Designing School Safe Rooms

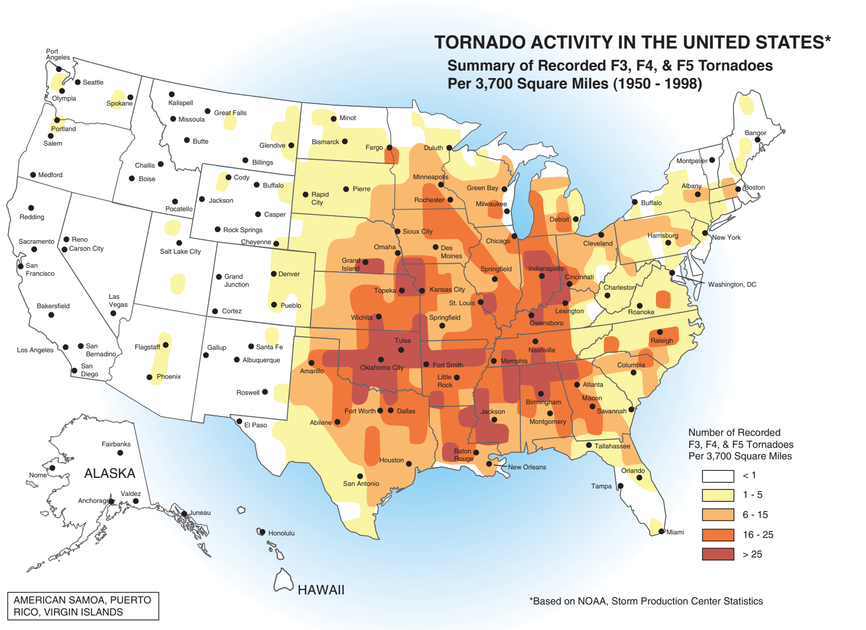
Creating safe havens in schools to protect against tornadoes can greatly aid communities while not blowing the budget if they are designed efficiently and early in the process

— By Brian M. Orr, P.E. and Brent M. Davis, P.E. S.E.

Recent devastating tornados in Missouri, Alabama and Mississippi have prompted school superintendents, public officials and building owners to more closely evaluate the benefits of incorporating tornado safe rooms into existing and new construction. These facilities can greatly aid communities without drastically impacting the construction budget thanks to efficient design techniques and funding grants.

In addition to budget impacts, tornado safe rooms often don't receive sufficient consideration because they presumably require a "bunker" appearance due to the protection restrictions that eliminate fenestration and visual accents. This representation is untrue, as numerous safe rooms have been successfully constructed as gymnasiums, higher-education classroom buildings, performing-arts centers and community centers.

Typically, schools and other public facilities are not specifically designed to protect occupants from tornadoes. Designated shelter areas in these facilities are generally hallways or areas not designed to withstand high winds and wind-borne debris. Designing to accommodate these needs will add significant value to the facility that will benefit users and the community.



Tornado activity occurs throughout the eastern half of the United States but particularly in the Midwest and South.

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Design Requirements

Code requirements for Safe Rooms include FEMA 361—Design & Construction Guidance for Community Safe Rooms, ICC-500—Standard for Design & Construction of Storm Shelters, and the locally-adopted building code. Section 423 of the 2009 International Building Code requires that shelters (and safe rooms) be built in compliance with ICC-500.

The publications' intent is to minimize the probability of death and injury during an extreme wind event by providing near-absolute protection for occupants of safe rooms. Also, if federal grant funding is involved, the plans must undergo a peer review along with a plan review by FEMA to ensure plans and specifications are in accordance with all code requirements.

To be sure, the design requirements of a safe room go above and beyond standard building design. Depending on the geographic location, design wind speeds range from 130 mph to 250 mph, and the facilities are required to meet specific flying-debris or missile-impact criteria. In the Midwest, where tornadoes are more prevalent and intense, safe rooms are designed for a 250-mph wind speed or the equivalent of an EF5 tornado (see chart).

The Dallas County School District in Buffalo, Mo., created a FEMA safe room for students during construction that added onto its gymnasium.

Design requirements create many potential challenges for the secondary use of the safe room.

The gym features a Frezno Trowel finish on the exterior of its precast concrete walls and a Steel Form finish on the exterior. The panels were cast by Prestressed Casting Co. in Springfield, Mo.

Other code requirements include a 100-pound-per-square-foot roof live load and modified load factors for load combinations, including wind effects. In addition to more stringent design requirements, a quality-assurance plan that incorporates Special Inspections is required during construction.

The size of a safe room is determined by the surrounding or target population. Codes require a minimum of 5 square feet of open space per person (10 square feet for wheelchair-bound and 30 square feet for bedridden) along with provisions for restrooms, backup power source, storage area and mechanical area. The target population for a community safe room is a 5-minute walking radius of the facility, or it can be limited to concentrated population centers, such as schools or higher-education facilities. The radius cannot exceed ½-mile in any direction. In addition, natural barriers, such as railroad crossings, creeks and highways, can limit the target population area.

Design Challenges

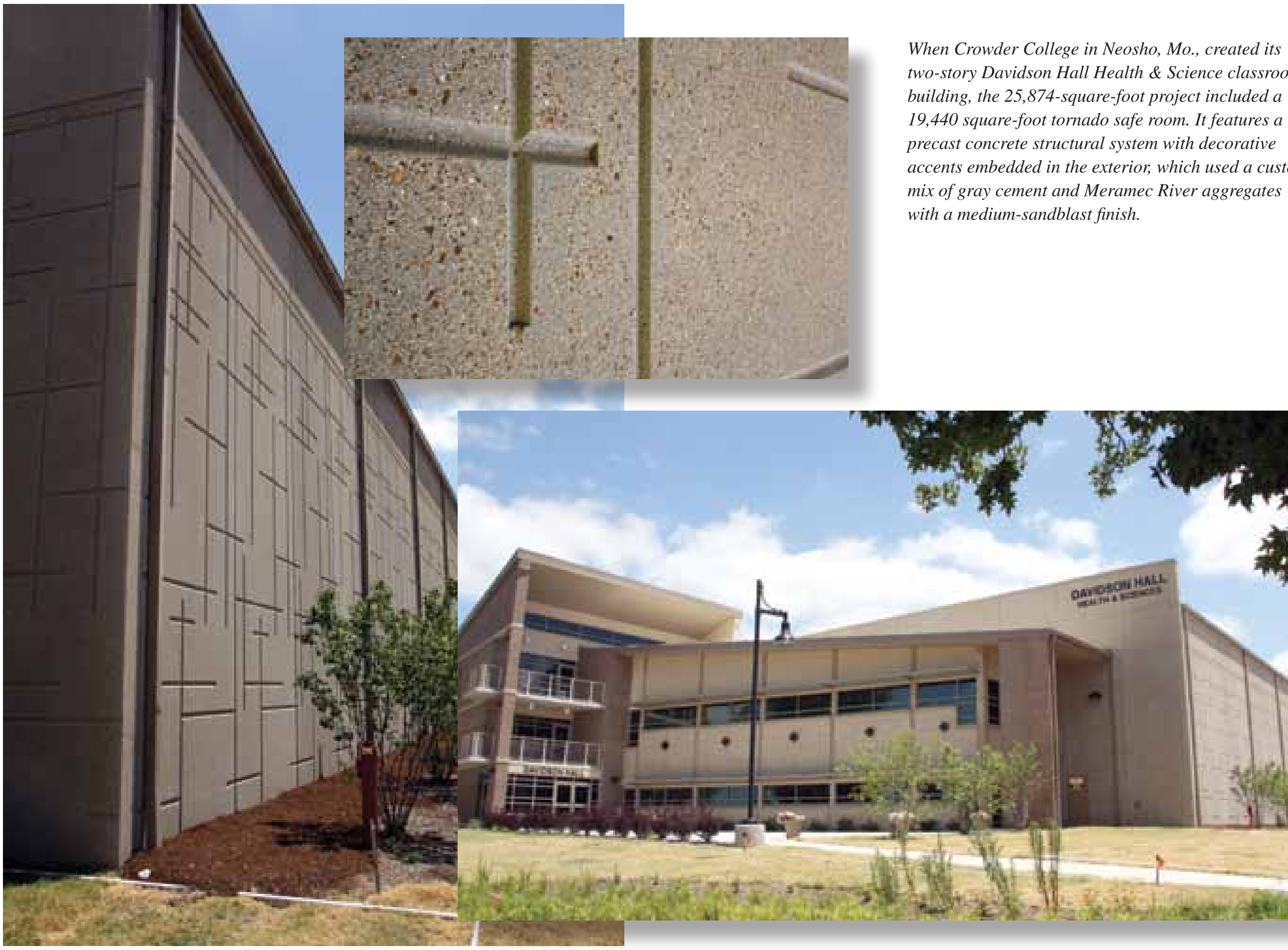
Design requirements create many potential challenges for the secondary use of the safe room. Challenges include daylighting, acoustics and overall aesthetic appearance. All openings and penetrations in the building envelope are required to meet the missile-impact criteria for the design wind event.

Providing glass that meets the requirements can be cost-prohibitive, but providing standard storefront glass with FEMA-rated door assemblies to act as storm shutters can reduce the budget impact of providing natural light. The hard materials such as concrete or CMU required to construct safe rooms can lead to poor acoustics in an open facility such as a gym or performing-arts center. Softer materials, including acoustical panels, drapes and gypsum soffits, can help improve acoustics.

Aesthetic challenges vary by the type of construction materials and the project's overall size. If the safe room is part of a larger project, the protected area can be incorporated within the new facility. If a stand-alone facility is planned, the choice of

Tornado Frequencies in the United States, 1950-2006

F Scale	Number of Tornados	Percentage of Total
F0	20,728	43.68%
F1	16,146	34.03%
F2	7,944	16.74%
F3	2,091	4.41%
F4	491	1.03%
F5	50	0.11%
Total	47,449	
Source: FEMA, 2008		



When Crowder College in Neosho, Mo., created its two-story Davidson Hall Health & Science classroom building, the 25,874-square-foot project included a 19,440 square-foot tornado safe room. It features a precast concrete structural system with decorative accents embedded in the exterior, which used a custom mix of gray cement and Meramec River aggregates with a medium-sandblast finish.

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construction materials grows in importance. Variations of CMU construction can be used, or precast concrete, which provides a great array of aesthetic options including different colors, forms, and textures, as well as veneered materials, such as brick or stone.

LEED certification, a growing desire for school administrators, creates another challenge for safe-roof design. While certain aspects of these designs can negatively impact the ability to meet LEED standards, such as daylighting, others offer huge advantages, such as energy efficiency through thermal mass, local materials, and recycled content. As with any construction project, a FEMA tornado safe room can achieve LEED certification with careful planning. A recently-completed safe room in the Midwest, which Toth and Associates was involved with, is in the process of being certified by LEED, with a Gold rating expected.

Typical Construction

Building-envelope requirements lead to facilities often constructed with precast concrete wall panels and double-tee girders for roof structures. Historically these have provided a cost-effective method of construction. Specifying certified precast concrete ensures a known quality-control process will be used (a requirement) and construction time can be better minimized and quantified. Another popular approach is concrete masonry-unit walls with a concrete-topped system of steel beams and metal deck. Other construction types have been used, including monolithic domes and cast-in-place concrete, but they are not as common.

When designing with precast concrete, the design team should consult with the local precaster prior to finalizing the layout. While the design process is the same as with a traditional project, typical connections or layouts may not work under the safe-room design criteria due to the extreme loads that are required. For example, a double door usually cannot be placed in a single panel, as the door must be centered on a panel joint. In addition, specific considerations are required for the uplift of the roof members to the wall panels and for transfer of the uplift and shear loads into the foundations.

While safe rooms can be located immediately adjacent to existing structures, it is recommended that they be separated from adjoining facilities with a non-FEMA rated connector installed between the buildings. This can eliminate the use of property-line foundations and avoid impacting the existing foundation, as the safe-room foundation loads are typically three to five times higher than traditional structures. With a creative design, the connector can be used to allow natural light and additional architectural features that complement the safe room's appearance and help it fit in with nearby buildings. The safe room also must be designed for the collapse load of all non-FEMA 361 buildings located nearby.

The design team has to consider how to provide and protect a back-up power source from the force of the tornado as well. Typically, a generator is installed and enclosed within a structure similar to that of the safe room. The fuel source also has to be protected, including any gas meters, a key element that often is overlooked by first-time designers. Some designers provide battery backups to avoid the cost of the generator and generator enclosure.

Designing safe-room doors and windows often frustrates designers. Fortunately, manufacturers are offering more products that comply with FEMA design guidance as more safe rooms are constructed. Careful consideration should be given to the specification of doors and windows, as FEMA does not approve or certify safe-room assemblies. The products have to meet stringent laboratory-test requirements outlined in the codes pertaining to safe rooms.

Fujita Tornado Damage Scale

EF0 Light: Chimneys are damaged, tree branches are broken, shallow-rooted trees are toppled.

EF1 Moderate: Roof surfaces are peeled off, windows are broken, some tree trunks are snapped, unanchored mobile homes are overturned, attached garages may be destroyed.

EF2 Considerable: Roof structures are damaged, mobile homes are destroyed, debris becomes airborne (missiles are generated), large trees are snapped or uprooted.

EF3 Severe: Roofs and some walls are torn from structures, some small buildings are destroyed, non-reinforced masonry buildings are destroyed, most trees in forest are uprooted.

EF4 Devastating: Well-constructed houses are destroyed, some structures are lifted from foundations and blown some distance, cars are blown some distance, large debris becomes airborne.

EF5 Incredible: Strong frame houses are lifted from foundations, reinforced concrete structures are damaged, automobile-sized missiles become airborne, trees are completely debarked.

Secondary Uses

A safe room's main function is to protect occupants from extreme environmental events, but the secondary use can be just as important to the owner, especially in mitigating budget costs. Secondary uses of safe rooms include (but are not limited to) gymnasiums, cafeterias, band rooms, classroom buildings, park facilities, and community centers.

Integrating a secondary use provides multiple benefits. The safe room can be used every day and not forgotten, ensuring everyone is comfortable with its use and knows its location. Specific maintenance costs are eliminated, as the safe room is part of everyday operations. Incorporating the facility into a larger project can help reduce out-of-pocket cost and possibly allow for other construction that could not be funded if a standalone safe room was created. The key benefit is that a refuge is specifically created for building users and the community rather than requiring them to gather in an area simply designated as least likely to fail.

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Safe Room Costs

Many factors influence the cost of a safe room. Key factors include number of uses, design simplicity, wind-speed design, debris-impact criteria, exterior wall and roof materials, and location with regard to foundation and site-development requirements. Costs generally range from $150-$240 per square foot, depending on geographic location and the secondary use.

The absolute range is much wider; safe rooms have been constructed for as little as $90 per square foot and as much as $490 per square foot. The increase in cost for constructing a structural system and building envelope that withstands 250-mph design wind speed rather than a standard 90-mph design wind speed is about 20% to 32%.

The impact on overall project cost is much higher for standalone safe rooms than for safe rooms incorporated into larger projects. The most cost-effective means of constructing a safe room is to incorporate it into a new facility in the initial planning stages. The relative cost per square foot for safe rooms included as a part of a building project is higher than typical construction due to the life-safety protection being provided. For large new building projects, however, the percent increase in overall project cost is quite small. Many safe rooms constructed as part of a new school add only 1 to 2% to the total project cost when the safe room is included in the design process from the beginning.

Federal Grants Available

Federal-grant opportunities can help cover costs for the design and construction of tornado safe rooms along with hurricane shelters. Grants can cover up to 75% of the FEMA-approved costs of a safe room. While various federal funding opportunities exist, there are two main avenues for public entities to pursue funding.

The first is the Pre-Disaster Mitigation (PDM) grant program, a nationally-competitive funding source. The other is the Hazard Mitigation Grant Program (HMGP), which is competitive at the state level and is funded based on declared disasters within a state. To determine if funds are available at a specific project site, contact the State Hazard Mitigation Officer or a local grant writer specializing in these grants.

Earlier this summer, our engineering firm created bid information for a tornado safe room designed to meet

This cutaway BIM drawing shows a gymnasium with a total-precast concrete structural system designed as a FEMA safe room for the Marquand Zion School District in Marquand, Mo. The 1,400-square-foot, two-story addition on the side of the 8,000-square foot gym qualifies as part of the safe room but contains restrooms below and mechanical systems above that feed into the gym. Photo: Toth and Associates

This BIM drawing shows the FEMA safe room designed for the Nixa School district in Nixa, Mo. Originally planned as a 10,000-square-foot building constructed of block and bar joists, Toth and Associates redesigned it as a total-precast concrete structure to convert it into a FEMA safe room eligible for federal funding. Only 4,000 square feet qualified for funding, but that savings, combined with cost efficiencies of the precast concrete design, made the new plan cheaper while also providing the safe-room benefits. BIM drawing: Toth and Associates

FEMA 361 as part of a new middle school being constructed in the Midwest. The safe room is approximately 12,000 square feet, and will be constructed with 12-inch-thick precast concrete wall panels and a double-tee roof structure. A bid alternate also was provided that consisted of 8-inch-thick precast concrete wall panels with a bar-joist and acoustical-deck roof system.

The low bid for the safe room was $1.79 million, or $149.17 per square foot, while the bid alternate was $1.38 million, or $115.00 per square foot. To offset the increased construction cost for the safe room, the school district applied for a safe-room grant under HMGP. The grant will cover up to 75% of FEMA-approved construction items.

It is estimated that the school district's portion of the safe-room construction will cost about $716,000 or $60 per square foot. This represents a cost savings of $664,000 to the owner over conventional construction for this same facility while providing added benefit of a community safe room designed to withstand 250-mph wind speeds. The owner's share for the project is estimated to be approximately 40% of the overall project cost, which is typical for similar projects.

These grants make a compelling case for architects to broach the subject of providing a tornado safe room within a school project if administrators don't request it on their own. Safe-room grants not only can reduce construction costs, allowing funds to be shifted to other areas, but they help create a safer structure providing added benefits to the community. Being aware of design and funding techniques provides designers with a significant value-added design element to offer to clients. ■

More Information

To learn more about requirements for FEMA safe rooms, visit:
http://www.fema.gov/plan/prevent/saferoom/index.shtm

http://www.fema.gov/plan/prevent/saferoom/fema361.shtm

To learn about grant programs, visit:
http://www.fema.gov/plan/prevent/saferoom/srfunding.shtm