Post-Tensioning Revisited

By John Crigler, P.E.

Monostrand tendons coiled, labeled and ready for shipment.

Post-tensioned concrete has been used for more than 40 years in the United States in a wide variety of construction projects. First used primarily in bridge construction, applications for post-tensioning now extend far beyond bridges to include tanks, office buildings, condominiums, hotels, parking structures, pavement, masonry, shear walls, single-family homes and more. Because post-tensioning can be combined effectively with other structural materials and has been used to strengthen steel, reinforced concrete, masonry and timber structures, as well as enhance and extend the capabilities of precast, pre-tensioned elements, the method's usage will continue to increase.

One reason for the increasing use of post-tensioning is the advancement in technology in recent years. While older post-tensioning systems focused more on obtaining the desired prestress force and less on durability, by improving the systems used to protect the prestressed steel from corrosion, the industry can now offer systems that deliver both. The advancements in corrosion protection are especially important in areas that experience significant exposure and damage from freeze-thaw cycles, de-icing salts, seawater, salt spray and other deterioration mechanisms.

Post-Tensioning vs. Pre-Tensioning

Both pre-tensioning and post-tensioning systems are used to create prestressed concrete. Pre-tensioned systems, however, must be fabricated in a precast plant and are limited to straight, harped or circular tendons. This method is also limited to straight or circular members. Because pre-tensioning is used only in precast elements, it is more difficult to construct continuous structures because of the necessary connections. Additionally, though the tendons in pre-tensioned concrete are protected from corrosion because they are in direct contact with concrete, the steel itself is not able to be encapsulated in any other manner. As such, any moisture migrating to the steel through cracks in the concrete could cause the tendons to corrode.

Post-tensioning, on the other hand, can be performed on the project site or in a precast yard. Post-tensioning tendons can be configured into almost any shape. This flexibility allows the post-tensioning to match exact design requirements with few limitations. And, depending on project needs, the tendons in a post-tensioned system can be unbonded or bonded. For corrosion protection, whether unbonded or bonded – post-tensioning has superior features.

Unbonded and Bonded Post-Tensioning Systems

Unbonded tendons typically consist of single (mono) strands or threaded bars that remain unbonded to the surrounding concrete throughout their service life – giving them freedom to move locally relative to the structural member. The strands in unbonded monostrand systems are coated with specially formulated grease, with an outer layer of seamless plastic extruded in one continuous operation to provide protection against corrosion. Depending on the application and the level of protection that is needed, the anchorages of unbonded monostrand systems may also be encapsulated. Unbonded monostrand systems are typically used in new construction for elevated slabs, slabs-on-grade, beams and transfer girders, joists, shear walls and mat foundations. Light and flexible, unbonded monostrand can be easily and rapidly installed – providing an economical solution.

Bonded post-tensioning systems are comprised of tendons from one to multiple strands (multistrand) or bars. For bonded systems, the prestressing steel is encased in a corrugated metal or plastic duct. After the tendon is stressed, cementitious grout is injected into the duct to bond it to the surrounding concrete. In addition, the grout creates an alkaline environment which provides corrosion protection for the prestressing steel. An advanced duct system, PT-Plus™, encases the prestressing steel in a corrugated duct and plastic coupler system.

Bonded strand post-tensioning systems can range from a single strand to 55 or more strands in a single tendon, while the anchorage assembly consists of local zone confinement reinforcement, bearing plate, anchor head, wedges and grout cap. Bonded multistrand systems, while used extensively in new construction of bridges and transportation structures, can be and have been successfully applied to commercial building structures. When these multistrand systems are used for large structural elements such as beams and transfer girders, design advantages include increased span lengths and load-carrying capacity and reduced deflection.

External and Internal Post-Tensioning

Tendons placed in the formwork prior to pouring the concrete are known as internal tendons. Most post-tensioning applications use internal tendons. In external applications, tendons are installed outside of the structural member. The system consists of prestressing steel, mechanical end anchorage devices and a corrosion protection system. External systems are generally installed in

Bonded multistrand grouting.

one of two configurations – either running straight between anchorages or through deviators to create harped profiles. The tendons are typically protected by high density polyethylene (HDPE) ducts filled with grout.

External systems, if designed accordingly, make it possible to control and adjust tendon forces, inspect for corrosion and, as necessary, easily replace the tendons. For these reasons, the primary application for external tendons is bridges where external multistrand systems are grouted in HDPE ducts. External tendon systems, however, can be applied to many types of structures and, in particular, provide effective strengthening reinforcement for retrofits.

Past Challenges Inspire Technological Advancement

Since post-tensioning was first used domestically, the industry has seen many technological advances. Improvements in systems include seven-wire strand with wedge-type anchorages, low relaxation strand, and the use of banded tendons in flat plates. Analysis techniques and design software have advanced, as have techniques for improving durability. These include extruded sheathing for unbonded tendons and encapsulated anchorages for enhanced corrosion resistance, plastic duct systems, and the development of non-bleed grouts.

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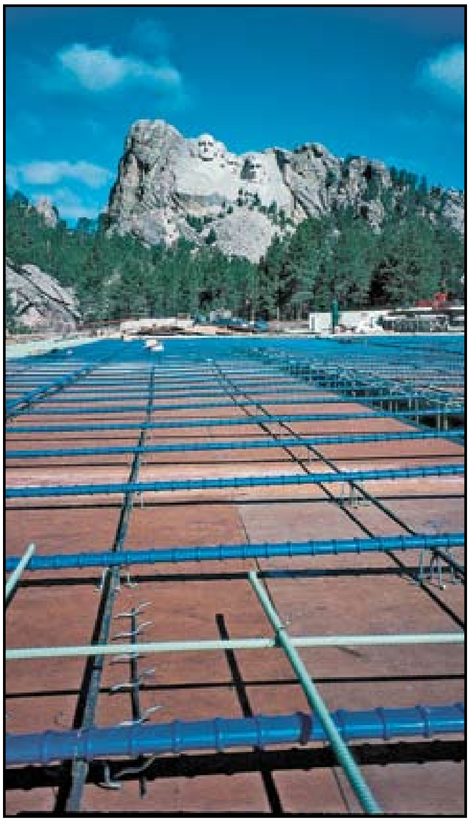


VSLAB+® bonded slab construction.

Flat plate slab construction using unbonded post-tensioning.

When some of the earliest unbonded post-tensioned buildings were about 15 years old, corrosion problems started to surface. It was apparent that some of the tendon corrosion protection systems used could not adequately protect the tendons in the most aggressive environments, such as where de-icing salts are used or in coastal areas that have a high salt content in the air. Starting in the 1980s, the Post-Tensioning Institute (PTI) developed tendon specifications designed to address the corrosion problems. PTI specified improvements which included sheathing, coatings and, in the most aggressive environments, complete encapsulation of the tendons.

With internal bonded and external tendons, grout is a key element of the overall corrosion protection strategy. Experience gained over many decades with grouted post-tensioning tendons has proven that cementitious grout provides excellent protection for the prestressing steel. The principle objectives of grouting are to protect the prestressing steel from corrosion by encasing it in a passive environment and filling the duct to minimize voids in the completed structure. To ensure the quality of grouting applications and the ultimate durability of the structure, in addition to other training classes and certification programs, PTI developed and administers grout training classes and certification procedures. Specialized equipment has also been developed to complement the process and ensure the highest quality product.

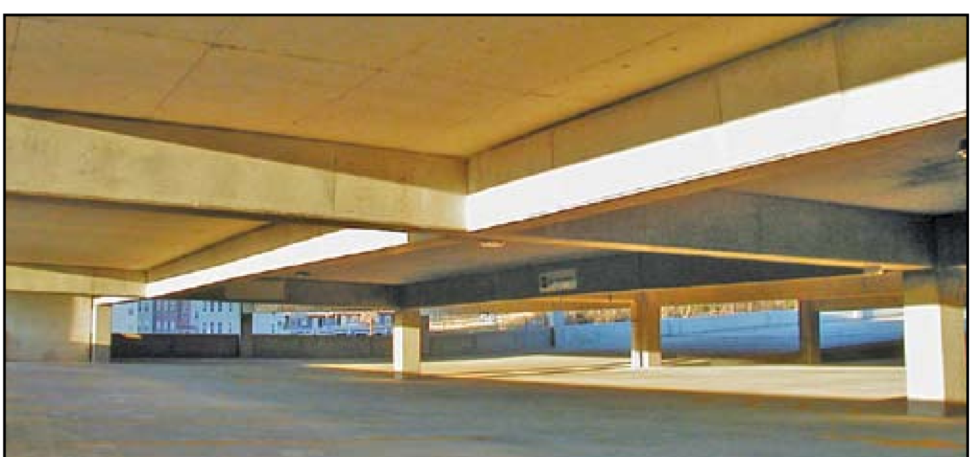
Mat foundation construction using monostrand tendons.

Benefits of Post-Tensioned Concrete

Post-tensioned structures offer numerous advantages. These include reduced dead load and member depth because of the decreased amount concrete required. There is also increased deflection control and greater crack control. The improved crack control also improves durability. In addition to these advantages, post-tensioning allows for increased span to depth ratios. This leads to lower building heights, which in turn reduces the heating and cooling volume and decreases the façade area of the structure.

For developers and owners of commercial buildings, the advantages of post-tensioning can make it a preferred reinforcing system. A traditional reinforced concrete building with two-way slabs requires more concrete, and thus more weight. As a lighter alternative, post-tensioned slabs require less concrete to achieve the same performance, thereby creating a structure with fewer shear walls, smaller columns and lower foundation loads. This results in more durable, efficient structures with longer clear spans.

Further, in corrosive environments, encapsulated bonded systems offer significant design advantages that lead to life-cycle savings. Because the amount of mild steel is reduced, particularly at the top zone of slabs, there is less steel to corrode should the concrete crack or spall. This is particularly important in parking garages where significant maintenance costs are due to repairs associated with spalled concrete from corroded rebar.



Bonded parking structure.

Another advantage of bonded post-tensioning is the inherent capacity to provide resistance to progressive collapse. This may be especially important in the event of localized blast loading. Like mild steel reinforcement, a bonded post-tensioning tendon is capable of developing its force in a relatively short distance along its length. In the event that an anchorage fails or a tendon is severed, the loss of tendon force would be localized. The remainder of the tendon would retain its force at the development length away from the failure point and would remain functional. This functionality can be considered in the design of a structure.

Bonded post-tensioning systems also allow for flexibility when future modifications to the building are needed. Tenant build-outs, remodeling and changes in a building's use may require modifications to the floor slabs. The use of bonded post-tensioning systems has allowed owners the flexibility to make these changes quickly, easily and cost-efficiently.

An example of an owner choosing bonded post-tensioning for the method's life-cycle savings is the Baltimore Washington International Airport Consolidated Rental Facility. The bonded post-tensioning system used in this structure provides total encapsulation of the strands using PT Plus™ plastic duct with watertight mechanical duct to anchorage couplers. The rental facility was completed in December 2003, and includes over one million square feet of elevated, post-tensioned, cast-in-place concrete. (**www.structural.net/News/Media_coverage/ci2505loper.pdf**)

Reasons to Consider Post-Tensioning

- Increased span to depth ratio, resulting in a reductionin construction materials and a subsequent reduction inoverall cost.
- Positive deflection control.
- Design flexibility.
- Joints in structures minimized or even eliminated.
- Improvements in the long-term durability of concrete structures exposed to aggressive environments.
- Greatly increased span lengths.

Completed structure with monostrand and bonded multistrand systems.

Bonded and unbonded systems can be mixed within a structure. An example of how bonded and unbonded systems were combined for economics, efficiency and design requirements is the W Victory Hotel & Residences in Dallas, Texas. The W Victory's concrete frame structure includes a combination of monostrand, unbonded post-tensioning systems and bonded, multistrand post-tensioning systems. The unbonded post-tensioned systems were used in typical levels, while the bonded post-tensioning systems were specified for the transfer girders on three levels to provide optimum crack and deflection control – features essential for transfer girders required to carry the loads from the multi-story structure. Additionally, bonded post-tensioning systems were used in exterior applications where corrosion could be an issue.

Post-tensioning has seen much development and many improvements over the past 50 years, resulting in the method now serving as a significant feature in mainstream construction. The next article in this series will review the contemporary uses of post-tensioning in building construction and how it can successfully be incorporated into a project design.▪

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