Expanding the Use of Post-Tensioning in Buildings

By John Crigler, P.E.

Part 1 of this series of articles on Post-Tensioning ran in the July 2007 issue of STRUCTURE® magazine. Visit **www.STRUCTUREmag.org** for archived articles.

The Pacific Place Building in Hong Kong.

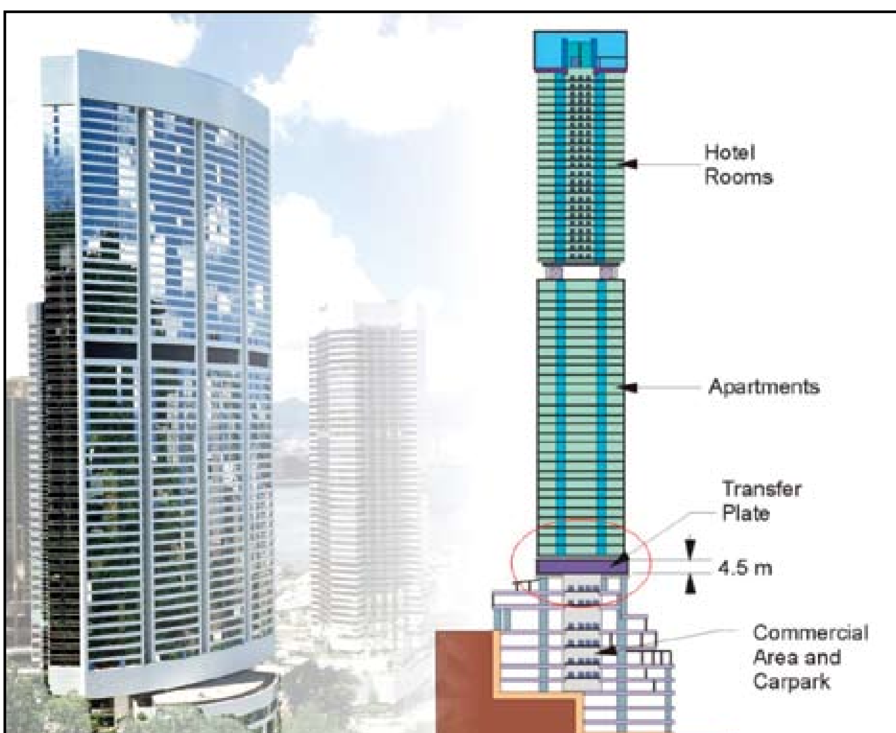
Buildings are created to achieve well defined goals. While there are many different systems used to realize these goals, the structural system plays a key role. For more than 40 years, post-tensioned concrete has been used in buildings. It is widely accepted by structural engineers for offices, parking garages, condominiums and apartments. Post-tensioning is particularly well suited to reinforce slabs. When compared to conventionally reinforced slabs of equal strength, post-tensioned slabs crack at a higher demand level which reduces deflection under service loads, permitting thinner slabs and/or longer spans. The result is a reduction in floor system weight which in turn reduces demand on the other structural members (columns and shear walls) and the foundations, while longer spans enhance the value of the building. For these reasons, the use of post-tensioning for building slabs will certainly continue to be the dominant application for post-tensioning in buildings.

Transfer Plates

The suspended floors in multistory buildings are generally supported by columns and load bearing walls. The layout and size of these elements help define the space available within the building. Floor framing systems are selected with consideration for both space needs and economics. In multistory buildings, the requirements may change from floor to floor. Therefore, the selection of a single framing system for an entire structure is not always ideal. As the population grows, the cost and availability of building sites will become more challenging and the need for multifunction multistory buildings will increase. This trend is seen in many areas of the U.S., where multifamily residential buildings are built with underground parking. These structures are built with hybrid framing systems consisting of post-tensioned slabs for the underground parking area, with a load bearing wood frame for the living area above.

In Hong Kong, where the population density is high and good building sites are scarce, multifunction high rise buildings are more common. For these buildings, post-tensioned transfer plates have been extensively used to adjust the floor framing system as the requirements change within the height of the building.

An early example of a large transfer plate is the Pacific Place building in Hong Kong. This 222-meter (728-foot) tall building consists of a large retail/commercial/parking area that extends up to the 57-meter (187-foot) level, with residential and hotel space above. The upper part of the building utilizes closely spaced supports which were suitable for the use, whereas the base of the building requires long spans. A 4.5-meter (14.7-foot) thick post-tensioned transfer plate is used at the 57-meter (187-foot) level to transfer the vertical



A rendering of the Pacific Place Building showing the transfer plate in relation to the various building sections.

loads between the building zones. While this is an early example, there have been more than 80 post-tensioned transfer plates constructed in Hong Kong over the last 20 years.

While the residential transfer plates that are more common here in the U.S. and the structures built in Hong Kong represent the range of possibilities, they both demonstrate the advantages:

- Accommodate irregular loading/support paths, which can be challenging with beam/girder framing systems
- Significant reduction in reinforcement
- Reduced construction time
- In many cases, reduction of depth which reduces the building height and weight
- Greater stiffness, which results in better cracking and deflection control.

Foundations

The use of post-tensioning in single family residential slabs on ground is currently the largest market segment for the industry. For this application, the post-tensioning tendons are usually installed concentrically in the slab without the benefit of the deviation forces which result from draped tendons that are normally used in elevated structures. While this approach is adequate for lighter loads, a different approach is needed for more heavily loaded foundations.

Two-way mat foundations are used to support multistory buildings. The principle of mat foundations is very similar to that of a floor slab turned upside-down. The distributed soil pressure applies uplift pressure to the bottom surface, which is held in equilibrium by the vertical concentrated loads from columns and walls. Similarly, strip foundations behave like upside-down beams.

Post-tensioning of mat and beam foundations has similar advantages to those in floors and beams:

- More uniform soil pressure distribution
- Increased shear resistance
- Reduction in thickness and reinforcement quantity
- Compressed construction schedule
- Improved cracking and deflection behavior
- Reduced excavation quantity and depth
- Improved water tightness

Basically, the designer has the choice between unbonded monostrand and bonded multistrand tendons. For thin slabs, including residential slab on ground, industrial floor slabs and low rise buildings, unbonded monostrands are a logical choice. Bonded multistrand tendons are best for larger foundations with heavier loads. They have higher capacity and are bonded, which improves crack control and local flexural behavior.

Precast

Today many bridges take advantage of the combined benefits of precast and post-tensioning, but the use of post-tensioning in precast buildings has been largely unexploited. While the benefits of precast elements are well known, the advantages of combining precast with post-tensioning are somewhat unrealized. Post-tensioning can be used to "splice" precast members together to build structures with fewer joints and bearings, which reduces maintenance and provides the structural benefits of continuous members and frames.

Construction of fully hybrid precast/cast-in-place buildings is perhaps the best way to optimize both. An example of this approach is the new Venetian Macao Resort. For this structure, continuous main beams with 20-meter (66-foot) and 30-meter (98-foot) spans were constructed using 4 inverted precast

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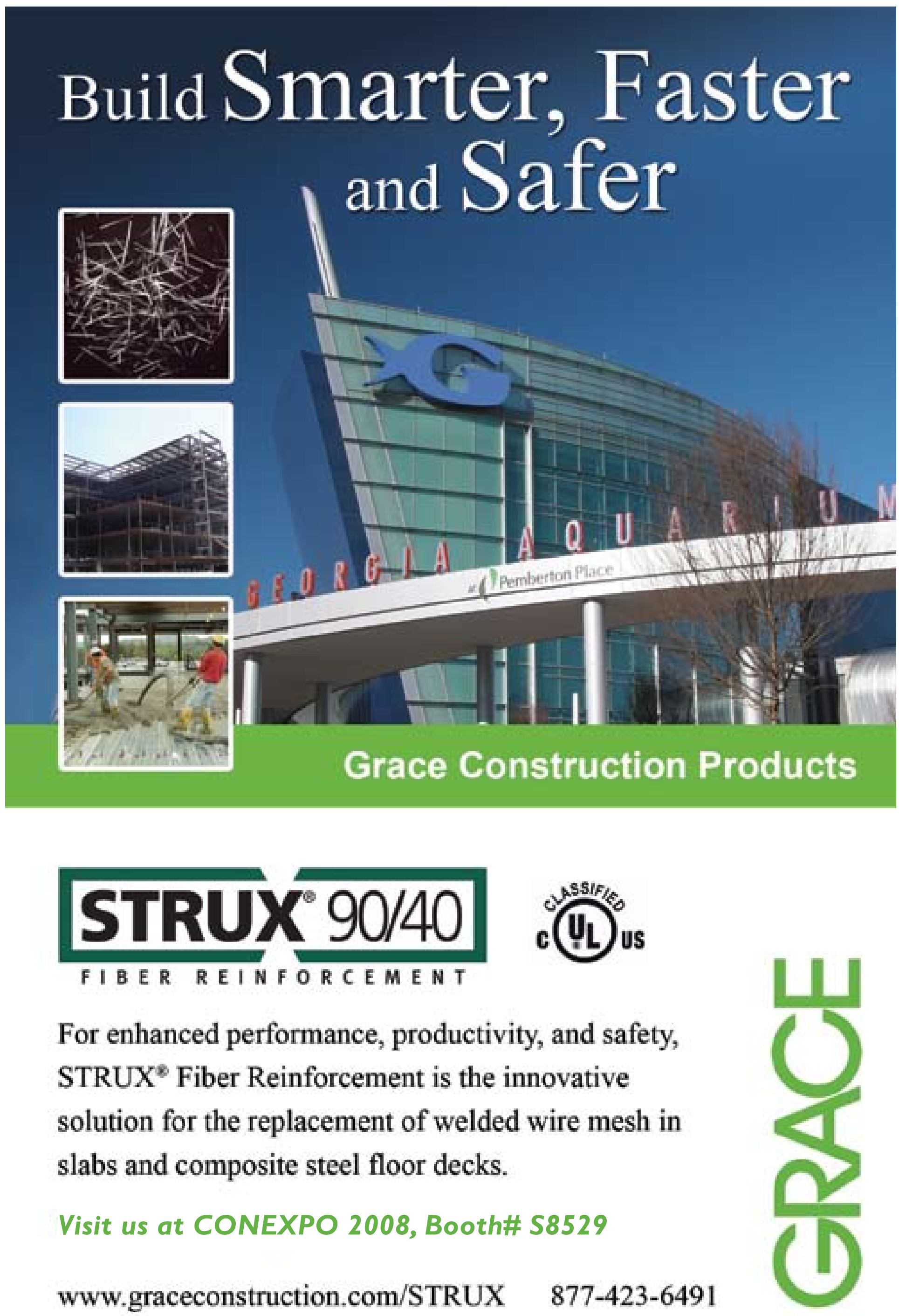

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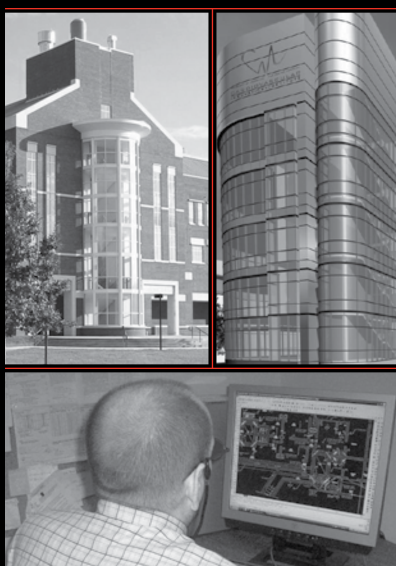

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The precast secondary beams are installed on top of the corbels of precast main beams after stressing the continuity tendons. The beams are T- or I-shaped to minimize the weight to 28 tonnes (30 tons) for erection. Half joints at either end of the beams are detailed by using strut-and-tie models to ensure the load transfer at the critical zones. In between the typically 4m (13ft) spaced secondary beams, 75mm (3 in) thick precast planks with cast in lattice girders are installed. Top slab reinforcement is fixed directly on top of the lattice girder to receive the in-situ cast topping.

Level 3 and Level 6 have typical bay layouts of 20m x 20m (66ft x 66ft) and 20m x 30m (66ft x 98ft). The structure consists of continuous post-tensioned framing beams, made up of semi-precast pre-tensioned beams supported on column heads. Simply supported precast and pre-tensioned T or I shaped secondary beams are supported on the continuous corbels on either side of the main beams. Precast planks are placed in between the secondary beams to receive a cast-in-situ topping. The precast beams and planks are installed by custom made high capacity traveling cranes, which allow placing 25 tonne (27.5 ton) beams at a 50m (164ft) radius.

beams (*see Figure 1 below*) combined with post-tensioning and cast-in-place concrete. These beams support the highly loaded floors, and serve as elements in the seismic/wind resisting frames. For this project, the system was selected to improve construction speed and reduce the impact of formwork and shoring on other trades.

Conclusion

The use of post-tensioning in buildings will continue to expand, with traditional applications dominating. Post-tensioned structures inherently use less material when compared with conventionally reinforced concrete. As we gain a better understanding of the impact of cement production on the environment, this factor will become increasingly important.

The next article in this series will address what to consider when incorporating post-tensioning into a structure's design. These include reviewing the applicable Post-Tensioning Institute (PTI) and American Society for Testing and Materials (ASTM) standards and their adequacy for the intended application, and selecting the appropriate materials.▪

An aerial view of the transfer plate under construction.

The details of the 4-in-1 semi-precast main beams play a vital role to the success of VSL's alternative design. The sequence of work is as follows:

- *Installation of 4 nos. of semi-precast main beams by heavy duty tower crane on column heads.*
- *Stitching of flanges of precast beams to ensure the structural integrity.*
- *Fixing of steel reinforcement cages and P-T ducts in between precast beams.*
- *In-situ concrete in-fill of main beam.*
- *Span by span stressing of continuity tendons across columns.*
- *Installation of precast secondary beams supported by corbels on main beams.*
- *Erection of precast planking supported by secondary beams.*
- *Fix top reinforcement and cast topping.*

Typical weights of precast beams are 20 to 28 tonnes (22 to 28 tons).

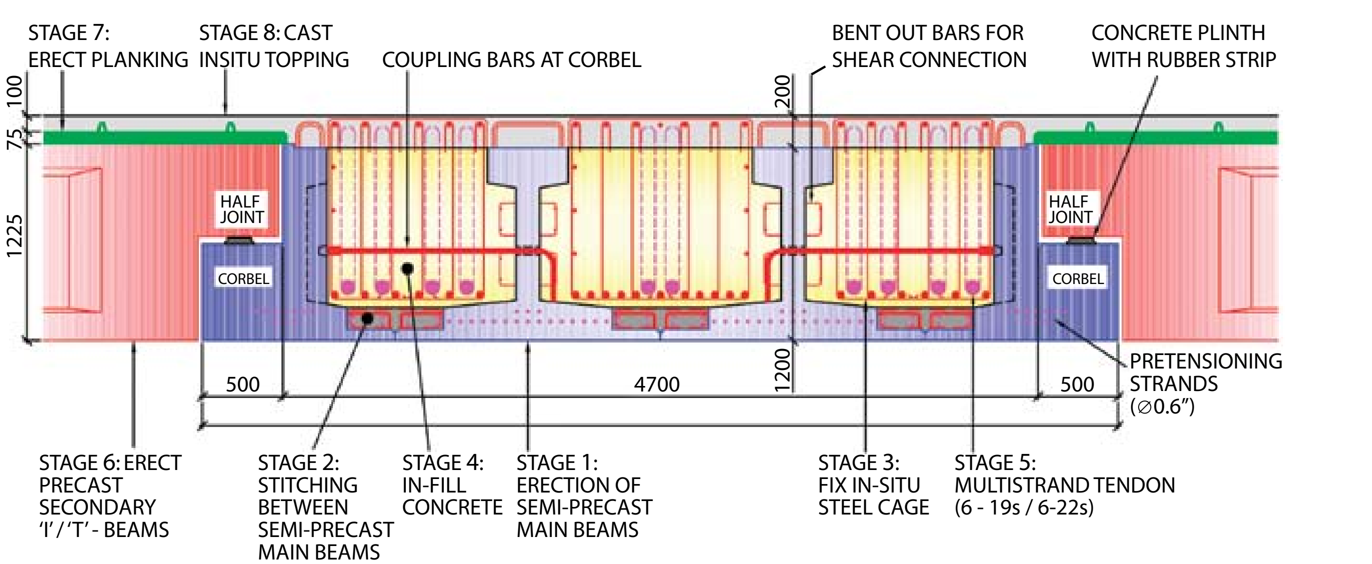

Figure 1: 4-in-1 semi-precast main beams in the sequence of works.

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