POST-TENSIONED, CAST-IN-PLACE PARKING STRUCTURES
Economic Construction

Cast-in-place, post-tensioned construction is one of the most economical construction systems available for parking garages. Over the life of the structure, the cost to maintain cast-in-place, post-tensioned parking garages is typically less than that of alternative systems.
In today’s marketplace, design and construction solutions must go beyond durability and economy to also offer low maintenance and a lighter footprint on the environment. Post-tensioned structures are a growing solution to meet this need. Properly designed and detailed, cast-in-place post-tension concrete parking structures are virtually crack-free, maintenance free and offer great aesthetic freedom and flexibility for today’s architectural designs.

**Aesthetics**

The architectural appeal of cast-in-place concrete is widely recognized. Curvilinear shapes and forms are easily achieved in a cost-effective manner with cast-in-place structures. Architectural treatments of exposed concrete are easily achieved with cast-in-place, post-tensioned concrete parking garages.

**Low Maintenance**

Loss of parking spaces during maintenance work results in loss of revenue and inconvenience to users. However, properly designed, detailed and constructed post-tensioned floors are relatively crack-free, resulting in minimal maintenance issues. Reduced cracking, combined with the use of epoxy coated reinforcing steel, encapsulated post-tensioning, low water/cement ratio, air entrained concrete, and concrete sealers make it possible to achieve floor systems with minimal maintenance in even the most aggressive environments.
Smooth Riding Surfaces

The elimination of closely spaced joints results in a superior riding surface. Differential deflections across joints are not an issue in cast-in-place post-tensioned floors. This creates a smoother and stiffer ride, with less bounce and vibration.

AIRPORT PARKING:
BWI Consolidated Rental Car Facility

To meet growing demand at the Baltimore Washington International Airport (BWI), a new state-of-the-art cast-in-place post-tensioned concrete parking garage was constructed to consolidate the airport’s eight rental car companies into one central location. The post-tensioning system allowed the column grid spacing to be increased to 60 by 60 feet to provide each car rental group with as much clear space at the bottom level as possible. Additionally, the floor-to-floor height was increased to 19 feet in order to provide customers with the feel of an open structure. The facility holds 8,300 spaces and frees up more than 1,000 prime parking spaces in BWI’s terminal parking garage.

COMMERCIAL PARKING:
Main Street Parking Garage

The 159,000-square-foot San Mateo Main Street Parking Structure, located downtown next to a commuter railroad right-of-way, included construction of a 380-space, five-story (one below grade) parking structure, plus improvements to a pedestrian area between the garage and the Century Theatres Complex. Extensive mitigation was necessary to accommodate the surrounding community, including sensitivity to construction noise, dust and vibration. The final construction cost of the garage came in at just over $12.2 million, which included adjacent street improvements (including the Main Street pedestrian area) and landscaping, demonstrating the cost effectiveness of post-tensioned garages.
Parking garage facility managers and owners expect their structure to be durable and have a long service life. Unfortunately, deterioration and corrosion can have dramatic effects on a concrete structure. The presence of concrete and steel combined with pedestrian and vehicular traffic lead to deficiencies such as corroding steel, cracking and spalling concrete and other signs of deterioration.

One growing solution for extending the useful life of a parking structure is the use of post-tensioning (PT) – a method of reinforcing or strengthening concrete or other materials with high-strength steel strands or tendons. Millions of square feet of cast-in-place, post-tensioned parking garages are built in the United States each year. According to an independent survey completed in 2000, cast-in-place, post-tensioned systems were the most frequently selected structural system. Post-tensioned parking garages continue to gain market share in terms of both the number of structures built and volume (number of spaces). When all of the factors are evaluated, it is easy to see why cast-in-place, post-tensioned concrete parking garages are the system of choice for the nation’s hospitals, universities, developers, parking operators, commercial owners and public institutions.

There are a number of factors to be considered when selecting a building system for use as a parking garage. Careful thought should be given to such long-term costs as maintenance and probable repairs, as well as an eye toward sustainability. Cast-in-place, post-tensioned concrete construction allows owners and designers flexibility and creativity in parking garage design.

**IDEAL REINFORCEMENT**

**Crack Control and Watertightness**

Post-tensioned structural systems eliminate closely spaced joints and help ensure watertightness by placing the floor in bi-axial compression, thereby controlling and counteracting shrinkage and flexural cracks. This is a very important advantage over other systems. Water and de-icer chemicals leaking through cracks can result in deterioration and costly repairs.

**Initial and Life-Cycle Costs Savings**

Economic analysis and competitive bids show that cast-in-place post-tensioned structural systems often provide initial cost savings when compared to other framing systems. When initial costs are close to those of other systems, life-cycle costs often show savings for cast-in-place post-tensioned systems.
Fire Resistance

The slab thickness and beam widths commonly used in post-tensioned structures provide fire ratings that meet code requirements. The thin-stemmed elements commonly used in other structural systems provide less concrete cover and lower fire-resistance ratings.

MIXED USE:
The Pike at Rainbow Harbor

The Pike at Rainbow Harbor Parking Structure in Long Beach, Calif. links the vibrant nightlife of Pine Avenue and activity of the Convention Center with the Aquarium of the Pacific and Rainbow Harbor. The seven-level parking structure provides 2,211 spaces for shops and visitors. To ease parking problems and keep traffic flowing efficiently, circulation is one-way, and spaces are angled at 70 degrees. The 10 entry/exit lanes flow by means of the circular ramp at the west end of the structure, allowing it to be filled or emptied quickly. This 475-foot-long cast-in-place, post-tensioned concrete structure is designed in a “streamlined modern” style, with metal panel accents.

AIRPORT PARKING:
Phoenix Sky Harbor Rental Facility

The Consolidated Rental Car Center at Sky Harbor International Airport is a 2.5-million-square-foot structure, earning the designation as Arizona’s largest building. The structure offers 5,600 covered parking spaces and nine freestanding rental car service centers. The design was based on achieving the smallest possible footprint, while staying within the boundaries of FAA height restrictions. Designers created massive 61-by 61-foot bays supported by columns and beams. A 5-inch post-tensioned slab is used between the beams. Other critical design factors included concerns about vibration from bus traffic, as well as the expansion and contraction of such a large concrete structure. The project used 760 miles of post-tensioned tendon.
Not only is post-tensioning a highly efficient structural system that offers many benefits in terms of durability and economics, but it also has proven to be a sustainable, low-environmental impact solution. Post-tensioning, compared to conventionally reinforced structures, uses less steel and concrete, while offering more usable space in a structure. Further, a majority of raw strand is made from scrap metal. Other key benefits include:

- Use of waste materials: waste products such as fly ash and silica fume can be used in concrete
- Concrete can be recyclable and is usually available locally
- Energy savings: structures constructed of concrete have a larger thermal mass, which absorbs energy slowly and holds it for much longer periods of time
- Reduction in greenhouse gases: the reduced energy requirements of a concrete structure can significantly reduce carbon dioxide emissions over its service life
- Durability – concrete is resistant to the ravages of fire and wind and free from rot, rust and termites
- Improved indoor air quality – concrete is inert and does not give off toxins gases or VOCs

Lighting and Security

The long spans, wide beam spacing, and flat surfaces provided by post-tensioned parking structures enhance lighting and improve patron security. In addition, cast-in-place, post-tensioned structures are brighter and present a cleaner appearance. The open structural systems also enhance lighting and create a more welcoming environment when compared to other systems.

Reduced Structural Depth

Structural depth reductions are often essential to meet building height restrictions and post-tensioning can reduce structural depths by one-third or more in comparison to other systems. In the case of underground parking garages, structural depth reduction is desirable to reduce excavation, soil retention system costs, and de-watering costs in sites with high water tables.
Deflection and Vibration Control

The pre-compression caused by post-tensioning makes the entire concrete section effective, which results in increased stiffness. Also, because of their draped configuration, post-tensioning tendons carry a significant portion of the dead-load directly to the columns. The net load, which is the load that produces deflections, is therefore reduced. The pre-compression, draped tendons and the monolithic nature of cast-in-place concrete garages significantly reduce deflection problems. The monolithic construction, continuity and rigid connections between beams and columns reduce vibrations.

COMMERCIAL PARKING:
NorthPark Center Expansion

In order to increase parking capacity, the Tampa International Airport (TPA) constructed a six-level garage to add 5,600 parking spaces. The 5,000-psi cast-in-place concrete, post-tensioned beam and slab structure has five elevated levels and is supported by an ordinary moment frame consisting typically of 28-inch by 28-inch columns, 16-inch-wide by 33-inch-deep post-tensioned beams, and 7-inch-thick post-tensioned slabs. Post-tensioning allowed the structure to have a well-lit and open environment that increases the safety and usability of the garage. Without post-tensioning, additional columns would have been required to support the structure, resulting in interrupted drive aisles, fewer usable parking spaces and interrupted visibility.

AIRPORT PARKING:
Tampa International Economy Parking

With a mall expansion in the works, it was necessary to construct two new parking garages, resulting in the addition of 1,671 and 2,235 parking spaces. Although precast was originally considered, with the pending holiday shopping season, the construction team selected a cast-in-place post-tensioned solution to meet the schedule. Both garages have very long plan dimensions and upturned perimeter beams along the garage perimeter were used. These beams provide structural support for the slab, resist car impact forces, and provide backup for the brick veneer. The use of post-tensioning enabled the exterior elevations and associated perimeter details.
Cast-in-place, post-tensioned construction allows for versatility in structural layout. Structural floor configurations are virtually limitless. Cast-in-place forms can be used to create helical ramps, spiral ramps, compound slopes and more. With cast-in-place, post-tensioned construction, you are not limited by standard pre-cast elements.

Construction with post-tensioning allows long column-free spans and is adaptable to other functional requirements of parking structures. Post-tensioned structures can easily accommodate slopes to drains, straight or curved ramps, warped surfaces that provide smooth transitions between ramps and level floors, and irregular plan layouts. There is no functional compromise as is often the case with other structural systems.

Research and experience have shown that post-tensioned structures inherently provide structural integrity under abnormal and catastrophic loading. Well detailed cast-in-place post-tensioned structures have significantly higher structural integrity, redundancy and resistance to catastrophic loading than precast systems.

One of the most important advantages of cast-in-place construction is greater control over the project’s cost and schedule. Many of the problems associated with having to rely on other suppliers are eliminated. Both the time and cost of hauling prefabricated pieces from the plant to the job site and the need for heavy lifting are eliminated. Large panel flying forms, modular forming systems and ever improving concrete technology continue to enhance the construction speed and economy of cast-in-place post-tensioned parking structures.

**Seismic Loads**

One only has to look to history to validate the proof of performance. Post-tensioned parking structures performed well in the 1971 San Fernando, 1989 Loma Prieta, and the 1994 Northridge earthquakes. Research has shown that, under some conditions, unbonded post-tensioning improves the behavior of moment frames under seismic loads. Code provisions developed by the Building Seismic Safety Council allow the use of unbonded post-tensioning in ductile moment resisting frames.

**Lateral Loads**

Monolithic connections between slabs, beams and columns provide rigid frame action to resist wind and moderate seismic loads. This frame action frequently eliminates the need for shear walls, which results in cost savings and more open and efficient parking structures with enhanced patron security.
INSTITUTIONAL PARKING:  
Hoag Memorial Hospital Presbyterian

With its beautiful exterior décor and large swimming dolphins stenciled into the walls, the 178,000-square-foot parking structure at the Hoag Memorial Hospital Presbyterian in Newport Beach, Calif., serves as a highly visible structure at the primary entrance of the hospital campus. In the event of an earthquake, the $9 million facility will provide access and egress for emergency vehicles. Post-tensioned systems were used to reduce the construction cost and meet the design requirements of the building.

INSTITUTIONAL PARKING:  
Multimodal Facility/Transit Center

The Multimodal Parking Facility/Transit Center, in Tacoma, Wash., is a two-phased parking facility that connects pedestrians to a multitude of transportation systems. Incorporating cast-in-place, post-tensioned concrete construction and a station facility separate from the parking structure allowed for consistent repetition of floor plans and structural details, expediting construction and therefore reducing construction costs. Phase I of the project provided a six-story, 1,250-car capacity structure and Phase II added a seven-story, 1,200 parking structure to the $29 million project. The project, as a whole, exceeded the owner’s expectations by doubling the capacity and keeping the original budget intact.

UNDERGROUND PARKING:  
Entry Pavilion

This unique underground-entry pavilion is a multi-level, cast-in-place, post-tensioned concrete parking structure placed completely underground and concealed by the reinstallation of the original landscaping, rendering the parking structure virtually invisible. The building is 202 by 275 feet in plan, with three below-grade parking levels and a plaza at grade for a total of 220,800 square feet. Perimeter concrete walls provide soil and lateral support. Post-tensioning benefits such as shallow floor-to-floor heights and long column-free spans were key to success. Because post-tensioned construction is well-suited to variability in form, this project was able to use custom beam sizes to maximize the load-carrying capacity of the members within the restricted height. Post-tensioning also helped achieve architectural effects.

INSTITUTIONAL PARKING:  
California State University

The 10-story, 1-million-square-foot parking structure on the campus of California State University not only provides much-needed parking for the school, but also stands as a visible symbol of the university. To make the double-trapezoid structure both structurally robust and aesthetically pleasing, cast-in-place concrete with unbonded post-tensioning was selected. One-way post-tensioning was also used in the 5-inch concrete slabs (which were prestressed according to a software-created design), while concrete special moment-resisting frames (SMRFs) were used to resist lateral loads. The initial phase of the structure was opened in 2005, with the second section following soon after in 2006.
Established in 1976, the Post-Tensioning Institute (PTI) is recognized as the worldwide authority on post-tensioning. PTI is dedicated to expanding post-tensioning applications through marketing, education, research, teamwork and code development, while advancing the quality, safety, efficiency, profitability and use of post-tensioning systems. Members of the Institute include major post-tensioning material fabricators in the U.S., Canada and Mexico, and manufacturers of pre-stressing materials in the U.S., Canada, Mexico, Japan and Europe, as well as companies supplying materials, services and equipment used in post-tensioned construction. In addition, PTI has more than 500 professional engineers, architects, inspectors and building officials as professional members.

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