

National September 11 Memorial Museum





The museum designed to address myriad memories and experiences sits at bedrock, the result of design innovation and complex engineering 70 feet below where the Twin Towers once stood.

TO ENTER THE NATIONAL SEPTEMBER 11 Memorial Museum is to step back in time, to that fateful day in 2001. The descent to the underground structure starts at the airy entry pavilion, the only building on Memorial Plaza. The plaza itself, which occupies approximately half of the World Trade Center's 16 acres of hallowed ground in Lower Manhattan where the Twin Towers once stood, serves as a green roof to the museum's structure, its giant reflecting pools and a grove of more than 400 white oak trees a stark contrast to the brute concrete and twisted steel on display below.

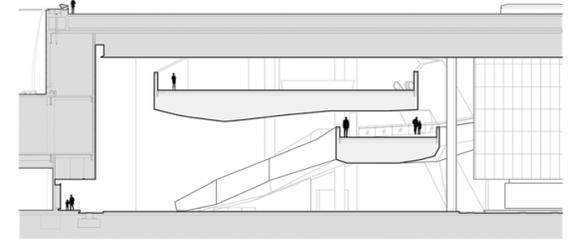
The entry pavilion and museum are actually two separate structures, by two different architecture firms. Both had to deal with programs and building

locations that changed dramatically over the course of more than a decade of planning and construction at Ground Zero. Davis Brody Bond (DBB), architect of the below-grade museum, had initially designed an above-ground entry pavilion by the West Side Highway, Oslo- and New York-based firm Snohetta, who had originally been commissioned to design the International Freedom Center on the northeast quadrant of the site as part of Daniel Libeskind's master plan, saw that large cultural project inflate then diminish, then eventually disappear. Instead, Snohetta became architect of the pavilion, which would eventually move to the east, between the footprints of the Twin Towers by Greenwich Street.

At the point Snohetta got involved, DBB had already designed much of the museum, conceptually at least, and footings and foundations were well underway. The two firms coordinated work to ensure the below-grade structure was designed appropriately to take the loads of Snohetta's building, an angular steel and concrete structure clad with stainless steel panels and glass that showcases two surviving 80-foot-tall steel tridents from the Twin Towers.

Above The Ribbon, a ramp that gently descends and guides visitors from the memorial plaza to the bedrock level alongside the preserved Survivors' Stair.

This page: James Ewing; facing page drawing and diagrams: Davis Brody Bond; opening spread: James Ewing



Above A north-south section looking west through the concourse lobby and Memorial Hall.
Below left A 3D image of architectural insertions into the World Trade Center site.
Below right A close up of the Ribbon model.

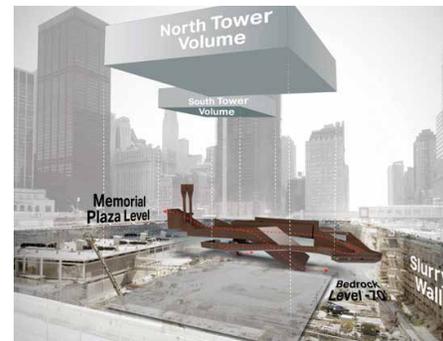
The entry pavilion shares its setting with Santiago Calatrava's new Port Authority Trans-Hudson (PATH) station, as well as with existing subway lines and secure parking facilities. Its structure straddles both the PATH station and the Memorial Museum, supported on only 12 points split between the station and museum, and on a reinforced concrete core to the south. Roughly 85 percent of pavilion columns are anchored to deep transfer girders extended from the system that supports the roof of the PATH mezzanine on the west side of Greenwich Street. The museum supports the remainder of the pavilion structure.

Careful coordination and analysis of the surrounding structural constraints was critical in identifying the limited support points for the pavilion, which resulted in many unusual spans and a unique steel framed structure with W36s and W40s throughout, according to Eileen Hatfield, a partner at Buro Happold, the pavilion's structural engineer. At the pavilion's north edge, an additional support point was required; however, the PATH station long span structure below could not support the pavilion loads. To provide the necessary support, a 22-foot-deep, full-story steel truss cantilevered from the pavilion core walls at level 3, providing a location to hang the floors below and effectively cantilevering a portion of the pavilion structure over the PATH station.

Similar constraints created unique challenges for the lateral stability of the pavilion, and affected its relationship to the museum structure. Because the reinforced concrete core providing lateral stability is directly above the PATH train tracks, transfer of lateral forces to the ground was difficult. Adding further complication, the long span PATH station structure was unable to accommodate additional lateral loads, so the lateral load was transferred to the museum below grade. To transfer the load, the pavilion is ringed with steel and reinforced concrete composite drag beams connected to museum shear walls.

Due to the museum's long spans and limited support points, the project required steel sizes as large as W40x503. More than 8,000 tons of structural steel was used in the 9/11 Memorial and Museum combined. (See articles on the entry pavilion structure and façade in *Metals in Construction's* Fall 2013 issue and at ominy.org/publications.)

The form for one of the museum's main architectural features, called the Ribbon, had also already been determined and materials selected when Snohetta became involved. "That shift for us from the west side to the east side as an entry point had very little consequence on the part of the Ribbon itself and how it worked," says Mark Wagner, project designer and associate partner at DBB. "In fact, it





Left The 36-foot-tall steel member known as the Last Column in Foundation Hall.

Below "Impact steel," a portion of the North Tower facade that was twisted by a direct hit from American Airlines Flight 11.

Bottom Concourse-level floor plan (left) and bedrock-level floor plan (right)



made the connections a little easier for us."

A broad stair—part of Snohetta's project—from the bright, daylight entry pavilion leads to the much more somber, wood-clad concourse lobby. There the Ribbon descent begins, providing a gently ramped path to slowly acclimate visitors to the experience to come. The faceted form winds between the aluminum-clad Tower Volumes—the other main insertion within the excavation that aligns with the footprints of the original Twin Towers and the pools above—and brings visitors to the bedrock level.

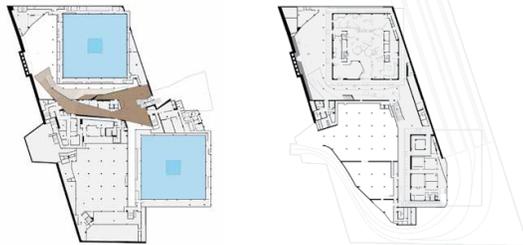
"At some point in the early discussions we talked about hanging the Ribbon and going through all these gymnastics to get it into place," recalls Wagner. "But later we committed to having a line of columns outside the aluminum volumes." DBB worked with WSP Cantor Seinuk on the overall structural design. A grid with columns spaced every 35 feet made traditional framing possible, with a steel-and-concrete deck to support the Ribbon. Along the south edge of the North Tower volume, which is the north edge of the Ribbon, a row of exposed columns allows the Ribbon to span between the wall and the columns and fill the space between the two.

The Tower Volumes, on the other hand, appear to hover in the expansive Foundation Hall, the main space of the museum. Throughout the design process, DBB met frequently with local community boards, firefighters, police officers, victims' families, and survivors groups. "One thing that kept coming back to us and was so powerful was the footprints of the towers themselves," says Wagner. "Because the way they saw it, if you were inside the building, you died. If you were outside, you lived."

DBB chose to float the volumes above those footprints so as to not create a traditional threshold, as if going through a door. Instead, visitors pass from a space with ceilings that are as high as 50 feet, to step under the heavy metal volumes. The footprints—the original box columns and footings—are preserved below.

The 15-foot cantilever, however, is relatively small given the available back span. It is supported by a very traditional structural grid and columns without the need for trusses, and is achieved simply with flat slab construction and reinforced steel.

One last major feature of the museum is an existing one. The World Trade Center's original slurry wall is a structural wall designed to be supported by lateral floor slabs—the original parking slabs below the towers. Without those lateral braces—and with the debris from the site that temporarily held it in place removed—the matter of how to hold the wall up became a big concern. Consulting engineers Guy Nordenson and Associates and Simpson Gumpertz & Heger devised a solution in which a 5-foot-thick



Photos this page: Jin Lee; diagram: Dave Brody, Benoit, facing; James Ewing



Above Approach to the slurry wall overlook from the museum's introductory exhibit.

concrete liner wall was placed in front of much of the 60-foot-high, 270-foot-long slurry wall. For the 70-foot portion that was left exposed in the Foundation Hall, another structural wall was built on the back side of it, allowing a full-height segment of the original wall to be exposed while also providing adequate waterproofing and blast protection. The liner wall on the back face was created by a series of vertical beams or pilasters at the joints in the slurry wall individually cast in self-supporting, hand-excavated pits, which were then joined together.

The area by the slurry wall is the only location in the museum where there are deep trusses. That triangular-shaped area is over 100 feet across, without columns, at its widest point. There, trusses that are over 10 feet deep support the plaza above.

"When we started this project, we had this idea that spaces needed to be column-free, that we needed big open areas to continue that sense of void the visitor had going to the site before anything had been built," Wagner says. "But in the end, we had a very straightforward, conventional structure to support it all—some trusses, simple cantilevers, nothing overly complicated." And in the end, it's an elegant simplicity that allows the focus to stay where it should be: on the museum's personal meaning for each visitor that passes through it. □

NATIONAL SEPTEMBER 11 MEMORIAL MUSEUM

Location: **National September 11 Memorial Museum at the World Trade Center, New York, NY**

Owner: **National September 11 Memorial Museum at the World Trade Center, New York, NY**

Architect: **Davis Brody Bond, New York, NY**

Structural Engineer: **WSP Cantor Seinuk, New York, NY**

Mechanical Engineer: **Jaros Baum & Bolles, New York, NY**

Consulting Engineers: **Guy Nordenson and Associates, New York, NY;**

Simpson Gumpertz & Heger, New York, NY (Slurry wall); Weidinger Associates, New York, NY (Blast design)

Construction Manager: **Lend Lease, New York, NY**

Curtain Wall Consultant: **Front Inc., New York, NY**

Structural Steel Fabricator and Erector: **W&W Steel Erectors, Oklahoma City, OK**

Miscellaneous Iron Fabricator and Erector: **W&W Steel Erectors, Oklahoma City, OK;**

Metro Steel Erectors, Inc., Brooklyn, NY

Architectural Metal Erector: **W&W Glass, Nanuet, NY**

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