Online Damage Report

The 6 May 2015 Great Plains Tornado Outbreak and Flooding

Underground Storm Shelter Lifted out of the Ground Due to Heavy Rainfall
(Image Courtesy: KOCO News)

University of Florida's Wind Hazard Damage Assessment Team

PI: David O. Prevatt, Ph.D., PE, dprev@ufl.edu

Contributing Authors:
Austin Thompson
David Roueche
Malcolm Ammons
Jeandonna Doreste

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E·S·S·I·E
Engineering School of Sustainable Infrastructure & Environment

Gator Engineering
University of Florida

Wind Hazard Damage Assessment Team
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Executive Summary

On May 6th 2015, a severe weather outbreak that produced a combination of tornadoes and flash flooding caused severe damage to buildings in Oklahoma, Kansas, and Nebraska. The media reported on one fatality in Oklahoma City, Oklahoma where a woman drowned in an underground cellar. There were also reports that in some flooded areas several storm shelters uplifted out of the ground during the intense 5- to 7 in. rainfall event. This WHDAG report examines the issues with the design of storm shelters from a multi-hazard perspective, as was intended by the current shelter design codes.

The appropriate location of tornado shelters continues to be a point of contention for some. Following the 2013 Mayflower, Arkansas tornado (see our Mayflower Tornado (WHDAG) 04/27/2013 report) in which a fatality occurred within an above-ground storm shelter, opinions in the media suggested that in future all storm shelters should be built below ground. It is not too far-fetched to hear an opposite opinion discussing the merits of having only above-ground storm shelters.. Thankfully, there is another approach, that of relying upon rational engineering design as is advocated in shelter design documents and press releases by the Federal Emergency Management Agency (FEMA), the International Code Council (ICC) and the National Storm Shelter Association (NSSA). These organizations propose approaches that structural engineers use every day to consider all risks and hazards in the structural design of buildings.

This report provides some perspective on the storm shelter design in order to provide the safest option for residents whether or not above- or below-ground shelters are used. Multi-hazard events at the level of the May 6th 2015 event are rare, particularly when considering the probability of impacts to a single home. These are the conditions that properly designed storm shelters are made to address – there should be no compromise with life safety, particularly when it could be ensured by straightforward, rational choices in the choice and installation of storm shelters.

The most practical approach to life safety in a natural hazard is identify the regional risk (of extreme winds and rains from tornadoes and accompanying severe storms), local risks (of flooding in low-lying areas) and to design a shelter based on the appropriate risk. While individually the risks are low, there is greater likelihood of flooding when a thunderstorm occurs. Design standards for storm shelters, such as FEMA P-361 and ICC 500, make it clear that underground storm shelters are not to be installed in flood plains and sufficient anchorage (or ballast) is needed to hold down the shelter in place against buoyancy forces that will attempt to lift it out of saturated soil in flooded conditions.

Our preliminary observations are presented in a general sense to clarify some issues and they are not intended to directly relate to the failures of underground storm shelters reported in the media last week. Still, we examine possible scenarios and develop an hypothetical engineering analysis using available facts collected from online sources and input from forensic engineers. The information is provided so that others may use this in further engineering analysis later as information becomes available.

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About the Wind Hazard Damage Assessment Team

This report was prepared from online sources by University of Florida civil engineering students in Prof. David O. Prevatt's Research Group. The study is done in parallel to our experimental research seeking to understand and quantify the strength of tornadoes and their impact on vulnerable wood-framed residential structures. Compilation of this information is part of student learning objectives in forensic engineering and post-disaster damage investigation.

The students gathered the information from reliable online sources, such as the National Weather Service, Accuweather, FEMA, the US Census Bureau and the national media. Photographs were also obtained from publicly available Twitter feeds.

Please visit our website, http://windhazard.davidoprevatt.com, for additional information, and to download previous damage reports, and filed survey results conducted by our group. Dr. Prevatt and his colleagues have published several papers on recent violent tornadoes that struck Tuscaloosa, AL, Joplin, MO, and Moore, OK. His group has also inspected damaged structures and compiled reports on tornadoes that occur in Florida. Information is also available on the research at www.davidoprevatt.com. Your questions and comments on any aspects of our work are most welcome. Please direct your enquiries to PhD Graduate Student, Mr. Austin P. E. Thompson, who can be reached at a.thomp@ufl.edu. Mr. Jeandona (JD) Doreste, is a civil engineering undergraduate student at UF and Webmaster of the Wind Hazard Damage Assessment Team site. JD is actively recruiting other UF students to join the team, and he can be reached at jdoreste1@ufl.edu.

The Wind Hazard Damage Assessment Team was created through support from the NSF Award #1150975. Its mission is to train university students interested in building construction, engineering and architecture in the forensic engineering and techniques for post-hazard damage surveys and data collection. The team has surveyed damage after several Florida tornadoes and continuously monitors the prevalence of tornadoes worldwide. Ultimately the Damage Assessment Team hopes to inspire upcoming engineers and building professionals in hopes to change the paradigm of widespread catastrophic damage to houses in tornadoes and other extreme wind events.

Forecasts and Predictions

The first outlook for tornado probability issued on May 6th identified a large region from Texas to Nebraska as having the potential for tornadoes within 25 miles. In the 4:30 UTC update, shown in Figure 1, this region remained largely the same, however the potential for strong tornadoes in central Kansas was identified. Just over 4 hours later, the potential for strong tornadoes was realized as the NWS issued a tornado emergency in the Oklahoma City area after there were several reported tornadoes of which the first struck Roseland Nebraska at 4:22 PM CDT.

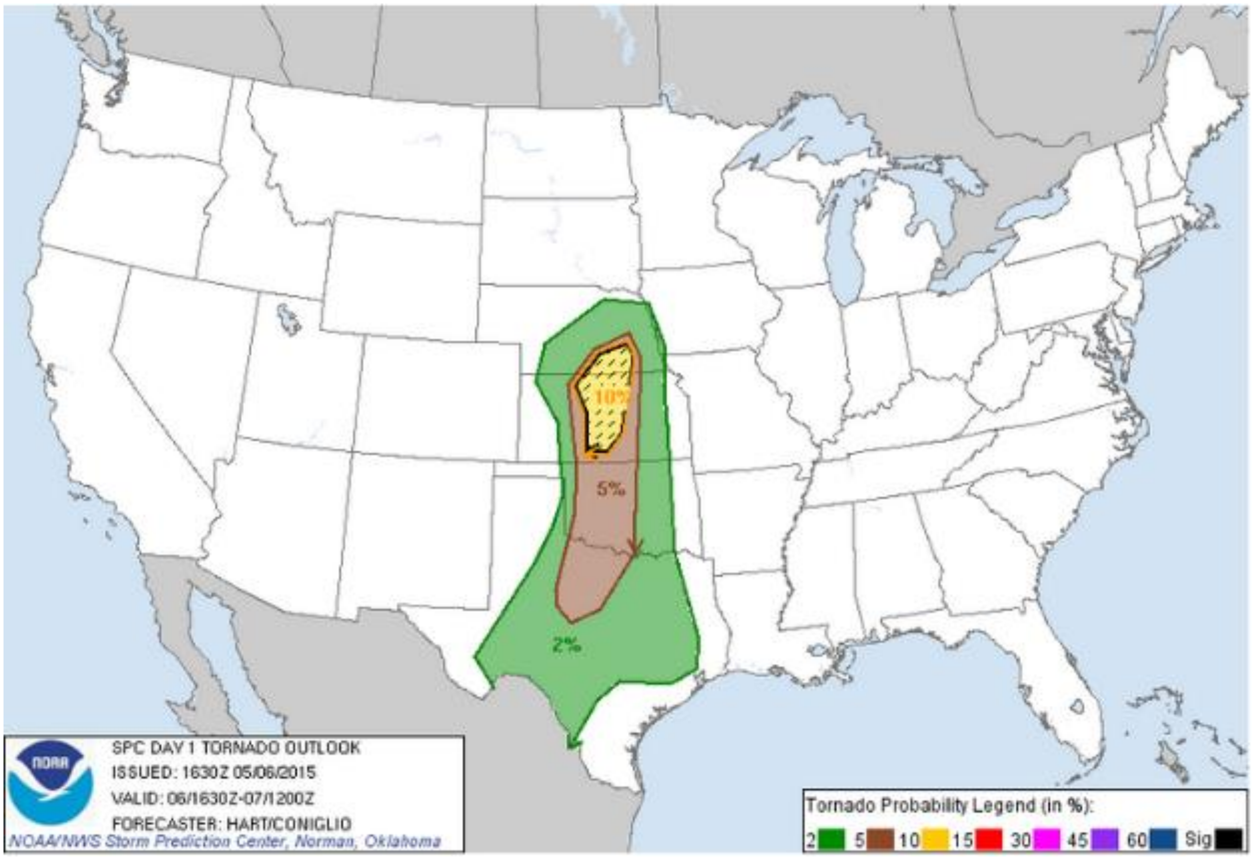

Figure 1: Tornado Probability for May 6, 2015 as Issued by NWS SPC at 11:30 AM CDT. The outlook was similar to those earlier in the day but identified a hatched region primarily located in central Kansas with a 10% or greater probability of EF2-EF5 tornadoes

Timing of Outbreak

The timeline of the tornado outbreak as it formed is given below. All times are Central Standard Time.

11:30 AM – SPC identifies region in central Kansas and Nebraska as having potential for strong (EF2-EF5) tornadoes.
04:22 PM – Tornado hit Hastings, NE
05:02 PM – Large tornado reported near Bridge Creek, OK
05:30 PM – The National Weather Service issued a tornado emergency for the Oklahoma towns of Newcastle and Bridge Creek, on the edge of the Oklahoma City area.
05:34 PM – "Large and extremely dangerous tornado" was reported near Scandia, KS

05:45 PM – A storm that produced tornadoes across parts of southwestern Oklahoma approached suburban Oklahoma City during the evening rush hour. Forecasters declared a tornado emergency for Moore, OK.

06:00 PM – Trained spotters confirmed a large tornado near western Norman, Oklahoma.

06:20 PM – The terminal at Will Rogers World Airport in Oklahoma City had to be evacuated as strong storms that produced tornadoes approached the area.

07:00 PM – A line of severe storms passed through Kansas, producing at least nine tornadoes.

09:45 PM – A flood emergency was been declared in Oklahoma City after storms dumped several inches of rain. A flash flood warning was in effect for parts of six counties in central Oklahoma until 9:00 a.m. Thursday.

Tornado Impacts

A summary of the primary towns and cities impacted by the tornadoes during the May 6 outbreak is given in Table 1. A preliminary map of the confirmed tornado tracks is provided in Figure 2.

<table>
<tr><th colspan="12">Table 1: Summary of Towns and Cities Impacted by Tornadoes</th></tr>
<tr><th>State</th><th>City</th><th>Population</th><th>EF Rating</th><th>Est. Peak Wind (mph)</th><th>Path Length (miles)</th><th>Path Width (yds)</th><th>Injuries</th><th>Fatalities</th><th>Buildings Damaged</th><th>Buildings Destroyed</th></tr>
<tr><td>NE</td><td>Roseland</td><td>248</td><td>EF1</td><td>110</td><td>3.85</td><td>300</td><td>0</td><td>0</td><td>>10</td><td>3</td></tr>
<tr><td>NE</td><td>Hardy</td><td>159</td><td>EF2</td><td>122</td><td>20.6</td><td>400</td><td>0</td><td>0</td><td><5</td><td>0</td></tr>
<tr><td>KS</td><td>Lincoln</td><td>3,174</td><td>EF0</td><td>75</td><td>8.5</td><td>100</td><td>0</td><td>0</td><td>N/A</td><td>N/A</td></tr>
<tr><td>KS</td><td>Mt. Hope</td><td>816</td><td>EF3</td><td>150</td><td>15.5</td><td>300</td><td>1</td><td>0</td><td>N/A</td><td>N/A</td></tr>
<tr><td>OK</td><td>Bridge Creek</td><td>336</td><td rowspan="2">EF2</td><td rowspan="2">130</td><td rowspan="2">10</td><td rowspan="2">1300</td><td rowspan="2">52</td><td rowspan="2">1</td><td rowspan="2">N/A</td><td>25</td></tr>
<tr><td>OK</td><td>Amber</td><td>430</td><td>10</td></tr>
<tr><td>OK</td><td>Norman</td><td>118,197</td><td>EF1</td><td>100</td><td>3</td><td>700</td><td>0</td><td>0</td><td>N/A</td><td>N/A</td></tr>
<tr><td>OK</td><td>Oklahoma City</td><td>610,613</td><td>EF2</td><td>130</td><td>1.3</td><td>400</td><td>12</td><td>0</td><td>N/A</td><td>N/A</td></tr>
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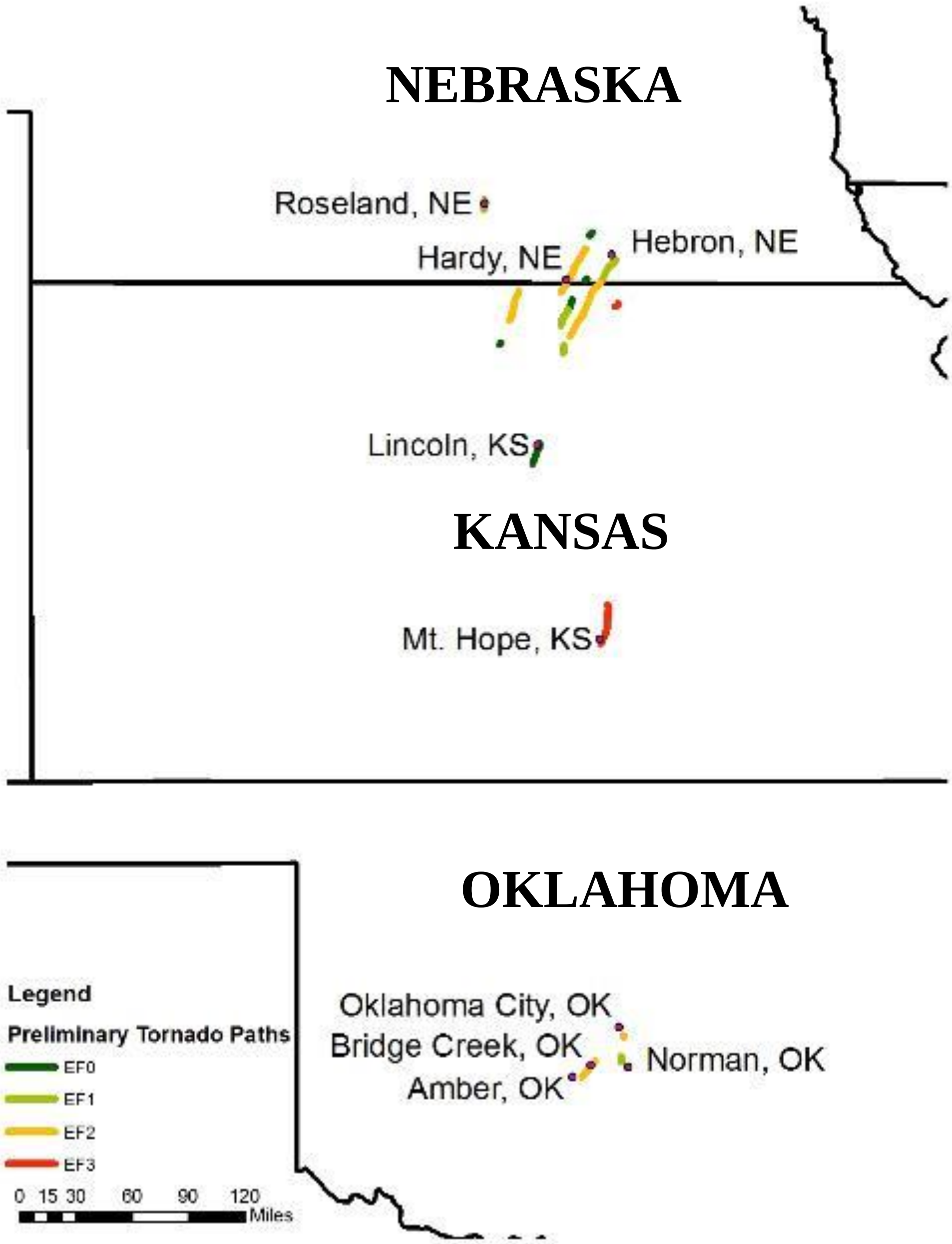

Figure 2: Preliminary May 6 Tornado Tracks in Oklahoma, Kansas and Nebraska
(Source of Track Data: NWS Damage Assessment Toolkit)

Summary of Damage

Kansas

Strong to severe thunderstorms affected portions of Central and South Central Kansas, mainly west of I-135 during the late afternoon and evening hours of Wednesday, May 6th. The severe weather occurred along and east of a dry line ahead of large storm system over the western United States. At least ten individual tornadoes have been confirmed by the National Weather Service in Kansas from the May 6 storms. The first tornado developed in Lincoln County about 7 miles southwest of Lincoln, KS causing EF0 damage south and east of town. An EF3 tornado developed near Mount Hope, KS and an EF2 tornado developed in the northern regions of the state, crossing the state line into Nebraska near Hebron, NE. Fortunately the majority of the region impacted by the strong tornadoes were rural, and no towns sustained direct impacts and no injuries or fatalities were reported. Most of the damage was sustained by farm buildings and homes on the outskirts of towns. However the damage to several homes was substantial, as shown in Figure 3.

Figure 3: Damage to House NE of Mount Hope (Source: NWS)

Oklahoma

The Oklahoma City metro area was again impacted by tornadoes on May 6, 2015. A large, violent tornado developed near Amber, OK and tracked along I44 near Bridge Creek, OK following a similar path to the 1999 F5 tornado. Fortunately the tornado dissipated before reaching Oklahoma City, although another smaller tornado formed from the same system and caused EF1 damage over a brief path in Norman, OK. A separate tornado did cause EF2 damage over a 1.3 mile path in downtown Oklahoma City, developing near southeast 56th street and Eastern avenue and moving northwest to West of interstate 35 and Southeast 44th street within the city limits of Oklahoma City. Due to the tornado threats, the terminal at Will Rogers World Airport in Oklahoma City was evacuated twice on Wednesday night. Several hundred people were moved into a tunnel beneath the terminal and were allowed to return to the terminal 1 hr. later.

Figure 4: Damage to the façade of the Norman Hotel in Norman, OK, indicated by the red circle. It is unclear what specific material is used for the façade. (Source: Weather Channel)

Figure 5: Roof removed from wood-frame structure near Chickasha, OK (Source: WSB-TV). Homes across the street are relatively undamaged.

Figure 6: Garage failure of wood-frame structure near Chickasha, OK (Source: WSB-TV)

Figure 7: Apartment building damaged in Oklahoma City, OK. Most of the roof and much of the walls in the top story were removed. (Source: KFOR-TV).

Nebraska

Several tornadoes were confirmed in Nebraska, with the heaviest damage occurring near Roseland, NE, a small rural town of fewer than 250 people. The tornado path was reported to be 3.85 miles long with a maximum path width of approximately 900 feet. Widespread damage occurred on the eastern side of Roseland. While several homes sustained damage, two homes sustained considerable damage. One of those homes slid from its foundation and another lost its entire roof structure. A large metal building with wood post frame construction was destroyed and tree damage was widespread throughout town. The tornado traveled just a few hundred feet east of Silver Lake School.

Figure 8: A metal-clad building with wood post frame construction destroyed in Roseland, NE (Source: NWShttp://media.graytvinc.com/images/Roseland+Tornado.jpg)

Performance of Underground Storm Shelters

The May 6, 2015 tornadoes produced both extreme winds, large hail and torrential rains, which resulted in multi-hazard risks to residential infrastructure and storm shelters. For the preceding damage reports it appears the largest tornadoes reported were EF-2 in Oklahoma and EF-3 in Kansas, producing estimated wind speeds up to an estimated 150 mph. In addition, some areas around Oklahoma City experienced exceedingly high rainfall totals of 5 in. to 7 in. within a single 24-hour period, making it the third-highest 24-hour rainfall total on record (NWS Norman). Due to the heavy rains, the National Weather Service in Norman, OK issued its first ever Flash Flood Emergency for this area at 9:19 PM CDT on May 6 2015. The 24-hour rainfall totals from the NWS' Advanced Hydrologic Prediction Service are shown in Figure 9 and represent quality controlled, multi-sensor (radar and rain gauge) precipitation estimates. The maximum rainfall estimated in the official NWS dataset was 5.62 inches. The NOAA Hydrometeorological Design Studies Center gives the 100-year 24-hour rainfall total for Central Oklahoma to be 9.35 inches.

The historically high rainfall totals and flooding impacted a number of underground storm shelters in Oklahoma City and nearby towns. A fatality occurred in southeast Oklahoma City when a woman sought shelter in an underground cellar but was trapped by a surge of floodwaters. Three instances of storm shelters becoming buoyant and floating out of the ground due to hydrostatic forces were reported; one in Noble, OK, one in Mustang, OK and a third at a location unknown at the time of this report but in the general Oklahoma City region. Photos of the three shelters are shown in Figure 10.

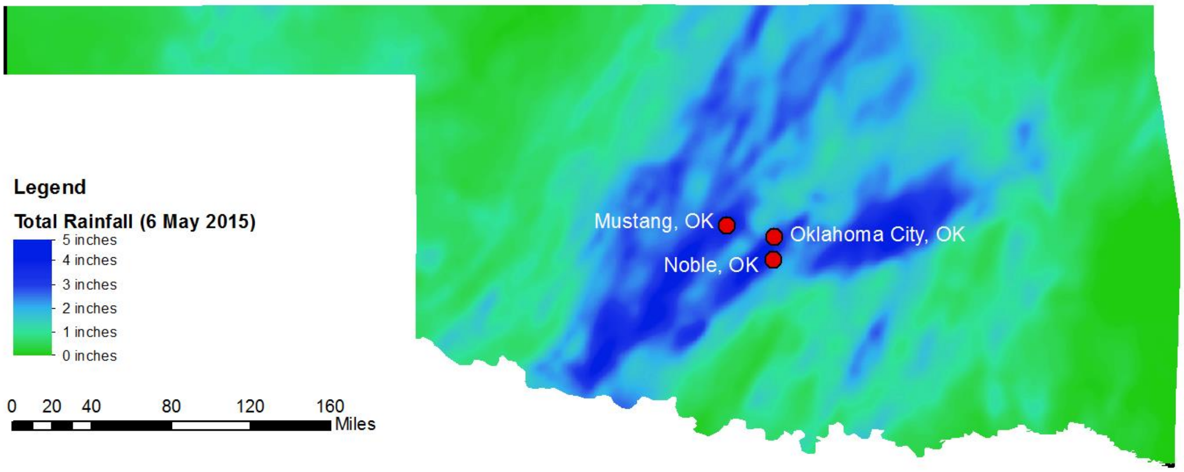

Figure 9: Estimated rainfall totals for 6 May 2015 in Oklahoma based on radar and rain gauges data gridded at 4 x 4 km resolution and interpolated in ArcGIS using universal kriging methods. All three locations of interested were located in regions which experienced some of the heaviest rainfall.

Only the exact location of the storm cellar fatality is known, and it is mapped in Figure 11 with the towns of Mustang, OK and Noble, OK along with the FEMA 100 year flood zones for this area. Without the exact locations of the storm shelters it cannot be determined whether they were located in a designated flood plain or not. The exact location of the fatality due to flooding of a storm cellar is known, and it was not located in a 100 year flood zone.

In addition to the flooded storm cellar which caused a fatality, there were several other reports of storm shelters flooding, forcing residents to abandon the shelters or not enter at all, even while tornado warnings were still in place. This placed residents in difficult situations, having no place of refuge even with tornadoes nearby. While in this case fortunately the tornado impacts were limited, the potential for combined flood and tornado hazards should be carefully considered in the choice and design of storm shelters. And from the anecdotal evidence provided here, the 100 year FEMA flood zones may not alone be adequate to determine whether flooding is a risk or not in every situation. In at least one area the flooding occurred outside the FEMA 100 year flood zones even though the 24 hour rainfall was less than the 100 year 24 hour rainfall total. This serves as a reminder that flood zones can change due to local site changes, construction or other circumstances and so good judgement should be used in determining whether underground storm shelters are suitable. A local water management official should be used as a resource if possible.

Despite the poor performance of the three storm shelters which are the focus of this report, it should be noted that there are at least 2,000 storm shelters in the Moore and Oklahoma City area, and despite widespread flooding and historical rainfall totals, only three reports of floating storm shelters were reported. Without knowing the exact location of the three floating storm shelters and any nearby storm shelters that remained in place, it is difficult to say with certainty whether these three shelters were truly an anomaly. But the indications are that overall, properly designed and installed storm shelters performed well even in a historical flood event, and the public should have complete confidence in such shelters. These shelter anchorage failures do serve as reminders of the importance of properly designing and installing storm shelters to withstand all hazards.

(a) This storm shelter was located in Noble, OK (OKCFox.com) and was installed in August 2014. It appears to be a steel storm shelter approximately 6 ft in height and covered with at most 1 foot of soil and sod. The water visible in the hole left by the shelter indicates that water table nearly reached ground level as the shelter lifted. The residents of the home were not in the shelter at the time it lifted. There is no evidence of any anchorage devices beyond the self-weight of the shelter itself.

(b) This storm shelter was located in Mustang, OK (KOCO 5 News) and also lifted during the heavy rains in Oklahoma on May 6. No details are available at this time on the shelter other than what is apparent from this photo. It appears to be a steel storm shelter also, about 6 ft in height, with minimal ground cover over the top. The residents were not in the shelter as it lifted and no anchorage devices are observable. The shelter appears to rely on self-weight alone to resist the buoyancy forces of the rising water.

(c) This is an indoor underground storm shelter located in S.E. Oklahoma City, OK (KOCO 5 News, Damon Lane). The shelter appears to be structurally isolated from the concrete slab foundation of the garage. No evidence of anchorage is visible, but more photos would be needed to fully ascertain this fact. The photo was taken May 10th, after several more days of heavy rainfall in the Oklahoma City, OK area.

(d) Aerial view of the home and accessory building where a woman was trapped inside an underground storm cellar and killed. The entrance to the cellar was located at the front of the building highlighted in red. Note the pond adjacent to the storm cellar location. The home was located near the intersection of S Midwest St and SE 164th in Oklahoma City, OK (KOCO 5 News). The cellar does not appear to be a designed tornado shelter in accordance with ICC 500 or FEMA P-361.

Figure 10: Three storm shelters came out of the ground in the Oklahoma City, OK region due to the heavy rains. (a) and (b) occurred on May 6, (c) occurred on May 10. (d) is the location of the fatality in an underground storm cellar that also occurred on May 6.

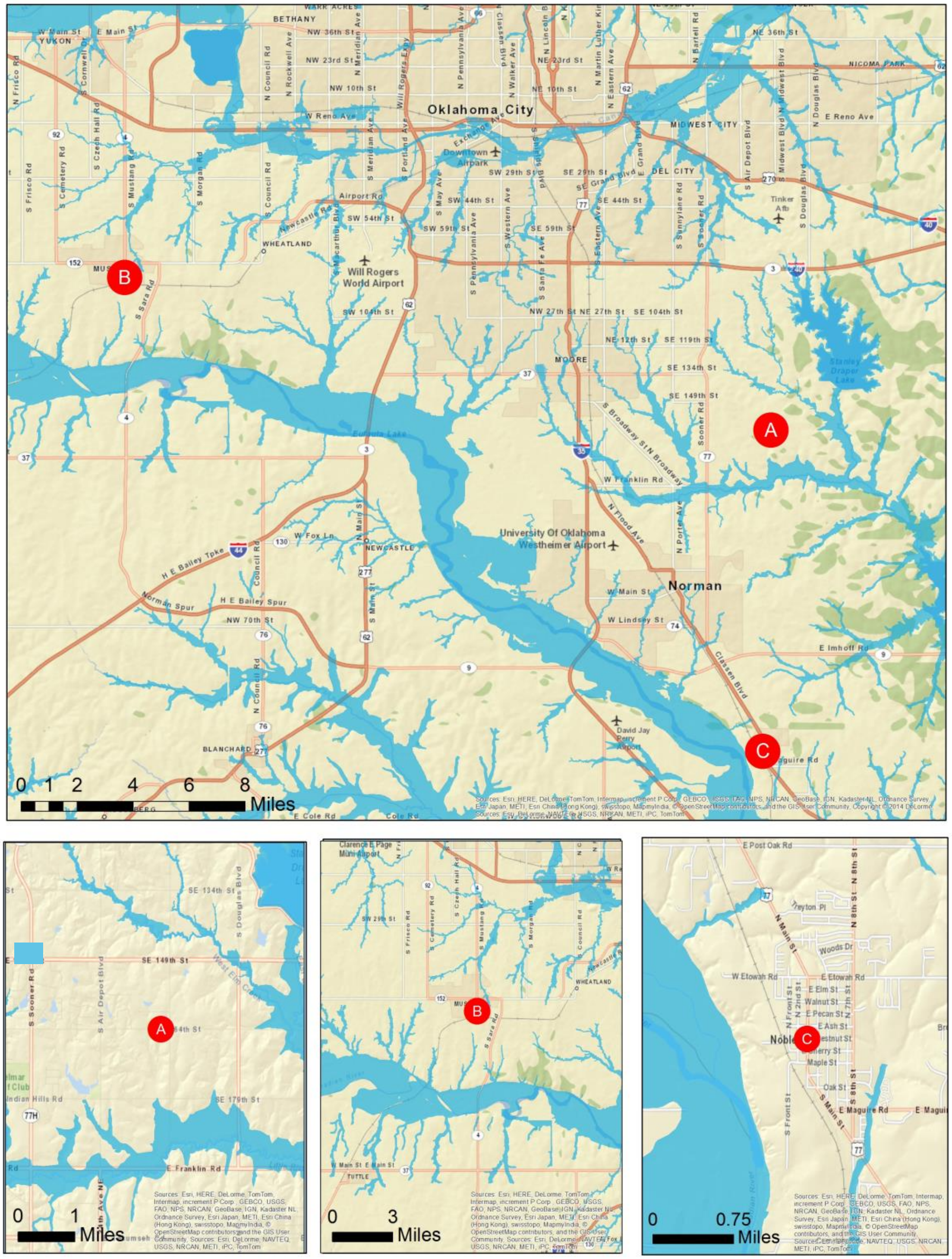

Figure 11: FEMA 100 year flood zones near Oklahoma City, OK (indicated by blue fill). (A) is the specific location of the fatality caused by flooding of underground storm cellar. (B) is the general location of Mustang, OK where a floating storm shelter was reported. And (C) is the general location of Noble, OK where another floating storm shelter was reported.

Consideration of Flooding in Storm Shelter Design

Flooding and buoyancy forces are both a consideration in storm shelter design standards, specifically ICC 500 Standard for the Design and Construction of Storm Shelters (2008 and 2014). Section 303.3 states that

> *"Underground portions of storm shelters shall be designed for buoyancy forces and hydrostatic loads assuming that the groundwater level is at the surface of the ground at the entrance to the storm shelter, unless adequate drainage is available to justify designing for a lower groundwater level." ICC 500 Section 303.3 (2014)*

Elevation requirements in Chapter 4 also require that the lowest floor used for the occupied shelter area of a residential tornado shelter be elevated to or above the higher of the elevations determined by:

> *1. The flood elevation corresponding to the highest recorded flood elevation if a flood hazard study has not been conducted for the area; or*
>
> *2. The minimum elevation of the lowest floor required by the authority having jurisdiction for the location where the shelter is installed.*

Based upon the siting requirements, underground tornado shelters should not be located in flood zones. Whether any of the storm shelters/cellars considered here were improperly sited is not known until the exact locations are obtained. Regardless of location however, the requirements of Section 303.3 still stand, and anchorage must be provided for underground storm shelters to resist the buoyancy forces present when the water table rises or if saturated soil envelopes the shelter. If friction forces are neglected, the forces on a simply shaped underground storm shelter are as shown in Figure 12. Note that if stairs are present, as is typical for underground storm shelters, the projected area of the stairs would also add to the buoyancy forces.

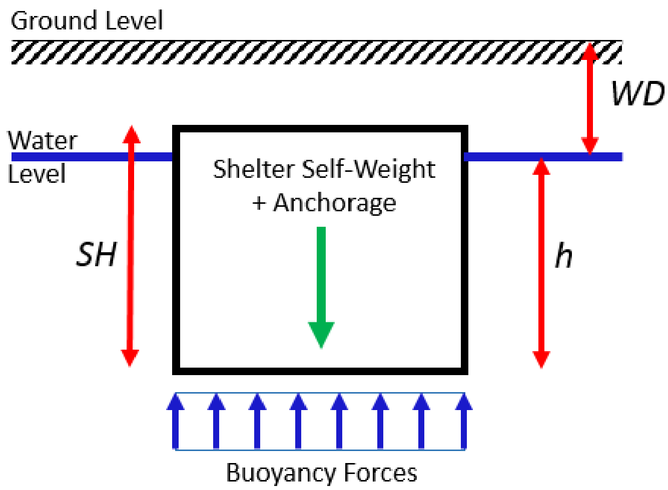

Figure 12: Simple force diagram for an underground storm shelter ignoring lateral and friction forces. (*WD*) is the depth from ground to the water level, defined here as the water table or surface of saturated soil enveloping the shelter; (*SH*) is the height of the storm shelter; (*h*) is the distance from the water level to the bottom level of the storm shelter.

The buoyancy forces estimated as weight of water displaced by the shelter volume that is below the water level, defined here as the water table or surface of saturated soil enveloping the shelter, as

$$F_B = \delta_w * h,$$

where δ_w is the density of water (62.4 pcf) and h is the distance from the water table to the bottom level of the storm shelter.

The force resisting this buoyancy force is partially provided by the self-weight of the storm shelter and other details that increase the load. Shelter manufacturers often hire structural engineers to perform engineering calculations to estimate the loading and to develop construction details for their storm shelters. We found several values on storm shelter manufacturers' websites, and when these are normalized by the area of the storm shelters themselves, the self-weight forces fell between 200 psf and 300 psf (9.6 to 14.4 kPa). This range was material dependent, for concrete and steel shelters. Some storm shelters built with lighter materials (such as Kevlar or fiberglass), included attachment points for adding concrete blocks as ballast to increase the weight of the entire system. Therefore without anchorage, and with the simple assumptions already stated above, the relationship between buoyancy force and the dimension h is given in Figure 13 for several different shelter weights. The buoyancy force is normalized to the self-weight of the storm shelter, so that a value of self-weight to buoyancy pressure ration of 1.0 is critical. When the ratio is less than 1.0, the buoyancy forces exceed the self-weight of the shelter and additional anchorage would be required.

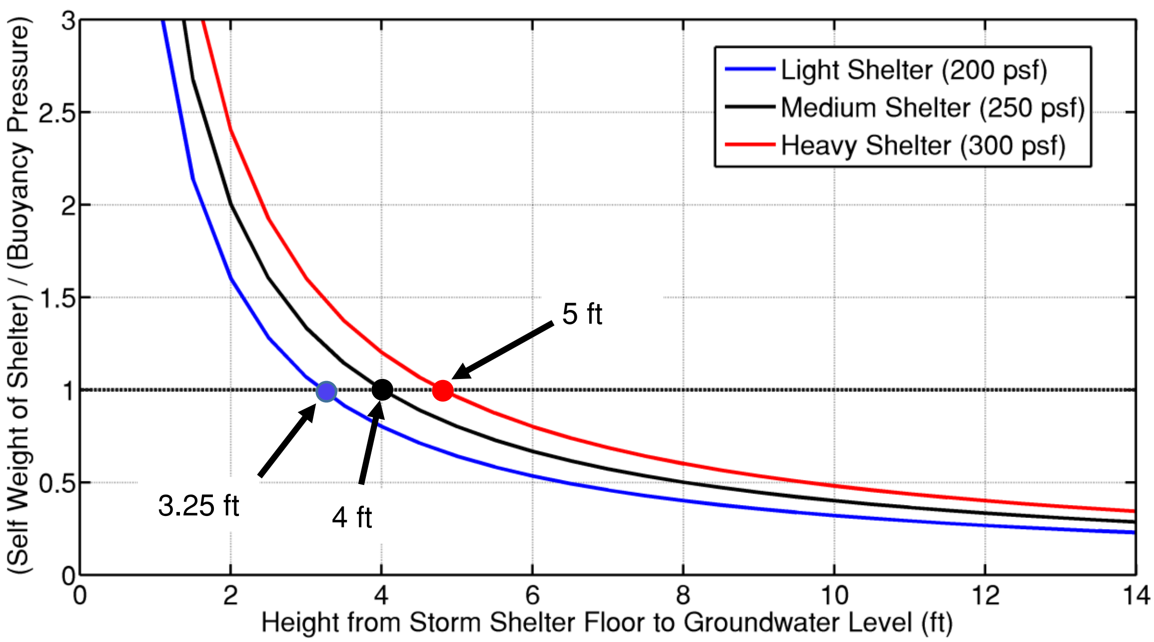

Figure 13: Critical distances from water table to storm shelter floor for light, medium and heavy storm shelters assuming a shelter height of 6 feet.

For storm shelters with self-weights between 200 and 300 psf, the water table need only be 3-5 feet above the floor of the shelter for the self-weight to be exceeded, triggering the need for additional anchorage and/or ballast to increase self-weight of the storm shelter. ICC 500 requires that underground storm shelter designs must assume that the water table is at the ground level, meaning that for a 6 foot high storm shelter, anchorage must resist the additional forces. This is exemplified for a series of cases below, assuming a 5ft wide x 5ft long x 6ft high steel storm shelter, which would appear to be similar to the storm shelters shown in Figure 10.

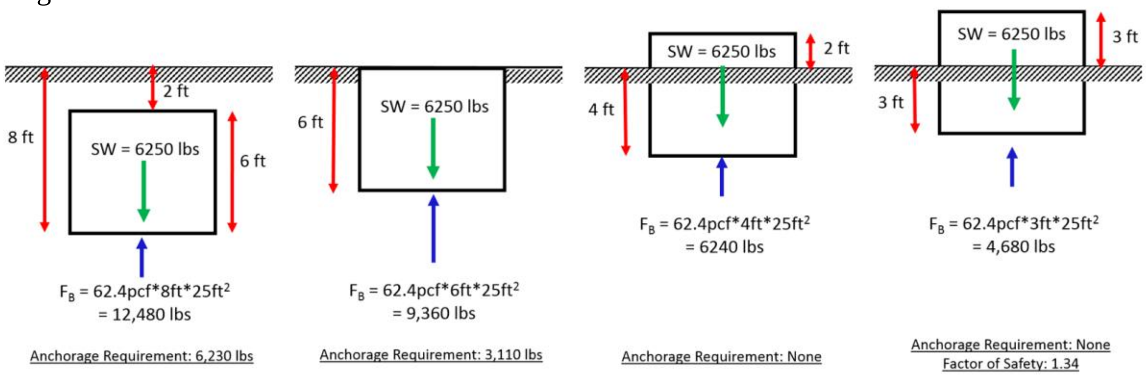

Figure 14: Anchorage requirements for underground storm shelters of various depths, assuming water table is at ground level (indicated by diagonal hatch) in accordance with ICC 500.

If ICC 500 Standards for the Design and Construction of Storm Shelters were used as a design basis, regardless of current water table existing at the time the shelter was designed, the underground storm shelters which lifted out of the ground appear to have been inadequately anchored. But a more in-depth analysis should be performed once more details are available to identify how similar failures can be prevented.

Summary

A tornado outbreak occurred on 6 May 2015 with multiple tornadoes confirmed in at least four states – Texas, Nebraska, Kansas and Oklahoma. While the overall impacts of this outbreak were minor compared to other recent tornado outbreaks of the past few years, there are still lessons to be learned. This WHDAG report focused mainly on the performance of storm shelters as a multi-hazard risk design challenge, combining historically high rainfall levels with extreme wind speeds (and debris impacts) generated by the tornadoes. The low levels of fatalities and injuries suggest that storm shelters provided and used in the areas are working to save lives. Indeed, a ballpark estimate of the numbers of storm shelters in the region shown in Figure 11 where the three storm shelter failures occurred at around 2000. The vast majority of underground shelters performed well   The Oklahoma population is sensitized to know when a tornado warning is issued, they should immediately seek shelter. However high water and flooding of some underground storm shelters would have prevented some residents from taking shelter within them. Tragically, one woman who sought shelter in an underground cellar in an older building on her property lost her life by drowning in the rising waters from the flooding. In three cases the hydrostatic lift forces were sufficient to cause three shelters to float up and rotate during the event. Other storm shelters had to be abandoned because they became flooded.

Storm shelters are to provide basic occupant life safety and so no fatalities or injuries should occur in the use of properly constructed and installed storm shelters, nor should flooding ever prevent the use of a shelter during severe weather. This high bar for storm shelters is necessary so that there is no doubt or delay in the users' minds on when to seek safety in a storm shelter. The best approach to provide this level of assurance is to have properly designed tornado shelters installed by contractors with experience in doing so. The design considerations include both wind forces and flooding issues, and neither of these can be ignored. The details of the construction and installation are of great importance, and homeowners are duly advised that the reputation of the storm shelter manufacturer, the engineering professional and the contractor must be stellar.

This report includes links to the NSSA, ICC and FEMA who can provide further details on the design and installation of safe tornado storm shelters. Every perceived shelter failure, whether or not they are due to construction and design errors raises concerns among communities facing a tornado warning. It is important to have a plan and know how to quickly get to a safe place of refuge during a tornado. While no engineering design provides an absolute level of safety against all magnitudes of hazards, storm shelters that follow published tornado storm shelter design criteria offer the best chance available to protect your family from injury or death. The availability of a properly designed and installed storm shelters, whether below ground or above ground offers peace of mind to owners and occupants of residential buildings in tornado-prone regions. For this reason we encourage thorough investigation of any issues related to the performance of storm shelters. It is equally important disseminate findings of such investigations widely among the public, and specifically in those communities likely to see further tornado activity during the spring of unsettled weather.

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NSAA (National Storm Shelter Association). News, training and resources about the choice, design and installation of storm shelters are available online at http://www.nssa.cc/.

About the PI

David O. Prevatt is an Associate Professor of Civil & Coastal Engineering, in the School of Sustainable Infrastructure & Environment, University of Florida, Gainesville, FL. He is a registered professional engineer registered in Massachusetts and in Trinidad and Tobago.

Peer-Reviewed Publications

Prevatt, D. O., Coulbourne, B., Graettinger, A., Pei, S., Gupta, R., and Grau, D. (2013). "Tornado of May 22, 2011 – Structural Damage Survey and Case for Tornado-Resilient Building Codes", 47 p. ASCE/Structural Engineering Institute, Reston, VA.

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