practical solutions

Externally Applied Post-Tensioning Systems

By K. Dirk Bondy, S.E.

The commentary to Section 18.22 of ACI-318-02 states that "External attachment of tendons is a versatile method of providing additional strength, or improving serviceability, or both, in existing structures." In my opinion, this is an understatement. Of course we can't expect codes to enthusiastically promote a given type of construction or retrofit method, but what method other than external post-tensioning (EPT) can add tremendous strength, recover deflections and actively "balance" loading while adding virtually no weight to the existing system? With all this power, however, comes responsibility. The designer and constructor must proceed cautiously and be fully aware of the potential ramifications of cutting into and placing large horizontal and vertical forces on an existing system.

Unstressed external slab tendons

External versus Internal

The initial reaction of many engineers to the idea of placing high-strength tendons *outside* of a framing system is that the design principles and guidelines of "normal" post-tensioning may not apply anymore. The fact is, however, that there are very few analytical differences between placing an unbonded tendon *inside* or *outside* of a concrete member. Remember, unbonded tendons placed inside of concrete do not satisfy strain compatibility with the surrounding concrete because of the fact that they are not bonded to that concrete. Therefore, when the tendons are placed outside of the concrete, the incompatibility of the tendons to the concrete remains the same but is just more visually obvious, leading many to a "gut" reaction that their thought process about post-tensioning must change.

Final stressed condition of external slab tendons

From a construction perspective, providing tendons outside of an existing member has many advantages. One significant advantage is that, unlike freshly cast concrete, the anchor will usually be placed against mature, hardened concrete that has much less likelihood of bursting under the bearing loads of the anchorage.

Another major advantage to EPT is that the tendons, supports and anchorages can easily be inspected during construction, and at any time in the future. This is very valuable not only for the initial construction of the EPT system, but for regular maintenance.

Stressing external tendons in an existing structure

Unlike cast-in-place post-tensioned construction, the equivalent or "balance" tendon loads are applied to the structure at discrete locations instead of uniformly along the length of the tendon. Typically, steel king posts will be used to apply point loads at selected locations on the existing structure, with the tendon in a "harped" or "double-harped" configuration as opposed to the parabolic profile typical in cast-in-place construction.

Close-up of the jack stressing the tendons

A typical steel king post

Galvanized anchor plate, barrel anchor and cap

The tendons and anchorage hardware used are very similar to that used in internal post-tensioning. Typically a thicker, more durable sheathing is used for external tendons since they are exposed to the environment, and the tendons are often galvanized. The anchor plates are typically flat such that even bearing against the existing concrete is achieved, and they too, along with the anchors themselves, are often galvanized. The wedges do not require any special treatment, since the hardened wedge metal itself is naturally corrosion resistant; however it is common to treat the cut tendon and anchorage with a corrosion resistant spray before capping.

Coring & Drilling

Virtually all EPT systems applied to an existing concrete structure will require drilling and/or coring through the existing concrete members (columns, beams, walls, etc.). It is very important when first schematically framing the EPT system to verify acceptable locations to core as well as anchor the tendons. Often these structures are older and have had many owners. This frequently results in a loss of the original structural drawings, making the utilization of x-rays sometimes necessary, particularly for post-tensioned buildings. In fact, even with the design and shop drawings, x-rays are often necessary for an unbonded post-tensioned structure to prevent drilling through a tendon. The x-ray operator will use the negatives to literally draw the rebar and post-tensioning locations on the concrete beam or slab (*Figure 1*).

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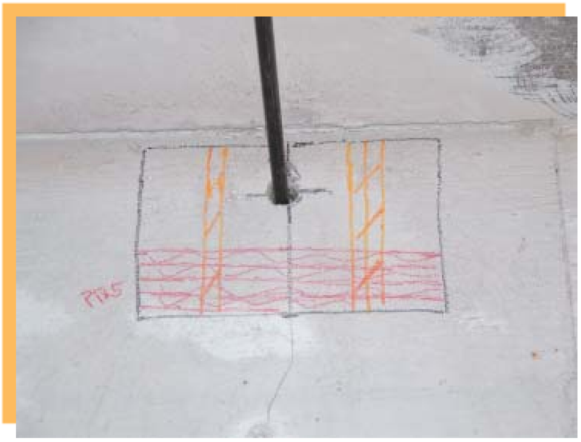


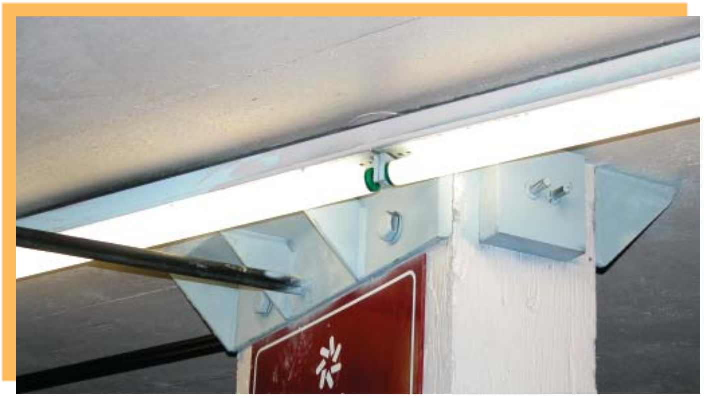
Figure 1: X-ray results showing post-tensioning and stirrups

It is imperative that experienced and highly skilled personnel perform the coring operations. They must be able to immediately identify when they have encountered rebar, post-tensioning or conduit. An experienced core driller will be able to identify when he is penetrating the plastic sheathing of a tendon and will stop before rupturing any wires in the strand, whereas a novice core driller could compromise the entire stability of the beam by severing tendons and/or critical rebar. An experienced core driller will often place a hole by first using a drill to create a pilot hole, and then using a slightly larger core drill at the same location. The drill is much less likely to sever a tendon and is typically not capable of penetrating rebar, making it a much safer device where the potential for conflict exists.

Coring through an existing beam

Anchoring the Tendons

The horizontal forces are applied at the anchorage locations, and these locations must be capable of resisting the bearing and shear forces generated by the anchor plates. Great care must also be taken when coring through columns. The engineer must verify that the column has adequate bracing through dowel action to the slab or beam for the externally applied anchorage loads, as well as capacity for any new vertical loads that the column may need to resist.



Anchoring at a column

Avoid Excessive Vertical Forces

Unlike traditional "passive" retrofit or strengthening systems, the controlling load condition with an EPT (or internal post-tensioning) system may be the "unloaded" condition. Designers who only analyze the fully loaded condition and provide post-tensioning that "balances" the applied loading may be overlooking an "over-balanced" condition when the applied loading does not exist. In rare cases, the existing system has been so severely jacked up that the post-tensioning has dislodged portions of the floor.

Protection of the EPT System

The environment and function of the external post-tensioning system will dictate the necessity for corrosion and fire protection of the tendons and hardware. In moist or corrosive environments galvanized tendons and anchorage hardware are often used, and the remaining hardware is either painted or also galvanized. However, the engineer must be aware that the galvanizing process of the tendons reduces the tendon ultimate strength and this must be accounted for in the design.

The Commentary to Section 18.22.4 of ACI 318-02 states that "Corrosion protection methods should meet the fire protection requirements of the general building code, unless the installation of external post-tensioning is to only improve serviceability." Many designers of EPT have argued successfully with the building official that if the structure has proven or can be shown not to be in danger of collapse without the external tendons, then fireproofing should not be necessary. Also, in some cases it has been successfully argued that a new or existing fire sprinkler system is an acceptable alternative to applied fireproofing. However, each city is different and the building official will ultimately make the final determination regarding fire protection.

Fireproofing on grounded external tendons

Stressing Tendons around Existing Obstacles

When properly designed and placed, the ability of the external tendons to traverse through the pipes, lights, and partition walls without disruption to the building function is one of the primary reasons to consider using an EPT system for strengthening. However, the designer and the contractor must verify that, when the tendons are stressed and take on their final taut form, no existing elements will be damaged. Most experienced EPT contractors will stress each tendon to approximately 500 pounds in order to verify that all king posts and supports are aligned correctly, and that obstacles such as utility pipes and lights will not be affected by the straightened tendons when fully stressed.

When to Use and EPT System

Externally applied tendons should be considered for all of the following conditions:

1. Strengthening an existing structure for added loading or occupancy change;
2. Strengthening an existing structure that has lost vertical load carrying capacity due to corrosion or deterioration;
3. When the space below needs to be maintained and cannot function properly with added structural elements;
4. When alternate strengthening systems would add a significant enough amount of weight to affect the existing column, foundation or seismic system capacity;
5. For recovering excessive floor or roof deflections (serviceability).

Avoiding plumbing obstacles

Cost Considerations

Obviously, the cost of an EPT system depends on numerous variables. Access, the number of elements requiring strengthening, the area requiring strengthening, the inadequacy of the existing system, acceptable anchorage locations, required treatment of the tendon system etc. are all contributors to the cost of the EPT system. Additionally, designing and implementing an EPT system is not an endeavor that should be attempted by novice engineers or contractors. In fact, the traditional design and bid process used for typical construction often leads to conflict… sometimes much worse in an EPT project. These projects have proven to be most successful when the engineer and contractor team together or are the same entity. Given that the existing conditions can almost never be totally anticipated in design, the actual design usually continues to be modified through construction. This mandates that the contractor and designer work as a team instead of the more traditional and often adversarial relationship.

A Final Note

Based upon our experience, the permitting process on large EPT projects can vary from receiving an "over the counter" permit to three months of multiple outside peer reviews. It is almost a guarantee that the building department will not have anyone employed with the relevant experience to provide a thorough review of the calculations and drawings for an EPT system. Therefore, they will either rely heavily on the engineer's ability to instill confidence in them that the design is sound and that no harm will come to the building, or go to an outside firm (or firms) to provide a review. Most cities do not want to be trail-blazers, so they will rely on the engineer to demonstrate the past performance of similar strengthening schemes. With all this in mind, the typical range of cost for a turn-key design-build EPT solution by an experienced engineer-contractor team has been between $12.50 and $25 per square foot (excluding fireproofing). This has proven to be extremely competitive with all other methods of strengthening existing buildings.▪

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