Museum Rises // Tower of Voices // Making the Most of Solar Energy // Rethinking Repaving

precast solutions

WINTER 2019

precast solutions

WINTER 2019
VOLUME 17 | NUMBER 1

ON THE COVER:
The new Flight 93 Memorial combines precast concrete and wind chimes to create a serene tribute to the victims of Flight 93.

Photo courtesy of PennStress

Precast Solutions
(ISSN 1934-4066 print, ISSN 1934-4074 online)
is published quarterly by NPCA,
the association of the
manufactured concrete products industry.

Publisher
Ty Gable

Executive Editor
Bob Whitmore

Managing Editor
Matt Werner

Associate Editor
Kirk Stelsel, CAE

Associate Editor
Sara Geer

Graphic Designer
Deborah Templeton

Advertising
Brenda C. Ibitz
(317) 571-9500
bibitz@precast.org

NPCA
Precast Solutions
1320 City Center Dr., Suite 200
Carmel, IN 46032
(800) 366-7731
(317) 571-9500 (International)
E-mail: npca@precast.org

WHAT'S INSIDE

Photo courtesy of of Paul Murdoch Architects

Tower of Voices:

A Lasting Tribute to the Heroes of Flight 93

Precast concrete and wind chimes provide a touching monument at the center of Flight 93 Memorial Park.

Mark Crawford

On Sept. 9, 2018, the National Park Service dedicated the Tower of Voices, an amazing monument that is the centerpiece of the Flight 93 National Memorial, a new national park in Somerset County, Pa. It was in this open field on Sept. 11, 2001, that United Airlines Flight 93 crashed after passengers stormed the cockpit, preventing the terrorist hijackers from attacking a key U.S. target – quite possibly the U.S. Capitol Building – making it hallowed ground.

Set among rings of trees, the Tower of Voices is a 93-foot tall precast concrete memorial that features 40 wind chimes – one for each crew member and passenger who died during the heroic struggle. As wind blows through the open structure of the monument, the 40 tones are meant to convey the serenity and nobility of the site and remind visitors of the final calls those passengers placed to loved ones.

More than 1,000 architectural and design firms competed for the honor to design the national memorial. In 2005, the project was awarded to Beverly Hills, Calif.-based Paul Murdoch Architects, in association with Nelson Byrd Woltz Landscape Architects. Murdoch and his team collaborated with the National Park Service and family members of the Flight 93 heroes to design the 2,200-acre memorial.

The Tower of Voices monument has 40 wind chimes, one representing each crew member and passenger who died during the heroic struggle on Flight 93.

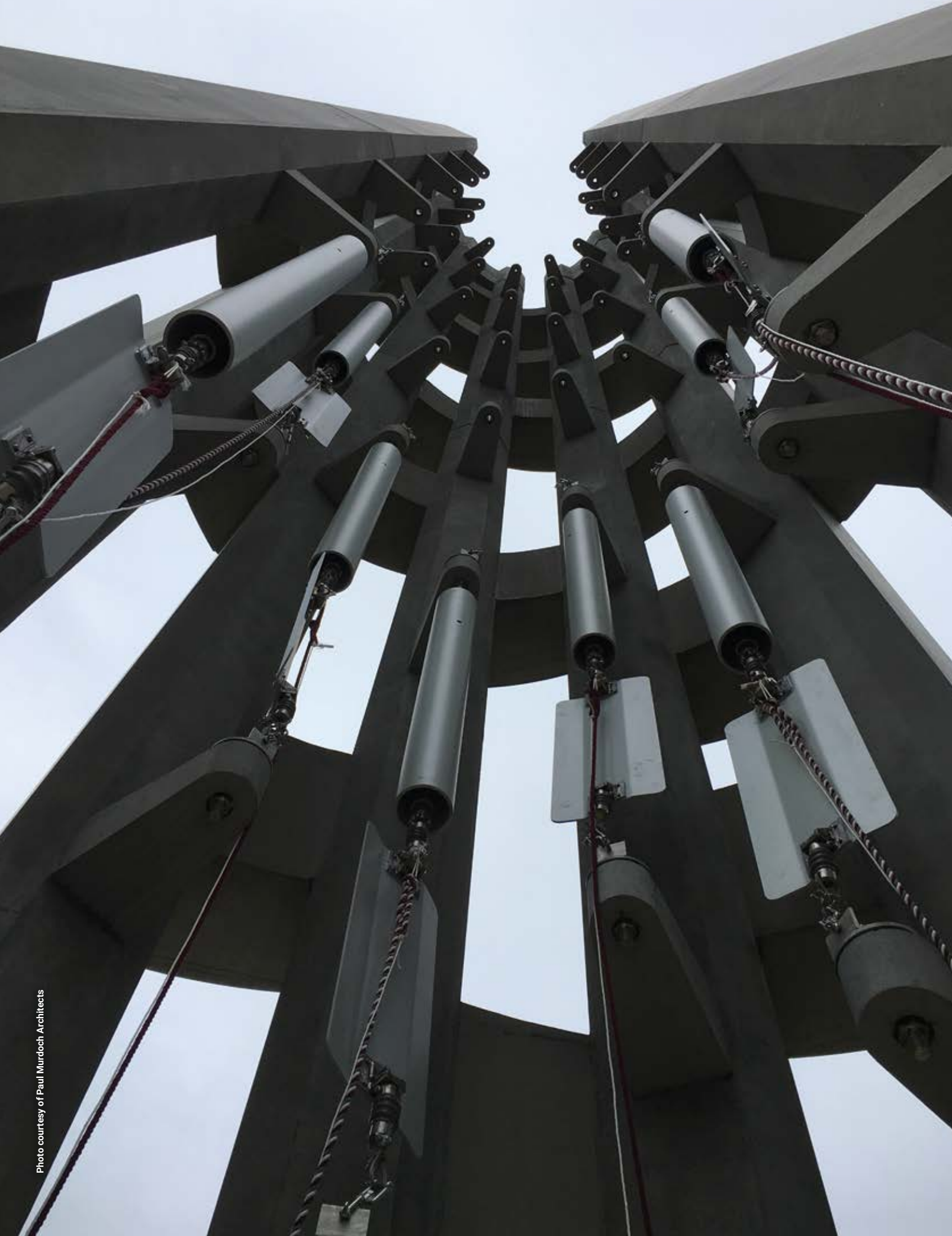

Photo courtesy of Paul Murdoch Architects

Crews assemble the reinforcement for the precast concrete columns and beams that make up the Tower of Voices Monument.

CREATING THE CHIMES

Designing a 93-foot-tall musical instrument holding 40 wind chimes – the largest in the world – was an immense technical challenge for Murdoch's team.

As a unique musical feature, the tower required a complex and innovative design process, including the cross-collaboration of experts including a musician, chimes artist, acoustical engineer and wind consultants. The size and complexity of the 40 chimes, and the variability of wind directions and velocities at the site, required an interactive process of testing and simulation to determine a final design.

"A back-and-forth process encourages input from each specialization to inform interdependent decisions and testing," Murdoch said. "This required musical tuning theory to establish the right tones, chime mock-ups for 3D recordings, computational fluid dynamic modeling to test tower shapes and simulate site conditions, and acoustic simulation in a sound lab to digitally test chime configurations in final tower volumes."

The team worked on the chime design for more than two years. The 8-inch-diameter aluminum tubes have half-inch-thick walls, vary in length from 5 to 10 feet and weigh up to 150 pounds. The length of each chime depends on the musical note and frequency it is designed to play. The chimes ring when they are struck by stainless-steel strikers that respond to sails moved by wind coming through the tower's open structure.

BUILDING THE TOWER

The chimes are supported by the C-shaped precast concrete tower, which opens toward the public plaza. The tower consists of approximately 274 tons of concrete and steel, or 141 cubic yards of concrete and 49,000 linear feet (9.25 miles) of reinforcing steel. The plaza is constructed on an earthen mound and surrounded by 208 trees, planted in concentric circles surrounding the monument. The arrangement of the trees is symbolic of the sound waves from the chimes. A lighted stone path winds through the trees, leading to the tower.

Twenty-five micro piles support the weight of the tower and the forces acting on the tower due to wind. Each micro pile consists of a 3-inch diameter, continuous high-strength steel rod grouted inside a 7-inch diameter steel casing that extends 83 feet below the surface of the plaza. The final 15 feet are embedded in bedrock. Each micro pile supports up to 160,000 pounds. The 25 micro piles are held together by a heavily reinforced 20-foot-by-20-foot-by-4-foot concrete cap. The total capacity of the cap is 4 million pounds. The piles, pile cap and tower are


Photo courtesy of Paul Murdoch Architects


Photo courtesy of Paul Murdoch Architects

protected with a grounding system extending from the foundation through the structure to the top of the cap and extending to each chime assembly.

The tower consists of 53 precast pieces produced by PennStress in Roaring Spring, Pa. The 16 column pieces, 35 beam pieces and two caps ranged in weight from 816 to 31,000 pounds. Precast concrete was selected for the tower walls because of the precision required for the complex and unusual shapes of the components. In fact, they were so unique that the steel forms fabricated specifically for the project will likely never be used again.

Russell Dickson, PennStress vice president of engineering, said despite the company primarily focusing on structural precast projects, there was no hesitation in providing the architectural precast elements.

"As soon as we realized what the project was and saw that precast was a major part of it, there was not an option to not do it," he said. "This was a project in our backyard and really does mean a lot to us as a company."

The high compressive strength of precast used in this project, roughly 7,000 psi, also improves the resistance of the structure to severe weather conditions, especially the freeze/thaw cycles of winter. Using precast also allowed the team to design and fabricate the components during the winter months.


Photo courtesy of Paul Murdoch Architects

Custom formwork was used to create the 53 unique pieces that make up the tower. Pieces ranged from 816 to 31,000 pounds.

Photo courtesy of Paul Murdoch Architects and Arup USA

Once the precast concrete segments were delivered to the site, they were linked together with connectors to form an open C shape that optimizes air flow through the tower walls to activate the chimes.

"The tapered column shapes were designed using computational fluid dynamics to study wind flow through the tower," Murdoch said.

The team spent more than 9,000 hours in development, design, logistics, multiple trial assembly procedures and casting sequencing to get to the point of on-site erection. Other digital and physical models were used to determine geometries and connections. PennStress used 3D printing technology to create prototypes to better understand the structural relationships between the tower columns and beams.

Photo courtesy of PennStress

Photo courtesy of Paul Murdoch Architects

The precast concrete pieces form a "C" shape that opens out to a public plaza. As the wind blows, chimes will ring out as a solemn remembrance of what happened on the site.

Photo courtesy of Paul Murdoch Architects

The result is beam shapes that curve to delineate the round footprint of the tower. The 20-degree angle of the connecting beams between the columns represents the angle of the branches of the hemlock trees that surround the crash site.

"The beam-to-column connections were challenging in terms of sloped/curved geometry, reducing the number of patches and alignments," Murdoch said. "There are approximately 844 Lenton connectors and 6,708 stirrups in the structure that splice discontinuous bars together."

PennStress decided that the slenderness of full-length columns

made them too susceptible to damage during shipping and erection. Instead, diagonal joints at varied locations roughly mid-height helped the columns blend in with the diagonal joints of the beams. Pockets and splines at the joints also aligned the column pairs vertically. In addition, it applied specialty coatings prior to shipment.

"Both water-repellent coating and anti-graffiti protection were required for the precast," he said. "Initial mock-up testing demonstrated a significant alteration to the desired light gray color of the concrete. After additional research and testing, we chose PROSOCO Blok-Guard Graffiti Control ll, which affected the appearance of the concrete the least."

A LASTING MEMORIAL

Constructing the Tower of Voices was funded by an approximately $6 million grant from the National Park Foundation. Visible from the highway, the tower marks the gateway to the national park. Murdoch hopes visitors to the memorial will reflect on the experience in deeply personal ways.

"We very consciously tried to create an openness to the experience and interpretation for everybody, and not to try to dictate what they would feel, but to let everybody have different angles of experience," he said.

Dickson said the entire company is proud of the way the project came out not only because of its complexity, but also what it means to the community.

"To think of what the 40 individuals did on that flight, anything that we could do to help remember them is a tremendous honor for us," he said. "That is something everyone here understands, and we don't forget that we're doing this for the 40 individuals who gave up their lives to save many others."

Collectively, the chimes produce an original "song" every time the wind blows through the tower.

"There are no other chime structures like this in the world," said Flight 93 National Memorial superintendent Steve Clark. "This unique structure completes all the major components of our permanent memorial in a most beautiful way. Not only is it the first thing visitors see and hear when they arrive at the memorial, it will also provide an opportunity for reflection as they depart." PS

Mark Crawford is a Madison, Wis.-based freelance writer who specializes in science, technology and manufacturing.

The Tower of Voices marks the gateway to Flight 93 Memorial National Park.

FLIGHT 93 NATIONAL MEMORIAL WINS WORLD ARCHITECTURE NEWS CONCRETE IN ARCHITECTURE AWARD

Here are some of the comments from jury members who selected this project for the 2017 World Architecture News Concrete in Architecture Award:

"It's stunning. The concrete is used perfectly to capture the kind of gravity and the momentous thing that it is there to commemorate. That's where concrete really shines in the use of this scheme. They've used it very particularly; it is quite a responsibility and they've taken it completely seriously."

"It's a wonderful use of the concrete from a technical point of view and I think it's been used very appropriately. It is a backdrop, it is solemn and quiet, yet bold, beautiful and dramatic. I love the color and the contrast of the different textures and where they are placed."

"A grand and fitting vision which envelopes a hugely significant site. Concrete as monument reflecting a sense of permanence. Lighter-built elements interplay, allowing optimism to lift above the mass of concrete."

Photo courtesy of Paul Murdoch Architects