Steel Solution for Envelope Missile Impacts

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When a major tornado happens, it is all over the news. And, every year, the average person may recall hearing about a dozen or so tornado events, if that. So it might be startling to know that, on average, the number of tornadoes that touch down each year in the United States, according to **www.ustornadoes.com**, is more than 1,200.

And then there are hurricanes. While fewer in numbers – approximately seven hurricanes strike the U.S. every four years, according to the National Oceanic and Atmospheric Administration (NOAA), and while limited in terms of areas effected, hurricanes are often devastating in terms of loss of life and property and typically last for days instead of minutes. Tornadoes are more likely to cause death due to the lack of warning and the inability of buildings to resist wind forces. The building codes do not mandate that all structures be designed for tornadic wind pressures, only those designated as shelters or safe rooms.

Some states, such as Alabama, now require all new schools and state college buildings to have tornado shelters attached or included within the building. In the case of elementary, middle, and high schools, this mandate is financially burdensome as construction budgets are tight. Roof systems in these buildings are typically framed with bar joists and metal deck or cold-formed steel trusses. Changing construction methods for the shelter increases costs. It is financially beneficial to stay with steel.

AISC's new Design Guide 35, *Design of Steel-Framed Storm Shelters*, summarizes up-to-date design requirements and guidance to incorporate storm shelters or safe rooms using typical industry-standard structural steel products and materials. The design guide presents a discussion regarding storm shelter design for both tornado and hurricane-force winds. Previous roof decking missile impact tests performed at Clemson University considered the performance of the screw attached to bare deck alone. The bare deck was required to absorb all of the energy created by the missile impact. This was not an economical material or installation solution. This article focuses on a steel industry effort to develop an improved solution for protection from missile impacts resulting from tornados.

Order of Magnitude

The primary difference in a building's structural system when designed for use as a storm shelter or safe room, as compared to conventional construction, is the magnitude of the design wind forces and the need to withdraw impacts of windborne debris. Safe rooms and storm shelters are designed to resist higher intensity wind speeds, which correspond to higher wind pressures than buildings designed for typical occupancies, including essential facilities, as well as windborne "missiles." (Note that it is important to understand that these two criteria are not concurrently occurring design events.)

ICC 500, *Standard for the Design and Construction of Storm Shelters,* and FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms*, employ the same criteria for wind speed determination and windborne debris criteria. However, FEMA opts to use the term "safe room" because the design guidance is intended to provide "near-absolute protection" from extreme wind events.

A storm shelter will typically be either an interior room within a building (*Figure 1*) or a designated wing of a building. However, the concepts presented in Design Guide 35 may also be employed for standalone structures or retrofitting of existing structures. While both ICC and FEMA address both community and residential shelters, Design Guide 35 focuses on community shelters.

Figure 1. Restroom St. Louis International Airport.

Test Protocol

Design Guide 35 summarizes existing test standards. All shelter envelope components must be designed for the impact of windborne debris as evaluated by the debris impact test of ASTM E1886, Standard Test Method for the Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials. ASTM E1886 defines the test apparatus and test missile, whereas ICC 500 defines the pass/fail criteria.

For tornado shelter design, the test missile is nominally 15 pounds. The test missile can be any common softwood lumber species, as defined by the *American Softwood Lumber Standard*, PS 20. The lumber must be grade stamped No. 2 or better and be free of splits, checks, wanes, or other significant defects. Also, the bow or warp of the missile must be such that stretching a string or wire on the board from end to end is within 0.5 inches of the 2x4's surface over its entire length. Both defects and bow may affect the performance of the missile, resulting in the missile absorbing some of the impact, thereby reducing the force applied to the test specimen.

Roof and wall surfaces are delineated based on their inclination from horizontal. Vertical surfaces of the shelter envelope, i.e., walls, are defined as surfaces inclined more than 30° from the horizontal. In contrast, surfaces inclined less than 30° from the horizontal, i.e., roofs, are treated as horizontal surfaces.

A tornado test missile is assumed to impact the test specimen at a designated speed, as summarized by *Table 1*.

Table 1. Speeds for tornado shelter missile.

Design Wind Speed, mph	Missile Speed and Shelter Impact Surface
130	80 mph vertical surfaces
	53 mph horizontal surfaces
160	84 mph vertical surfaces
	56 mph horizontal surfaces
200	90 mph vertical surfaces
	60 mph horizontal surfaces
250	100 mph vertical surfaces
	67 mph horizontal surfaces

ICC 500 Chapter 8 defines the impact locations for wall, roof, and openings, i.e., doors and windows. The impact locations vary with the test assembly configuration, as illustrated in *Figure 2*.

For any roof or wall construction, no more than three impacts are to be made on any one test specimen. Where more than three impacts are required, multiple identical test specimens are to be used. ICC 500 defines the pass/fail criteria as follows:

- Any perforation of the interior surface of the tested component of the shelter envelope by the missile constitutes failure.
- Specimens or load-bearing fasteners shall not become disengaged or dislodged during the test so as to endanger occupants. The pass criterion is defined as specimens or fasteners failing to penetrate a witness screen comprised of #70 unbleached kraft paper located within five inches of the interior surface of the test specimen.
- The permanent deformation of an interior surface of the test specimen shall not exceed three inches.
- Excessive spalling shall not occur, if applicable.

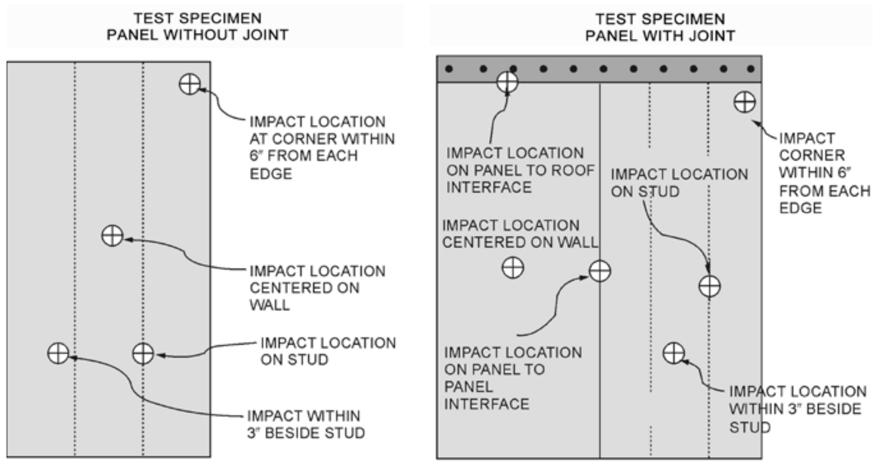

Figure 2. Typical Test Specimens (Excerpted from the ICC 500: ICC/NSSA Standard for the Design and Construction of Storm Shelters: Copyright 2014. Washington, D.C.: International Code Council. Reproduced with permission. All rights reserved. www.ICCSAFE.org.)

Industry Impact Tests

The goal of a 2016 industry-supported missile impact test program was to assess the performance of more cost-effective assemblies than had been previously tested. The 2016 tests were performed at Texas Tech's National Wind Institute Debris Impact Facility and utilized common steel construction methods and materials (*Figure 3*):

- 18 and 20 gage, 1.5-inch-wide rib steel metal deck (commonly referred to as Type B deck)
- 12K5 open web steel joists
- HSS 6×3×⅛
- Nail base insulation consisting of 3-inch polyisocyanurate with 1-inch spacers and ⅝-inch CDX plywood.

Five test series were performed:

- Series 1 – 20 gage decking supported on open web steel joists
- Series 2 – 18 gage decking supported on open web steel joists
- Series 3 – 18 gage decking supported on HSS
- Series 4 – 18 gage decking supported on open web steel joists
- Series 5 – 18 gage decking supported on HSS

Series 1, 2, and 3 were exploratory tests. The test missile penetrated the Series 1, 20 gage decking; thus, subsequent testing focused on the 18 gage decking. Series 4 and 5 were duplicate tests to verify the performance for the 18 gage decking.

Design Guide 35 summarized the research recommendations. Based on the test performance, Series 4 and 5 were deemed to be adequate for horizontal (roof assemblies with a slope of 30° or less) applications for design wind velocities of 250 mph. Series 4 assembly was deemed acceptable for vertical (wall or roof assemblies having a slope over 30°) applications for design velocities of 250 mph. Series 5 assembly was also deemed acceptable for vertical applications if a minimum ⅝-inch-thick gypsum board was employed as an interior finish. A screw dislodged during the test, but the kraft paper was not in place during the tests. The researchers judged that the gypsum board would be adequate to capture the screw that dislodged. Typically, the gypsum board would be required to achieve the building code required membrane fire protection.

Figure 3. Typical test specimen. Courtesy of Ken Charles and Texas Tech.

Design Guide 35 addresses the most current requirements and considerations for storm shelter and safe room design. It should prove to be an invaluable resource and push your next shelter design project to be as safe and cost-effective as possible. The design guide provides the design engineer with alternative economic systems for inclusion in a tornado shelter design. For those projects that employ steel bar joists, metal deck, and an insulated nail base, it allows a tested assembly to be incorporated into the overall building design. Schools utilizing masonry walls, steel bar joists, and metal roof decks can be designed with the same materials throughout. Changes in the area of the building designated as a tornado shelter consist of using the same tradesmen to increase the robustness of the construction. This is accomplished through the closer spacing of bar joists, the use of slightly heavier metal deck, and thicker masonry walls with more grout and reinforcing steel. This approach compares favorably with the use of alternative construction, which may require additional subcontractors and tradespeople.

Steel has the properties conducive to the utilization of steel-based roof and wall assemblies to achieve economical shelter design. Engineers have always been able to design these structures for strength, supporting their designs with calculations for bending stresses, shear, and pullout and pullover of fasteners. The missing link, so to speak, was the reaction of the assemblies to missile impact. With the recent testing for missile impact that utilized the entire roof and wall assembly to absorb the energy, economical steel-based shelter design can be technically justified. AISC and its industry partners have given the design engineer the tools needed in the form of Design Guide 35. The guide is available at **www.aisc.org/dg**, where you can also access AISC's entire library of Design Guides.▪

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