Resiliency in Action

Projects around the country show precast concrete's ability for ensuring structures withstand the worst nature can create

— Craig A. Shutt

A number of factors allowed the precast concrete panels on the Imax Theater addition to the Warren Theater in Moore, Okla., to survive intact when tornadoes hit the area in May. Patrons survived without injury, and the theater was turned into an emergency center. Photos: Coreslab Structures (OKLA), Inc.

More attention is being paid to structural resiliency today as natural disasters—including tornadoes, earthquakes, hurricanes and wildfire—seem to increase in frequency and intensity. As owners and designers look for ways to boost protection in a cost-effective way, they are discovering the benefits of the inherent resiliency offered by high-performance precast concrete structural and envelope systems.

Designers are gaining awareness of the benefits of designing resiliency into projects, but it's important to understand what that encompasses. In part, resiliency can be defined as durability, or the long-term performance in a given exposure environment. For instance, a concrete structure exposed to cyclic freeze-thaw conditions must be designed with dense, low-permeable, air-entrained concrete to provide excellent resistance in those circumstances.

But resiliency goes beyond durability to include less frequent, often more extreme, events. Designing for high seismic control and such weather conditions as high winds, hail, heavy rains, and other localized events can be critical.

Resiliency also encompasses sustainability, which means to create without negatively affecting the environment or wasting limited resources. Certainly, not needing to rebuild a structure after an extreme event provides high sustainability by saving materials and energy, not to mention saving lives.

Recent examples show some of the ways that high-performance precast concrete designs can provide the kinds of long-term resiliency that pays off throughout the building's service life.

Oklahoma Theater

The Warren Theatre's IMAX addition stood in the path of an EF-5 tornado that tore through Moore, Okla., on May 20, 2013. The destruction around the theater from the tornado, whose winds reached as high as 200 mph, was near total. But the theater itself withstood the barrage and offered a safe haven for about 50 patrons, then served as an emergency rescue center afterward.

The addition was constructed with precast concrete load-bearing and nonload-bearing wall panels, but it was designed to standard ASCE wind loading for the area (i.e., 90 mph) and not to the higher FEMA 361 requirements, according to Sean Morris, chief engineer at Coreslab Structures (OKLA) Inc., which supplied the precast concrete components.

The structure features wall panels as tall as 57' 4", some of which had clear spans exceeding 54 feet. The size was required to provide the sight lines and height required for the large IMAX movies, Morris explains. The majority of the structure was constructed with load-bearing wall panels to support the steel-framed roof, while a handful of the wall panels were nonload-bearing panels.

Four key factors helped the theater withstand the battering it took, which included being impacted by wind-borne debris of all shapes and sizes.

1. **Building style.** The theater needed a large, open space with no windows to project its large-size movies in darkness. "The building lent itself to being resilient," says Morris. The lack of doors and windows created large expanses of solid panels. "The debris-impact resistance of the solid panels prevented an increase in the internal wind pressures that could have created the effect of blowing up the structure like a balloon," he says.
2. **Seismic requirements.** Ironically, a key ingredient in its resiliency was that designers had to incorporate design elements to withstand a fairly high seismic event. "Building codes seem to have placed more emphasis on designing structures for higher seismic forces than for higher wind pressures in the Oklahoma City area, while it appears that the opposite should be the case." In fact, more tornadoes hit the area after the big one on May 20th. "It's ironic that the connections we created to withstand a seismic event have instead turned out to be more useful for enduring an extreme wind event."
3. **Tall walls.** One of the major design changes to make the panels more resilient was the way they were connected to each other, he explains. This was done both to meet seismic needs but especially due to the tall clear spans that were needed. Most of the wall panels were cast with pilasters on each side, which created C-shaped cross-sections. The panels were 6 inches thick, with the 12- by 16-inch rectangular pilasters flanking them for nearly their entire height.

   This approach reduced shipping weights on the panels, which were already high due to their size, while ensuring the panels would be secure for their over 54-foot clear span. "Clear spans of that much are a tall order," he says. "The pilaster system gave us a nice lateral load-resisting system that helped resist the tornado's high winds, too."
4. **Prestressing.** In addition to creating the secure connection system, the precaster prestressed the panels to provide added strength. The goal was to prevent any bowing or cracking over the length of the clear span, but it also provided durability that hadn't been planned. "The prestressing is a huge reason the panels performed so well," he says. "It made them virtually impact resistant."

That was apparent from the debris field seen after the storm. Some of the theater's signage was completely destroyed, while other pieces had been thrown to the other side of the interstate. A number of smashed-in cars were strewn about, some so demolished it was difficult to identify make or model.

"There's no doubt the panels were impacted by debris, but it appeared, upon visual inspection, that none of the panels had even cracked. The pilaster system and the prestressing in particular gave the panels the extra out-of-plane bending resistance they required."

Approximately 50 patrons were inside the theater when the tornado hit, according to local reports. They rode it out safely after employees herded them into the hallways and had them sit tightly against the walls. Once it passed, IMAX manager Ales Ansari calmed those in the vicinity then helped evacuate elderly patients and mothers with newborns from the hospital across the street, which was heavily damaged. An emergency rescue center was set up in the theater, coordinated by a graduate nursing student who had been in the theater, according to the Norman Transcript.

Three days later, the theater reopened for business, hoping to return some normality to lives that will take a long time to truly return to normal. The town is grateful to the theater, says Deidre Ebrey, Moore's director of economic development. She told the local Channel Nine News that the theater and its employees "were a major component in saving lives for those who sought refuge there. It was a meeting place. It is much more than a business."

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.

Rockaway Beach Boardwalk

Another precast concrete structure survived the most devastating wind event in years—Hurricane Sandy, which hit the Rockaway Beach Boardwalk in Queens, N.Y., in 2012. Older timber sections of the boardwalk were completely destroyed, flinging windborne debris into the air to become projectiles. But one 10,000-linear-foot section remained virtually intact because

Precast concrete panels, formed to resemble five textured planks, were used in rows of five to produce an upgraded 10,000-linear-foot boardwalk in Queens, N.Y. The panels withstood Hurricane Sandy, the only portion of the boardwalk to remain intact. Photos: Steve Kenepp, U.S. Concrete Precast Group.

it had been replaced several years earlier with precast concrete planks.

The project had been commissioned in 2010 as a design-build project by the City of New York Parks and Recreation Department. "It was unusual for them to let a project as design-build, but they wanted repairs to the boardwalk to be completed quickly and as cost effectively as possible," explains Jeff Sa, director of construction for Padilla Construction, which headed the design-build team. U.S. Concrete Precast Group supplied the precast concrete components.

The design they created reused the existing timber substructural piers, timber and concrete pile caps, and concrete bents. But they replaced the timber boardwalk superstructure. "It was heavily deteriorated, and we decided to avoid heavy maintenance in the future by using precast concrete rather than wood," Sa says.

The project was designed in-house with the aid of the precaster, who was selected based on past experience with the company's attention to quality, he adds. "Our key challenge was to design a system to attach the new planks to the existing pile caps and ensure they would resist uplift." Their goal was to meet AASHTO H20 truck-load standards, which is somewhat robust but not extraordinarily high. "We knew of some past flooding problems, so we wanted them to be able to withstand a storm," he explains. "But we hadn't anticipated Hurricane Sandy's winds," which reached 115 mph.

The boardwalk features 8- by 20-foot precast concrete planks with four alternating textures created with formliners within each panel to mimic the variety found on a traditional wooden boardwalk. Five panels were needed to span the 40-foot-wide boardwalk.

Miniature Double-Tee Design

The panels were designed as miniature double tees, with two stems projecting from the underside. The stems were slid over the pile caps, fasteners were drilled into the cap, and the plank was bolted to it. "It was a fairly simplistic system, but it worked very well," Sa says. "The pieces were installed very quickly with this design."

The 10,000 feet of boardwalk was completed in three phases, which played to precast concrete's strength, he notes. "The precaster began fabricating pieces early in the process, so we could connect the first set of planks while we finalized the design of the second phase and surveyed the third phase." Not all of the pile caps were at the same height, requiring drawings to be shared with the precaster to ensure planks would fit properly to provide a smooth and level surface.

The resulting boardwalk was the only part of the structure to survive. It remained intact after the hurricane passed. "Cracks developed in a few of the panels, but they were easily repaired," Sa says. None of the panels had to be replaced. Not only did that allow the boardwalk to survive, but it prevented any part of it from adding to the problems caused by windborne debris.

"I think this approach to these projects will begin to be done more often as officials realize the benefits, not only in resisting storms but in not becoming part of the problem," Sa says. Designers must be careful in designing the pieces and work with a precaster known for high quality, he warns. "It's possible to overdo the camber or get aesthetics that aren't successful," he notes. "The quality of the precaster is critical."

For more information on these or other projects, visit www.pci.org/ascent.

Above-Ground Shelters Gain Popularity

With devastating weather events gaining a higher profile, many municipalities and developers are reviewing their building codes, existing emergency plans, and available structures to ensure they are providing as much protection as possible. In some cases, they are turning to FEMA-approved, precast concrete, above-ground shelters to serve as safe havens.

These safe rooms have long been a topic for schools in the Midwest, where protecting children during tornadoes and high winds has become a key concern. FEMA has grant programs available that can help schools design new additions, such as gymnasiums, to serve the additional role of storm protection. (For more on these projects, see the Summer 2011 issue of *Ascent*.)

Precasters have designed a number of these facilities for school districts in Kansas, Arkansas, and Missouri following recent tornadoes, says Sean Morris, Coreslab Structures (OKLA) chief engineer. "Many of them have a dual use, such as for gyms or music rooms," he says. "Oklahoma, our home state, has been slower to see the benefits, but we're trying to change that."

The facilities, designed to withstand winds up to 250 mph, feature precast concrete structural systems including double tees, beams, columns, and structural walls with architectural finishes. An alternative design provides load-bearing precast concrete walls that support the roofing members. Typically, the precast concrete walls are prestressed and 12 inches thick for walls as tall as 30 feet, providing strong protection.

FEMA funding can offset the added cost for the project, Morris notes. In some cases, the added funding makes the robust structure cheaper than the original design's budget.

Administrators in Newcastle, Okla., for instance, constructed a community center with a robust precast concrete structure to serve as a storm shelter and received enough FEMA funding after the fact that it could reallocate funds to construct a new police station with a similar design. (It didn't request FEMA funding for the second structure, as FEMA requires funded shelters to be open to the public during a storm, which would not be feasible for the first-responders' center.)

A number of building types offer great potential for these shelters, Morris notes. Nursing homes, where residents have little mobility, benefit greatly, as above-ground storm shelters require no elevators that could become inoperable if electricity failed. Apartments, warehouses, and data centers also offer strong options.

At least one university has asked for designs for an underground precast concrete shelter, he notes, and Coreslab Structures (OKLA) Inc. has been involved in plans for a new water treatment plant designed to remain operable after sustaining an encounter with an EF-5 tornado.

More Information

To learn more about requirements for FEMA safe rooms, visit: http://www.fema.gov/plan/prevent/saferoom/index.shtm and http://www.fema.gov/plan/prevent/saferoom/fema361.shtm. To learn about grant programs, visit: http://www.fema.gov/safe-room-funding.

The Oakdale High School in Oakdale, Okla., was designed with a total-precast concrete system, including double tees spanning 68 feet and 12-inch insulated precast concrete sandwich wall panels, which included 2 inches of insulation. Using 12-foot-wide wall panels and 8-foot-wide double tees allowed every third double tee to cross the wall joint and lock the panels together, reducing connections to resist loads across the joints. The building meets FEMA standards for safety.