



Concrete Masonry Storm Shelter Design Guide

CMU-MAN-005-15



**MASONRY &
HARDSCAPES**

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Preface

Purpose of this document

The NCMA Education and Research Foundation program has provided a grant for the production of this document. The Foundation is dedicated to supporting research to better our codes and standards for masonry design and to promote interest in the use of concrete masonry as a building material.

The purpose of this document is to provide architects and engineers with information and guidance that will assist them in the decision-making and design process for utilizing concrete masonry as the primary structural wall element to resist the wind loads and debris impact produced by tornadoes and hurricanes.

The focus of this document is primarily masonry storm shelters for tornadoes however many of the same concepts can be utilized for protection against hurricanes. There are several differences between tornado and hurricane shelters that will be discussed in this document and further detailed information for hurricane shelters can be found in the FEMA P-361 (2015), and the ICC 500 (2014). Masonry has been proven a viable option for use on both tornado and hurricane storm shelters in the past and for years to come.

It is the intent to provoke thought and creativity all the while keeping designers going down the narrow path of shelter design, yes, narrow path. This document addresses many of the basic shelter design highlights but should not be construed a comprehensive guide that considers all shelter design scenarios, all code requirements, and/or all guideline requirements.

With storm shelter design, one is dealing with extreme forces that most architects and engineers are not accustomed to tackling in every day building designs. Storm shelters MUST withstand these forces and if designed incorrectly and/or constructed incorrectly, it could cost many individuals the ultimate price. Storm shelter design mistakes may not expose themselves until the occupants of that shelter need it the most and at that point, it is too late to remedy the situation. It cannot be stressed enough that if one has never designed a storm shelter before, seek assistance from an experienced storm shelter designer.

Corey Schultz, AIA
Schultz Squared Architects LLC
Wichita, Kansas



Introduction

Tornadoes-What are they?

Tornadoes come in many different shapes, sizes, and intensities. Their paths can be as little as a few yards wide up to 1-2 miles in width. They can be slow or fast moving, and they can be on the ground for a very short period of time with some extending for 20 to 30 miles in length. Tornadoes can form and grow in intensity very quickly. Typically, tornadoes are associated with thunderstorms called *supercells*, but we know very little about how tornadoes actually form. Tornadoes, sometimes referred to as “The Finger of God” accomplishes only two things; death and destruction. Whether it is plant life, animal life, humans, or the built environment, they wreak havoc on everything in their path. The National Oceanic and Atmospheric Administration (NOAA) defines a tornado, as “a narrow, violently rotating column of air that extends from the base of a thunderstorm to the ground” (NOAA, 2014). Many variables determine the make-up of any given tornado, some of which are not agreed upon in the meteorological world. These variables make prediction of exact locations and time of potential tornadic activity very difficult to pinpoint.

Geographical conditions play a big role in the formation of tornadoes. With the Rocky Mountains as a western barrier, the Gulf of Mexico providing moisture, and cool, dry air from Canada, tornadoes are most prevalent in an area commonly referred to as “Tornado Alley”. This area also known as the Great Plains typically has the most number and the most intense tornadoes (wind speeds and size) however, tornadoes have touched down in all the 48 Continental United States and have been documented in many countries all over the world. (NOAA, 2014) In the United States, tornados also frequent the Mississippi Valley, Great Lakes, Ohio Valley, Tennessee Valley, South Atlantic Coast, and Gulf Coast regions. They can occur at any time on any given day if the weather conditions are right. Large intense tornadoes can and do occur outside of Tornado Alley. Examples of this are the 1974 “Super Outbreak” which struck the Ohio Valley, Tennessee Valley, and the South Atlantic Coast regions and the 2011 Tuscaloosa-Birmingham, Alabama tornado. Tornadoes can also be associated with hurricanes. These tornadoes are typically smaller in size and intensity, but they can still be deadly.

The map below is a compilation of data for tornadic activity between 1950 and 2011,

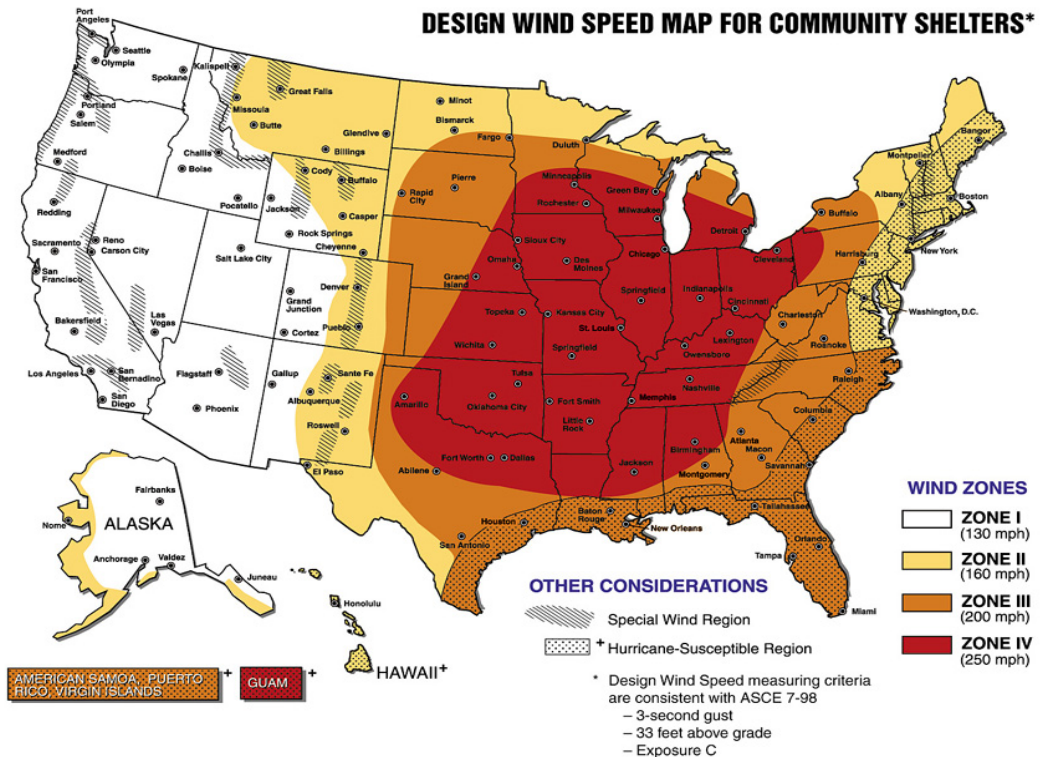


Figure 1-Design Wind Speed Map-Provided by FEMA

which provides designers a basis for design.

Who is Vulnerable to Tornadoic Events?

There are many who are vulnerable to tornadoic events. First, an individual being located in one of the geographical regions noted above, at the right time of the year, during the right time of the day can be at risk. Depending on the longitude and latitude, tornadoes can begin in February and run through November, which obviously is most of any given year. Secondly, those individuals or groups of people who are in a “transient” state i.e. away from very familiar surroundings where one can easily and quickly make educated choices as to their wellbeing in the event of a tornado. Examples could be in a hotel, at work, at school, in an airport, at a big box store, etc. These are locations where one is dependent on others to instruct them where to go in a tornadoic event. Finally, those that do not have access to a designed/engineered and/or tested storm shelter area specifically designed to withstand a tornadoic event whether or not you are in a transient state. If you live in one of the geographical regions noted above, are at home completely comfortable

and knowledgeable with your surroundings but you do not have access to a tornado shelter, then you are vulnerable.

The advances in radar technology have cut warning times of possible tornadic events to an average of approximately 13 minutes (NOAA, 2014). This warning time is crucial for the survivability of a tornadic event. Why? Because most people do not live/work/pray and/or play 24/7 in a building that is designed and engineered to withstand a tornadic event. If one has a shelter available to them, typically they have to travel some sort of distance, maybe a few feet to a few miles all of which takes time. So the longer the warning period, the better chance someone can make it to a storm shelter safely.

In some circumstances, data may be just as important to an organization as the people who work there. Along with employees, companies may elect to protect client files, servers, data backup, etc. That information that may not be easily replaced. So not all storm shelters are just for people.

What Can Be Done To Protect People?

Engineered storm shelters.

- In 1975, the TR-83A (TR-83A Interim Guidelines for Building Occupant Protection from Tornadoes and Extreme Winds) document was published. First of its kind, it assisted architects and engineers in designing tornado shelters. This document was created prior to the majority of the research in wind science that is utilized today. Subsequently, designers have the benefit of the FEMA P-361 (2015), FEMA P-320 (2015), and the ICC 500 (2014) for reference and assistance in designing storm shelters for both hurricane and tornadic storms. The FEMA P-361 is geared toward residential and community storm shelters, the P-320 toward residential and small business, and the ICC 500 toward both residential and community type storm shelters.
- FEMA has coined the phrase “near absolute” protection meaning that if you design, construct, and manage a storm shelter per the FEMA P-361 (2015) guidelines, then the occupants should have protection from a tornado or hurricane with little if any injuries and no deaths within the storm shelter.
- Storm shelters can be and have been designed and constructed of masonry to resist the forces of 250 mph winds in varying shapes and sizes to protect a single person up to a few thousand. These shelters can be designed to resist either hurricane forces, tornadic forces or both.

Community versus residential storm shelters

- The definition of a community shelter per FEMA P-361 and the ICC 500 is any shelter that is not residential.
- The definition of a residential shelter is any storm shelter with an occupancy of 16 or less serving dwelling units.
- Therefore, by definition;
 1. Any shelter serving a school or business for example is a community shelter regardless of the number of occupants.
 2. A storm shelter that serves an apartment building that serves 17 occupants is a community shelter.
 3. A storm shelter that serves an apartment building that serves 16 occupants is a residential shelter.
 4. A storm shelter that serves a single-family residence is a residential shelter.

Public use shelters

- If a storm shelter falls into the community category only means it is not a residential shelter. Whether it is a storm shelter that only serves a specific occupant group like an office building, or school or a storm shelter that is open for public use is the choice of the person or organization that owns and operates the shelter. For clarification, a community shelter does not have to be a public shelter but a public shelter must be considered a community shelter.
- There are numerous issues to consider when deciding to open a shelter to the public. The following are a few of the considerations:
 1. Who opens the shelter and when is it physically opened?
 2. What if the person delegated to open the shelter does not show up?
 3. Who operates the shelter?
 4. Who operates the protective devices that are an important part of the shelter's protective envelope?
 5. What are the rules of the shelter, and what if someone breaks the rules?
 6. Who is responsible if something goes wrong and people are injured?
 7. What happens if someone shows up with their pet; dog, cat, snake, lizard, etc.?
 8. How many occupants does the shelter need to be designed to accommodate?
 9. What if someone steals something from the shelter after the event is over?
 10. How does one account for the number of occupants and what if more people show up to use the shelter than what it is designed to accommodate?

If You Call It A Storm Shelter, It MUST Be A Storm Shelter!

If one was to ask a person, one not involved with designing or building storm shelters, “What defines a storm shelter?” The answers would be varied but many would say “A basement”, “A concrete box without windows”, “An interior space on the lowest level of a building”, etc. The fact is storm shelters come in many shapes, sizes, and materials many of which have utilized concrete masonry units for the wall structure. The problem to date, more in the realm of storm shelters for tornadoes than hurricanes, this is a highly unregulated market. Therefore, one can claim something as a “storm shelter” and it not meet any code standard and/or guideline and unfortunately may give little if any level of protection in a tornadic storm. It is truly a “Buyer Beware” market. This also applies to concrete masonry shelters. Masonry shelters must be engineered not only to withstand the debris impact created by a tornadic storm but it must also be designed to withstand the extreme wind loads associated with these type of storms.

In areas where tornadoes are prevalent, the public relies on building owners to have an actual storm shelter; and they depend on the design team to be competent and qualified to design a storm shelter properly for that owner. The public relies on the contractor and sub-contractors including masons to be craftsmen and build the storm shelter per the plans and specifications. If there is failure at any of these levels, it could cost someone their life. The public typically does not have time to research who designed or who constructed any given shelter, attempting to determine whether or not it has been designed and/or constructed properly when they are seeking shelter from a hurricane or tornado. They have to depend upon the building owner to instruct them where to go to seek shelter.

This is not a time for designers to be so creative that they lose site of the task. The purpose of a storm shelter is to keep someone safe in the event of a storm. If a designer pushes the proverbial “envelope” and potentially utilizes storm shelter structural elements or protective devices for which they were never intended, and it has happened, it could cost someone their life.

When the public occupies a storm shelter, their expectations are that they will survive the storm that is upon them. Again, they are solely dependent upon everyone involved in the design and construction of the shelter that in fact it is truly a storm shelter.

Design Items to Consider

Difference between a Storm Shelter and Safe Room

Previous versions of the FEMA P-361 and ICC 500 had different requirements. So in order to differentiate them FEMA elected to call their types of shelters “safe rooms” while the ICC 500 called them “storm shelters”. Prior to the 2014 versions of these documents the differences included but were not limited to community/residential shelter definitions, peer reviews, and some flooding issues. Today, the documents are very similar except for some flood issues. There is a matrix located in the FEMA P-361 (2015) appendix that denotes the differences between the documents.

In either case, whether it be a storm shelter or safe room, reinforced masonry is an accepted material for the walls of the shelter/safe room.

What Are The Key Differences Between Tornado And Hurricane Storm Shelters?

Wind Load Criteria

- The tornadic storm wind speed, generally speaking, is typically higher than with hurricanes. The 250 mph wind zone is much larger than the 225 mph hurricane zones that occur in limited areas along some coastal regions.

Missile testing protocol

- Per the ICC 500-2014¹ the testing protocol for storm shelters for tornadoes is a 15 pound, wood 2x4 propelled at 100 mph in the horizontal direction for vertical surfaces and 67 mph in the vertical direction for horizontal surfaces for the 250 mph wind zone.²
- The test missile for hurricane storm shelters is a 9 pound, wood 2x4 tested at 1/2 (.50) the design wind speed in the horizontal direction for vertical surfaces and 1/10 (.10) the design wind speed in the vertical direction for horizontal surfaces.

¹ Reference ICC 500, Section 305.1.1 and Chapter 8.

² Reference ICC 500, Table 305.1.1 for test missile speeds in other wind zones.

- It must be noted when considering materials, especially opening protective devices, the designer must understand which testing protocol has been utilized. Many manufacturers note their products are “storm resistant” but what does that actually mean? Items tested for the hurricane protocol typically will not pass the tornado testing protocol. Therefore, designers should understand that a tornado shelter item that is listed as “Miami-Dade County Approved”, may not work in a tornado shelter.

Duration

- The design duration for a tornado storm shelter is 2 hours while for a hurricane the duration is 24 hours. This difference has many effects on the human factors for storm shelters.
 1. Occupancy density is reduced in hurricane storm shelters due to the need for sleeping arrangements where tornado shelters with the shorter duration have no need for shelter occupants to sleep at the facility.
 2. Toilet facilities in hurricane shelters may require bladders for both fresh water and wastewater. Torrential rains, localized flooding, and/or storm surge can have major effects on water treatment facilities and therefore must be accounted for in hurricane shelters. The short duration of the tornado shelters minimizes the requirements for the same type of on site storage of water/waste.
 3. Food prep facilities may be required to prepare meals for the extended duration of hurricane shelter. Food prep creates refuse that also needs to be accounted for in hurricane shelters.
 4. Lighting in all storm shelters is an extremely important human factor for any shelter regardless of type and size. Lighting can be accomplished in a 2 hour period with battery backup type systems but can be difficult for the 24 hour duration of a hurricane shelter. Emergency power is critical in hurricane shelter to supply lighting as well as support for food prep facilities, communication systems, and ventilation systems.

Continuous Load Path, “The Golden Rule”

Continuous Load Path is “The Golden Rule” for storm shelter design. Think of this as a continuous chain that begins at the roof, continues through the roof/wall connection, through every masonry course, down through the wall/floor connection and into the

Continuous Load Path is “The Golden Rule” for storm shelter design.

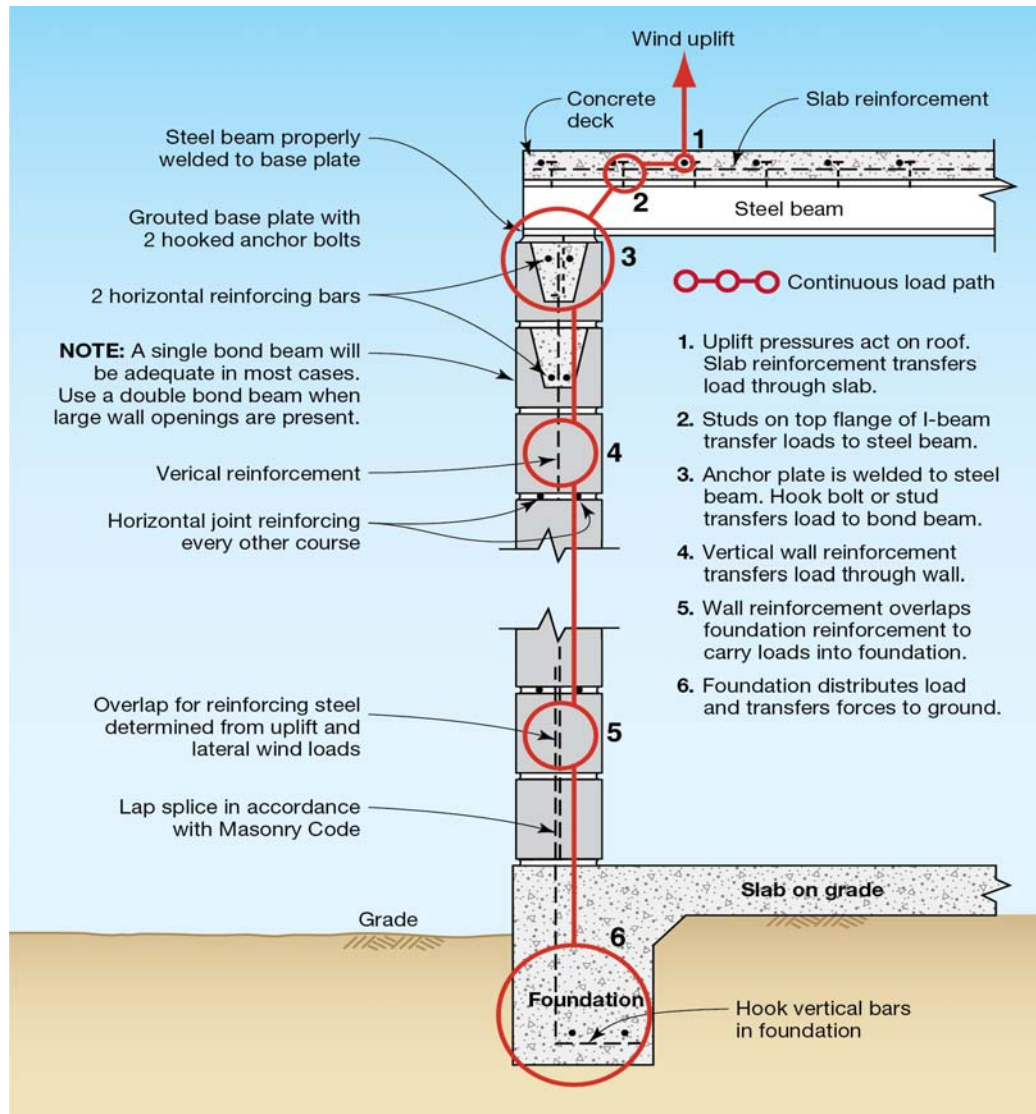


Figure 2 Continuous Load Path Diagram (provide by FEMA)

is to have a path to distribute load from one element into another until it reaches the foundation system. This MUST be accounted for in the entire shelter and it is not limited to the structure. This rule also applies to opening protective systems, doors, windows, and mechanical openings. With a door, the load moves from the door panels to the hinges/latches, into the door frame, through the frame anchors, into the masonry jambs down to the floor, and so on.

For designers, it is imperative that one comprehends this concept and can apply it to every decision that one makes during the design of the storm shelter. After all, a storm shelter is only as good as its weakest link.

Shelter Myths

There are many myths associated with storm shelters and the storms themselves. Many of these myths stem from the fact that there is a lot that we have yet to learn about storms and their effects on the built environment. Much research has been conducted but no one can answer why in a tornado, one building is destroyed and 6 feet away another appears to be untouched. Why a building may be all but destroyed except for a few walls and those walls have pictures still hanging on them. Why a pre-engineered metal building is all but destroyed by a tornado but the 16' high brick veneer over the metal building remains in place. There are many things that to date, we just do not understand about tornadoes so that leads to speculation and myths. Below are a few of those myths floating around out there.

- “NO STRUCTURE CAN SURVIVE AN EF-5 TORNADO!” On the contrary, there have been numerous documented cases of storm shelters that have survived direct hits from EF-5 tornadoes. Many of which were construction of concrete masonry units. Concrete masonry CAN be engineered to withstand the loads, both debris impact and wind loads. Reference the Structural Issues section for more information.
- “Tornado storm shelters must be below ground”. Most recently, during a major tornadic event, a local television station meteorologist made on air statement to those in the potential path of the tornado, “If you do not have an underground shelter then you need to leave NOW!” This statement has fueled this myth. The fact is storm shelters have been designed, engineered, and constructed above ground for many years.
- “Must be a Dark Concrete Box”. First of all, not all shelters are made of concrete. Concrete masonry construction has been used all over the country for both hurricane and tornado shelter alike. It is encouraged to make the storm shelter multi-use for day-in and day-out activities so shelter owners can get the proverbial “best bang for their buck”. If the shelter design allows, a shelter owner will use this space more for other activities rather than just for a tornado shelter. Fortunately, we do not experience tornadoes in any one given location every day, week, and year. Storm shelters can look and feel like any normal building space if designed correctly. And contrary to many beliefs, tornado shelters can have windows but the window openings must be protected with an engineered and tested assembly.

- “We only need the structural envelope”. Many designers believe that only the structural envelope needs to be addressed with storm shelters and no doubt, it is the prime component. However, the human factor issues are extremely important also. People deal with stress in many different ways. It is important to make sure that people are kept calm and comfortable so no one feels the need, for whatever reason to leave the shelter at the worst time, opening a door, and potentially exposing all the shelter occupants to the wind and debris.

Three Phases of a Tornadoic Event to Consider

Many storm shelter designers believe the only thing they need to worry about is when the event is occurring. This position is highly prevalent in the pre-manufactured shelter industry. They also need to consider what is going on prior to the tornadoic event and what occurs after the storm has passed. The following are issues to consider:

Pre-Event

1. Opening the shelter
2. Getting occupants to the shelter
3. Getting the shelter locked down
4. Keep occupants away from exterior walls due to Kinetic energy
5. Keeping people calm

Event

1. Passive systems commence
2. Structural Envelope resisting wind loads and debris impact
3. Keeping people away from opening protective devices so they do not inadvertently/purposely open the device
4. Keeping people calm

Post Event

1. Evacuation of shelter occupants
2. Treating any possible minor injuries
3. Keeping people calm
4. Returning shelter to original condition for multi-use activities

Spaces Conducive For Storm Shelters

Open spaces with little to no furniture or furnishing which can be easily stacked or folded.

- This allows for maximum occupant load all the while the space can be used for other functions on a day-in and day-out basis.

Spaces which have restrooms already programmed with them.

- Restrooms and potable water shall be included in all community shelters and hand-washing facilities shall be included in community storm shelters with an occupant load over 50. Utilizing spaces that already have a restroom facilities associated with them eliminate the need to add additional facilities.

Spaces very close to occupants who do not move quickly or cannot move.

- As discussed in the Introduction of this paper, time can be a critical factor when determining whether someone is going to be protected in a tornado. The quicker one can get to the shelter, the greater the possibility of being protected. In a K-12 school for example, it is the youngest students that move the slowest therefore, it would be better to locate the shelter in that portion of the building. In medical facilities, there are patients that cannot be moved in a wind event. That may be where the shelter or one of the shelters for that facility is located.

Spaces with limited openings, i.e. doors, windows, mechanical, plumbing, etc.

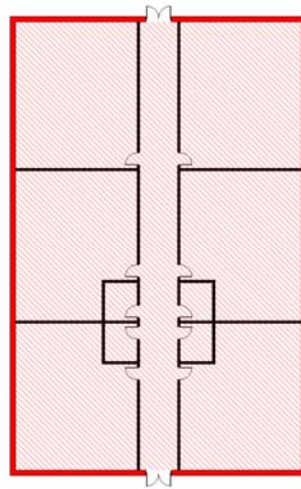
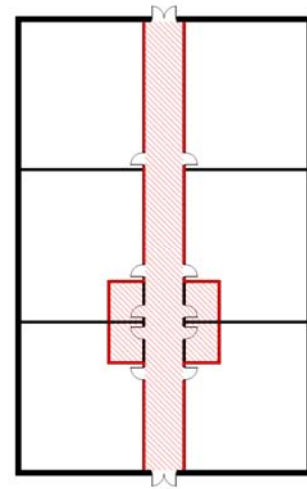
- Openings are the hardest and most expensive items to contend with in a storm shelter. There are many protective devices on the market today but most are relatively expensive. Limited openings means lower initial construction costs AND the lower potential for problems should one of the devices fail to function properly. However, limiting window openings in a multi-use storm shelter could be detrimental to the day-in and day-out use of the space.

Examples of good spaces

- Kindergarten room
 1. Typically larger than normal classrooms
 2. Furnishings are typically table and chairs rather than desks
 3. Typically have toilets associated with the room
 4. Small children do not move very fast.

- Multipurpose spaces
 1. Typically large open space
 2. Limited furnishings
- Training/Classrooms Rooms
 1. Large open spaces
 2. Limited furnishings
- Conference Rooms
 1. Smaller open spaces
 2. Typically for smaller occupancies
- Employee Break Rooms
 1. Large opens spaces for larger number of occupants
 2. Furnishings can easily be moved.
 3. Limited openings
- School Music Rooms
 1. Large open space
 2. Furnishings can easily be moved.
 3. Benefit of sound control for normal use due to the mass of construction elements
- Cafeterias
 1. Large open spaces
 2. Limited and/or stackable furnishings

- Corridors
 1. Corridors work well as shelter space provided the walls separating the corridor from adjacent spaces are not the “exterior” shelter walls. Corridors that are within the shelter envelope work well. See diagrams below and additional discussion provided in the next section..

**GOOD****NOT-SO GOOD**

Examples of Not-So-Good spaces (they can be utilized as shelters but have issues to consider)

- Basements
 1. Basements are not in the wind stream therefore the walls do not have to be designed to resist the horizontal wind loads or debris impact however, the walls now have to be designed to withstand the soil pressures and need to be waterproofed to eliminate potential water intrusion. Unless the shelter is entirely underground, the roof of the shelter would require to be engineered to resist storm loads imposed on it, including the potential collapse of the building above.
 2. Not all soil conditions are conducive to the installation of basements. In some cases soil movement, water table levels, etc. make underground shelters impractical.
 3. ADA accessibility can be expensive to comply with in basement shelters. Lengthy ramps or some type of mechanical vertical transportation needs to be provided. If the mechanical vertical transportation includes a platform lift or an elevator, backup power needs to be provided for this equipment to insure operation when the occupants need it. Doors to elevators have not been tested therefore if the debris has a direct “line of sight” through the sets of

elevator doors into the shelter then some sort of vestibule/alcove would need to be provided.

4. Post event evacuation for shelter occupants can be problematic due to exterior stairwells drifting with debris.
 5. Natural ventilation options may be restricted. Reference [Ventilation Strategies](#).
 6. There may be other code issues to consider by possibly having an assembly occupancy below the level of exit discharge and along with other fire related requirements.
- Restrooms
 1. Sanitary conditions vary from building to building but in many, it is not an ideal place for people to sit on the floor if they need to, especially in a school.
 2. Water closets, urinals, lavatories, and toilet partitions with doors take up a lot of floor space that could be utilized by occupants.
 3. The utilization of required restrooms needs to be preserved for use by all the shelter occupants. If the restrooms are full of people, then that may make it a little difficult for someone to “use the facilities” when needed. The plan to move 8-10 occupants out of a restroom and swap with 1 individual in the shelter proper does not work. The shelter proper will be short on area for 7-9 occupants with this strategy.
 - Corridors
 1. Although corridors have very little furnishings, are close to occupants, and are at the interior of the building, they also typically have numerous door openings. Door openings are relatively expensive and construction costs add up quickly. The odds of one of these openings not operating when the shelter needs to be locked down in an event increases with the number of openings.
 2. Doors designed to resist tornado wind loads and debris impacts are relatively heavy. Small children may have difficulty opening these doors.
 3. Separation of the corridor shelter roof from the remainder of the host building can be difficult and/or expensive.
 - Stair Enclosures
 1. Stair enclosures typically do not have restroom facilities associated with them and may make it difficult to do so.
 2. Stair enclosures are utilized for a path of egress, from upper level corridor, into the stair enclosure providing the vertical transportation to a level of exit discharge. In many cases, the doors to the stair enclosures swing into the enclosure and have panic devices on them. THIS WILL NOT WORK FOR A STORM SHELTER! Reference section on [doors](#).

3. Stair enclosures can and do extend several stories above the ground level and now one must contend with increased wind speed. Reference section on Multi-story shelters.
- Multi-story (above grade) storm shelters
 1. This is an old adage regarding seeking shelter in a storm”,...go to the lowest level possible...” There is a reason for this. The higher one goes from the ground level, the wind speed increases. This is due in part to friction from building structures, trees, and topography. There are a lot more “things” at ground level that actually reduces the wind speed than there are at 50'-100' above the ground level. Therefore, if one's shelter is multi-story, the increased wind speed needs to be addressed. A two-story shelter is possible but anything higher should be avoided.

Examples of space that should be avoided

- Storage Rooms
 1. Storage rooms typically are filled with items that are not easily removed and in some cases, fill the room completely. For this reason, they should be avoided.
- Equipment Rooms
 1. Mechanical, electrical, data rooms can have items in them that could be potentially dangerous for any occupant let alone being used for shelter space that has a high occupancy density. Someone could be inadvertently pushed into a hot service, moving pulley, electrical device, etc. Avoid these spaces.

New Versus Retrofit

This is a common question amongst designers and building owners. If an owner has a masonry building, then why not just protect the openings and call it good or grout some existing CMU cores? On the surface, this may sound like a logical solution however, if one has ever designed a storm shelter; you quickly begin to understand the unknowns of retrofitting an existing building. Questions like:

1. What were the exact materials used in the original construction?
2. Was it actually constructed per the original contract documents?
3. Were there any undocumented field changes during construction?
4. How does the designer ensure the continuous load path is maintained?
5. Are the foundations designed for the wind loads of a storm shelter?
6. How do you physically and economically install rebar and grout into the existing masonry walls?

7. If opening protective devices are installed in new or existing wall openings, will the existing wall construction support these devices when the actual loads are imposed on them?
8. Will this provide the shelter occupants the protection they expect OR is the owner/design team not providing them with an actual shelter?
9. What liability does a design team bring to itself by attempting a retrofit on an existing masonry structure?

It is much more likely that a design team can properly design and engineer a new shelter than to retrofit an existing building. With that said, the reference to “new” could be free standing, an addition, or a shelter constructed completely within a host building or anywhere in between. Reference [Siting the shelter](#). For a new shelter, the design team knows exactly how the shelter was designed, materials specified, how it was constructed, variations to the construction documents during construction, etc.

Funding/Costs

Many have questioned the benefit versus cost of storm shelters. Many believe that the cost is too high when you take into account the odds of a storm hitting any particular structure. If you look at the community of Moore, Oklahoma, they have had three EF-4/5 events over a 14-year period well exceeding the reoccurrence factors. Is this an anomaly? Maybe, maybe not, only time will tell. Unfortunately, many lives were lost in those three Moore events including seven children at Plaza Towers Elementary School in 2013.

According to the Federal Aviation Administration (FAA) report (2008) Benefit-Cost Analysis, the Value of a Statistical Life (VLF) meaning simply what a human life is worth to determine the benefit of preventing fatalities. This value in 2008 was set at \$5.8m³.

If one compares the cost of a four classroom school addition, spread footing, masonry bearing cavity wall, masonry partitions, steel bar joist roof structure with light gauge metal deck to the premium cost to make that same structure a storm shelter for tornadoes that would support 600 occupants. In 2014 dollars, in the mid-west, there may be a \$.5m-\$1m premium cost to the base construction. Compare that premium cost to the VLF for all the

³ This same value is utilized by FEMA's Benefit/Cost Analysis program along with many other variables. The program is available at <http://fema.gov.benefit-cost-analysis>.

occupants, $600 \times \$5.8\text{m} = \3.48b (with a "B"). In this example, we are talking about kids that obviously are not at their full earning potential as an adult would be, therefore maybe \$3.48b is too high of an amount. Cut that in half or use 1/3 that amount. We are still comparing \$1m to \$1b.

Value maybe in the eye of the beholder however, the case above is one that is difficult to challenge.

Currently, FEMA has a couple of different funding sources for storm shelters. The first is the Pre-Disaster Mitigation (PDM) grant program and the other is the Hazard Mitigation Grant Program (HMGP). The PDM grant is a lottery type grant where one must apply along with hundreds of other applicants from across the country for varying mitigation project for many types of potential disasters including earthquake, flooding, wind, ice, fire, etc. A certain amount of money is allocated annually and they fulfill these applications based on need. The number of applications is fulfilled until the money is all allocated.

The HMGP grants are a post disaster grant that kicks in where there is a Presidential declaration of a disaster. The amount of money is allocated based on a particular disaster. This can be a large amount of money, in the 10's of millions to small amounts. The money is provided to a sub grantee, which may be a State, County, or City. The sub grantee then distributes the money based on mitigation applications. Requirements are different from state to state, and region to region.

Further information can be obtained for these grants at www.fema.gov.

Codes/Guidelines/Standards

FEMA P-320 (2014) and FEMA P-361 (2015)

- Both of these documents are produced by FEMA and are available free of charge at www.fema.gov.
- The FEMA P-320 is written in regards to small storm shelters for residential and small business use for both hurricane and tornadic storms. The document has construction plans that have been engineered and can be used by home and small business owners. Concrete masonry units are utilized in a couple of the examples. Depending on the end user's construction capabilities, some of these examples are beyond the weekend Do-It-Yourselfers. It should also be noted the use of these prescriptive designs for small business puts the shelter into a community shelter definition that will have additional requirements as outlined in the FEMA P-361 (2015).

- The FEMA P-361 is a guideline for mainly community storm shelters although residential shelters are mentioned. Many jurisdictions have ordinances that state that if you are building a community shelter, it must follow the P-361 guideline. If the project you are designing is receiving FEMA grant moneys, then it **MUST** follow the FEMA-361 (2015) guideline.
- The FEMA P-361 (2015) has been revised to follow the general outline of the ICC 500 (2014). There are a few differences between the two documents that are outlined in the Appendix of the FEMA P-361 (2015).

ICC 500-2014 and the IBC 2015 Shelter requirements

- In 2008, the International Code Council (ICC) collaborated with the National Storm Shelter Association (NSSA) to produce the ICC 500 that was recently revised in 2014. This document is a code standard for storm shelters to be used in conjunction with the International Building Code (IBC).
- In the IBC 2009 and 2012 editions, the code simply stated that IF you are going to building a storm shelter, it must follow the ICC 500 requirements.⁴
- In the IBC 2015⁵, the reference to storm shelters has changed. The code now states that if you are designing/constructing an critical emergency operations facility such as 911 call stations, emergency operation centers and fire, rescue, ambulance, and police stations, that are located within the 250 mph wind zone as mapped in the ICC 500⁶, then a storm shelter meeting the requirements of the ICC 500 SHALL be installed in that facility. The only exception is a building that already meets the ICC 500. So no more choices by owners and/or design teams if the structure is within the 250 mph wind zone and the jurisdiction has adopted the IBC 2015.

Revisions to the 2015 IBC now require storm shelters that meet the ICC 500 2014 in critical facilities and group E occupancies.

⁴ Reference IBC 2009 and IBC 2012, section 423.

⁵ Reference IBC 2015, section 423.3.

⁶ Reference ICC 500-2014, Figure 304.2(1), Shelter Design Wind Speeds for Tornadoes.

- The IBC 2015⁷ goes on to state that group E occupancies with 50 or more occupants within the 250 mph wind zone as mapped in the ICC 500 SHALL have a storm shelter meeting the requirements of the ICC 500 that is large enough to house the entire occupant load of the E occupancy. There are a couple of exceptions to this:
 1. Group E occupancies that are day care centers
 2. Group E occupancies that are accessory to religious facilities
 3. If the building already has or is a storm shelter that meets the ICC 500

So again, no more choices by owners and/or design teams whether or not PreK-12 schools in the 250 mph wind zone get a storm shelter.

- The 250 mph wind zone mapped by the ICC 500-2014 affects areas in 23 states of the continental US and generally affects regions with tornadic activity.
- It should be noted the risk assessment⁸ for tornadoes in the FEMA P-361 states the 250 mph wind zone and the 200 mph wind zone have the same risk. With that said, it is encouraged to consider shelters in the 200 mph zone for the same facilities noted above.

Concrete Masonry Unit Storm Shelters Option

Concrete masonry construction as we know it today has been a part of the construction industry for well over 100 years and has been utilized for many types of structures. Many designers have chosen this material as the prime building material for many reasons. Concrete masonry has been utilized to resist hurricanes for many years, also for small residential tornado shelter. Within the last 15 years, it has been used for the main wind force resisting system in large, community shelters. Why? For the following reasons:

Inherent strength and durability

- Concrete masonry units are very strong and can be utilized not only as a structural bearing wall system, it can be designed as the main wind force resisting system, and at the same time, resist the debris impact. Many different sizes have been tested for debris impact but it should be noted as with any other material utilized in

⁷ Reference IBC 2015, section 423.4.

⁸ Reference FEMA P-361 2015

tornado shelter designs, it is the wind load forces that *usually* govern the design of the wall system.

- The sheer weight of the CMU wall systems, especially when the grout and reinforcing are accounted for, can be leveraged by the structural engineer to resist wind uplift forces.
- The strength of the CMU makes the material durable for many situations including multi-use tornado shelters. For shelters in schools, fire stations, police stations, ambulance garages, 911 dispatch, emergency operation centers, and industrial settings, etc., where durability is required for day in and day out use, CMU is a good choice.

Inherent fire resistance

- Per the ICC 500⁹, storm shelters shall be isolated from host building by 2-hour fire separation. The fire resistance of CMU works well for the fire separation requirement without the need for additional materials to achieve the required resistance. This allows the designer to leverage the CMU for not only the storm shelter requirements but also for fire resistance.

Provides an interior finish that is common and acceptable to end users

- Concrete masonry construction is commonly utilized in many different buildings and exposed to view making it the finish wall material. Again, allowing the designer to leverage the use of CMU not only as the protective envelope of the shelter but also the finish material on the interior.

Readily Available Material and Labor

- There are numerous plants across the country that produce concrete masonry units making the product readily available for use in storm shelter construction in storm prone areas.
- Masons, whether it be union or open shop are also abundant in the same areas. It is imperative that masons produce their work with the utmost diligence, skill, and craftsmanship. Lives depend on it.

⁹ Reference ICC 500, section 601.1.

Flexible to use with 8" modular units

- The CMU modules make them very flexible both in the horizontal and vertical directions. Other storm shelter materials have much larger modules, which begins to limit their flexibility.

Excellent use where sound control is desired

- Due to the mass of CMU along with the grout in the CMU cores that is associated with storm shelter design, it works very well with the concepts associate with sound control. Designers can take advantage of this by utilizing the shelter space for activities that generate noise or spaces where the activity within the shelter space requires limited outside noise. Examples of this in schools are vocal and instrumental music rooms, multipurpose rooms, or special needs classrooms spaces. Other spaces could include conference rooms, training rooms, testing rooms, and fire station dormitories.

Efficient

- Concrete masonry construction is conducive to both small and large shelters where as other material may work well for one or the other but not both.
 1. Small shelters utilizing CMU have the advantage of the dead load of the material helping to withstand the uplift and overturning forces. Many of the lighter weight shelters must add additional dead load to the foundation system to resist the same loads.
 2. Some materials/systems are not efficient is smaller shelters due to the cost of manufacturing and shipping. Efficiency comes in repetition, right where CMU shines.
- Shelters constructed of CMU have the benefit of using the same material efficiently for not only the main wind force resistant system but also for internal bearing walls and interior partition walls, all the while efficiently utilizing the exact same material. This can possibly eliminate, from any given project, two trades.
 1. Utilizing one material works well when one is designing a multiuse shelter. In these cases, the shelter components should be in the background, ready to be used when needed, but still in the background. The shelter should support the day in and day out use of the structure.

Architectural Issues

More than just a structural problem

There are many facets to a storm shelter. Many designers believe that the one and only thing that needs attention is the structural envelope of the shelter. After all, as long as you keep the debris and the wind out of the shelter then one has succeeded, correct? One sees this position regularly in the pre-fabricated shelter industry. Storm shelters are much more than a structural problem. They have many human factors that need to be considered. But why concern ourselves with human factors? It is extremely important to keep storm shelter occupants as calm as possible.

We humans are all different when it comes to dealing with events that create a lot of stress and/or anxiety. Some individuals curl up in a corner not wanting to be bothered, some don't feel they can breathe or they hyperventilate, some become claustrophobic, for some, the "fight or flight rule" applies and yet, some deal with stress very well. However, picture yourself in a storm shelter with a couple of hundred other individuals, many of which you may not know personally, a tornado is bearing down on the storm shelter and someone loses their composure; they do not feel they are getting any fresh air or not enough air. This person heads for one of the doors, opens it, and the inflow wind of the tornado catches the door and almost rips it off the hinges. It damages the door to the point that it cannot be closed or latched. Now there is a breach in the structural envelope. Not because the door failed, but because someone had a human factor problem. Now, due to the breach, everyone in that particular shelter is at risk.

It is imperative that designers consider these human factor issues, these architectural issues. Masonry can be a big part of level of comfort. People are accustomed to seeing this material used in familiar situations. People have a level of comfort that masonry is strong and can be protective in a storm. Masonry, in fact can be a part of the human factor solution.

Storm Shelter Occupancy

Multiuse storm shelters

- For storm shelters that are normally occupied for other purposes like classrooms, conference rooms, cafeterias, etc., the applicable construction codes for that normal occupancy shall apply¹⁰. For example, if you have a multiuse storm shelter that consists of a school cafeteria that is designed for a normal occupant load of



*Figure 3 Ewalt Elementary School Classroom
USD 402 Augusta, Kansas
Storm Shelter (Tornado) constructed of concrete masonry
Photo by PBA Architects*

125, but during a tornadic event, the occupant load may raise to 600. Under normal circumstances, the building code would require that space to have an automatic fire sprinkler system due to the number of occupants (600) in this space. However, since this is a multiuse storm shelter, the normal occupant load of 125 may be considered and therefore the automatic fire sprinkler system requirement

¹⁰ Per ICC 500-2014, section 104.1

does not apply. This may also apply to the number and width of required exits and mechanical code ventilation requirements.

- Storm shelters are not utilized for protection day-in and day-out. Therefore, in most circumstances, it is by far better to utilize the shelter for some other conducive occupancy so the building owner gets the best monetary value from the shelter. The shelter components, masonry walls, shelter doors, windows or window shutters, etc. can be in the background and not affect or inhibit the normal everyday use of the space.

Single use storm shelters

- For dedicated storm shelters areas utilized solely as a storm shelter, the occupancy shall be classified as an A-3¹¹. This designation will define the requirements of the model building code for that occupancy.
- Single use storm shelters may be less expensive regarding initial costs, however because they sit empty most of the time, the owner of the structure does not have any opportunity to acquire any return on that initial investment. In addition, single use shelters, over time have a tendency to become storage areas due to their lack of regular use. Storage items may not be easily removed when the shelter is needed. This may reduce the intended occupant load of the shelter.

Peer review

Peer reviews are an extremely important element of the process of designing storm shelters. It is most important for those novice shelter designers that have had very little experience with storm shelter design. A shelter design problem may not affect the day-to-day use of a multiuse shelter. However, that same problem may expose itself at the **exact moment** that shelter occupants may need the protection of the shelter the most. This may have significant consequences to the safety and welfare of the occupants. At that point, it is too late.

Peer reviews should be conducted by experienced shelter designers with the goal of minimizing the liability exposure to the designer of record as well as eliminating shelter design problems.

¹¹ Per the ICC 500-2014, section 104.2.

Construction Document Requirements

The ICC 500 has a section¹² dedicated to the requirements of the construction documents. These requirements are there to assist not only code officials but also peer reviewers, people reviewing the drawings for grant requirements, and facility owners/managers. In some cases, it can be very difficult to determine the design criteria, and even the location of the storm shelter itself without the knowledge of the original design team.

Special Inspections

Special inspections are to construction as peer reviews are to the design. One can design the highest quality shelter but the shelter will only be as good as the quality of the construction materials and the construction itself. There are many parts and individual pieces in the construction process all of which need to achieve a continuous load path. Oversight of this construction process for storm shelters is import to the success of the shelter.

Special inspections for masonry construction is critical to assure proper placement and sizes of reinforcing (both vertical and horizontal), placement of grout, imbed plates, and connections to foundations and roofs.

Quality Assurance Plans

Quality assurance plans go hand in hand with the construction's quality control and includes the identification of the load transfer elements, testing requirements, special inspections, and the distribution of the information to ensure that people involved with the construction know their duties, roles, and requirements. The goal is to assure that everyone involved in the construction of the shelter understands and acknowledges the importance of the quality of construction and their role in that process.

¹² Refer to ICC 500-2014, section 107.



Opening Protective Devices

In the past 14 years, there have been numerous types of doors, windows, louvers, and other opening protective devices that have been on the market. This makes openings in CMU shelter walls much easier to address than in years past. The following are design considerations:

Opening size

- The ICC 500-2014¹³ requires manufacturers that chose to provide more than one size of opening protective device to test the minimum and maximum size openings that may be utilized. Designers must understand what has been tested and what are the limitations of what can be used in their designs.

Relationship between wall and opening

*Figure 4 Opening Protective Device
Window Shutter in Concrete Masonry Shelter Wall
Photo by PBA Architects*

- When detailing an opening protective device in a concrete or masonry wall, it is important to understand that the device is a part of the wall system therefore the

¹³ Reference ICC 500-2014, section 803.1.

devices must be located within the exterior and interior surface of the CMU wall. In addition, it is important to understand the anchorage requirements of the protective device including offset from wall face, spacing, anchorage depth, and any other specific anchorage requirements.

Door swings

- It is extremely important that shelter designers understand that ANY doors that have panic device hardware **MUST** open to the exterior of the shelter. The panic device **MUST** be on the interior side of the shelter. **THIS IS NOT AN OPTION!** Panic devices are designed to open with minimal pressure. If one would place the device on the exterior of the shelter, the pressure of the wind alone would activate the device, let alone any debris that may hit the device. If the shelter doors open during the event, all of the shelter occupants could be at risk.
- Double egress doors are not conducive for use on shelters of any type.

Window shutters

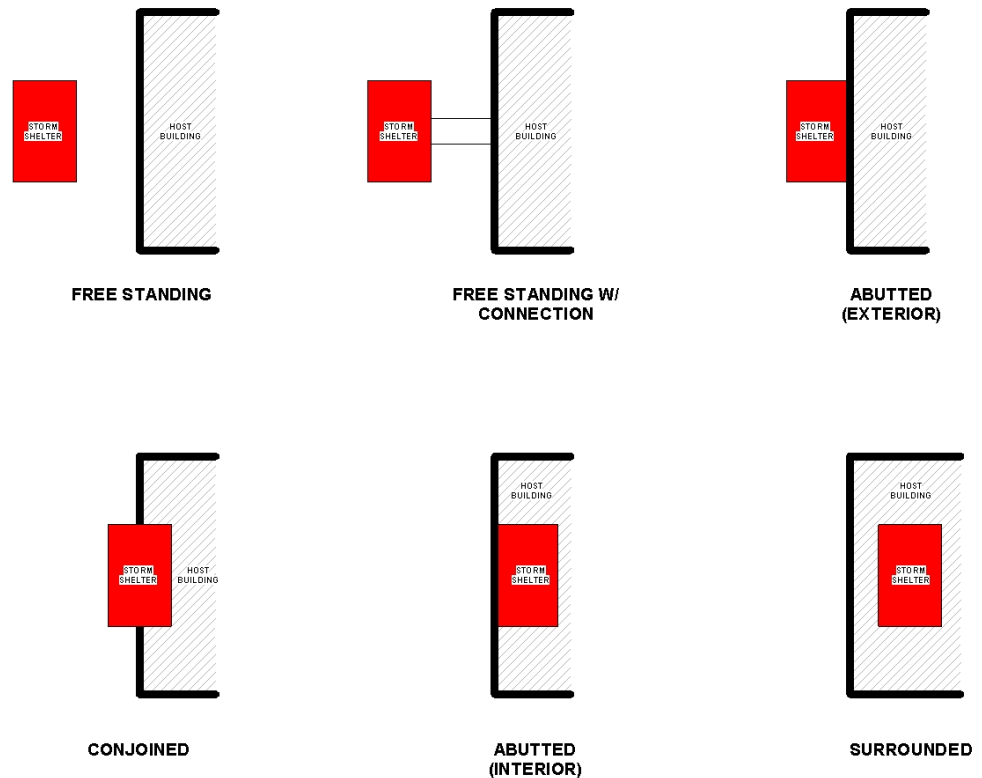
- Designers need to be cautious of the use of an operable window and a tornado shutter. Depending on the configuration of the operable window sash, specifically hopper, there may be a conflict with the sash and the frame of the shutter.
- It is recommended to provide laminated glass in a window with a shutter. Inflow winds can exceed 100 mph, which may carry small debris that could break the window glass making it difficult to close the shutter. If the shutter is not able to be closed, storm shelter occupants could be in harms way.

Siting the shelter.

Location

- There are generally six shelter-siting concepts relative to host buildings. Each has their pluses and minuses that need to be considered when determining the location of the storm shelter. Ideally, the shelter is located near the center of the host building or adjacent to where a majority of the population that the shelter supports is located within the host building.

- Six shelter configuration concepts



Shelter Configuration Descriptions

- Free standing-completely separated from host building, no physical connection
 1. Use: New Building or Addition
 2. Advantages
 - 2.1 No fire separation requirements.
 - 2.2 Ease of construction with no disruption to host building activities
 - 2.3 Flexibility of location
 - 2.4 Separation of roof and wall construction from host building
 - 2.5 Ventilation options are open
 - 2.6 Post event evacuation from shelter easier
 3. Disadvantages
 - 3.1 Occupants must be exposed to the elements to get to the shelter
 - 3.2 May not be conducive to multi-use activities
 - 3.3 More difficult to share infrastructure with host building

- Free standing with connection
 1. Use: New Building or Addition
 2. Advantages
 - 2.1 Minimal fire separation requirements.
 - 2.2 Ease of construction with little disruption to host building activities
 - 2.3 Occupants may access storm shelter without being exposed to the elements
 - 2.4 Conducive to multi-use activities
 - 2.5 Easy to separate roof and wall construction from host building
 - 2.6 Ventilation options are open
 - 2.7 Post event evacuation from shelter easier
 3. Disadvantages
 - 3.1 Possible location limitations with building addition scenarios
- Abutted (Exterior)
 1. Use: New Building or Addition
 2. Advantages
 - 2.1 Potential ease of construction with little disruption to host building activities
 - 2.2 Occupants may access storm shelter without being exposed to the elements
 - 2.3 Conducive to multi-use activities
 - 2.4 Easy to separate roof and wall construction from host building
 - 2.5 Ventilation options are open
 - 2.6 Post event evacuation from shelter easy based on shelter exit locations
 3. Disadvantages
 - 3.1 Maximized fire separation requirements.
 - 3.2 Construction of large foundation relative to existing building wall may be problematic
 - 3.3 Possible location limitations with building addition scenarios
 - 3.4 Potential for host building equipment or high wall impact on storm shelter
- Conjoined
 1. Use: New Building
 2. Advantages
 - 2.1 Limited exterior finishes.
 - 2.2 Occupants may access storm shelter without being exposed to the elements
 - 2.3 Conducive to multi-use activities
 3. Disadvantages
 - 3.1 Larger fire separation requirements.
 - 3.2 Difficult to separate roof and wall construction from host building
 - 3.3 Ventilation options become limited
 - 3.4 Potential for host building equipment or high wall impact on storm shelter

- Abutted (Interior)
 1. Use: New Building or Addition
 2. Advantages
 - 2.1 Occupants may access storm shelter without being exposed to the elements
 - 2.2 Conducive to multi-use activities
 3. Disadvantages
 - 3.1 Construction difficult with major disruption to host building activities in building addition scenario
 - 3.2 Difficult to separate roof and wall construction from host building in building addition scenario
 - 3.3 Maximized fire separation requirements.
 - 3.4 Construction of large foundation relative to existing building may be problematic
 - 3.5 Possible location limitations with building addition scenarios
 - 3.6 Ventilation options are limited
 - 3.7 Potential for host building equipment or high wall impact on storm shelter
 - 3.8 Post event evacuation from shelter more difficult

- Surrounded
 1. Use: New Building or Addition
 2. Advantages
 - 2.1 Occupants may access storm shelter without being exposed to the elements
 - 2.2 Centralized location
 - 2.3 Conducive to multi-use activities
 3. Disadvantages
 - 3.1 Construction difficult with major disruption to host building activities in building addition scenario
 - 3.2 Difficult to separate roof and wall construction from host building in building addition scenario
 - 3.3 Maximized fire separation requirements.
 - 3.4 Construction of large foundation relative to existing building may be problematic
 - 3.5 Possible location limitations with building addition scenarios
 - 3.6 Ventilation options are limited
 - 3.7 Potential for host building equipment or high wall impact on storm shelter
 - 3.8 Post event evacuation from shelter difficult

Laydown hazards

- Laydown hazards need to be considered when determining location of the shelter. Hazards include but are not limited to overhead power lines, radio towers, taller structures adjacent to the storm shelter, roof mounted equipment adjacent to the shelter. These items could create additional impact forces on the shelter that need to be accounted for in the structural design of the shelter.
- Other laydown hazards that could affect shelter occupants are overhead power lines. This may not be a structural hazard but may be an obstacle for shelter occupants gaining access to or egress from the shelter.

Parking lots

- Automobiles are notorious for becoming large debris in tornadoes. Designers should consider this when siting the shelter. Vehicle(s) thrown into the storm shelter could put stresses on it for which it was not designed.



*Figure 5 Greensburg, Kansas Hospital
Photo by Corey Schultz*

Additions to existing building considerations

- When a storm shelter is an addition to an existing building, as discussed location is an important factor that can be a challenge. Locations may not be ideal. Shelter foundations can be rather large and when a shelter addition is located directly adjacent to an existing building, they can be a problem. Fire separation maybe somewhat of a challenge, and finally, exiting from the existing building into the shelter or vice versa due to door swing/panic device issues. Reference [Opening Protective Devices](#).
- Some type of physical connection from the existing building and the shelter addition is preferred. Associated with tornadic storms can be inflow winds carrying small debris, torrential rain, and/or large hail. Without some sort of connection, these hazards can make accessing the shelter by occupants in the host building very difficult.

Flooding considerations

- Storm shelters should not be constructed in flood prone areas. Leading up to a tornadic storm, there could be several days of rain saturating the ground creating

localized flooding. If the storm shelter is in floodwaters, shelter occupants are not going to be able to access the shelter, or utilize the shelter. Many maybe counting on the use of the shelter but if located in a flood prone area, shelter use may not be dependable.

Occupancy density

The ICC 500-2014¹⁴ has a matrix for the base occupant load factors for both tornado and hurricane shelters based on residential or community application,, type of shelter and accounting for those in wheelchairs or those that may be bed ridden both of which require more floor area.

There are two different shelter area calculation methods per the ICC 500-2014¹⁵. They are based on the timing of information that the design team has available to them when planning a storm shelter.

If a designer knows the exact net area available to storm shelter occupants during the initial plan layout of the storm shelter, then one can use the number of occupants multiplied by the occupant load factor to determine the amount of net area required and apply that to the design. The use of this method is typically limited to space without any furnishings or spaces with fixed seating.

The other method more commonly used allows designers to utilize a usability factor which accounts for the unknown information early in the design process i.e., wall thickness, furniture, equipment, millwork, etc., items, which occupy floor space. These factors are applied to the gross area of the shelter to determine the area available to the shelter occupants. The factors are based on the designer's best judgment of how the space is going to be utilized in the end. It is encouraged to be conservative with these factors. There must be adequate space for the shelter occupants when they seek shelter.

To put the usability factor into perspective with masonry construction, nominally, a five lineal feet section of a 12" CMU wall occupies approximately the same space as one shelter occupant.

¹⁴ Reference ICC 500-2014, Tables 501.1.1 and 502.4 for community and residential shelters respectively.

¹⁵ Reference ICC 500-2014, section 501.1.2.

Fire Separation

Fire has been a documented result of tornadoes. Broken natural gas lines are a large contributor to this. However, when the tornado siren is activated, some people have a tendency to drop everything they are doing and head for cover. In some situations, the activity left behind could cause a fire. Shelter occupants need to have added protection from this possible hazard. Post event, shelter occupants may not be able to leave the shelter immediately due to debris blocking exits hence, the requirement for the added protection.

Fortunately, concrete masonry construction is inherently fire resistive making it relatively simple for designers to comply with this requirement.

Protection of Critical Support Systems

Generators, mechanical equipment, uninterrupted power supplies are all considered a part of the critical support systems. In order for them to operate and provide support when shelter occupants need them, they have to be protected from storm wind loads and debris. A generator supplying power to the lighting and mechanical system does not work well with a piece of debris penetrating the engine block. These system need to be protected as if they are shelter occupants. The same concrete masonry construction providing protection to the shelter occupants can be utilized to protect these critical systems.

Shelter Operation and Management

A very important aspect to the success of a storm shelter is its operation and management. Many building owners do not understand all of the issues associated with properly operating the components of the shelter that have been included by the design team, i.e. proper operation of the active opening protective devices, the operation of the ventilation system, etc. Many building owners do not understand the management issues of the shelter either. When does the shelter need to be opened? Who is going to open the shelter? Who is their backup? When does the shelter need to be secured? Who locks the doors? How do you keep items in a multiuse shelter from disappearing? Are pets allowed in the shelter including dogs, cats, bird, snakes, and reptiles? These are just a few of the questions that need to be answered as a part of the shelter management plan. Reference [Public use shelters](#).

Designers have a tendency to step away from the project once the construction is complete without having an operations and management plan dialog with the owner. With that, the shelter may not be operated properly and therefore shelter occupants could be at

risk. Unfortunately, many shelter designers do not understand all the issues that need to be considered hence the lack of consultation with the shelter owner.

If the designer does not understand the operation/management, it is strongly encouraged that they seek experienced help with this issue. If a storm shelter is not operated properly, then it could be as dangerous to an occupant as not having a shelter.

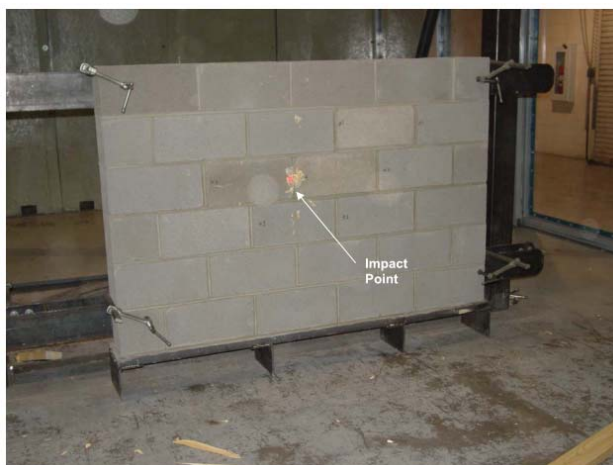
Structural Issues

Loads

The loads and load combinations used for the design of a tornado shelter are determined in accordance with ASCE 7, as modified in ICC 500-2014. The wind pressures are determined using the “SHELTER DESIGN WIND SPEEDS FOR TORNADOS” located in the ICC 500-2014, reference [Tornadoes-What are they?](#) for wind speed map. The ICC 500-2014 also includes a minimum roof live load design requirements of 100 pounds per square foot. Although the wind loads and roof live loads are forces primarily governing a shelter design, other loads such as the snow load, seismic loads, earth pressure, etc. can also affect the design of the shelter, especially in a localized area.

Hydrostatic, flood, and buoyancy forces also need to be addressed for the underground portions of the shelter with the assumption that the groundwater level is at the entrance of the shelter unless adequate drainage is available to justify a lower groundwater level.

For determining the wind design pressures, atmospheric pressure change (APC) can be calculated using the internal pressure coefficient of an enclosed building ($GC_{pi}=\pm 0.18$) provided certain criteria is met. However, using the internal pressure coefficient noted in the exception of the ICC 500-2014 ($GC_{pi}=\pm 0.55$) can be beneficial and, although the design pressures will be increased, will not require additional shelter penetrations (and associated costs) or assurance that the venting will remain clear over time and during an event.



Debris Impact

- Windborne debris is another vital and extremely important design requirement of the shelter. According to the ICC 500-2014, the design missile is defined as a 15 pound 2x4

*Figure 6 NCMA Debris Impact Specimen-
Reference NCMA MR-21 Report*

traveling at various speeds depending on the design wind speed and the direction of the missile¹⁶. The designer should note that the ASCE 7-10 defined design loads and designing for impact are two, totally independent-design requirements and the more stringent criteria or design requirement will govern the construction. There are many tested assemblies that have been conducted on several different types of materials in many different labs. Although many designers that get caught up in the debris testing alone because it is the most dramatic and impressive test, they may be secondary to the wind loads imposed upon those same assemblies. Therefore, the debris impact test should be considered a starting point only.

- Debris impact is primarily determined through testing defined in the ICC 500-2014¹⁷. Currently, the minimum requirement for masonry walls to resist debris impact is fully grouted 6" with #4 rebar at 32" on center vertically¹⁸, however, ASCE 7-10 load pressure design will often govern the actual wall thickness and reinforcement requirements. Other tested assemblies meeting the minimum requirements for debris impact can be found in the FEMA 361 2014, Texas Tech's National Wind Institute, Underwriters Laboratory, Warnock Hersey, and wall or roof-opening assembly manufactures.

Foundations

Foundation elements need to be designed not only for bearing capacity, but also for overturning, uplift, and sliding which will often govern the design of the foundation system. Special consideration should be considered for the connections of the shelter superstructure to the foundation system, and often the slab on grade will be needed to laterally brace the shelter walls. In many cases, the storm shelter footing can be quite large and heavily reinforced.

Shelter Adjacent to Host Building

- Typically, shelters are designed next to existing construction, or as part of a larger construction area. Therefore, the impact of a storm shelter addition adjacent to an existing building must be addressed, not only for the shelter's impact on an
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¹⁶ Reference ICC 500-2014, Table 305.1.1.

¹⁷ Reference ICC-500-2014 Section 305.1.1 and Chapter 8.

¹⁸ Reference NCMA MR-21 Report dated September 26, 2003 available at <http://ncma-br.org/pdfs/masterlibrary/MR21.pdf>.

adjacent foundation system, but to ensure the load transfer is consistent with the design assumptions made.

Storm Shelters Sitting on Slabs

- Caution should be used for designing shelters that only sit on a slab-on-grade. Although the ICC 500-2014 allows shelters to be supported on a slab on grade only, the connections and capacity of the slab need to meet the load transfer of the shelter's superstructure can be very difficult to verify with engineering calculations.
- It should be noted that there is an exception in the ICC 500-2014¹⁹ for designing of slab-on-grade supporting shelters complying with Section 301. Concrete and concrete masonry shelters in residences may be installed on an existing slab-on-grade without foundations provided, 1) calculated soil pressures under the slab do not exceed 2,000 psf, 2) the shelter is anchored to the slab at the corners and each side of any door openings, and 3) the slab is not contributing to the overturning of the shelter. This is due in part to the physical size limitation and the dead weight of the shelter that is resisting overturning of the shelter.

Walls

The primary function of the walls is to resist the lateral forces, debris impact, and provide load transfer of the roof structure to the foundation system. For masonry walls, reinforcing is the primary wall component of the wall to resist the wall-bending, shear, and uplift forces and the masonry units, solid grouted, are used for the compression loads and impact resistance. Often dowels and/or weld plates are incorporated for the connections to the shelter roof and foundation system.

Wall Openings

- Openings pose a unique challenge to the wall system. The walls surrounding the opening need to be designed for the concentrated force of the lintel and sill, in addition to the attachment of the opening door or window assembly, which is typically designed by the assembly supplier. The designer should note that the corner force winds often exceed tested fabricated elements so opening in the corners should be minimized or eliminated.

¹⁹ Reference ICC 500-2014, Section 308.1.1.1.

Load Transfer

- The use of horizontally spanning element, such as masonry bond beams, can be used in load transfer between vertical elements and to distribute the corner force winds or concentrated load locations.

Wall Control Joints

- Due to the rigidity and construction materials of the wall system, control joints may be needed for crack control, especially during construction and when exposed to thermal movement. These joints are typically located for crack control and for architectural appearance, but they need to be coordinated with the structural system to ensure the design assumptions of the structural elements are being met. Care should be taken not to exceed the maximum opening size requirements of the ICC 500-2014.²⁰ If exceeded, by the code standard, the control joints will be considered openings and will require protection.

Roof Structure

Roof structures typically consist of construction that has rigidity and structural capacity to resist the gravity and uplift forces applied. This roof system will also need to be able to have large diaphragm shear capacities without excessive deflections and be able to develop chord, strut, and drag forces as necessary.

Roof Openings

- Similar to the wall structure, openings in the roof system can be challenging, and openings should be avoided in the corners zones and edge zones where increased wind pressures are assumed.

Storm Shelter Penetrations

Penetrations into the shelter are required to be protected when the penetration is greater than the allowable opening of the ICC 500-2014²¹. Penetrations can be protected with an approved impact assembly or a baffled constructed system. A common impact assembly

²⁰ Reference ICC 500-2014, Section 306.8.

²¹ Reference ICC 500-2014, Sections 306.7, 306.8, and 309.

used to protect penetrations is steel plate with supplemental reinforcing to resist the lateral and gravity loads applied to the assembly.

The designer should note, although the test assembly for missile impact is a 2x4, other material should be considered as missiles when protecting penetrations into the shelter. Other material could be as small as a pebble or as large as an automobile. Although the ICC 500-2014 does not specifically comment on how to address these additional debris elements, engineering judgment should be used to consider other items that could become missiles and to determine the forces exerted by the missile and its design criteria.

Miscellaneous Issues

Hazards

- Sometimes, a shelter will be located adjacent to a taller new or existing structure such as a communications tower, gymnasium, or adjacent structure with roof top units. As required by the ICC 500-2014, lay down, rollover, and collapse hazards of adjacent structures need to be considered in the design of the shelter.²² In addition, impact loads and material performance as a result of the impact, such as spalling or excessive deflection, need to be addressed.

Items Connected to the Shelter

- Adjacent or adjoining elements to the shelter can either be designed as part of the shelter, or designed to fail or break-away during the tornado without being detrimental to the shelter performance or missile protection. Often, creating a “weak link” in the load path of the supported element can be used and meet the requirements of the ICC 500-2014.

Interior Elements

- Interior, non-structural elements also need to be fastened or supported for movement and forces during a tornadic event to ensure they do not become an interior source of debris. Interior forces can develop from roof flutter, interior pressure differentials, lateral pressures through a baffle assembly, etc. Because movement during the extreme loads can cause deflection, cracking, and lateral displacement, connections should be primarily used in a shear capacity and be

²² Reference ICC 500-2014, Section ???

redundant. Connections for ductwork, lighting, ceilings, etc. could also be fastened to the supporting elements similar to the fastening required in higher seismic regions.

Structural Observations

- Structural Observations are general conformance, visual reviews by a registered design professional (preferably the Structural Engineer of Record) at critical stages of construction. The design stages typically include foundation construction, wall construction and roof construction. Experience indicates that performing the observations early in the required stage of construction can be beneficial to the project and a final review of the structural system can help ensure conformance with the contract documents.

Construction

As stated throughout the document, quality assurance is critical during the construction of the project, and is especially true in masonry construction with all the “pieces and parts”. Therefore, the implementation of Special Inspections, testing, and Structural Observations identified in the Quality Assurance Plan and acknowledged by the Contractors can be vital.

For masonry construction, the designer may or may not chose to enforce certain testing requirements that are in addition the minimum testing needed in the codes and standards. However, if the construction materials or construction techniques do not conform to the contract documents or assumed structural properties, structural capacity may not be sufficient to resist the loads or the missiles that could impact the shelter.

Mechanical/Plumbing Issues

Ventilation Strategies

Storm shelter occupants need some sort of ventilation that provides fresh air replacing build-up of carbon dioxide, body odors, and heat. This can be accomplished with two separate strategies, natural or mechanical ventilation. The ICC 500-2014²³ spells out the requirements for each of the systems. The following are advantages and disadvantages of each.

Natural Ventilation

- Advantages
 1. Most cost economical of the two systems
 2. Simple system relying on convection
 3. Utilized less floor space than mechanical systems
 4. Does not require backup power for operation
 5. System can utilize concrete masonry construction to protect shelter occupants
- Disadvantages
 1. May not circulate air efficiently

Mechanical Ventilation

- Advantages
 1. Circulates air efficiently
 2. May provide tempered air
 3. System can utilize concrete masonry construction to protect shelter occupants

²³ Reference ICC 500-2014, Section 702.

- Disadvantages
 1. Much higher cost than natural ventilation.
 - 1.1 Requires more protected floor area for the system.
 - 1.2 Requires power back up system that must be protected.
 2. Backup power system may have long-term annual maintenance costs associated with it.

Natural ventilation strategies should include addressing small debris, which can pass through open louvers that have been tested as required with the 100 mph 15 lb 2x4. Sand, gravel, glass shard can make their way through the louver in the air stream. This could create large problems for shelter occupants. Consider designing an alcove similar to the alcove entries shown in Chapter 8 of the ICC 500-2014. Instead of moving people into the shelter, you are moving air. Occupants are then protected from the small debris.

This air alcove can easily be constructed of concrete masonry units.

Storm Shelter Penetrations

In a typical structure, there can be numerous utility/ventilation penetrations into any given space. With storm shelters, in order to insure the integrity of the shelter envelope, penetrations through the protective envelope should be minimized especially those that do not support the storm shelter itself. As discussed earlier, storm shelter penetrations can be difficult and expensive to address therefore they should be avoided where possible. These penetrations may include but not be limited to ductwork, vent pipes, roof drains and leaders, floor sinks, hydronic lines, domestic hot/cold water lines, gas lines, compressed air lines, and other potentially hazardous lines.

If running some of these lines is unavoidable which more than likely is going to be the case, and the openings are greater than 3 ½ square inches or 2 1/16” in diameter per the ICC 500-2014²⁴, some type of engineered protective device needs to be provided for that opening. Unfortunately, there are very few if any manufactured items that fit this bill. Therefore, the structural engineer (not mechanical engineer) must design a custom protective device. Depending on the opening, it could consist of an “L” shaped duct constructed from sheet steel or a sheet steel shroud type device. In either case, the

²⁴ Reference ICC 500-2014, section 309.1.

potential path of any debris needs to be analyzed to determine the size of the protective device. It should be assumed that whatever line is penetrating the shelter would not be there during the event therefore one needs to consider the entire size of the line's rough opening when determining potential debris path. Anchorage of the device to the wall or roof system also needs to be designed for debris impact as well as wind pressure.

Finally, these opening protective devices will have a much better chance of surviving and doing the job that they need to do i.e. keeping debris from entering the shelter area if they are located on the protected side of the shelter envelope. If they are on the exterior side, large debris could tear the device of the wall/roof potentially exposing shelter occupants to wind borne debris.

Gas Lines

- Natural gas lines seem to make their way into storm shelters for either gas fired mechanical units or hot water heaters. Designers must be aware there is a potential for a gas line entering the shelter could to be damaged where it enters the shelter and possibly leak gas into the shelter area. This could pose a hazard to the shelter occupants. To combat this, it is recommended to utilize a remote solenoid valve on the supply side of the shelter that fails closed. With this, the designer is taking advantage of the fact typically; electricity is the first utility that is lost in a storm thus closing the valve. If a generator is provided, this valve should NOT be connected to emergency power. You want the valve to be remote from the shelter so that the flow of gas is stopped away from the shelter minimizing the chances of gas entering the shelter area.

Sanitation Facilities

Storm shelters except those associated with one- and two-family residence require toilet facilities and in larger shelters hand washing facilities required per ICC 500-2014²⁵. These facilities MUST be within the shelter envelope. Shelter occupants cannot be expected to leave the shelter to use these facilities. There are a couple of design approaches that meet these requirements. ADA requirements must be considered. It is suggested to visit with the local Authority Having Jurisdiction (AHJ) to determine what is acceptable in any given location.

²⁵ Reference ICC 500-2014, section 702.2

Obviously, an ADA compliant water closet with grab bars located in a room for privacy may be required as a minimum in a shelter, which requires toilet facilities. The requirement for handicap accessibility dictates this. However, when multiple fixtures are required, one can begin to use portable, chemical type toilets that can be placed in a space that is not being utilized by shelters occupants, i.e. storage room, mechanical space, etc. to be used as a make shift restroom without the need for additional plumbing.

Hand washing can be accomplished with a lavatory, sink, or possibly hand sanitizing stations. Check with the local AHJ to determine what is acceptable.

Drinking water can be provided through bottled water, drinking fountains, sinks, and/or lavatories. It is recommended with sinks or lavatories for sources of drinking water, disposable drinking cups are provided within the shelter.

Water Supply

If dealing with a shelter associated with a host building, during an event, one has to assume the host building has been destroyed. If the design requires a supply of water for drinking, hand washing, and/or toilet use, and if water supply lines are ran overhead from the host building to the storm shelter, then in theory the water supply will be nonexistent post event. Shelter occupants may not be able to exit the storm shelter due to debris blocking exit doors or subsequent storms in the area and may still need the sanitation facilities.

It is recommended that water supplies to the storm shelter run underground (via buried trench and/or underground tunnel) from the water main entrance to the shelter.

Electrical Issues

Backup Power

Backup power must be provided for mechanical ventilation schemes and/or lighting. This can be done via a powered generator, un-interrupted power supply system (UPS), or individual batteries (lighting only). Whatever case, the back up power system must be protected from the effects of the extreme wind and debris. Reference [Protection of Critical Support Systems](#). Each backup power scheme has its own advantages and disadvantages.

Generators

- Advantages
 1. Provide continuous power for lengthy period of time for both lighting and mechanical ventilation systems and may be utilized for the host building systems.
- Disadvantages
 1. Single point power source without redundancy.
 2. Initial cost is high for the generator and transfer switch alone for short duration of a tornado shelter
 3. Should utilize diesel or bottled LP-fueled type due to post event natural gas utility is quickly shut off.
 4. Continual, long term maintenance costs for owner
 5. Must be protected similar to shelter occupants requiring additional protected floor area.
 6. Fuel supply must be protected.
 7. Must provide fresh air for engine combustion/cooling and provisions for exhaust and this opening must be protected.

UPS

- Advantages
 1. Compact
 2. Minimal annual maintenance
 3. Can provide power for limited lighting and ventilation for short period of time
 4. Less initial cost than generator

- Disadvantages
 1. Single point power source without redundancy.
 2. Higher initial cost than battery backup.
 3. Power output may be limited.
 4. Component life span may be 10 years at best.

Battery

- Advantages
 1. Compact
 2. Low initial cost
 3. Can provide power for limited lighting for short period of time
 4. Less initial cost than generator and/or UPS
 5. Multiple point power source providing redundancy.
 6. Inexpensive replacement costs.
- Disadvantages
 1. Typically not available for providing power for mechanical ventilation systems
 2. Shorter life span.
 3. Power output is limited.

Lighting

Storm shelters in many cases when secured can be very dark due their nature of having limited openings, shutters over windows, etc. People in high anxiety situations like a tornadic event, deal with sensory perception loss issues in many different ways. Loosing light to the point that one cannot see their hand directly in front of their faces can make the strongest of people a little uncomfortable much less with those that are under a large amount of stress. The loss of light can exacerbate those problems. It is very important that people have enough light that they can see everyone else, can make their way through the shelter to the toilet facilities, make their way to the exits when the “all clear” is sounded and finally to make them feel at ease as much as possible.

Lighting, whether it be by flashlights or lighting fixtures, need to have some sort of backup power source and if accomplished by batter backup, it is strongly suggested to have redundancy and/or alternate methods of provide light, i.e. chemical light sticks. Light sources from fossil fuels or open flame, i.e. camping lantern, candles, etc. should not be used.

Conduit Penetrations of shelter envelope

Since most electrical engineering drawings are diagrammatic in nature, sometimes it is difficult to determine how many conduits and of what size will actually be penetration the concrete masonry walls. As stated prior, there are limitations on sizes of openings through the protective envelope. Those limitations are 3 1/2" square inches in area or 2 1/16" diameter. Anything larger must be protected as if it is an opening. Now by itself, a 3/4" conduit penetrating a 1" diameter hole in a CMU wall falls well within the limitations, however, it must be understood when several of the same conduit are put side by side, bundled, or stacked, the limitations can and will be exceeded. These penetrations need to be separated with enough wall between them that if hit by debris, it does not punch through into the shelter. The structural engineer should determine what the spacing of conduits should be and referenced on the electrical drawings. It is suggested to have a general note on the electrical drawing similar to the following:

"Any penetration greater than 3 1/2" square inches or 2 1/16" diameter shall be protected as a shelter opening. This includes multiple conduit through the same penetration. Protect openings as required with a tested or engineered system."

It is also recommended where possible to run conduit under floor to minimize the shelter envelop penetrations. Keep distribution panels within the shelter to a minimum.

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Contact Information

National Concrete Masonry Association

Tel 703-713-1900

Fax 703-713-1910

www.ncma.org

Corey Schultz, AIA

Vice President

Schultz Squared Architects LLC

Tel 316-425-7745

Fax 316-425-7753

corey@schultzsquared.com

Scott Mauler, PE

Owner

Mauler Engineering, LLC

Tel 316-558-8100

Fax 316-558-8102

scott.mauler@maulerengineering.com