

May 20, 2013 Moore, OK Tornado Shelter Performance Report
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Introduction

Prior to the May 20, 2013 tornado, Moore, Oklahoma was hit by two severe tornadoes on May 3, 1999 and May 8, 2003. All three tornado tracks can be seen in Figure 1 where the May 3, 1999 path is indicated in red, the May 8, 2003 path is indicated in blue, and the May 20, 2013 path is indicated in green. There are slight overlaps of the tornado May 3rd path with both the May 8th and May 20th paths. Figure 2 shows the population density of the city at the time of the May 20, 2013 tornado.

Above and below ground shelters were inspected after the May 3, 1999 tornado and it was found that some met or exceeded the Federal Emergency Management Agency (FEMA) 1998 guidelines, while others failed in compliance (Gardner, Mehta et al. 2000). Most notable deviation from the guidelines appeared to be sub-standard door construction and locking inadequacies. Instances of door failure and damaged ventilation components were recorded and issues with damage to ventilation components. Storm shelter maintenance also proved to be major contributing factors in the failures, including deterioration and rusted hinges and latches due to improper waterproofing and painting. The number of shelters in Moore had increased thanks to the FEMA shelter incentive grant program. It must be noted that many newer shelters, including several above ground shelters, were not in the tornado path (Kiesling and Tanner).

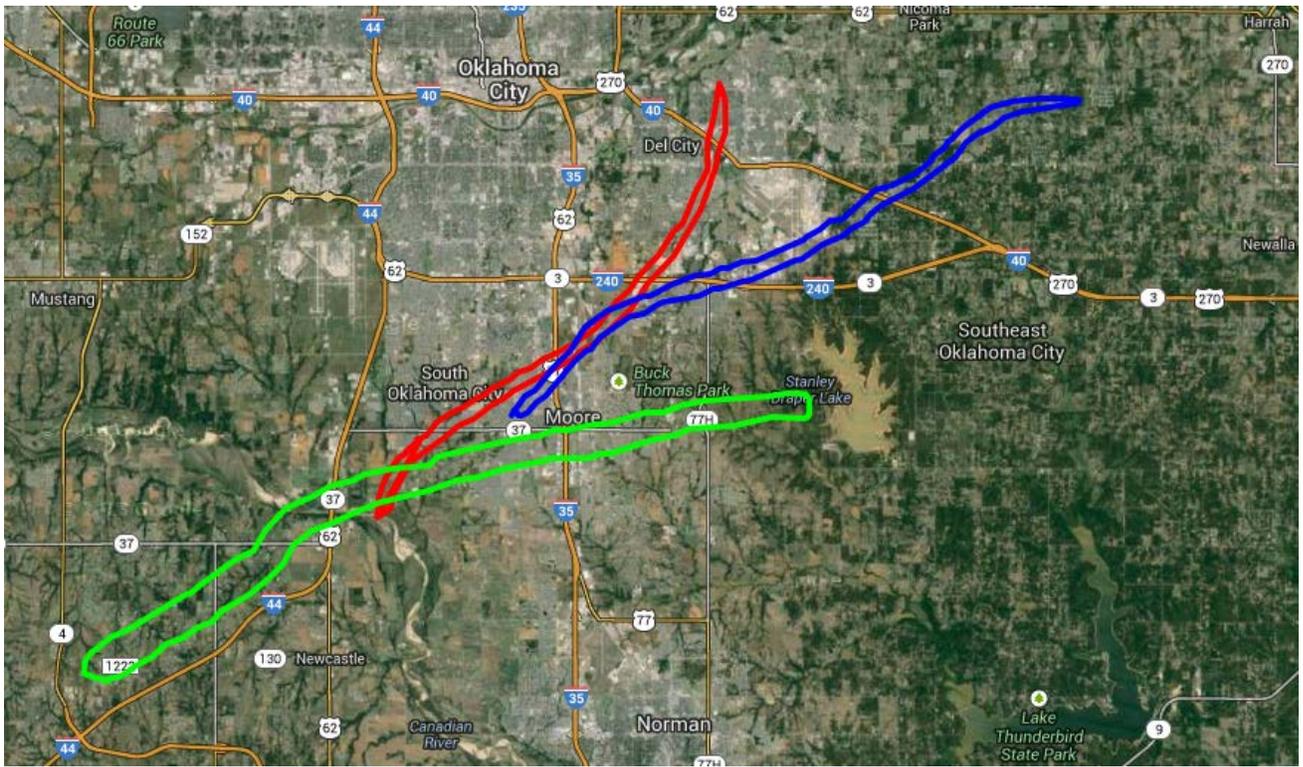


Figure 1. An analysis of three tornado paths through Moore, OK done by WDT, Inc. Red is the May 3, 1999 path, blue is the May 8, 2003 path, and green is the May 20, 2013 path. (Google_Maps 2013)

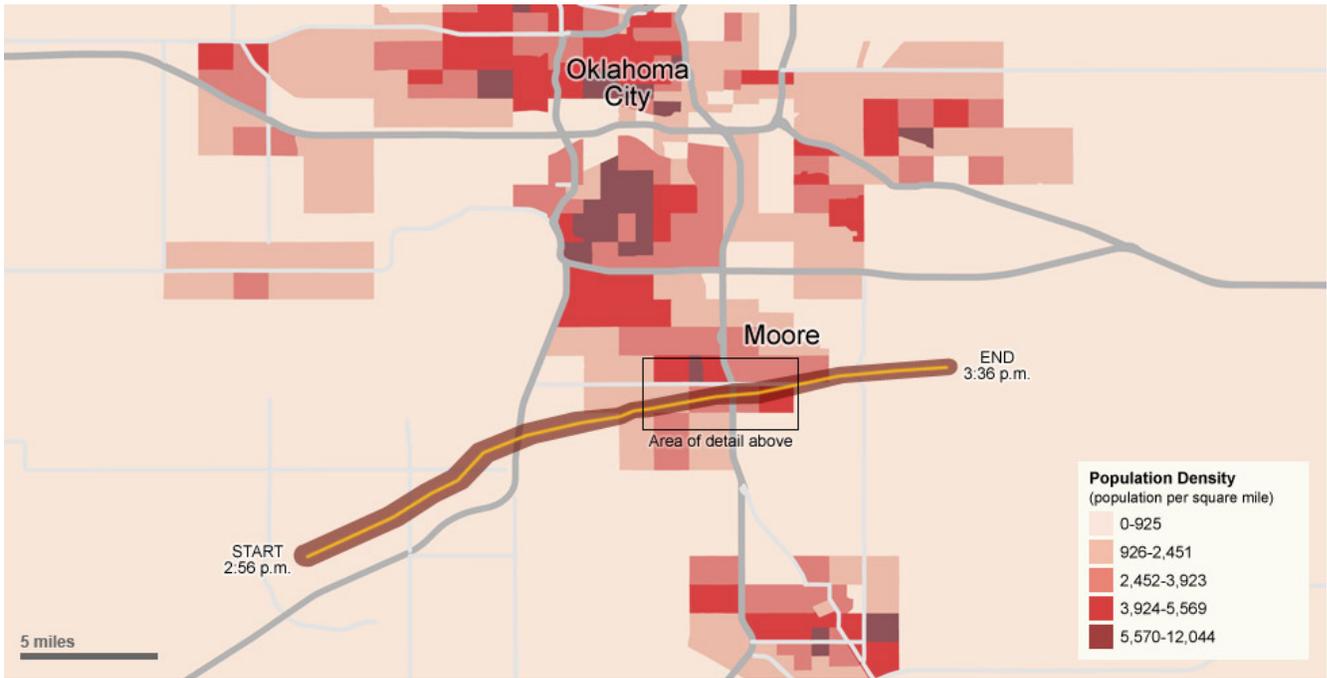


Figure 2. Population density in Moore and Oklahoma City, Oklahoma (Source: URS).

EF Scale

The Enhanced Fujita Scale (EF-Scale) was developed at Texas Tech University to rate intensity of tornadoes before being adopted by the National Weather Service in February 2007 (WISE 2006). There are 28 Damage Indicators (DI) 23 of which are building types ranging from small barns (SBO) to automobile showroom (ASR) and strip mall (SM). For each DI, a set of Degree of Damage (DOD) is identified to describe the level of damage sustained. For One and Two-Family Residence (FR12), the Degrees of Damage are numbered between 1 (threshold of visible damage) to 10 (slab wept clean). In addition, three wind speeds are estimated for each DOD to account for inherent uncertainties in construction quality, design, and maintenance: expected (EXP), lower bound (LB), and upper bound (UB). For example, EXP, LB and UB wind speeds causing DOD5 of FR12 (i.e. entire house shift off foundation) are 121mph, 103mph, and 141mph respectively. Meanwhile, a range of wind speed is defined to rate a specific tornado intensity: EF0 (65-85mph), EF1(86-110mph), EF2(111-135mph), EF3(136-165mph), EF4(166-200mph) and EF5(>200mph). However, wind speed estimation was provided by a panel of experts following the elicitation protocol established by the Senior Seismic Hazard Assessment Committee (SSHAC, 1997). Therefore, correlation of observed damage with wind speeds that caused the damage is important in understanding the uncertainties (variation) in the observed damage at a location and in calibrating/verifying the wind speeds in the EF-Scale.

An EF- rating was assigned to each shelter site by Professor Tanner, and is shown on the maps in Figures 3, 4 and 5 with a corresponding legend in Tables 1 and 2.

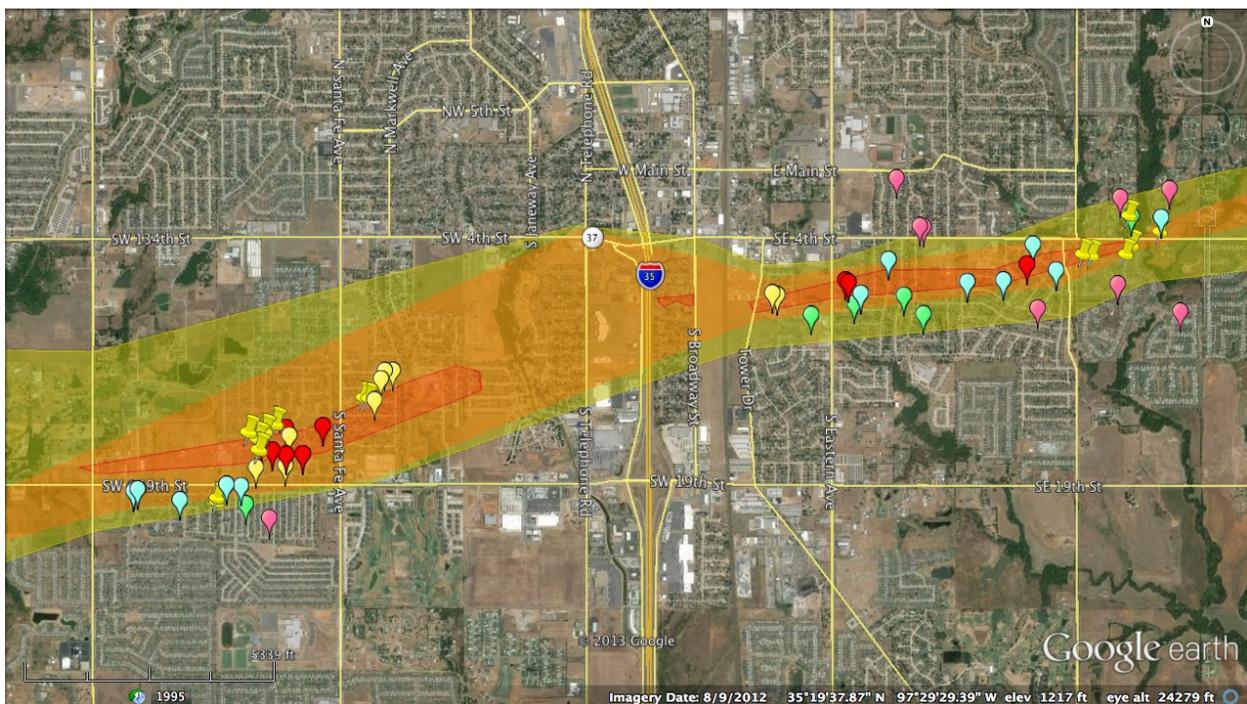


Figure 3. EF ratings from shelter visits Sunday, May 26, 2013.

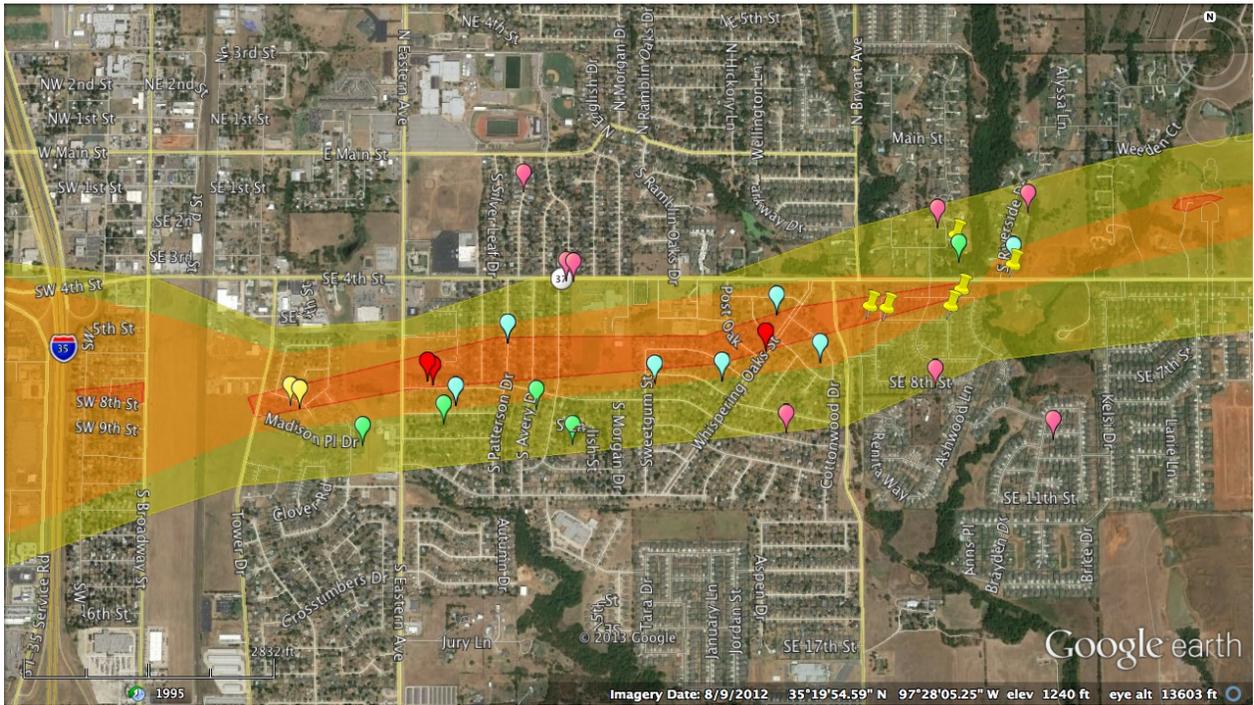


Figure 4. EF ratings from shelter visits Monday, May 27, 2013.

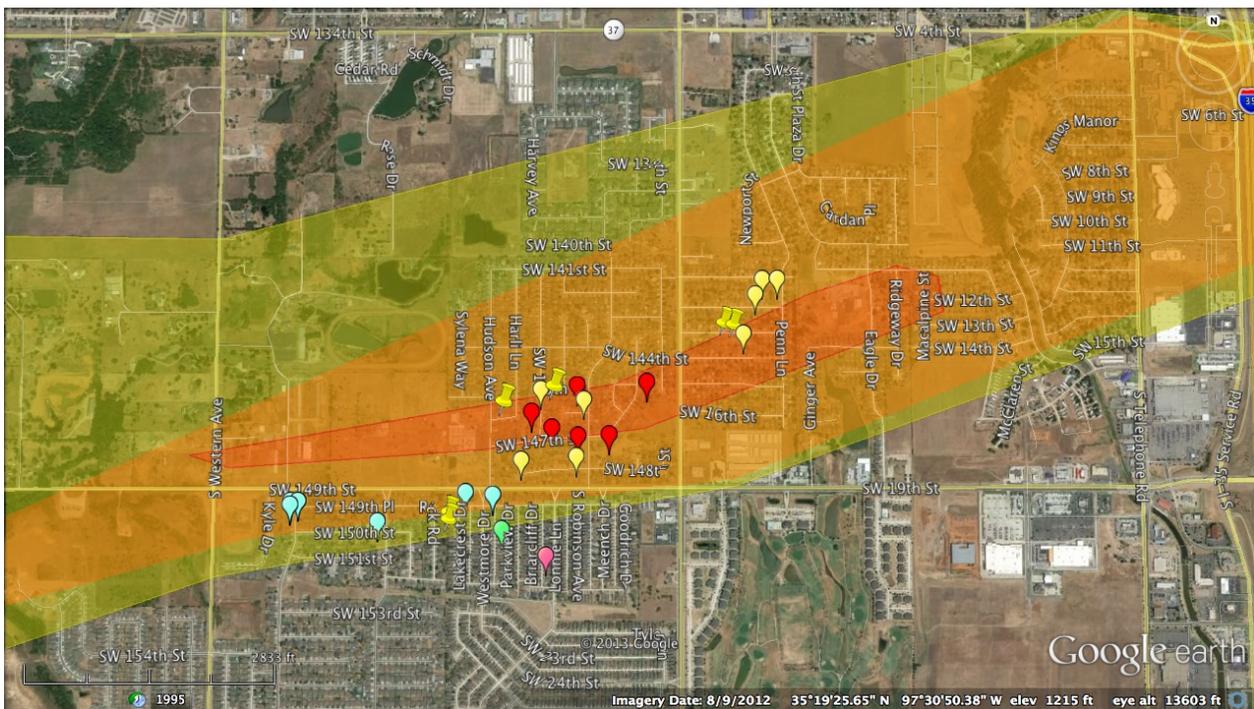


Figure 5. EF ratings from shelter visits Tuesday, May 28, 2013.

Table 1. EF rating given by Texas Tech team at specific location.

Symbol	On-Site Storm Strength Assessment
	EF-0
	EF-1
	EF-2
	EF-3
	EF-4
	Information missing

Table 2. EF rating given by the National Weather Service for the areas shaded in Figures 3, 4, and 5.

Color Fill	NWS Storm Rating
Yellow	EF-0
Orange	EF-2
Red	EF-4

Objectives

The objective of the Moore, Oklahoma post-storm investigation was to assemble data on storm shelter performance within the path and close proximity of the tornado. This is important to establish validity of the use of storm shelters, both above and below ground, and to identify issues with shelter designs, construction techniques, or materials that need to be addressed for future storm shelter design and installation. To obtain this data, the team mapped the track of the tornado and overlaid the locations of storm shelters from the FEMA database, National Storm Shelter Association (NSSA) database, and the Oklahoma Sooner Safe Room Association (OUSSRA) database. All storm shelters that did not appear to be affected by the tornado were deleted off the list of potential site visits. Storm shelters that were not contained on lists were found amongst the debris, and some storm shelters were incorrectly tagged with GPS coordinates and/or addresses. Difficulties locating some storm shelters also arose due to the destruction of street signs and land marks.

The team assessed the storm shelters by first evaluating their performance based on observation of their current condition. Shelters were further documented by size, manufacturer, and date of installation if available. Then they were cross referenced with the databases to determine if the shelter was tested per guidelines from the International Code Council, National Storm Shelter

Association, and Federal Emergency Management Agency (FEMA 2008, FEMA 2008, ICC and NSSA 2008). An EF rating for the specific site of the storm shelter was assigned by the principal investigator. When possible, the owner of the storm shelter was interviewed to obtain additional information such as when, why, and how they purchased the storm shelter; who occupied the shelter (including pets) during the storm, what relationship were they to the owner; the amount of warning time they had; the amount of time they waited before taking shelter; and the amount of time they took shelter after the tornado hit.

Shelter Databases and Survey Zones

Prior to team deployment three databases containing the locations of storm shelters and safe rooms were acquired from FEMA, NSSA and the OUSSRA. The NSSA database included addresses for 236 shelters in Moore, OK, less than 80 of which were located within the tornado track. The FEMA database included addresses and GPS coordinates for 96 shelters and safe rooms, all of which were within the track. The OUSSRA database contained addresses for 98 shelters, less than 40 were in the track. Based on shelter densities and geographic delimiters Moore was divided into three Zones to facilitate logistics (Figure 6). Zone 1 contained shelters and safe rooms west of Briarwood Elementary, including where the 1999 and 2013 tornado paths crossed as seen in Figure 1. Zone 2 contained shelters and safe rooms east of Briarwood Elementary to I-35. Zone 3 contained all of the shelters and safe rooms east of I-35.

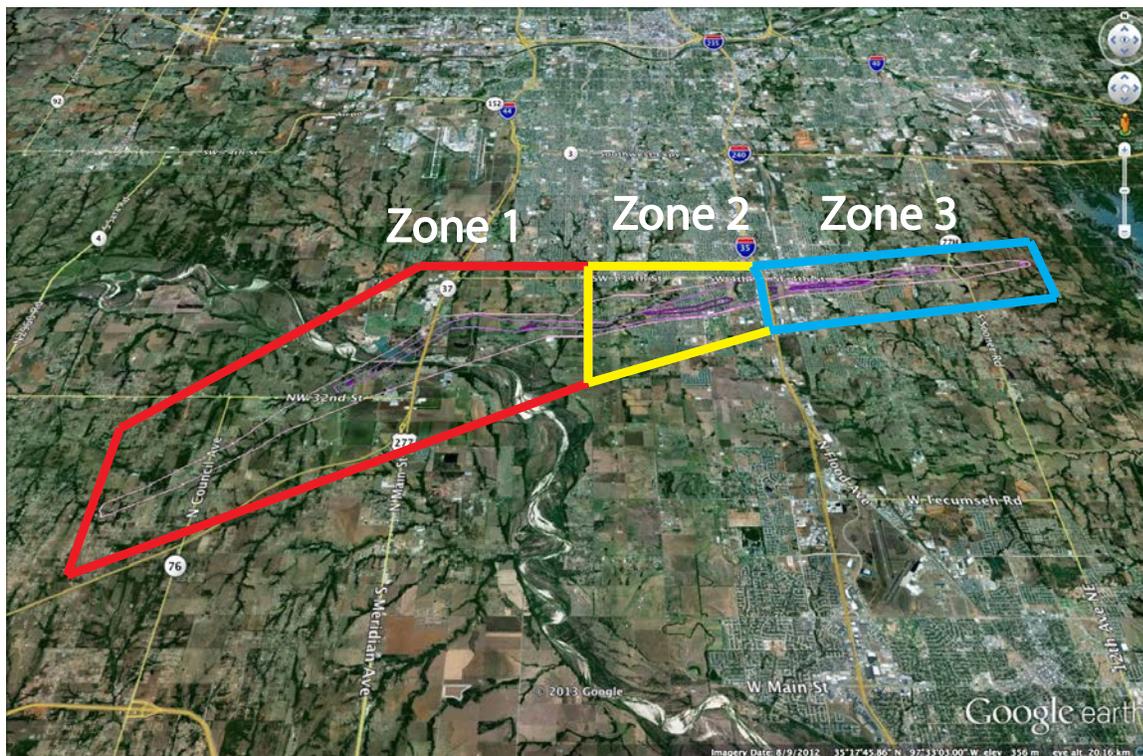


Figure 6. Geographic breakup of the tornado track into zones.

Observed Shelter Performance

A table of the shelter performance for all the shelters documented is shown in Table 3 at the end of the section. Per ICC 500, the shelter must have a door type that has been tested to withstand applicable debris impacts, include 3 locking points, and 3 hinges. The shelter must have easily accessible egress as well as proper drainage. Minimum stair tread depth for residential shelters is 8 inches and the maximum riser height is 9 9/16 inches. Proper drainage is determined based on the shelter site and type of shelter, but in all cases prevents water from entering the shelter.

I. Exterior Below Ground Shelter

a. Flush-to-the-ground

The team documented eight flush-to-the-ground shelters, all of which had hinged swinging doors. One shelter (No. 47) sustained a significant failure as the door was blown off due to rusty hinge pins with sheer failure (seen in Figure 7). The door of another shelter (No. 14) was stuck shut and the homeowner, an elderly man, opted to take shelter in an interior bathroom of his home with his pets. 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 slightly above-ground to allow water runoff to flow around the opening, and as the result had been flooded with 6 inches to 4 feet in depth of water. Flooding was a common complaint among homeowners. Many homeowners were under the impression that they were safer in below ground shelters even though most of the units were not tested per building standards.



Figure 7. Door failure when accessing shelter with only a single lock point (No 47).

b. 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. As with below In Figure 8 a clam shell shelter (No. 3) was designed with only one lock, two hinges, and sustained vent damage at an EF-2 rated location. In Figure 9 a clam shell shelter with a tested door that included three locks and three hinges was documented at an EF-4 rated location. A flat-top clam shell shelter (No. 17) was documented in an EF-2 rated location, as seen in Figure 10. Performance of these types of shelters was good. Accessibility to the shelters can be an issue because this type is always located outdoors and the distance people must travel to take shelter needs to 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. Standing water of several inches was also commonly observed.



Figure 8. Clam shell shelter with an insufficient locking system and damaged vent at an EF-2 rated location (No. 3).



Figure 9. Clam shell shelter with a tested door that has three locks and three hinges at an EF-4 rated location (No. 28).



Figure 10. Flat top clam shell shelter with three locks at an EF-2 rated location (No. 17).

II. In-garage floor

Twenty in-garage floor shelters with heavy sliding doors were documented. All appeared to have performed reasonably, with no major failures. Figure 11 shows a shelter (No. 12) with a stair entry that would not allow for easy access, an inadequate locking system, and some flooding at its bottom in an EF-3 rated location. Other issues were similar to exterior below ground shelters such as door thickness, locking systems, roller bearings, stairs, and drainage. Figures 12 and 13 are tested shelters (No. 9 and 61) 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 again they felt safer in a below ground shelter.



Figure 11. In-garage storm shelter with inadequate stairs, locking system, and flooding in the bottom at an EF-3 rated location (No. 12).



Figure 12. Tested shelter at a location assigned an EF-4 rating (No. 9).



Figure 13. Tested NSSA shelter at a location assigned with an EF-0 rating (No. 61).

III. Dome

Two dome style shelters were inspected. The shelter pictured in Figure 14 (No. 43) was cast in place concrete with double plywood doors with 18 or 20 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 an 1/8 inch steel door. It was partially above-ground, located in an EF-4 rated location, and can be seen in Figure 15 (No. 40). Both appeared to have survived the storm with no major failures, although the construction of the door of the first dome shelter was inadequate.



Figure 14. 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 (No. 43).



Figure 15. Dome shelter partially above-ground located in an EF-4 rated location (No. 40).

IV. Above ground

Eight above ground safe rooms were documented. Six had been tested, and it was noted that most of these safe room manufacturers proudly displayed their company name on their products. Figure 16 is an untested above ground storm shelter (No. 25) 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 safe rooms 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 doors did not appear to be tested units. One of these shelters (No. 49) is shown in Figure 17. Figure 18 shows a tested steel shelter (No. 46) that performed very well. Some above ground safe room owners still questioned if they were safe because they were not below ground.



Figure 16. An above-ground tested safe room that survived EF-4 wind speeds (No. 25).



Figure 17. An above-ground, concrete safe room that also served as a walk-in closet at an EF-2 rated location (No. 49). The concrete was tested, but the door was not.



Figure 18. Above-ground tested steel shelter that performed very well in an EF-3 rated location (No 46).

Recommendations

- 1) A list of every storm shelter and safe room indicating the GPS data taken at the shelter door location needs to be aggregated for local emergency responders. First-responders need to have a list of locations immediately available to begin searching for survivors. Directly following the event is a time-critical period, especially given the repeated observation of water infiltration into belowground shelters. Some municipalities have started such a list, however, not every storm shelter owner knows that it exists and the benefits of being added to it. The existence of the list needs to become public knowledge, although the contents of the list need to remain for emergency personnel use only.
- 2) Public information campaigns need to include three of the observations made on this deployment:
 - a. Disprove the myth that “only below-ground shelters are safe in severe tornadoes.”
 - b. Below ground shelters can be difficult for people of advanced age, or people with physical disabilities. Specifically, those handicaps that make traversing stairs difficult or manifest in situations of extreme stress.

Table 3. Documented storm shelters and their performance for the May 20, 2013 Moore, OK tornado.

Storm Shelter Performance Documentation for May 20, 2013 Moore, OK Tornado

No.	EF Rating	Shelter Type	Location	Tested	Manufacturer	Purchase Date	No. of Occupants	Occupant Type	Shelter Size (WxLxD)	Locks	Hinges	Vents	Shelter performance
1	2	in-ground	exterior	No				family	8' x 12'	3 - "sort of" (1" chain and 1/4" eyebolt)	3		Reasonable - vents blown away, door thickness and locks insufficient, approx. 18 ga door
2	4	in-ground	garage	No					3' x 7'-4" x 4'-5"	2 - chain			Good
3	2 @ house/ 4 for area	clam	exterior	No		"11-1-C"			6' x 8'	1	2	1	Good
4	2	in-ground	garage	No		already in home at purchase	5	2 adults, 2 children, 1 dog	3' x 7'-4" x 4'-5"	2			Good
5	2	in-ground	porch	No			10	adults and children	7'-2" x 7'-2" x 6'-11"	3 - (2) 1" chain, (1) latch			
6	1	in-ground	back porch	No			0		3' x 7'-4" x 4'-5"	1	2		Lost 1 vent, only 1 lock, not used, 4' of water at bottom
7	1	clam	exterior	Yes	Hausner?				6' x 8'	3	3		Good
8	2 @ house/ 4 across st.	in-ground	garage	No			9	4 adults, 4 children, 1 dog	3' x 7'-4" x 4'-5"	2	sliding		Good
9	4	in-ground	garage	Yes	Smart Shelter	2011	3	1 adult, 2 children	3' x 7'-4" x 4'-5"	2	sliding		
10	4	in-ground	garage	No					3' x 7' x 4'	2	sliding		
11	1	in-ground	back porch	No					3' x 7'-4" x 4'-5"	2- (1) latch, (1) chain	3	2	
12	3@house/ 4 for area	in-ground	garage	No					2'-2" x 5'-4" x 4'-2"	1 (improper)	sliding		Ok
13	3	in-ground	garage	No					3' x 7'-4" x 4'-5"		sliding		
14	2	in-ground	backyard	No			0		6' x 14' x 7'	3		2	6" of water inside
15	2	in-ground	garage	No			3	3 adults	2'-2" x 5'-4" x 4'-2"	1 (improper)	sliding		Ok
16	2	in-ground	garage	No			8	3 family, 3 neighbors, 2 dogs	3' x 7' x 4'-6"	2	sliding		
17	2	clam	exterior	No					5' x 7' x 6'-6"	3		1	Good - 1" of water
18	1	above-ground	garage	Yes	Ground Zero	Apr-13	4	3 adults, 1 child, pets	4' x 6' x 6'-6"	4 - slide bolts	4	covered vents	Good
19	0												unconfirmed
20	2	clam	exterior	No					6'-3" x 8'-3"	1 lock	2	2	
21		in-ground	garage	No			0		3' x 7'-4" x 4'-5"		sliding		Good
22													unconfirmed
23													unconfirmed
24	2	above-ground	garage	Yes	Vortech	approx. 1 year ago	5	2 adults, 3 dogs	4' x 8' x 6'-6"	3 point lock			Good
25	4	above-ground	garage	Yes							7		
26	4	in-ground	garage	No					3' x 7'-4" x 4'-5"				

27	4	clam	exterior	No		"G 5-18"			6'-3" x 8'-3"	1 latch	2	2	
28	4	clam	exterior	Yes	Hausner?				6'-3" x 8'-3"	3 (Hanson)	3		Good
29	3	clam	exterior	Yes	Hausner				6'-3" x 8'-3"	3	3		Good
30	3	clam	exterior	No	Looks like Hausner		Possibly 2		6'-4" x 8'-4"	3	3	2	Good
31	4	in-ground	garage	Yes	Ground Zero				3' x 7' x 4'-6"	1			Good
32	0	above-ground	garage	Yes	Family Safe	2011	5	3 adults, 2 children, pets	4' x 6' x 7'	3 (epoxy set)			Good
33	0	above-ground	garage	Yes	Family Safe	Feb 2013	1	1 adult	4' x 6' x 7'	3 Schlage dead bolts	4		Good
34	0	in-ground	garage	No	possibly Storm Safe	2008	13	5 adults, 5 children, 2 dogs, 1 cat (neighbors and friends)	3' x 7' x 4'-6"	2 chain	sliding		Good
35	2												unconfirmed
36	1 (barely)												
37	3	in-ground	garage	Yes?	StormSafe				3' x 7'-4"	2 chain	sliding		
38	3	clam	exterior	No		"10-5-4"			6'-3" x 8'-3"	1	2	2	
39	4												unconfirmed
40	4	dome							7' diameter, 5' high	3 heavy duty gate locks inside			
41	4	clam	exterior	No		"2 5-3-01"			6'-3" x 8'-3"	1	2	2	
42	4	clam	exterior	No					6'-3" x 8'-3"				
43	3	dome	exterior	No					oval 5' x 7'	1	2	2	
44	3	clam	exterior	No		"5 5-8-01"			6'-3" x 8'-3"	1	2	2	
45	3	in-ground	garage	Yes	FlatSafe				2'-2" x 6' x 3'-4"	2 chain			
46	3 (high)	above-ground	garage	Yes	Ground Zero				4' x 6' x 6'	1 dead bolt			
47		in-ground	back porch	No					10' x 16' x 7'-2"	1 latch	2 (missing)	2	rusted, pins sheared off, door failed
48		clam	exterior	No		"5-17-03"			6'-3" x 8'-3"		2	2	
49	2	above-ground	closet	Yes - concrete, No - door					9'-8" x 9'-6"	3		2	
50	2	above-ground	closet	Yes - concrete, No - door					3' x 4'	3		0	
51	0	in-ground	garage	Yes	FlatSafe	2004	4	2 adults, 2 children	5' x 5'	2 chain			
52	0	in-ground	garage	Yes	FlatSafe	2008	2	2 adults	3' x 7'		sliding		
53		in-ground	back porch			2003	1	1 adult	10' x 10'			2	
54	1	clam	exterior	No		"9-12-09"			6'-3" x 8'-3"	1	2	2	

55		in-ground			Ground Zero							
56		in-ground	garage	No					3' x 7'-3" x 5'		sliding	
57		in-ground	garage	No					3' x 7' x 5'	2 chain	sliding	Good
58		in-ground	garage	Yes	StormSafe				3' x 7' door (padlocked)		sliding	2
59	0											unconfirmed
60	0	clam	exterior	No	Bullseye (maybe - Harrah, OK)	2001	9	7 adults, 2 children	6'-3" x 8'-3"	1 latch	2	2
61	0	in-ground	driveway	Yes	FlatSafe	2011	4		3' x 7' x 6'		sliding	

- c. Below ground shelters can begin to fill with water before the inhabitants can successfully operate the door to leave the shelter after the storm has passed.
 - d. Outdoor shelters must be maintained annually with rust removal and repainting.
 - e. Additional locking systems should be added to the existing shelters that only have one lock.
- 3) Following future events, a digital survey can be distributed to increase datasets for phenomena not requiring direct forensic investigation. Examples include: shelter age, reason for purchasing, federal programs owners participated in during purchasing, number of people sheltered, relations of those sheltered to the owner, how long before the event did occupants shelter, time spent in the shelter, and more. A sample survey has been generated using Google's Documents system and appended to this document. Utilizing an already existing, and easily accessible system like Google's will allow for rapid distribution of the digital survey, at a proper time, following any future event. The digital survey can also be done totally blind to maintain anonymity in respect to shelter owners who value privacy. Lastly, the digital survey will allow expedient data analysis of a sample set that can grow as the number of respondents increases.

Conclusion

The TTU May 3, 1999 Moore, OK storm investigation, along with the FEMA Mitigation Assessment Team, revealed the presence of numerous below ground shelters. Following the admonitions of local media, many residents fled their homes, two of which were killed seeking shelter under a local underpass (Miller, Doswell et al. 1999). One above ground shelter was observed in Dell City, OK standing on the lawn of Beth Bartlett, President Bill Clinton authorized the first FEMA Shelter Incentive Program. The Bartlett shelter can be seen in Figure 19. TTU investigation of the May 8, 2003 tornado led to the find of new below ground and above ground shelters constructed to the FEMA P-320 (1998).



Figure 19. Beth Bartlett and her mother standing inside her above ground storm shelter where they took cover during the May 3, 1999 tornado.

Investigations of the May 20, 2013 Moore tornado revealed an increase of population of exterior underground shelters, plus the popularity of a new in-garage floor underground shelter. Many of the shelters and shelter doors had been tested at the NWI Debris Impact Facility at TTU. Furthermore, numerous above ground shelters were observed, both constructed on site, and prefabricated steel units.

A representative sample of 61 shelters of a possible 200 shelters included in three databases was observed and studied. All three types of shelters, exterior below ground, in-garage floor, and above ground shelters experienced various EF storm strengths, including EF-4, leading to no loss of life.

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Appendix

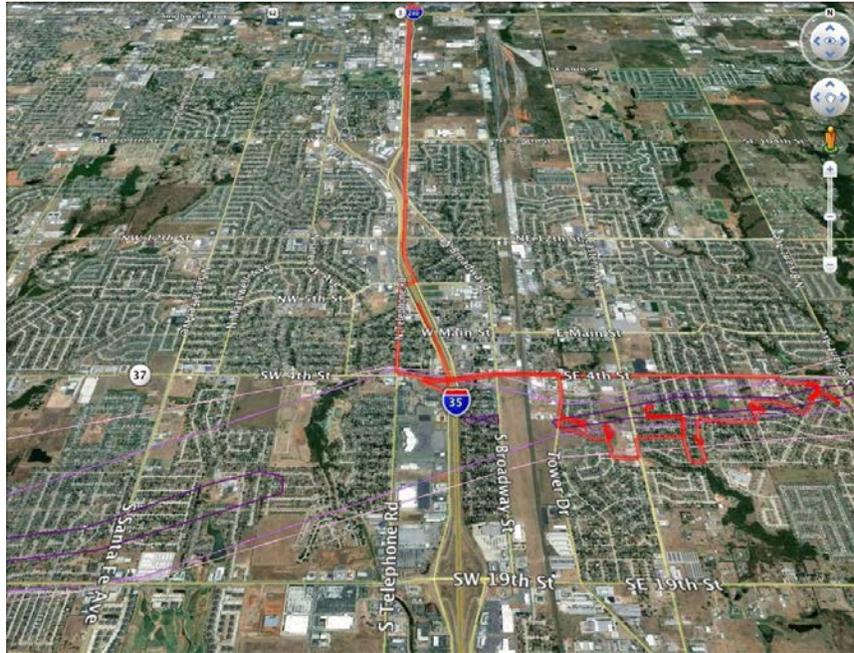


Figure 1. GPS tracking of storm shelter observation trail from Sunday May 26, 2013.

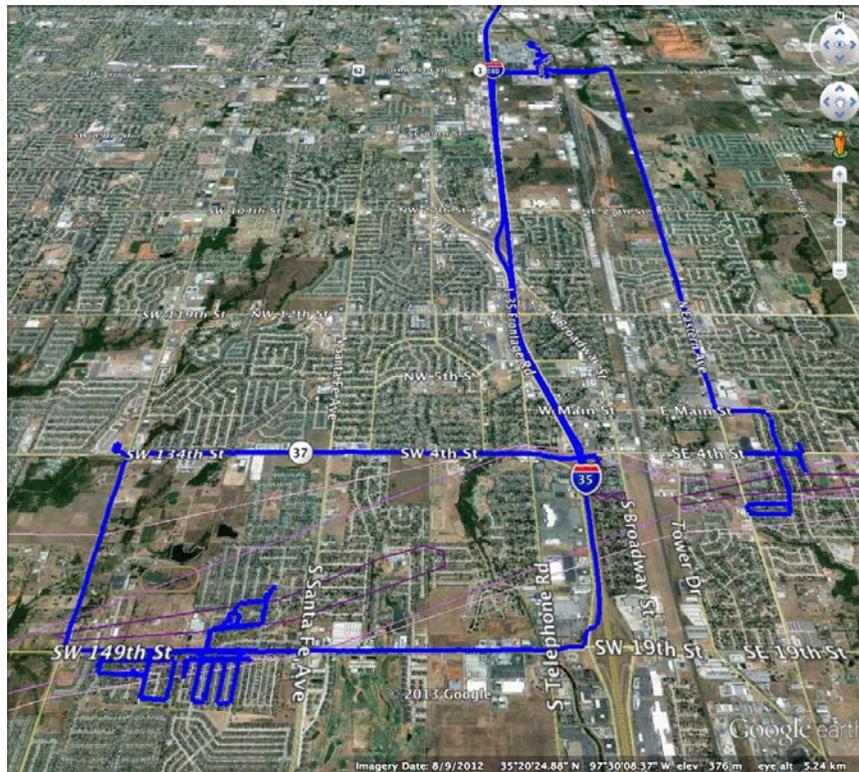


Figure 2. GPS tracking of storm shelter observation trail from Monday May 27, 2013 (Incomplete because the GPS receiver lost power at some point near the end of the day).

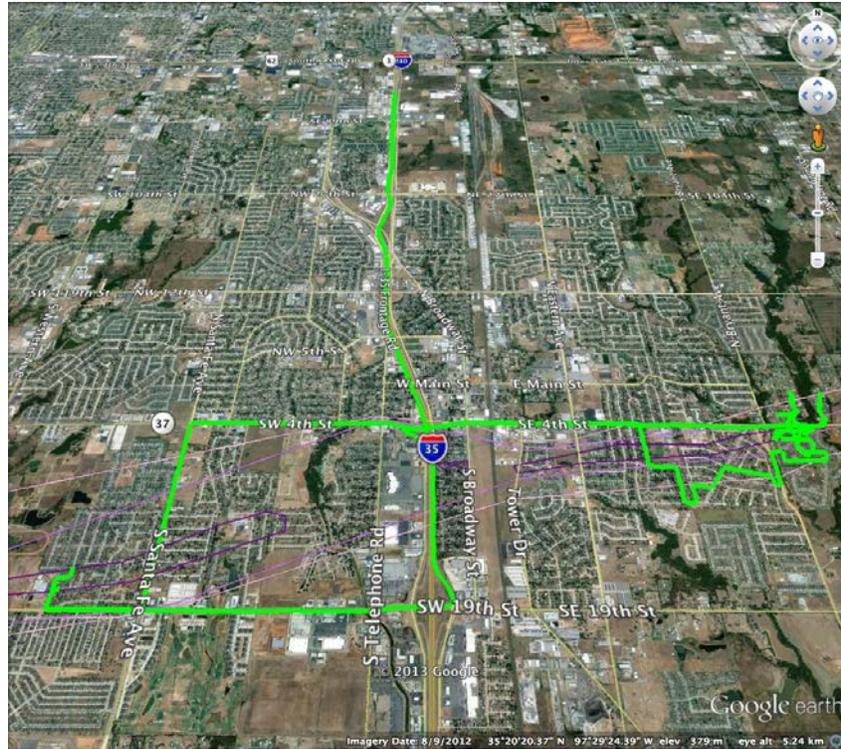


Figure 3. GPS tracking of storm shelter observation trail from Tuesday May 28, 2013.

Damage Documentation Form

IMPORTANT: Be sure to inform the owner that all information will be kept anonymous. Tell them you will not disclose their name, their address, or any personal information about them or their property.

* Required

1. Physical Address *

.....

2. Database Identification

Mark only one oval.

- FEMA
- NSSA
- OK Sooner Safe Room
- n/a (i.e. Discovered)

3. Database Identifier

.....

4. Longitude *

.....

5. Latitude *

.....

6. Did you purchase this shelter *

Mark only one oval.

- Yes
- No
- Not Sure
- Other:

7. Year Purchased or Installed

.....

8. Shelter Type

Mark only one oval.

- Above Ground, Inside
- Above Ground, Outside
- Below Ground, Inside
- Below Ground, Outside

9. Width (ft)

.....

10. Length (ft)

.....

11. Depth (ft)

.....

12. Depth (ft)

.....

13. How many people were in your shelter during the tornado?

.....

14. Relation of people sheltered to the owner

Check all that apply.

- Family
- Friends
- Neighbors
- n/a

15. How much warning did you have (minutes)?

.....

16. How long before the tornado did you shelter (minutes)?

.....

17. **Did your neighbors know about the shelter before the tornado?**

Mark only one oval.

Yes

No

Not Sure

n/a

18. **Did you take part in a shelter rebate program?**

Mark only one oval.

Yes

No

Not Sure

n/a