Ocosta Elementary School in Westport, Washington, contains a 55 by 155 ft building—completed in 2016—that houses the school’s gym, cafeteria, and music room. The building also functions as a tsunami-resistant vertical evacuation structure, the first to be built in the United States as part of a building.
INFRASTRUCTURE SOLUTIONS:
SCHOOLS OFFER RESILIENCY

Public K–12 school infrastructure in the United States received a D+ on ASCE’s 2017 Infrastructure Report Card. This poor performance is a significant issue for communities on a daily basis, but it particularly affects periods of special need, such as when natural disasters strike. School buildings are often used as emergency shelters during or after natural disasters, and buildings that can function optimally before, during, and after these events are important for communities’ long-term health and resilience. Examples of school districts striving to make their schools multifunctional can be found around the country.

BY CATHERINE A. CARDNO, PH.D.

ACROSS THE UNITED STATES, there are close to 100,000 public school buildings used by nearly 50 million K–12 students and 6 million adults, according to the 2017 Infrastructure Report Card issued by ASCE. Public schools are integral to a community’s existence. Besides being places of learning, they can serve as community hubs and meeting places. And when disaster strikes, public schools are often used as areas of refuge during the event and as shelters or resource distribution points afterward. These roles require “facilities that are maintained to function in emergencies and resilient to quickly recover,” the report card notes.

If a community is to fully recover after a disaster, these buildings need to quickly transition back to normal operations so that students’ education can continue. “Many schools require upgrades to effectively fulfill this important community purpose, including windows that can withstand high winds, structures designed to survive earthquakes, and rooms
specifically designed as shelters from tornadoes,” the report card states.

Despite this need, schools as a category performed poorly on the report card, receiving a D+. While this represents a slight improvement over the D- they received in the 2013 report card, significant work is still necessary in the category. The 2017 report card states that 53 percent of public schools need repairs, renovations, and modernizations to reach a “good” condition. “In many cases, planning is lacking, as four in 10 public schools currently do not have a long-term educational facilities plan in place to address operations and maintenance,” the report card states. While these conditions primarily relate to schools’ ability to perform their day-to-day operations, they can also significantly impact schools’ ability to perform during and after disasters as well.

Funding for construction is a sticking point for the overall condition of school buildings in the United States, and it varies by state. At one end of the spectrum, 12 states do not provide direct support for capital construction at schools, and at the other end, 5 states pay for nearly all their school districts’ capital costs. For the 33 remaining states, state contributions vary, the report card notes.

Design professionals work daily on repairing, rehabilitating, and designing schools and may miss the opportunity to integrate community resilience into the process. Examples show how some districts are tackling the issue, even with tight budgets in place.

Engineers’ contributions to the creation of resilient schools can be more than just integrating specific design elements into individual projects. Advocacy work is crucial at the local, state, and federal levels to create safer schools in the United States. This work can take many forms, extending from individual advocacy and research to updating design guides and policies.

The impact of severe natural hazards on communities and their populations varies significantly. Earthquakes can cause catastrophic, widespread damage with no warning, while hurricanes can also cause widespread devastation but typically come with warnings that enable populations to prepare and evacuate. Tsunamis and tornadoes can obliterate buildings and communities, but they, too, often come with brief warning windows that are often long enough for people to take shelter in their immediate vicinity.

If communities hope to bounce back after disasters, they need to consider the consequences of the hazards that affect their region and plan for the recovery of their schools, housing, and jobs in the days, weeks, and months after an event, says Barry Welliver, S.E., the owner and principal engineer of BHW Engineers based in Draper, Utah, and the chair of the Oakland, California-based Earthquake Engineering Research Institute’s School Earthquake Safety Initiative.

In the aftermath of a disaster, “one thing that everyone has to keep in mind is the importance of schools to a community’s resilience,” notes Ayse Hortacsu, P.E., M.ASCE, the director of projects at the Redwood City, California-based Applied Technology Council, a nonprofit research organization that studies the effects of natural hazards, particularly earthquakes, on the built environment. “It’s a big component that keeps people in their homes so that they can return to their jobs,” she says. If parents don’t have a safe place for their children to go during the day, they can’t work. And if parents can’t work, communities cannot recover. “In the last ten years or so we’ve started thinking broader and started to [realize that resiliency] is not just electrical power and water; you also need to have your schools online, and you have to have your grocery stores online so that you can continue life,” Hortacsu says.

And just because a community expects to use a school as a shelter after a significant natural disaster, it does not mean that the building and its infrastructure have actually been designed for that purpose, according to Kent Yu, Ph.D., P.E., S.E., M.ASCE, a founding principal at Soft Consulting Group in Beaverton, Oregon. Yu is a former chair of the Oregon Seismic Safety Policy Advisory Commission. Typically, emergency managers “assume that schools will be around” after an earthquake, but often schools have not been designed to be usable postevent, Yu explains. It is therefore crucial to design schools to function properly as emergency shelters if that is what they are expected to do, he says. And a plan must be in place to transition schools back to normal operations within two to four weeks after an event.

Schools are ideal shelters or resource distribution points because they are well-placed, well-known public buildings. “Uniquely among public facilities, schools are distributed throughout neighborhoods and, postdisaster, could be more accessible for many people than other public buildings when walking might be the only option,” said Richard L. Steinbrugge, P.E., M.ASCE, in written statements to Civil Engineering. Now retired, he was formerly the executive administrator for facilities for the Beaverton School District. “Schools have large spaces—cafeterias, gyms, et cetera—to support many people. They also tend to have large fields that could support tent shelters and helicopter drop zones when roads are out,” he noted.

But being a resilient school is about more than just the buildings. “A resilient school is one that invests in its staff, students, and infrastructure before a disaster strikes to ensure that if a disaster occurs, the people and place are able to respond effectively and recover quickly,” said Lori Peeke, Ph.D., a professor of sociology at the University of Colorado Boulder and the director of its Natural Hazards Center, who wrote in response to questions posed by Civil Engineering. “This definition is ‘hazard-agnostic’ in that it refers to broader investments in people, as well as in school facilities, to ensure effective preparedness, response, and recovery.”

Engineers’ contributions to the creation of resilient schools can be more than just integrating specific design elements into individual projects.
In 2017, the Federal Emergency Management Agency (FEMA) published Safer, Stronger, Smarter: A Guide to Improving School Natural Hazard Safety (FEMA P-1000). Prepared by the Applied Technology Council, with a number of contributing authors, including Peek, the guide was developed for school administrators, staff, and concerned parents to provide advice on successful operational policies and practices as well as recommendations for how to improve school facilities to resist natural hazards. (Previous publications, including the Design Guide for Improving School Safety in Earthquakes, Floods and High Winds [FEMA P-424], published in 2004 and updated in 2010, have been geared toward design professionals.)

"Typically, we write for engineers, but in this one [FEMA P-1000] we specifically want to speak to school administrators, principals, parents, and even teenagers who want to educate themselves," according to Hortacsu. "The whole purpose was to give them actionable advice and the necessary knowledge without getting bogged down in engineering details," she notes. This includes consideration of the nonstructural elements within a building that could become projectiles or hazards in their own right during and after an event, even if a building is designed for immediate occupancy.

Persuading communities to plan for resiliency can be seen as an overwhelming endeavor. However, starting with one project—or type of project, such as schools—can start the conversation. "Schools in particular are poised as a very good target for communities to start out on this venture of what resiliency means in the community," says Welliver, who was also the project technical director for FEMA P-1000. There is a broad audience within a community with a vested interest in the schools and their operations, he notes.

In areas prone to earthquakes and hurricanes, educating the public about the importance of resilient schools requires advocating for buildings that are not only designed to exceed existing building codes so that they can remain in use after events but also designed to include specific amenities so that the buildings can perform as emergency shelters if needed.

Designing a building to meet the code requirements means that the building is expected to preserve the life of its occupants, but it does not mean that a building will remain usable after an event. Going beyond the code and creating schools that will protect their occupants and help preserve their community postdisaster was particularly important for the Beaverton School District, located west of Portland. "The Oregon Resilience Plan, published in 2013, was the wake-up call that got our attention," Steinbrugge said.

This plan, issued by the Oregon Seismic Safety Policy Advisory Commission when it was led by Yu, outlined the risks and challenges that would arise from the next Cascadia subduction zone mega-earthquake, which could be a moment magnitude 9-plus earthquake. "As one of the largest and fastest-growing school districts in Oregon, Beaverton has been very fortunate in receiving consistent community support of}
bond measures for the construction of new schools to accommodate growth and for modernization of older schools," Steinbrugge noted.

In 2014, district officials decided that the seven new schools being designed and built needed to address the seismic risks identified by the resilience plan, according to Steinbrugge. As a result, the buildings' structural systems exceed the building code requirements and are designed at the same level as are emergency responder structures such as fire stations and hospitals. In addition, the buildings include elements necessary for their use as community shelters by providing adequate restrooms for large populations and space for family pets to be sheltered; mechanical and electrical systems with fuel storage and solar panels capable of operating after an event; and water hookups so that tanker trucks can fulfill the shelters' water needs even if the area's water utility system is not functional.

These additions balanced the resiliency needs against the available budget, ultimately adding just 2 to 3 percent to the buildings' costs, according to Steinbrugge. "There were great pressures to minimize scope increases and find cost savings in order to meet the program commitments made to the community," he explained. "Thus, district staff knew we needed to be very strategic." While the team members recognize that they added design features to support shelters in only 7 of the district's 30 schools, they felt it important to start somewhere.

Yu, who was a key adviser on the Beaveron School District's resilience plan in 2015, says the team held to the idea that "perfect is the enemy of good," and getting the effort started with a few schools was a crucial first step.

"This opportunity could not be allowed to just slip away waiting for new regulations to be adopted," Steinbrugge explained. In addition, the team publicized its choices to help others in their school resiliency efforts. "We wanted to broadly share what we did with other school districts and public agencies so [that] they would not have to start from square one [but] instead could begin where we left off to further refine their own approach to resilient public facilities as future construction programs presented those opportunities."

IKE EARTHQUAKES, the challenge in hurricane-prone areas is "to get school districts and architects and engineers to be aware and to advocate for best practices when it comes to design," says Thomas Lee Smith, AIA, ESEI, MASCE, a consultant in Rockton, Illinois, who also participated in the creation of FEMA P-1000. "Particular attention needs to be given to the design of the building envelope and roof top equipment."

"The biggest challenge for designing hurricane shelters in schools is that the clients (e.g., school districts) typically don't want them," said Marc L. Levitan, Ph.D., the lead research engineer for the National Windstorm Impact Reduction Program at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. Levitan wrote in response to questions posed by Civil Engineering. This disinterest from school boards is because "such facilities are not used to shelter school populations, but rather they are used as community shelters to safely house evacuees (for up to 24 hours) during the hurricane," Levitan explained. While state and local emergency management agencies often push for the inclusion of shelters in schools, those requests may arrive too late in the design process, according to Levitan. In budget-strapped school districts, it can be difficult to find the funds to pay for such upgrades when they will not directly benefit school-related activities.

For tornadoes and tsunamis, the design goal is focused on shorter-term refuge from storms. In these cases, the focus has to be on protecting the school population during an event. "There is a significant difference between our strongest hurricane and our strongest tornado," Smith says. "Even our strongest hurricanes have speeds that we can design for economically."

The same cannot be said when there is a direct hit by a strong tornado. Tornadoes are the most violent of all atmospheric storms, according to the National Oceanic and Atmospheric Administration (NOAA). About 1,200 hit the United States each year, many in the central United States in an area commonly referred to as "Tornado Alley," according to NOAA. Wind gusts in the most destructive of these storms can reach more than 200 mph.

Because tornadoes are such strong storms, the definition of a resilient structure changes, according to Smith. "Normally we don't design the entire building for tornado loads," he says. "If we get a strong tornado, you just expect to have a whole lot of damage." For buildings in the path of a tornado, the goal is occupant protection. "If we have what I consider a resilient building for tornadoes, that means we have a place for occupants to go where they would be protected," Smith explains.

These might be called tornado shelters, as they are under the International Code Council's 500-2014 Standard, or safe rooms, as FEMA refers to them in the third edition of its design guidance publication FEMA P-361, he says. (These are ICC/NSSA Standards for the Design and Construction of Storm Shelters [2014] and Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms [2015], respectively.) In a large school building, the safe room or tornado shelter would be a small portion of the building for the occupants to go to during storms with the expectation that they would be protected. The 2015 edition of the International Building Code added a new requirement that tornado shelters be included in certain buildings, including new school construction located in areas at highest risk for tornadoes, he says. But not every state affected by tornadoes has adopted this provision, Smith explains.

"The challenge there is our existing schools [and] getting people to think that they need to take action, because the probability of a strong tornado, or any tornado, hitting a given school is a pretty low probability," Smith says. And with everything that is going on with people's lives, it's hard to get them to understand that this issue should be taken care of now, he notes. However, it is a danger that should be taken seriously. "Preliminary analysis of NOAA data by NIST indicates that on average, about 26 schools per year are damaged or destroyed by tornadoes in the United States," Levitan said.

One of the biggest challenges regarding tornado shelters is their cost. Typically, it is more cost efficient to build a new stand-alone structure, such as a gym, cafeteria, or media center, that can also function as a tornado shelter rather than to retrofit
In general, however, "there seems to be much less resistance to installation of tornado shelters (versus hurricane shelters) in schools since these shelters are used to protect the children and staff during the school day," Levitan says. Indeed, "many communities also make the decision to open school tornado shelters to the public during hours and days when school is not in session, providing an even greater benefit to the community," he says.

Another option in tornado-prone regions is to install safe rooms in classrooms. While it might not be the best option for every school, installing steel tornado-safe rooms in every classroom and cafeteria was the solution for one small school district in rural Arkansas. For Dennis Truxler, superintendent of Quitman Public Schools, the immediate access of the shelters was of particular importance because two nearby school districts, Vilonia and Mayflower, were struck by tornadoes in 2014.

An added benefit of the shelters is that they are made of ballistic steel so that they can also be used to protect the students in the event of an active shooter entering the building, according to Truxler. The shelters are constructed of steel panels with covered ventilation ports at the top and bottom to ensure adequate air circulation during a shelter-in-place event. The panels are fitted together and bolted to a concrete floor that is at least 4 in. thick, according to Truxler. The panels can be used to construct shelters of varying size and configuration, including L shapes, depending on the capacity and room layout needs, and the door can be locked from the inside to block intruders from entering. Like any wall in a classroom, the shelters can also be used to display posters, student work, etc.

"Since implementation, we've conducted three drills over the course of the year, and in every drill, in less than two minutes we had every staff and student in a shelter with the door shut and latched, and..."
Truxler says. The capacity of the shelters for each room has been designed so that there is adequate space to move around so that people do not feel cramped or crowded, he says. The project was funded from the district’s maintenance and operations budget, and 54 shelters—the smallest fitting 15 people and the largest 200 people—were installed at a cost of about $900,000, Truxler says.

Ultimately, as existing schools without shelters are removed from service and new schools are built with shelters, the issue of unprotected students will eventually resolve itself in 50 years or so, Smith estimates. “But over the next couple decades, we’re going to still have a lot of kids going to schools that are not as well prepared to deal with the strong tornadoes, and trying to get communities aware and taking action on that is a real challenge.”

A step in the right direction, Smith says, would be to have all existing schools in high-risk zones evaluated by architects or engineers to determine where the best available refuge area in each school is located. “Now, it may not be a [perfectly] safe location and people could get injured or killed there, but at all the places they could go in the building, this [would be] the best place to go,” he says. And while this evaluation could help, “many schools have yet to take that action,” he says.

The safest areas in which to seek refuge from tornado hazards, including extreme winds, wind-borne debris, and collapse hazards, are typically identified through a combination of plan review and facility inspection, according to Levitan. “Experience from many years of poststorm disaster investigations has shown, for example, that areas of buildings with long-span roofs, exterior rooms with glazed openings, and spaces on the top floor of a building are often more susceptible to wind damage than basements and interior rooms on lower floors.” (This selection process benefits from guidelines for schools published in 2009 by FEMA in the second edition of Tornado Protection: Selecting Refuge Area in Buildings [FEMA P-431], according to Levitan.)

As with tornadoes, school resilience in tsunami inundation zones focuses closely on occupant safety during an event. For a school located in an inundation zone, there are two choices: create a shelter on-site for students, faculty, and staff or relocate the school so that it is outside the inundation zone. The former is what the Otosta Elementary School in Westport, Washington, did in 2016. The 55 by 155 ft building that houses the school’s gym, cafeteria, and music room is also a tsunami-resistant vertical evacuation structure, the first to be built in the United States as part of a building. (Read “Preparing for Inundation,” Civil Engineering, December 2018, pages 44–51).

The latter is how Oregon’s Seaside School District is addressing the issue of its schools’ locations. Seaside is located in a flat, coastal area with two rivers that run through it parallel to the coastline before emptying into an oceanide estuary. To the north of the estuary is the city of Gearhart. Nine miles south is the coastal city of Cannon Beach, with a winding waterway that extends through the city. Douglas C. Dougherty, Ph.D., is the superintendent emeritus of the Seaside School District, which encompasses all three cities, and the former Oregon earthquake commissioner representing Oregon’s universities, colleges, and K–12 schools. As superintendent of the school district
from 1998 to 2017, Dougherty held student safety as one of his highest priorities, he wrote in response to questions supplied by Civil Engineering.

His goal was to relocate schools that were in the tsunami inundation zone to facilities outside the zone. While the initial focus was on the danger to the district’s Cannon Beach Elementary School, it turned out that four of the district’s five schools could be impacted by tsunamis. This was discovered during a study conducted by the Oregon Department of Geology and Mineral Industries (DOGAMI). The results were released in 2009 in Tsunami Hazard Assessment of the Northern Oregon Coast, which examined the historic tsunami record of the Cannon Beach area going back 10,000 years to establish what the highest inundation had been.

“To everyone’s surprise, DOGAMI found previous Cascadia events that inundated well over twice what they had assumed,” Dougherty said. “The principal researchers told me that to be safe, the school needed to be relocated above 80 feet in elevation. Four of our five schools were less than 15 feet in elevation. In addition, structural engineers told me that each of those four schools in the tsunami inundation zone would likely collapse in a Cascadia earthquake. Not only would we need to relocate Cannon Beach Elementary but the other schools as well.”

Because there was no land at a high enough elevation within Seaside, Cannon Beach, or Gearhart for the schools to be located outside the inundation zone, the district had to secure a building site outside the cities’ boundaries—most likely from a private landowner, according to Dougherty. The only property that could meet DOGAMI’s recommendations was private forest land to the east of Seaside that was owned by the Weyerhaeuser Co., a forest products company headquartered in Seattle. “After many years of evaluating the land and negotiating with Weyerhaeuser—and using the media to support our case—Weyerhaeuser graciously donated 80 acres of forest land to our new K–12 school campus,” Dougherty said. The campus is designed to be immediately occupied after a Cascadia mega-quake and will open in fall 2020. It was funded through a $99.7-million bond passed by the community in 2016, according to Dougherty. It will hold the four schools that the district is relocating and sit adjacent to the fifth school that is located outside the inundation zone.

For many people—school administrators and parents included—it is not until a natural disaster strikes that they realize how important it is to ensure that school buildings are protected for the safety of their occupants and to ensure their ability to support the recovery. “Given that there are many other pressing threats facing schools, as well as challenges—including budget shortfalls, teacher shortages, and shortages of vital supplies—I know that planning for a natural hazard that may be a ‘low probability’ but ‘high consequence’ event can be very difficult to do,” Peak said.

This is why the efforts of engineers to effect change through design in their construction and rehabilitation projects and in advocacy for policy and standards changes are so important.

Cardno

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