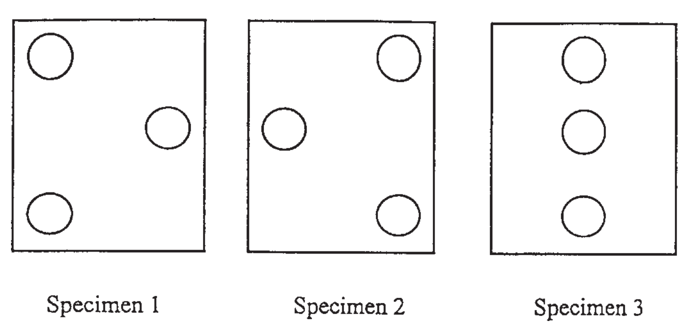

FIG. 2 Impact Locations for Small Missile Test (Each Type of Infill)

5.4.1 The air pressure portion of the test shall use the test loading program in Table 1. Select P_{pos} and P_{neg} for the maximum inward (positive) and maximum outward (negative) air pressure differential for which qualification is sought.

5.4.2 Porous shutter assemblies whose aggregate open area exceeds 50 % of their projected surface area that pass the small missile test and that are not subject to the large missile test need not be tested for the air pressure portion of the test described in this section.

5.5 For porous storm shutter specimens that are tested independently of the fenestration assemblies they are intended to protect, measure and record both the maximum dynamic deflection and the residual deflection following the impact test and measure and record the maximum deflection in combination with the residual deflection during the air pressure cycling test. Measure all deflections to the nearest 2 mm (0.1 in.).

6. Missiles

6.1 The specifying authority shall select an applicable missile by defining a level of protection, a wind zone, and an assembly height above the ground.

6.2 The applicable missile from Table 2 shall be chosen using Table 3, unless otherwise specified.

6.2.1 Unless otherwise specified, select the appropriate level of building protection from 6.2.1.1-6.2.1.3 and enter Table 3 or Table 4 at the appropriate column.

6.2.1.1 *Enhanced Protection (Essential Facilities)*— Buildings and other structures designated as essential facilities, including, but not limited to, hospitals; other health care facilities having emergency treatment facilities; jails and detention facilities; fire, rescue and police stations and emergency vehicle garages; designated emergency shelters; communications centers and other facilities required for emergency response; power generating stations; other public utility facilities required in an emergency; and buildings and other structures having critical national defense functions.

6.2.1.2 *Basic Protection*— All buildings and structures except those listed in 6.2.1.1and 6.2.1.3.

6.2.1.3 *Unprotected*— Buildings and other structures that represent a low hazard to human life in a windstorm including, but not limited to: agricultural facilities, production greenhouses, certain temporary facilities, and storage facilities.

6.2.2 Unless otherwise specified, select the wind zone based on the basic wind speed as follows:

6.2.2.1 *Wind Zone 1*— 110 mph (49 m/s) ≤ basic wind speed < 120 mph (54 m/s), and Hawaii.

6.2.2.2 *Wind Zone 2*— 120 mph (54 m/s) ≤ basic wind speed < 130 mph (58 m/s) at greater than 1.6 km (one mile) from the coastline. The coastline shall be measured from the mean high water mark.

6.2.2.3 *Wind Zone 3*— 130 mph (58 m/s) ≤ basic wind speed ≤ 140 mph (63 m/s), or 120 mph (54 m/s) ≤ basic wind speed ≤ 140 mph (63 m/s) and within 1.6 km (one mile) of the coastline. The coastline shall be measured from the mean high water mark.

6.2.2.4 *Wind Zone 4*— basic wind speed > 140 mph (63 m/s).

TABLE 1 Cyclic Static Air Pressure Loading

Loading Sequence	Loading Direction	Air Pressure Cycles	Number of Air Pressure Cycles
1	Positive	0.2 to 0.5 P_{pos}	3500
2	Positive	0.0 to 0.6 P_{pos}	300
3	Positive	0.5 to 0.8 P_{pos}	600
4	Positive	0.3 to 1.0 P_{pos}	100
5	Negative	0.3 to 1.0 P_{neg}	50
6	Negative	0.5 to 0.8 P_{neg}	1050
7	Negative	0.0 to 0.6 P_{neg}	50
8	Negative	0.2 to 0.5 P_{neg}	3350

TABLE 2 Applicable Missiles

Missile Level	Missile	Impact Speed (m/s)
A	2 g ± 5 % steel ball	39.62 (130 f/s)
B	910 g ± 100 g (2.0 lb. ± 0.25 lb.) 2×4 in. 52.5 cm ± 100 mm (1 ft - 9 in. ± 4 in.) lumber	15.25 (50 f/s)
C	2050 g ± 100 g (4.5 lb. ± 0.25 lb.) 2×4 in. 1.2 m± 100 mm (4 ft ± 4 in.) lumber	12.19 (40 f/s)
D	4100 g ± 100 g (9.0 lb. ± 0.25 lb) 2×4 in. 2.4 m ± 100 mm (8 ft ± 4 in.) lumber	15.25 (50 f/s)
E	4100 g ± 100 g (9.0 lb. ± 0.25 lb.) 2×4 in. 2.4 m± 100 mm (8 ft ± 4 in.) lumber	24.38 (80 f/s)

TABLE 3 Description Levels

NOTE 1—For Missiles B, C, D, and E also use Missile A for porous shutter assemblies (see 8.4).

Level of Protection	Enhanced Protection (Essential Facilities)		Basic Protection		Unprotected	
Assembly Height	≤ (30 ft) 9.1 m	> (30 ft) 9.1 m	≤ (30 ft) 9.1 m	> (30 ft) 9.1 m	≤ (30 ft) 9.1 m	> (30 ft) 9.1 m
Wind Zone 1	D	D	C	A	None	None
Wind Zone 2	D	D	C	A	None	None
Wind Zone 3	E	D	D	A	None	None
Wind Zone 4	E	D	D	A	None	None

TABLE 4 Desciption of Levels for Rooftop Skylights in One- and Two-Family Dwellings

NOTE 1—The term "One- and Two-Family Dwellings" includes all buildings included under the scope of the International Residential Code 2000 published by the International Code Council.

Level of Protection	Enhanced Protection (Essential Facilities)		Basic Protection	
Assembly Height	≤ (30 ft) 9.1 m	> (30 ft) 9.1 m	≤ (30 ft) 9.1 m	> (30 ft) 9.1 m
Wind Zone 1	D	D	A	A
Wind Zone 2	D	D	B	A
Wind Zone 3	E	D	C	A
Wind Zone 4	E	D	C	A

7. Pass/Fail Criteria

7.1 In Wind Zones 1, 2, and 3, the specifying authority shall select an applicable pass/fail criterion based on 7.1.1 and 7.1.2.

7.1.1 *Fenestration Assemblies and Non-Porous Shutter Assemblies*—The test specimen shall resist the large or small missile impacts, or both, with no tear formed longer than 130 mm (5 in.) or no opening formed through which a 76 mm (3 in.) diameter solid sphere can freely pass when evaluated upon completion of missile impacts and test loading program.

7.1.2 *Porous Shutter Assemblies Tested Independently of the Fenestration Assemblies They are Protecting*:

7.1.2.1 There shall be no penetration of the innermost plane of the test specimen by the applicable missile(s) during the impact test(s).

7.1.2.2 Upon completion of the missile impact(s) and test loading program, there shall be no horizontally projected opening formed through which a 76 mm (3 in.) diameter solid sphere can pass.

7.2 In Wind Zone 4, the specifying authority shall select an applicable pass/fail criterion based on 7.2.1 and 7.2.2.

7.2.1 All test specimens shall resist the large or small missile impacts, or both, without penetration of the inner plane of the infill or shutter assembly, and resist the cyclic pressure loading specified in Table 1 with no tear formed longer than 130 mm (5 in.) or no opening formed through which a 76 mm (3 in.) diameter solid sphere can freely pass.

7.2.2 The overlap seams of a shutter assembly shall not have a separation greater than 1⁄180of the span or 13 mm (1⁄2 in), whichever is less, after impact. The length of the the separation shall not be greater than 900 mm (36 in.) or 40 % of the span whichever is less.

8. Product Qualification

8.1 When all test specimens submitted have met the requirements of this specification based on the pass/fail criteria described in Section 7, the set of test specimens shall be accepted according to the designated building classification, wind speed and assembly height.

8.2 If any test specimen fails to meet the requirements of this specification as described in Section 6, the set of test specimens shall be rejected.

8.3 Porous shutter assemblies that are tested independently of the fenestration assembly shall be accepted for installations in which they are offset from the fenestration assemblies by the greater of the following:

8.3.1 The maximum dynamic deflection, as measured in 5.5 plus 25 %, or,

8.3.2 The sum of the maximum deflection and the residual deflection, as measured in 5.5 plus 25 %.

8.4 Any test specimen that has passed the large missile impact test is not required to pass the small missile test, except for shutter assemblies that contain openings greater than 5 mm (3⁄16 in.), projected horizontally.

8.5 Substitutions shall be according to the following criteria:

8.5.1 Successful tests of a fenestration assembly shall qualify other assemblies with thicker or equal glazing and thicker or equal interlayer of the same glass type and treatment, provided the glazing detail is unchanged.

8.5.2 Successful tests of a fenestration assembly shall qualify other assemblies of the same type that contain smaller sashes, panels or lites at equal or lower design pressures provided the same methods of fabrication are used and the anchorage of the lites is unchanged. Smaller assemblies shall not exceed dimensions of the tested width or height.

8.5.3 Successful tests of a fenestration assembly shall qualify other assemblies with the same glazing type and treatment that are tinted, heat absorbing, reflective, or otherwise aesthetically modified, provided the requirements of 8.5.1 and 8.5.2 are satisfied.

8.5.4 Successful tests of a fenestration assembly that contains construction to improve thermal efficiency of frame or sash, shall qualify other assemblies that do not contain construction to improve thermal efficiency provided the same extrusions are used and the requirements of 8.5.1 and 8.5.2 are satisfied.

8.5.5 Successful test of a fenestration assembly shall qualify other assemblies containing a frame or sash having a greater section modulus provided the construction details and reinforcement remain unchanged and the requirements of 8.5.1 and 8.5.2 are met.

8.5.6 Successful tests of a shutter assembly shall qualify other assemblies of the same or less area, and the same or greater section modulus, provided the construction details and reinforcement are unchanged.

8.6 Manufactured assemblies successfully tested shall not be combined unless the structural supports and connections between assemblies have been designed for the wind loads.

8.7 Qualification at any load level automatically includes qualification for all lower load levels.

9. Compliance Statement

9.1 Report the following information:

9.1.1 Detailed description of test specimen(s) and test results in accordance with the Report section of Test Method E 1886.

9.1.2 Missile type and cyclic loading pressure(s) for which the test specimen qualified.

9.2 Attach a copy of the test report from Test Method E 1886, to Compliance Statement for this specification.

10. Keywords

10.1 building envelope; curtain walls; cyclic pressure loading; doors; fenestration; hurricanes; missile impact; storm shutters; windborne debris; windows; windstorms

APPENDIXES

(Nonmandatory Information)

X1. BREACHING OF THE BUILDING ENVELOPE

X1.1 *Damage and Internal Pressurization*—Windows, doors, and curtain walls are building envelope components (defined as "components and cladding," in ASCE 7-98) often subject to damage in windstorms. Windborne debris impact can not only cause failure of these building envelope components but can also expose a building's contents to the damaging effects of continued wind and rain. From a structural perspective, a potentially more serious result can be internal pressurization of the building. When the windward wall of a building is breached, the internal pressure in the building increases resulting in larger outward acting pressure on the other walls and roof. Similarly, when a breached wall is subject to leeward wall pressures, the internal pressure in the building decreases possible resulting in larger inward acting pressures on the other walls and roof. Depending on the size of the breached envelope components, the building may be classified as a "partially enclosed building" as defined in ASCE 7-98. For this classification of building, the internal pressure coefficient increased to + 0.55 (from + 0.18 for an enclosed building) and to − 0.55 (from −0.18 for an enclosed building) this represents more than a three fold increase in internal pressure and, if not accounted for in design, can significantly increase the net pressure (both positive and negative) for which the envelope components were designed.

X1.1.1 ASCE 7-98 specifies that buildings in "wind borne debris regions" having glazing in the bottom 60 feet that is not designed or protected from missile impact, have such glazing be treated as openings for the purpose of classifying a building as "enclosed" or "partially enclosed." This may require these buildings to be designed for larger internal pressures if classified as a "partially enclosed building". It is the intent of this ASTM specification to quantify the requirements for windborne debris impact.

NOTE X1.1— Dade[5] **(1)** and Broward **(2)** counties, SBCCI Standard SSTD 12 **(3)**, and The Texas Department of Insurance Building Code for Windstorm Resistant Construction **(4)** do not limit missile impact protection to the bottom 60 ft (m)).

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

X1.2 *Design Pressure and Product Qualification Under This Specification*:

X1.2.1 The air pressure cycling portion of Test Method E 1886 applies pressures that are a function of *P*, where *P* denotes the maximum inward (P_{pos}) and outward (P_{neg}) air pressure differentials, which are either specified or are equal to the design pressure. "Design pressure" is defined in Test Method E 1886 as follows:

> ″—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 specification and concept. This pressure is determined by either analytical or wind tunnel procedures (such as specified in ANSI/ASCE 7).″

X1.2.2 ASCE 7-98 defines the fenestration as "components and cladding." The procedure for determining the design pressure for components and cladding is different for low-rise buildings (buildings having a mean roof height less than or equal to 18.2 m (60 ft) than for other buildings not classified as low-rise buildings. In either case, the design pressure is a function of several parameters including Importance Factor (I), Exposure Category (A, B, C, or D), topography and Topographic Factor (K_{zt}), Mean Roof Height (h), height of the fenestration assembly above the ground, location (zone) of the fenestration assembly on the building elevation, and the Effective Wind Area (A) of the fenestration assembly. Only the latter parameter, Effective Wind Area (A), is under the control of the building designer and fenestration manufacturer.

X1.2.3 All of these parameters should be considered when selecting P_{pos} and P_{neg}. When defining substitution criteria the specification addresses only one of these, area of assembly, in 8.5.2 ("Successful tests of a fenestration assembly shall qualify others of the same type that contain smaller sashes, panels or lites assemblies at equal or lower design pressures..."). Section 5.4.1 of this specification states that the selection of P_{pos} and P_{neg} should be made "*...for which qualification is sought.*" A conservative approach would base P_{pos} and P_{neg} on the highest factor for each parameter (that is, open exposure, tallest building, highest importance factor, edge location and smallest area). An alternate approach should explicitly state what assumptions were made for each parameter in the selection of P_{pos} and P_{neg}.

X2. IMPACT RISK ANALYSIS

X2.1 *Summary of Risk Parameters* in Ref **(5)**—The report discusses the following parameters that affect the risk of building damage from windborne debris:

X2.1.1 Wind velocity,

X2.1.2 Type and quantity of missiles in the wind-field generated from ground sources,

X2.1.3 Type and quantity of missiles in the wind-field generated from building sources, as function of the quality of construction,

X2.1.4 Density of buildings,

X2.1.5 Shape and height of buildings, and

X2.1.6 Percentage of glazed openings.

X2.2 The report combines a hurricane wind field model, a missile generation model, a missile trajectory model and an impact model to produce a risk analysis. The output is expressed in terms of curves of specified impact energy resistance or impact momentum resistance levels plotted on a graph with reliability (*R*) (from 0.75 to 1.00) on the vertical axis and wind velocity (from 110 to 170 mph peak gusts) on the horizontal axis. Plots have been generated for single story detached residential buildings, for two different values for the quality of construction and density of buildings, and three different values for percentage of glazed openings.

X2.3 *The Performance Objective of This Specification*

X2.3.1 This specification establishes missile impact criteria for all building types and occupancies. The antecedents for this effort are the criteria established in Australian National Standards **(6)** the Florida counties of Dade **(1)** and Broward **(2)**, in SBCCI Standard SSTD 12 **(3),** and in the Texas Department of Insurance Building Code for Windstorm Resistant Construction **(4)**. All of these are based on analysis and judgement of experts after many years of windstorm study. The Twisdale et. al. study represents new inputs into this body of analysis and experience. Since it so far has covered only a very limited range of buildings out of the total scope of this specification, its application to the development of this specification has also required a degree of judgement.

X2.3.2 The energy and momentum curves included in the Twisdale et. al. **(5)** report are referenced to a zero energy or momentum curve, that can be interpreted as the reliability achieved at various wind speeds when no impact resistance is provided. Other curves describe reliability versus wind speed at increasing amounts of impact resistance, for example 10, 20, 50, 100, 200 and 300 lb of momentum. All the curves illustrated by Twisdale et. al. **(5)** including the zero resistance curve, demonstrate reliability above 0.85 at 110 mph wind speed. Reliability diminishes rapidly, with varying slopes, at higher wind speeds.

X2.3.3 Two approaches can be taken to using these curves to inform the specification process:
the absolute reliability approach, and
the relative improvement approach.

X2.3.4 *The absolute reliability approach* establishes the objective of achieving a specified level of reliability, say 0.90, by specifying the appropriate impact resistance for different wind speeds, and, possibly, building types. This approach is attractive because it enables the definition of reliability to be consistent with the reliability objective of traditional structural design. However, it has two disadvantages in this case:

X2.3.4.1 The curves plotted are actually average values and should be thought of as broad fuzzy bands with large confidence bounds due to the many uncertainties embedded in the analytical models that produce them. Therefore, establishing a specified reliability level may be misleading without extensive qualifying statements.

X2.3.4.2 The curves diminish so fast at higher wind speeds that the levels of resistance required to achieve high values of reliability at these wind speeds would require impact energies and momenta far in excess of anything considered heretofore, and possibly in excess of the capabilities of the apparatus specified in Test Method E 1886.

X2.3.5 *The relative improvement approach* takes its cue from the zero protection curves, and establishes the objective of achieving a specified proportional improvement in reliability. A 50 % improvement, .50 to .75, 0.60 to 0.80, 0.70 to 0.85, 0.80 to 0.90 etc., could be the objective. The curves illustrated by Twisdale et.al., for the limited range of parameters analyzed, suggest that a 50 % or better improvement can be achieved by providing impact protection from a 4100 g (9 lb) 2 by 4 travelling at 15.24 m/s (50 f/s). This is of the same order of magnitude included in the Australian, SBCCI, Florida and Texas standards.

X2.3.6 Thus, the proposed specification can be justified on the basis of the relative improvement approach and its relation to previous research and antecedents. It can be further refined as more analytical information is developed.

X3. ASSEMBLY HEIGHT ABOVE THE GROUND

X3.1 Section 6.1 of this specification establishes assembly height above the ground as one of three parameters to be used in the selection of an applicable missile. Unless otherwise specified, Table 3 is to be used. Table 3 uses two height categories: ≤ 9.1 and > 9.1 m (30 and 30 ft). Various 2 by 4 in. lumber (large) missiles representative of ground-level debris and structural debris are specified in the former (≤ 9.1 m (30 ft)) 2 steel balls (small missiles) representative of roof gravel are specified in the later (> 9.1 m (30 ft). The assembly height subject to large missiles may be increased by the specifying authority where it determines that the assembly is exposed to structural debris from adjacent structures.

REFERENCES

(**1**) "Section 2315 Impact Tests for Windborne Debris," South Florida Building Code – Dade County Edition, Metro Dade County, Miami, FL, 1994, pp. 23-33 – 23-38.

(**2**) "Section 2315 Impact Tests for Windborne Debris and Section 2316 Impact Test Procedures," South Florida Building Code – Broward County Edition, Broward County Board of Rules and Appeals, Ft. Lauderdale, FL, 1994, pp. 23-24 – 23-21.

(**3**) *SBCCI Test Standard for Determining Impact Resistance from Windborne Debris,* Southern Building Code Congress International, Inc., 900 Montclair Road, Birmingham, AL 35213-1206, 1994.

(**4**) *Building Code for Windstorm Resistant Construction*, Texas Department of Insurance, 33 Guadalupe Street, Austin, TX 78714-9104, 1997.

(**5**) Twisdale, L.A., Vickery, P.J., and Steckley, A.C., *Analysis of Hurricane Windborne Debris Impact Risk for Residential Structures*, Applied Research Associates, Inc., Raleigh, NC, March 1996.

(**6**) Standard Australia, *Australian Standard SAA Loading Code, Part 2: Wind Loads*, North Sydney, New South Wales, Australia 2060.