EVALUATING REFUGE AREAS IN TOPEKA SCHOOLS

August 23, 2000

Prepared by:

Greenhorne & O'Mara, Inc.
9001 Edmonston Road
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In Association with:

PBA Architects
Wichita, Kansas

Under Contract to:

State of Kansas – Division of Emergency Management
2800 SW Topeka Boulevard
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1. INTRODUCTION

BACKGROUND

On May 3, 1999, devastating tornadoes struck south central Kansas. The losses in human life and property that resulted from these tornadoes underscored the need for mitigation strategies. A Federal Emergency Management Agency (FEMA) Building Performance Assessment Team (BPAT), made up of national experts in building and wind science, studied the damage and provided recommendations to help to reduce the impact of future tornadoes. One of the recommendations in the report was to design and construct refuge areas in public schools in tornado-prone areas.

Following the damage investigations, FEMA released a BPAT report (*FEMA 342: Midwest Tornadoes of May 3, 1999: Observations, Recommendations, and Technical Guidance*, October 1999) and the *National Performance Criteria for Tornado Shelters* (May 1999) to provide technical guidance on designing and constructing refuge areas. The most recent shelter publication is *FEMA 361: Design and Construction Guidance for Community Shelters* (August 2000), which provides detailed guidance for engineers and architects on evaluating tornado hazards, designing shelters to resist extreme winds, and designing shelters to resist windborne debris (missiles).

Under the Hazard Mitigation Technical Assistance Program (HMTAP), Greenhorne & O'Mara, Inc. (G&O) developed the Tornado Refuge Area Evaluation Checklists for FEMA. Evaluation Checklists for High-Wind Refuge Areas are included in *FEMA 361*. The checklists may be used as part of consistent evaluations and rankings of tornado refuge areas in public buildings. The checklists were first used during a workshop in February 2000 to evaluate school refuge areas in Wichita, Kansas, and to train engineers, architects, and emergency managers who evaluate school refuge areas. The checklists were also used at a second training workshop sponsored by the Kansas Division of Emergency Management (DEM) that was conducted in Topeka, Kansas, in June 2000.

PROJECT DESCRIPTION

G&O and PBA Architects, under contract to the Kansas DEM, used the checklists to assess the vulnerability of refuge areas in seven Topeka schools to high-wind events and other natural hazards. The DEM contacted a number of school districts to solicit interest in refuge area evaluations. Unified School District 501 (USD 501) in Topeka responded and G&O, PBA, and USD 501 selected the seven schools that were evaluated.

After evaluating the seven schools, three of the schools were chosen by G&O, PBA, USD 501, and DEM to be further discussed as case study schools. A case study consists of a review of building plans, site inspection and evaluation, a general engineering analysis, and retrofit recommendations. The case studies were chosen to illustrate the methodology application to other schools in the Topeka area and the state of Kansas.

Technical assistance under this task included a training workshop conducted by G&O and PBA on June 29, 2000. The workshop presented evaluation techniques and mitigation strategies as well as an overview of the effects of high-wind events on the built environment. One of the USD 501 schools was used during the workshop as a training example in using the evaluation checklists.

ORGANIZATION OF REPORT

This report presents the procedures and findings of the school evaluations conducted for the Topeka Public School District USD 501. Section 2 details the **Project Approach** and methodology used to perform the evaluations. Section 3, **Observations During Refuge Evaluations,** presents the results of the site inspections and screening process, as well as the basis for the selection of the case study schools. **The Case Study Evaluations, Analyses, and Conclusions** are presented in Section 4. Each case study school is evaluated through field observations, plan review, and structural analysis. In Section 5, **Recommendations**, G&O has provided alternative mitigation options for each case study, including retrofits for near-absolute protection, and recommendations to improve the level of protection.

LIMITS OF LIABILITY

The evaluations performed were based on information readily available from visual site inspections, building plans and drawings, and studies of similar facilities. We assume that all information collected from the building plans accurately represented actual building construction. No destructive or invasive tests were performed to confirm the accuracy of the drawings. No discussions were held with the structural engineers and architects who designed the schools, and no design calculations or design assumptions were reviewed beyond those described on the drawings.

Assessing the expected building performance for specific natural hazards is based on a limited review of those elements considered most likely to fail during a severe natural hazard event. Other failure modes may exist and may limit the building's performance. This project provides a reasonable assessment of the expected performance of a building's critical elements. Our evaluations are not a guarantee that any building can or will withstand the forces of a natural hazard event.

2. PROJECT APPROACH

ASSESSMENT METHODOLOGY

G&O developed a method of rapid visual screening of proposed tornado refuge areas using a checklist evaluation process. This assessment technique was used to identify school refuge areas that are vulnerable to damage from tornadoes.

Seven schools that represented the inventory of USD 501 were selected for evaluation. Building plans for these schools were provided by USD 501 for review of the structural design and construction details of the identified refuge areas, as well as selecting other possible refuge areas. The availability of design and building plans is critical to the evaluation process because interior finishes prevent the observation of certain details, such as the presence of reinforcing bars in masonry block walls, or structural connections within the building. When plans are unavailable, a conservative approach is assumed and the worst case scenario is recorded. Some schools did not have complete building plans; this was noted on the evaluation checklists (see Appendix A). Site visits were conducted to confirm the information provided by the plans and to gather site-specific information. The shelter evaluations took place between June 26 and 28, 2000. The results of the shelter evaluations are presented in Section 3 of this report and summarized on the checklist summary score sheets in Appendix B.

Existing tornado refuge plans were reviewed based on guidance provided by the *National Performance Criteria (NPC) for Tornado Shelters* and *FEMA 361*. Both of these documents specify that all facility occupants should be able to reach the refuge area within 5 minutes of notification. In evaluating school refuge areas, access time for all occupants was a factor.

At each school, the checklists were used to evaluate existing refuge areas and to select potential new refuge areas within a school (see Appendix C). The schools identified for this project had tornado shelter plans in place as required by the State of Kansas. These plans specified where each school occupant was to go in the event of a tornado. School administrators selected the existing refuge areas, which typically consisted of interior spaces located in basements or on the first floor. When feasible, the identified areas were located away from heavily glazed areas and unsupported, long span roof systems.

In cases where the current space was considered insufficient according to FEMA guidelines, additional areas were chosen. FEMA uses 5 square feet (SF) per person to assess required space for tornado refuge areas. To calculate the usable space, 85 percent of the available space was assumed. In the case of bathrooms, only 50 percent of the available space was assumed as usable space. In a few instances, new areas were selected for evaluation because they contained tornado-resistant features such as reinforced concrete walls or roofs and were not being used under the existing tornado shelter plan.

Three schools were selected for further evaluation to illustrate the different types of refuge areas and construction typical of the school districts. The tornado refuge areas in the three schools were evaluated for their ability to survive a 250-mph tornadic event (based on guidance

from *FEMA 361*). General conclusions, evaluations, and recommendations are provided in Section 5 of this report.

SELECTION OF CASE STUDY SCHOOLS

The selection of the case study schools was made in consultation with the Topeka School District staff and DEM. The vulnerabilities and deficiencies identified by the evaluation checklists for each school's identified refuge areas are specified in Section 4.

- A.J. Stout Elementary School has construction that is typical for older schools in the USD 501 inventory and for older elementary schools within the state. This school scored the highest on the evaluation checklists, indicating a high vulnerability to tornado events.

- Marjorie L. French Junior High School and Ross Elementary School were selected as the second case study schools. French and Ross are representative of schools that utilize basement areas for refuge from tornadoes. French is also representative of a moderate school population (625 students and staff) and the refuge area at Ross is a strong candidate to be retrofitted to the criteria presented in *FEMA 361*. These schools scored some of the lowest scores on the evaluation checklists.

- Topeka High School was selected to represent the needs of the large school capacities common to high schools in the state. It also presented an opportunity for revision of its existing tornado plan based on the findings during the evaluation. This school recorded one of the highest (most vulnerable) scores on the checklists and presented the opportunity to illustrate how the score of the evaluation checklists, and the associated vulnerabilities, could be reduced through better planning and some retrofitting.

EVALUATION CHECKLISTS

The checklists were developed using current engineering guidelines (such as the American Society of Civil Engineers design load standard *ASCE 7-98*, *FEMA 361*, FEMA's *NPC*, and FEMA's National Earthquake Hazard Reduction Program [NEHRP]) and research data.

The objectives of the checklists are twofold: first, they are designed to identify structural and non-structural vulnerabilities to high-wind events; and second, they are designed to rank a group of facilities to indicate which schools have the least structural resistance to high-wind forces and are in most need of retrofitting solutions.

The checklists are divided into five sections; the evaluation process is based on a multi-hazard approach with an emphasis on the wind hazard:

- General Building Information
- Selecting the Refuge Area
- Wind Hazard Checklist
- Flood Hazard Checklist
- Structural Seismic Hazard Checklist

In the General Building Information section, data pertaining to the building site are gathered. The school name, address, and point of contact are collected as well as historical information on building performance, maintenance problems, and repairs. Other data collected for this section include school population, building size and shape, power sources, and an assessment of the surrounding environment and general condition of the building.

In the section titled Selecting the Refuge Area, the user is guided through a process to identify potential refuge areas, eliminating areas that are more vulnerable to high-wind events and focusing on those areas that provide more protection. Several areas may be needed to accommodate all school occupants. The first step in selecting the refuge area is to calculate the required space needed for the maximum possible number of occupants (e.g., students, staff, etc.) at any given time. The next step is to look for available space, noting accessibility and potential vulnerabilities.

After the refuge areas have been identified, the scored sections of the checklists are completed for the refuge areas of the building only. The wind, flood, and seismic hazard checklists consist of detailed questions with penalty points applied to answers that indicate inadequate building strength or unfavorable circumstances in response to hazard conditions. The checklists are used to gather information that provides a “big picture” and enables a thorough assessment. Scores on the checklists will highlight specific deficiencies and provide the means to rank a group of facilities. The scores will identify refuge areas that are candidates for retrofit designs as well as those that are poor candidates for retrofits because of excessive vulnerabilities.

The wind hazard checklist is divided into four parts that were developed to gather building information related to common failure modes from the effects of tornadoes:

Structural Issues - Building materials used for framing and wall construction as well as other critical building components are identified. Continuous load path and the overall structural resistance of the refuge area are assessed.[1]

Cladding and Glazing Issues - Non-structural components that are often vulnerable to wind pressures and windborne debris (missile) impact are identified. Examples of these components are windows and roof coverings.

Envelope Protection - Refuge area walls and roof coverings are evaluated for their susceptibility to a breach by either missile impact or high wind pressures. When the building envelope is breached, additional wind pressures are imposed on interior surfaces.

Non-structural Issues - Issues related to the adequacy of a refuge area that do not concern building performance are evaluated (i.e., Americans with Disabilities Act (ADA) accessibility, the availability and sufficiency of a back-up power source, and having an evacuation plan in place prior to a severe event).

[1] A continuous load path transfers all loads (downward, upward, and lateral) from the roof structure to the walls and foundation. The "links" of the chain are structural members, connections between members, and any fasteners used in the connections. To be effective, each "link" in the continuous load path must be strong enough to transfer loads without breaking, or the building will be vulnerable to failure.

Flood and seismic hazards are also evaluated using checklists to ensure that the school is not vulnerable to multi-hazards. If a multi-hazard vulnerability exists, it is important that a mitigation strategy be developed that responds to all possible hazards. The Topeka area has a moderate susceptibility to flood and seismic hazards, so it is important to complete these less detailed, but important hazard checklists.

The flood hazard checklist relies on information obtained from a Flood Insurance Rate Map (FIRM) and the associated Flood Insurance Study (FIS). A FIRM is a map that delineates the 100-year flood elevations and flood hazard areas in a community. This section also examines localized flooding and drainage problems that may exist outside the floodplain. The seismic hazard checklist is based on the 1997 Uniform Building Code Seismic Zone Map of the United States. On this map, Topeka is shown as being located in Seismic Zone 2, indicating a low-to-moderate probability of a seismic hazard.

EVALUATION CRITERIA

All of the elements in the checklists were rated for susceptibility to damage from high winds. The criteria for this rating were developed from a review of the latest research and published data on tornado induced failure mechanisms. The references used in this report are listed in Appendix D and include FEMA documents, university research reports, and engineering codes and standards. Additionally, the G&O engineering team relied on expert judgement for situations for which technical information was not available. G&O's extensive experience in assessing the performance of similar structures provided the basis for these assessments.

The checklists assist the inspector in identifying a high-wind event. This high-wind event considers both the pressures induced by the fast moving wind and the windborne debris generated by a tornado.[2] Topeka is located in Zone IV of the design wind speed map found on page 16 of the evaluation checklists. Based on this wind speed and the guidance of *FEMA 361*, the refuge area at a particular school in Topeka was evaluated for vulnerability to damage from:

- 250-mph winds (measured as 3-second peak gust @ 33 feet above grade)
- Windborne debris represented by a 15-lb 2x4 wood member traveling at 100 mph horizontally or 67 mph vertically

As previously mentioned, the availability of building plans (both architectural and structural) is essential for a meaningful evaluation. Therefore, schools without full plan sets were either not evaluated or were penalized heavily during the evaluation. To address the needs of all students in USD 501, an elementary school, a middle school, and a high school were selected for use as case studies. Each of these types of schools has different building construction and layouts that present challenges when designating and evaluating tornado refuge areas. Due to additions over

[2] Winds within a tornado are typically categorized as vortex winds and inflow winds. Vortex winds (the fastest winds associated with the tornado) are the rotational winds of the tornado that typically cause the most damage. Inflow winds move radially toward a tornado vortex; the effects of these winds can be felt up to 1 mile away from some tornado vortices. Inflow winds can have speeds over 100 mph as they approach the vortex. These winds may also cause significant damage to buildings.

the years, none of the three high schools in USD 501 had a complete set of building plans available for evaluation. However, Topeka High School had the most complete set of building plans and was selected as a case study school. Section 5 of this report will discuss the findings from this evaluation and the increased penalty due to a lack of building plans.

It should be noted that these evaluations were conducted with the best information available at the time of the inspections. If these or any other evaluations are completed with only part of the required information available, it is in the best interests of USD 501 and DEM to revise the evaluations after the information comes available to ensure the most accurate inventory of the tornado refuge areas at the schools.

3. OBSERVATIONS DURING REFUGE AREA EVALUATIONS

OBSERVATIONS

The seven schools chosen for evaluation were Ross elementary, Stout Elementary, Bishop Elementary, Lundgren Elementary, Williams Magnet Elementary, French Junior High School, and Topeka High School. Site visits were conducted at each of these schools to verify information obtained from building drawings and to complete the checklists. Discussions with USD 501 and school staffs provided historical details regarding school equipment, building performance, and operations plans.

All schools evaluated met the basic requirements of the Kansas Department of Education of identifying tornado refuge areas within each school and practicing tornado drills at least three times per year. All schools had documented times of all occupants reaching the refuge areas during their tornado drills. With the exception of a single test at French Junior High School, all drill times were below the 5-minute time recommended in *FEMA 361*. Most schools used directional signs to guide students, faculty, and staff to the refuge areas. Additional signs were posted at the refuge areas (see Figure 3-1).

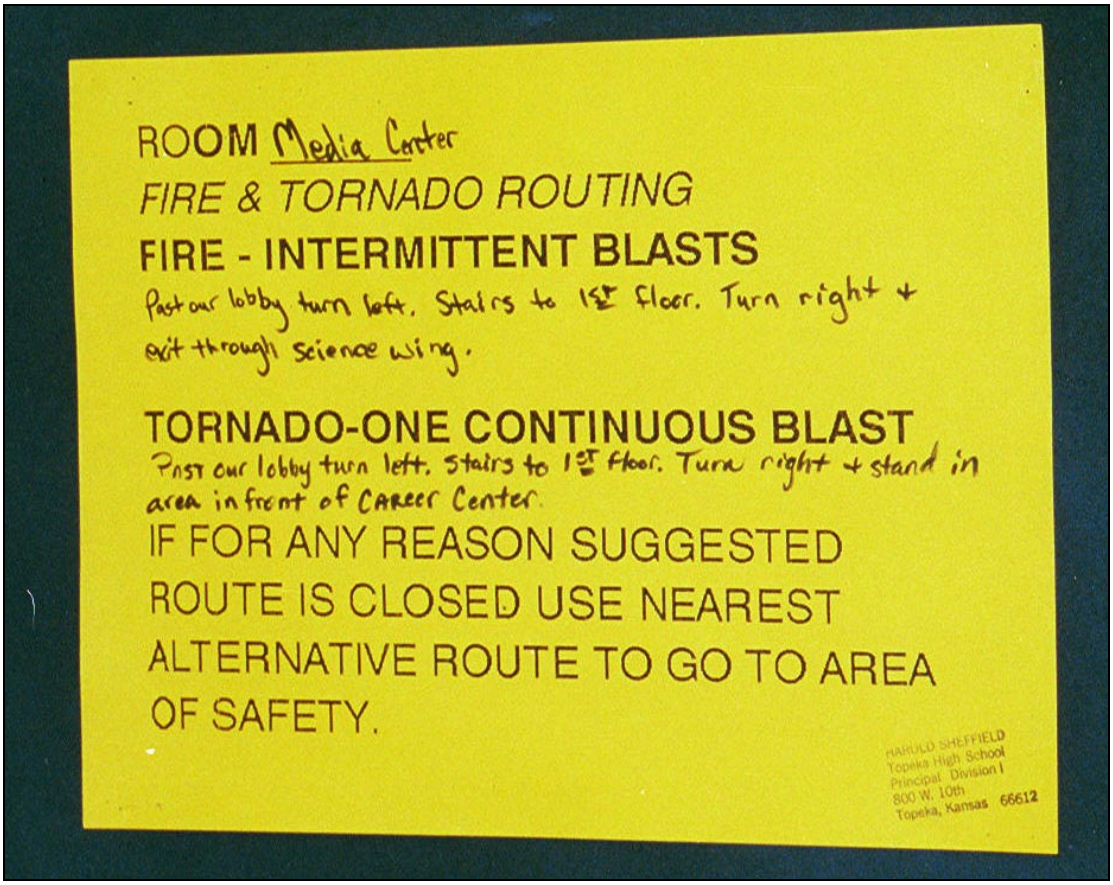

Figure 3-1: Example of signage directing students from a media center to a tornado refuge area (Topeka High School).

Six of the seven schools were constructed to building codes developed prior to 1970, and the ages of the schools ranged from 30 to 71 years old. Williams Magnet Elementary School was constructed in 1995 to the 1991 Unified Building Code (UBC), which is a model building code accepted by many communities in Kansas as their building code for non-residential construction. The Kansas Department of Education currently requires that new schools must, at a minimum, be designed to the 1991 UBC. The 1991 UBC requires wind loads to be considered in the design of buildings; *ASCE 7-98* is the most up to date engineering standard for wind design. *FEMA 361: Design and Construction Guidance for Community Shelters* is the only publication that outlines design procedures for high-wind shelters.

Many of the schools in USD 501 have basements that are designated as tornado refuge areas (see Figure 3-2). Of the refuge areas evaluated for USD 501, the basement areas had some of the lowest scores on the evaluation checklists; areas with lower scores are less vulnerable to damage.

Figure 3-2: This multi-purpose room also functions as a tornado refuge area at Ross Elementary School.

Schools with basements that were evaluated for this project were Lundgren and Ross Elementary schools and French Junior High. All three basements were constructed with reinforced concrete walls and roofs. Reinforced concrete has proven capable of resisting high-wind loads and impacts from windborne debris. The vulnerable areas in the basements were limited to doors and windows, and were minimal due to the small percentage of window and door area when compared to the total wall and roof area of the refuge areas.

Two of the schools inspected use hallways that were not designed for use as tornado refuge areas. Figure 3-3 shows a hallway refuge area in Topeka High School. The two schools scored high on the evaluation checklists. The hallways have reinforced concrete frames with non-load bearing infill walls of clay glazing tiles.

Figure 3-3: A hallway used as a refuge area at Topeka High School.

Hallway refuge areas that are constructed with a concrete or steel frame will be able to resist more wind loads before being damaged from high winds and wind pressures than unreinforced masonry walls (URM). However, this improved level of protection is often negated by the vulnerability of the roof deck, unreinforced walls between the frame members, and the doors and windows in the hallways. Although the frame may remain standing during a high-wind event, loss of the roof deck, walls, windows, or doors within a refuge area may result in death or injury. These vulnerabilities are common to all schools and will be discussed later in this section.

Hallway refuge areas constructed with URM walls have no means of carrying wind loads from the roof system to the foundation. A structure must transfer loads through a “continuous load path” if it is to provide protection without structural collapse during a high-wind event. Although some of the schools have concrete roof systems, others have steel joists/decks or all wood roof structures that are not connected to the walls or foundation. These roof systems are extremely vulnerable to failure during a high-wind event and can become separated from the structure. Figure 3-4 illustrates a roof failure that occurred at Griffenstein Elementary outside of Wichita as a result of the May 3, 1999, tornadoes.

Figure 3-4: Roof failure at a school with load bearing URM walls and no structural connection of the roof to the walls.

Two schools had specifically designed tornado refuge areas. Maude Bishop Elementary School has a multi-purpose area that was designed in the late 1960s to resist tornadoes. Although no design parameters were indicated on the building plans, the reinforced concrete construction with steel beams supporting a reinforced concrete roof provides improved protection for individuals seeking shelter during a tornado. Although this school had a refuge area with a strong structural system and walls, openings in the walls and potential localized flooding at the site resulted in an increase in the evaluation checklist score. This emphasizes the need for a multi-hazard approach to shelters.

The other school with a designed tornado refuge area was Williams Elementary Magnet School, which was built in 1995 with hallways specifically designed to act as tornado refuge areas (see Figures 3-5 and 3-6). Although it predates most testing and research on tornado shelter design, the construction used in the refuge areas in Williams meets many of the criteria specified in *FEMA 361* and exemplifies what can be done to strengthen an area against wind and windborne debris.

FEMA 361 recommends design criteria for community shelters. These criteria include reinforced masonry or concrete walls, short roof spans, structurally independent refuge areas, no windows, and steel doors without windows.

Figure 3-5: Hallways designed to function as tornado refuge areas at Williams Elementary Magnet School.

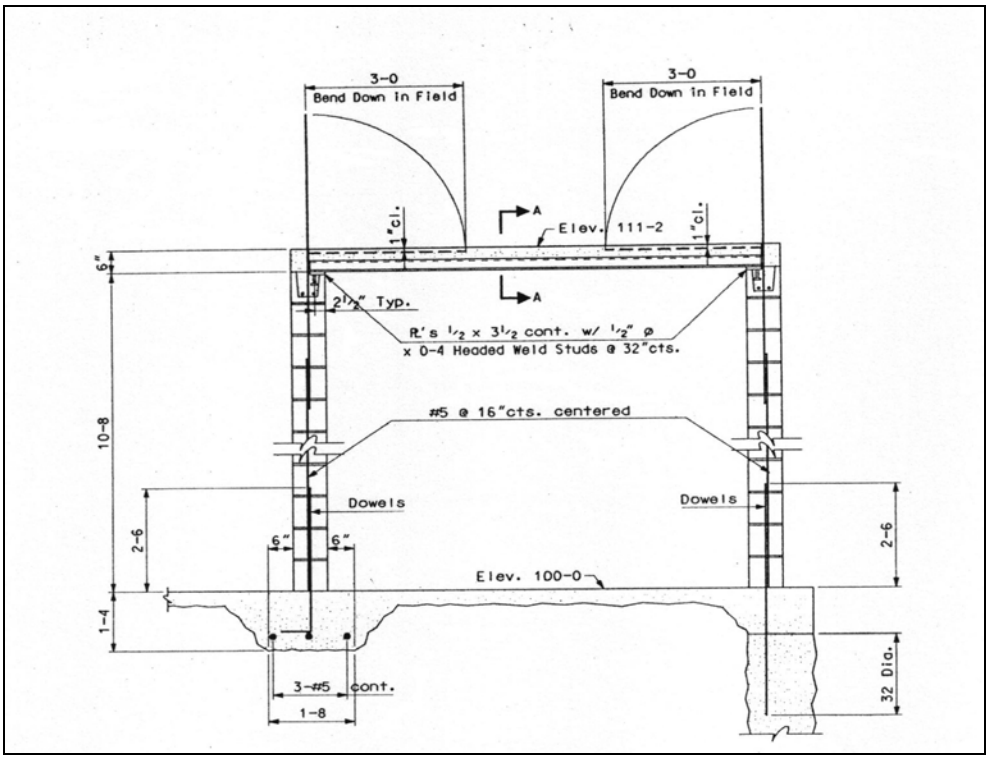

Figure 3-6: Elevation plan detail of the engineered hallways designed as tornado refuge areas at Williams Elementary. Note: To comply with the guidelines of *FEMA 361*, the vertical reinforcing steel should be placed in every cell.

COMMON VULNERABILITIES AND OBSERVATIONS

All of the schools had some vulnerability to wind and windborne debris; however, very few shelters in the country meet the new criteria for shelter design presented in *FEMA 361*. The most common vulnerabilities observed are summarized here.

A continuous load path is critical to the performance of high-wind refuge areas. Schools constructed prior to the 1990s tend to have minimal load paths for resisting lateral and uplift loads because building codes did not require engineers to consider these loads. However, areas designed as shelters, basements, and steel and reinforced concrete framed buildings may not have the ability to provide protection from the strongest of tornadoes (e.g., an F5 tornado), but they do provide high levels of protection. Refuge areas in basements are an integral part of the building foundation and generally have a continuous load path if the basement roof or ceiling is positively tied to the walls. In either case, an engineering analysis should be performed to identify the anticipated protection level for the refuge area (e.g., the wind speed that may cause a structural failure should be determined). Older schools in Kansas, without basements and with load bearing walls generally are unreinforced and have no load path to resist lateral and uplift loads. Such structures are likely to experience significant structural damage during a tornado.

Unprotected glazing is also critical in the performance of refuge areas. Windows and doors with glazing in interior corridors are vulnerable to damage from wind pressure and missile impact (see Figure 3-7). Door materials that failed missile impact testing were also a common deficiency. Testing has indicated that wood doors or doorframes are not capable of withstanding wind pressures or windborne debris associated with severe tornadoes. Another concern was the lack of adequate door hardware; three hinges and three latches are recommended (six total points of connection between the door and the doorframe). The door hardware observed at the schools does not provide a connection to the frame that would be capable of withstanding tornado forces.

If a door, window, or even a wall fails from wind pressures or windborne debris, the result can be catastrophic for the building. If one of these elements fails on the windward side of the building, wind will rush into the building and increase internal pressures. Such pressurization can result in internal wind pressures that are twice as high as pressures in buildings that remain enclosed (no wind or debris inside the building). Figure 3-8 illustrates this concept. Structural failures experienced during high-wind events can often be traced back to the pressurization of the structure when a wall, door, or window is lost on the windward face of a building.

Refuge areas need to provide usable space, free of clutter and obstructions that prevent rapid access. In most instances, the observed refuge areas were multi-purpose areas or bathroom/locker rooms (see Figure 3-9). Most of the multi-purpose areas would house all students, faculty, and staff during the tornado drills at the *FEMA 361* recommended 5.0 ft^2 per person. In a few instances, portions of designated refuge areas were used for storage, but none of the evaluated refuge areas were used primarily for storage. The remainder of the refuge areas were hallways that were free of obstructions. When areas have been filled with desks, furniture, and other stored items, the usable shelter space is reduced.

Figure 3-7: Classroom doors along hallway refuge area at A. J. Stout Elementary. Note: The wood doors have glass view windows, and only four points of connection (three hinges and one latch); wood doors have failed missile impact testing.

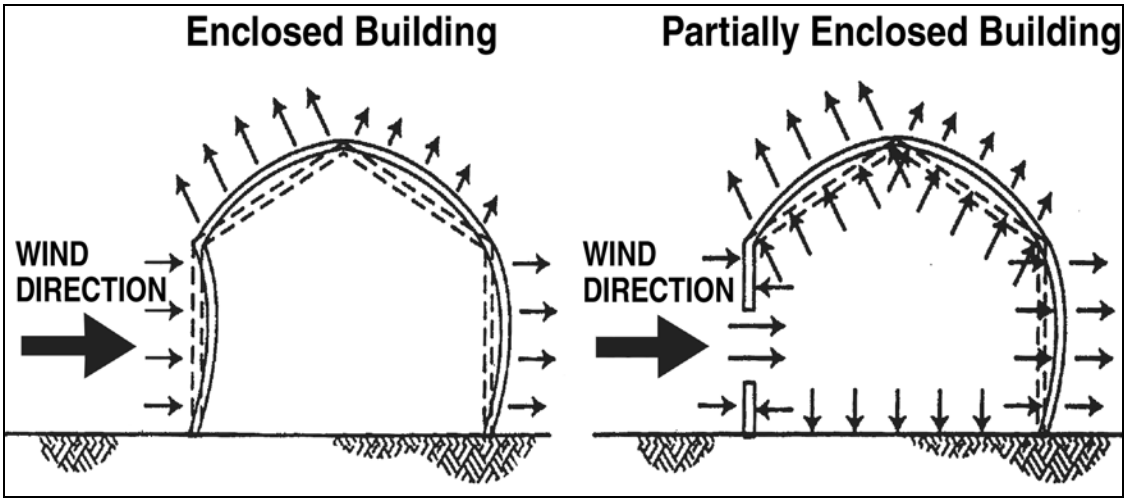

Figure 3-8: Increased wind pressures in a partially enclosed building.

Figure 3-9: The refuge area at French Junior High School is a multi-purpose area converted to a classroom setting. The furniture in this area reduces the usable square footage in this particular refuge area.

Throughout Kansas, schools use portable classrooms (portables) to handle fluctuations in school population. Portables perform poorly during a tornado; however, no portables were observed at the schools evaluated for USD 501. It is important to note that portable classrooms are not designed for wind speeds over 90 or 100 mph (3-second gust) and therefore should not be designated as refuge areas. It is important to remember that use of portables increases the required square footage of the school's tornado refuge area. When portables must be used at a school, the tornado refuge plan should be reviewed to ensure adequate square footage is provided. Furthermore, use of portables at schools requires occupants to evacuate to the main building for protection during a high-wind event.

Debris material in and around schools can become missiles and endanger building occupants. Missiles are often in the form of trees, light poles (from athletic fields), telephone poles, portable buildings, and debris piles of wood pieces, broken furniture, and metal scraps. The grounds of the evaluated schools and their surrounding neighborhoods were relatively free of potential debris. Potential debris sources at the schools were generally limited to roof ballast (stones placed on roof surfaces as part of the roof covering) and large trees adjacent to a few of the schools as shown in Figure 3-10. Also note the skylights located above the refuge area that are susceptible to damage from windborne debris.

Figure 3-10: Roof ballast and trees adjacent to the A. J. Stout Elementary School present a moderate debris hazard at the site. The large trees could reach the hallway designated as a refuge area if they fell during a wind event.

The evaluation checklists also address threats that accompany flood and seismic events. There were no significant flood hazards at the seven schools evaluated. Only one of the schools (A. J. Stout Elementary) was located within a 500-year floodplain. FEMA recommends that all shelters be located outside and above the elevation of the 500-year floodplain. It should be noted that the Flood Insurance Rate Maps (FIRMs) for this area were produced in 1981 and these data may not be accurate if development occurred in this area after the maps were developed. No schools were located within the 100-year floodplain or in Special Flood Hazard Areas (SFHAs). One school (Maude Bishop Elementary) did have a localized site-flooding hazard. Because all the schools were located in Topeka, they have a low-to-moderate seismic threat. Due to the ages of the schools evaluated, they were not constructed to current seismic codes and exhibit vulnerabilities to seismic damage.

None of the schools had refuge areas that provide near-absolute protection according to the guidance in *FEMA 361* (i.e., meeting all criteria on the evaluation checklists without penalty). The schools that provide the best level of protection were Williams Magnet, which was designed specifically as a tornado refuge area (see Figures 3-5 and 3-6) and the schools with basement shelters; Ross Elementary, Lundgren Elementary, and French Junior High School. In most cases, the refuge areas used in the schools were in portions of the building that provided the best protection available. Protection could be improved at all schools by considering modifications to the existing buildings. Near-absolute protection in many cases, however, would require costly retrofits or new tornado refuge areas.

4. CASE STUDY EVALUATIONS, ANALYSES, AND CONCLUSIONS

This section summarizes the existing conditions of the refuge areas of the schools selected for further analysis as case studies. Vulnerabilities to the refuge area structure from wind and windborne debris are listed and a summary of the engineering analysis procedures and conclusions are provided.

Engineering analysis of the refuge area ideally considers only the refuge area and assumes the rest of the structure has been damaged or destroyed during a high-wind event. This approach leads to treating interior walls and the overhead ceiling or roof structures as exterior surfaces exposed to wind and windborne debris. However, this analysis approach cannot be adopted for some structures because the refuge area would not be self-supporting without the surrounding structure. Stout Elementary is an example of such a structure. French Junior High School refuge area was treated as structurally independent as the reinforced concrete construction resulted in a potentially self-supporting structure.

A .J. STOUT ELEMENTARY SCHOOL

A. J. Stout Elementary School, built in 1955, is a one-story building that is roughly rectangular in shape (see Figures 4-1 and 4-2). There have been no permanent additions to the school and no portable units (temporary classrooms) are currently being used. The combined maximum student, faculty, and staff population that requires refuge is 360 people. Stout had the highest score on the evaluations performed for this project with a total score of 176. See Appendix B for the summary score sheet and Appendix C for the checklist for Stout.

Figure 4-1: A. J. Stout Elementary School.

Shaded areas in Figure 4-2 indicate the locations of the refuge areas used in the school's tornado plan. Refuge areas "A" and "B" are located in the main north-south hallway. Students are instructed to stay away from glazed areas and intersecting hallways during high-wind events. This is important because there are no interior doors within the hallways to isolate the refuge areas within the building. Also exterior doors were observed to have only three or four points of connection (not the recommended six points) and are approximately 50 percent glass. An interior view of a refuge area in the school is shown in Figure 4-3.

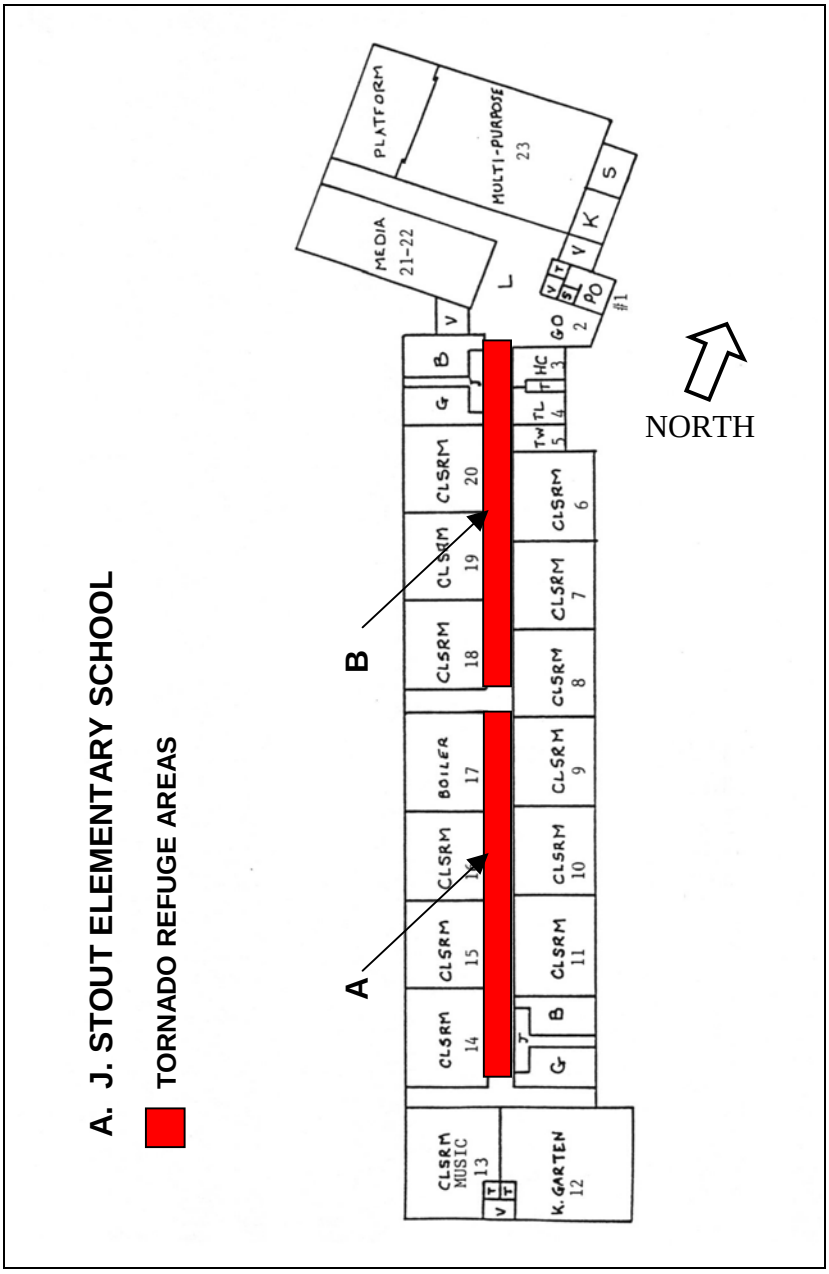

Figure 4-2: Stout Elementary School floor plan.

The school is constructed with unreinforced masonry (URM) interior and exterior load bearing walls that support the roof system. The roof system has a lightweight concrete deck supported by steel I-beams that span from east-to-west across the main north-south hallway. The beams

are connected to the URM walls with anchor bolts. At the north end of the school, there is a variation in the wall construction. Wood arch frames with URM infill walls are the main structural system used in the multi-purpose (lunch and stage area) room. A built-up roof covering with aggregate (stone) ballast covers the entire school.

Figure 4-3: Interior view of refuge area in main north-south hallway at Stout Elementary.

The refuge area is defined by interior URM walls that separate the classrooms from the hallway/corridors. Exterior doors are light gauge metal with glazing supported by light gauge metal frames. Interior doors are wood with view windows supported in wood frames. The roof of the refuge area has a steel beam supporting the concrete deck described above. The refuge area is not structurally independent of the remainder of the school. The square footages of the refuge areas are listed in Table 4-1. The total available refuge area averages 4.65 ft^2 per person, which is slightly below the recommended 5.0 ft^2 per person.

Table 4-1: Refuge area usable space at Stout Elementary School.

Required Space (RSF*)	***Refuge Area Space (ASF*)***	***Usable Space (USF*)***
360 x 5 = 1,800 ft^2	A: 1,032 ft^2	1,032 x 0.85 = 877 ft^2
	B: 936 ft^2	936 x 0.85 = 796 ft^2
	TOTAL = A + B	**TOTAL USF = 1,673ft^2**

*See calculations on evaluation sheet in Appendix C for additional details.

Observations

- The walls are load bearing and constructed of unreinforced masonry (masonry without vertical reinforcing steel). Exterior walls are covered with a brick masonry veneer. Interior walls are one course of URM block. Unreinforced masonry has little capacity to resist uplift and lateral wind forces and is likely to fail in bending if subjected to high-wind forces. The refuge area walls are susceptible to failure from wind pressures and windborne debris during a high-wind event. To resist wind forces and windborne debris, the walls must be fully grouted and reinforced in every cell.

- The refuge area roof structure consists of steel beams supporting a concrete deck (see Figure 4-4). The connection between the deck and the beams was not indicated on the plans. The ability of this connection to resist wind forces acting on the roof cannot be verified and is anticipated to be inadequate. The steel beams rest on masonry walls and a stud extends from the bottom of each beam into the exterior wall. Although this connection provides some uplift and shear capacity at this connection, it is unlikely to have the capacity to resist the high-wind forces.

- The roof is not structurally independent. If uplift forces cause any portion of the school roof to blow off, refuge area occupants will be exposed to falling debris. Although the roof is constructed of heavy material (concrete deck with steel beams), preliminary calculations indicated that wind forces (for a 250-mph wind) pulling upward on the roof are greater than the dead weight of the roof itself by a factor of 5.

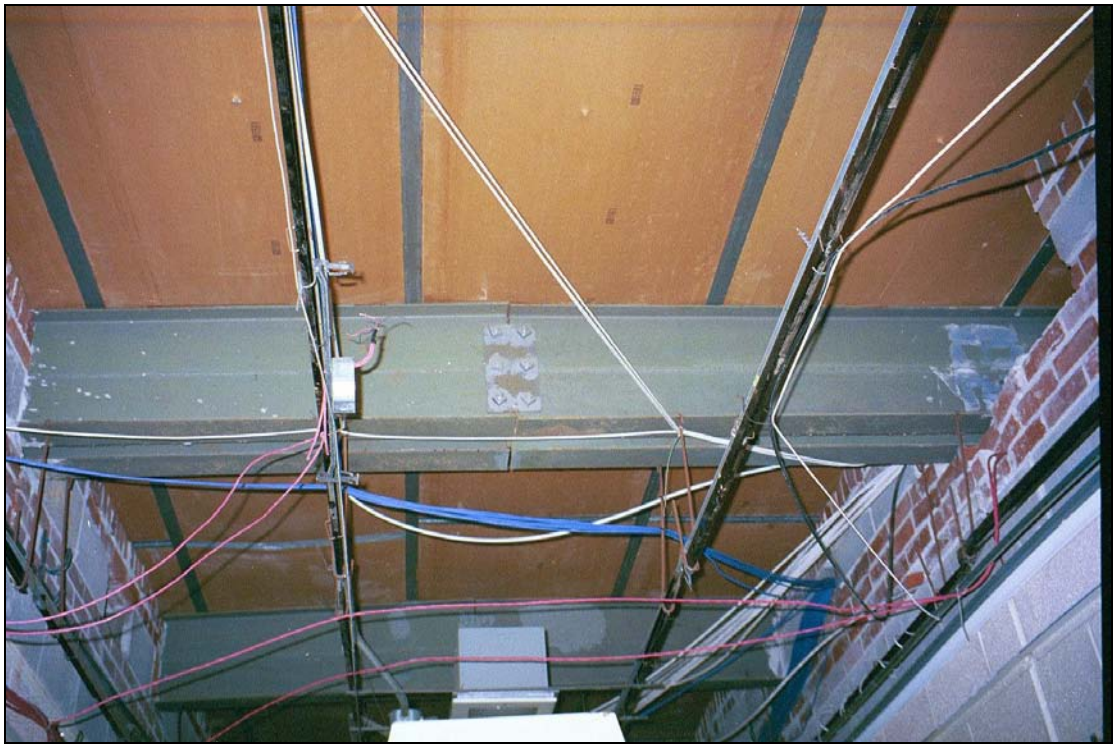

Figure 4-4: The roof structure above the refuge area at Stout Elementary.

- A continuous load path from the roof system to the foundation does not exist. The connections in the roof system provide some capacity, but were not designed to transfer uplift loads and therefore may fail during a high-wind event. The masonry walls are unreinforced and there is no positive tie to the foundation; the walls are therefore unable to transfer the loads from the roof structure to the ground.

- The longest unsupported span to thickness ratio of the unreinforced masonry wall is 51.75, which greatly exceeds the allowable value for high-wind regions per AFM 32-1095 (see Appendix A). The walls are long and slender and may be vulnerable failure from wind pressures. This vulnerability will increase if the roof separates from the top of the URM wall during a high-wind event.

- Skylights are located along the hallways identified as refuge areas. Figure 4-5 shows the skylights from the roof of the building. The skylights are not connected to the roof deck to resist uplift forces from the high-wind event. The translucent materials in the skylights have not been tested for resistance to windborne debris. In addition, there are new air handling units on the roof and skylights that could be damaged. Roof-mounted equipment is likely to blow off and leave holes in the roof. The chimney over the refuge area is a potential collapse hazard.

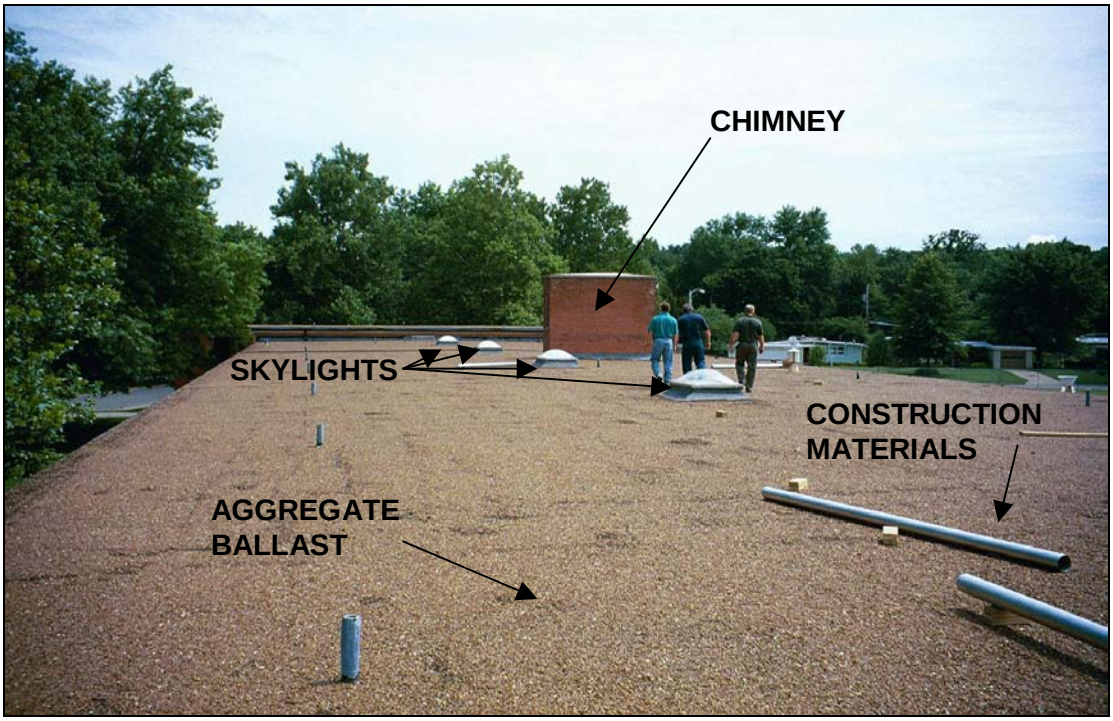

Figure 4-5: Skylights on the roof of Stout (directly atop refuge areas). These skylights are vulnerable to damage from wind pressure and windborne debris. The potential debris hazards in this photo are the aggregate ballast, the trees adjacent to the school, the loose construction materials from a current HVAC project, and the chimney.

- The roof requires modification to improve performance during high-wind events. The roof covering is a built-up roof with aggregate ballast, increasing the debris hazard at the site.

There is a considerable amount of glazing throughout the school. There is glazing at each entrance, and the classrooms, and the east-west hallways.

- Each hallway refuge area (A and B) is open at the north and south ends. Occupants located at the ends of each refuge area have little or no protection from wind and windborne debris that breaches the exterior doors and windows (see Figure 4-6). Wind and debris could easily enter the refuge areas.

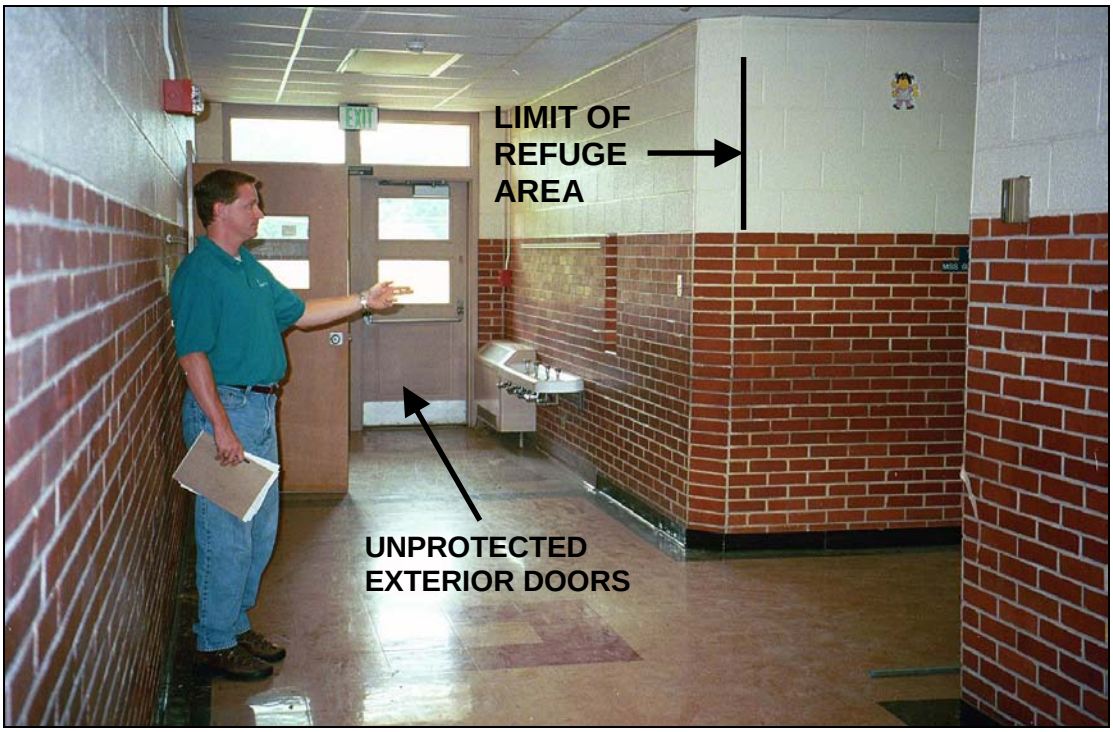

Figure 4-6: End of refuge area at south end of school. There is no door or barrier at the end of the refuge area to protect occupants from wind and debris that may enter through unprotected exterior doors.

- Refuge area A is accessed by 9 wood doors with glass view windows and wood frames; refuge area B is accessed by 11 similar doors (see Figure 4-7). The doors open from the refuge area to classrooms, storage areas, or bathrooms and need to be able to resist wind and windborne debris. However, wood doors and doorframes are not capable of resisting high-wind pressures and debris. Only heavy gauge steel doors without windows (supported by steel frames) meet the design criteria of *FEMA 361*. Furthermore, no window system has been tested that withstands the design missile. No doors have adequate connection hardware. All doors should have six points of connection: three hinges and three points of latching, where all latching mechanisms must be activated by a single panic bar.

- There are no portable units on the school site. The school does not have a backup power source. Battery powered backup lights are located within the refuge area and building maintenance personnel indicated they have a 2 to 4 hour duration.

Figure 4-7: Wood doors and doorframes leading into and out of the refuge area.

Structural Analysis

Design wind pressures were calculated using *ASCE 7-98* for the 250-mph wind design speed per *FEMA 361* guidelines. The school was analyzed as an entire system and critical elements (components) within the refuge area were also analyzed for resistance to wind pressures. Wind pressures were applied to the building exterior, but, if a breach occurs, internal wind pressures are applied directly to the refuge area. Wind pressures were calculated for the exterior walls and the roof elements acting as a main wind force resisting system (MWFRS) where building elements transfer wind loads to the ground. The MWFRS includes structural elements providing support and stability for the overall structure and generally receives wind loads from more than one surface of the building. Elements of the building envelope (the building exterior) that do not qualify as part of the MWFRS are identified as components and cladding, which receive wind loads directly and transfer the load to other components or to the MWFRS. Design wind pressures predicted to act on the exterior walls are listed in Table 4-2 and shown in Figure 4-8.[3]

[3] These wall and roof wind pressures were calculated assuming a partially enclosed building model. If the building becomes breached, the increase in internal pressures has already been accounted for in the analysis method. Wind pressures for walls, roof surfaces, and components and cladding were calculated using the guidance in *FEMA 361* and the methodology of *ASCE 7-98: Minimum Design Loads for Buildings and Other Structures*. The following assumptions were used for the calculations: Importance Factor = 1.0, Site Exposure C, Directionality Factor = 1.0, and Internal Pressure Coefficient = +/- 0.55.

Table 4-2: Design wind pressures for walls at Stout Elementary School.

Wall (approx. 11 feet high)	***Design Wind Pressure****	***Internal Pressure***
Windward	+167 psf (acting toward surface)	Negative
Leeward (wind parallel to ridge)	-110 psf (acting away from surface)	Positive
Leeward (wind normal to ridge)	-133 psf (acting away from surface)	Positive
Side	-156 psf (acting away from surface)	Positive

* psf – pounds per square foot

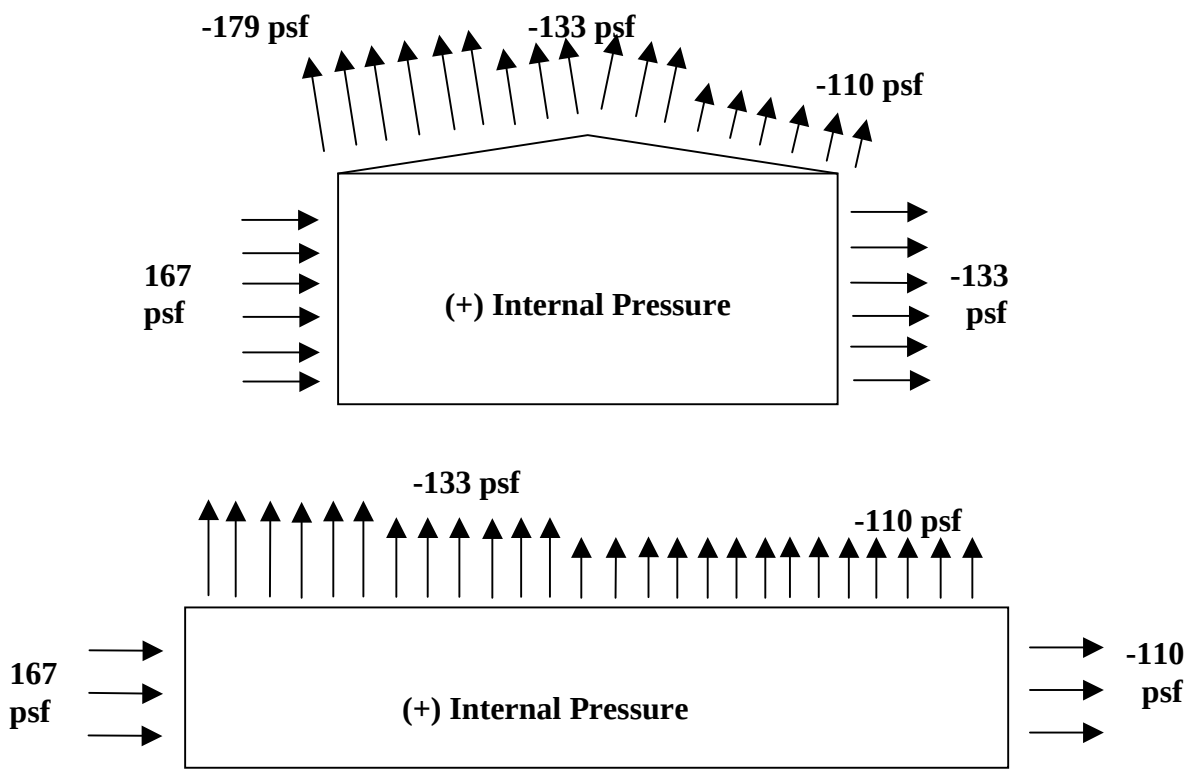

Figure 4-8: Design wind pressure on the walls and roof for Stout Elementary

To put these numbers in perspective, an 8-inch thick unreinforced masonry wall was analyzed for bending over the wall height from wind pressures. The maximum allowable tensile bending stress in a masonry wall is 50 psi (pounds per square inch) per the 1999 Masonry Standards Joint Committee Code, Table 2.2.3.2. If a 10-foot high wall is assumed, the maximum wind pressure the wall can resist without experiencing bending failure is 21 psf, much less than the predicted wind pressures ranging from 110 psf to 167 psf indicated above. Roof pressures were also calculated for wind directions either normal or parallel to the ridge. Wind pressures acting on the walls and roof of the refuge areas are presented in Table 4-3 and Figure 4-8.

Table 4-3: Design wind roof pressures at Stout Elementary School.

Horizontal Distance from Windward Edge	***Design Wind Pressure with Positive Internal Pressure (Loss of Windward Wall, Window, or Door)***
0 to 11 ft	-179 psf (acting away from surface)
12 to 22 ft	-133 psf (acting away from surface)
> 22 ft	-110 psf (acting away from surface)

The structural members of the roof, which consist of steel beams, concrete decking, anchor bolt connections, and unknown connections between the slab and the beams, will likely fail from the forces associated with wind speeds lower than 250 mph. To substantiate the vulnerability of the roof structure, a steel beam was analyzed for bending resistance. The wind pressures resulting from 250-mph wind speeds were applied to a 12B16.5 steel beam and the resulting bending stresses were above the allowable bending stress for the steel beam (22,000 psi). Also, the withdrawal capacity of the anchor bolt connections at the top of the wall is likely to be exceeded. The concrete deck connection to the steel beams is unknown and separation of the deck from the beams would likely occur.

A wind analysis of components and cladding was performed for windows, doors, and roof covering materials. Table 4-4 shows the design wind pressures that were calculated using the 250-mph wind speed.

Table 4-4: Design wind pressures for doors and windows at Stout Elementary School.

Component	***Within 5 Feet Of Building Corners***	***All Other Locations***
Doors	-211 to 238 psf (acting outward)	184 to 211 psf (acting outward)
	+170 to 184 psf (acting inward)	170 to 184 psf (acting inward)
Windows	-184 to 245 psf (acting outward)	184 to 211 psf (acting outward)
	+170 to 197 psf (acting inward)	170 to 197 psf (acting inward)
Roof coverings	-211 to 347 psf (acting outward)	197 to 211 psf (acting outward)

Doors and windows need to resist wind pressures as high as 245 psf. Door and window failures during high-wind events are commonly observed and lead to internal pressurization. The refuge area at Stout Elementary School has several exterior doors and windows. If a breach occurred that caused an exterior wall or door failure, classroom doors along the refuge area corridor would also be subjected to high-wind pressures and missile impact forces. The wood doors and windows at the school were not designed to resist these pressures and are, therefore, not expected to withstand these pressures.

Roof cladding materials on the roof crest could receive uplift pressures as high as 211 psf to 347 psf along the edges and corners of the roof, respectively. The edges alone along the roof would experience approximately 211 psf of uplift pressure and at least 197 psf on the interior sections of the roof. These pressures would result in forces that would tear the roof covering and possibly pull the concrete deck from the supporting steel beams.

MARJORIE L. FRENCH JUNIOR HIGH SCHOOL

Marjorie L. French Junior High School is a one-story building with a basement area below the gymnasium (see Figures 4-9 and 4-10). The school was constructed in 1970 and encompasses more than 30,000 square feet. The majority of the construction of the school is masonry wall construction with a basement area constructed of reinforced concrete.

Figure 4-9: View of the main entrance to French Junior High School.

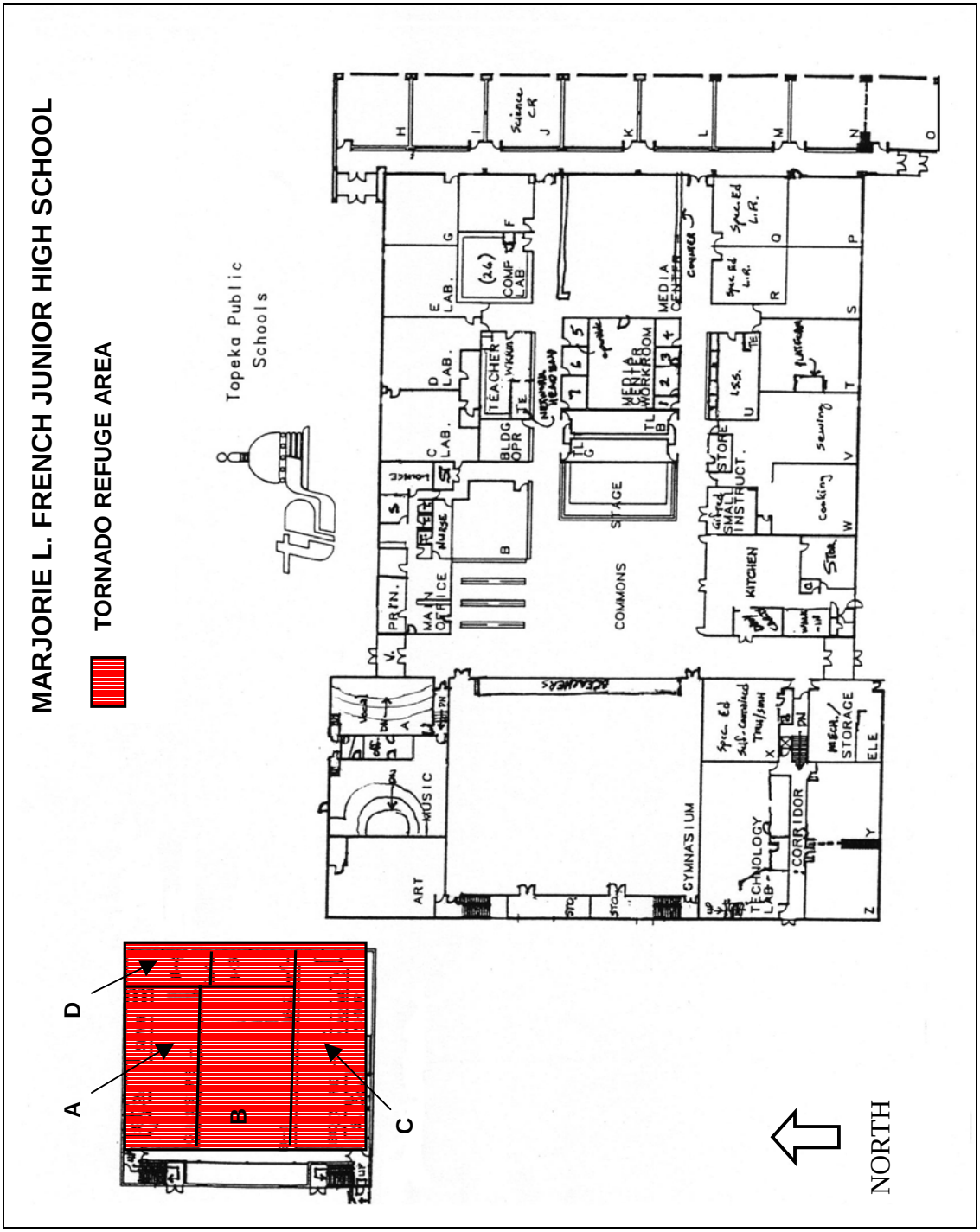

Figure 4-10: Tornado refuge areas at French Junior High School. All refuge areas are located in the basement of the building.

The designated tornado refuge areas at French are located in the basement area in both the men's and women's locker rooms and the multi-purpose room between the two locker rooms. The refuge areas are required to accommodate 650 students, faculty, and staff. Usable square footage is calculated on the evaluation checklists. The required space should provide at least 5 square feet per person. When an available area is being evaluated, the area should be calculated (Available Square Footage [ASF]) and then 85% of that area be considered as usable (Usable Square Footage [USF]). When bathrooms or rooms with furniture or other difficult to move obstructions are considered, only 50% of the available area should be considered usable. During the plan review of French, 85% of the available space in the multi-purpose room was considered usable. During the site visit, it was determined that the multi-purpose room was being used as in a classroom setting with a significant number of desks. Therefore, a recalculation of the refuge area using only 50% of the multi-purpose room resulted in a lack of usable refuge space. However, an additional classroom in the basement, when considered as part of the refuge area, provides the usable square footage required for the school population (see Table 4-5 and Figure 4-10).

Table 4-5: Refuge area usable space at French Junior High School.

Required Space (RSF*)	***Refuge Area Space (ASF*)***	***Usable Space (USF*)***
650 x 5 = 3,250 ft^2	A: 1,400 ft^2	1,400 x 0.50 = 700 ft^2
	B: 2,870 ft^2	2,870 x 0.50 = 1,435 ft^2
	C: 1,680 ft^2	1,680 x 0.50 = 840 ft^2
	D: 420 ft^2	420 x0.85 = 357 ft^2
	TOTAL = A+B+C+D	**TOTAL USF = 3,332 ft^2**

*See calculations on evaluation sheet in Appendix C for additional details.

French had the second lowest score of the evaluations performed (i.e., it was ranked as second best out of those evaluated), with a total score of 85. See Appendix B for the summary score sheet and Appendix C for the checklist. Observations regarding French and Ross Elementary, schools with basement refuge areas, are provided in this section. The two schools have similar strengths and vulnerabilities due to type of construction found in their refuge areas.

The basement refuge area is beneath the gymnasium. The roof system of the refuge area is the floor system of the gymnasium and is a reinforced concrete slab supported on reinforced concrete beams. The exterior walls of the basement are also constructed with reinforced concrete. The roof structure is supported at the ends by the exterior walls and at intermediate locations by reinforced concrete columns and beams. Interior walls in the basement are URM block walls that span between the columns and the exterior walls or from column to column. Figures 4-11, 4-12, and 4-13 show the women's locker room (A), the multi-purpose room (B), and the men's locker room (C) refuge areas, respectively.

Figure 4-11: French Junior High School refuge area A – women's locker room.

Figure 4-12: French Junior High School refuge area B – multi-purpose room.

Figure 4-13: French Junior High School refuge area C – men's locker room.

Observations

- The exterior walls are load bearing and constructed of reinforced concrete. Concrete walls designed for use as foundation walls are fully reinforced with steel bars. Although two walls are completely below grade, the north and west walls are partially exposed above grade. These walls have enough thickness to resist windborne debris impact from the high-wind event (15-lb missiles traveling horizontally at 100 mph). Furthermore, the reinforcing steel in the wall overlaps the reinforcing steel in the roof slab, creating a continuous load path between the roof and exterior walls. A continuous load path is also provided throughout the interior of the basement area where reinforced concrete beams are connected to and supported by reinforced concrete columns. This same construction was observed in the basement tornado refuge area at Ross Elementary (see Figure 4-14).

- The refuge area roof deck/elevated floor consists of a concrete slab supported by concrete beams. The refuge area roof slab is approximately 4 inches thick. Concrete roof slabs less than 6 inches thick can be damaged by falling debris, but the reinforced roof deck at French meets the missile impact criteria for a 15-lb 2x4 wood member falling vertically at 67 mph.

- There is no equipment or roof covering to be damaged during a high-wind event because the roof of the shelter is the floor of the gymnasium.

Figure 4-14: Basement refuge area at Ross Elementary. Reinforced concrete wall and slab construction with interior beams and columns is similar to the basement refuge area construction at French Junior High School.

- There are no windows in the basement refuge area at French. This reduces the risk of damage from windborne debris at the site. Ross Elementary does have two windows in the basement refuge area (see Figure 4-15). Although the windows are vulnerable to damage from wind and windborne debris, they were located in deep reinforced concrete window wells that were protected with heavy metal grates.

- The doors to the basement areas and the vents for the air-handling system are two potential ways for wind and windborne debris to enter the refuge area at French. The doors are light gauge metal doors (some with view windows) supported in light gauge metal frames. The doors adjacent to the women's locker room are offset from the exterior doors, providing protection from direct missile impact. The exterior doors adjacent to the women's locker room are light gauge metal doors with large wood or particle board panels mounted above the doors. These exterior doors and panels are likely to fail during a wind event and subject the basement doors to high-wind pressures (see Figures 4-16 and 4-17). All interior doors are wood and vulnerable to damage from wind pressures.

- Exterior doors adjacent to the men's locker room entrance do not provide an alcove type protection. These exterior doors and the doors behind them are vulnerable to wind pressures and windborne debris (see Figure 4-18).

- None of the doors have adequate connection hardware. All doors should have six points of connection: three hinges and three points of latching.

Figure 4-15: Windows in basement refuge area at Ross Elementary.

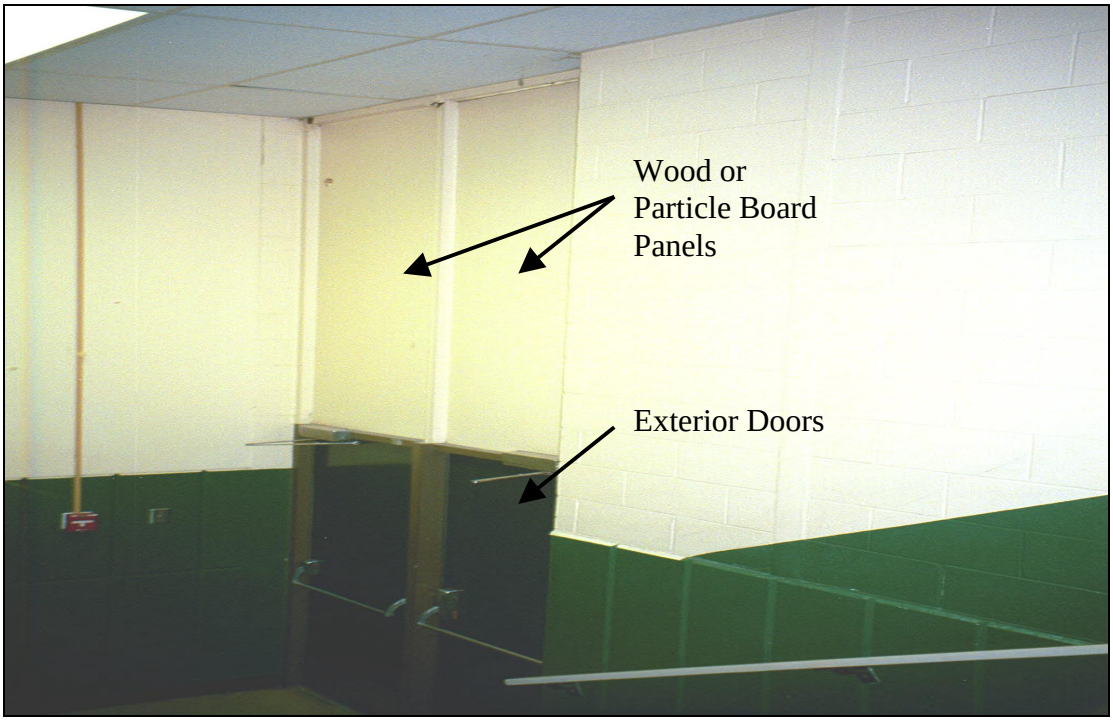

Figure 4-16: Exterior doors near the women's locker room end of the basement at French Junior High School.

Figure 4-17: Stairs leading down to refuge area entrance at women's locker room from doors in Figure 4-16. This alcove will protect the doors at the base of the stairs from windborne debris.

Figure 4-18: Unprotected exterior doors at basement entrance to refuge area at men's locker room at French Junior High School.

- Vents for the mechanical system are at grade on the west side of the building and are vulnerable to damage from windborne debris (see Figure 4-19). A metal vent cover in the mechanical room is located on the interior of the reinforced concrete wall; however, this cover is not capable of resisting debris impact from the design missile (see Figure 4-20) and should be replaced with a 14-gauge metal cover.
- There are no portable units on the school site.
- A ramp at the basement entrance to the men's locker room is the only means of egress for individuals in wheelchairs or for those who are otherwise non-ambulatory. For refuge area purposes, this ramp may not be considered ADA-compliant. Access has been provided, but because users of this entrance are required to travel outside and farther to reach the refuge area, it may not be considered equal access (see Figure 4-19).
- Timely access of all occupants to the refuge area is a potential problem. FEMA recommends that all occupants reach the refuge area within 5 minutes. There are only two points of internal access, both via stairs, and only one access point with a ramp (requiring users to go outdoors to access the refuge area). Three of the four tornado drills performed by the school during the 1999-2000 school year resulted in all occupants reaching the shelter in less than 4 minutes. However, one drill required approximately 6.5 minutes for all occupants to reach the refuge area.

Figure 4-19: Exterior view of west side of French showing ramped egress to refuge area at the men's locker room entrance. Unprotected vent is also visible on the left side of the photograph.

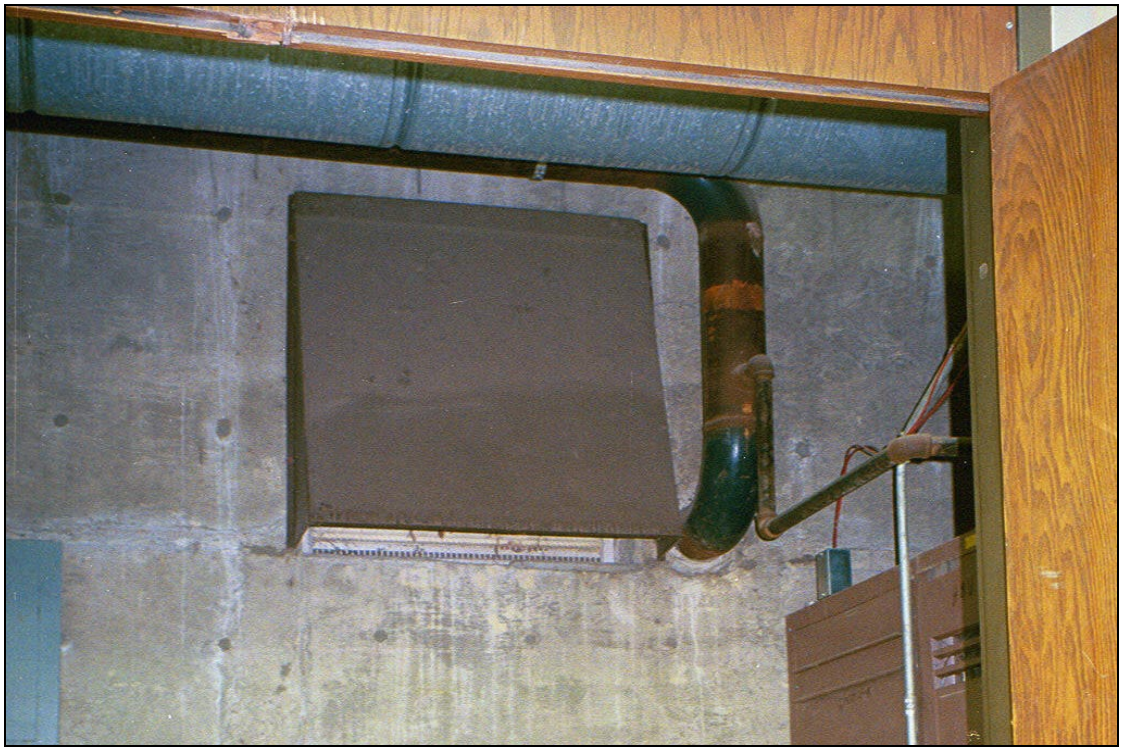

Figure 4-20: Vent protection at louvered intake at ground level. Although this metal cover provides some resistance to windborne debris, it should be replaced with a 14-gauge metal cover.

- The school does not have a backup power source. Battery powered backup lights are located within the refuge area and building maintenance personnel indicated they have a 2 to 4 hour duration.

Structural Analysis

The structural strengths at French Junior High School and at Ross Elementary School are very similar. Although the refuge areas are basements, wind loads are calculated on the refuge areas as if the building above has been swept away during the wind event. Therefore, the small sections of wall that extend above grade are evaluated for wind loads acting toward and against the structure. Also, the roof of the refuge area is evaluated as if no building remains atop the elevated slab. It should be noted that the reinforced concrete roof structure, with reinforced concrete beams connected to the foundation, provides far more wind resistance than the roof structure at Stout Elementary School.

The wind pressures calculated for a tornado event are similar to those calculated for Stout Elementary School. The wind pressures were calculated for the MWFRS walls and roof structure of the refuge area. Components and cladding loads were calculated for the doors and for potential basement windows. The highest wind pressures expected to act on the walls are tabulated in Table 4-6 (see footnote 3 on page 23).

Table 4-6: Design wind pressures for walls at French Junior High School.

Wall (approx. 4 feet high)	***Design Wind Pressure***	***Internal Pressure***
Windward	+167 psf (acting toward surface)	Negative
Leeward	-133 psf (acting away from surface)	Positive
Side	-156 psf (acting away from surface)	Positive

A reinforced concrete wall 6 inches thick with #4 reinforcing steel at 12 inches on center (vertically and horizontally) can be 8 feet high and 8 feet wide and withstand the wind pressures and windborne debris impacts from the high-wind event. The basement walls at both French and Ross have less than 8 feet of wall extending above grade to be acted upon by wind. These walls also have more reinforcing than the minimum specified above and are thicker than 6 inches. These walls should withstand the wind forces from a 250-mph wind event.

Calculated wind pressures on the roof are presented in Table 4-7 and Figure 4-21. (The basement is essentially square so the wind direction is not critical for these calculations.) Also, because the exposed height of the basement wall is small, the wind speedup over the roof surface is not as significant as it is for a full, single-story structure. Therefore, the region of high suction pressures on the roof is relatively small.

Table 4-7. Design wind roof pressures at French Junior High School.

Horizontal Distance from Windward Edge	***Design Wind Pressure with Positive Internal Pressure (Loss of Windward Wall, Window, or Door)***
0 to 4 ft	-179 psf (acting away from surface)
4 to 8 ft	-133 psf (acting away from surface)
> 8 ft	-110 psf (acting away from surface)

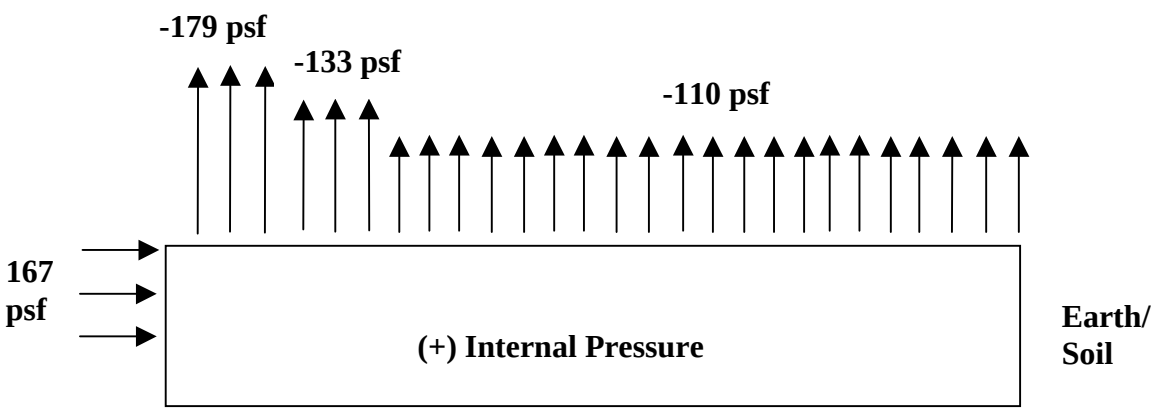

Figure 4-21: Design wind pressures on the roof and walls of the refuge area at French.

The slab above the refuge area has a small vulnerability to breach from the missiles larger than the design missile impact because it is 4 inches thick, not the FEMA recommended 6 inches thick. Recent missile impact tests have shown that, depending upon the reinforcement, 4-inch reinforced concrete slabs can withstand the missile impact. A slab with reinforcement similar to the refuge area roof area at French has not been tested.

The roof structure has reinforced concrete joists spanning between reinforced concrete beams that support the roof slab. This system will proved a significant amount of protection and can withstand heavy wind forces and damage without failure. However, a detailed concrete design analysis to determine the failure capacity of the concrete roof system (columns, beams, joists, and slabs) was beyond the scope of this project.

In order to prevent a breach in the basement of the building, doors must be strong enough to withstand wind pressures and missile impacts. Wind pressures acting on the doors are presented in Table 4-8. Wind pressures on windows in basement refuge areas are also presented in the table.

Table 4-8: Design wind pressures for doors and windows at French Junior High School.

Component	***Within 4 Feet of Building Corners***	***All Other Locations***
Doors	-204 to 232 psf (acting outward)	-197 to 211 psf (acting outward)
	+177 to 191 psf (acting inward)	+177 to 191 psf (acting inward)
Windows	-231 to 265 psf (acting outward)	-204 to 238 psf (acting outward)
	+197 to 211 psf (acting inward)	+197 to 211 psf (acting inward)

Doors and windows must resist wind pressures as high as 232 psf and 265 psf, respectively. Door and window failures during high-wind events are commonly observed and lead to internal pressurization. The refuge area at French has two exterior doors and five interior doors that need to resist these forces. There are no windows at the refuge area at French. Ross Elementary has two sets of doors and two windows that need to resist these forces. At this time, neither school has the proper doors, door frames, door hardware, or window protection in place to resist these forces. The lightweight metal and wood doors and windows at the school were not designed to resist these pressures and are, therefore, not expected to withstand them.

TOPEKA HIGH SCHOOL

Topeka High School was designed in the late 1920s and constructed in 1930-1931 (see Figure 4-22). The school is a three-story building with multiple basement levels. The main core of the building is rectangular. Two wings extend to the south of the main building at 45 degrees; each wing also has three stories. The tornado refuge areas for the schools are located on the first floor of the building in the main hallways and the hallways of the two wings. The refuge areas are divided into 18 areas in the tornado refuge plan (see Figure 4-23). The maximum anticipated capacity of the refuge areas is 2,200 students, faculty, and staff.

Topeka High School recorded the second highest score on the evaluations performed for this project with a total score of 167.5. See Appendix B for the summary score sheet and Appendix C for the checklists. Multiple evaluation checklists were used at Topeka High to document the existing refuge areas at the school and for proposed alternate refuge areas.

Figure 4-22: The main entrance and tower at Topeka High School.

A full set of structural and architectural plans was not available at the time of the evaluation. The school was evaluated in its current condition with the current set of building plans. Penalty points were assessed for the lack of building plans and the lack of information that was needed to complete the checklists. The score of the existing hallway refuge areas could be easily reduced by 30 points, to 137.5, with a re-evaluation using a complete set of building plans.

The Observations section for Topeka High will outline the vulnerabilities of the existing first floor refuge areas. Recommended alternate refuge areas that provide improved protection over the first floor hallways will also be discussed. These alternate areas were evaluated and their scores are presented on the summary score sheet in Appendix B and the checklists in Appendix C. The alternate refuge areas will also be discussed in the Observations section. Section 5 of the report presents recommendations for Topeka High that will apply to the existing first floor refuge area and to the alternate refuge area. The recommended alternate refuge area utilizes some of the basement areas that were relatively clear and available. All occupants could not fit in basement areas, so hallways that were protected from exterior entrance areas were chosen to meet the remaining space requirements. The recommended refuge areas include the basement, the seating area around the swimming pool, the men's and women's locker rooms, and hallway refuge areas 1, 2b, and 18 only. Table 4-9 presents the square footage calculations for both the existing and the recommended tornado refuge plans.

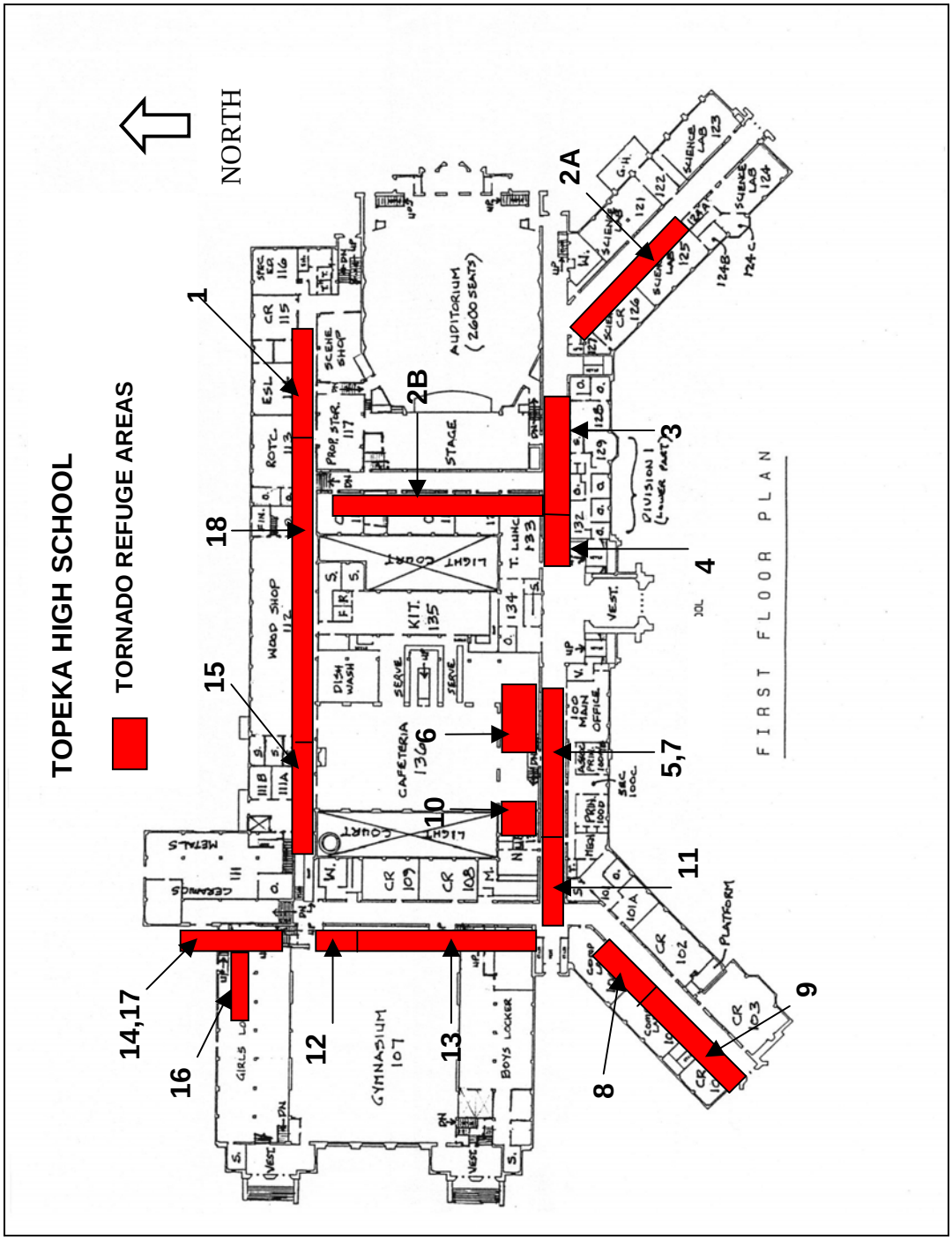

Figure 4-23: Existing refuge area plan for Topeka High School (shown on the first floor layout).

Table 4-9: Refuge area usable space at Topeka High School.

Required Space (RSF*)	***Refuge Area Space (ASF*)***	***Usable Space (USF*)***
Existing Tornado Refuge Plan		
2,200 x 5 = 11,000 ft^2	1: 840 ft^2	840 x 0.85 = 714 ft^2
	2a: 648 ft^2	648 x 0.85 = 551 ft^2
	2b: 1,150 ft^2	1,150 x 0.85 = 978 ft^2
	3: 1,022 ft^2	1,022 x 0.85 = 869 ft^2
	4: 392 ft^2	392 x 0.85 = 333 ft^2
	5,7: 1,176 ft^2	1,176 x 0.85 = 1,000 ft^2
	6: 880 ft^2	880 x 0.85 = 748 ft^2
	8: 480 ft^2	480 x 0.85 = 408 ft^2
	9: 840 ft^2	840 x 0.85 = 714 ft^2
	10: 308 ft^2	308 x 0.85 = 262 ft^2
	11: 686 ft^2	686 x 0.85 = 583 ft^2
	12: 360 ft^2	360 x 0.85 = 306 ft^2
	13,15: 1,675 ft^2	1,675 x 0.85 = 1,424 ft^2
	14,17: 384 ft^2	384 x 0.85 = 326 ft^2
	16: 320 ft^2	320 x 0.85 = 272 ft^2
	18: 1,780 ft^2	1,780 x 0.85 = 1,513 ft^2
	TOTAL = (Areas 1 thru 18)	**TOTAL USF = 11,001 ft^2**
Recommended Tornado Refuge Plan		
2,200 x 5 = 11,000 ft^2	Pool/Basements: 5,555 ft^2	5,555 x 0.85 = 4,723 ft^2
	Locker rooms: 6,184 ft^2	6,184 x 0.50 = 3,092 ft^2
	1: 840 ft^2	840 x 0.85 = 714 ft^2
	2b: 1,150 ft^2	1,150 x 0.85 = 978 ft^2
	18: 1,780 ft^2	1,780 x 0.85 = 1,513 ft^2
	TOTAL = (Σ Areas)	**TOTAL USF = 11,020 ft^2**

*See calculations on evaluation sheet in Appendix C for additional details.

Observations

Observations have been divided into two groups: the existing and the recommended tornado refuge areas. The first group of observations applies to the existing refuge area plan and the refuge areas identified on the first floor of Topeka High.

Existing Tornado Refuge Area Plan

- The primary structural system carrying loads at Topeka High is a reinforced concrete frame that provides a continuous load path from the roof structure of the building to the foundation. It also provides a continuous load path for lateral and uplift loads acting on the hallways designated as refuge areas. A reinforced concrete slab, supported by reinforced concrete beams, makes up each elevated floor of the school and the roof of the hallway refuge areas. It is reasonable to anticipate that the structural frame will have the capacity to resist wind loads from the high-wind event because of the size of this reinforced concrete frame.

- The refuge area roof deck/elevated floor consists of a concrete slab supported by concrete beams. The thickness of the refuge area roof slab is unknown because structural plans were not available. Concrete roof slabs less than 6 inches thick can be damaged by falling debris, but reinforced roof decks at least 4 inches thick have met the missile impact criteria for a 15-lb 2x4 wood member falling vertically at 65 mph.

- There is no equipment or roof covering to be damaged during a high-wind event because the roof of the shelter is the floor of the school.

- Exterior walls within the columns and beams of the frame are URM clay block with a brick masonry veneer (see Figure 4-24). URM clay block does not have the ability to carry lateral wind loads that will accompany the high-wind event. These walls are vulnerable to failure from wind pressures alone, like the walls at Stout Elementary. URM clay block cannot withstand impact from the design missile. Although the brick masonry veneer improves the impact resistance of the wall, the wall is likely to be breached by windborne missiles during a high-wind event.

Figure 4-24: Exterior walls at Topeka High School.

- Interior walls between the columns and beams of the concrete frame are URM clay block and structural glazed tile (see Figure 4-25). These walls are the walls of the refuge areas and are even more vulnerable to failure from wind and windborne debris than the exterior masonry walls with a brick veneer. In addition, these interior walls span long lengths, both vertically from floor to roof beam and horizontally from column to column. These long spans further increase the vulnerability to wind and windborne debris because the wall slenderness increases the likelihood that it may become unstable when acted upon by wind forces or impacted by debris.

- Throughout much of the first floor, granite wall panels are attached to the URM walls. Although these panels (see Figure 4-26) may increase the resistance of the URM walls, they are not continuous through the hallways and their connection to the URM walls is unknown.

- There are windows at classrooms and offices along the hallways at Topeka High. The windows increase the risk of damage from windborne debris at the site. Although the windows are located on the "inside" of the building, they are the "outside" of the refuge area. When exterior windows on the building are breached, these windows must separate the refuge area from wind and windborne debris. To date, no window system has been tested that withstands the design missile.

Figure 4-25: URM clay block interior walls adjacent to a concrete column at Topeka High School. Note: The presence of the vertical piping decreases the ability of the interior wall to resist lateral wind loads without failure.

Figure 4-26: Interior granite wall panels in the some of the first floor refuge area hallways.

- The exterior doors accessing the hallway refuge areas are vulnerable to damage from wind and windborne debris. Most of the exterior doors are aluminum doors, many with large windows, and supported in aluminum doorframes. These exterior doors and frames are likely to fail during a tornado (see Figure 4-27). In addition, only two of the corridors are completely interior and have no exterior openings (see Figure 4-23). Corridors open to the exterior at both ends are vulnerable to wind damage and wind and debris passing through the refuge areas.

Figure 4-27: Exterior doors at Topeka High School looking from refuge area 11.

- All interior doors accessing the refuge areas are wood and open from offices, classrooms, storage areas, or bathrooms. These doors should provide protection for occupants from wind and windborne debris. However, wood doors and wood doorframes are not capable of resisting wind pressures and debris. Only heavy gauge steel doors without windows (supported by steel frames) meet the design criteria of *FEMA 361*.

- None of the refuge areas have doors to seal the refuge areas at exterior doors, hallway intersections, stairwells, and potential hazard areas. Therefore, when occupants are seeking refuge at the ends of each hallway refuge area, there is little or no protection from wind and windborne debris that may have breached the exterior doors and windows (see Figure 4-28). Wind and debris could easily enter the refuge areas.

Figure 4-28: South hallway refuge areas at Topeka High School with no doors to protect the occupants of the refuge area from vulnerable areas of the building from wind and windborne debris. This hallway could become a wind tunnel if doors at both ends are breached.

- None of the doors have adequate connection hardware. All doors should have six points of connection: three hinges and three points of latching.

- There are currently no portable units on the school site.

- Elevators and a ramp on the first floor adjacent refuge areas 12 and 18 provide access to the refuge areas from all areas of the building. The refuge areas appear to be ADA-compliant (see Figure 4-29).

- Timely access for all occupants to the refuge areas does not appear to be a problem. Although, there are a large number of students and staff that need to take refuge from a tornado at THS, timed drills from the 1999-2000 school year all were all conducted in less than the FEMA recommended 5-minute travel time.

- The school does not have a backup power source. Battery powered backup lights are located within the refuge area and building maintenance personnel indicated they have a 2 to 4 hour duration.

Figure 4-29: Ramp between refuge areas 12 and 18 providing ADA access.

Recommended Tornado Refuge Area Plan

After review of the available plans and the site visit to Topeka High School, additional areas were identified at the school for use as refuge areas in the basement areas below the main school, which includes the area around the basement pool, and the men's and women's locker rooms, the hallway near the freight elevator, and storage areas near stairs to the kitchen (see Figure 4-29A). Observations relating to these recommended areas are presented below and improvement and retrofit options are presented in Section 5.

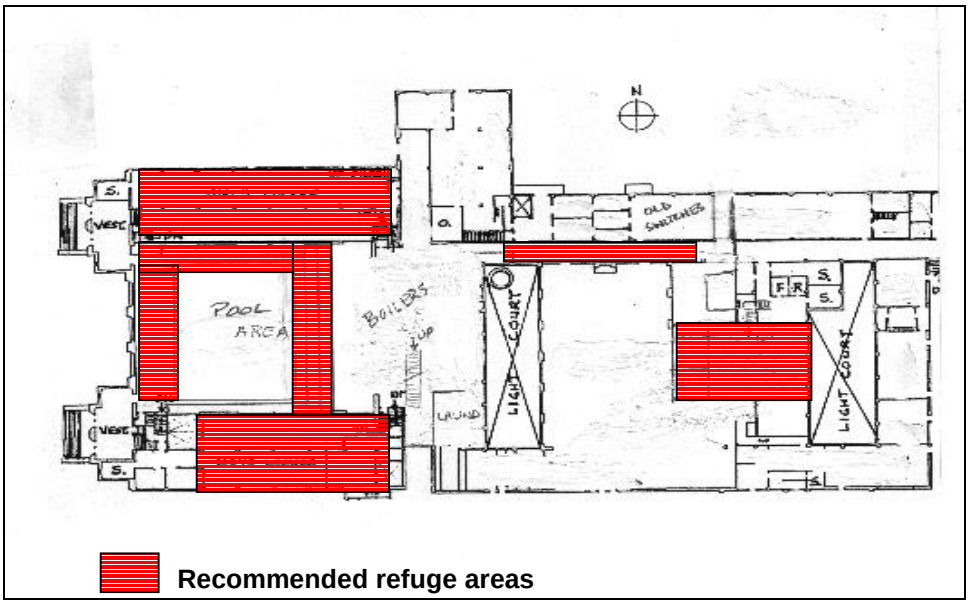

Figure 4-29A: Recommended basement refuge areas for Topeka High School.

- The primary structural system carrying loads in the basement locker room areas and pool areas is a reinforced concrete frame that provides a continuous load path from the roof structure of the building to the foundation. It also provides a continuous load path for lateral and uplift loads acting on the basement hallways and pool view areas designated as refuge areas. A reinforced concrete slab, supported by reinforced concrete beams, makes up each elevated floor of the school and the roof of these refuge areas. It is reasonable to anticipate that the structural frame will have the capacity to resist wind loads from the high-wind event because of the size of this reinforced concrete frame (see Figure 4-30). A locker room area designated as a refuge area is shown in Figure 4-31.

Figure 4-30: Pool viewing area in the basement that can be used as a tornado refuge area.

- Exterior walls of the locker rooms are constructed of URM clay block with a brick masonry veneer (see Figure 4-32). URM clay block does not have the ability to carry lateral wind loads that will accompany the high-wind event; it also cannot withstand impact from the design missile. Although the brick masonry veneer improves the impact resistance of the wall, the wall is likely to be breached by windborne missiles during a high-wind event. However, some of the locker room walls have as much as one third of their height below the adjacent grade, providing some protection for the walls.

- Concrete walls designed for use as foundation walls in the basement and pool areas are fully reinforced with steel bars. Most of the basement walls are completely below grade, but some wall sections are partially exposed above grade. Although the design plans for the walls were not available, basement walls of this type typically have enough thickness to resist windborne debris impact from the high-wind event (15-lb missiles traveling horizontally at 100-mph). Furthermore, the reinforcing steel in the wall overlaps the

reinforcing steel in the roof slab (elevated floor above), creating a continuous load path between the roof and exterior walls.

Figure 4-31: Locker room area that can be used as a tornado refuge area.

Figure 4-32: Exterior walls of a Topeka High School locker room. The windows have been removed from the exterior walls.

- Interior walls between the columns and beams of the frame in the locker rooms are URM clay block and structural glazed tile. These walls act as the walls of the refuge areas on the basement side of the locker rooms and beneath the bleachers off the locker rooms. Although the interior walls are vulnerable to wind and windborne debris, the basement and the steel bleachers provide additional protection for these walls. Interior walls in the basement and pool areas are contained within the basement (below ground level) and are not susceptible to wind and windborne debris.

- The refuge area roof deck/elevated floor in the pool, the basement, and the locker room areas consist of a concrete slab supported by concrete beams. The thickness of the refuge area roof slabs is unknown because structural plans were not available. Concrete roof slabs less than 6 inches thick can be damaged by falling debris, but reinforced roof decks at least 4 inches thick have met the missile impact criteria for a 15-lb 2x4 wood member falling vertically at 67 mph.

- Because the roof of the shelter is the floor of the gymnasium, there is no equipment or roof covering to be damaged during a high-wind event.
- There are windows in only two areas of the basement areas. One of these areas is adjacent to the boiler room/laundry area and is proposed for use only as access to the refuge area in the basement. The second area with windows has two windows that face into a three-story courtyard area (designated “light court” on Figure 4-23). The courtyard provides some protection for these windows.

- There are no windows in the basement pool refuge area.

- The windows that were formerly along the exterior walls of the locker room areas have been removed (see Figure 4-32). The window area has been closed up, but the resistance of these closed windows is unknown because design plans were not available. Although these areas may not be fully impact-resistant, they should provide improved protection for occupants within the locker room refuge area.

- Exterior doors to the basement are constructed of light gauge metal, without windows, supported by light gauge metal frames. Although these doors do not meet the design standards of *FEMA 361* for wind pressure and windborne debris impact for doors at refuge areas, they provide improved protection for refuge areas when compared to the glazed exterior doors of the first floor refuge areas.

- None of the doors have adequate connection hardware. All doors should have six points of connection: three hinges and three points of latching.

- Timely access of all occupants to the refuge area is a potential problem. FEMA recommends that all occupants reach the refuge area within 5 minutes. Although there are multiple points of stairway entry to the basement, there is only a freight elevator, which is not ADA-compliant. Also, because this is a recommended revision to the plan, there is no documented travel time to the recommended refuge areas.

- The school does not have a backup power source. Battery powered backup lights are located within the refuge area and building maintenance personnel indicated they have a 2 to 4 hour duration. Additional emergency lights would need to be installed in the basement areas.

Structural Analysis

Both the existing tornado refuge plan and the recommended refuge plan require the use of hallway areas on the first level of the school. When evaluating multiple refuge areas at a school, the score from the most vulnerable area must be assigned to the school, because some students, faculty, and staff are required to use this area. The existing tornado refuge plan at Topeka High utilizes the first floor hallways. The recommended plan uses first floor hallways protected from exterior entrances, the locker rooms (at ground level and below ground level), and some basement areas. Using the reasoning and methodology mentioned above, the following loads are calculated for all areas in both the existing and recommended refuge areas (see Tables 4-10 through 4-12).

Wind pressures were calculated for the walls and the roof acting as the MWFRS. The MWFRS is an assemblage of structural elements assigned to provide support and stability for the overall structure and, as a consequence, generally receives wind loading from more than one surface of the building. Elements of the building envelope (the building's exterior) that do not qualify as part of the MWFRS are identified as components and cladding. Components and cladding receive wind loads directly and transfer the load to other components or to the main system. Design wind pressures predicted to act on the exterior walls and the MWFRS are listed in Table 4-10 for all refuge areas at Topeka High (see footnote 3 on page 23).

Table 4-10: Design wind pressures for walls at Topeka High School.

Wall (approx. 12 feet high)	***Design Wind Pressure***	***Internal Pressure***
Windward	+167 psf (acting toward surface)	Negative
Leeward	-133 psf (acting away from surface)	Positive
Side	-156 psf (acting away from surface)	Positive

The reinforced concrete frame will provide a load path to carry loads calculated in Table 4-10. However, the capacity of the frame and the roof system cannot be evaluated until design plans are available for the school. Engineering experience indicates that, although the building is designed to an older code (1920s design and construction), it is likely that the frame will resist the loads because of the strength required for a three-story reinforced concrete structure. Roof pressures were also calculated (see Table 4-11 and Figure 4-33). The tabulated roof pressures are for wind approaching the building from any direction.

Table 4-11: Design wind roof pressures at Topeka High School.

Horizontal Distance from Windward Edge	***Design Wind Pressure with Positive Internal Pressure (Loss of Windward Wall, Window, or Door)***
0 to 12 ft	-179 psf (acting away from surface)
13 to 24 ft	-133 psf (acting away from surface)
> 24 ft	-110 psf (acting away from surface)

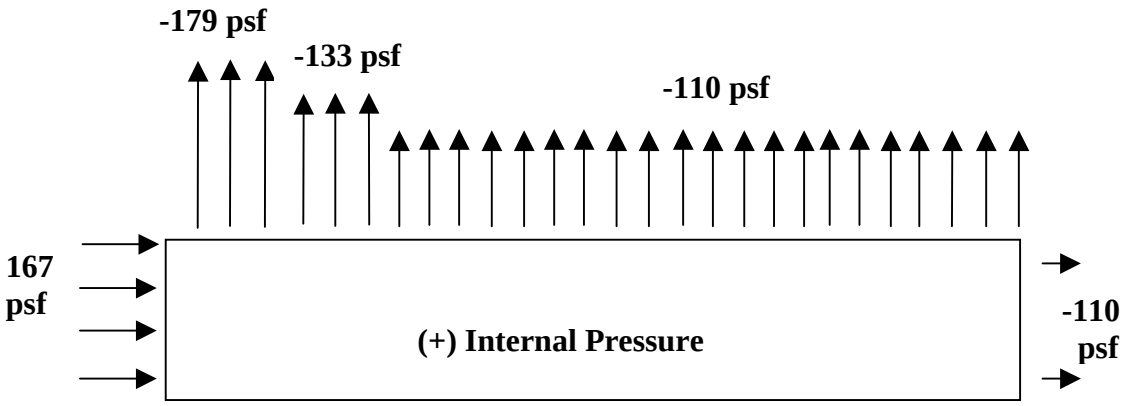

Figure 4-33: Design wind pressures on the refuge areas at Topeka High School.

The reinforced concrete slab above the refuge area has a small vulnerability to breach from the missiles larger than the design missile impact because it is constructed of reinforced concrete likely to be at least 3 inches thick; this slab depth would be half of the FEMA recommended 6-inch thick refuge area roof slab. Recent missile impact tests have shown that, depending upon the reinforcement, 4-inch reinforced concrete slabs can resist the missile impact.

The roof structure is reinforced concrete joists spanning between reinforced concrete beams. This construction, combined with the reinforced concrete slab, results in a roof system that provides some protection for its occupants for all tornadoes. The exact level of protection could be determined through an engineering analysis when design plans for the building are provided.

A collapse hazard from the building itself is a potential at this site. All refuge areas are located beneath at least two upper building levels. Some areas are adjacent to a large central tower structure at the building entrance and a brick masonry chimney located at the north end of the west courtyard (light court).

A wind analysis of components and cladding was performed for windows and doors of the refuge areas. Components and cladding loads are not pertinent for the refuge area roof because the elevated floors act as the roof. The components and cladding design wind pressures in Table 4-12 were calculated using the 250-mph wind speed.

Table 4-12: Design wind pressures for doors and windows at Topeka High School.

Component	***Within 5 Feet of Building Corners***	***All Other Locations***
Non-load Bearing Interior Walls and Doors	-211 to 238 psf (acting outward)	-184 to 211 psf (acting outward)
	+170 to 184 psf (acting inward)	+170 to 184 psf (acting inward)
Windows	-184 to 245 psf (acting outward)	-184 to 211 psf (acting outward)
	+170 to 197 psf (acting inward)	+170 to 197 psf (acting inward)

To put these numbers in perspective, an 8-inch thick URM wall was analyzed for bending in the vertical direction. The maximum bending stress for a vertical span is 50 psi. If a 10-foot high span is assumed, the maximum wind pressure the wall can take without experiencing a bending failure is 21 psf, which is much less than the predicted wind pressures ranging from 170 to 184 psf indicated above

Doors and windows must resist wind pressures as high as 245 psf. Door and window failures during high-wind events are commonly observed and lead to internal pressurization. The refuge areas at Topeka High rely on many exterior doors to resist these extreme pressures. If a breach occurred (e.g., an exterior wall or door failure) in these doors, the refuge areas on the first floor would be exposed to severe winds and windborne debris. Furthermore, interior walls, doors, and windows may experience the wind and debris from a high-wind event when classrooms are breached. Classroom, office, and other doors and windows along the refuge area corridor would also be subjected to high-wind pressures and missile impact forces. The wood doors and windows at the school were not designed to resist these pressures and are, therefore, not expected to withstand these pressures.

Therefore, the hallways are the most vulnerable areas of the proposed refuge areas because the walls of the refuge area are susceptible to damage during a high-wind event. The walls of the locker room have a construction similar to the hallway walls. The locker room walls are less vulnerable because of fill that is adjacent to the walls of the locker rooms on the south side of the gymnasium, reducing the wall span opposed to wind pressures.

The least vulnerable refuge areas are the basement and pool areas. These areas are below ground level on all sides. Only the roof of the refuge areas will experience wind and debris from a tornado. The locker rooms are vulnerable to damage from wind and windborne debris between the pool area and the hallway (see Appendices B and C). Although the locker rooms have a reinforced concrete frame to provide a continuous load path and fewer doors than the hallways, the walls of the locker rooms are still vulnerable to damage from wind pressures and windborne debris.

5. RECOMMENDATIONS

There a number of measures that can be taken to increase the level of protection in existing refuge areas and they are described for each case study under “Improving Refuge Areas”; however, these refuge area improvements will not achieve near-absolute protection. Retrofit options that will achieve near-absolute protection for these schools will require more extensive reconstruction and cost. These measures are proposed in the “Retrofit Options” sections.

A.J. STOUT ELEMENTARY SCHOOL

Improving Refuge Areas

- Install tornado-resistant doors at the north and south hallway entrances of each refuge area and at the intersection of the hallways to seal off the openings. Classroom doors and door frames should also be replaced.
    - Use steel doors with 14-gauge skin with 20-gauge metal ribs and honeycomb core or polystyrene in-fill.
    - Use six points of connection for each door, including three point latches. (NOTE: The building code requirements for egress in Topeka dictate that doors into and out of areas with occupancies of 50 persons or more must use "panic" hardware. Thus any three-point latch system used in the 50+ person occupancies must be connected to "panic" bar hardware.)
- Remove all skylights and seal any openings under the direction of a structural engineer. Possible solutions might be to install a 14-gauge steel plate or a pre-cast concrete slab at each skylight opening. The slab should be at least 6 inches thick and reinforced with #4 rebar at 12 inches on center, each way.
- Eliminate debris sources by replacing the aggregate ballast roof covering with a new roof covering that does not require ballast. Trim all trees that hang over the roof of the school.
- Securely fasten roof-mounted equipment with an adequate number of fasteners to resist the design wind pressures.
- Install a backup power system in a protected area.

Retrofit Options

<u>Option 1</u>

- Implement all improvements described above.
- Reinforce and anchor the chimney to prevent collapse.

- Install/construct pilasters to shorten unsupported spans of interior walls to 10 feet 8 inches to reduce wall slenderness.

- Reinforce masonry corridor walls with vertical reinforcing steel and grout in every cell.

- Connect walls to the foundation and roof structure with reinforcing steel. Install a reinforced concrete bond beam at the top of the masonry wall.

- Retain a design engineer to perform a detailed analysis of the refuge area per the guidelines of *FEMA 361* to clarify the level of protection provided by the refuge area.

Option 2

- Implement all improvements described above.

- Reinforce and anchor the chimney to prevent collapse.

- Using the existing walls as formwork, build a 6-inch thick reinforced concrete wall against the hallway side of the corridor walls. Tie the walls into the existing foundation (the existing foundation may require modification). Install a reinforced concrete roof system atop the new concrete walls, below the existing roof structure. Design the new corridor design using the guidance found in *FEMA 361*. (Note: The existing corridor is currently 8'-0" in width. The installation of these walls would reduce the corridor width to 7'-0". By code, the ***minimum*** width is 6'-0". Doors in any position cannot reduce the *required* width by more than 1/2. Based on 25 students per classroom, the *required* width of the corridors is 5'-10". Putting new doors and frames into the new wall will not reduce the required width by more than 1/2. This option will meet code.)

Option 3

- Design and construct a dual-use tornado safe room addition per current *FEMA 361* guidelines. The addition should be large enough to accommodate the entire school population.

MARJORIE L. FRENCH JUNIOR HIGH SCHOOL

Improving Refuge Areas

- Install tornado-resistant doors to shield refuge areas from wind pressures and windborne debris at entrances and stairways.

  - Use steel doors with 14-gauge skin with 20-gauge metal ribs and honeycomb core or polystyrene in-fill. If double-door configurations are needed for access, see *FEMA 361* for guidance on installing reinforced steel doorframes to accommodate this need.

  - Use six points of connection for each door, including three point latches. (NOTE: The building code requirements for access in Topeka dictate that doors into and out of areas with occupancies of 50 persons or more must use "panic" hardware. Thus

any three-point latch system used in the 50+ person occupancies must be connected to "panic" bar hardware.)

- Replace interior doors with steel doors throughout the basement area. Use of these doors throughout the refuge area adds improved protection for the occupants. The doors of the mechanical room should also be replaced with metal doors and metal door frames.

- Replace metal vent protectors (inside the mechanical room in the basement) with vent protectors/covers constructed from 14-gauge steel and bolt the coverings to the reinforced concrete wall.

- In basement refuge areas with windows:
  - If the window is located within a window well, install a heavy gauge metal grate at the top of the window well. Bolt the grate into place to resist uplift wind forces and movement if struck by windborne debris.
  - If the window is not protected with a window well, remove window and close up with fully grouted masonry block or brick.
- Install a backup power system in a protected area.

Retrofit Options

<u>Option 1 – Basements with no windows.</u>

- Implement all improvements described above.

- Replace wood panels above exterior doors to basement area with 14-gauge steel panels.

- Revise the existing tornado refuge plan to comply with square footage guidelines for tornado-resistant safe rooms (5 square feet per person). The basement is large enough to accommodate the entire school population, but the plan needs revision to include classroom area “D” identified in Section 4.

- Retain a design engineer to perform a detailed analysis of the refuge area per the guidelines of *FEMA 361* to clarify the level of protection provided by the refuge area.

<u>Option 2 – Basements with windows.</u>

- Implement all improvements described above.

- Remove windows and close up openings. The openings need to be closed with reinforced concrete, reinforced masonry, or 14-gauge steel panels designed and attached per the guidelines of *FEMA 361*.

- Retain a design engineer to perform a detailed analysis of the refuge area per the guidelines of *FEMA 361* to clarify the level of protection provided by the refuge area.

TOPEKA HIGH SCHOOL

Improving Refuge Areas

- Install steel doors at all exterior building egress points. Most areas had two sets of doors with aluminum frames and glass exterior doors and no doors at the inside door frame. Install the new steel doors such that a vestibule could be created with the steel doors; the existing exterior aluminum and glass doors could remain in place and the new steel doors could be installed on the hallway side of the vestibule.

    - Use steel doors with 14-gauge skin and with 20-gauge metal ribs and honeycomb core or polystyrene in-fill. If double-door configurations are needed for egress, see *FEMA 361* for guidance on installing reinforced steel door frames to accommodate this need.
    - Install steel doors at ends of hallways designated tornado refuge areas to protect these areas from wind and windborne debris that may be moving through adjacent hallways.

- Use six points of connection for each door, including three-point latches. (NOTE: The building code requirements for egress in Topeka dictate that doors into and out of areas with occupancies of 50 persons or more must use "panic" hardware. Thus any three-point latch system used in the 50+ person occupancies must be connected to "panic" bar hardware.)
- In hallways along offices and classrooms, remove all windows and close up wall area with reinforced masonry or reinforced concrete.
- Minimize use of first floor hallways as refuge areas, particularly those exposed directly to exterior entrances, by revising the tornado refuge plan to include the locker rooms, the pool area, and the basement. Implement the revised plan and perform practice drills to ensure travel time is less than the FEMA recommended 5 minutes.
- Install a backup power system in a protected area.

Retrofit Option

The first floor hallways will be very difficult and expensive to retrofit to provide near-absolute protection as defined in *FEMA 361*. Furthermore, Topeka High School is a historic structure and any major renovations to the first floor may be difficult to institute. To achieve near absolute protection for all building occupants, all individuals seeking refuge should be provided refuge below the first floor of the building or in newly constructed shelter areas.

- Implement all improvements described above.
- Remove windows and close up openings with reinforced concrete, reinforced masonry, or 14-gauge steel panels designed and attached per the guidelines of *FEMA 361*.
- Reinforce and anchor the chimney to prevent collapse.

- Retain a design engineer to perform a detailed analysis of the basement and pool area refuge areas per the guidelines of *FEMA 361* to clarify the level of protection provided by the refuge area.

- To provide the required refuge area for all building occupants, above grade areas will be needed. Provide protection from wind and windborne debris by casting a reinforced concrete wall 6 inches thick against the exterior walls of the locker rooms. Tie the new walls into the existing floor, columns, and roof beams.

- Use the space in the courtyards (light courts) to construct shelter areas designed to the design guidance of *FEMA 361*. These shelters would only be a single-story in height, minimizing the impact to second and third floors that look into the light courts. Placement of single-story shelters in these two areas would eliminate the need to use the hallways on the first floor and provide additional square footage for the recommended refuge area plan, which, if implemented, would provide 4.5 square feet per person.

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