Analysis of the Above-ground Shelter Door Failure
April 27, 2014 Tornado, Mayflower, Arkansas

[1]Larry J. Tanner and [2]Ernst W. Kiesling

Sunday, April 27, 2014, at approximately 7:26 pm CDT (0026 UTC), the community of Mayflower, Arkansas, was struck by a large tornado which continued and struck Vilonia, Arkansas, around 7:50 pm CDT (0050 UTC). The three deaths in Mayflower and nine deaths in Vilonia were attributed to this tornado. Multi-story homes were destroyed or damaged and concrete road barriers were moved and overturned. Given these Damage Indicators and Degrees of Damage, the NWS rated the storm an EF-4 with winds estimated at 166-200 mph (267-322 km/h).

One death in Mayflower occurred when the storm door on the home above-ground shelter was impacted by storm debris. According to the surviving homeowner, all three dead bolts were engaged initially. A missile of unknown weight and speed struck the center of the door which resulted in the door bending and withdrawal of the center dead bolt and death of one homeowner.

Surviving above-ground shelter with failed door

Above-ground Shelter Door Research

Engineers and researchers at Texas Tech University have been studying tornado and other storm damage since 1970. Using reverse calculations of failed structures, 200 mph tornado was the dominant maximum damaging storm speed. A 250 mph ground speed tornado was therefore set as the design benchmark provide a 1.25 Factor of Safety. This benchmark was later adopted in the FEMA Publications P-320, *Taking Shelter from the Storm: Building a Safe Room Inside Your House*,(1998); FEMA *National Performance Criteria for Tornado* Shelters, (1999);[3] FEMA *Design and Construction Guidance for Community Shelters* (2000),[4] and later, ICC/NSSA-ICC-500 *Standard for the Design and Construction of Storm Shelters* (2008)[5].

The first publication of the above-ground tornado shelter concept was released in 1974. Shelter construction at that time was basically relegated to reinforced concrete or masonry. The door system was a steel plated, multi-layer, plywood sliding door. Testing of commercial hollow metal steel doors began 1997 at the National Wind Institute (NWI), Debris Impact Facility (DIF) and continues to date. It should be noted that with decreasing dimension and quality of plywood, and the offshore manufacturing of sheet steel and hardware, that allowable tolerances of manufacturing have been maximized. Testing of tornado doors is therefore a process of qualifying a door assembly complete with the door, locking hardware, and door frame. The qualified assembly is unique to brands and models tested. Substitution of brands, models, or type of door construction invalidates the assembly qualification.

Mayflower Door Analysis

Given the number of site constructed above-ground shelters since the mid-1970s, the shelter door failure in the April, 2014 Mayflower Tornado initiated great concern by industry, engineers, and researchers regarding the nature of the failure. With the assistance of members of the National Storm Shelter Association (NSSA), the door and frame was transported to the NWI DIF for dissection and analysis. Expert witnesses of this work included, E.W. Kiesling, PhD., P.E., NSSA Executive Director; Jim Bell, ASSA ABLOY Door Security Solutions; Claus Heide, V.P., Deansteel Manufacturing Co.; and Tim Marshal, P.E., Meteorologist, HAAG Engineering, The Principal Investigator for NWI DIF was Larry J. Tanner, P.E., NWI Research Assistant Professor and Manager of the NWI DIF. Student lab assistants included Sierra Conner, Tanner Pletcher, and Rudy Rivera.


Door frame installed in shelter

Door Frame

The door frame was installed as a "wrap-around" of the 8-in. concrete masonry, grout filled, without any apparent wall anchorage. The frame measured 8 ¾-in. wide, with a 2-in. return, a 1 7/8-in. door rabbit, a 5 ¼-in. soffit, and was 18 ga. in metal thickness. The frame further contained 10 ga. hinge reinforcements, a 14 ga. lock box, and 22 ga. strike mud boxes.


Grout filled frame without anchorage

Door Frame Anchorage

Safe Room Door frames are required by FEMA P-320 and ICC-500 to have the equivalent shear strength of (5) 3/8-in. bolts in each jamb and (3) 3/8-in. bolts in the door head.

Door

The door measured 3-ft. wide x 6-ft. 8-in. x 1 ¾-in. thick and was clad with 18 ga. metal skins that half-wrapped the jamb edge channels. The door was prepared for three dead bolts and a latch set.

It was sliced in three locations to investigate the internal construction. The edge channels were 1 11/16-in. x 5/8-in. x 16 ga. with door skins projection welded at 2 ½-in. centers along the top and bottom channels and 5-in. centers along the edge channels. Numerous projection welds were discovered to have failed. Hinge reinforcement was 4 ½-in. x 1 ½-in. x 11 ga. The hardware reinforcement consisted of 16 ga. partial boxes, tack welded to the edge channel. The door core was a standard ¾-in. x ¾-in. honeycomb. No vertical steel stiffeners were included in the door construction.

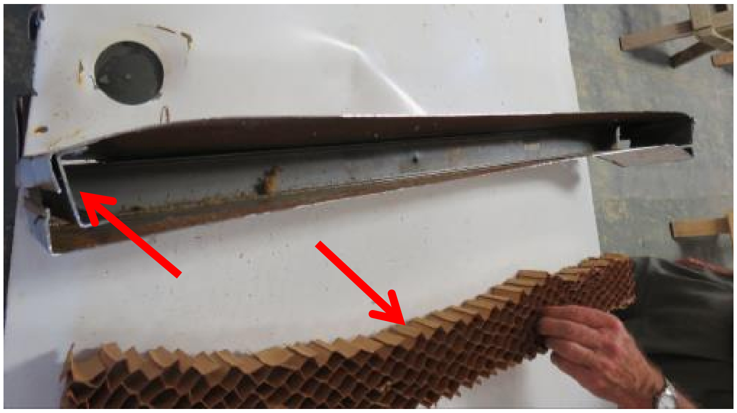

Door received for examination


Door edge separation at latch and deadbolt location


Using bar codes on the door, the manufacturer of the door was determined to be Republic Doors & Frames, DM Series, SDI 100 Grade 2 and Model 1 (Heavy Duty, minimum 18 ga., hollow steel composite.

Republic Doors and Frames manufactures FEMA 320 & FEMA 361 Tornado Doors. The DMS Series is not intended for use as an above-ground safe room door.


Door sliced for internal investigation


16 ga. Edge Channels and honeycomb core


11 ga. Hinge reinforcement


Lock/Latch and Deadbolt 16 ga. stiffeners

Minimum Safe Room Door Specifications

- *14 ga. door skins*
- *14 ga. edge channels*
- *14 ga. vertical stiffeners*
- *10 ga. hinge reinforcement*
- *10 ga. lock box reinforcement*

Note: Each tested manufacturer builds doors differently based on proprietary equipment, breaks, shears, and methods of assembly.

Door Hardware

The attached door hardware included branded (3) Residential Grade deadbolts and a latch/lock. Hinges were branded 4-in. x 4-in. x 0.130 (5-knuckle) commercial grade.

Safe Room Hardware

FEMA P-320 requires six points of connection of the door to the frame:

- *(3) Grade 1 deadbolts*
- *(3) Heavy duty hinges preferably ball-bearing*
- *Full headed American hinge screws*

Note: Foreign hinges are manufactured to minimum tolerances, thereby requiring the bugle head of the screw to be undercut in depth.

Damaged Deadbolts

Damaged Hinges and Screws

Conclusions

The crease on the door face would appear to be caused by the impact of a sheet material, possibly a piece of roof decking. Given the debris impact standard of a 15 lb. wooden 2-in. x 4-in. propelled at 100 mph by a 250 mph ground speed tornado, a 45 lb. x 4-ft. x 8-ft. x 7/16-in. OSB roof decking would be propelled by that same storm at approximately 35 mph, and the resulting Momentum and Kinetic Energy would have been the same. Therefore, the door was not impacted by some astronomical object traveling at a high rate of speed. Door failure resulted from the improper usage of a door, frame, and hardware not intended for tornado safe rooms.

Recommendations:

- *Site constructed tornado shelters should be constructed in strict accordance to FEMA P-320*
- *Safe Room doors should be FEMA 320 "Tested Door and Hardware Assemblies"*
- *Refer to the NWI website* http://www.depts.ttu.edu/nwi/research/DebrisImpact/Reports
- *Door manufacturers should provide notices to resellers and wholesalers of the dangers of selling non-tested door products for tornado safe rooms.*

Mayflower, Arkansas Door Damage

This tragedy highlights the dangers of the deviation from tested FEMA P-320 door assemblies. This investigation is Phase I of a three phase project:

Phase II: This project will identify other common non-tested door assemblies that have been installed in tornado shelters. A sample of these doors will be pressure and impact tested to determine their level of performance with regard to the FEMA P-320 and ICC/NSSA-500 standards. Levels of performance will be further documented using high speed photography. Methods of onsite mitigations will be developed and tests of the stronger assemblies conducted.

Phase III: A peer-reviewed paper for publication, including Social Media, will be written in this phase.

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[1]Larry J. Tanner, P.E., R.A., Research Assistant Professor NWI, Manager Debris Impact Facility, Texas Tech University
[2]Ernst W. Kiesling, P.E., PhD, Research Professor NWI, CEO, National Storm Shelter Association