Banding Together to Reach Out

Teamwork and post-tensioning result in 40 ft cantilevers in the Novartis Radiation Oncology Building

by Douglas P. González, Michael W. Hopper, and Carol Hayek

Designed by Maki and Associates and architect of record Gensler, the 185,000 ft^2 (17,190 m^2) Novartis Oncology Research Building reflects the fast-paced nature of innovation in healthcare research, a field in which it's common for teams to form and disperse within a matter of months. The building is an integral component of the campus master plan, which consists of five office and research facilities connected by a central park and oriented to promote freedom of movement. Its design incorporates the open environment concept into a five-story structure by reinterpreting the campus layout as a vertical campus of office neighborhoods, anchored by two-story "community parks" that link research teams on different floors.

To create a perimeter band of free-flowing workspaces with maximal views of the surrounding landscape, the designers significantly set back the columns from the façade, resulting in long-span cantilevers and large, column-free expanses (Fig. 1). The use of a bonded post-tensioning (PT) system was crucial to realizing the simple yet structurally complex design and achieving the desired open spaces. However, the quantity and density of PT (Fig. 2) necessary to meet performance requirements posed challenges in design and construction, met only through open, creative, and precise collaborative efforts between the owner, builders, manufacturers, installers, and designers.

Fig. 1: View of the Novartis Oncology Research Building during construction

Fig. 2: Workers place PT tendons in a floor slab

Novartis Campus Masterplan

Novartis' corporate ambition is to gather the most talented pharmaceutical professionals in the world and place them in highly collaborative environments for cutting-edge medical research. To fulfill this aim, the company decided to transition the facilities at its North American headquarters, located at the 190 acre (77 ha) East Hanover, NJ campus, from manufacturing and production to research. Accordingly, Novartis developed a guiding long-term master plan that organizes many evolving teams into a singular campus of "villages" connected spatially and socially via a central park, as shown in Fig. 3(a). Their vision was to create a truly interactive campus environment that bridges the gap between individual and collective workplaces.

Oncology Building Architectural Concept

The design architect, Fumihiko Maki, applied the scheme of the campus master plan to the building concept, where the villages became neighborhoods and the central park became community parks, thus providing a framework for individual team and collective workplaces to be organized within the building. The result is a 185,000 ft^2 program developed within a 99 x 335 ft (30 x 102 m) footprint and five floors, including 440 workstations and associated amenities, as shown in Fig. 3(b).

Based on research of Novartis' operations and desired team approaches, Maki proposed that the ideal balance and interaction between individual team workstation areas on each floor would be created with two office neighborhoods, each with about 50 people, connected via two-story community parks. Central to Maki's concept was the ability for research teams to easily reorganize as needed, unencumbered by vertical building structure. To accomplish the open space plan and accentuate the exposure to the nearby forests outside the campus, the building columns would have to be significantly set back from the façade—a serious structural challenge.

Structural System Development

The challenge was met by the structural engineers at Leslie E. Robertson Associates (LERA), New York, NY, who studied and proposed variations of a concrete flat slab system that tapered in depth from 20 in. (508 mm) at strong column support zones to 8 in. (203 mm) at the perimeter (Fig. 4). To control deflections and provide efficient tensile reinforcement for the cantilevered office slabs, they also proposed a bonded PT system. The outcome is a repetitively formed concrete structure that cantilevers approximately 30 ft (9.1 m) to the side perimeters at each floor level (with a 40 ft [12.2 m] reach at the building corners, as shown in Fig. 5). The 20 in. thick backspans of the cantilevers provide the structural thickness for the long span areas (up to 72 ft [21.9 m]) of the community parks.

The use of two-way post-tensioned slabs helped to avoid the complexities and expenses of fabricating structural steel framing moment connections in two directions. By providing intrinsic fire proofing and finishes, the system also allowed the structural floor depth to be minimized and the ceiling heights and open façade to be maximized. As a bonus, the interior placement of the 36 in. (915 mm) diameter concrete columns minimized the number of columns and defined the interior circulation paths.

An open, collaborative dialogue with Maki informed the development of the curtain wall. To preserve openness, Maki wanted to limit the number of façade mullions, and this led to the use of 14 ft wide by 7 ft tall (4.25 by 2.1 m) glazing panels. Particular attention was given to the interaction between the curtain wall and cantilevers. Hanging the mullions from the upper roof slab with only lateral support provided by the office floors ensured that there would be no impact on the curtain wall system from the movement of the typical cantilever floor. To support the additional curtain wall loading, the roof

Fig. 3: Novartis facilities plans: (a) campus masterplan; and (b) Oncology Research Building stacking diagrams and floor plan

slab was increased by 6 in. (152 mm) over the typical floor thicknesses.

Realizing the Design

Performance requirements for the cantilevered slabs posed unique challenges in design and construction, particularly because the quantity of PT tendons was over three times the quantity of a typical flat-plate post-tensioned slab. The level of difficulty was compounded by the fact that structural steel is the most common system in the New Jersey market. The successful realization of the final building called for a carefully considered, precise, and creative collaboration between the owner, design team, and builders.

First, a dialogue was started with the owner and builders, including PT manufacturers and installers, to explain the job in detail and solicit their input on aspects of implementation, such as tendon and anchorage availability, that were incorporated into the design. Introductions were made between the major concrete trade contractors in the area with PT contractors so that they could work together with confidence. High-strength concrete (8000 psi [55 MPa]), newly available in this market, was specified for the slabs and columns for further efficiency. The specified bonded tendon system, with grouted ducts to enhance performance and achieve redundancy, was endorsed by the PT contractors as being cost-effective for this structure. The architectural team coordinated the various building systems with the post-tensioned structure to ensure that field cutting, core drilling, and post-installed anchors would not be regularly required.

Deflection of the cantilevered slab edges was a major design and construction consideration, and understanding creep movement during and after the installation of the curtain wall was critical. The load balancing effect from PT minimizes the cantilever deflections due to the slab's self-weight, and it helps counteract long-term deflection due to creep. LERA performed extensive analyses, using multiple models, to best predict the

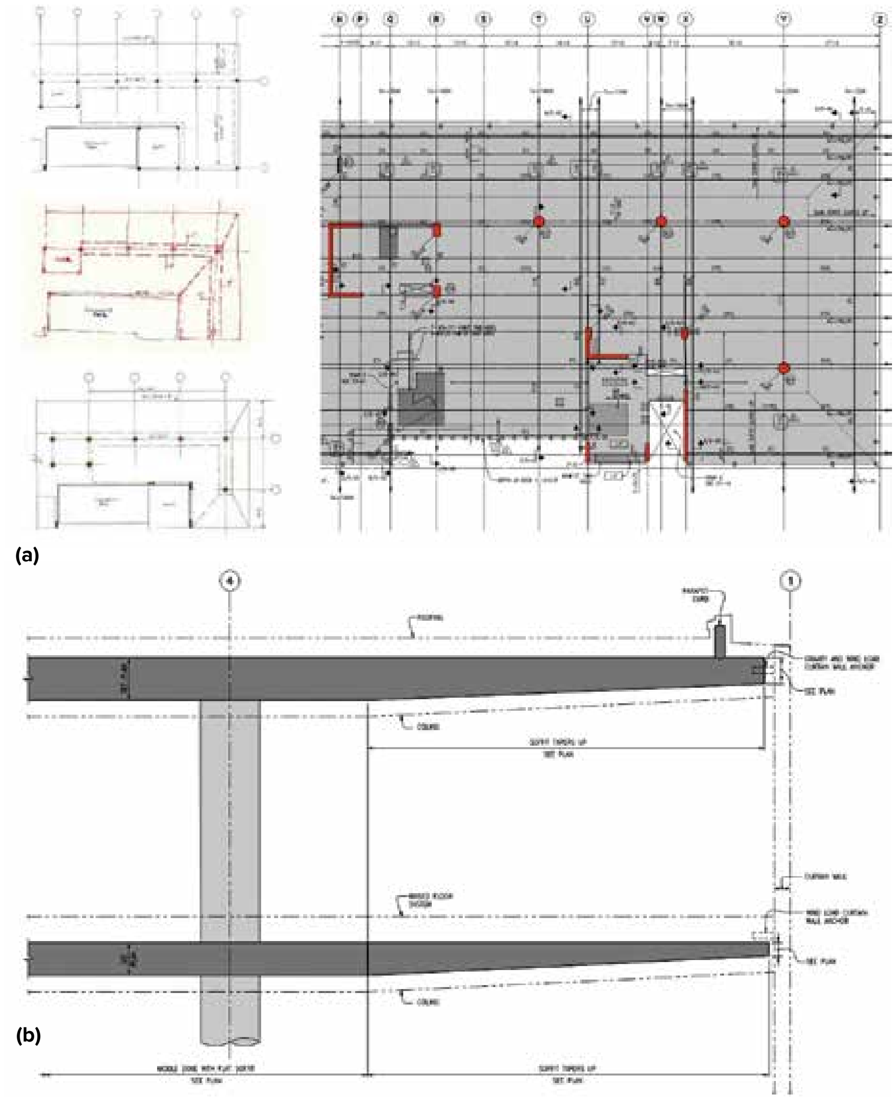


Fig. 4: Structural concept development: (a) flat slab system; and (b) typical floor and roof cross sections

Fig. 5: View of 40 ft (12 m) cantilever at corners

long-term deflections of the cantilevered slabs and assist the team in coordinating façade installation (Fig. 6).

These models included the time-step method by Nilson,[1] and an approach for PT structures as presented by ADAPT Corporation.[2] Additionally, long-term deflections were calculated using the method provided in the ACI 318 Code.[3] The method, intended for estimating deformation of cracked, reinforced concrete, was used as a benchmark for maximum predicted deflections. Because the PT slabs were designed to be uncracked, it was an appropriate upper-bound estimation. In the end, these various models provided a range of calculated values, and were combined with engineering judgment to report expected building movements to the curtain wall design consultant.

The maximum calculated long-term deflections are 1.5 in. (38 mm) at the roof slab and 1.75 in. (45 mm) at the typical floor slabs. These values characterize the movements of the cantilevers occurring after the façade is installed, and they include the instantaneous deflections from the weight of the finishes and the live loads, as well as the creep effects from the self-weight, PT, and finish and façade weight. The slabs performed as expected, with the site-measured deflections correlating well with the time-dependent calculated values.

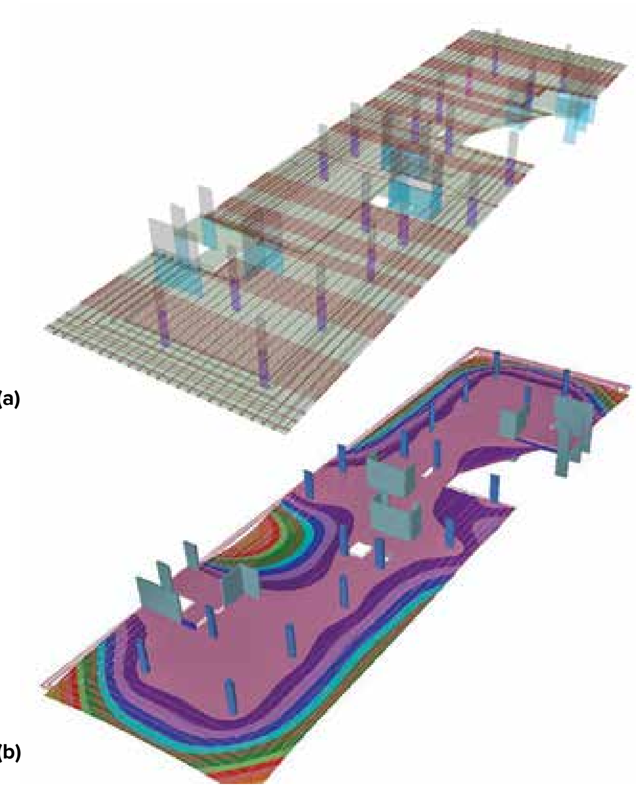


Fig. 6: Deflection analyses were conducted using finite element models: (a) model of a typical floor; and (b) example graphical output showing maximum deflections at corners and long-span region. Calculated maximum long-term deflections, including creep associated with self-weight, PT effects, finishes, and façade, were 1.5 and 1.75 in. (38 and 45 mm) at the roof and typical floor, respectively

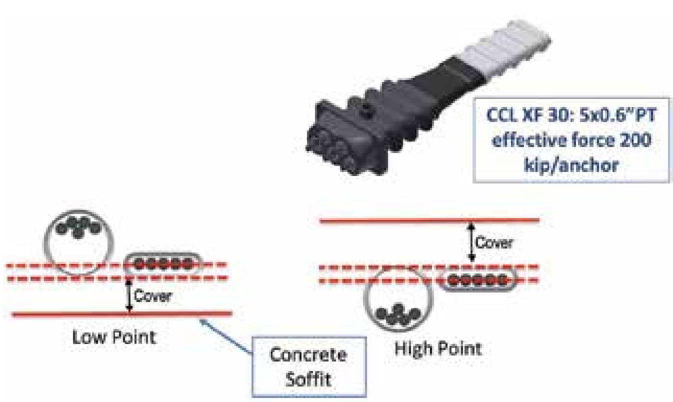


Fig. 7: The selected PT system comprises flat ducts. In contrast to circular ducts, flat ducts result in more efficient tendon eccentricities at both the high and low points in the tendon profile

Choice of Bonded Flat Tendon System

The initial design called for a bonded system, similar to the one used for bridges, using circular ducts that require heavy multi-strand stressing equipment. To speed up and facilitate the construction process, the PT system supplier, CCL, proposed an alternative PT system using its XF bonded flat slab system. This PT system can accommodate five, 0.6 in. (15 mm) diameter strands—equating to an effective PT force (after all losses) between 150 and 200 kip (670 and 890 kN) per anchor—and allows the strands to be individually stressed. The switch to the flat system simplified the stressing operation significantly so it would be similar to normal monostrand applications. In addition, the use of this system yielded efficient tendon eccentricities close to those attained with an unbonded monostrand system at both low and high points (Fig. 7).

High PT Forces

In each direction, the required PT forces after all losses were 75 kip/ft (1100 kN/m) with 315 psi (2.17 MPa) in precompression at the typical floors and 150 kip/ft (2200 kN/m) with 480 psi (3.30 MPa) precompression at the roof. Such forces are not typically encountered in PT slab construction, where forces are normally in the range of 10 to 20 kip/ft (145 to 290 kN/m) with precompression values between 125 and 300 psi (0.860 and 2.07 MPa).[4,5] Coupled with the long aspect ratio of the building, these high forces necessitated thorough restraint and PT loss calculations. Studies were conducted in design, and again during construction, to evaluate the effects of precompression on slab shortening and building movement.

To study the restraint impacts from elastic and long-term shortening of the slabs, the average effective PT forces were applied to three-dimensional (3-D) finite element models of the slabs (Fig. 8(a)). The PT forces were scaled up to account for creep and shrinkage effects to study the impacts from restraint over time. The analyses showed that the restraint of shortening imposed at the supports had only a minor impact on the PT force distribution. The yellow shaded areas in Fig. 8(b) highlight tensile forces that are predominantly the result of the terminating PT tendons at slab steps. Additional reinforcing bars were provided at these locations to resist the tensile forces.

The design team was also concerned about the effect of slab shortening on the walls (shown in Fig. 8(c)). The shortening analysis results showed that the high precompression forces could potentially crack the shear walls at the time of stressing (at that time, there would be little gravity load because the slabs were shored, and the PT force would be at its maximum). However, it was decided that special shortening relief details were not necessary because the project team could live with the minor cracking in the core walls.

Ultimately, the concrete contractor proposed using three placements per floor and using a stressing sequence that was coordinated to centrally locate the core walls within each placement. This sequencing minimized the initial restraint and resulted in less shortening restraint effects than indicated by LERA's initial full-building analysis.

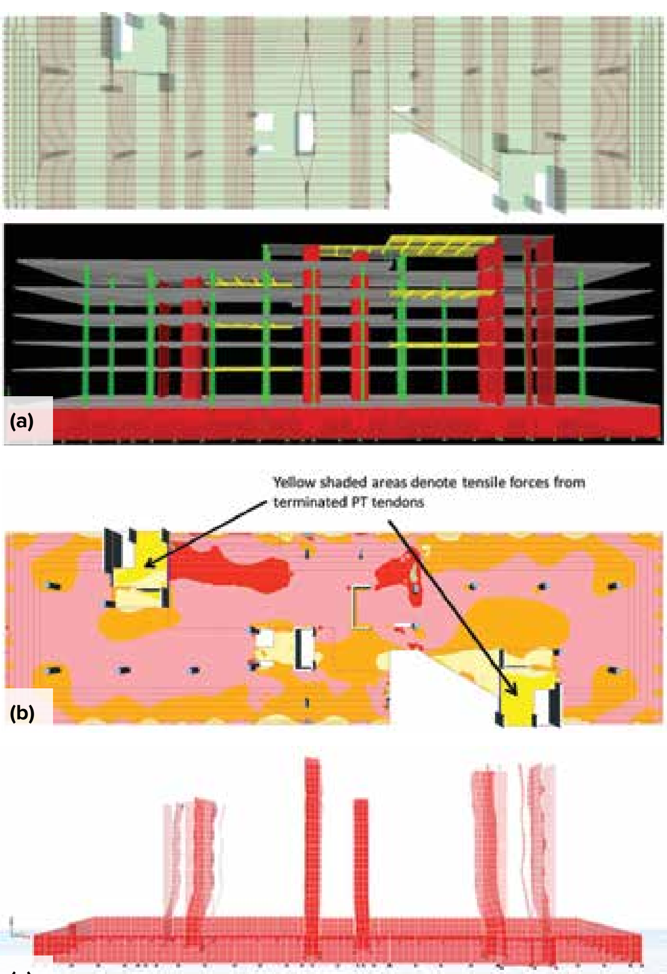


Fig. 8: Three-dimensional finite element analyses were also used to study the effects of the high precompression forces in the slabs: (a) model schematic; (b) example graphical output showing effects of shear walls on slab stresses; and (c) output showing magnified deformation of the shear walls

To ensure that the specified final effective PT forces were met, losses were calculated at various sections along the tendons and under different load combinations. Long-term losses depend on the applied stresses at the tendon level because the strands are grouted[6] and have the same deformation compatibility as the surrounding concrete. While in some instances average PT losses can be taken, the design team felt a more accurate PT loss calculation was warranted. This included evaluating horizontal sweeps and different tendon profiles and lengths, as well as evaluating long-term losses. The final effective forces ranged from 35 to 39 kip (155 to 174 kN), representing a 10% maximum variance. This is quite a high value, showing that averaging would have been unsuitable for this project.

PT Detailing Challenges

The contractor, the design team, and CCL worked together on construction details at critical locations. Critical details included placement of PT tendon at congested areas such as through column cages, as well as placement of PT anchorage at the slab edges, where they had to be coordinated with curtain wall embeds. Typical column reinforcement cages were detailed to allow two bonded PT tendons to pass through the cage in each direction. Mechanical couplers were required for the columns' vertical bars to limit the reinforcement ratio at splices. Some columns were designed with certain vertical bars omitted to permit the placement of PT anchors at congested locations.

At the cantilever areas, the tapering slab required coordination between the tendon profile and the sloping soffit. CCL built a 3-D model to extract the PT chair heights at different sections along the cantilever length, allowing the construction team to measure the profile heights from the bottom of the slab, as is typical for slabs with horizontal soffits.

As the roof slab required 150 kip/ft precompression, it was not feasible to have a typical banded-uniform tendon layout. In the banded direction, the PT tendons with each duct housing 5 x 0.6 in. strands were spaced as close as possible at 9 in. (229 mm) on center. This meant that 25 ducts (with a total of 125 strands) were spread across a width of 19 ft (5.8 m), occupying about 55% of the bay width. Consequently, weaving of the PT tendons between the banded and the uniform direction was unavoidable. A detailed tendon installation sequence was provided to assist with the installation. Because the tendons were so closely spaced, fitting the PT anchors in the banded direction in one layer was also not achievable. A detailing configuration for the anchors in the form of a zigzag layered pattern (Fig. 9) made the anchor placement possible while still providing a sizeable concrete block behind the anchors to resist bursting during stressing. The PT tendons were then flared out from the slab edges to form one layer within the slab.

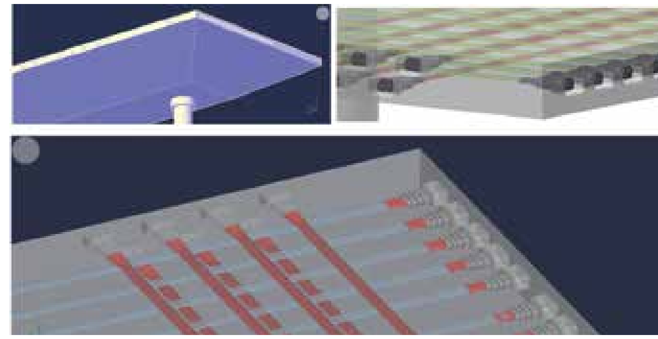


Fig. 9: Tight spacing of the banded PT tendons made it necessary to weave the PT tendons and configure the anchors in a zigzag layered pattern

PT Prefabrication Station

The project schedule did not allow for typical construction practices seen in PT slabs. With the amount of PT involved, it made sense to have tendons prefabricated. CCL worked with

Fig. 10: Tendons were assembled and then lifted onto the slab formwork

the contractor to set up a prefabrication station and train a team of installers so that they could work in parallel while the formwork system was being placed. Strands were cut to length and placed in PT ducts using customized PT equipment. The assembled tendons were then lifted onto the slab (Fig. 10). The full-time presence of a Post-Tensioning Institute (PTI)-certified supervisor was effective in ensuring that the installation ran smoothly and site issues were promptly solved.

PT Grouting

Grouting was particularly challenging, as the project was constructed in the wintertime in New Jersey, with expected temperatures falling well below freezing. Per the PTI grouting specification,[7] when temperatures in the concrete surrounding the ducts are expected to fall below 35°F (2°C) within 48 hours, no grouting should be carried out with normal grout mixture and without proper heating. Cold weather procedures before, during, and after grouting were put in place so that the grouting operations could continue through the winter season and prevent project delays.

Conclusions

The Novartis Oncology Research Building embodies the themes of transparency and open collaboration, in the structure itself and in its design and construction. The use of a bonded PT system was critical to achieving up to 40 ft cantilevers and 72 ft spans. However, the quantity and density of PT required, in combination with an accelerated project schedule, posed a difficult challenge in design and construction — a challenge that was only overcome through an open, intricate collaborative effort between the owners, builders, manufacturers, installers, and designers.

References

1. Nilson, A.H., *Design of Prestressed Concrete*, second edition, John Wiley & Sons, Inc., New York, 1987, pp. 346-347.

2. Aalami, B.O., "Deflection of Concrete Floor Systems for Serviceability," ADAPT Corporation, Redwood City, CA, 2008, 28 pp.

3. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05)," American Concrete Institute, Farmington Hills, MI, 2005, Ch. 9, Par. R9.5.2.5, p. 113.

4. "PTI DC20.9-11: Guide for Design of Post-Tensioned Buildings," Post-Tensioning Institute, Farmington Hills, MI, 2011, 73 pp.

5. ACI Committee 423, "Recommendations for Concrete Members Prestressed with Unbonded Tendons (ACI 423.3R-05)," American Concrete Institute, Farmington Hills, MI, 2005, 21 pp.

6. Kelley, G.S., "Prestress Losses in Post-Tensioned Structures," *PTI Technical Notes*, No. 10, Sept. 2000, 6 pp.

7. "PTI M55.1-12: Specification for Grouting of Post-Tensioned Structures," Post-Tensioning Institute, Farmington Hills, MI, 2012, 60 pp.

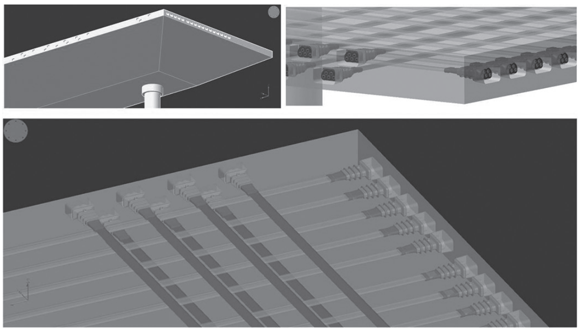
Selected for reader interest by the editors.

Douglas P. González is an Associate Partner at Leslie E. Robertson Associates (LERA), New York, NY. He is Past President of the Structural Engineers Association of New York (SEAoNY) and has served on the SEAoNY Board since 2011. He is a member of the Post-Tensioning Institute (PTI). He previously led the ASCE Metropolitan Section Structures Group, and he has assisted the NYC Building Department with their update of the building code. He received his MS from Cornell University, Ithaca, NY, and his BE from The Cooper Union, New York, NY.

Michael W. Hopper is an Associate at LERA. He is a member of PTI and the Structural Engineers Association. He received his MS and BS in architectural engineering from Pennsylvania State University, University Park, PA.

ACI member **Carol Hayek** is Chief Technical Officer at CCL International, Jessup, MD, and a lecturer on prestressed concrete design at Johns Hopkins University, Baltimore, MD. She is Chair of Joint ACI-ASCE Subcommittee 423-F, Sustainable Prestressed Concrete, and a member of Joint ACI-ASCE Committee 423, Prestressed Concrete. She is a Fellow of PTI, a member of the PTI Technical Advisory Board, and Chair of the PTI Building Design Committee. She is also a member of *fib* Commission 5 Reinforcements. She received her MSE and PhD in civil engineering from Johns Hopkins University and her MBA from ESA Business School, Beirut, Lebanon, in partnership with ESCP Business School, Paris, France.

wGVxǽOhhŠ
$ tÔOtǽ
hpǽdhpÔ
pptoŽ{
y15 pÔ
ǽpÔ
ǽMsTlhPC ǽ
PC PǽU
gtTsloMh{ CCL pǽÔ
pC Pǽ
ǽÀVOth{
PC pǽU.
hpǽhpǽh PC Pâ
ǽÔpǽhǽ
pTI ǽU
Mhhǽr>
h{
y-âÄ
ǽtY
9GXsloMhhǽ
Xtpǽh{ PTI ǽt
ǽSU 48 Ž
2 ǽ
Ä&CǽMǽ
loxsMǽM9ǽ
ǽǽbpY
BtǽU
h{



$ y0pǽ$Pǽ

$ yǽ1$Pǽ

yŠ

ǽpQ
ǽǽ
-SMo.oM 12.2 m ǽ
Ò 21.9 m ǽhŠk
ǽ PT ǽÔǽApǽh{
T` PCǽ
SMoǽlhǽ
Pǽ
ǽsǽ{

y/

Douglas P. Gonzalez, Michael W. Hopper and Carol Hayek, lBanding Together to Reach Outz, Concrete International, vol.39, No.10, pp.23-29, Oct. 2010

€ß Y

345 Ä ǽ ǽ 2015 å 1 Dþ pp.76-83ǽ

²åD Q