Construction Issues

discussion of construction issues and techniques

Post-Tensioned Concrete Construction

Tendon Repairs and Modifications

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Post-tensioning is the most significant development in the concrete construction industry since steel reinforcement was first employed in the mid-1800s. Post-tensioning (PT) delivers roughly four times the tensile strength compared to conventional reinforcement and significantly reduces (or eliminates) concrete cracking, thus enabling thinner slab construction – reducing the environmental impacts, saving material and labor costs, and shortening construction schedules. Post-tensioning also brings a host of seismic advantages to a structure and enables architects to employ concrete in artful shapes and sizes once thought impossible.

Consequently, post-tensioning in new construction has blossomed in the United States since the 1950s. And, as with any technological advent, the decades following its introduction saw significant improvements in PT techniques and materials. The original button-headed wire with heavy wax paper wrappings has been replaced by higher grade steel strand, excellent anchorages, injection ports, grout caps, polypropylene ducts, improved grouts, and an array of customizable installation techniques to best suit the slab or beam's design and use.

However, construction concerns arise as structures built in the industry's formative years, and newer structures for that matter, are remodeled, repurposed, or repaired. The PT remodel industry steadily grows because generations of structures erected using this technology are coming to the ends of their useful lives. These are mostly parking garages and mid-rise buildings erected in the 1960s and 1970s. Construction from the 1970s tends to be particularly "light," with design engineers saving every foot of rebar and pound of concrete possible, making for underbuilt structures by today's standards. By the 1990s, PT had been primarily refined into the processes and materials employed today, making remodeling and repairs easier. Also, in previous generations, life-cycle calculations were not given the importance or precision that they are today, so it is little wonder that older buildings require work to extend their usefulness.

Even recently erected structures may require significant work. Perhaps a landlord wishes to add or change utilities in a building or redesign the floor layout. Perhaps a cracked slab has exposed a section of strand, or an exposed anchorage has corroded, or a contractor has cut into a slab and unintentionally severed a PT strand. This article provides an overview of a few common situations and solutions for PT tendon replacement, repair, and remodeling in older and modern commercial structures alike.

Contemporary Concerns

Each project brings unique challenges, so begin by consulting an experienced and competent post-tensioning engineer. Simply because one has successfully repaired or remodeled a building from the same region or date as a previous project does not mean that the prior experience can inform the final details of a new situation. In fact, it is possible for an older building to show dramatic PT variation *within a single building*, such as button-headed PT on one level and steel-rod PT on another. Also, without the PT shop-drawings, even in a newer building, the actual placement of the tendons and interactions of the tendons are not known without some investigation informed by experience. So, before any slab or beam is touched, seek professional guidance. What follows are general thoughts based on years of industry experience.

First, slab and beam cracking is a common concern and an indication that attention and repairs are needed. Are the cracks deep? If so, the engineer must ascertain the cause. Often the culprit is not the concrete or post-tensioning work. Most likely, it is the original design. Design issues likely mean expansive, expensive repairs rather than a localized and inexpensive solution. To the surprise of many engineers, it is often possible to replace the tendons in existing slabs and beams to increase their strength and close the cracking. One caveat worth mentioning involves epoxy. If the cracks are old, an owner may have filled them with epoxy to improve aesthetics or to protect the slab or beam from water intrusion. However, if the filler epoxy reached the strand, PT replacement is significantly more challenging. A second, clear sign of trouble in an older building is deflection in any region: slab, beams, columns, walls, or ceiling. Again, the engineer must discover the cause of the deflection and draw up the remodel action plan accordingly. Deflection generally indicates a more serious design issue than cracking.

Parking garage projects account for a great deal of PT work because the technology suits the structures so well. Transportation needs also change over time, requiring garage modifications. Required live load increases can create challenging situations. It is more likely that a garage will experience live loads near or over capacity than a mid-rise residential building. However, the PT remodel process is usually much easier than in a tenanted building as there is so much working room, and the garage can usually be closed while work is done. Both slabs and beams can be remodeled. Repairs are common too.

Mid-rise buildings with PT slabs rarely experience the live load issues of parking garages. However, slab repairs required to address broken or damaged tendons, or modifications required

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for remodeling, are often more challenging to engineer solutions for, primarily because the impact on tenants must be considered. In general, there are two basic techniques for accomplishing a PT project in a mid-rise building – clearing a large portion of the building to do all of the work in one phase or performing the work in multiple phases over a more extended period.

The first approach involves shoring three to four stories below the repair floor. This will mean the evacuation of a significant part of the building, interrupting work and rents for the tenants and owner. Also, the shoring itself is costly to erect. The main advantage of this technique is for the PT repair crew since they have free access to the floors and their work can be accomplished quickly. Additionally, if a building has serious design flaws, this technique will probably be the only remodel means available to an owner.

The second approach can be accomplished without traditional shoring. Most structures, even the "lighter" 1970s structures, can usually be remodeled by working on every third strand, one at a time, and proceeding down the slab. This means the crew will usually make at least three passes over the slab, spending significantly more time on the floor than with the shoring method. However, the combined benefit to tenants (they can remain on all other floors) and the crew (they do not need to erect costly shoring) usually makes the added time and labor for the PT crew on the individual floors well worth it, from a cost analysis and tenant relationship standpoint. This method requires evacuation of the remodel floor to clear that floor's live load. Live load elimination means that a single strand being replaced in any given location will not affect the slab negatively. Usually, the slab has enough tension reinforcement to absorb the relatively minor, temporary changes in force due to remodel activity. This technique has been employed for applications from simple single-floor, single-strand replacement to multi-floor cutouts for elevator shafts and upgraded escape routes. The amount of actual disruption such remodeling may cause tenants largely depends on the state of the slab. For instance, if the strand is snagging in its ductwork for some reason, small windows to the strand will be jackhammered in the slab to identify and remove the issue, thereby increasing potential tenant disruption.

This process of removing a live load and treating the work one strand at a time probably suggested itself by early repair of failed strands, whether due to crumbling concrete at an anchor head, a slipping head from a now-obsolete coil anchor, or an unintentional cut through a strand from a trade worker. In these cases, the tension from one strand was lost, but the slab did not fail because building specifications called for at least that much extra carrying capacity, even in older structures. It is readily inferred, then, that one may approach a repair with a similar mindset, one strand at a time. However, if a strand fails or is unintentionally cut, seek professional guidance. It cannot be left cut or un-tensioned simply because one sees no cracking, buckling, or other negative signs in the slab. The force changes will have an effect over time, and it is essential that the slab tension capacity is put back into balance to ensure safe and consistent operation for present and future use of the structure. If one discovers deflections of any kind (sagging, buckling, leaning, etc.) in a building, consult an engineer. If the deflection occurs while a crew is working or people are in the building, the building must be evacuated immediately until an engineer investigates the situation and clears the building for reoccupation. This, of course, is true of buildings constructed with or without post-tensioning.

Figure 1. Worker repairs parking garage slab PT strand with couplers.

Example Repair: Simple Repair

Often the best approaches to forming a sounder general understanding of a subject are to consider specific cases. First, consider a common issue: the repair of a single broken tendon, and second: the creation of a new opening as part of a remodel project.

Typically, commercial buildings are built with 0.5-inch diameter, 7-wire monostrand tendons. Modern materials and techniques make most unbonded tendon repair or replacement a routine event. Older button-headed tendons usually feature grease and paper conduit. This conduit is known for inconsistencies that make tendon replacement difficult and, therefore, most button-headed repairs will be splices. If button-headed tendon replacement is required, it may only be possible to run a smaller gauge tendon in its place, and engineers will need to be consulted to ensure that the result remains safe and balanced. In some cases, the new strand may be welded onto the end of the old tendon and pulled through, enabling a 0.5-inch diameter monostrand tendon to replace a 0.5-inch diameter button-headed tendon, despite some conduit issues.

Finding the break is usually not a problem, even when hidden in the slab. A scan with a noninvasive ground penetrating radar device provides a wealth of information concerning the location, size, and material of all slab-encased elements. Also, if the broken tendon is to be pulled out for removal, the lengths of each segment can be determined to verify the break location.

The first step in construction is to locally shore the work area and to chip away the concrete to expose the broken tendons (*Figure 1*). This must be done with care to avoid damaging adjacent tendons. In most situations, a single broken tendon will be repaired with a splice and re-tensioned rather than entirely replaced. However, if the tendon shows rust or other material damage, it will need replacement.

Example Repair: Complicated Case

If a single-strand repair or replacement represents the basic end of the repair spectrum, a large, multi-floor slab cutout for a new stairway or elevator may serve as the more complicated and challenging end of

Figure 2. PT worker detensioning a tendon to prepare for strand replacement.

Figure 3. Slab opening with antiquated button-headed wire system.

the spectrum. A few warnings should be heeded. First, plan on tenant evacuation and building shoring. Retrofits of this nature require open access to ensure safe and timely project completion. Second, review the original plans and scan the slabs to avoid locations of bundled tendons.

Third, even if extensive shoring is temporarily taking load from any columns, avoid destructive construction techniques near them. Besides the obvious need to protect essential building structures, tendon work near columns poses two risks: 1) tendons are often bundled near columns, and bundled tendons are more challenging to work with than single tendons, and 2) tendons are often nearest the top of the slab surface at column locations. Because splice and anchor retrofits need to be fully buried in the slab once the work is complete, much more of the slab must be broken out when repairing any tendon that approaches the surface of the slab. Such tendons must be re-profiled by breaking out and excavating under a tendon, resulting in a redistribution of stress and incurring extensive slab demolition.

As mentioned above, tendons are more challenging to repair when bundled. Therefore, when possible, engineers should avoid bundled locations when selecting a work location, especially when working with a multi-floor cutout. Sometimes surrounding tendons will pinch a tendon in the bundle and hinder the work. The tendon may bind when being de-tensioned. The conduit may collapse when the tendon is removed (again, welding on a new tendon to the old for pull-through replacement may prevent this). Any work done at a bundle location runs a higher risk of damage to other tendons and of increasing labor, material costs, and project-completion time.

Once planning, blocking, de-tensioning, cutting, and demolition are complete, the tendons are replaced or spliced with appropriate anchors, in a manner similar to that for the single tendon project, and the slab is reconstructed. *Figure 2* shows the de-tensioning of the tendons at the end of a beam. The process of slab tendon de-tensioning is similar. A safety item to note is that slab ends must be guarded with perimeter blocking (typically with a heavy wood or steel beam) when the tendons are first cut. The force released by a cut tendon may cause the tendon to break through its grout cap and pose a threat to nearby people or equipment. The contractor must ensure that, before any cutting takes place, safety blocking protects any strand ends that might release force. Once the de-tensioning and demolition are complete, the profile of the tendons can also be adjusted within the work area to address the new structural spans and geometry. Once the tendon work is finished, including the addition of new end anchorages, the concrete floor slab is recast with rebar reinforcement (*Figure 3*). Bonding agents help rapid set repair mortars tie into the existing slab. The slab opening may call for a turned down beam to rim the cutout for reinforcement, aesthetic look, or other mounting needs (such as serving as an anchor for railing attachments). Once the concrete cures, tendons are re-tensioned as in new construction (*Figure 4*), and the cutout is ready for new service (*Figure 5*).

Conclusion

Hopefully, these brief thoughts and examples will serve to clarify basic PT repair and remodeling processes. Like the development of many industries since the 1950s, construction methods and materials have refined dramatically, even within one of the most ancient building materials on earth: concrete. The post-tensioning skill and experience of engineers, crew leaders, and crews means that new and renovated post-tensioned structures can grow in scale, number, and elegance.▪

Figure 4. Worker re-tensions a repaired strand.

Figure 5. A successful PT slab cutout for a new staircase.