Common Post-Tensioning & Construction Issues

By Bryan Allred, S.E.

Figure 1: Slab crack due to the restraint of the perimeter masonry walls

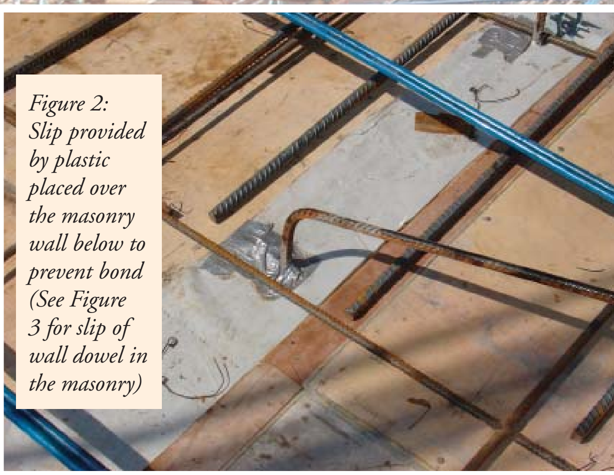

Figure 2: Slip provided by plastic placed over the masonry wall below to prevent bond (See Figure 3 for slip of wall dowel in the masonry)

Figure 3: Slip detail using foam rubber around masonry wall dowels

Over the last two years, I have participated in a post-tensioned concrete design seminar series for the Post-Tensioning Institute (PTI) that has covered the majority of the U.S. From these seminars, my own experience in engineering and observing post-tensioned concrete, several design and construction issues appear to be consistent among most engineers and contractors.

Balance Loads

When designing a post-tensioned slab or beam, the first thing experienced post-tensioning engineers check is what balance load is being produced by the tendons. The balance load is the upward force created by the load in the tendons trying to straighten out from their concave drape in the concrete. The balance load will minimize and often effectively remove the dead weight of the concrete from the stress and deflection calculations. With the concrete dead weight removed, the long term deflection multipliers of 3 to 5 are irrelevant, since the initial dead load deflection is basically zero.

A "good" balance load is typically between 70 and 100 percent of the weight of the tributary structural floor system. Superimposed dead (partitions, flooring, ceiling, mechanical, etc.) and live loads are not included in this percentage, since they will not be present at the time of stressing. Many new post-tensioning engineers over-look balance loads since they are not a code requirement and low/high values will not generate "red" flags by most commercial software.

Applying more balance load than the systems weighs is called over balancing. This can occur on every post-tensioned project, but is typically prevalent on slabs that will support large superimposed loads or slabs that are too thin for their respective spans. Over balancing can provide a numerical solution to satisfy the allowable stress requirements, but may create other issues. The problem occurs during stressing when the tendons begin pushing up with more force than the weight of tributary system. This net upward force can result in large tension stresses at the bottom of the slab/column joint, where there is typically little or no rebar, or it can actually lift up the slab. Unlike rebar, which only activates when loaded, too much balance load (number of strands and/or drape) can significantly impact the slab.

Slip Connections

A post-tensioned system will move approximately 20 to 30 percent more than conventionally reinforced concrete. A good rule of thumb is that a post-tensioned system will roughly 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, this edge would move about ½-inch. If this edge movement is prevented, the slab or restraining element will most likely crack. Slab restraint is typically caused by concrete or masonry walls that are hard connected at the perimeter of the structure (*Figure 1*). In addition to having more movement, a post-tensioned slab will have substantially less rebar than a conventional system, one of the main economic benefits. Restraint cracks are often large and noticeable since a post-tensioned slab does not have the excess rebar to minimize and distribute cracking. Permanent slip details are critical for the performance and aesthetics of post-tensioned concrete.

Typical slip details utilize felt, building paper or plastic to eliminate the bond of the slab to the walls (*Figure 2*). When rebar is required between the slab and the walls, pipe insulation or foam rubber surrounding a portion of the dowel can be used to allow relative movement without activating the dowel in shear friction (*Figure 3*). Pour (also called *delay*) strips are often used in post-tensioned buildings to minimize restraint issues and to create stressing locations. When done properly, pour strips work very well, but they are only a temporary solution. Pour strips typically remain open for approximately 45 days, however, the slab may move for another year if not more. If permanent slip details are not used, a pour strip by itself will provide only a minor amount of relief.

Pour Strips

Pour strips 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 should be completely separate. Any reinforcement crossing the slab edges will act as a tension tie, restrain the relative movement of the two slabs and will most likely cause cracking. All rebar and post-tensioning, including drag and chord reinforcement, are to be lapped inside the pour strips (*Figure 4*).

Contractors should pay special attention to verify if the engineer requires the edges of the pour strip to remain fully shored after the tendons have been stressed. The confusion occurs because, after a successful stressing, the majority of the slab (except the pour strip) is structurally stable and the forms and shores can be removed. Without re-shores, the midspan pour strips can create large cantilevers resulting in significant deflections and moments that were never intended or reinforced by the engineer.

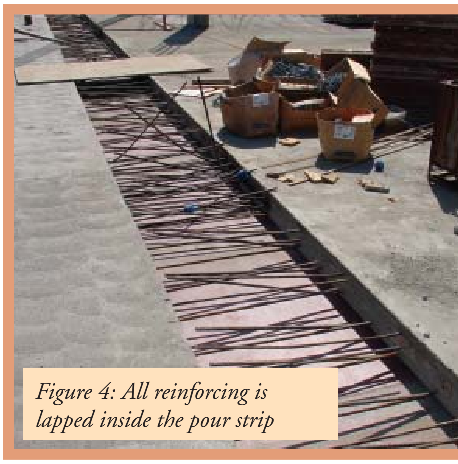

Figure 4: All reinforcing is lapped inside the pour strip

Tendons in Two Way Slabs

Two way post-tensioned slabs are constructed with tendons grouped together in a 4- to 5-foot wide band in one direction, and uniformly spaced tendons in the other. At the job site, the system resembles a one way slab (uniform tendons) that is supported by an embedded slab beam (banded tendons) that runs along the column line (*Figure 5*). The most effective and efficient layout for the two way system is to locate all of the banded tendons in the upper most layer (least amount of top cover) at the columns. With this layout, all of the banded tendons will have their maximum effective depth, and only two of the uniform strands across the entire tributary width will have a reduction. This is the closest way to achieve equal strength in both directions without additional strands or rebar.

Figure 5: Two way slab reinforcing

A common placing error occurs when the all of the banded tendons are placed below the two column uniform strands. If this occurs, the entire banded direction will lose between ½- to 1-inch of its effective depth d (*Figure 6*). For an 8-inch slab, a loss of 1-inch of effective depth at each column will result in approximately a 17 percent loss in balance load and moment capacity.

Increased Cover for Fire Protection

Post-tensioning strands have different cover requirements, depending on if they are located in restrained or unrestrained spans. The reference to restrained or unrestrained has nothing to do with the type or location of the lateral system. It 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.

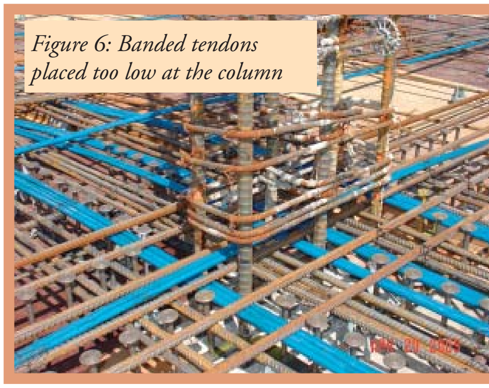

Figure 6: Banded tendons placed too low at the column

For a 3 hour fire rating, per table 720.1 of the IBC, the minimum bottom cover for the tendons is 2 inches, while it is only 1 inch for rebar. This significant difference in cover is frequently missed and is a direct code violation. One retrofit option is to have plaster or other fire rated material applied to the slab/beam around the low point of the tendon to increase the fire rating. In post-tensioned slabs or beams, the cover to the strands should typically be greater than the rebar in the end (unrestrained) bays.

Water Proofing

Compressing concrete by using post-tensioning does not make the concrete water proof. Concrete by nature is a porous material and adding some amount of compression does not suddenly make it non-porous. Post-tensioning will probably enhance the natural water tightness that concrete possess, but it will never be water proof.

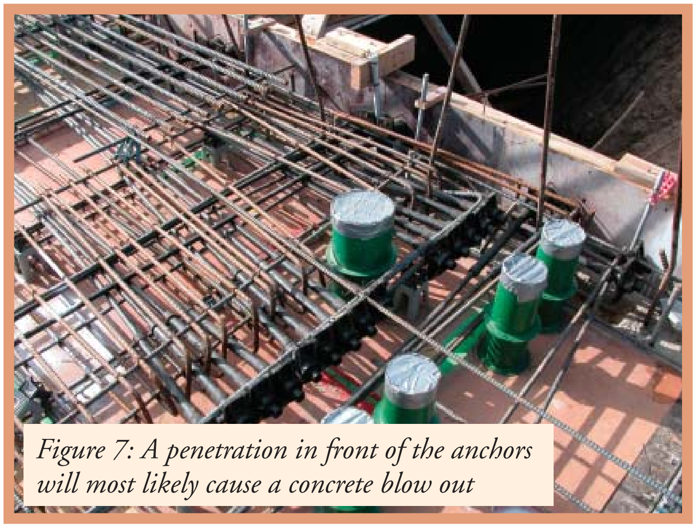

Figure 7: A penetration in front of the anchors will most likely cause a concrete blow out

I have heard several engineers and contractors make the argument that water proofing at roof slabs is not required with a post-tensioned system. This argument is wrong and can open the engineer to increased liability for water intrusion issues. An argument can easily be made that more post-tensioning actually makes the system less water proof. For higher values of pre-compression, the slab will experience larger movements which may induce restraint cracks. No matter how much reinforcement is put into the slab, a crack is definitely not water proof. Water intrusion can be seen though the crack in the post-tensioned roof slab in *Figure 1*.

Concrete Blow Outs

Each tendon, whether there in a small slab on grade or a 30-story hotel, will be loaded to approximately 33,000 pounds during stressing. This force is then transferred to the concrete through the bearing of the ductile iron casting anchor. If the concrete is not well vibrated, penetrations are located in front of the anchors (*Figure 7*), or congested rebar prevents a uniform bearing surface, a concrete blow out is likely (*Figure 8*). The concrete will literally explode as the anchors crush into the slab or beam, which then can cause the hydraulic jack to move suddenly and violently. For this reason, only trained professionals should operate or be anywhere near the jack during stressing. If the penetrations can not be relocated away from the anchors, steel pipes should be added around the openings to resist the anchorage force.

Drilling into a Post-Tensioned Slab

There are several myths about post-tensioned concrete, but the most prevalent one I hear is that it is practically impossible to drill into a post-tensioned slab. The impossibility comes from the unknown location of the tendons and anchors. In general, 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.

Figure 8: Concrete blow out at a congested anchorage zone

Existing tendons can be located simply by the use of a pacometer (hand held metal detector) or an x-ray. With the x-ray in hand, the technician should be able to draw the tendon locations directly on the concrete

Figure 9: Tendons are marked to facilitate future tenant improvements

surface. I have personally used a $40 metal detector and located tendons inside a 12-inch wide beam. For new office buildings where tenants frequently change, we recommend marking one side of the slab so that future tenants will know exactly where the strands and anchors were placed (*Figure 9*).

Smooth Tendon Profiles

The tendons should be draped vertically and horizontally in a smooth gradual profile. Tendon discontinuities will attempt to straighten out during stressing and produce localized point loads on the slab. The tendons in *Figure 10* will create a downward force that is no where near a band or a vertical support. Instead of picking up the concrete, the reverse curvature will push down into the lightly reinforced slab below, most likely causing cracks or a small blow out. These tendon kinks 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.

Figure 10: Reverse curvature of the tendons will push down on the slab

The above list of "issues" is certainly far from complete, but represents common items that I frequently encounter. With the advancement of computer software, the calculation part of post-tensioned concrete has becoming more accurate, efficient and visually stunning. Even with these improvements, the software still does indicate where the system will lock up and where cracks are likely to occur. Good detailing and layout are critical for successful post-tensioned concrete. If you have questions on any aspect of post-tensioning, I recommend using the discussion forum on the PTI web page (**www.post-tensioning.org**). Most questions will receive several responses and hopefully will answer your question.▪

Bryan Allred, S.E. is Vice President of Seneca Structural Engineering, Inc. in Laguna Hills California. Bryan specializes in reinforced concrete buildings utilizing post-tensioned floor systems, the retrofit of existing buildings using external post-tensioning and post-tensioned slabs on grade. He can be reached at **bryan@senecastructural.com**