POST-TENSIONED CONCRETE WITH UNBONDED TENDONS BECOMES THE PREDOMINANT STRUCTURAL MATERIAL IN U.S. SKYSCRAPERS

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Authorized reprint from: December 2018 issue of the PTI Journal

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A BRIEF HISTORY OF PT

Post-tensioning (PT) has been used in the United States as a form of concrete reinforcement since the late 1950s. Single-strand tendons with ductile anchors were used for most PT applications by the mid-1970s.[1] The modern version of extruded sheathing matured in the 1980s and the encapsulated anchor system was the norm for corrosive environments in the 1990s. In 2011, ACI code and PTI specification required an encapsulated unbonded PT system for elevated slabs, such as high-rise floors. Whereas an encapsulated system cost more than a non-encapsulated system, it did not deter the conversion of many conventionally reinforced concrete slabs to PT slabs during the 2000s.

TALL BUILDINGS IN GENERAL

The need for tall buildings is predicated by economic ability to house a rising urban population in conjunction with a limited supply of expensive land. In 1990, 33% of the world's population lived in an urban environment. According to a United Nations study in 2010, that figure will increase to 80% in 2050.[2] More buildings of 200 m (660 ft) height or greater were completed in 2017 worldwide than in any other year, with a total of 144 completions, marking the fourth consecutive record-breaking year.[3] There is not a universal definition of "tall building" because it is relative to the surrounding buildings and urban background. For the sake of simplicity, this article will define a "tall building" or "skyscraper" as a building taller than 100 m (328 ft).

PTI JOURNAL, V. 14, No. 2, December 2018. Received and reviewed under Institute journal publication policies. Pertinent discussion will be published in the next issue of *PTI JOURNAL* if received within 3 months of the publication.

The United States will have (387) 100-meter-plus buildings completed between 2010 and 2020. As expected, a clear majority of tall buildings are in New York City, Chicago, Miami, Houston, and several other major metro cities (Fig. 1).

BENEFITS OF PT IN TALL BUILDINGS

Unbonded post-tensioned concrete contributes to several major benefits to the construction of a tall building. Two key benefits of post-tensioned concrete are the ability to have thinner slabs without increased deflection, and a reduced floor-to-floor height compared to structural steel or concrete solely reinforced with reinforcing bar. According to a Post-Tensioning Institute study, 10 floors of structural steel have an overall height of 38 m (125 ft) versus only 33 m (108 ft) for 10 floors with PT. The reduction in building height, while retaining the same area of horizontal real estate, could translate into potential material savings for other vertical elements such as concrete columns/shear-walls, building façades, vertical MEP piping, stairwells/elevators, and interior walls. Operationally, there would be a reduction in the energy required to vertically transport liquids/gases or people. Less is more.

The reduction in above-grade building materials transfers down to the below-grade building materials. A lighter building could facilitate a reduction in foundations and retaining walls. Accordingly, the diminished excavation would lower the building's impact on erosion of the surrounding land. Additionally, this could improve the seismic behavior of the building.

Fortunately, unbonded post-tensioned buildings can be constructed with a quick schedule. It is not uncommon to have a 3-to-5-day pour cycle for a high-rise PT building, even in a city with a high urban density. In Chicago, contractors routinely use a 60 MPa (8750 psi) concrete mixture to

stress tendons the day after the placement. A quick construction schedule reduces the strain on the surrounding ecosystem and infrastructure, as well as reduces construction labor and equipment costs.

THE CHICAGO EXAMPLE

Chicago is the birthplace of the modern-age skyscraper and has been at the forefront of skyscraper design. Prior to 1960, 90% of its 100 m+ buildings were built solely with structural steel, while only 6% were with all forms of concrete. After 1960, almost 80% of its 100 m+ buildings were built solely with concrete.[4] Furthermore, a growing percentage of those concrete skyscrapers are constructed using unbonded post-tensioning as elevated concrete slab reinforcement.

Between 1980 and 2006, less than 5% of Chicago's 100 m+ buildings had post-tensioned slabs, whereas roughly 50% of its 100 m+ buildings, either completed or under construction between 2007 and 2017, had PT slabs. Post-tensioned floors are in 75% of Chicago's tallest 100 buildings completed between 2010 and 2020. This trend can be illustrated one company's[5] timeline of 100 m+ buildings that will be completed between 1981 and 2010 (Fig. 2).

Between 1981 and 2006 (26 years), our company had completed only five 100 m+ buildings. Candidly, most of these buildings only had post-tensioned concrete in the lower garage levels, with other structural material in the upper levels. Between 2007 and 2020 (14 years), that number had ballooned to thirty-nine 100 m+ buildings. Conversely, most of these buildings had post-tensioned concrete at all elevated levels.

Chicago's increased use of unbonded post-tensioned concrete in skyscrapers has propagated to other major U.S. metros such as Honolulu, Houston, Miami, and Seattle. Until recently, the use of unbonded PT has been almost non-existent in New York City—the largest construction

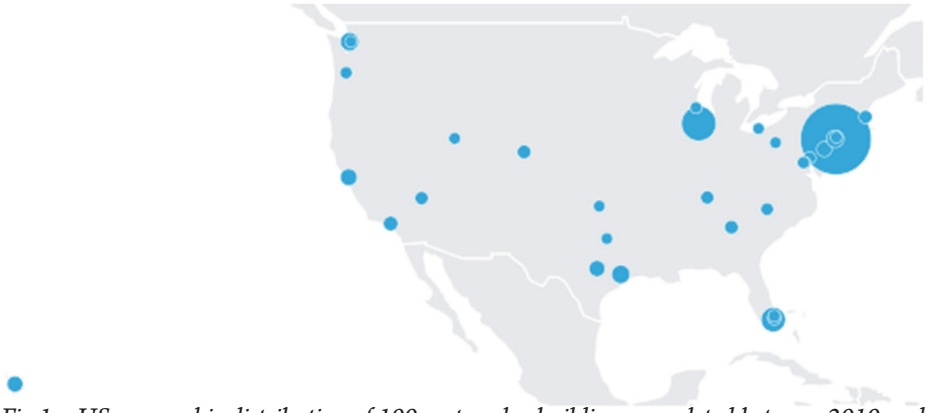

Fig 1—US geographic distribution of 100-meter-plus buildings completed between 2010 and 2020.[1]

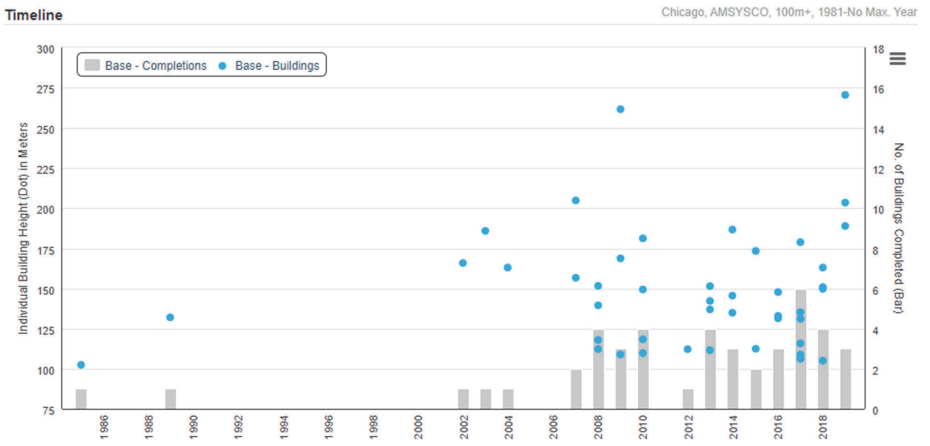

Fig. 2—AMSYSCO's timeline of 100-meter-plus buildings completed between 1981 and 2020.[4]

Fig. 3—55 Hudson Yards.[6]

market in the United States. However, 55 Hudson Yards, a 51-story office tower, was recently topped out at a height of 237 m (778 ft) (Fig. 3). According to the project's structural engineer, the PT solution was more attractive financially than the original steel frame solution.[4] A successful PT project should help propagate the use of PT within a new metro market.

IDEAS FOR THE FUTURE

Targeted data-driven marketing is required to sustain the significant market share currently enjoyed by unbonded PT. A public database of tall PT buildings (TPTB) could act as the PT industry's resume for designers and developers who are unfamiliar with PT. The TPTB database would favor comparably to the limited examples of tall-timber database[7] and even structural steel. Additionally, this could help the PT industry penetrate the commercial high-rise office market. At present, most TPTBs are residential and/or hotels.

Unbonded post-tensioned concrete has a place globally as a form of structural material in skyscrapers. While other forms of post-tensioning have made in-roads in Australia, the Middle East, and the United Kingdom high-rise market, unbonded PT is rarely used outside the United States. Unbonded PT is governed by the IBC and ACI 301, ACI 318, and ACI 423. The short-term hurdle of educating designers, owners, and politicians abroad and investing in a local manufacturing supply chain can be offset by the long-term economics of lower construction and building operational costs.

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