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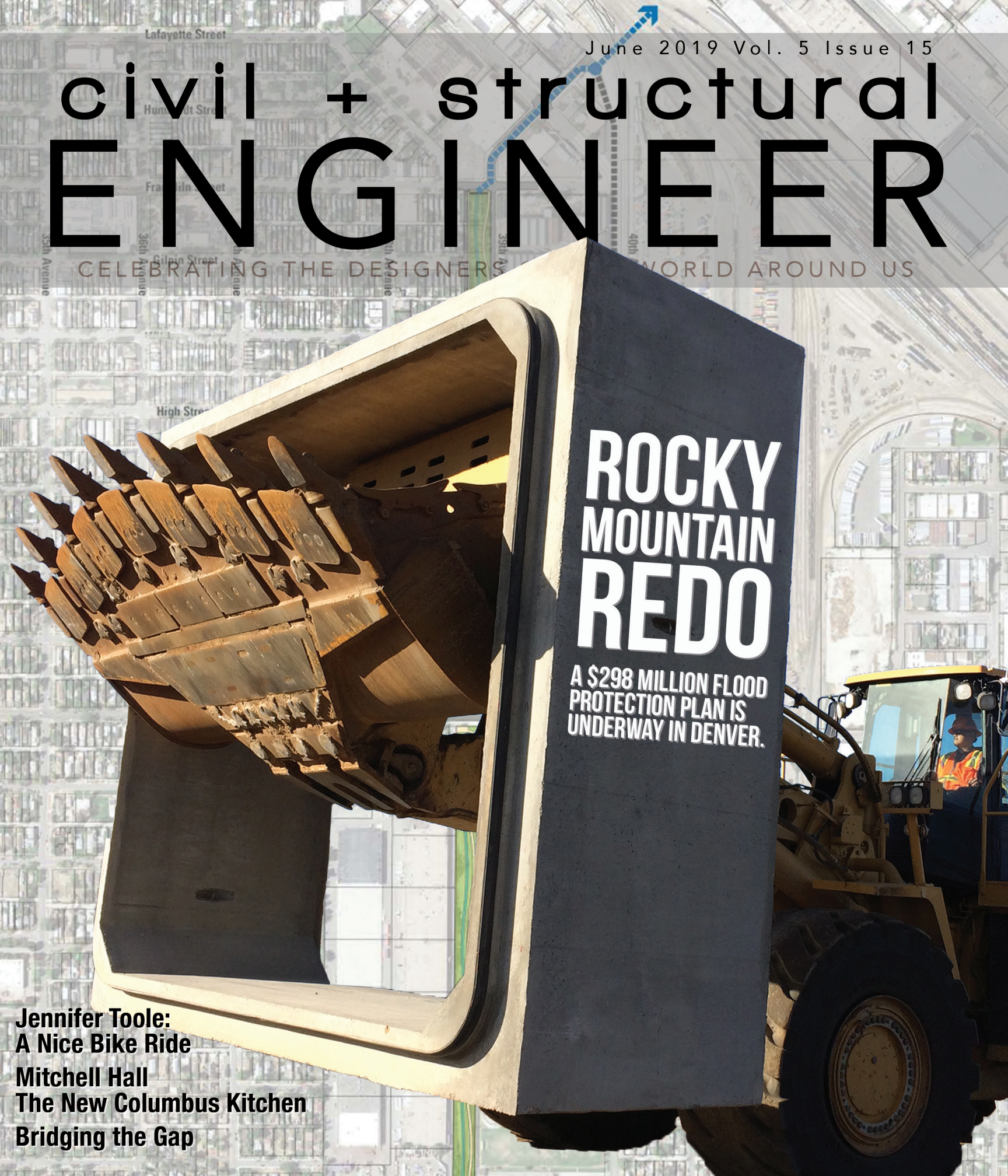
civil + structural ENGINEER

CELEBRATING THE DESIGNERS [illegible] WORLD AROUND US



ROCKY MOUNTAIN REDO

A $298 MILLION FLOOD PROTECTION PLAN IS UNDERWAY IN DENVER.

Jennifer Toole:
A Nice Bike Ride

Mitchell Hall
The New Columbus Kitchen

Bridging the Gap

CURVILINEAR GEOMETRIES

POST-TENSIONED CONCRETE ALLOWS BUILDERS TO DO MORE WITH LESS

By Kristin E. Dispenza

ENGINEERS FACE A PARADOXICAL CHALLENGE: making skyscrapers ever taller, yet making them lighter-weight and less material-intensive. One solution has been the increased use of post-tensioned concrete. Post-tensioning is a method of reinforcing concrete (or other materials) with high-strength steel tendons, improving the performance of the concrete by taking advantage of concrete's high compressive strength characteristic to provide additional tensile strength. Cast-in-place post-tensioned concrete is as durable as traditional concrete but is more structurally efficient.

"The high-strength steel and concrete that are necessary for stressing also increase the member capacity, resulting in a reduced amount of required conventional reinforcement," explained Michael Hopper, Associate, LERA. "The result is shallower structural members, compared to conventional reinforced concrete systems."

Longer, thinner slabs allow for reduced floor-to-floor heights, optimizing the number of building stories that can fit within a given height limit. Fewer column supports are required, so design flexibility and usable space are maximized.

Post-Tensioning: Why Now?

Curvilinear geometries, stories that are offset from floor to floor, and transparent facades are all characteristics of contemporary skyscrapers. The open spaces and long spans that facilitate this type of design rely on fewer interior columns, more frequent use of cantilevered floors, and flexibility in load distribution.

"Designers have known for quite some time that cast-in-place, prestressed (post-tensioned) concrete was the most effective way to build offices, residential towers and parking structures," said Russell L. Price, executive vice president, Suncoast Post-Tension, Ltd. "And as floor slab profiles become more complex, with fewer rectangular shapes, floor slab edges on many newly-designed structures vary widely, not only from project to project but even between floors on the same project. Prior to the availability of design software, design analysis was complex enough to discourage the use of post-tensioning. Once computers could support the designing of floor systems, post-tensioning went from being the design teams' third or fourth choice to being their first choice because designers understood the benefits that cast-in-place post-tensioned concrete brought to high rise building construction."

A striking illustration is the Seminole Hard Rock Hotel & Casino, currently under construction in Hollywood, Florida. The building will stand at 450 feet tall and will be shaped like the body of a guitar. To replicate the curvature of a guitar, floor slabs are deeply set back from floor to floor and columns could not be arranged in a grid. Nevertheless, post-tensioning offered the flexibility to "sweep" or curve the tendons

The Roy and Diana Vagelos Education Center at the Columbia University Medical Center. *Photo: Post-Tensioning Institute*

The Seminole Hard Rock Hotel & Casino in Hollywood, Florida. ***Photo: Post-Tensioning Institute***

to follow the column lines and limited the deflection of the long slab cantilevers necessary to meet the changing shape at each floor. This allowed the curtain wall system to fit the curved shape of the structure. The vision for the Roy and Diana Vagelos Education Center at the Columbia University Medical Center – a 107,000 square-foot, 15-story medical education facility – was to provide an interdisciplinary learning environment. Architects designed a cascade of spaces across the building's southern façade, which required vertical load paths that would leave the stacked spaces intact. The engineering solution includes an architecturally exposed pair of inclined composite concrete columns to support the cascade floors. The sloping columns create thrusts that are resisted by in-floor trusses constructed with post-tensioning and high-strength rebar. Cantilevered floor plates up to 26 feet in length leave the façade column-free, allowing building edges to be defined by specially-designed glass plates that do not align in plan.

"In complex structural systems such as this, engineers must coordinate expected deflections with the other building systems, such as facade attachment locations or other exterior enclosure requirements, moveable partitions, or equipment that is impacted by motion," said Hopper. "Using post-tensioning, LERA's engineers were able to confidently calculate the expected deflection of the slabs in the Education Center, ensuring that the glass panels would not break due to unexpected building movement. Post-tensioning offers a reduction in long-term creep deflections because of its tuned load balancing."

"Using post-tensioning improves calculations of deflection in two ways," said Carol Hayek, Chief Technical Officer, CCL. "Firstly, through load balancing, actual deflections are reduced. Secondly, there is less uncertainty in the calculations. This is because reinforced concrete slabs are always designed as a cracked section. To calculate a cracked section, one has to consider many different properties, such as variations in the mix, differences in curing, and so on, so the resulting deflection calculation is an estimate. But post-tensioning calculations are limited to an uncracked section; one can use the full section to reduce load."

Post-tensioning reduces or eliminates cracking by pre-compressing the cross-sectional areas that would otherwise experience large tensile stresses when loaded (if the post-tensioning were not present). Designers can use post-tensioning to control and limit tensile stresses to ensure that concrete sections remain uncracked.

The architectural trend of using exposed concrete as a finish surface also benefits from post-tensioning. Exposed concrete is not only the finish surface for the mixed-use Reston Station OB1 located in Reston, Virginia, but expresses the building's structural system. Exoskeleton columns slope at 11 degrees from vertical and around this exoskeleton a transparent, "glass box" aesthetic was desired by the designer. Thin, cantilevered floors and concealed anchors minimize the amount of structure visible in these glazed areas. The building's floor slabs contain distributed tendons in the east-west direction; these tendons are crossed at midspan to conceal dead-end anchors inside the exterior columns and allowed the tendons to be stressed at the spandrel beams. Post-tensioned slabs help resist thrusts created by the inclined columns. Post-tensioned concrete also offers cost savings because it is quicker to construct. For the Address Boulevard Hotel in Dubai, UAE, indirect cost savings were achieved through an accelerated construction program that included the ability to remove formwork every three days as opposed to the 15 days for traditional methods. These indirect savings were in addition to direct cost savings associated with reduced material usage and reduced loads, which engineers at StrongForce estimate to be approximately 20 percent for the slab system in its entirety.

Wind and Seismic Loading

Upon its completion in 2019, NEMA Chicago will be one of the tallest unbonded post-tensioned towers in the United States, standing at 76 stories and 887 feet (270.4 m).

"Post-tensioning provides tall buildings like NEMA Chicago with the strength necessary to resist lateral forces from wind loads," explained Neel Khosa, vice president, AMSYSCO, Inc.

Some areas are starting to use post-tensioning for seismic resistance. Post-tensioning cables remain elastic under loading and their self-centering behavior limits deformation, keeping buildings from overturning, according to Hayek.

"An increasing number of buildings in California are using hybrid systems of vertically-placed post-tensioning cables combined with rebar (which helps dissipate energy) to improve seismic performance. Vertical applications of post-tensioning can even be used to correct tilting buildings. Additionally, adding compression to the system for resisting lateral loads results in thinner walls—another material-saving, square-foot-increasing benefit of post-tensioning," said Hayek.

Urban Site Constraints

Hudson Yards is a 28 acre (11.33 ha) mixed use development on the west side of Manhattan that is expected to be complete in 2024. For much of the site's history it was occupied by rail yards and it will again be an active rail hub once the Hudson Yards development is competed. A centerpiece of the development is 55 Hudson Yards, a 51-story commercial office building that is one of the first fully concrete framed high-rises of its class in New York City.

"Until recently, the use of unbonded PT has been almost non-existent in New York City – the largest construction market in the United States," said Khosa. "55 Hudson Yards has paved the way for a few other skyscrapers that utilize unbonded post tensioning."

"Concurrent with the Hudson Yards development, New York's Metropolitan Transportation Authority installed a new subway station as part of the Number 7 Line Subway Extension," said Florian B. Aalami, President and CEO, ADAPT Corporation. "The station was built with an arrangement of caissons that, it was anticipated, could carry loads consistent with steel tower construction. Developers of Hudson Yards, however, desired the speed and cost advantages of concrete construction."

This presented engineers with the challenge of transferring loads away from caissons in the center of the building footprint, which were inadequate to support the weight of concrete. They developed a unique arrangement of "draped," post-tensioning tendons that use hyperstatic reactions to counteract the weight of the concrete structure and reduce natural load paths. Tendons were anchored between the 10th floor (at locations near the exterior columns) and the 8th floor (at the building's two interior columns), across a distance of 98 horizonal feet. Tendons were stressed from the 10th level.

Developers of 55 Hudson Yards also desired multiple areas across the floor plates that could be cut by building tenants during renovations in order to achieve double-height spaces. Tendons laid in a uniform arrangement (spaced at regular intervals in both directions) would have made it impractical to cut through slabs. Therefore, a flat-slab floor system was designed that arranged post-tensioning cables in a banded radial configuration, leaving large areas within the slab cable-free.

Enormous flexibility in transferring loads is another benefit of post-tensioning. When the layout of columns in a building's base (or any other vertical section) can't directly transfer loads from upper floors, a transfer slab can be created using post-tensioning, with the slab effectively supporting building levels above it.

Parking, loading docks, city utility easements and more posed limitations on structural support placement at the base of the Ritz-Carlton Residences Waikiki Beach (Phase 1), in which opened in 2016. To support seven floors of podium structure, four post-tensioned transfer girders and a two-story post-tensioned concrete truss were designed by Baldridge & Associates Structural Engineering to span 120 ft (37 m). Post-tensioning was used in the top and bottom chords of the truss to help control deflections and vibrations. Throughout the building, more than 50 major transitions were required for the vertical elements. With no columns going to the ground in their original location and some elements shifting in plan several times throughout the height of the building, offset foundations and columns, as well as sloping columns, were used to shift support locations through varying floor layouts.

With skyscraper cities continuing to grow, there will be an ongoing demand for architecturally varied skylines and structurally efficient buildings. Cutting-edge engineering techniques such as post-tensioning can help design teams meet these demands.

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