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Evaluation of shelter performance following the 2013 Moore tornado

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Abstract. Moore, Oklahoma was hit by an EF5 tornado on May 20, 2013. The tornado track slightly overlapped with two previous tornadoes that occurred on May 3, 1999 and May 8, 2003 respectively. A research team from Texas Tech University was deployed to investigate the performance of shelters based on observation of their post-storm conditions. Sixty-one shelter units were further documented by size, manufacturer, and date of installation if available. Then they were crossed referenced with the external databases to determine their compliance with design and construction standards by the International Code Council/National Storm Shelter Association and/or criteria from the Federal Emergency Management Agency publications. Wind intensity was estimated for each shelter location using the EF scale. Results showed a marked increase in the number of exterior underground shelters as well as the popularity of a new in-garage floor underground shelter design. All of the units provided protection for their occupants with no loss of life reported. However, one older shelter had a door failure due to neglect of maintenance. Recommendations were made to improve future performance of shelters.

Keywords: tornado; storm shelter; safe room; shelter; Moore, Oklahoma 2013 tornado

1. Introduction

Moore, Oklahoma has experienced three major tornado events in the past fifteen years on May 3, 1999, May 8, 2003, and the most recent on May 20, 2013. All three tornado tracks can be seen in Fig. 1 where the May 3 path is indicated in red, the May 8 path is indicated in blue, and the May 20 path is indicated in green. There are slight overlaps of the May 20 tornado with both the May 3rd and May 8th tornadoes. Above- and below-ground shelters were inspected after the May 3, 1999 tornado and it was found that some met or exceeded the construction guidelines first released by the Federal Emergency Management Agency (FEMA) in the late 90s while others failed in compliance (Gardner *et al.* 2000). Most notable deviation from the guidelines appeared to be sub-standard door construction and inadequate locking mechanisms. Instances of door failure and damaged ventilation components were recorded. Shelter maintenance also proved to be major contributing factors to failures, including deterioration and rusted hinges and latches due to

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improper waterproofing and painting. By the May 8, 2003 tornado the number of shelters in Moore had increased thanks to the FEMA incentive grant program which offset part of the cost of installing a shelter for homeowners. It was estimated that the percentage of residential shelters increased from about 5-10% of residential units having a shelter to approximately 16%, based on the number of registered shelters (Graettinger *et al.* 2014). It is unclear how many nonregistered shelters there may be. Note that many newer shelters, including several above ground shelters, were not in the May 8th tornado path (Kiesling and Tanner 2003). It was obvious that the number of shelters seems to have increased again from the May 8th tornado, but so many unregistered shelters were found that it did not seem possible to make a good estimate on the statistics based on the number of registered shelters.

2. Objectives

The objective of the Moore, Oklahoma post-storm investigation was to assemble data on shelter performance within the path of the tornado. It is important to establish validity of the use of shelters, both above and below ground, and to identify issues with shelter designs, construction techniques, or materials that need to be addressed for future shelter design and installation. Success stories have proven that shelters do save lives during a tornado, yet people should not be given a false sense of security with inadequately designed and constructed shelters. There were 126 fatalities in the Joplin, Missouri tornado in 2011 which may have been due to the poorly constructed housing (Paul and Stimers 2012). This may not have been the outcome if Joplin had shelters in as concentrated numbers as Moore, Oklahoma.

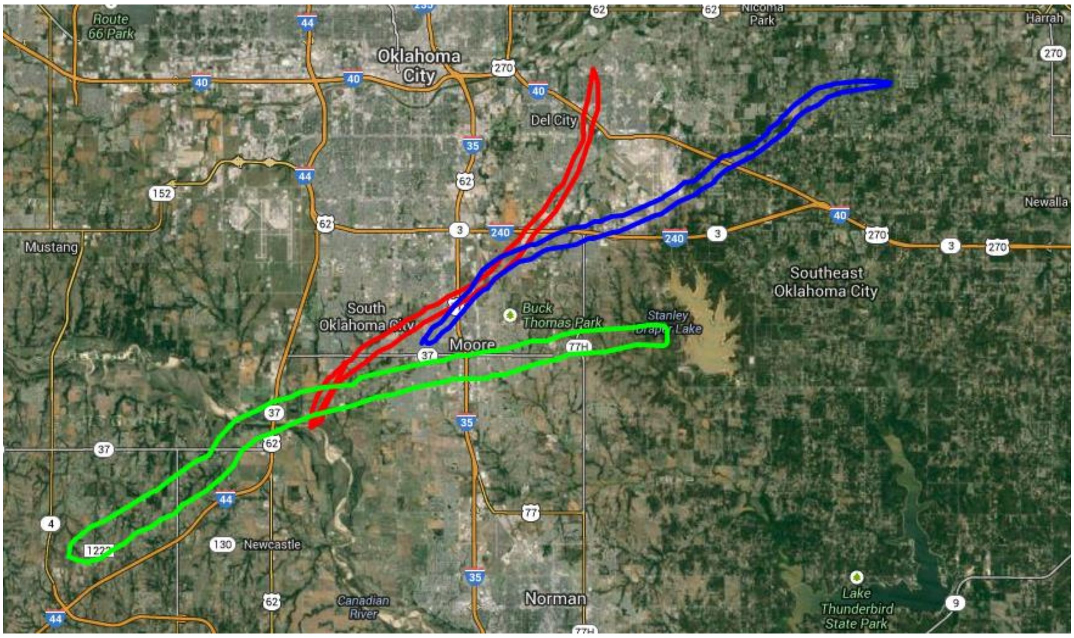

Fig. 1 Representation of three historical tornado paths through Moore, OK (May 3, 1999 path is in red, the May 8, 2003 path is in blue, and the May 20, 2013 path is in green). (WDT, Inc.)

Fatalities are 61% to 85% higher on weekends than weekdays (Simmons and Sutter 2009). Weekends are when people are home and more likely to use their own personal shelter rather than take shelter in a workplace or commercial building. It is advantageous for homeowners to invest in a shelter for peace of mind during a tornado. Burgess *et al.* (2014) found only nine homes within the path of the Moore tornado that were "well built" enough to justify using them as damage indicators for an EF5 rating.

To obtain the shelter performance data, the team mapped the track of the tornado and overlaid the locations of shelters from the FEMA database, National Storm Shelter Association (NSSA) database, and the Oklahoma Sooner Safe Room Association (OUSSRA) database. All shelters that did not appear in or near the tornado path were deleted off the list of potential site visits. Several shelters that were not listed in the databases were found amongst the debris, and some were tagged with incorrect GPS coordinates and/or addresses in the databases. Difficulties locating some shelters also arose due to the destruction of street signs and landmarks.

The team assessed the shelters by first evaluating their performance based on observation of their condition and the Enhanced Fujita (EF) scale rating for each specific site location. Shelters were further documented by size, manufacturer, and date of installation if available. Then they were crossed referenced with the databases to determine if the shelter was tested per guidelines from the ICC/NSSA *Standard for the Design and Construction of Storm Shelters* (ICC 500), FEMA P-361 *Design and Construction Guidance for Community Safe Rooms*, and FEMA P-320 *Taking Shelter from the Storm Building a Safe Room for your Home or Small Business*. An EF rating for the specific site of the shelter was assigned. When possible, the owner of the shelter was consulted to obtain additional information such as when, why, and how they purchased the shelter; who occupied the shelter (including pets) during the storm; what was relationship of the occupants to the owner; the amount of warning time; the amount of time they waited before taking shelter; and the amount of time they remained in the shelter after the tornado hit.

3. Observed shelter performance

Different types of shelters were observed and they were grouped into the following categories: exterior below-ground, indoor below-ground, and above ground. Some categories were divided into multiple sub-categories. The team is not aware of any deaths or injuries from any persons using a shelter, regardless of whether or not they were adequately designed and constructed. However, it should be noted that the inadequately designed and constructed shelters could have easily failed if they had been subjected to the worst case scenario for debris impacts and wind pressures that are designed and tested for when adhering to FEMA guidelines and ICC 500 standards.

3.1 Exterior below-ground shelters

Below-ground shelters are shelters that are placed with the majority of the structure underground with the earth serving as protection from debris impacts. Proper anchorage is required for these types of shelters to ensure that they do not pop out of the ground from the negative pressures from the tornado and ground moisture, and any portion of the shelter not covered with at least 12 inches of compacted dirt for horizontal surfaces and 36 inches for vertical surfaces needs to be able to pass the debris impact testing criteria as listed in Chapter 8 of ICC 500.

Four types of exterior below-ground shelters were documented during the investigation: flush-to-the-ground, clam shell, dome, and indoor below-ground shelters.

3.1.1 Flush-to-the-ground

The team documented eight flush-to-the-ground shelters, all of which had hinged swinging doors. One shelter sustained a significant failure as the door was blown off due to sheer failure of rusty hinge pins (seen in Fig. 2). Proper maintenance could have prevented this, as well as having door assembly complying with ICC 500 or FEMA P-361 criteria. The door of another shelter was stuck shut and the homeowner, and elderly man, opted to take shelter in an interior bathroom of his home with his pets. Again, proper maintenance of the door may have prevented this issue. Additional deficiencies with shelters of this type were related to door thickness, locking systems, hinges, stairs, and drainage. Many of such shelters were not properly designed with beveled edges to allow water runoff to flow around the opening, and had been flooded with 6 inches to 48 inches of water. Flooding was a common complaint among homeowners, however, many homeowners were under the impression that they were safer in below ground shelters and were unaware of shelter installation and testing guidelines and standards.

3.1.2 Clam Shell

Fifteen clam shell shelters were documented with no observed major failures. However, deficiencies were found consistently in doors and ventilators. Many doors had only one locking latch and an insufficient number, and inadequate type of hinges. In Fig. 3, a clam shell shelter was designed with only one lock, two hinges, and sustained vent damage at an EF-2 rated location. In Figure 4, a clam shell shelter with a tested door that included three locks and three hinges was documented at an EF-4 rated location.

Fig. 2 Door failure when accessing shelter with only a single lock point (No 47). Photo credit: Larry Tanner

Fig. 3 Clam shell shelter with an insufficient locking system and damaged vent at an EF-2 rated location. Photo credit: Pataya Scott

A flat-top clam shell shelter was documented in an EF-2 rated location, as seen in Fig. 5. Performance of these types of shelters was good. Accessibility to the shelters can be an issue because these types of shelters are located outdoors and the distance people must travel to take shelter must be considered when deciding placement. One shelter was located about 100 feet from the house, which could pose a greater threat to potential occupants if they need shelter quickly. Although the ICC 500 requires shelters to be 150 feet or less to the residence it is serving, it is advisable to place shelters as close and easily accessible as possible to reduce the threat of injury from debris while traveling to the shelter and to reduce the time it would take to get to the shelter. Standing water up to several inches was commonly observed in these as well.

Fig. 4 Clam shell shelter with a tested door that has three locks and three hinges at an EF-4 rated location. Photo credit: Larry Tanner

Fig. 5 Flat-top clam shell shelter with three locks at an EF-2 rated location. Photo credit: Pataya Scott

3.1.3 Dome

Two dome style shelters were inspected. The shelter pictured in Fig. 6 was cast in place concrete with double plywood doors with light gauge steel skin cladding, one lock, and two hinges per door. The shelter was observed at an EF-3 rated location. This shelter also had a few inches of standing water in the bottom. The other dome shelter the team documented had 3 heavy-gauge locks with a 1/8 inch steel door. It was partially above-ground, located in an EF-4 rated location, and is shown in Fig. 7. Both appeared to have survived the storm with no major failures, although the construction of the door assemblies were inadequate per ICC 500 and FEMA P-361.

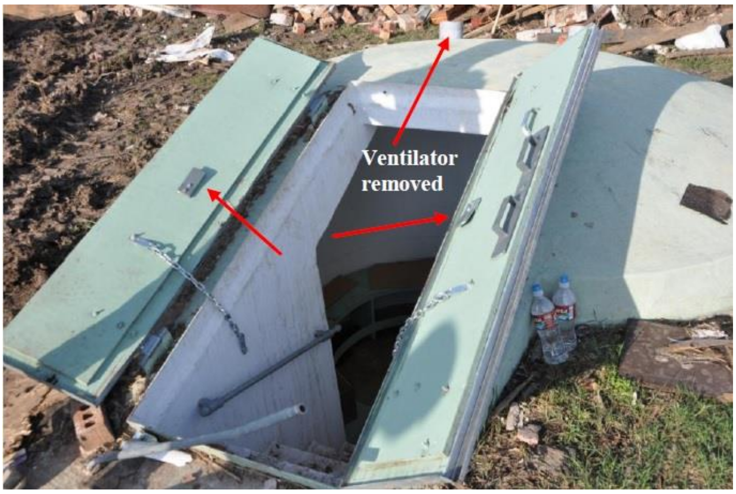

Fig. 6 Dome shelter with an inadequate door system that included a plywood and light gauge sheet metal clad door, single locking point, and ventilator removed at an EF-3 rated location. Photo credit: Larry Tanner

Fig. 7 Dome shelter partially above-ground located in an EF-4 rated location. Photo credit: Stephen Morse

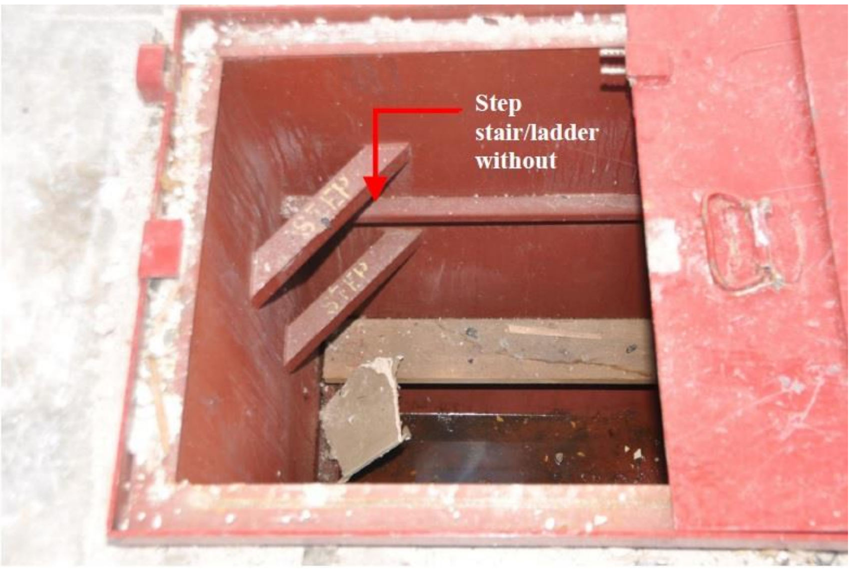

Fig. 8 In-garage shelter with inadequate stairs, locking system, and flooding in the bottom at an EF-3 rated location. Photo credit: Larry Tanner

3.2 Indoor below-ground shelter

Twenty in-garage floor shelters with heavy sliding doors were documented. All appeared to have performed reasonably well, with no major failures. Fig. 8 shows a shelter in an EF-3 rated location with a stair/ladder entry that would not allow for easy access, an inadequate locking system, and some flooding in the bottom. Parked cars over the shelter proved to be a hindrance on accessibility to the shelter in some instances. When a car is pulled forward over the shelter, people who are mobile enough could gain access, however, access could be prevented if the car is not far enough forward or people accessing the shelter have limited mobility. Other issues were similar to exterior below ground shelters such as: door thickness, locking systems, roller bearings, stairs, and drainage. Flooding from drainage seemed to be a problem not fully considered, homeowners did not need to worry about flooding of the shelter when it was protected by the garage structure. After the tornado destroyed the garage around the shelter, then water would drain into them from rain, broken water lines, or even ruptured above-ground swimming pools. Figs. 9 and 10 are tested shelters that performed very well in an EF-4 and EF-0 rated locations respectively. Homeowners indicated they preferred the in-garage style shelter because it was cheaper, installation was quick, it did not take up any space, and it gave them confidence by being underground.

3.3 Above-ground shelter

Eight above-ground shelters were documented. Six had been tested, and it was noted that most of these shelter manufacturers displayed their company name on their products while most of the underground shelters did not. Fig.11 is an untested above-ground shelter that was in the garage of the home in an EF-4 rated location, and survived without any failures, even though the rest of the home was destroyed. The other two shelters that were not tested were located on the same street of a fairly new, well built neighborhood. These were builder installed walk-in closets made of concrete. The concrete portions of the shelters had been tested, however, the door assemblies did not appear to be tested. One of these shelters is shown in Fig.12.

Fig. 9 Tested shelter at a location assigned an EF-4 rating. Photo credit: Pataya Scott

Fig. 10 Tested NSSA shelter at a location assigned with an EF-0 rating. Photo credit: Pataya Scott

Fig. 13 shows a tested steel shelter that performed very well. Some above-ground shelter owners still questioned if they were safe because they were not below ground. Other investigation teams had documented an above-ground, insulated concrete form (ICF) waffle grid shelter in Newcastle, Oklahoma that had been hit by the tornado and suffered perforations in the walls from metal rods (FEMA 2014, Standohar-Alfano *et al.* 2014). This occurrence, among other issues with the construction and inability to ensure that the waffle grid system is sufficiently filled during the building process, has led to the deletion of the waffle grid ICF safe room design information in future versions of the FEMA guidelines.

Fig. 11 An above-ground tested shelter that survived EF-4 wind speeds. Photo credit Pataya Scott

Fig. 12 An above-ground, concrete shelter that also served as a walk-in closet at an EF-2 rated location. The concrete was tested, but the door was not. Photo credit: Larry Tanner

Fig. 13 Above-ground tested steel shelter that performed very well in an EF-3 rated location. Photo credit: Larry Tanner

4. Standards and guidance

The terms safe room and storm shelter are often used interchangeably, but there is a difference between the two. Safe rooms follow criteria set forth in FEMA P-361, and storm shelters follow the ICC 500 standard. These guidelines and standards were developed to ensure occupant protection for people utilizing these areas during a high wind event. The original concept of the storm shelter or safe room was first published in 1974 after small rooms were often found intact while the rest of a home was destroyed in a tornado (Kiesling *et al*. 2009). Six years later FEMA released *TR-83A Interim Guidelines for Building Occupant Protection from Tornadoes and Extreme Winds*. This later became preceded by the first edition of FEMA P-320 published in 1998, the first edition of FEMA P-361 released in 2000, and the first release of the ICC 500 in 2008. FEMA P-361 guidelines meet or exceed ICC 500, but in many ways they are very similar. FEMA guidelines do not have to be followed and are purely recommendations unless funding for the shelter is provided by FEMA or agencies appointed by FEMA to distribute funding. The ICC 500 was adopted by the 2012 International Building Code, and is thereby required to be complied with by cities who have adopted it.

FEMA P-361 defines residential shelters, as the ones observed in this investigation, as shelters designed for occupancy of 16 or less (Ch. 2.1), and the ICC 500 provides the extra clarification that it is also located at a place of dwelling. These residential shelters must be located within 150 feet from the residence in which it is serving per ICC 500 Section 403.1, and all of the shelters we observed appeared to comply with this criterion. This is extremely important when time is of the essence to take shelter, and the shorter the distance, the less chance of being struck by flying debris or hail. Missile impact testing and wind pressure testing are requirements for the walls, roof, and door assemblies (ICC 500Section 306.2) which differ in requirements between hurricane shelters and tornado shelters unless the shelter is for use in either a tornado or hurricane. Then the more stringent of the requirements must be met. Tornado shelters are required to resist missile impacts from a 15 lb 2 x 4 traveling at a speeds corresponding with the design wind speed of the shelter which can be found in Table 305.1.1 of ICC 500. FEMA P-361 recommends all residential shelters to be designed for the maximum design wind speed of 250 mph (Ch. 3.1), while the ICC 500 allows design engineers to determine the necessary design wind speed in accordance with the shelter location (Section 304.2). Residential shelters typically do not have any glazing and none were seen with glazing on this observation trip. The ICC 500 has provisions for residential shelters for flooding which require the minimum floor elevation of the shelter to be determined based on the applicable flood criteria such as the floodplain ordinance of the community or one foot above the highest recorded flood elevation (Section 401.1.2). It is unclear how these could be applied to below-ground shelters; however, this is more of a problem for hurricane shelters or shelters in areas that frequently flood.

Shelters must be easily accessible and provide a means of egress that is not difficult for the intended occupants and does not require any special knowledge or tools to operate or lock the door. Below-ground shelters are the most susceptible to difficulties complying with this. The team witnessed several shelters that were not easily accessible because of inadequate egress. Stairs should have minimum treads of 8 inches and a maximum rise of 9 9/16 inches per ICC 500 (Section 502.3.1). Residential shelters are not required to comply with ADA, but homeowners who are either disabled or have minimal mobility, or their family members are disabled or with minimal mobility, must consider this issue. Above-ground shelters seem to be the best option for this situation.

Ventilation is very important for shelters because it allows fresh air to penetrate the shelter for occupants and relieves some of the positive and negative pressures associated with high winds and structures. Residential shelters only need natural ventilation, but these air intake openings must be protected from debris impacts and infiltration of small debris and mud. This is possible with screens or mesh covering. Many of the shelters seen during the observation trip had small debris and mud that had come in through the ventilation system. ICC 500 requires venting area to be 2 square inches per occupant, and these openings are permitted to be used for atmospheric pressure changes (Section 702.1.1).
The analysis of the shelters and evaluation against FEMA publications and ICC 500 standards are based on the versions that were available at the time of the tornado event which were the third edition of FEMA P-320, second edition of FEMA P-361, and ICC 500-2008. The FEMA publications and ICC 500 standard have since been updated or are in the process of being updated.

5. Conclusions

The shelters documented on this post-storm damage survey were mostly not compliant with shelter guidelines or standards. The most common portion of the shelters that did not comply were the door assemblies. These were either inadequacies with the materials themselves, thickness of the material, or inadequate locking points and hinges. Flooding was another common issue among outdoor shelters, or in-garage shelters which were in garage structures that were destroyed and no longer shielding them from flowing water or falling rain.

The shelters observed performed relatively well with the exception of the shelter with the door failure. The rest all appear to have been able to protect their occupants against the winds and debris, however, there were several instances of shelters that were not adequately designed or constructed. These should be updated to meet FEMA P-361 and/or ICC-500 guidelines and standards before trusted with life safety protection. Recommendations for future work is to examine the shelters again if another tornado passes through the same area and see if improvements have been made after the inadequacies have been brought to light.

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