Innovative connections create seamless look in monument

On September 11, 2001, United Flight 93 was hijacked by terrorists and crashed in a field in Somerset County, Pa. All 40 passengers and crew died. Seventeen years later, a precast concrete memorial was erected in their honor.

"The Tower of Voices monument is unlike any in the country," says Greg Gorman, senior vice president and chief operating officer of PennStress, the precaster for the project. The 93 ft (28.3 m) tall precast concrete tower wraps around 40 aluminum wind chimes, each of which was made to produce a unique musical note representing the individual voices of those who were lost. The tower features a C-shaped cross section that allows sound from the chimes to reflect outward from the open side in a fan-shaped pattern.

"It was a great honor to be a part of this project," Gorman says. "It was also a great challenge to produce and erect."

The intricate design required a durable material that could adapt to the unique curvature of the tower while providing a resilient structure that would last for decades. That's why the designers chose precast concrete; however, the geometry and precision required went beyond any typical precast concrete structure. "Every piece had to be perfect," Gorman says. "There was no room for error."

To meet these exacting standards, Gorman's team used three-dimensional (3-D) building information modeling (BIM) to design each piece and created multiple mock-ups to ensure that the pieces fit together perfectly and that no interferences would occur.

As they assembled these models, they realized there was a problem. The 36 beams and columns had to be connected to create a C-shaped core with a skewed beam layout. Using traditional connections would have resulted in nearly 700 patches, degrading the appearance. "Even on the best day, a patch is noticeable," Gorman says.

After of hours brainstorming solutions, evaluating 3-D–printed models, and testing different construction techniques, the team finally came up with a solution: cast open-ended hollow beams with openings for connections to be threaded through to the center.

Details from the 3-D BIM were used to create the one-of-a-kind forms for the project, and Pennstress's team cast several sample beams to be sure they could meet the zero tolerances. In conjunction with the erector, PSI, all the bugs were worked out in the plant to avoid field crew issues. One example of using a new process to help enable a blemish-free appearance was in the way the precast concrete was handled. To avoid surface marks once the pieces were cast, PennStress rigged a system to hang each piece so it would minimize contact of any surface during curing.

Integrating BIM and precast concrete enabled the precision necessary to use only internal connections in this precast concrete memorial to the passengers and crew of United Flight 93, which crashed in Somerset County, Pa., on September 11, 2001. Courtesy of Brenda Torrey, Friends of Flight 93.

The final structure was assembled over two months. It is self-supporting and doesn't require any bracing or other nonessential additions. The structure is designed to generate music even when the wind speed is very low.

Gorman says that they may never have an opportunity to reuse the innovative solutions they came up with for this monument, but that's okay. "It was a totally one-off project, and we take a lot of pride in having been a part of it," he says.

—Sarah Fister Gale

Using ultra-high-performance concrete enabled an open and light design for the precast concrete panels that form the facade of the new Manateq headquarters building complex in Doha, Qatar. Courtesy of Doha Cladding Solution, Ayman Badr.

UHPC helps Manateq headquarters make a strong statement

An eye-catching complex of four office buildings near the Hamad International Airport in Doha, Qatar, is the new headquarters for Manateq, the country's leading developer of industrial zones, logistics parks, and warehousing parks. The design ties in to the emir of Qatar's goal of creating a solid infrastructure in which medium-sized enterprises of non-oil-related industries can prosper and grow. It was conceived of as a composition of four inverted cubes sheltering an internal oasis. The outside of the iconic building is designed to reflect the Manateq brand and reinterpret traditional Qatari architecture using a modern architectural language.

Production of precast concrete panels for the Manateq headquarters facade used vertical glass-reinforced plastic forms and self-consolidating ultra-high-performance concrete to ensure an architectural finish on all surfaces. Courtesy of Doha Cladding Solution, Ayman Badr.

Inspired by Manateq's logo, the parametric facade optimizes daylighting throughout the offices. To achieve a structure that is long lasting, high quality, and low maintenance, ultra-high-performance concrete (UHPC) was selected as the material for the permanent shading construction. The facade elements were produced within Doha using this material, which is highly adapted to local climatic conditions to stand up to corrosion, dust, and so on.

The single concrete panels are about 9 m (30 ft) long and 3.3 m (10.8 ft) wide. Because all panels are visible from the outside as well as from inside the offices, all surfaces had to have an architectural finish. Because there is a groove on both sides of the curved panels, production was done in vertical glass-reinforced plastic molds using self-consolidating concrete.

The contractor for the shading elements was Doha Cladding Solution (DCS), which entered into the business of UHPC facade elements in 2015. Rather than purchasing ready-made dry mixes of mortar or concrete, the company reached out to Dyckerhoff, the German branch of the international cement producer Buzzi Unicem Group. With the high-performance binder Nanodur, DCS was able to create a UHPC mixture design on short notice and adapt this mixture to varying requirements to accommodate the mold, mixer, and temperature as well as changes in raw materials, strength, flowability, and ductility.

Bid documents required a UHPC with a strength of more than 150 MPa (21.7 ksi) and a flexural tensile strength of the uncracked concrete (strength of concrete paste, limit of elasticity, modulus of rupture) with a minimum of 12 MPa (1.74 ksi). The Young's modulus had to exceed 55,000 MPa (7980 ksi). Deviations, bowing, and warpage due to production and shrinkage also were restricted. The binder and admixtures were imported from Germany, aggregates from India, and steel fibers from China.

Dowels were used to provide a strain-free attachment to the steel framework. Drilling and setting the dowels on-site compensated for the tolerances on the structure. Intensive testing was performed to check the stability of the connections in three directions. A further challenge was the installation of the elements that overhang the steel frame.

—Bernhard Sagmeister