Courtesy of Brett Beyer.

INSIDE THE BOX

By Michael Hopper, P.E.

THE EFFICIENT FORM OF THE DAVID RUBENSTEIN FORUM

The David Rubenstein Forum at the University of Chicago is a new center for intellectual exchange, scholarly collaboration, and special events. Designed by Diller Scofidio + Renfro (Architect of Record) and Brininstool + Lynch (Associate Architect), in collaboration with LERA Consulting Structural Engineers, the 97,000-square-foot structure consists of a 2-story podium and a 10-story tower of meeting room and social space *neighborhoods*, which are staggered to varying degrees. Conceived as a scholarly retreat from the hustle-and-bustle of downtown Chicago, the bold new conference center shifts the paradigm from traditional sprawling conference centers and hotel ballrooms. The Forum's conference centers are stacked vertically and can accommodate gatherings from 75 to 600 people. Friedman Hall, a 285-seat auditorium, boldly cantilevers 40 feet to capture the picturesque view over the tree-lined Midway Plaisance on the University's iconic campus. The Forum has become a unique scholarly resource for the University and, despite opening during the COVID-19 Pandemic, has already hosted several notable events, including a talk by former President and University of Chicago professor Barack Obama.

The structural system comprises a series of simple individual structural elements stacked in a harmonious form to efficiently create the desired open spaces, yielding column-free spans of up to 65 feet. Incorporating post-tensioned concrete into the structural design was crucial to achieving the design's long spans, cantilevers, and column-free spaces. At 166 feet tall, the Forum rises over 100 feet above the surrounding tree line, striking a dynamic form that symbolically ties together the history of Chicago's Midway Plaisance, the University's heritage and ambitions, and the architectural legacy of the area.

Structural Design Process

The staggered neighborhoods of the tower posed a complex engineering challenge that was ultimately solved with a unique structural system of stacked concrete boxes. Like how folding cardboard into a box allows it to be stronger than if it were flat, the Forum's concrete structure is an efficient form for achieving the desired cantilevers and clear spans. None of the structural elements work particularly

"INNOVATIVE STRUCTURAL DESIGN ENABLES LONG SPANS AND CANTILEVERS THAT DEFINE A STUNNING ARCHITECTURAL FORM."

The tower's efficient form is derived from a box-like structure created by the unique stacking of slabs and cantilevered walls.

At the podium, a pair of steel roof trusses rest upon and are transferred by a system of cantilevered post-tensioned slabs and beams at Level 2.

hard in isolation, but together, they work harmoniously to meet the project's requirements.

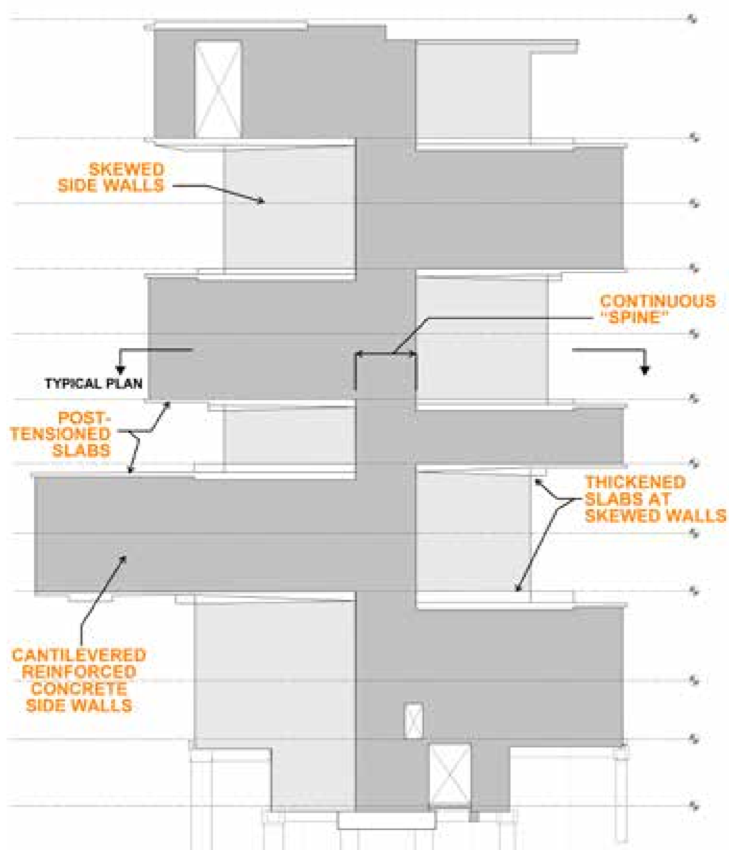
LERA collaborated closely with DS+R through multiple massing schemes and design iterations. Several core design principles held true across the various schemes that informed the structural systems, which were key to helping meet the goals for the project. These included:

- **Openness** – to capture views of the University, the Chicago skyline, and Lake Michigan, as well as to allow for free stacking of the neighborhoods and flexibility of event planning without the need for expensive structural transfers.
- **Simple Use of Familiar Materials** – to enable the efficient construction of conventional structural elements and technologies commonly used in the Chicago concrete market.
- **Unique Form** – to "stitch" the north and south sides of Chicago together while simultaneously taking advantage of the prominent site location on the Midway Plaisance to create a highly visible landmark.
- **Balance** – to achieve the cantilevers to the north and south while minimizing the structural work required in the building's "spine" and interior core.

Turner Construction Company, the project's general contractor, and R. Olson Concrete Construction were involved early in the pre-construction planning through a design-assist role. With input from the post-tensioning supplier, the contracting team reviewed and priced the various design schemes while providing construction feedback to the design team. This process helped the team arrive at the as-constructed design, which met the project's budget and wherein the innovation of the structure lies in its simplicity. In the tower, post-tensioned slabs and walls are stacked in an efficient form to create the desired open spaces, which proved economical because it allowed the contractor to build with the same materials and systems used on typical concrete projects in Chicago.

The Tower

The main support for the tower is provided by a pair of 12-inch-thick, conventionally reinforced concrete side walls that are skewed from neighborhood to neighborhood. These side walls, and the slabs connected to them, work together compositely to form the stiff box-like structures that cantilever out to the north and south. The back-and-forth cantilevers are balanced to help minimize the amount of bending induced into the building's spine and central core, which enables the use of thin 8-inch-thick shear walls around the elevators and egress stairs, where space is limited and coordination of systems is critical. In addition to designing the side walls for the cantilever spans, designing the walls for the out-of-plane moments due to the fixity of the slabs to the walls proved to be an essential design consideration. Four rectangular concrete columns



An elevation of the folded side walls (looking east).

also support the slabs and are located just outside the central core to preserve the open concept.

Unbonded post-tensioning is used in the floor slabs, which form the top and bottom of the stacked boxes, to enable the 65-foot spans between the side walls and reduce the tensile stresses in the top of the cantilevered boxes. These long, column-free spans are an essential component of the functionality of the building, maintaining openness throughout. Dubbed *sculpted slabs* by the design team, the typical slabs are 10 inches thick and are only thickened (or *sculpted*) where needed. For example, thickening occurs where the side walls are skewed and do not align from the floor above to the floor below, and at interior-to-exterior transitions to reduce deflections where the façade attaches to the building structure. The result is a long-span slab that is efficiently constructed with simple, flat formwork and allows for an efficient distribution of ductwork due to the absence of interior beams.

The stacked neighborhoods were modeled in multi-story post-tensioning analysis and design software to capture the composite behavior between the slabs and the cantilevered side walls in the post-tensioning design. This resulted in an average effective post-tensioning force for a typical floor slab of about 35 kips/foot, which is a modest increase over normative post-tensioned slabs with shorter spans, demonstrating the system's efficiency.

An important part of the design process was the coordination of expected slab movements with the façade contractor, Glass Solutions, Inc. Post-tensioning not only helped limit the deflections of the slab but because it precompresses the concrete to eliminate cracking, the anticipated deflection values could be reported to the façade contractor with precision and confidence. Expected deflections were reported to the contracting team at three stages: 1) The elevation of the slab at the time of façade installation; 2) the deflection of the slab due to the weight of the façade; and 3) the long-term deflection, including creep effects, after the façade was installed. This effort was crucial in coordinating the installation and alignment of important architectural finish details and ensuring the façade connections and joints were detailed for the movements.

The structural design took advantage of the high-strength concrete available in Chicago. All concrete used in the superstructure has a compressive strength of 8,000 psi or higher. In addition to using high-strength concrete, the modulus of elasticity and a low 28-day drying shrinkage limit were specified, along with additional rebar placed in the slabs along the walls. These additional requirements served to minimize the likelihood of developing cracking in the slabs due to the restraint-to-shortening effects caused by the robust side walls.

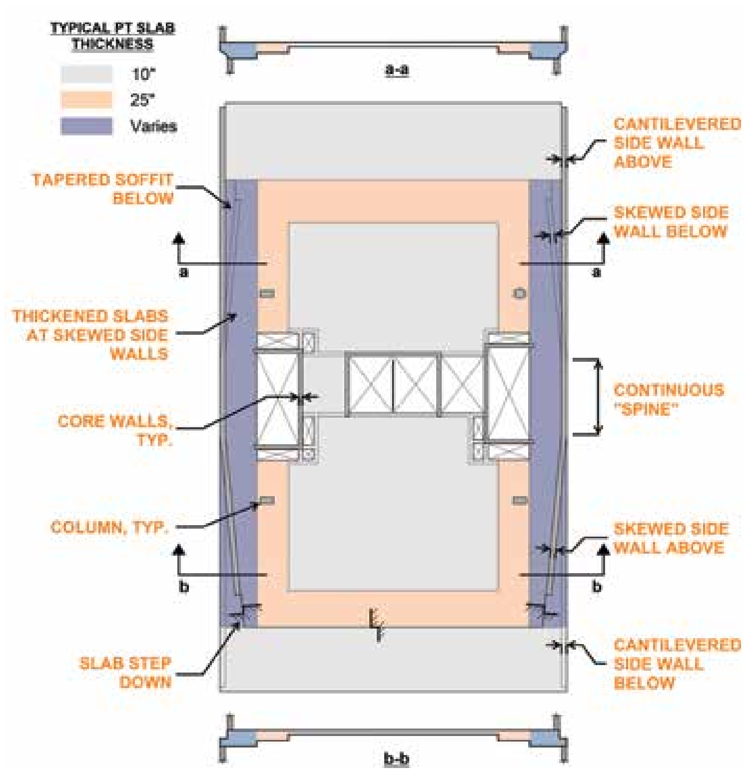
The Podium

As with the tower, the principle of openness remained key at the podium. Here, however, the clear span over the University Room – a large multipurpose space on the 2nd Floor accommodating up to 600 people – is 105 feet, as compared to the 65-foot clear spans in the tower. The design uses a pair of steel roof trusses, which in turn rest upon, and are transferred by, a system of cantilevered post-tensioned slabs and beams at Level 2 to accomplish this longer span.

To allow for a high ceiling at the interface with the façade, the trusses are set back from the south edge of the University Room, which also requires the steel roof beams to cantilever from the trusses.

Staged stressing of the Level 2 post-tensioned beams was necessary. Therefore, 50% of the PT tendons were stressed after casting the Level 2 slab, and the remaining tendons were stressed after the University Room roof slab-on-metal-deck was cast.

A technical challenge with the structural design of the podium was understanding how the cantilevered post-tensioned slabs and beams at Level 2 impacted the movement of the steel framing at the roof. The façade was initially conceived to be hung from the tips of the cantilevered roof beams. However, the deflection curvature of the slabs at Level 2 and the roof are in opposite directions, which created a unique worst-case scenario on the project for the façade detailing, and would have resulted in a large joint where the floor meets the façade. To accommodate the large differential deflections and to help achieve the important finish details at the floor-to-façade interface without a joint, LERA recommended base loading the façade onto the Level 2 post-tensioned slabs and beams and concealing the large movement joint in the ceiling where it would be out of view.



A typical "sculpted" post-tensioned slab. These slabs strike a balance between using minimal material quantities and ease of forming while allowing for a more efficient distribution of ductwork from the core due to the absence of interior beams.

Conclusion

The design of the Rubenstein Forum was a significant challenge, but, ultimately, it was executed in a simple way that successfully achieved the aspirations of the University of Chicago and DS+R, and it has already become a beacon for the campus and surrounding community. Its striking architectural form was made possible by the stacked concrete boxes, an example of the true integration of architecture and structure.▪

Michael Hopper is an Associate Partner with LERA in New York, NY. He serves on PTI's DC-20 Building Design Committee and teaches the Design of Concrete Structures at Princeton University in Princeton, NJ (michael.hopper@lera.com).

Project Team

Owner: University of Chicago, Chicago, IL
Structural Engineer-of-Record: LERA Consulting Structural Engineers, New York, NY
Design Architect/Architect of Record: Diller Scofidio + Renfro, New York, NY
Associate Architect: Brininstool + Lynch, Chicago, IL
General Contractor: Turner Construction Company, Chicago, IL
Concrete Contractor: R. Olson Concrete Construction, Chicago, IL
PT Supplier: AMSYSCO, Romeoville, IL
Steel Contractor: Waukegan Steel, Waukegan, IL
Curtain Wall Contractor: Glass Solutions, Inc., Itasca, IL
Structural Software Used: ETABS, SAP, ADAPT Builder

The staggered design of the tower features cantilevers of up to 40 feet. Courtesy of Brett Beyer.