



## APPENDIX A.1 – TEST PROTOCOLS

The National Wind Institute, Debris Impact Test Facility (NWI - DIF) at Texas Tech University (TTU) performs debris impact tests on storms shelters, shelter components, and building materials to evaluate their ability to resist various types of projectiles propelled at different speeds in accordance to accepted and proposed test protocols as follows:

### A.1.1 - Protocols for Debris & Hail Impact Testing

<b>Protocol 1</b>	Hurricane envelope impact by a 9 lb. wood 2”x4” propelled at 34 mph, in accordance with the Florida Building Code, the International Code Council, and the Texas Dept. of Insurance windstorm Resistant Construction Guide.
<b>Protocol 2</b>	Hurricane shelter speed impact by a 9 lb. wood 2”x4” propelled at 0.40 x the design wind speed (mph) for horizontal impacts and 0.10 x the design wind speed (mph) for vertical impacts, in accordance to the proposed ICC 500 <sup>1</sup> – ICC/NSSA Standard for the Design and Construction of Storm Shelters.
<b>Protocol 3</b>	Hurricane shelter speed impact by a 9 lb. wood 2”x4” propelled at 0.50 x the design wind speed (mph) for horizontal impacts and 0.33 x the design wind speed (mph) for vertical impacts, in accordance with FEMA 320, “Taking Shelter from the Storm,” 2008 Edition and FEMA 361, “Design and Construction Guidance for Community Safe Rooms,” 2008 Edition.
<b>Protocol 4</b>	Tornado shelter speed impact by a 15 lb. wood 2”x4” propelled at 100 mph for horizontal impacts and 67 mph for vertical impacts, in accordance with FEMA 320, “Taking Shelter from the Storm,” 2008 Edition and FEMA 361, “Design and Construction Guidance for Community Safe Rooms,” 2008 Edition, and the ICC-500 Standard for “The Design and Construction of Storm Shelters,” 2008 Edition. <sup>1</sup>
<b>Protocol 5</b>	Department of Energy (DOE) Impact Standards
<b>Protocol 6</b>	Hail impact testing of roofing products per ANSI/FM 4473
<b>Protocol 7</b>	Hail impact testing in accordance to the <i>Guidance Document for the Assessment of Hailstone Impact Resistance of Vertical and Near Vertical Surfaces</i>

<sup>1</sup>The ICC 500 – ICC/NSSA Standard for the Design and Construction of Storm Shelters is a referenced standard in the 2009 editions of the International Residential Code and the International Business Code. This is a Life Safety Standard for protection from tornadoes and hurricanes. For hurricanes the Standard uses an Extreme Wind Map with wind speeds starting at 225 mph and with contours along the Atlantic and Gulf Coast stepping inland in 10 mph increments to 160 mph. Doors are required by ICC-500 to withstand design pressures + a design safety factor of 1.2.



### **A.1.2 - Introduction**

All testing is conducted by a registered professional engineer (Engineer of Record). The primary objective in debris impact testing of storm shelters and shelter components is to assure compliance with a high standard of performance in protecting shelter occupants from wind-borne debris. Performance criteria include preventing perforation of the shelter or component by the design missile and preventing deformations which could cause injuries to the occupants.

### **A.1.3 - Test Criteria**

The testing described is for simulated windborne debris. The primary simulations are impacts of a 2x4-in. wood board traveling along the board's longitudinal axis, striking the test subject perpendicular to the test subject face. Standards that use this type of simulated debris include ASTM E 1886-05 & ASTM E 1996-06 "Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protection Systems Impacted by Missiles and Exposed to Cyclic Pressure Differentials," SSTD 12-99 "SBCII Test Standard for Determining Impact Resistance From Windborne Debris;" ANSI A250.13-2003, "Testing and Rating of Severe Windstorm Resistant Components for Swing Door Assemblies;" FM 4473, "specification Test Standard for Impact Resistance Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls, July 2005; ICC 500 – "ICC/NSSA Standard for the Design and Construction of Storm Shelters;" and Texas Tech University, Wind Science and Engineering's Tornado Test Criterion adopted by the Federal Emergency Management Agency in publication FEMA 320, "Taking Shelter from the Storm," and FEMA 361, "Design and Construction Guidance for Community Shelters." The hurricane test criterion is addressed in Article A.1.1, Protocols 1-3 and uses a 9-lb. 2x4-in. wood board, called a missile. The missile speed therein described is a function of the guideline selected and the hurricane wind speed chosen from the guideline. The tornado test criterion found in Article A.1.1, Protocol 4, uses a 15-lb. 2x4-in. wood board traveling horizontally at 100-mph, which corresponds to a 250-mph wind, and is the criterion used in designing vertical surfaces for occupant protection. The criterion for falling debris from a 250 mph tornado is a 15-lb. 2x4-in. board traveling at 67-mph (two-thirds the horizontal speed), striking perpendicular to the surface. The one-third criterion is used for surfaces horizontal to the ground and inclined less than 30-degrees. Lesser tornado missile impact speeds for decreased tornado wind speeds are included in the test regimen and are addressed in FEMA 361. Additional factors of safety are inherent in the criterion, since there is a very small probability that a missile will be traveling along its axis and will strike perpendicular to the surface.

Different types and sizes of projectiles are tested in accordance to Protocol 5, DOE Standards. Impact speeds are as specified in the Standards.

Hail impact testing of roofing products per ANSI/FM 4473, Protocol 6. Hail impact testing in accordance to the *Guidance Document for the Assessment of Hailstone Impact Resistance of Vertical and Near Vertical Surfaces*, Protocol 7.

#### **A.1.4 - Test Procedure**

Shelter impacts are conducted in accordance to the Guidelines. Shelter appurtenances, vents, louvers, windows, or installed electrical equipment, shelving seats, etc., are impacted by a single missile if they are perceived by the Test Engineer of Record as vulnerable with regard to Life Safety.

Laboratory pressure tests are not conducted on shelters and shelter panels. Numerical analysis of wind pressures is outlined in the above listed standards in the A.1.3 - Test Criteria. Pressure tests are required for swinging door assemblies in accordance to FEMA 320, FEMA 361, and ICC-500. Pressure testing is conducted in accordance to ASTM E-330. Test pressures are dependent upon the storm wind speed selected and the location of the door in the building envelope per ASCE 7-10. A 1.20 safety factor must be included in the design pressures to meet the requirements of ICC-500.

#### **A.1.5 - Pass/Fail Criteria**

- A.1.5.1 The criterion, Protocols 1-4, for the shelter/shell/panel test pass/fail is as follows:**
- A.1.5.1.1 The test subject must be impacted by a minimum of three missiles in the areas as described in Articles A.1.3 and A.14;
  - A.1.5.1.2 The missile may penetrate that test subject, but may not perforate the safe side (back face) of the subject;
  - A.1.5.1.3 The test subject's permanent deflection after impact must be less than 3-in.;
  - A.1.5.1.4 Segments, spallings, or otherwise de-laminated portions of the test subject, though still attached to the subject, may not extend into the safe compartment 3-in. or more; and
  - A.1.5.1.5 Segments of the test subject or appurtenances attached to the test subject must not be ejected or otherwise released into the safe compartment by the impact force.
  - A.1.5.1.6 Door assemblies manufactured to SDI and DHI standards must hold the required test pressures,
- A.1.5.2 The pass/fail criterion for Protocol 5 is in strict accordance to the DOE Standards.**
- A.1.5.3 The pass/fail criterion for Protocol 6 is in strict accordance to ANSI/FM 4473, *Test Stand for Impact Resistance Testing of Rigid Roofing Materials by Impact with Freezer Ice Balls***
- A.1.5.4 The pass/repairable/fail criterion for Protocol 7 is strict accordance to *Guidance Document for the Assessment of Hailstone Impact Resistance of Vertical or Near Vertical Surfaces, 2015.***



- A.1.5.3.5 Maintain locked and firmly attached two door points of locking and hinging. FEMA 320/361 recognizes that one test missile can destroy or otherwise disengage one locking point or one hinge. The guideline therefore requires that at least two locking points remained engaged and doors with only two points of locking must have both locks remain engaged and locked at the conclusion of the impact tests. Door does not have to be operable at the conclusion of the impact or pressure tests.
- A.1.5.3.6 Pass/fail rating of the door relates to the full door assembly, including door, locking hardware, hinge, hinge screws, and door frame. Tested frame attachment connectors must be equal to or less than shear strength that is commonly specified and used for the intended installation.

### **A.1.6 - Test Equipment**

#### **A.1.6.1 Debris Impact Air Cannon:**

- A.1.6.1.1 Air Tank – 30 gallon, Manchester Model Number 301853.
- A.1.6.1.2 Air Over Air Valve – Valworx Model Number 564015 4-in. butterfly valve, double acting, EPDM with solenoid actuator.
- A.1.6.1.3 4-in. aluminum quick coupler to connect barrel to valve.
- A.1.6.1.4 4-in. or 6-in. x 20-ft. long Schedule 40 PVC barrel, depending upon test.
- A.1.6.1.5 Pair Optical Timing Sensors – Keyence Model Number PZ251R and PZ125T 12/24-volt.
- A.1.6.1.6 National Instruments (NI) Data Acquisition Card (DAC) with custom software installed on control panel computer.
- A.1.6.1.7 Control panel with laser sighting and a three stage firing system.
- A.1.6.1.8 Horizontal articulating cannon carriage with DC motor drive and variable speed controller.
- A.1.6.1.9 Cannon carriage mounted to a hydraulic scissor lift on wheels - Autoquip Model Number 84B16F20.
- A.1.6.1.10 Steel reaction frame made of vertical and horizontal steel beams anchored to the floor to provide simple support at the top and bottom of the test specimen.

#### **A.1.6.2 Hail Cannon**

- A.1.6.2.1 6 gallon air tank, with 2” pneumatic hose, 2” manually operated butterfly valve; and calibrated digital pressure gauge.
- A.1.6.2.2 ???Speed Recorder
- A.1.6.2.3 ???Electronic scale

#### **A.1.6.3 Testing Equipment Calibration**

- A.1.6.3.1 Digital scales, pressure gages, micrometers, and caliper are ISO 17025 calibrated and certified by an ISO 17025 calibration laboratory.
- A.1.6.3.2 Projectile speed calibrated with Olympus iSpeed 3 HD 16 GB camera, 1280 x 1024 resolution @ 2,000 fps, maximum 150,000 fps.



### **A.1.7 - Use of Testing Report, TTU and NWI Logos**

The written report and supplemental photos and/or videos may be referenced or distributed by your company. But, Texas Tech University (TTU) cannot endorse products nor can the name of the University or any of its units or personnel be used in advertising without first securing written permission from the University. Any misuse or misrepresentation of the report and/or pictures will result in action being taken by the University against the responsible parties.

Storm shelter manufacturers or producers that have had products tested at Texas Tech University can use the Texas Tech University National Wind Institute (NWI) logo provided they conform to the following:

A.1.7.1 The Texas Tech University National Wind Institute logo may not be so prominent as to mislead the public or unduly play upon the Texas Tech University Wind Engineering name.

A.1.7.2 Whenever the logo is used, one of the two alternative statements below is to be employed in the text:

A.1.7.2.1 Tested – whole shelter:

The use of the Texas Tech University National Wind Institute logo signifies that the complete shelter structure was tested and successfully passed missile impact resistance tests at Texas Tech University.

A.1.7.2.2 Tested shelter component/product component:

The use of the Texas Tech University National Wind Institute logo does not signify that the entire shelter structure/entire product assembly was tested at Texas Tech, but rather only [shelter component/product component – name explicitly] was tested and successfully passed missile impact resistance tests at Texas Tech University.

A.1.7.3 All advertising and promotional texts containing the use of the Texas Tech University, National Wind Institute logo are to be presented to the Texas Tech University Office of Technology Transfer and Intellectual Property for review and approval before distribution.

Texas Tech University will challenge any use of the Texas Tech University National Wind Institute logo that does not conform to the above standards.