Understanding can help contractors avoid common problems

Issues in Post-Tensioned Construction

By Bryan Allred

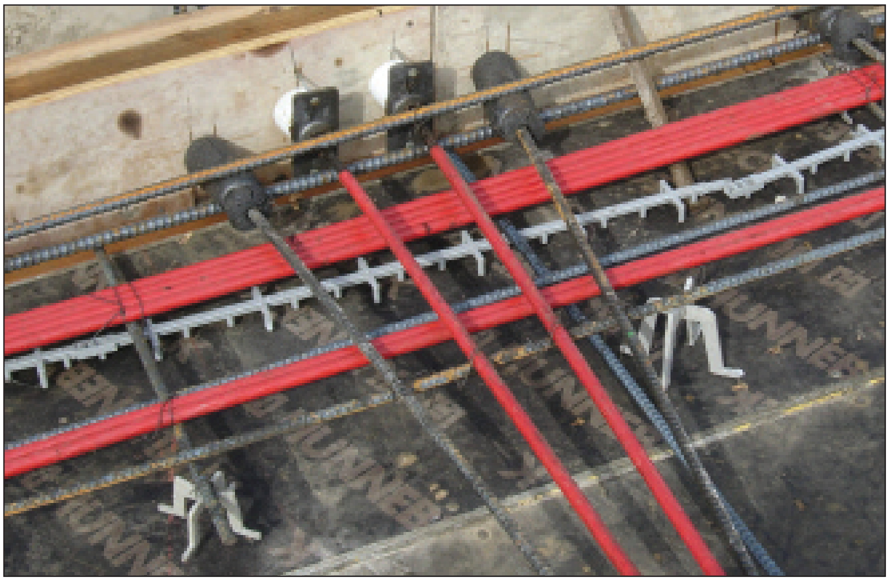
Post-tensioned concrete construction is a little different than standard reinforced concrete construction. There are several construction issues with post-tensioned concrete that I have found consistently among engineers and contractors. Understanding the causes of some of these problems should help contractors build better post-tensioned structures.

Top: Post-tensioning tendons are draped within the slab cross section. Bottom: Significant over-balancing of the weight of the concrete with post-tensioning can actually lift and crack the slab.

Post-tensioning actively loads the structure

One of the main differences between a post-tensioned beam or slab and a typical reinforced concrete element is that the strands drape or profile inside the concrete—their vertical location changes along the length of the member. The tendon profile, which is typically in a concave shape, will try to straighten itself out when stressed. This creates an uplift load (also called a *balance load*) on the concrete that minimizes and often effectively removes the dead weight of the concrete from the stress and deflection calculations.

Since post-tensioning places an active load on the structure, care must taken during construction to make sure the locations of the tendons match the engineer's drawings. Inaccurate tendon locations can greatly increase the uplift force on the slab. The most common cause for incorrect tendon placement is discrepancy between the structural drawings and the supplier's shop drawings.



Top: To prevent restraint, plastic is placed along the top of a wall that the slab is crossing. Bottom: The black foam rubber around the first few inches of the dowels coming out of the adjacent wall will allow the post-tensioned slab to shorten during tensioning without cracking the slab.

The inspector and the contractor must verify that the layout conforms to the structural drawings, not just the shop drawings.

Applying uplift loads that are larger than the weight of the floor can cause problems during stressing when the tendons begin pushing up with more force than the concrete weighs. This net upward force can result in large tensile stresses at the bottom of the slab/column joint, where there is typically little or no rebar, and can actually lift the slab. Unlike with rebar, which activates only when loaded, too much uplift load (whether due to the number of strands or increased drape) can significantly impact the slab.

Slip connections are critical

A post-tensioned system will move 20% to 30% more than conventionally reinforced concrete. A good rule of thumb is that a post-tensioned system will move about 1 inch for every 100 feet of slab that is not restrained by a lateral system. If the edge of the slab is 50 feet away from the nearest shear wall, when post tensioned this edge will move in about ½ inch. If this edge movement is prevented, either the slab or the restraining element will most likely crack.

Slab restraint is typically caused by concrete or masonry walls that are connected at the perimeter of the structure. In addition to having more movement, a post-tensioned slab will have substantially less rebar than a conventional system, which is one of the main economic benefits. But since a post-tensioned slab does not have excess rebar to minimize and distribute cracking, restraint cracks will be large and very noticeable. The use and proper construction of slip details is therefore critical for the performance and aesthetics of post-tensioned concrete.

Typical slip details use felt, building paper, or plastic to eliminate the bond of the slab to the walls. Many restraint cracks have been created by engineers or contractors who underestimated the strength of the bond between a slab and concrete or masonry walls. When rebar is required between the slab and wall, pipe insulation or foam rubber surrounding a portion of the dowel can be used to allow relative movement without activating the dowel.

Pour strips

Pour strips are specific to post-tensioned structures and are typically located at the midspan or quarter point of the bay. To provide any crack control benefit, the slabs on each side of the pour strip have to be completely separate when the tendons are stressed.

Reinforcement must be discontinuous across a pour strip.

Any reinforcement extending from one slab into the other will act as a tension tie, restrain the relative movement of the two slabs, and most likely cause cracking. All rebar and post-tensioning must be lap spliced inside the width of the pour strip only after the tendons have been stressed.

Contractors should pay special attention to whether the engineer requires the edges of the pour strip to remain fully shored after the tendons have been stressed but before the concrete has been placed to tie the two slabs together. The confusion occurs because after a successful stressing, the majority of the slab (except the pour strip) is structurally stable and does not require the forms or reshores for stability. But without edge reshores, these midspan pour strips before they are filled with concrete to tie them together can result in large cantilevered sections of slab on either side that can result in significant deflections and cracking from loads that were never intended or reinforced by the engineer.

Increased cover for fire protection

Post-tensioning strands have different cover requirements depending on whether they are located in restrained or unrestrained spans. Whether a slab is restrained or unrestrained is a function of the expansion potential of the slab due to fire. An unrestrained span is the first or last span in the direction of the tendon.

For a three-hour fire rating, according to Table 720.1 of the *International Building Code,* the minimum bottom cover for post-tensioning tendons is 2 inches, while it is only 1 inch for rebar. This significant difference in cover is frequently overlooked and is a direct code violation. One retrofit option is to have plaster or other fire-rated material applied to the slab or beam around the low point of the tendon to increase the fire rating. In post-tensioned slabs, the cover to the strands should typically be greater than the cover to the rebar in the end (unrestrained) bays.

Waterproofing

A common myth is that post-tensioning will create waterproof concrete. Unfortunately, this is not true. Concrete by nature is a porous material and adding some amount of compression does not suddenly make it non-porous. When designed and built correctly, post-tensioning will enhance the natural water tightness that concrete possesses, but it will never be waterproof.

In fact, one could argue that more post-tensioning actually makes the system less waterproof. For higher values of post-tensioning, the slab will experience larger movements, which can induce more restraint cracks. No matter how much reinforcement is put into the slab, a crack is never waterproof.

Concrete blowouts and tendon profiles

Whether in a small residential slab on grade or a 30-story hotel, each tendon will be loaded to roughly 33,000 pounds during stressing. This force is transferred to the concrete through the bearing of the ductile iron casting anchor against the concrete. If the concrete is not well vibrated near the anchors, if penetrations are located in front of the anchors, or if congested rebar prevents a uniform bearing surface, a concrete blowout is likely. The concrete will literally explode during tensioning as the anchors crush into the slab or beam, which then can cause the hydraulic jack to move suddenly and

Left: Slab penetrations too close to anchors can result in blowouts. Right: This horizontal blowout resulted from tendons that were curved in a very tight radius. On the left side of the photo, the imprint of the tendons prior to stressing can be seen approximately 12 inches away from their current location. During stressing, the tendons straightened and the concrete in the curve was unable to resist the localized lateral thrust.

These tendons will create a downward force that is nowhere near a band or a vertical support and that can cause cracking or a small blowout.

violently. For this reason, only trained professionals should operate or be anywhere near the jack during stressing. If penetrations can't be relocated away from the anchors, steel pipes should be placed around the openings to resist the anchorage force.

Blowouts can also occur away from the anchors in the middle of the slab. These blowouts typically are caused by extreme horizontal or vertical tendon curvatures that create localized forces in the slab. Horizontal curving of the tendons is often done to avoid penetrations, slab openings, and embedded items that prevent typical strand placement. During stressing, the tendons tend to straighten and the concrete in the curve is unable to resist the localized lateral thrust.

For horizontal curves, a good practice is to start curving the tendons in the middle part of the slab so sufficient concrete and rebar are present to resist any lateral thrust. Curving tendons near the top of the concrete has led to problems since the concrete has minimum cover and rebar can't be added. If extreme curves are unavoidable, hairpins are often used to "pull back" the thrust into the main slab.

Vertical draping of the strands is one of the main benefits of post-tensioning, but this needs to be done smoothly and gradually. Tendon discontinuities will produce localized point loads on the slab. Tendons draped in a reverse curve over other tendons will create a downward force. Instead of picking up the concrete, this reverse curvature will push down into the lightly reinforced slab below, most likely causing cracks or a small blowout. Reverse curvatures are typically caused by the tendons being kicked off their chairs, wrong chairs being used, or the strand being tied off to a piece of rebar that has been moved after the tendon was secured.

Drilling into a post-tensioned slab

Another popular myth with post-tensioned slabs is that it is very difficult to drill into an existing slab because of the unknown location of the tendons and anchors. But as long the tendons and the concrete in front of the anchors are not damaged, drilling into a post-tensioned slab is a fairly routine issue.

Existing tendons can be located using a pacometer (handheld metal detector) or an X-ray device. With the X-ray in hand, a technician can mark the tendon locations directly on the concrete surface. I have used a $40 store-bought metal detector and located tendons in a 12-inch-wide beam. For buildings where tenants change frequently, we recommend marking one side of the slab so future tenants will know exactly where the strands and anchors were placed.

The above list of "issues" is nowhere near complete but represents common items that I frequently come across. For other questions, the Post-Tensioning Institute has recently completed the sixth edition of its *Post-Tensioning Manual*, which covers a large range of topics for post-tensioned buildings and is useful for contractors as well as engineers. ■

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This small blowout is a result of a localized low point in the tendons between two higher points. Note the gap beneath the tendons and the slab, indicating how much the tendons lifted.