EVALUATION OF ABOVE GROUND STORM SHELTERS

STRATEGIC MANAGEMENT OF CHANGE

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ABSTRACT

This research project analyzed the capabilities of above ground storm shelters as designed by the Wind Engineering Research Center (WERC) and the Federal Emergency Management Agency (FEMA), and the events and factors that create the need for them. The problem prompting this research project was that the Lubbock Fire Department and its personnel are located in a FEMA designated high-risk wind zone and are exposed on a yearly basis to possible injury or death due to extreme wind events such as tornadoes. It was the purpose of this research to evaluate if the cost effectiveness and risk performance of above ground storm shelters built into the newest LFD fire stations justified adding these type of shelters into the remaining existing fire stations in the LFD.

This research employed evaluative research methodology to: (1) identify if there was a need for shelters in the LFD; (2) evaluate if above ground storm shelters were truly effective; and (3) assess whether or not ground storm shelters should be placed in all LFD stations.

Procedures that were used to complete this research included a literature review of magazines, journals, fact sheets, textbooks, and a review of LFD construction documents. Semi-structured intervals were also conducted with personnel from the Wind Engineering Research Center. Utilizing software created by FEMA, a benefit cost analysis comparing installation cost of an above ground storm shelter in relationship to tornado risk was developed.

The results of this research showed that above ground storm shelters, when constructed according to WERC and FEMA requirements, have the best possible

combination of cost-effectiveness and protective mitigation features that exists today, and utilizing this type of shelter will result in fewer fatalities, fewer injuries and less damage in the event of a high energy wind event such as a tornado or hurricane.

The recommendations resulting from this research include: (1) the LFD should include in its budgetary planning activities, the retrofitting of above ground storm shelters into the remaining six unprotected fire stations; (2) lobbying the support of LFD personnel, city and community leaders; and (3) utilizing the information in FEMA 361 to facilitate the retrofitting process of above ground storm shelters into existing LFD fire station.

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INTRODUCTION

Every year Lubbock Fire Department (LFD) responders must deal with the threat of tornadoes and other extreme windstorms that cause injuries, death and widespread property damage. As emergency responders we are not immune to the dangerous forces of extreme winds or the anxiety created by the threat of an approaching tornadic storm. According to the Federal Emergency Management Agency (FEMA) publication #320: *Taking Shelter from the Storm* (1998) "Almost every state in the United States has been affected by extreme windstorms such as tornadoes and hurricanes" (p.1).

In light of the extreme weather related dangers involved and regardless of the normal resistance to change, the LFD has opted to break with tradition and change the way that it seeks to provide storm protection for its personnel. Beginning in 1998 the LFD started incorporating into the design of new fire stations, hardened above ground storm shelters for the purpose of protecting personnel from extreme wind events.

The problem prompting this research project was that the Lubbock Fire Department and its personnel are located in a FEMA designated high-risk wind zone and are exposed on a yearly basis to possible injury or death due to extreme wind events such as tornadoes.

The purpose of this research was to evaluate if the cost effectiveness and risk performance of above ground storm shelters built into newest LFD fire stations justified adding these type of shelters into the remaining existing fire stations in the LFD. This research employed evaluative research methodology to answer the following questions:

1. Is there a need for shelters in the LFD?
2. Are above ground storm shelters truly effective?

3. Should above ground storm shelters be placed in all LFD stations?

BACKGROUND AND SIGNIFICANCE

The City of Lubbock is located in the Texas panhandle in an area known as the South Plains, and has a population of 200,000 in an area covering 130 square miles with 255 firefighters located at 14 fire stations. The department responds to approximately 5,000 incidents per year and provides fire, heavy rescue, water rescue, hazardous material response, and first responder's services to its citizens. At an elevation of 3,200 ft. (975.4 m) above sea level, Lubbock’s summers are warm and breezy, its winters are mild, and the city enjoys all four seasons. The city is considered by FEMA to be in a high-risk wind zone, where shelter is suggested to be an effective protective mechanism for tornadoes.

A tornado is defined as a violently rotating column of air extending from a thunderstorm to the ground. The most violent tornadoes are capable of tremendous destruction with wind speeds of 250 mph or more. Damage paths can be in excess of one mile wide and 50 miles long. Although tornadoes occur in many parts of the world, these destructive forces of nature are found most frequently in the United States east of the Rocky Mountains during the spring and summer months. During the spring in the Central Plains, thunderstorms frequently develop along a "dryline," which separates very warm, moist air to the east from hot, dry air to the west. Tornado-producing thunderstorms may form as the dryline moves east during the afternoon hours.

Along the front range of the Rocky Mountains, in the Texas panhandle, where Lubbock is located, and in the southern High Plains, thunderstorms frequently form as air near the ground flows "upslope" or toward higher terrain. If other favorable conditions exist, these thunderstorms can produce tornadoes. Tornadoes can occur at any time of the year. However, in the South Plains area, the peak tornado occurrence is in March through May.

Traditionally, tornadoes in the South Plains area are most likely to occur between 3 and 9 p.m. and on an average move from southwest to northeast, but tornadoes have been known to move in any direction. Their average forward speed is 30 mph but may vary from nearly stationary to 70 mph.

On May 11, 1970, at 9:46 P.M. the City of Lubbock was struck by a large tornado with 27 lives lost and several major injuries sustained by LFD personnel. The communications center, located in fire station #1, was totally destroyed and the rest of station #1 was heavily damaged. No calls could be received or dispatched to any of the substations. The fire dispatcher on duty was disabled with an injury that ultimately cost him the sight of one eye. A few minutes prior to the descent of the tornado, the men on duty rushed to the apparatus room in an attempt to raise the overhead doors; however, the wind was already so strong that it was impossible to raise them. The men then donned their bunker gear and found what protection they could. The doors of the apparatus room blew in and propelled one firefighter 30 feet down a hall. Most of the personnel sought shelter under the trucks as the east wall of the station blew out and the roof collapsed in on them. The roof was prevented from collapsing completely by the snorkel truck, which was parked by the east wall of the building. With the roof resting on the snorkel truck, the personnel were able to escape the heavily damaged building after the tornado had passed.

In the years since the 1970 disaster some efforts have been taken to address this problem. Between the years of 1970 and 1998, four new fire stations were constructed (Sta.'s #1, #3, #12, #14). Three of these four stations (sta.'s #1, #12, #14) were built without a protective shelter, but with an increased emphasis on building strength with strict adherence to the building code. While not a panacea, and certainly not a replacement for underground storm shelters, it did indicate that tornado and extreme wind hazards where being taken into consideration. The forth station (station #3) was constructed with the same adherence to the building code and with a concrete lined basement beneath it for storm protection. Station #11, which had been built prior to 1970 also had a below ground basement. Up until 1998, station #3 and #11 were the only stations with protective storm shelters.

After 1998, a major change in the approach to storm shelter protection was adopted by the fire department administration. This change was to incorporate hardened shelters into the design of all new fire stations, as with station #3 and #11's underground basements, however, the new shelters were to be placed above the ground. Since 1998, the LFD has built five new fire stations (sta. #2, #4, #5, #7, #15) that have incorporated this new style storm shelter into the design of the station. Station #2, is attached to LFD headquarters and the above ground storm shelter contains the dispatch center and a conference room.

Currently there are a total of seven stations (sta.'s #2, 3, 4, 5, 7, 11,15) with storm shelter protection and all seven stations were constructed with the shelters in place as part of the original construction design. The remaining seven stations (sta.'s #1, 6, 8, 9, 10, 12, 14) do not have storm shelter protection. Although the Fire Chief is supportive, there are no announced plans to install shelters in the remaining unprotected stations. There is no station #13 on the LFD. The new technology driving this change was emerging from the Texas Tech University, Wind Engineering Research Center (WERC) that is located in Lubbock. The research at the WERC indicated that if the occupants of a building retreated to a safe, specially designed and constructed shelter area, deaths and injuries would be avoided. Furthermore, above ground storm shelters designed and constructed according to these principles would provide a near-absolute level of protection for the occupants. If the claims for above ground storm shelters are valid, it would mean significant cost savings in comparison to below ground storm shelters. Additional research collaborating these claims would be very useful in justifying the expenses of adding these type shelters to the remaining fire stations in the near future and spreading the knowledge of this style of storm protection to other departments across the nation.

The National Fire Academy (NFA) Strategic Management of Change course was instrumental in the research and development of this research project. Module two's "Change Management Model" module was used as the guide for completion of this applied research project. The first task in the planning phase "examining the forces for and against change" provided the pathway for determining the resistance to or benefits from creating a vision of a forward thinking technological advanced fire department. The passive resistance or acceptance of LFD personnel to the subject of storm shelters indicates that more information is needed. A key parameter to the success of this research project was to provide realistic research data to the Fire Chief and personnel of the Lubbock Fire Department and provide other departments with a comprehensive review of above ground storm shelters.

LITERATURE REVIEW

A literature review for this project was conducted to identify existing research on the subject of above ground storm shelters and the events and factors that create the need for them. The literature review involved a search of magazines, trade journals, fact sheets, textbooks, prior Executive Fire Officer (EFO) applied research projects and LFD construction documents. Those sources found to be relevant to this research project were summarized and included in the report.

Characteristics of Tornadoes

According to the *Glossary of Meteorology* (Huschke 1959), a tornado is "a violently rotating column of air, pendant from a cumulonimbus cloud, and nearly always observable as a funnel cloud or tuba" (n.p.).

Tornadoes are one of the most destructive forces of nature known to man. Each year tornadoes kill and injure a significant number of people and cause millions of dollars in property damage. According to the *National Oceanic and Atmospheric Administration* (1991), "on average, more than 1,200 tornadoes have been reported nationwide each year since 1995. Since 1950, tornadoes have caused an average of 89 deaths and 1,521 injuries annually. Although timely watches and warning have resulted insignificant reductions in deaths and injuries in the last 10 years the need for readily available shelters remains an important issue" (n.p).

According to the Federal Emergency Management Agency publication, FEMA 361 *Design and Construction Guidance for Community Shelters* (2000) "tornadoes are extremely complex wind events that cause damage ranging from minimal or minor to extensive devastation" (p.3-2). In the FEMA 361 simplified tornado model, there are three regions of tornadic winds:

- Near the surface, close to the core or vortex of the tornado. In this region, the winds are complicated and include the peak at-ground wind speeds, but are dominated by the tornado's strong rotation. It is in this region that strong upward motions occur that carry debris upward, as will as around the tornado.
- Near the surface, away from the tornado's vortex. In this region, the flow is a combination of the tornado's rotation, inflow in the tornado, and the background wind. The importance of the rotational winds as compared to the inflow winds decreases with distance from the tornado's vortex. The flow in this region is extremely complicated. The strongest winds are typically concentrated into relatively narrow swaths if strong spiraling inflow rather that a uniform flow into the tornado's vortex circulation.
- Above the surface, typically above the tops of most buildings. In this region, the flow tends to become nearly circular.

Tornadoes are commonly categorized according a scale, which was created by the late Dr. Tetsuya Theodore Fujita, University of Chicago. Dr. Fujita (1971) developed an indirect system of classifying tornadoes by intensity. This classification system is known as the Fujita Scale, or simply the F-scale. The F-scale as listed in FEMA 320 *Taking Shelter from the Storm* (1998) (p.2) has 6 categories of damage:

- F0 - Light: Chimneys are damaged, tree branches are broken, shallow-rooted trees are toppled.
- F1 - Moderate: Roof surfaces are peeled off, windows are broken, some tree trunks are snapped, unanchored mobile homes are overturned, attached garages may be destroyed.
- F2 - Considerable: Roofs structures are damaged, mobile homes are destroyed, debris becomes airborne (missiles are generated), large trees are snapped or uprooted.
- F3 - Severe: Roofs and some walls are torn from structures, some small buildings are destroyed, non-reinforced masonry buildings are destroyed, most trees in forest are uprooted.
- F4 - Devastating: Well-constructed houses are destroyed, some structures are lifted from foundations and blown some distance, cars are blown some distance, large debris becomes airborne.
- F5 - Incredible: Strong frame houses lifted from foundations, reinforced concrete structures are damaged, automobile-sized missiles airborne, trees are completely debarked.

The F-scale should be used with great caution. Tornado wind speeds are still largely unknown; and the wind speeds on the F-scale have never been scientifically tested and proven. Different winds may be needed to cause the same damage depending on how well built a structure is, wind direction, wind duration, battering by flying debris, and a bunch of other factors. Also, the process of rating the damage itself is largely a judgment call -- quite inconsistent and arbitrary (Doswell and Burgess, 1988). However, even though, F-scale wind-to-damage relationships are untested, unproven and contain flaws, the F-scale is the only widely used tornado-rating method, and probably will remain so until ground-level winds can be measured in most tornadoes.

Tornado Alley is a nickname in the popular media for a broad swath of relatively high tornado occurrence in the central United States. This area stretches from West Texas to Kansas, Oklahoma and the rest of the Midwest. The majority of the tornadoes recorded annually in the U.S. occur in this vicinity. Texas has the most with almost 100 setting down every year. Most recently, Concannon, et al., (2000), prepared a "Tornado Alley" map (Appendix A) using significant tornado data indicating the area of greatest incidence. It is in this tornado alley where the city of Lubbock is located and the LFD must conduct operations and at the same time provide protection to its own personnel in the event of a tornado strike.

Above Ground Storm Shelter Characteristics

Above ground storm shelters are intended to provide protection during a short-term high-wind event such as a tornado. FEMA 361 *Design and Construction Guidance for Community Shelters* (2000) describes two types of community shelters:

- stand-alone shelter - a separate building (i.e., not within or attached to any other building) that is designed and constructed to withstand high winds and the impact of wind-borne debris (missiles) during tornadoes, hurricanes, or other extreme-wind events.

- internal shelter - a specially designed and constructed room or area within or attached to a larger building; the shelter (room or area) is designed and constructed to be structurally independent of the larger building to provide the same wind and missile protection as a stand-alone shelter.

FEMA 361 *Design and Construction Guidance for Community Shelters* (2000) states that:

> Shelters designed and constructed in accordance with the guidance presented in this manual provide "near-absolute protection" from extreme-wind events. Near-absolute protection means that, based on our knowledge of tornadoes and hurricanes, the occupants of a shelter built according to this guidance will be protected from injury or death (p.1-2).

The FEMA 361 manual discusses shelter location, design loads, and performance criteria that should be considered for the design and construction of above ground storm shelters. The loads that will act on a tornado shelter will be a combination of vertical and lateral loads. FEMA 361 *Design and Construction Guidance for Community Shelters* (2000) recommends the use of ASCE 7-98 for the calculation of all loads acting on a tornado shelter. When wind loads are considered in the design of a building, lateral and uplift loads must be properly applied to the building elements along with all other loads. The design of the shelter relies on the approach taken in ASCE 7-98 to determine other loads that may act on the shelter. The *International Building Code* (IBC) (2000) and *International Residential Code* (IRC) (2000) also reference ASCE 7-98 for determining wind loads.

FEMA 361 *Design and Construction Guidance for Community Shelters* (2000) states:

> The majority of the wind load provisions are based on wind tunnel modeling of building considering non-cyclonic, straight-line winds. Most wind engineers believe that the results from these wind tunnel tests can be used to determine wind pressure from hurricanes. Tornado wind fields are believed to be more complex than the winds modeled in wind tunnel tests that form the basis for the wind loads calculated in ASCE 7-98. However, in investigations of buildings damaged by tornadic winds, the damage is consistent with damage caused by the forces calculated by ASCE 7-98. For this reason, use of ASCE 7-98 provisions provides a reasonable approach to calculating wind loads for tornadoes, even thought it is know that these winds are more complex than the wind field used in the models (p.5-5).

In addition to meeting wind load requirements, a structure's roof, walls, doors and windows must also be resistant to missile impacts. From over 30 years of post-disaster investigations after tornadoes and hurricanes, the Wind Engineering Research Center, (WERC) *Design of Residential shelter from Extreme Winds* (1998) concluded that the missile most likely to perforate building components is a wood 2x4 member weighing up to 15lb.

According to FEMA *National Performance Criteria for Tornado Shelters* (1999) (Appendix B) "Loads from wind-borne missile impacts must be considered. For design purposes, it is assumed that the design wind speed of 250 mph propels a 15-lb. missile horizontally at 100 mph. The design missile is a nominal 2x4 wood board, weighing 15 lbs., striking the shelter enclosure on end 90^0 to the surface. The vertical missile design speed is 2/3 of the horizontal speed or 67 mph." (p.4).

FEMA 361 *Design and Construction Guidance for Community Shelters* (2000) requires that a 100-mph missile speed be used for missile impact resistance for FEMA designated wind zones I-IV. The limited testing performed at missile speeds lower than the 100-mph impact speed did not provide conclusive data or result in cost savings great enough to justify varying missile impact criteria.

Factors For Change

According to FEMA 361 *Design and Construction Guidance for Community Shelters* (2000) many factors influence the decision to build above ground storm shelters, they include:

- the level of risk
- the consequences of a tornado (injury or death)
- the cost of constructing an above ground shelter

Of the factors that influence this decision process, the potential for death or injury is the foremost reason to build a shelter, however, this is directly related to the level of risk involved. According to the tornado zone map (Appendix C) in the FEMA publication FEMA 320: *Taking Shelter from the Storm* (1998) (p. 3) and the wind zone map (Appendix D) in the same publication (p.6), Lubbock is located in a wind zone III region with 11 to 15 tornadoes recorded per 1,000 square miles annually. By taking the regional information from these two maps and extrapolating it to the risk worksheet found in FEMA 320 (p. 8) (Appendix E) it is determined that Lubbock and the surrounding area is rated as a high-risk for extreme winds and a shelter is the recommended method of protection.

Yet, even living and working in a high-risk region does not mean that change will be embraced overnight when it comes to above ground storm shelters. Billy Frost (1993) said, " 'Change' is a word that prompts many reactions in fire service personnel. Many see it as something to fear, or that they simply don't understand, and consequently they resist it" (p. 122). Randy Bruegman (1994) states:

> One of the most interesting aspects of the fire service is that our heritage and traditions can so often cloud our vision of the future. For many organizations and chief officers it's very difficult to step outside of the established range of what is comfortable or what has been done in the past (p.102).

Williness to pay for a mitigation measure is highly dependent on perception of the uncertain hazard. According to V.K. Smith (1986), "perceived characteristics of hazards not statistical/technical estimates of risks, determine individual valuations of safety" (n.p). Similarly, slovic et al., (1980) says "People respond to the hazards they perceive not the true probabilities of the hazards" (p.181).

In a survey study, McDaniels, et al., (1992) examined the relationship between risk perception and willingness to pay for increased safety. They developed a conceptual model and a contingent valuation and risk perception survey for ten technological hazards. Death rates were known and the risks were relatively common knowledge for five well-defined hazards. Their conceptual model expressed the maximum williness to pay for risk reduction as a function of socioeconomic variables (income, age base, level of risk, exposure to hazard, and family size) and perceived characteristics of a hazard (voluntariness, severity, knowledge, control, and dread).

Their survey included open-ended questions to measure the maximum williness to pay. In addition, eight psychometric scale type questions were used to detect risk perceptions. According to fifty-five completed surveys, “williness to pay for less defined risks is most influenced by levels of dread and severity" (p. 495).

People do not believe that a disaster can happen to them unless the probability of occurrence is at such a high level that it shocks them out of their level of comfort. According to Cook, (1989) "even when change is desirable and will benefit all those affected by it, a department leader should remember that a fire department is a complex system shaped by its traditions and bound by a bureaucracy highly resistant to change. By its very definition, a system is a group of items or parts, forming a whole, that tends to exist in an equilibrium. It is the nature of all systems to maintain stability and balance. In other words systems tend to do what they were originally designed to do. The system and its inhabitants desire to maintain the status quo and resist any intrusion or disruption" (p. 74).

However, in the area of protection from natural disaster, the demand for change may be increasing across the country. James Lee Witt (2000) said, "natural disasters are getting more frequent and more severe, tornado activity, we see now, normally starts in the spring of the year, starting in January" (n.p).

In the long run, resistance to change may be overcome by the unstoppable power of a tornado and the convenience of above ground storm shelters. According to FEMA 361 *Design and Construction Guidance for Community Shelters* (2000) potential advantages of an internal above ground shelter include:

- A shelter that is partially shielded by the surrounding building may not experience the full force of the tornado wind.
- A shelter designed to be within a new building may be located in an area of the building that the building occupants can reach quickly without going outside.
- Incorporating the shelter into a planned renovation or building project may reduce the shelter cost.

In summary, the literature discussed and supported the need for above ground storm shelters in the remaining unprotected LFD fire stations. The city is considered by FEMA to be in a high-risk wind zone with 11 to 15 destructive tornadoes striking within a 1000 square mile area annually, where shelter is the recommended protective mechanism for tornadoes.

Review of past research by the WERC and FEMA showed that shelters designed and constructed in accordance with the guidance presented in the FEMA 361 manual provide "near-absolute protection" from extreme-wind events. The literature review made it clear that there is a definite need for shelter protection from tornadoes in the Lubbock region and that above ground storm shelters are extremely effective in providing this protection. Furthermore, extending this program to the balance of fire stations within the department, would be in line with the original change factors of strengthening the community and making the best use of material resources and personnel in the LFD that prompted the above ground storm shelters being placed in the new stations.

PROCEDURES

Evaluative research was the method used in determining the recommendations for adding above ground storm shelters LFD responders into every fire station in the LFD. The research procedures used in preparing this paper began with a literature review at the Learning Resource Center (LRC) at the NFA in August of 2000. Additional information was gathered from the Wind Engineering Research Center library located at Texas Tech University, the LFD library and through the use of the Internet.

The literature targeted magazines, journals, newsletters, fact sheets and prior Executive Fire Officer (EFO) applied research projects and LFD construction documents for the rationale on determining the capabilities above ground storm shelters. Applicable national standards, such as ASCE regulations, were also researched to ensure uniformity between parochial and national concerns.

Multiple parameters were studied in conducting this research project. The objectives were to research information about above ground storm shelters and to: (1) identify the need for shelters in the LFD; (2) evaluate if above ground storm shelters are truly effective; and (3) assess whether or not above ground storm shelters should be placed in all LFD stations. A key parameter to the success of this research project was to provide realistic research data to the Fire Chief and personnel of the Lubbock Fire Department and provide other departments with a comprehensive review of above ground storm shelters.

The first step in this project was to conduct interviews with the project leaders of the Wind Energy Research Center (WERC) at Texas Tech University. The first interview was with Larry Tanner, who is a Senior Research Associate with WERC, and is a member of the in-residence shelter research team, charged with developing public information documents - information and outreach. The purpose of this interview was to determine what are the characteristics of above ground storm shelters and how could they be best utilized protecting LFD responders.

The next interview was with Russell Carter, who is a Senior Research Associate and manages the debris launch facility of the WERC. The purpose of this interview was to determine what are the main hazards of high-energy wind events, such as tornadoes, and how effective are above ground storm shelters against these hazards. The results of these informal interviews are included in the "Results" section of this report.

The next step in this project was to develop an actual benefit cost analysis (Appendix F) of installing an above ground storm shelter in relation to the risk of a tornado impacting the LFD. This analysis was developed so that the project focus chosen would satisfy the threat protection needs of LFD responders and was created by utilizing the benefit cost analysis software developed by FEMA for above ground storm shelters.

One need identified was to promote the benefits and protective factors of this type of shelter to LFD personnel so that they will have confidence in these shelters in the event of another tornado strike on Lubbock. Additional needs included research verifying the protective claims of these type shelters, these protective factors would be very useful in justifying the expenses of adding these type shelters into the remaining fire stations in the city and spreading the knowledge of this style of storm protection to other departments across the nation.

Limitations

This research had limitations. The first limitation was the fact that there was no verifiable research performed by the City of Lubbock's Construction Manager prior to building these type shelters into the design of the new stations. While FEMA has developed standardized construction criteria for this type of project in homes and community shelters, formalized standards for building them into fire stations have not yet been created. Reference material was extremely limited outside of the circle of FEMA and the WERC. Research related to this subject was restricted to reports available in magazines, trade journals, fact sheets, textbooks, prior Executive Fire Officer (EFO) applied research projects and LFD construction documents. Recommendations were made on the basis of reference material available to the researcher operating within the above-mentioned constraints.

Definition of Terms

The material and terms contained in this research report are presented in a clear and unambiguous manner, in order to communicate the overall intent and message to the reader. However, much of the material referenced in this report is industry specific and requires a key to understand the terms used. For an in-depth list of acronyms and abbreviations, please reference FEMA 361 *Design and Construction Guidance for Community Shelters* (2000) (p.xix).

RESULTS

Using a literature review, the research questions were answered and conclusions were drawn about the need and benefits of above ground storm shelters in LFD fire stations. For the researcher, it was clearly indicated that this type of shelter is the most realistic and cost effective solution that exists today to the threat of tornadoes.

Is there a need for shelters in the LFD?

A tornado is a violent windstorm characterized by a twisting, funnel-shaped cloud. It is spawned by a thunderstorm (or sometimes as a result of a hurricane) and produced when cool air overrides a layer of warm air, forcing the warm air to rise rapidly. The damage from a tornado is a result of the high wind velocity and wind-blown debris. Tornado season in the U.S. is generally March through August, although tornadoes can occur at any time of year. They tend to occur in the afternoons and evenings, over 80 percent of all tornadoes strike between noon and midnight.

Tornadoes produce the most violent winds on earth. Tornado winds can approach speeds as high as 300 miles per hour, travel distances over 100 miles and reach heights over 60,000 feet above ground. The best protection during a tornado is in an interior room on the lowest level of a building, preferably a hardened shelter.

Each year over three billion man-hours are spent in the United States under tornado watches. In more than half the watches issued, a tornado occurs somewhere within the watch area. People in tornado prone areas experience anxiety and loss of productivity unless a safe place is readily available. According to John J. Kelly Jr., (2000) Director of the National Oceanic and Atmospheric Administrations (NOAA) National Weather Service. "Since 1998, nearly 2,700 tornadoes have killed almost 200 people and devastated numerous communities" (n.p). Kelly explains that the United States is the most severe weather prone region in the world, due to the 10,000 severe thunderstorms, and 1,000 tornadoes that occur in the USA each year on average.

A review of statistical data at NOAA's National Severe Storms Laboratory of severe storm data from 1980 to 1994 indicates that the peak threat for tornadoes in the southeastern United States occurs during March and April. Then the tornado threat moves west and north, peaking in tornado alley – including Texas, Oklahoma, Kansas, Nebraska, Iowa and eastern Colorado – in May and early June. Although tornadoes do occur throughout the world, the United States experiences the most intense and devastating tornadoes.

Are Above Ground Storm Shelters Truly Effective?

Post-storm inspections of hundreds of homes in more than 90 towns and cities struck by tornadoes revealed that in many instances a small room in the central portion of the house remained standing even when the house was severely damaged or completely destroyed (WERC, 1998). The idea was then conceived that these interior rooms could economically be strengthened to provide a high degree of occupant protection.

Mr. Russell Carter, Associate Director of Missile Impact Studies at WERC has conducted extensive research to better understand and mitigate the effect of severe winds. More than 90 windstorms have been investigated across the country so that damage can be better understood and designs for mitigation developed.

An informal phone interview with Mr. Carter was conducted in order to determine what are the main hazards of high-energy wind events, such as tornadoes, and how effective are above ground storm shelters against these hazards. Mr. Carter concurred with FEMA that above ground storm shelters afford "near absolute" protection against tornadoes, as defined previously in this report. Mr. Carter reports that above ground storm shelters would provide protection against a 250 mph tornado and that the "the 250 mph wind zone rating for the Lubbock, TX area covers 99.7% of all tornadoes that have been studied in the last fifty years."

Mr. Carter reports that tornado-generated missiles (flying debris) create the greatest threat to occupants of homes that are struck by severe wind. These missiles, very often, perforate conventional walls and roofs. In order to provide a high degree of occupant protection, the shelter must be designed to prevent perforation by missiles on all surfaces--walls, roof, and door. The missile chosen for shelter design testing is a 2x4-inch timber plank weighing approximately 15 lbs., striking on end at 100 mph for walls and doors and at 67 mph for roof/ceilings. Mr. Carter has conducted extensive testing by using a compressed air cannon to thrust missiles at various building sections.

Construction Cost

The most cost-effective means of constructing a shelter at a site is to incorporate the shelter into a new building being planned for construction. The cost to design and construct hardened shelters within new buildings is much lower than in retrofit situations, in which above ground storm shelters are installed into an existing building.

According to Mr. Carter construction costs vary in different parts of the country. Factors affecting cost include size of shelter, materials chosen, type of door and accessibility for construction in retrofits. However, material costs for new construction of an 8'x8' shelter on an average range from $3,000 to $8,000, including door and hardware. Construction cost for retrofitting or adding an above ground shelter into an existing building would run on an average 30% higher than new construction cost for the same size shelter. However, even at the higher rate the cost of an above ground shelter is substantially less than that of a basement.

In order to compare the benefits of an above ground storm shelter to the construction cost in numerical form, the benefit cost analysis software developed by FEMA (Appendix F) was utilized. A total project cost of $15,000 was estimated to retrofit an above ground storm shelter into an existing fire station with an average staffing of eight personnel. The total expected annual benefits due to avoidance of injuries and death over a twenty year period for Lubbock County is $3,813 per fire station. The Annualized project cost are $1,416 leaving an expected annual net benefit of $2,397 per fire station with an above ground shelter.

Requirements For An Above Ground Shelter

Typical construction practices for homes and schools in the United States reflect little or no emphasis on structural engineering, especially when it comes to factoring in wind resistance. Individual components of the average home may be inadequately connected and not sufficiently linked to other elements. However, it is imperative that we design to resist wind storms (Clemson, 2000).

Adequate fasteners are the key to satisfactory structural performance of the shelter. The roof must be securely anchored to the walls, the walls to each other, and the walls to the foundation. These connections are necessary to insure structural integrity and to prevent the shelter from overturning. FEMA 361 *Design and*

Construction Guidance for Community Shelters (2000) states that the requirements for an above ground shelter are:

- Good Accessibility
- Resistance to Wind Forces
- Adequate Fasteners
- Adequate Coverage
- Resistance to Missile Perforation

For the above ground shelter to be effective, it must be readily accessible from all parts of the building. The central portion is the favored location, for added protection as well as accessibility. The shelter must be able to resist the forces that extreme winds or interacting structural components place upon it. The above ground shelter is designed to withstand wind speeds of 250 mph, which accounts for virtually all tornadoes which have occurred in the U.S..

Should Above Ground Storm Shelters be Placed in all LFD Stations?

During the research process of this project a personal interview was conducted with Mr. Larry Tanner, who is a Senior Research Associate with WERC, and is a member of the in-residence shelter research team, and charged with developing public information documents. The purpose of this interview was to determine characteristics of above ground storm shelters and how could they be best utilized protecting LFD responders.

Mr. Tanner reports that above ground storm shelters or "safe rooms" are reinforced small rooms built in the interior of a building, which are fortified by concrete and/or steel to offer extra protection against tornadoes, hurricanes and other severe windstorms. They can be built in a basement, or if no basement is available, on the ground floor. In existing buildings, interior rooms or closets can be fortified into shelters.

This fortification of the walls and ceiling of a shelter is a result of need for protection from flying debris and keeping the structural components intact during total structural loads created by 150-250 mph winds (which exceeds the speeds found in most tornadoes) from any direction. Mr. Tanner advises flying debris is the biggest tornado hazard and that's why one needs to put as many walls as possible between oneself and the tornado. Interior hallways, rooms or corridors, which are exposed to the outside through windows, doors or walls of glass can turn into a death trap of flying broken glass.

For LFD responders to respond to the needs of the community operationally and rapidly, they must be provided protection, in order to be part of the solution and not become part of the problem. However, as unlikely a tornado strike is in any given locale, its potential devastating impact makes it vital to LFD responders, to provided short term protection to help in the long term recovery of the community. While, the requirements for these shelters won't come cheap and they will compete for budget dollars from other important needs, it is important to install these shelters in all of the existing fire stations, because, they will ultimately save lives.

Since we are a tax-supported department, we must first gain the support of the community and the community leaders. To achieve the objective of acquiring support for the funding of installing above ground storm shelters into fire stations requires an in-depth analysis of community standards and governmental organizations. The framework of these organizations becomes the framework in which one is required to function and develop support for fire department funding. A major ally is an informed public, an informed and concerned public wields a significant amount of power. The steps for obtaining community support include: identifying tornado hazards, assessing the Lubbock community's attitudes and needs, implementing planning within the government, evaluating resources, and initiating a public education program.

Listed below are some preliminary steps for obtaining community support:

- Use "windows of opportunity" (e.g.. heightened levels of awareness and interest in the aftermath of a disaster) to create change.
- Identify and cultivate a wide range of potential allies, both inside and outside the emergency response organizations.
- Be a source of accurate, easily understood, and timely information.
- Be sensitive to the various needs of the diverse constituencies that make up the community.
- Emphasize team building among agencies, and identify and work toward this common goal.
- Help bridge the gap between specialists and politicians views of reality by effectively communicating the risk of disaster.

In summary, we possess unprecedented means to anticipate hazards, protect citizens and property, and reduce accompanying disruption caused by tornadoes. We in the emergency services should lead the community in assigning a priority to mitigation efforts to protect our people from injury and death. These efforts include disaster-resistant construction, retrofitting of existing structures, and protection of critical infrastructure—communications, electricity, gas, water.

Providing above ground storm shelters in the remaining fire stations that do not yet have protective shelters will strengthen the community and make the best use of material resources and personnel. Above ground storm shelters, when constructed according to WERC and FEMA standards, have the best possible combination of cost-effectiveness and protective mitigation features that exists today. Having these shelters in all fire stations will result in fewer fatalities, fewer injuries and less damage in the event of another tornado strike. These type of positive mitigation efforts and results will go far in obtaining community support.

DISCUSSION

The literature review confirmed the authors opinion that tornadoes are a real and continuing threat in the Lubbock area and that the LFD must be prepared to respond to and deal with this type of emergency event. The damage from tornadoes comes from the strong winds they contain. The biggest threat to people from tornadoes comes from flying debris. It is expected that wind speeds can reach as high as 300 mph in the most violent tornadoes. Wind speeds that high can turn broken glass and other debris into lethal missiles.

Wind-borne missiles range in size from roof gravel to large objects such as railroad cars or storage tanks. Bailey (1984) categorized missiles as small, medium or heavy. The small missile category includes roof gravel, tree branches and pieces of lumber. Small diameter pipes, steel roof joists and small beams comprise typical missiles in the medium category. Utility poles, large diameter pipes, automobiles, railroad cars, and storage tanks fit into the heavyweight missile class (n.p).

The author of this research project has reached the conclusion that having an above ground shelter built into all fire stations would be an effective mitigation measure that could help protect fire department personnel from injury or death caused by the dangerous forces of extreme winds. The FEMA Fact Sheet: *Tornado Safety Tips Brochure* (1999) states:

- Mitigation includes any activities that prevent an emergency, reduce the chance of an emergency happening, or lessen the damaging effects of unavoidable emergencies. Investing in preventive mitigation steps now, such as checking local building codes and ordinances about wind-resistant designs and strengthening unreinforced masonry, will help reduce the impact of tornadoes in the future.

Two important components of hazard mitigation for tornadoes are assessing the vulnerability of buildings and infrastructure, and increasing building and infrastructure resistance to damage caused by tornadoes. This increased damage resistance is achieved through improvements in the construction methods, and the materials used for both new construction and for retrofitting existing structures.

The literature review confirms and supports the fact that the best way for the LFD to serve the best interests of the city and its citizens is to provide protection to its personnel, so that they may serve the needs of the community in the aftermath of a tornado disaster. Above ground storm shelters are the best way to provide this protection, specifically shelters that are designed to provide near absolute protection from the high winds expected during tornadoes and from associated flying debris, such as wood studs, that tornadoes usually create. They can also relieve some of the anxiety created by the threat of an oncoming tornado or hurricane.

It is the opinion of this author that above ground storm shelters have the best possible combination of cost-effectiveness and protective features against wind-borne missiles that exists today. Having these shelters in all fire stations will result in fewer fatalities, fewer injuries and less damage in the event of another tornado strike. According to Fischer, et al., (1991) "individuals consider themselves responsible in the case of any threat to their own health, on the other hand, the government is stated to be responsible for managing environmental risks" (n.p).

It is up to the local governments to have a community readiness system in place for their citizens and provide the resources and protection to their emergency responders to achieve those goals. The two most common reasons for a lack of shelters are low budgets and the *perception* that tornadoes do not present a significant risk in an area. The latter is false, and the former is a matter of fiscal priorities.

The implications of the literature review are clear. Above ground storm shelters provide an excellent level of protection from tornadoes and the accompanying wind-borne missiles. No new technology or unusual building skills are required in construction and the associated costs are nominal when compared to the benefits to the LFD and the community.

RECOMMENDATIONS

The main emphasis of any department that seeks to change the way things were done in the past and utilize new technologies must be on strengthening the community and making the best use of material resources and personnel. Above ground storm shelters fulfills those requirements and those first responders agencies that have the benefit of such shelters will undoubtedly suffer fewer fatalities, fewer injuries and less damage in the event of a tornado. Therefore, it is recommended that the LFD should add into its budgetary planning activities, the retrofitting of above ground storm shelters into the remaining seven unprotected fire stations.

It is also recommended that the LFD should lobby the support of LFD personnel as well as city and community leaders. Identified steps for obtaining community involvement include, assessing the communities attitudes and needs, implementing planning within the government, evaluating resources, and initiating a public education program about wind zone risk. A primary focus of this effort should be to place research information on the shelters that are in the new LFD fire stations on the departmental Internet web page. Thereby allowing access to up-to-date information to LFD personnel, concerned citizens, and to other emergency response organizations that are seeking information on the subject. Above all, opportunity for public involvement is essential.

In order to facilitate the process of retrofitting above ground storm shelters into existing buildings it is recommended that the LFD utilize the recently released First Edition of Design and Construction Guidance for Community Shelters (FEMA 361). This detailed design manual was developed in collaboration with the Wind Engineering

Research Center of Texas Tech University, Clemson University, the International Code Council, the U.S. Department of Education, and the American Red Cross.

The shelters described in FEMA 361 are designed to protect large numbers of people, and are intended to provide near absolute protection from tornadoes and the wind-borne missiles that tornadoes create. These shelters can economically provide a high degree of occupant protection and provide for faster disaster recovery after a tornado.

In Summary, The recommendations resulting from this research include: (1) the LFD should include in its budgetary planning activities, the retrofitting of above ground storm shelters into the remaining seven unprotected fire stations; (2) lobbying the support of LFD personnel and city and community leaders; and (3) utilizing the information in FEMA 361 to facilitate the retrofitting process of above ground storm shelters into existing LFD fire station.

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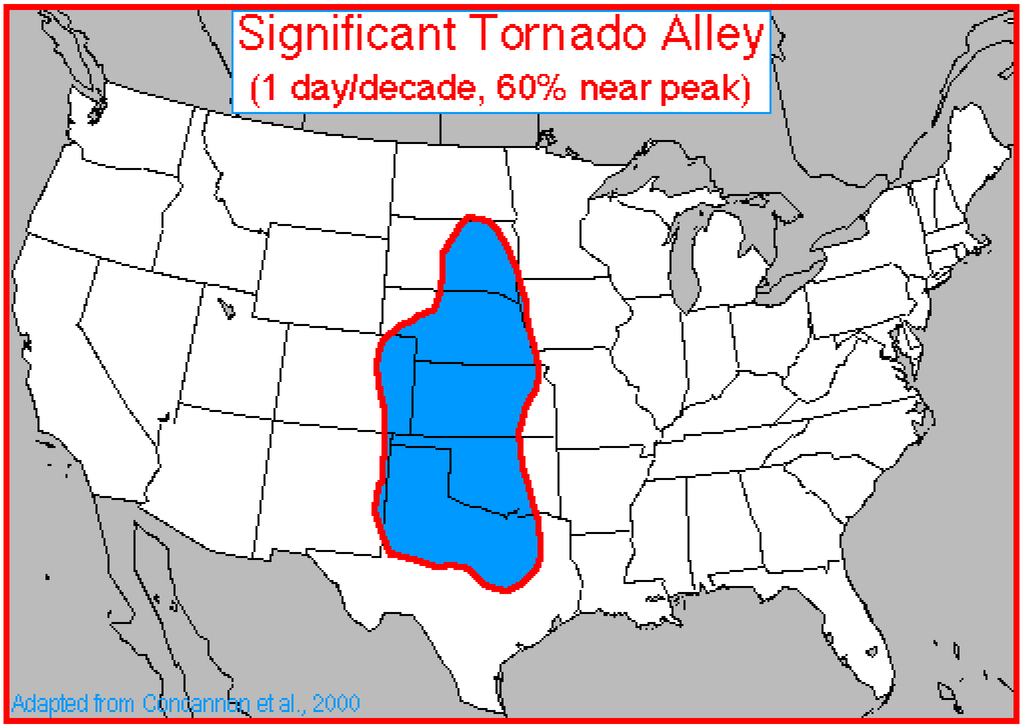
APPENDIX A


Significant Tornado Alley
(1 day/decade, 60% near peak)
Adapted from Concannon et al., 2000

APPENDIX B

National Performance Criteria for Tornado Shelters
Federal Emergency Management Agency
Mitigation Directorate
Washington, D.C.

Comments and Questions

The Federal Emergency Management Agency, in cooperation with the Wind Engineering Research Center at Texas Tech University, has developed these performance criteria for tornado shelters. Comments on these criteria should be directed to:

Program Policy and Assessment Branch
Mitigation Directorate
Federal Emergency Management Agency
500 C Street, S.W.
Washington, D.C. 20472
e-mail: building.science@fema.gov

Technical questions on these performance criteria should be directed to:

Wind Engineering Research Center
Texas Tech University
Box 41023
Lubbock, TX, 79409-1023
(888) 946-3287 ext. 336
e-mail: ltanner@coe.ttu.edu

Limit of Liability

These performance criteria are based on extensive research of the causes and effects of windstorm damage to buildings. Shelters designed and built to these performance criteria should provide a high degree of occupant protection during severe windstorms. Any variation from these design or construction performance criteria, or deterioration of the structure, may decrease the level of occupant protection during a severe wind event.

Because it is not possible to predict or test for all potential conditions that may occur during severe wind storms or control the quality of the design and construction, the Federal Emergency Management Agency, Texas Tech University and others involved in the development of this performance criteria do not warrant these performance criteria.

The Federal Emergency Management Agency, Texas Tech University and others involved in the development of these performance criteria neither manufacture nor sell shelters based on these performance criteria. The Federal Emergency Management

Agency, Texas Tech University and others involved in the development of these performance criteria do not make any representation, warranty, or covenant, expressed or implied, with respect to these performance criteria, or the condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect what so ever. The Federal Emergency Management Agency, Texas Tech University and others involved in the development of these performance criteria shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and other performance of shelters built from these performance criteria or from the maintenance thereof.

Introduction

Shelters constructed to these performance criteria are expected to withstand the effects of the high winds and debris generated by tornadoes such that all occupants of the shelter during a tornado will be protected without injury. These performance criteria are to be used by design professionals, shelter manufacturers, building officials, and emergency management officials to ensure that shelters constructed in accordance with these criteria provide a consistently high level of protection. The following describes the performance criteria.

Performance Criteria

1. Resistance to Loads from Wind Pressure for Shelters

   a) Wind pressures are to be determined using ASCE 7-95 *Minimum Design Loads for Buildings and Other Structures* (or revisions to this standard). Pressures for the Main Wind Force Resisting System (MWFRS) are to be used for the walls, ceiling, structural attachments and foundation system. Pressures for Components and Cladding are to be used for the door(s) and other attachments to the exterior of the shelter. For computing wind pressures to be used as a service load, the wind velocity (V) shall be 250 mph (3-second peak gust).

   b) The shelter walls, ceiling and floor will withstand design pressures such that no element shall separate from another (such as walls to floor, ceiling to walls). Such separation shall constitute a failure of the shelter.

   c) The entire shelter structure must resist failure from overturning, shear (sliding), and uplift from design pressures. *Note: For the in-residence shelter designs described in FEMA 320, ceiling spans and wall lengths were less than 8 feet and the design of the wall and ceiling was governed by the need for missile protection. For larger shelters, the capacity of structural elements to withstand the forces described in above in 1. (a) shall be determined by engineering analysis. For larger shelters, the plans in FEMA 320 can be used only for missile (airborne debris) resistance.*

   d) The Allowable Stress Design (ASD) method shall be used for the shelter design for any of the construction materials selected (concrete, concrete masonry, wood, etc.). Unfactored load combinations shall be used in accordance with ASCE 7-95 for allowable stress design. Because of the extreme nature of this design wind speed, other environmental loads, such as flood or earthquake loads, should not be added. An alternative design method for materials with accepted Load and Resistance Force Design (LRFD) standards may be used in lieu of ASD.

e) No importance factor shall be added to the pressure calculations because the extreme nature of the design event already accounts for critical nature of the shelter. Therefore, the importance factor (I) used in the design computations shall equal one. The internal gust coefficient (GC_{pi}) shall be for buildings with no openings.

f) In the event that the roof of the shelter is exposed at grade, the roof of the shelter shall be able to resist wind pressures as determined in sections 1(a) through (e).

2. Windborne Missile Impact Resistance On Shelter Walls and Ceiling

a) Loads from windborne missile impacts must be considered. For design purposes, it is assumed that the design wind speed of 250 mph propels a 15-lb. missile horizontally at 100 mph. The design missile is a nominal 2x4 wood board, weighing 15 lbs., striking the shelter enclosure on end 90^0 to the surface. The vertical missile design speed is 2/3 of the horizontal speed or 67 mph. For Below-Grade Shelters, only the impact from vertical missiles on the shelter roof must be considered. *Note: From testing, it has been shown that the primary failure of enclosure materials from missile impact has been shearing of the material due to the high velocity and that missile perforation resistance is provided by a material (or combination of materials) that provide energy dissipation of the missile impact.*

b) The walls and ceiling of a shelter must resist perforation by the design missile such that the missile does not perforate the inside most surface of the shelter. Only shelter wall openings used for access are permitted. Windows, skylights, or other similar openings shall not be used unless they have been laboratory tested to meet the missile impact criteria of section 2(a). *Note: The Wind Engineering Research Center at Texas Tech University has tested numerous materials and material combinations and should be contacted regarding performance of those materials. For in-residence shelters, the designs of FEMA Publication No. 320 <u>Taking Shelter From the Storm: Building a Safe Home in Your Home</u> should be used. For other than in-residence shelters, it is recommended that materials proven to provide the required stiffness and missile impact resistance such as reinforced concrete or reinforced concrete masonry should be used.*

c) Alternative materials and material combinations for both shelter walls and ceilings shall be permitted after testing has proven the alternative materials will meet the missile impact criteria contained herein. *Note: Existing missile impact standards in the Standard Building Code, the South Florida Building Code, the Texas Department of Insurance Code, and ASCE 7 do not include missiles of the size, weight or speed of those discussed in these performance criteria. Therefore, those standards may not be used to determine applicability of alternative materials and material combinations for tornado-generated missiles.*

3. Other Loads

- The designer should assess whether an adjacent structure is a liability to the shelter, that is, if it poses a threat to the shelter from collapse. If the adjacent structure is deemed a liability, the loads imposed upon the shelter due to the collapse of this adjacent structure shall be considered as an additional impact load on the shelter.

4. Shelter Access Doors and Door Frames

   a) Shelter entry doors and their frames shall resist the design wind pressures for components and cladding in section 1 of this criteria and the missile impact loads of section 2 of this criteria. Only doors and their frames that can resist calculated design wind pressures and laboratory tested missile impacts are acceptable. All doors shall have sufficient points of connection to their frame to resist design wind pressure and impact loads. Unless specifically designed for, each door shall be attached to their frame with a minimum six points of connection. *Note: See the design specifications and details for shelter doors in FEMA publication 320 for additional guidance. Door designs and materials of construction included in FEMA publication 320 were developed through calculations and laboratory testing at Texas Tech University.*

   b) A protective missile resistant barrier is permitted to protect the door opening. The door should then be designed to resist wind pressures.

   c) The size and number of shelter doors shall be determined in accordance with applicable fire safety and building codes. In the event the community where the shelter is to be located has not adopted current fire safety and building codes, the requirements of the most recent editions of a model fire safety and a building code shall be used. *Note: The design specifications and details for shelter doors in FEMA publication 320 are for single swinging doors not exceeding 3 feet in width. No laboratory missile impact testing has been performed on double swinging doors or other door configurations other than 3 feet wide single swinging doors.*

5. Shelter Ventilation

   a) Ventilation for shelters shall be provided through either the floor or the ceiling of the enclosure. A protective shroud or cowling, meeting the missile impact requirements of section 2 of these criteria, must protect any ventilation openings in the shelter ceiling. The ventilation system must be capable of providing the minimum number of air changes for the shelter's occupancy rating. In the event the community where the shelter is to be located has not adopted a current building and/or mechanical code, the requirements of the most recent edition of a model building code shall be used. *Note: Ventilation may be provided with ducts to an outside air supply.*

b) If ventilation to the shelter is provided by other than passive means, then all mechanical, electrical and other equipment providing this ventilation must be protected to the same standard as the shelter. In addition, appropriate design, maintenance and operational plans must ensure operation of this equipment following a tornado.

6. Emergency Lighting

- Emergency lighting shall be provided to all shelters serving over 15 persons.

7. Shelter Sizing

- The following are minimum floor areas for calculating the size of shelters:

• Adults	5 square feet per person standing
• Adults	6 square feet per person seated
• children (under the age of 10)	5 square feet per person
• Wheelchair bound persons	10 square feet per person
• Bed-ridden persons	30 square feet per person

8. Shelter Accessibility

a) The needs of persons with disabilities requiring shelter space must be considered, and the appropriate access for such persons must be provided in accordance with the Americans with Disabilities Act (ADA).

b) In designing shelter(s), the designer shall consider the time required for all occupants of a building and facility to reach refuge in the shelter(s). *Note: While the National Weather Service has made great strides in providing warnings, to provide greater protection, it is recommended that in locating shelters or multiple shelters, all occupants of a building or facility should be able to reach a shelter within 5 minutes, and that all occupants should be in a shelter with doors secured within 10 minutes.*

9. Emergency Management Considerations for Shelters

a) Each shelter shall have a tornado emergency refuge plan; this plan is to be exercised at least twice per year.

b) Shelter space shall contain, at a minimum, the following safety equipment:
   - Fire extinguisher surface mounted on the shelter wall. In no case shall a fire extinguisher cabinet or enclosure be recessed into interior face of the exterior wall of the shelter.
   - Flashlights with continuously charging batteries
   - First aid kit rated for the shelter occupancy
   - Potable water in sufficient quantity to meet the drinking needs of the shelter rated occupancy for 8 hours
   - A NOAA weather radio with continuously charging batteries

c) The following placards and identification shall be installed in each building with a shelter other than shelters within single family residences:
   - The location of each shelter shall be clearly and distinctly identified with permanently mounted wall placards located throughout the building that direct the building occupants to the shelter.
   - The outside of all doors providing access to a shelter shall be clearly identified as a location to seek refuge during a tornado.
   - Placards shall be installed on the inside of each shelter access door or immediately adjacent that instructs shelter occupants on how to properly secure the shelter door(s).

10. Additional Requirements for Below Grade Shelters:

- The shelter must be watertight and resist flotation due to buoyancy from saturated soil.
- The shelter must contain either battery-powered radio transmitters or a signal-emitting device to signal the location of the shelter to local emergency personnel should occupants in the shelter become trapped due to debris blocking the shelter access door.

11. Multihazard Mitigation Issues

a) Flooding
   - No below grade shelter shall be constructed in a Special Flood Hazard Area or other area known as being flood prone.
   - In the event that an above ground shelter is located in a Special Flood Hazard Area (SFHA)of other known flood prone area, the floor of the shelter shall be elevated to or above the Base Flood Elevation or other expected level of flooding.
   - All shelters constructed in a SFHA and/or other regulatory floodplain areas shall conform to state and local floodplain management requirements.

b) Earthquake

- Shelters located in earthquake prone areas shall be designed and constructed in accordance with seismic safety provisions contained in local building codes. In the event the community where the shelter is to be located has not adopted a current building code, the requirements of the most recent edition of a model building code and/or the National Earthquake Hazard Reduction Program Recommended Provisions shall be used.

12. Construction Plans and Specifications

- Complete detailed plans and specifications shall be provided for each shelter design. Sufficient information to ensure that the shelter is built in accordance with both the specific requirements and intent of these performance criteria shall be provided. *Note: The plans and specifications found in FEMA publication 320 are a good basis for developing plans (including standardized details) and specifications.*

13. Quality Control

- The quality of both construction materials and methods shall be ensured through the development of a quality control program. This quality control program shall identify roles and responsibilities of the contractor, design professional, and local permit official in ensuring that the shelter is constructed with materials and methods that meet the requirements stipulated in the plans and specifications developed from these performance criteria.

14. Obtaining Necessary Permits

- Prior to beginning construction, all necessary state and local building and other permits shall be obtained and clearly posted on the job site. *Note: Model building codes do not address the design of a tornado shelter. Therefore the owner and the design professional should ensure that the shelter is properly designed and constructed.*

Sources of Additional Information

FEMA has developed two publications that may be of assistance in developing tornado shelter designs:

- FEMA TR-83B *Tornado Protection: Selecting and Designing Safe Areas in Buildings*
- FEMA 320 *Taking Shelter From the Storm: Building a Safe Room Inside Your House*

A copy of FEMA 320 can be ordered by calling 1-888-565-3896. FEMA TR-83B, and all other FEMA publications, may be ordered by calling 1-800-480-2520.

APPENDIX C

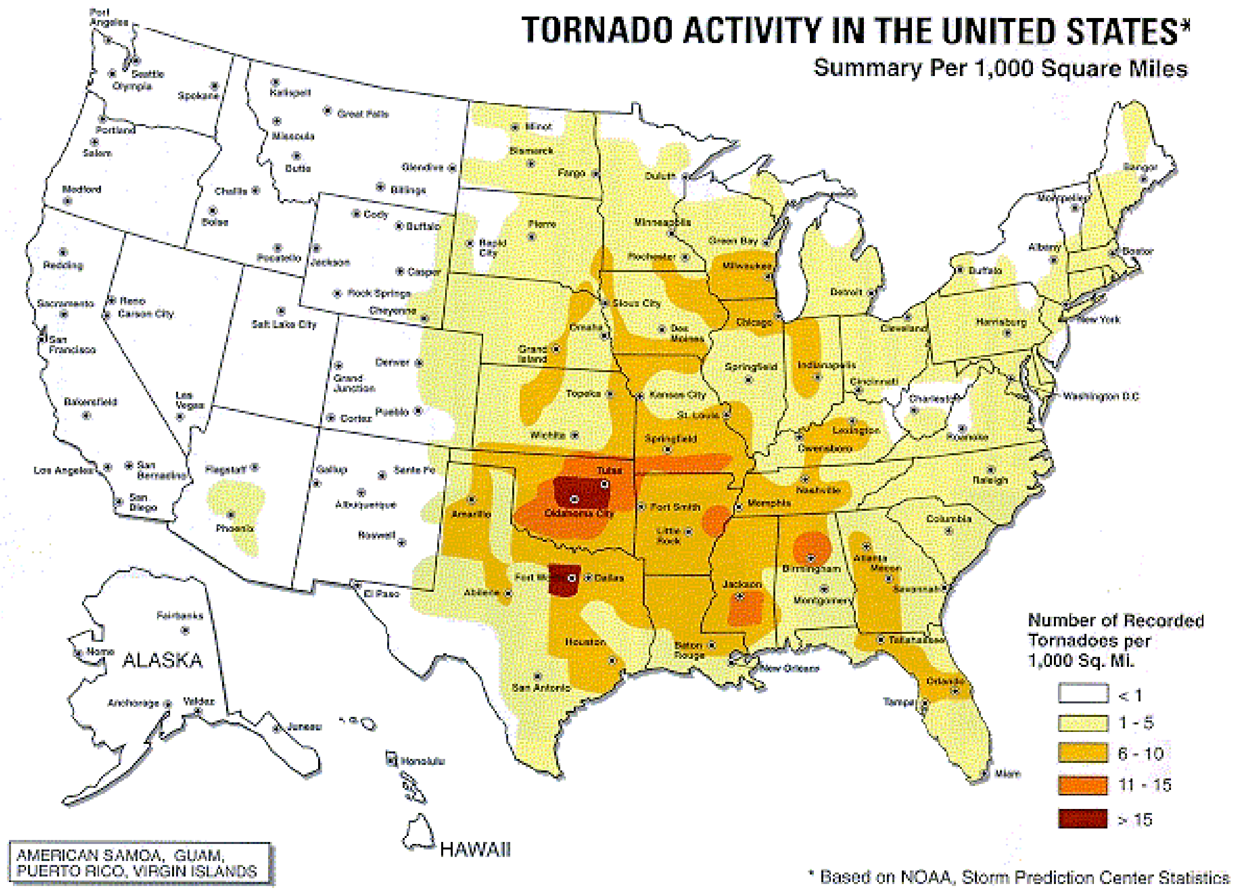


Figure I.1 The number of tornadoes recorded per 1,000 square miles

APPENDIX D

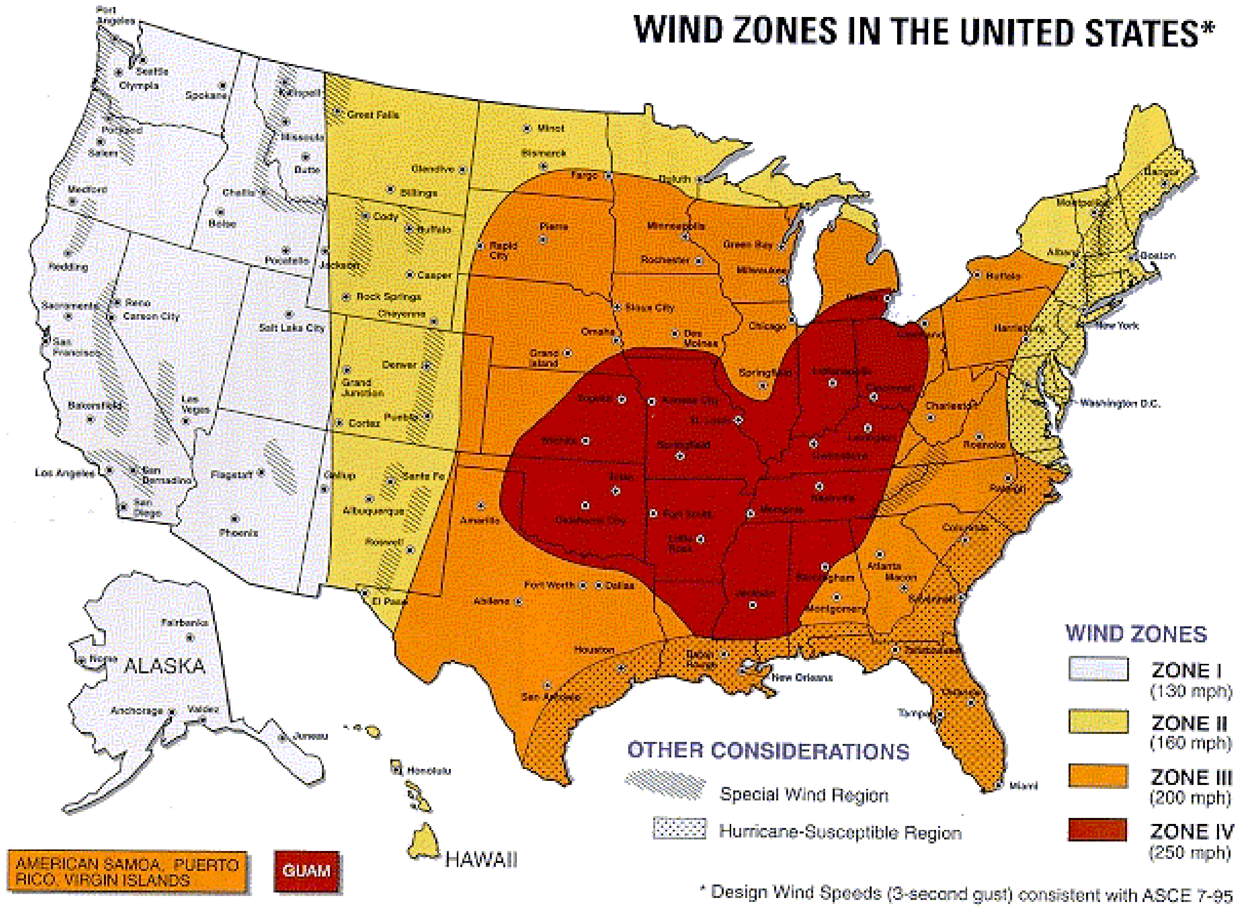


Figure I.2 Wind zones in the United States

APPENDIX E

NUMBER OF TORNADOES PER 1,000 SQUARE MILES (See Figure I.1)	WIND ZONE (See Figure I.2) I	II	III	IV
<1	LOW RISK	LOW RISK ★	LOW RISK ★	MODERATE RISK
1 - 5	LOW RISK	MODERATE RISK ★	HIGH RISK	HIGH RISK
6 - 10	LOW RISK	MODERATE RISK ★	HIGH RISK	HIGH RISK
11 - 15	HIGH RISK	HIGH RISK	HIGH RISK	HIGH RISK
>15	HIGH RISK	HIGH RISK	HIGH RISK	HIGH RISK

LOW RISK Need for high-wind shelter is a matter of homeowner preference

MODERATE RISK Shelter should be considered for protection from high winds

HIGH RISK Shelter is preferred method of protection from high winds

★ Shelter is preferred method of protection from high winds if house is in hurricane-susceptible region

APPENDIX F

SUMMARY

Building Name:	Fire Station #1
Address:	1202 18th
Location:	Lubbock, TX

Disaster No.:	010001	Project No.:	EFO 2001
Scenario Run ID:	Lubbock, TX	Analyst:	Greg Lee

INPUT DATA

Shelter Construction:		Unreinforced Masonry & > 7% window area	
Building Dimensions (ft)	150 X 150	Shelter Area (sq. ft):	250
Hurricane Occupancy:	0	Max. Tornado Occupancy:	8

Tornado Counties:	0 miles around target county.	No. of Counties:	1

Mitigation Description:	Above Ground Shelter Project		
Project Cost(s):	15,000	Maintenance ($/yr):	0
Project Life (yr.):	20	Discount Rate (%):	7
Injury Cost ($):	12,500	Death Cost ($):	2.200,000

BENEFIT COSTS ANALYSIS

Tornado Benefits ($/yr):	3,813	Net Benefits ($/yr):	2,397
Hurricane Benefits ($/yr):	0	BC Ratio:	2.69
Total Benefits ($/yr):	3,813	Lives Saved:	0.03 in 20 years
Total Cost ($/yr):	1,416	Injuries Avoided:	0.09 in 20 years