

Analysis of the Above Ground Shelter Door Failure

April 27, 2014 Tornado, Mayflower, Arkansas

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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). (Wikipedia.org)

One death in Mayflower occurred when the storm door on the home above ground residential 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 failure of the center dead bolt and the shearing of the top dead bolt leading to the death of one of two occupants.

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 set as the design benchmark, and given that wind pressure is proportional to the square of the wind speed, this benchmark would provide a 1.56 Factor of Safety. The 250 mph standard was later adopted in the FEMA Publications P-320, *Taking Shelter from the Storm: Building a Safe Room inside Your House* (FEMA, 1998); *FEMA National Performance Criteria for Tornado Shelters* (FEMA, 1999); *FEMA Design and Construction Guidance for Community Shelters* (FEMA, 2000); and later, *NSSA/ ICC-500 Standard for the Design and Construction of Storm Shelters* (ICC, 2008). The first publication of the above ground tornado shelter concept was released in 1974 (Kiesling, 1974). Early designs used materials and construction methods familiar to homebuilders. 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. However, the overseas manufacturing of sheet steel, door hardware, and their manufacture to maximized allowable tolerances have introduced performance challenges. 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.



Surviving above ground shelter with failed door

Mayflower Door Analysis

Given the number of above ground shelters site constructed 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 assembly 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, Exec. 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. Dr. Kishor Mehta, Horn Professor at Texas Tech, and currently serving the National Science Foundation (NSF) witnessed the forensic investigation of the door assembly. Student lab assistants included Sierra Conner, Tanner Pletcher, and Rudy Rivera.

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. face, a 1 15/16-in. door rabbit, a 5 ¼-in. soffit, and 18 ga. in metal thickness. The frame further contained 10 ga. hinge reinforcements, and 22 ga. strike mud boxes.



Door frame installed in shelter



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 3/4-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 1/2-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 1/2-in. x 1 1/2-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 3/4-in. x 3/4-in. honeycomb. No vertical steel stiffeners were included in the door construction.



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 manufacture FEMA 320 & FEMA 361 Tornado Doors (DE Series). The DM Series is not intended for use as an above ground safe room door.



Door received for examination



Door edge separation at latch and deadbolt location
(door shown upside down to expose severe damage)



Door Sliced for internal investigation



16 ga. Edge Channels and honeycomb core



11 ga. Hinge reinforcement



Lock/Latch and Deadbolt reinforcement - 16 ga. partial lock box

Minimum Tested Safe Room Door Specifications

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

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

Door Hardware

The attached door hardware included (3) Residential Grade deadbolts and a latch/lock, all were branded Design House. Hinges were 4-in. x 4-in. x 0.130 (5-knuckle) standard duty, branded Cal-Royal.

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 and Latch Bolt



Damaged Hinges and Screws



Conclusions

The crease on the door face and the material deposits on it would appear to be caused by a sheet material, possibly a piece of plywood or OSB roof decking. The performance of bodies impacted by another body is best described by formulas for Momentum ($p = \text{mass} \times \text{velocity}$) and Kinetic Energy ($K_e = \frac{1}{2} \text{mass} \times \text{velocity}^2$). Momentum is a vector with magnitude and direction, whereas, Kinetic Energy is scalar with only magnitude. Momentum best indicates penetrability of the impacted subject, whereas Kinetic Energy describes the channeling of energy across the face of a subject to all the connecting points (locks and hinges). In the case of the Mayflower door, the door was not sufficiently stiff to be penetrated by the Momentum of the assumed OSB sheet. However, the door was sufficiently flexible to catastrophically bend and damage the hardware indicating that Kinetic Energy was instrumental in the door failure. Similar failures of sub-standard door assemblies have been documented in the DIF Laboratory. It therefore appears that 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. Just because it was a steel door did not qualify it to be a tornado safe room door.



Recommendations:

- Site constructed tornado safe rooms should be constructed in strict accordance to FEMA P-320
- Safe Room doors should be FEMA 320 "Tested Door and Hardware Assemblies"
- For tested door 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.

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.

Phase III: Methods of onsite mitigations will be developed and tests of the stronger assemblies will be conducted. A peer-reviewed paper for publication, including Social Media, will be written in this phase.

Works Cited

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